OpenFOAM을 이용한 소형 훈련정 자항해석

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NEXTfoam

open source CFD consulting

개요

- 배경
  - 전산유체역학(Computational Fluid Dynamics, CFD)을 이용한 선박의 저항/자항해석
    - 편리하고 안정적인 상용프로그램 이용이 일반적
    - 오픈소스 프로그램(OpenFOAM)으로도 선박의 저항/자항해석의 연구가 활발히 진행됨

- 목적
  - OpenFOAM을 이용하여 개발된 선박성능해석 프로그램인 **ESPER**를 이용하여 소형 고속선의 저항, POW, 자항해석 활용 가능성 평가

  - G/T 30 Ton class 조종사 생환훈련정에 대한 저항/자항/POW 해석

Open-source CFD program

➢ OpenFOAM

- General-purpose Multiphysics program
- Complex to use
  - Require to expertise
- Low cost
  - No license cost, publicness
- Easy to access the source-code
  - Applicable the latest-technology

Customized Program

Classification	Packages	Cost(dollar)
Open-Source	OpenFOAM, SU2, Astro	0
Open-Source wrapper	Visual-CFD, simFlow, SimScale, Caedium	18,500
Integration CAD Packages	SolidWorks, Autodesk, Inventor CFD	5,500~150,000
Professional Packages	**Automobile:** CONVERGE, AVL Fire, **Electrical** and **Electronics:** FloTHERM, **Oceanography:** FINE/Marine, **D.C.:** 6Sigma, **E.F.:** XFlowCFD	5,500~371,000
Comprehensive Packages	Fluent, Star-CCM+, COMSOL, AcuSolve	93,000~371,000

지배방정식

- Governing equation

$$\nabla \cdot \mathbf{U} = 0$$

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla \cdot (\rho \mathbf{U}\mathbf{U}) = -\nabla p + \rho \mathbf{g} + \nabla \cdot \mathbf{T}$$

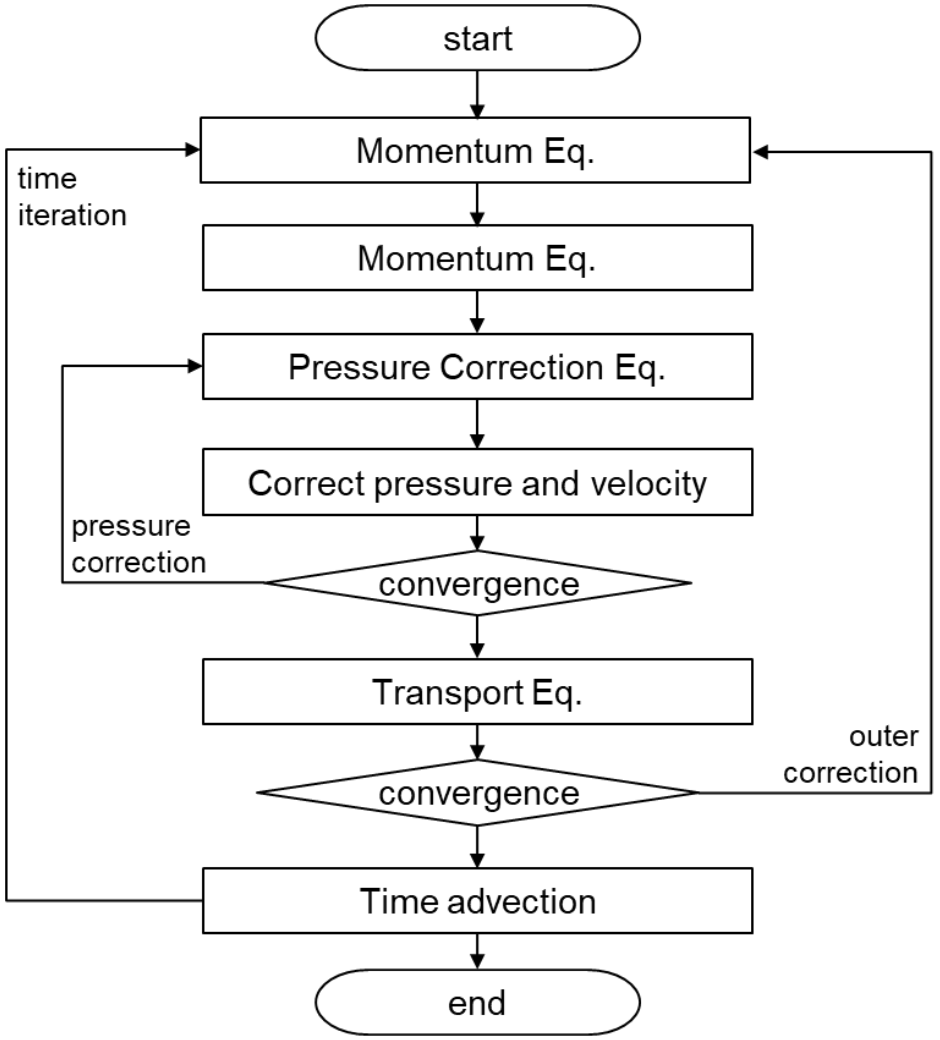
Substitution of pressure term

$$p_{rgh} = p - \rho \mathbf{g} \cdot \mathbf{x}$$

$$\nabla \cdot \mathbf{U} = 0$$

$$\frac{\partial \rho \mathbf{U}}{\partial t} + \nabla \cdot (\rho \mathbf{U}\mathbf{U}) = -\nabla p_{rgh} - \mathbf{g} \cdot \mathbf{x} \nabla \rho + \nabla \cdot \mathbf{T}$$

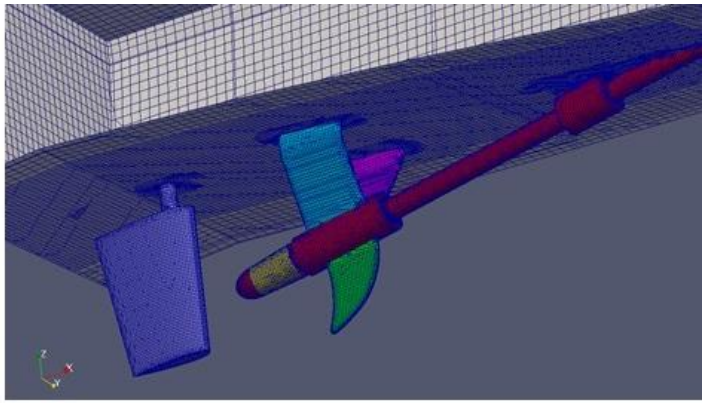
- 유동의 변화가 없더라도,
  자유 수면에서의 p_rgh의 구배는 있다.



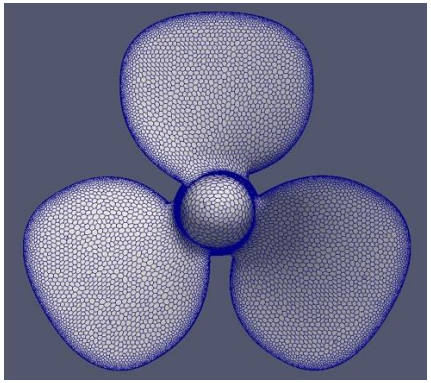
PIMPLE(PISO+SIMPLE) algorithm

계산조건 및 방법

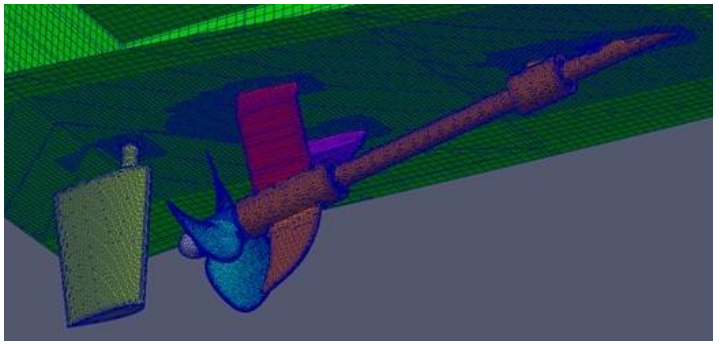
- 저항해석
  - 축척비 : 1/12 (모형선 크기)
  - 속도 : 3.712 m/s (모형), 25knots (실선)
  - 2가지 조건에서 계산 : even keel, trim -0.369m (heave & pitch 자유)



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

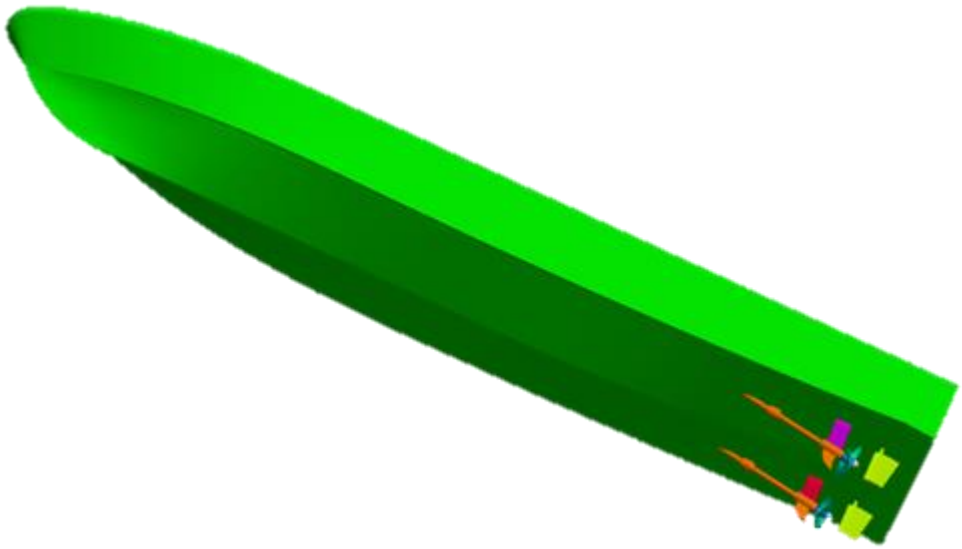


- 자항해석
  - 축척비 : 1:1 (실선 크기)
  - 속도 : 25knots
  - 2가지 조건에서 계산 : even keel, trim -0.369m (heave & pitch 자유)
    - Even keel : 1000 RPM, 1030 RPM
    - Trim -0.369m : 990 RPM, 1010 RPM



계산조건 및 방법

- 해석 프로그램
  - ESPER (OpenFOAM solver)
    - 자유수면 : VOF
    - 프로펠러 회전 : 슬라이딩 격자
    - 난류모델 : kOmegaSST
    - 선체자세변화 : 동적격자

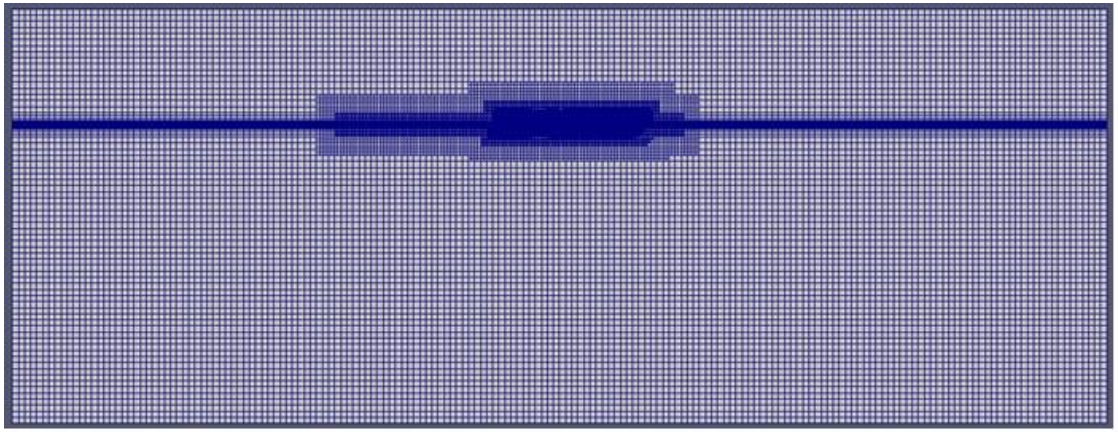


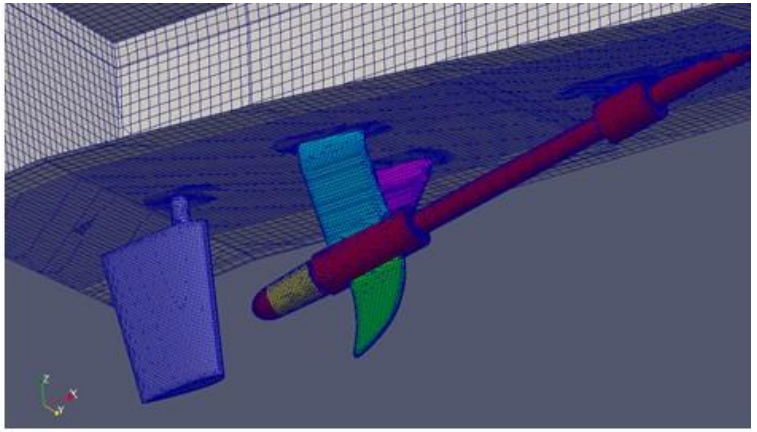
	Symbol (unit)	Scale	
		Full	Model
Hull			
Length between perpendicular	LPP (m)	22.0	1.83
Breadth	B (m)	4.9	0.408
Draft, moulded	TF (m)	1.02	0.085
	TA (m)	1.02	0.085
Wetted surface area	WSA (M2)	108.9	0.756
Displacement volume	DISV (m3)	52.9	0.0306
LCB from AP (+,fwd)	LCB (m)	8.990	0.749
Propeller			
Diameter	D (m)	0.950	0.1188
Pitch	P (m)	1.005	0.1256
Boss ratio	-	0.21053	
Number of blades	-	3	

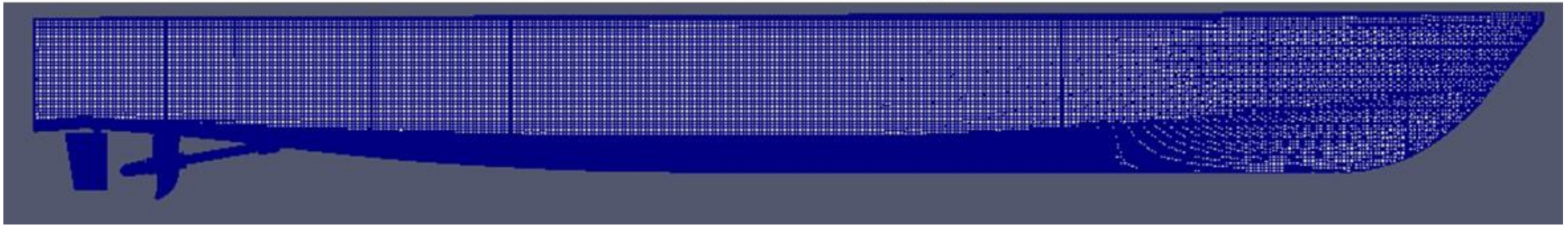
저항해석

➢ 해석 조건

- 속도 : 3.712 m/s
- 격자
  - 총 격자 수 : 약 246만 개
  - Y^+ = 약 50
- 축척비 : 1/12 (모형선 크기)
- 해석 케이스
  - Even keel 조건 & Trim -0.369m 조건
  - Trim과 Sinkage 자유







저항해석

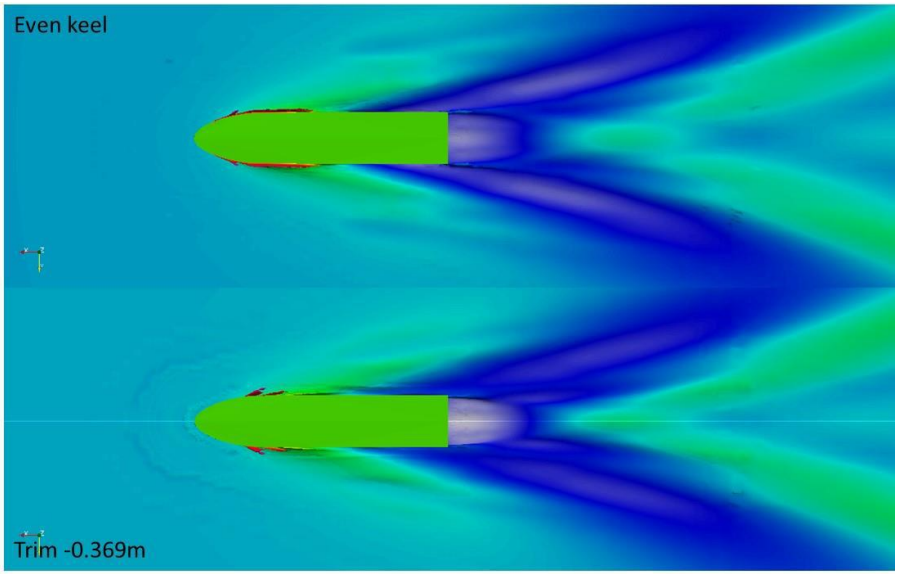
➢ **해석 결과**

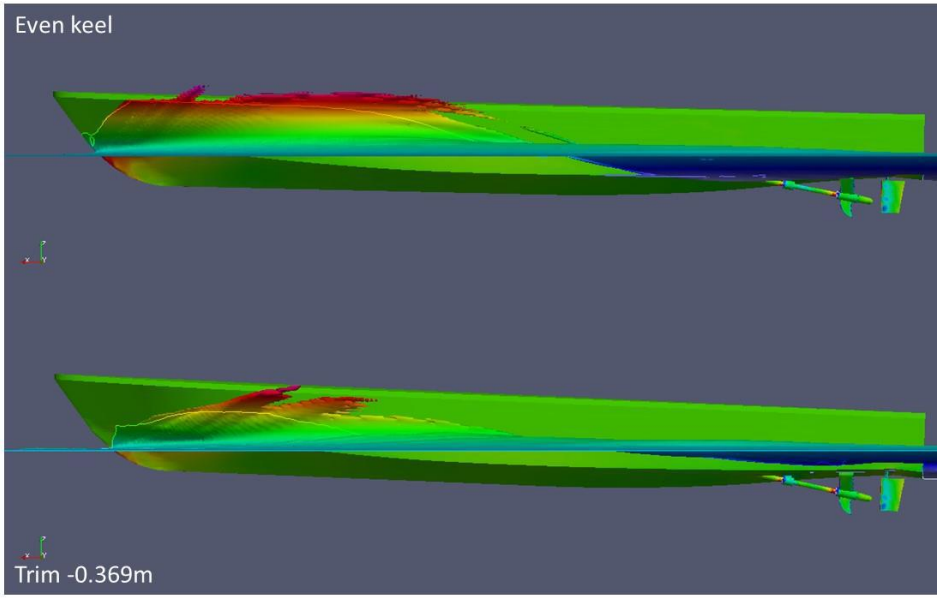
- 오차
  - Even keel
    - 저항 : 0.2 %
    - Trim : 0.23 deg.
    - Sinkage : 0.21 m
  - Trim -0.369m
    - 저항 : 1.8 %
    - Trim : 1.69 deg.
    - Sinkage : 0.011 m

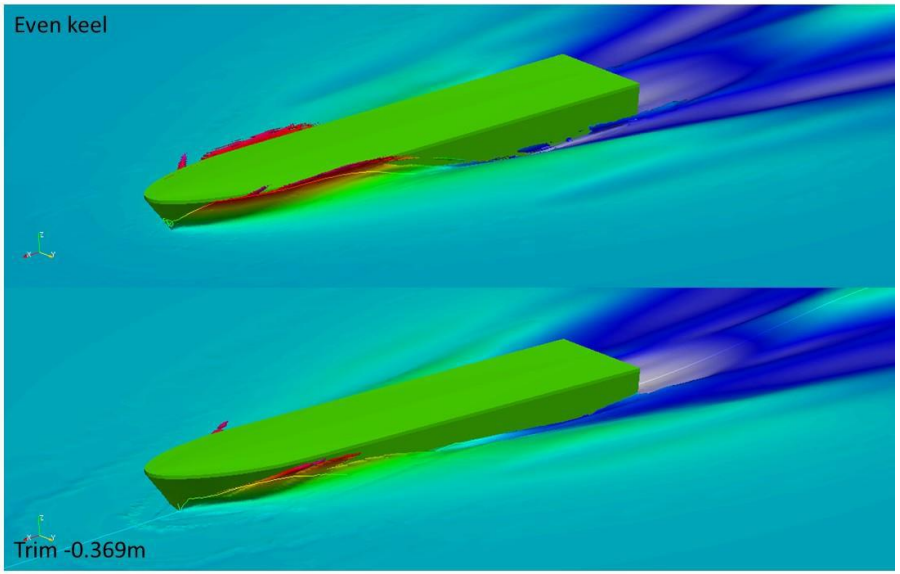
	Even keel		Trim -0.369m	
	Exp.	Cal.	Exp.	Cal.
R_{TM} (N)	47.7	47.6	44.4	43.6
R_{FM} (N)	17.3 (ITTC'57)	21.4	17.4 (ITTC'57)	19.7
R_R or R_P (N)	30.4	26.2	27.0	23.8
C_{TS} (C_A = 0.4e-3)	8.01	8.00	7.43	7.27
R_{TS} (kN)	74.4	74.3	68.5	67.1
Trim (deg.)	1.43	1.20	1.95	3.64
Sinkage (m)	0.27	0.06	-0.014	-0.003

저항해석

- 선체 주위 파형 분포 비교

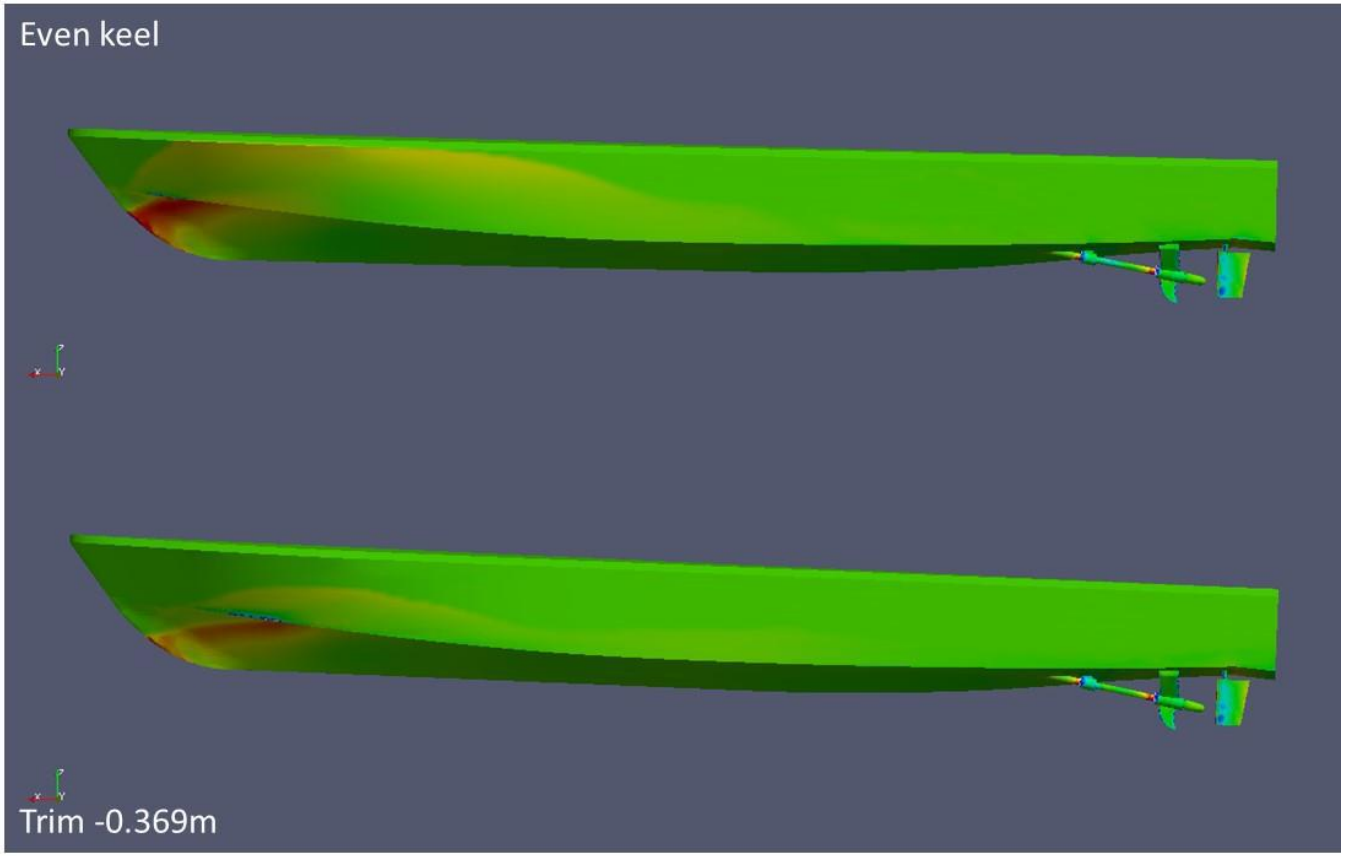




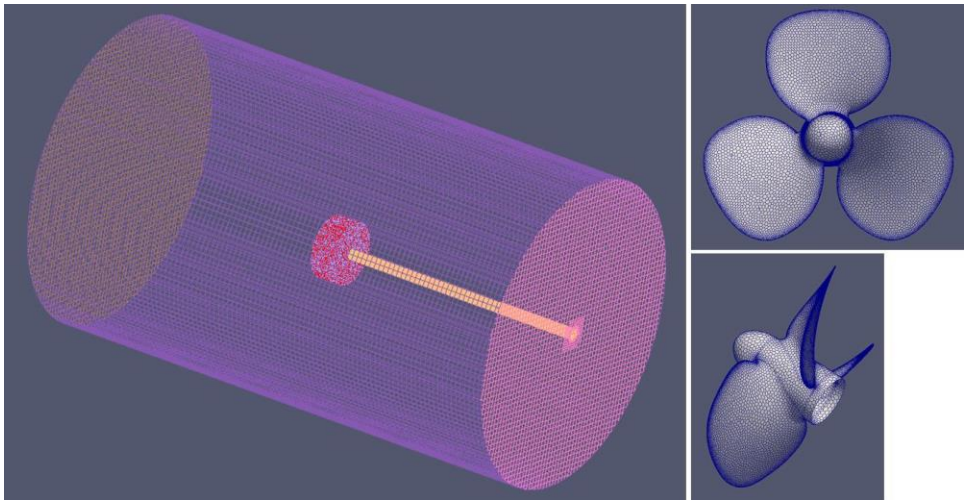


저항해석

- 선체 주위 압력 분포

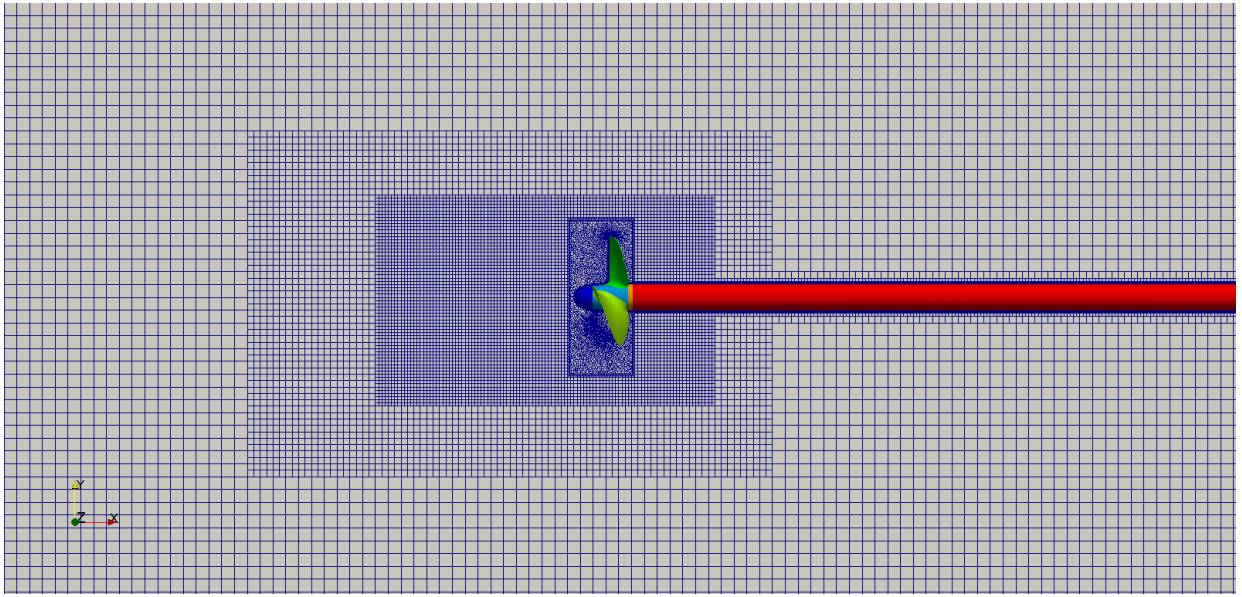


프로펠러단독성능해석



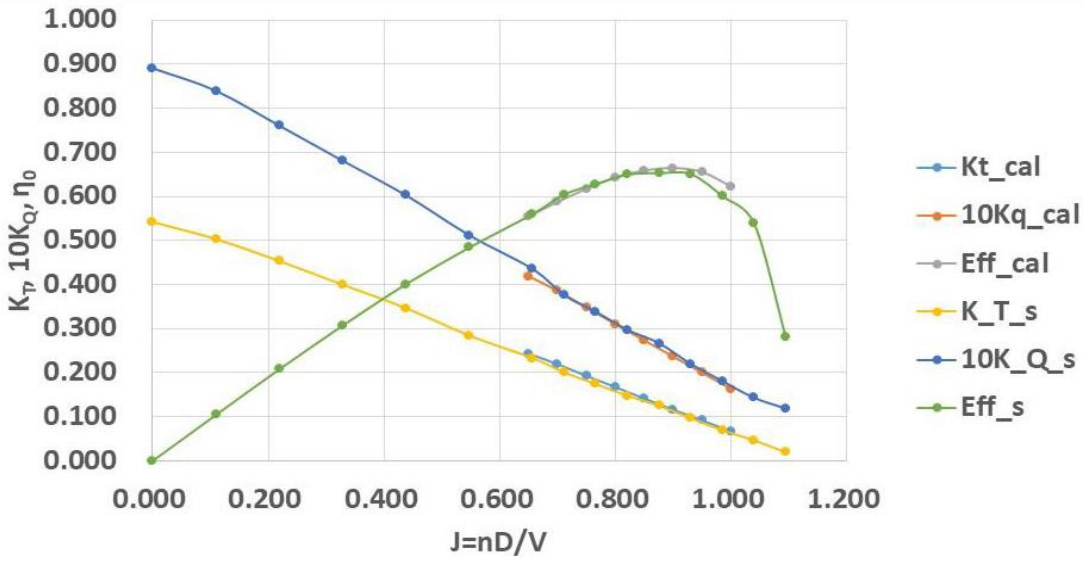
➢ 해석 조건

- 축척비 : 1:1 (실선 크기)
- 속도 : 25 knots
- 전진비 : 0.65 ~ 1.00 (0.05 간격)
- RPS : 16.7
- 격자
  - 총 격자 수 : 약 133만 개
  - Y^+ = 약 70



프로펠러단독성능해석

- 프로펠러단독성능 결과
  - 실험과의 오차 : 최대 5%

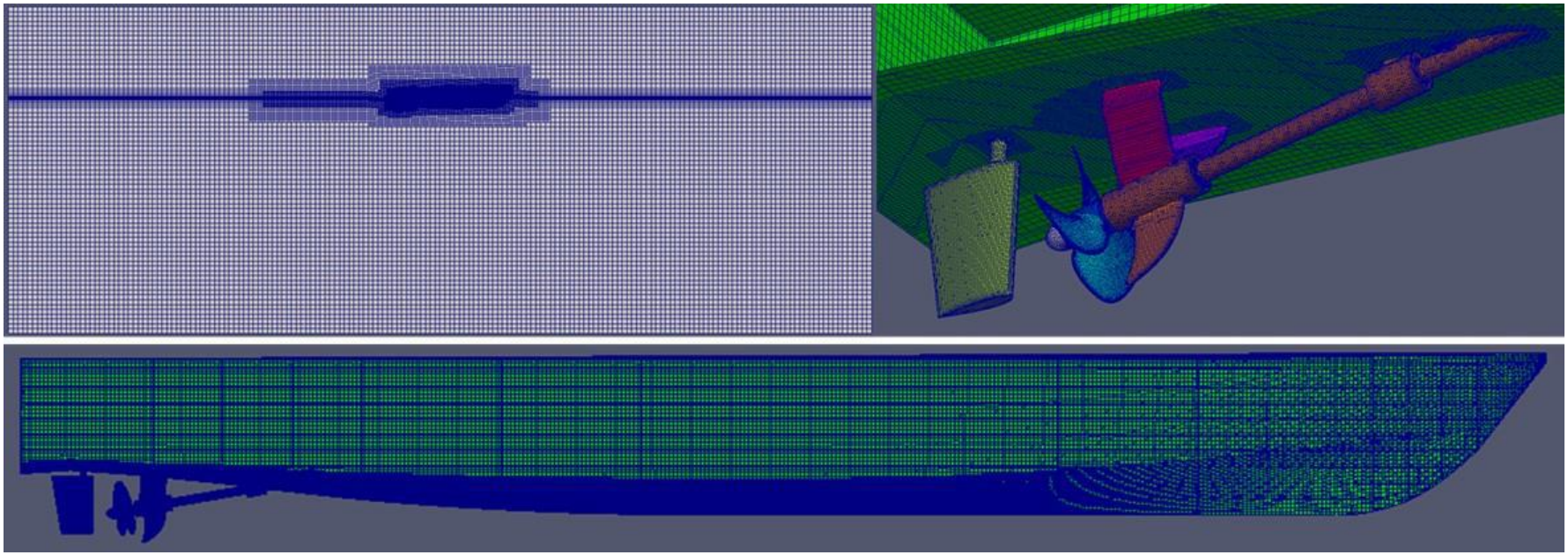


J	V (m/s)	Thrust (kN)	Torque (kNm)	K_T	$10K_Q$	η_0
0.650	9.500	55.0	9.000	0.243	0.419	0.554
0.700	10.292	49.6	8.298	0.219	0.386	0.588
0.750	11.083	43.6	7.480	0.193	0.348	0.617
0.800	11.875	37.8	6.671	0.167	0.310	0.643
0.850	12.667	32.0	5.874	0.141	0.273	0.659
0.900	13.458	26.3	5.086	0.116	0.237	0.665
0.950	14.250	20.7	4.300	0.092	0.200	0.655
1.000	15.042	15.2	3.509	0.067	0.163	0.623

자항해석

➢ 해석 조건

- 축척비 : 1:1 (실선 크기)
- 속도 : 25 knots
- Trim과 Sinkage 자유
- 격자
  - 총 격자 수 : 약 330만 개
  - Y^+ = 약 50
- 해석 케이스
  - Even keel 조건 & Trim -0.369m 조건
  - Even keel 조건
    - 1000 RPM & 1030 RPM
  - Trim -0.369m 조건
    - 990 RPM & 1010 RPM



자항해석

➢ **해석 결과**

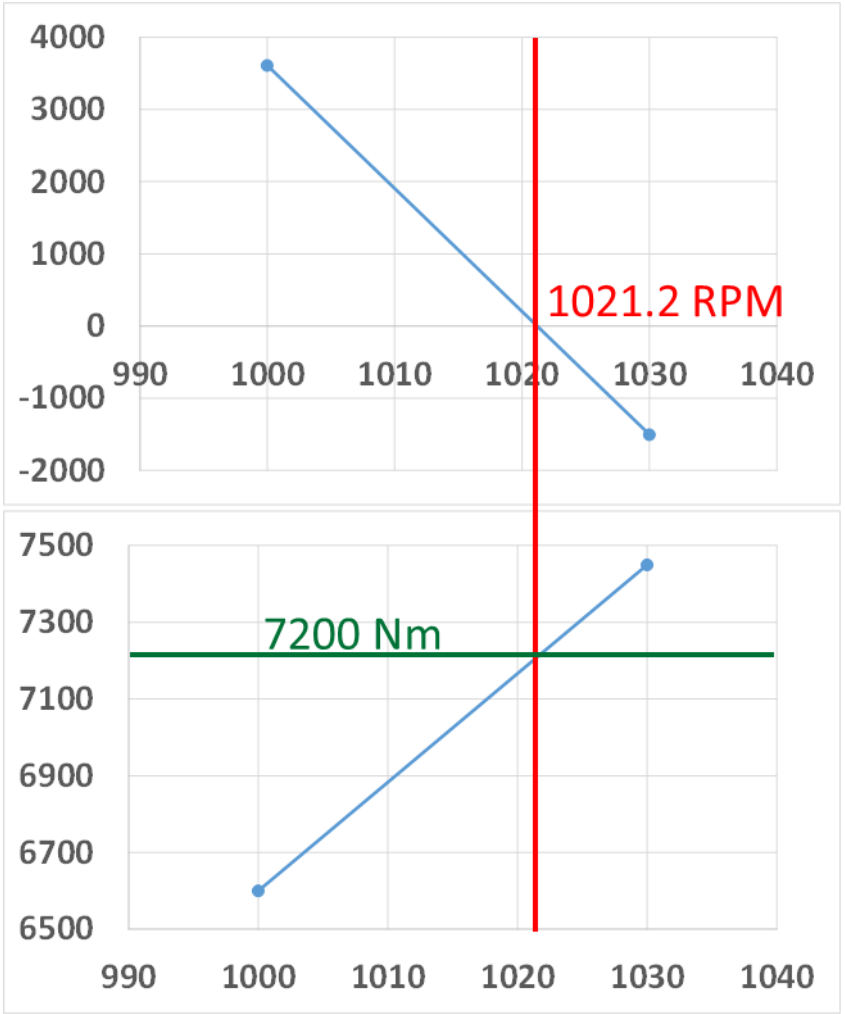
- Even keel 조건
  - 프로펠러 회전속도 별 자항해석

    (1000 RPM & 1030 RPM)

RPM	Resistance (N)	Thrust (N)	Torque (Nm)	Resistance - Thrust (N)
1000	39260	35650	6600	3610
1030	39660	41160	7450	-1500
1021	39542	39542	7200	0

  - 자항점
    - 회전 수 : 1021.2 RPM (106.9 rad/s)
    - 토크 : 7200 N*m
    - 전달 출력

      7200 x 106.9 = 770.0 kW



자항해석

➢ **해석 결과**

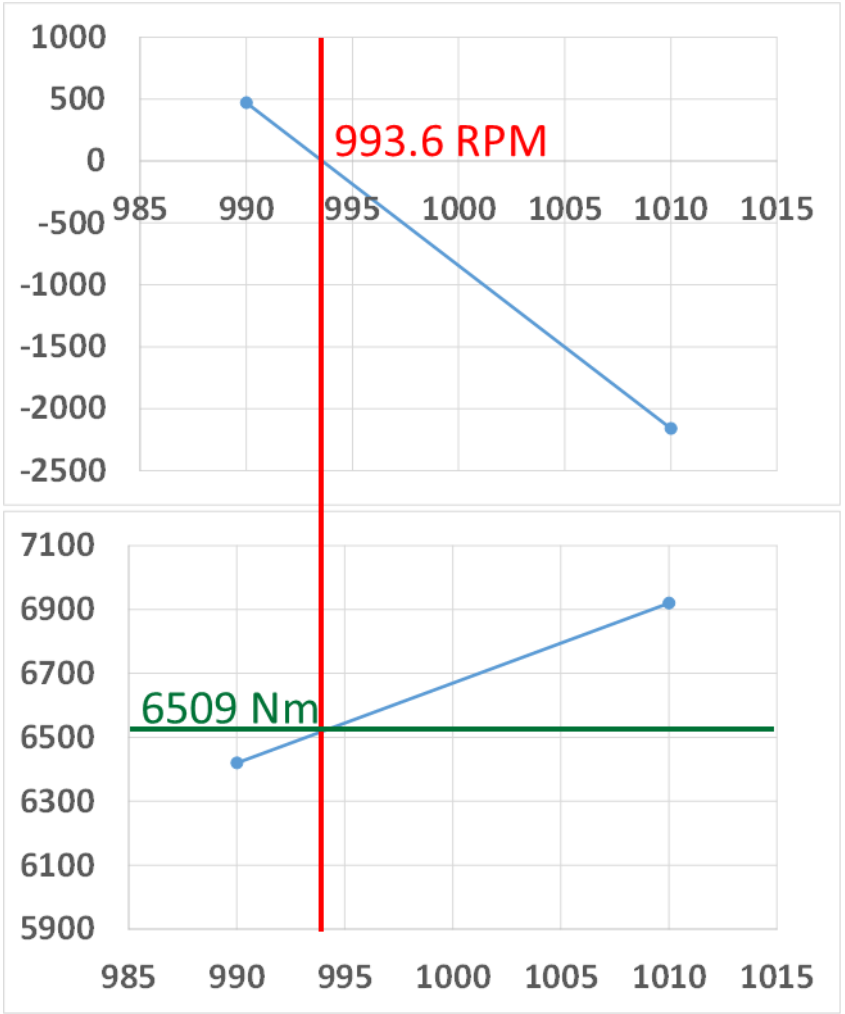
- Trim -0.369m 조건
  - 프로펠러 회전속도 별 자항해석

    (990 RPM & 1010 RPM)

RPM	Resistance (N)	Thrust (N)	Torque (Nm)	Resistance - Thrust (N)
990	35770	35300	6420	470
1010	36740	38900	6920	-2160
994	35943	35943	6509	0

  - 자항점
    - 회전 수 : 993.6 RPM (104.0 rad/s)
    - 토크 : 6509 N*m
    - 전달 출력

      6509 x 104.0 = 676.9 kW



자항해석

- 자항성분

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

$$\eta_H = \frac{1-t}{1-w} \qquad \eta_R = \frac{Q_0}{Q}$$

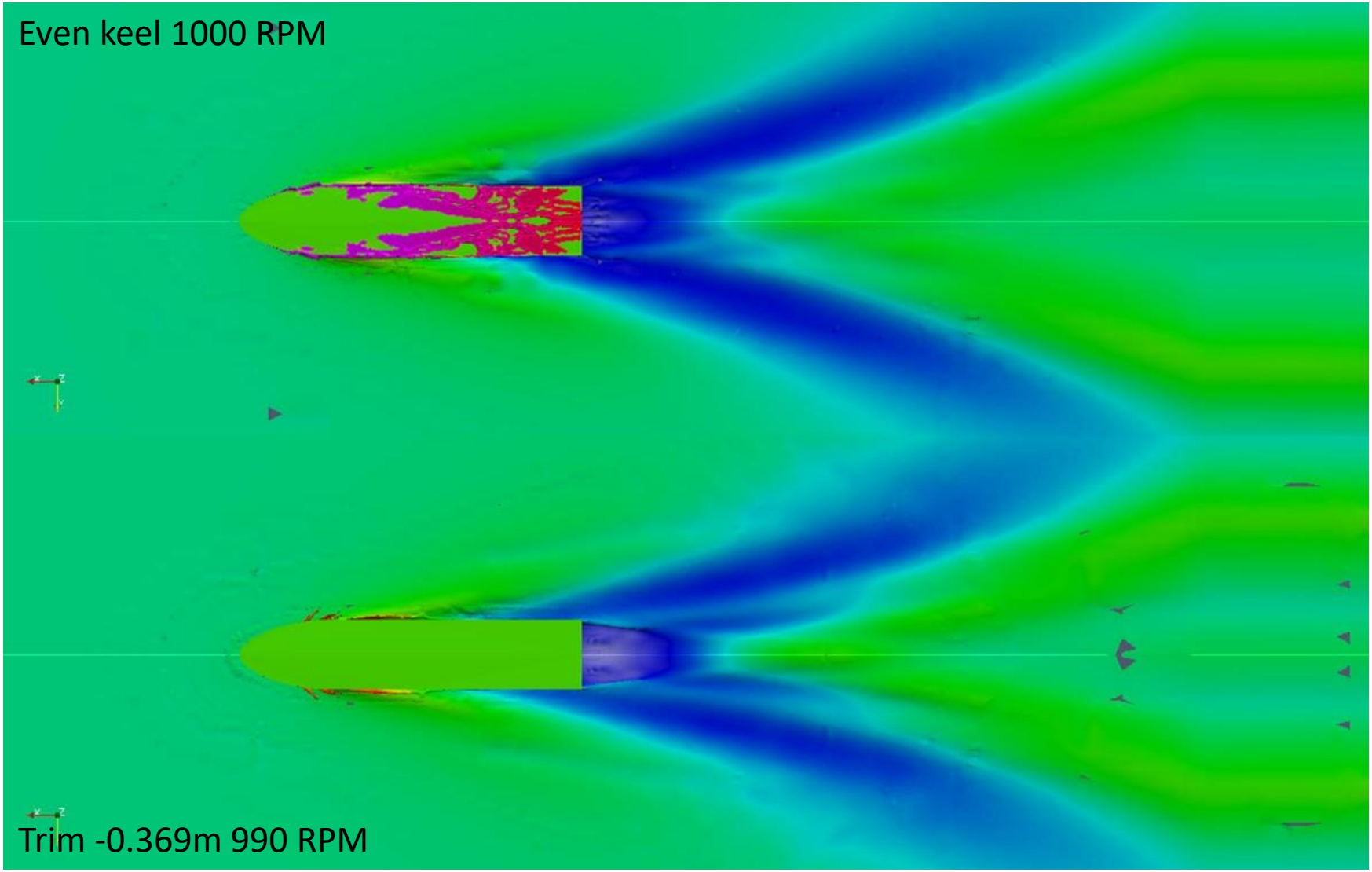
η_0 from POW test

	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

	J_v	J_a	w	t
Even keel	0.795	0.789	0.0076	0.0605
Trim -0.369m	0.817	0.806	0.0135	0.0666

	Q_0 (Nm)	Q (Nm)
Even keel	7135	7200
Trim -0.369m	6400	6509

자항해석



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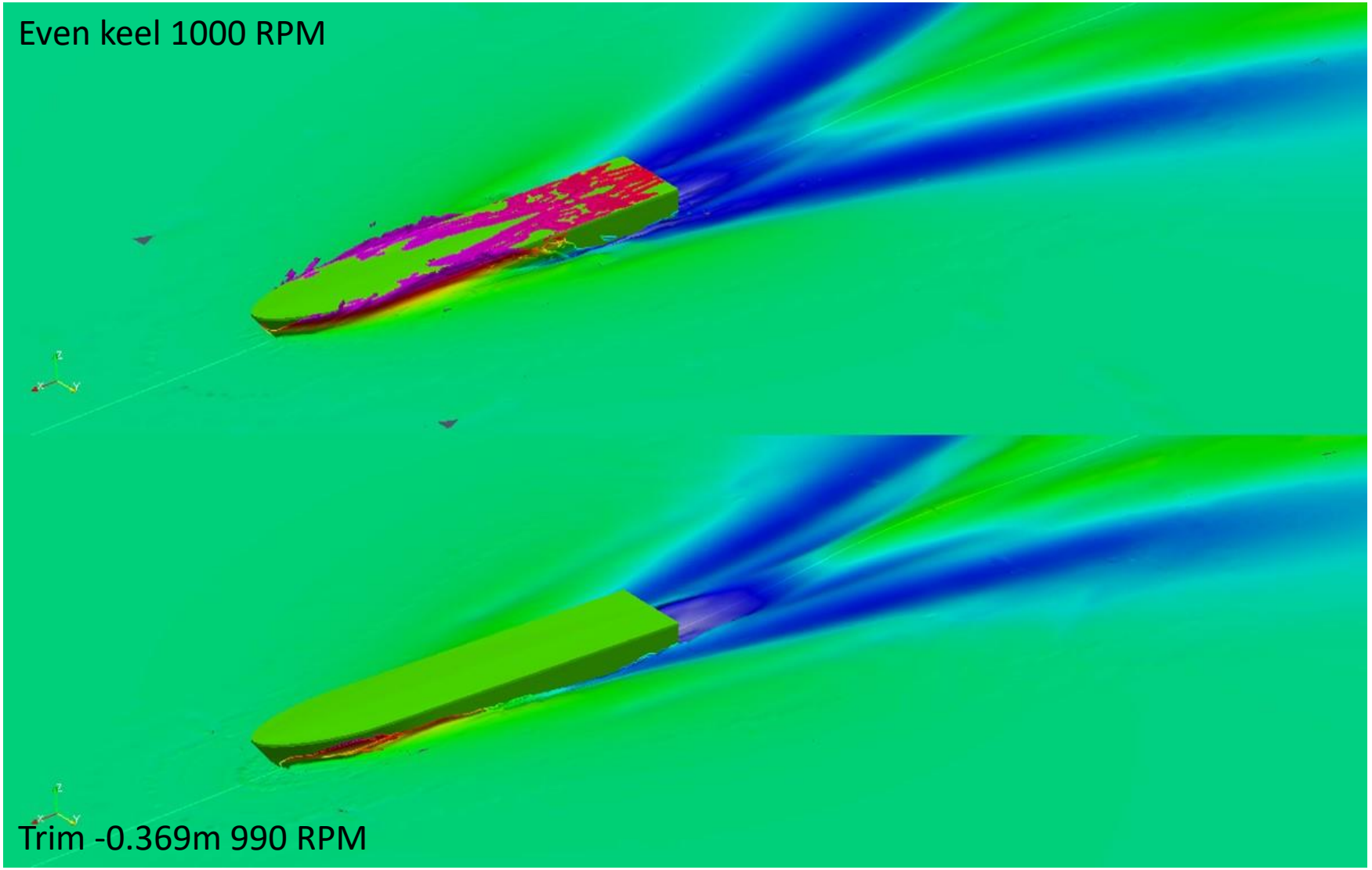

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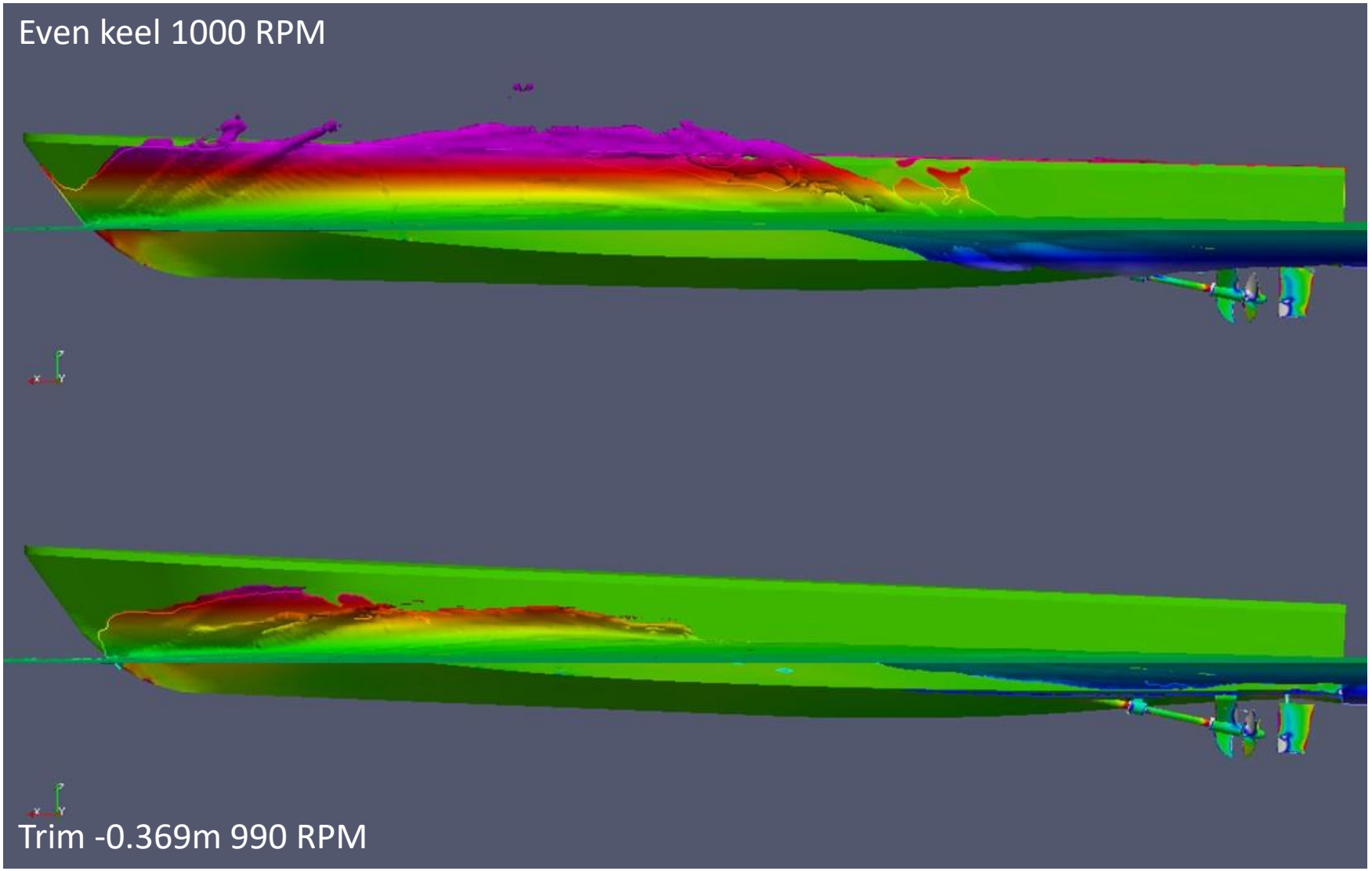

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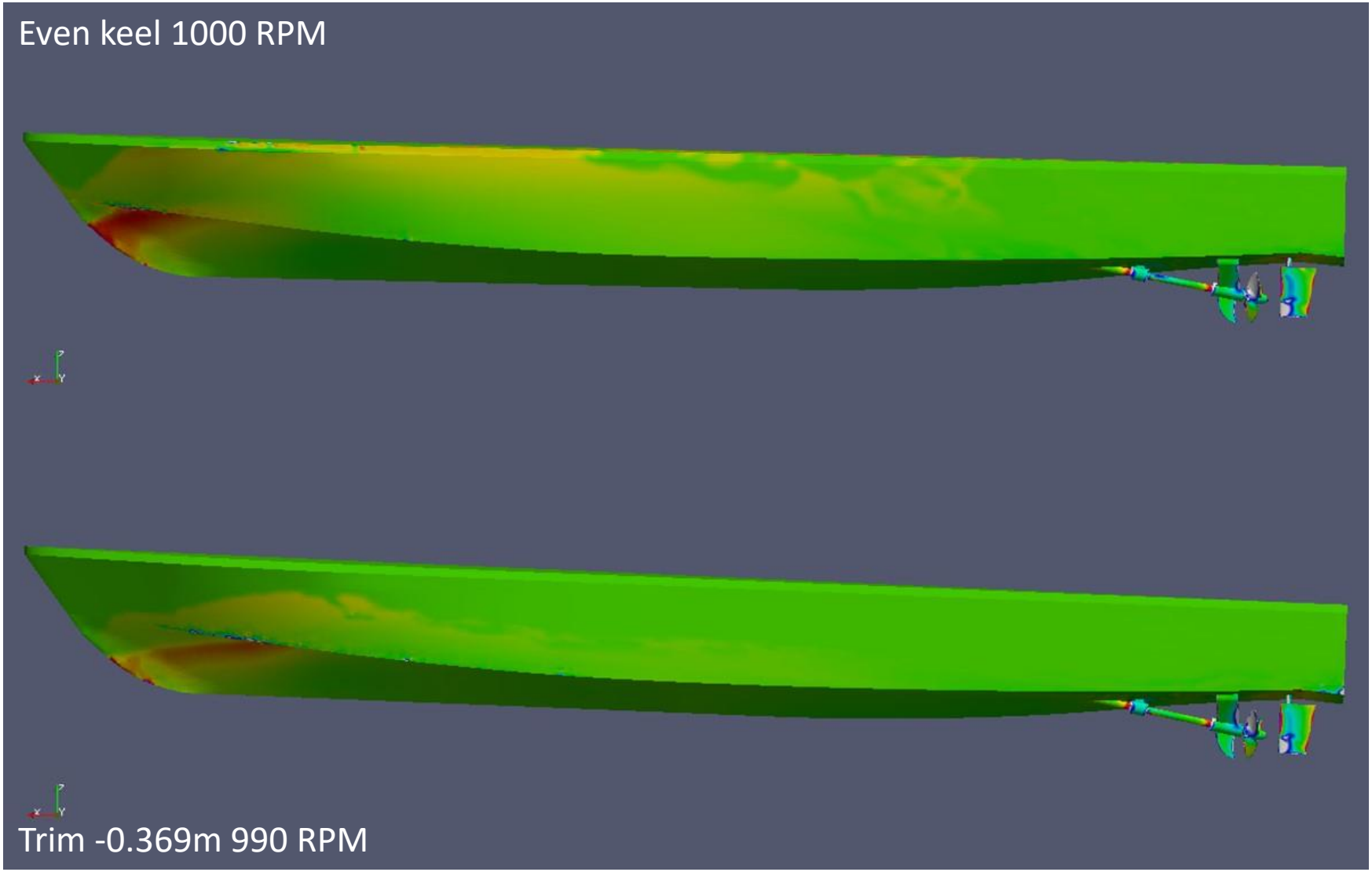

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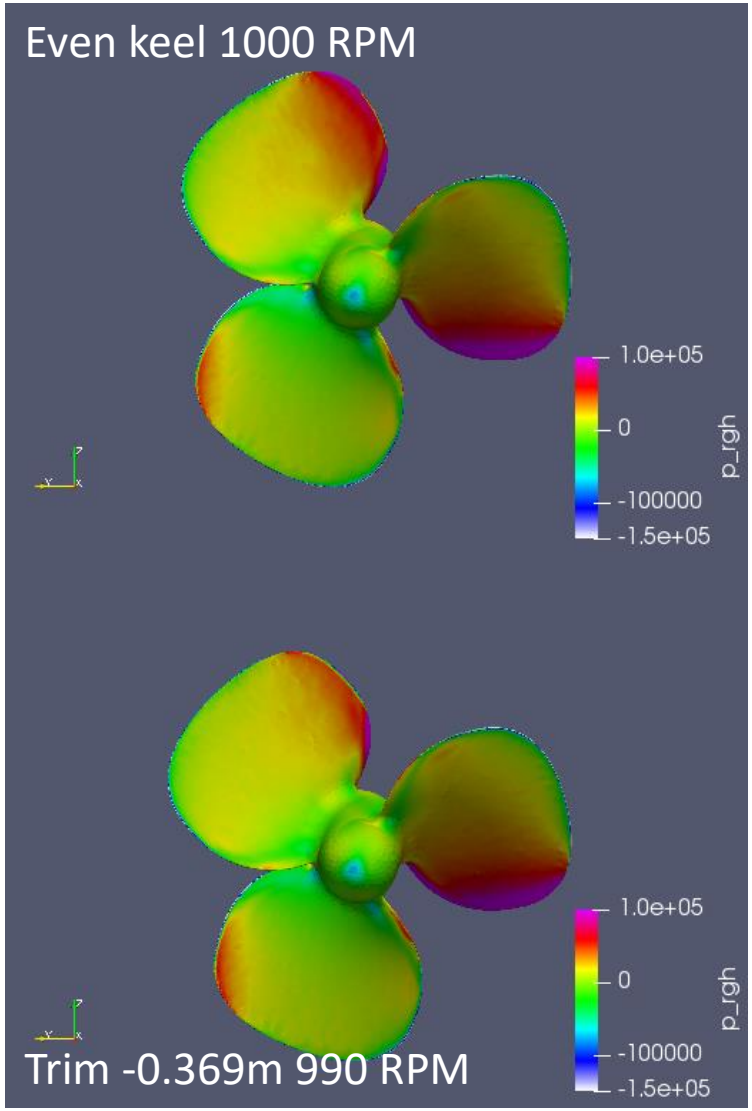
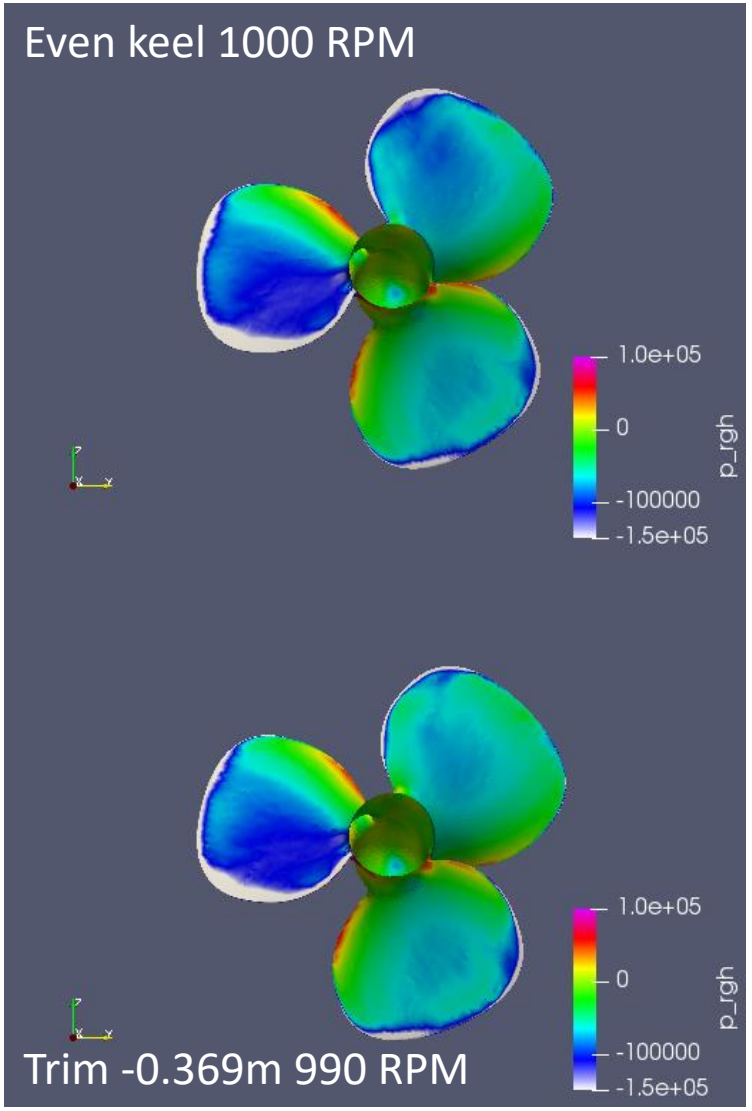
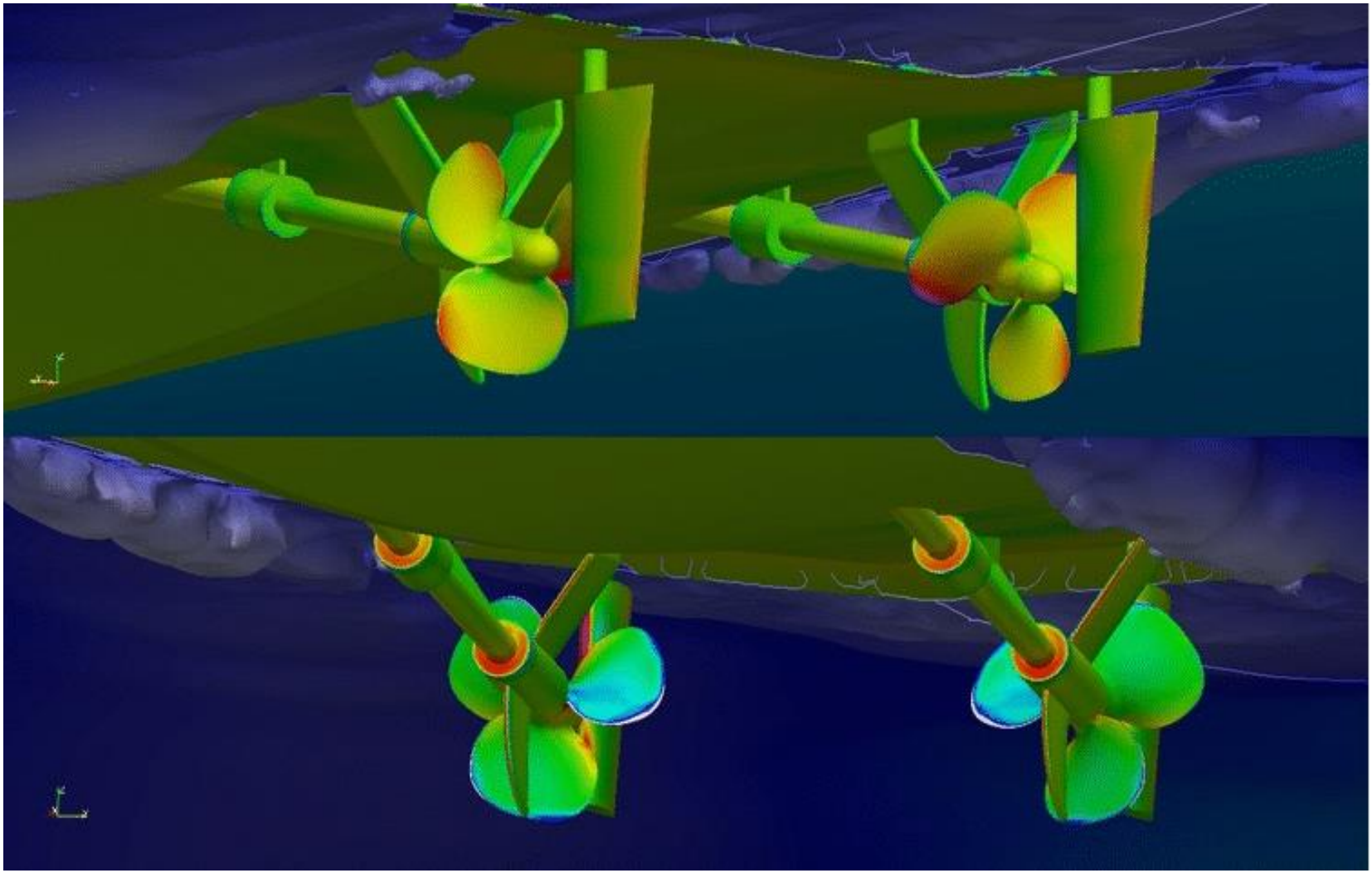

Even keel 1000 RPM
1.0e+05
0
-100000
-1.5e+05
p_rgh
Trim -0.369m 990 RPM
1.0e+05
0
-100000
-1.5e+05
p_rgh


Even keel 1000 RPM
1.0e+05
0
-100000
-1.5e+05
p_rgh
Trim -0.369m 990 RPM
1.0e+05
0
-100000
-1.5e+05
p_rgh

자항해석

- 1000 RPM even keel condition



결론

- 30톤급 조종사 생환훈련정의 자항성능을 수치적으로 해석함
  - 저항해석과 POW해석을 수행하여 실험결과와 비교하여 해석 프로그램의 적합성을 검증
    - 저항해석 오차 : 약 2%
    - POW 해석 오차 : 약 5%

  - Even keel 조건과 trim -0.369m 조건에서 자항해석을 수행
    - 저항해석 POW해석으로 보아 약 7%의 오차 예상됨
    - Even keel 조건
      - 1000RPM과 1030RPM에서 자항해석을 수행하고 보간하여 자항점에서의 추력을 추정
      - 25 knots 자항을 위해 필요한 전달 출력 : **1440.0 kW**
    - Trim -0.369m 조건
      - 990 RPM과 1010 RPM에서 자항해석을 수행하고 보간하여 자항점에서의 추력을 추정
      - 25 knots 자항을 위해 필요한 전달 출력 : **1353.8 kW**

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