

오픈폼을 활용한 선박 성능해석 패키지 'ESPER' 개발

2018년 해양과학기술협의회 공동학술대회

2018년 5월 24~25일

제주 국제컨벤션센터(ICC)

김현식, 정광열, 길재흥

(주) 넥스트폼

연구배경 및 목표

➤ 연구배경

- CFD를 이용한 선박 성능 평가 활발히 활용
 - CFD 해석 프로그램 라이선스 비용 발생
- 다양한 선속과 흘수에서 최적화된 선박 요구 증대
 - 과도한 해석 계산 시간으로 인한 CFD 활용 한계

➤ 연구목표

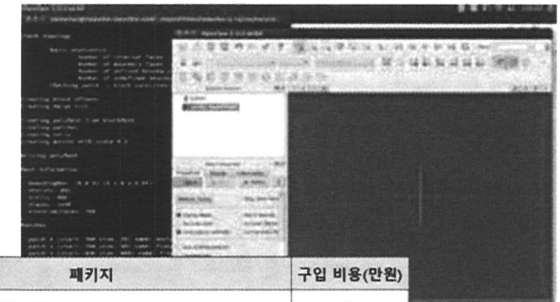
- 라이선스 비용이 발생하지 않는 저항해석 프로그램 개발
 - 오픈소스 라이브러리인 OpenFOAM 활용
- 해석시간 단축
 - 수치 안정성 확보를 통한 수렴 성능 향상
 - 쉘 스크립트를 통한 다양한 해석 케이스 셋팅 및 계산
 - 체적력을 이용한 선체 저항 성능 계산(Actuation Disk Model)

오픈소스 CFD 프로그램

➤ OpenFOAM

- 범용 다물리학 프로그램
 - 유체, 열, 전자기장, 입자
- 사용법이 복잡
 - 전문 지식 요구
- 저비용
 - 라이선스 없음, 공공성
- 코드 접근성이 용이
 - 진보된 해석 기법 도입 가능

전용 특화 프로그램



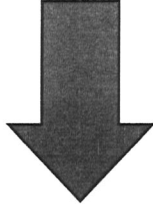
구분	패키지	구입 비용(만원)
오픈소스	OpenFOAM, SU2, Astro	0
오픈소스 래퍼	Visual-CFD, simFlow, SimScale, Caedium, HELYX	2000
CAD 통합 패키지	SolidWorks, Autodesk Inventor CFD	600~16000
전문 패키지	자동차: CONVERGE, AVL Fire, 전기전자: FloTHERM, 해양: FINE/Marine, 데이터센터: 6Sigma, 외부유동: XFlowCFD	600~40000
포괄 패키지	Fluent, Star-CCM+, COMSOL, AcuSolve	10000~40000

수치해석 방법

➤ 지배방정식

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

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

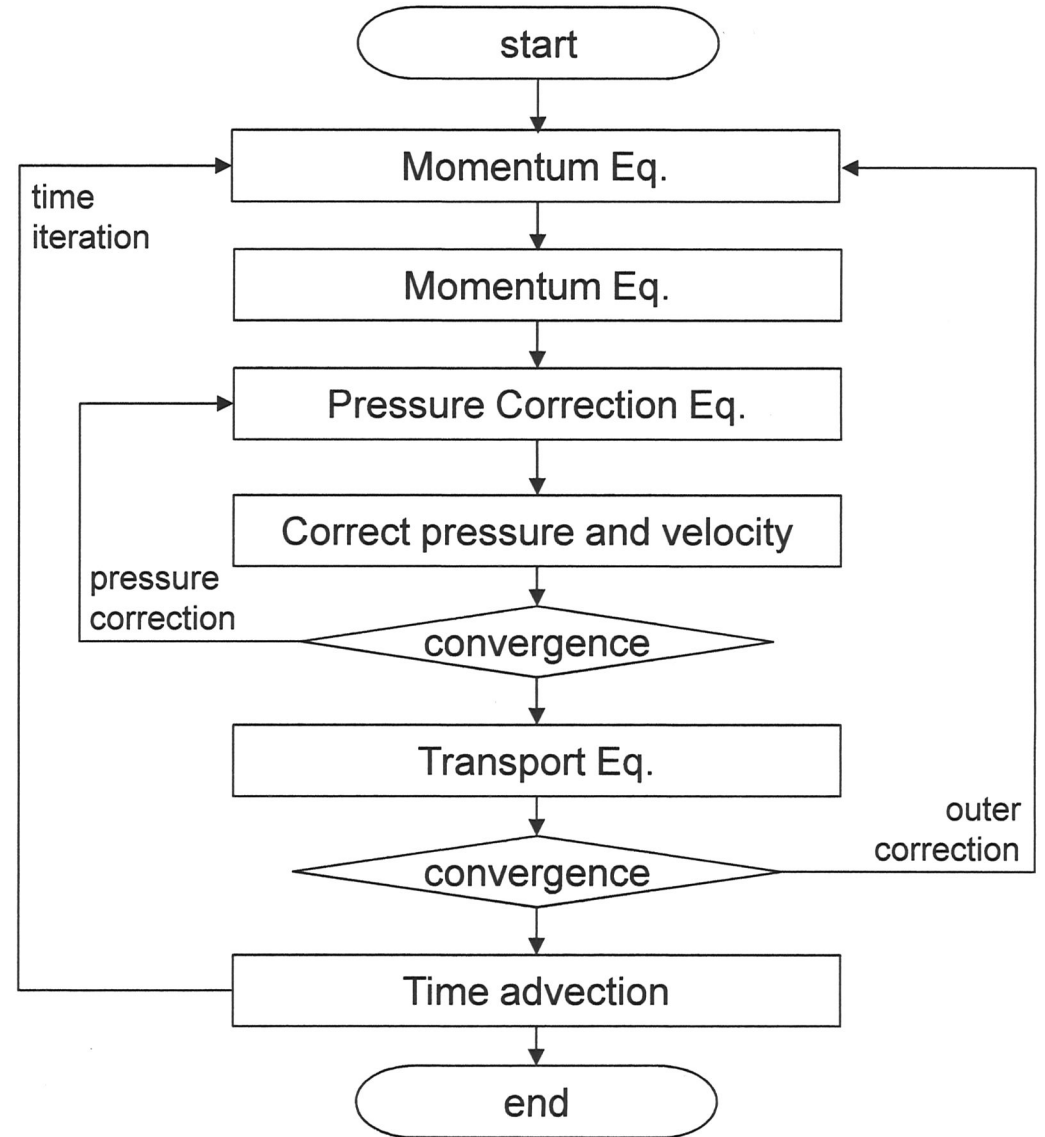

 압력항을 치환
 $p_{rgh} = p - \rho \mathbf{g} \cdot \mathbf{x}$

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

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

유체가 정지해 있어도, 밀도구배가 있는 자유수면에서는 p_{rgh} 의 구배가 존재

- 난류모델 : SST $k-\omega$



PIMPLE(PISO+SIMPLE) 알고리즘

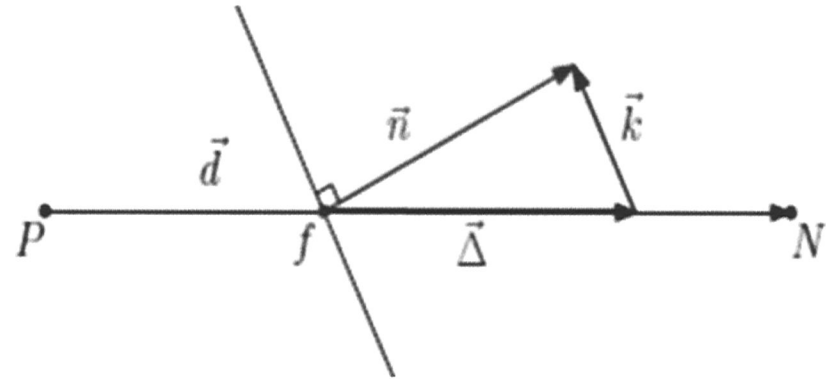
➤ 비직교격자의 안정화

- 압력 포아송 방정식의 라플라시안 항
 - 음해적 처리가 어려움

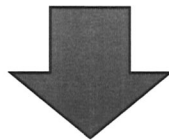
$$\nabla^2 p = s$$

- 압력의 구배를 양해적으로 처리

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



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



- \vec{k} 가 커지면 해가 불안정
- 완화계수를 이용하여 안정성 향상

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

➤ 파도 감쇠

▪ 감쇠 영역

- 유입부 : 계산영역의 10% 길이
- 유출부 : 계산영역의 20% 길이

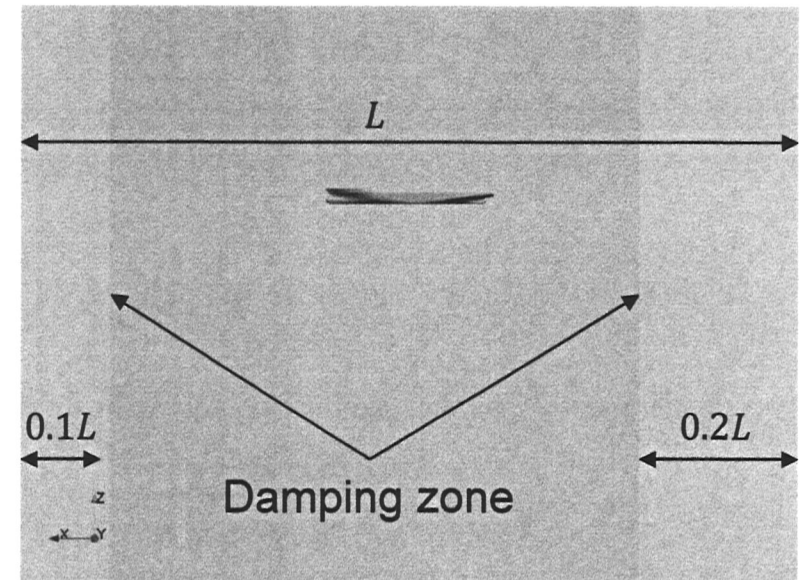
▪ 감쇠 방법

- 유동을 두 가지 성분으로 가정

$$\mathbf{U}_{\text{calculated}} = \mathbf{U}_{\text{disturbed}} + \mathbf{U}_{\text{inflow}}$$

- 교란된 성분에 1이하의 수를 곱하여 인위적으로 감쇠

$$\mathbf{U}_{\text{new}} = \mathbf{U}_{\text{inflow}} + \gamma \mathbf{U}_{\text{disturbed}}$$



➤ 유출입경계조건

▪ 압력의 유출부 경계조건

- $0.001 < \alpha < 0.999$: Neumann
- $0.001 > \alpha$ or $0.999 < \alpha$: Dirichlet

	Inflow	Outflow	Others
Velocity	Dirichlet	Neumann	symmetry
Pressure	Neumann	Neumann or Dirichlet	
VOF	Neumann	Neumann	
Turbulence	Dirichlet	Neumann	

➤ 동적격자 (항주자세)

- 보존방정식

$$\frac{d}{dt} \int_V \phi dV + \oint_S ds \cdot (\mathbf{U} - \mathbf{U}_{mesh}) \phi = \oint_S ds \cdot \mathbf{q}_\phi + \int_V s(\phi) dV$$

$$\frac{d}{dt} \int_V dV - \oint_S ds \cdot \mathbf{U}_{mesh} = 0$$

- 격자의 변형

If $d \leq d_{in}$ then $\mathbf{R} = \mathbf{R}_{ship}$

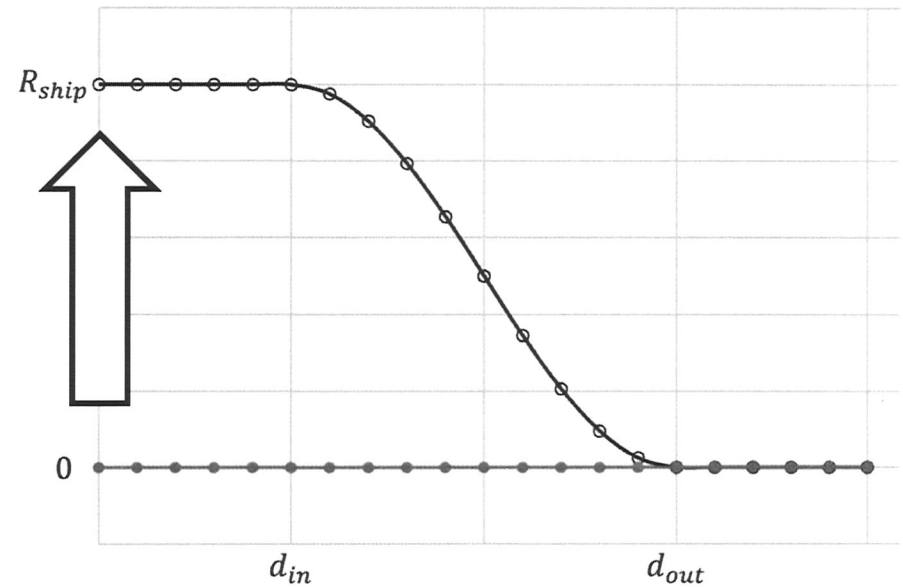
If $d_{in} < d \leq d_{out}$ then $\mathbf{R} = \mathbf{R}_{ship} \cdot \frac{\cos\left(\frac{(d-d_{in})\pi}{(d_{out}-d_{in})}\right) + 1}{2}$

If $d > d_{out}$ then $\mathbf{R} = \mathbf{0}$

$$\mathbf{R}_{new} = \mathbf{R}_0 + \mathbf{R}$$

- 격자의 속도

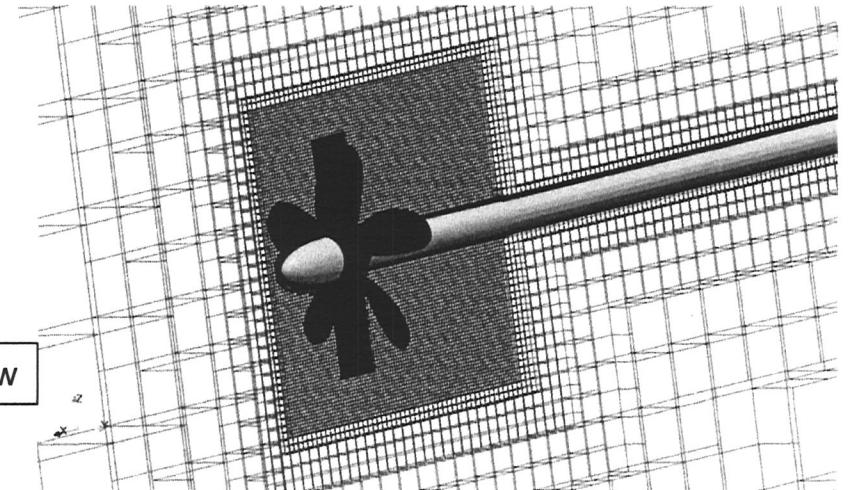
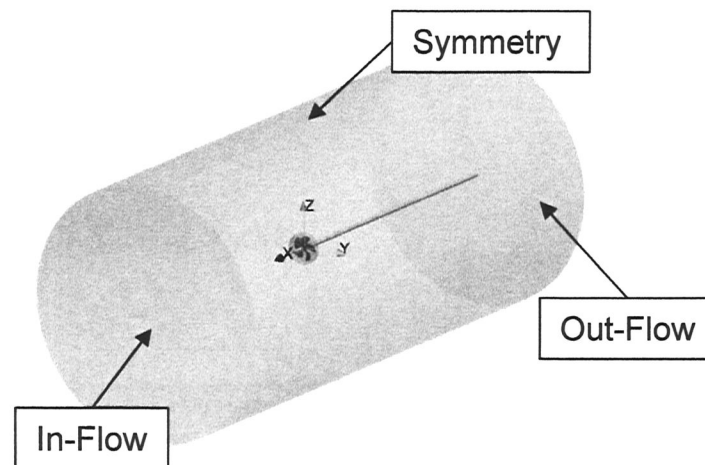
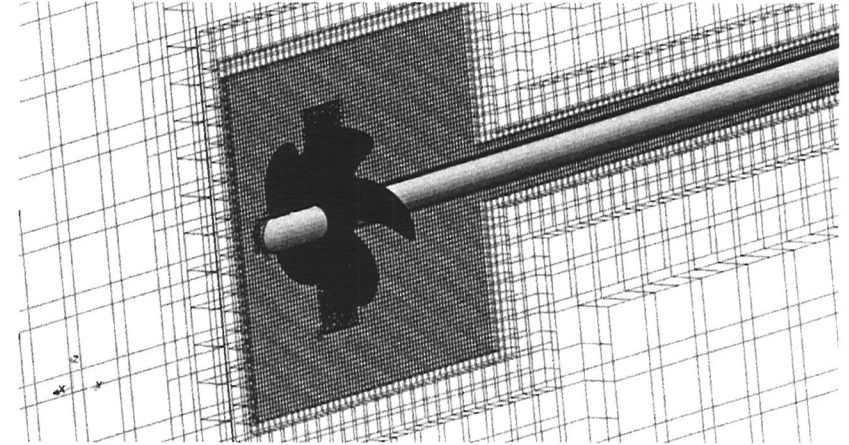
$$\mathbf{U}_{mesh} = (\mathbf{R}^{n-1} - \mathbf{R}^n) / dt$$



수치해석 검증 – Propeller Open-Water Test

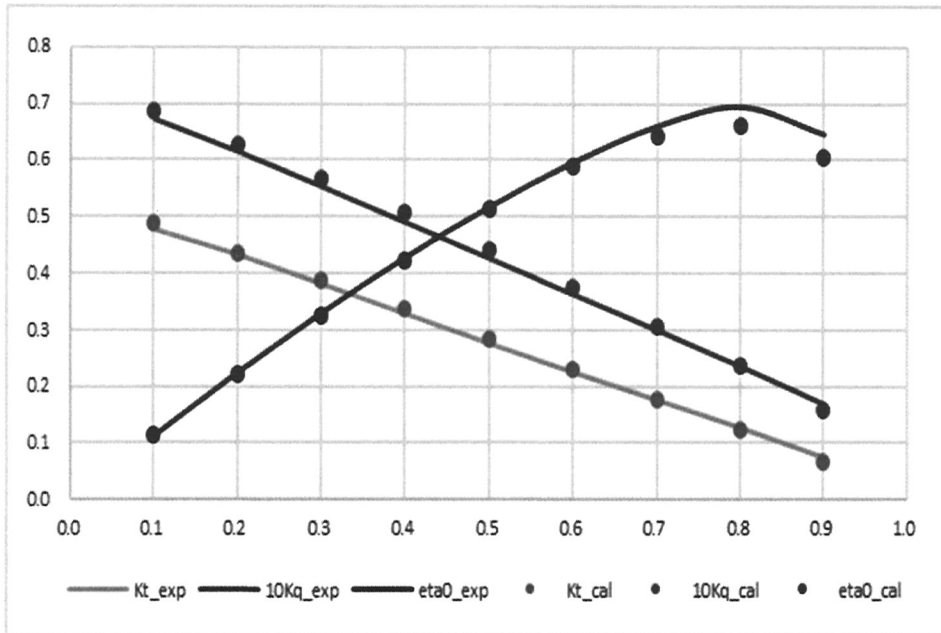
➤ Simulation conditions

- Propeller
 - KP505(Top) / MP687(Bottom)
- Mesh
 - Propeller region : poly-hedral
 - Outer region : hex-hedral
 - Total number of grid : about 2 million
 - $Y^+=50$ at $0.7R$
- Rotation control
 - MRF Model

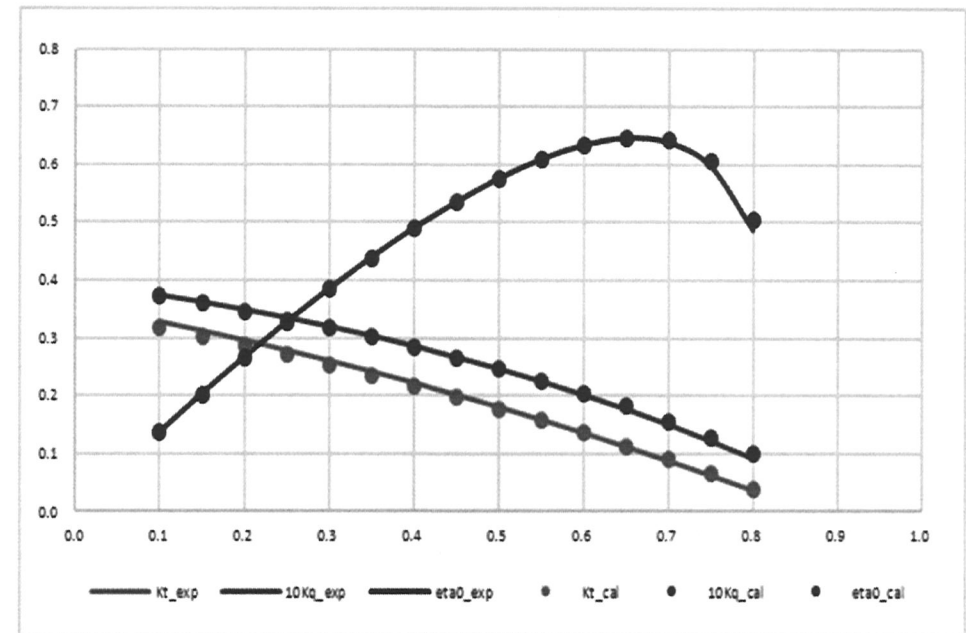


➤ Verification results

- Thrust, Torque and Efficiency coefficients



KP505



MP687

수치해석 검증 – Resistance

➤ Simulation conditions

▪ Target ships

- KCS (항주자세 고정)
- JBC (항주자세 자유)

▪ Mesh

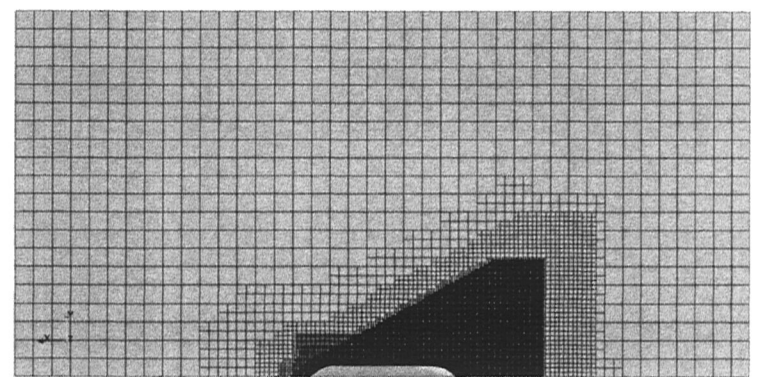
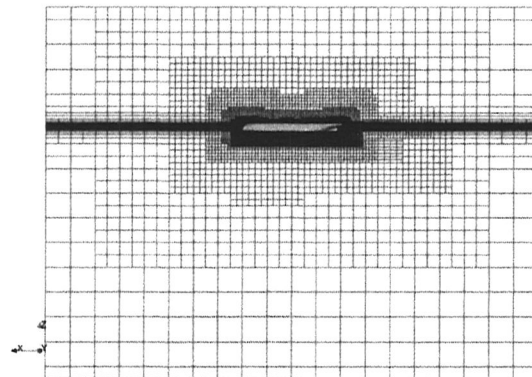
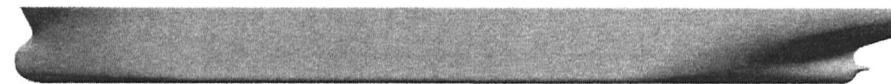
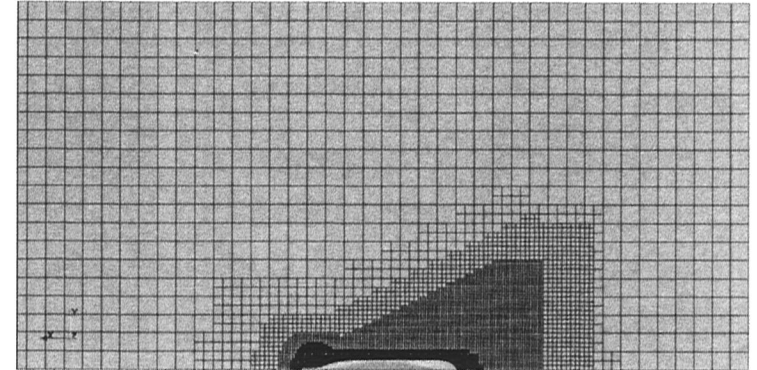
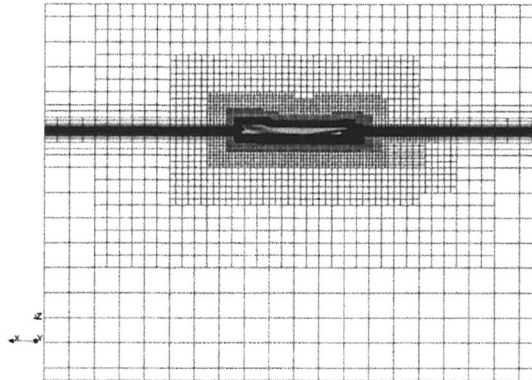
- The number of prism layers : 6
- Total number of grid
 - KCS : 1 million
 - JBC : 2 million

▪ Froude Number

- KCS : 0.260
- JBC : 0.142

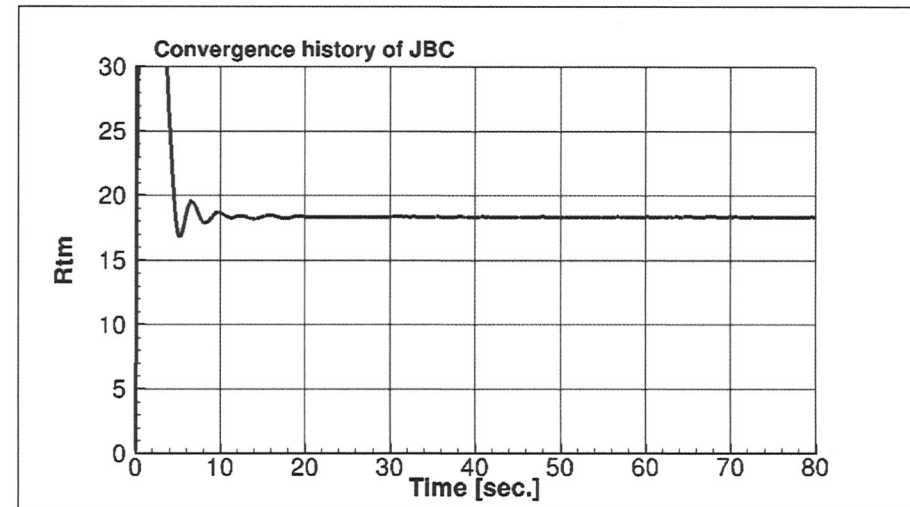
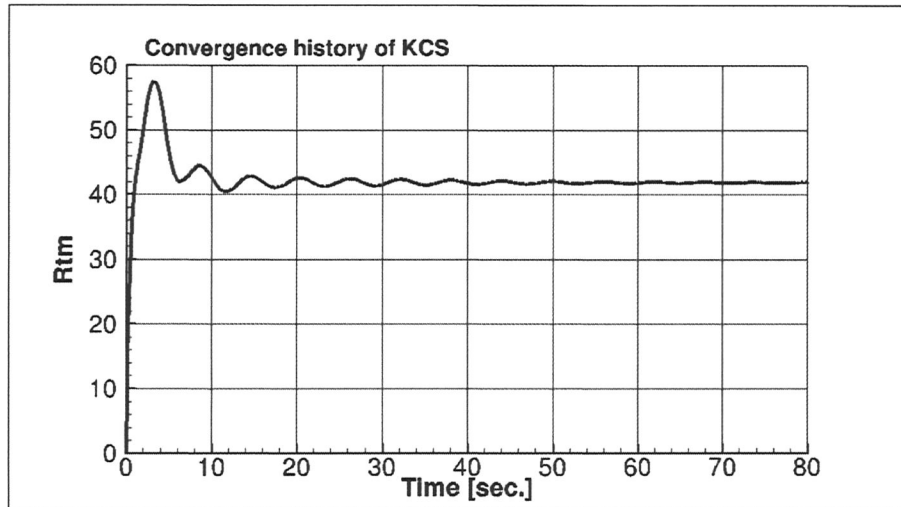
▪ Reynolds Number

- KCS : 1.40×10^7
- JBC : 7.46×10^6



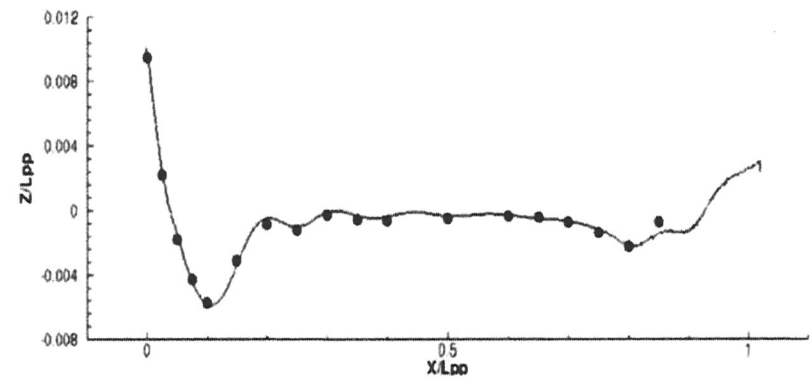
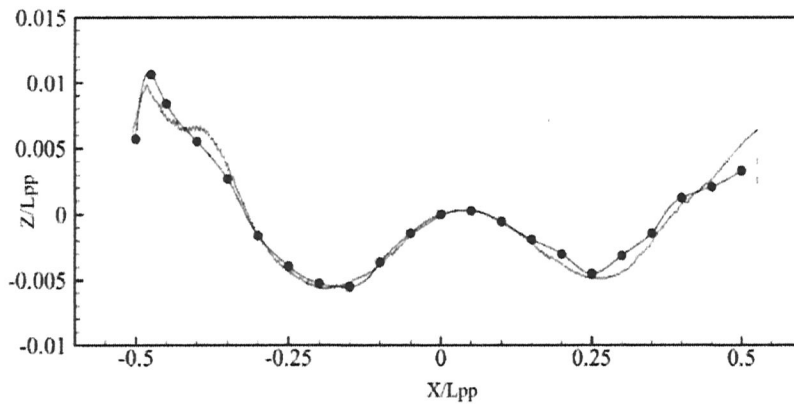
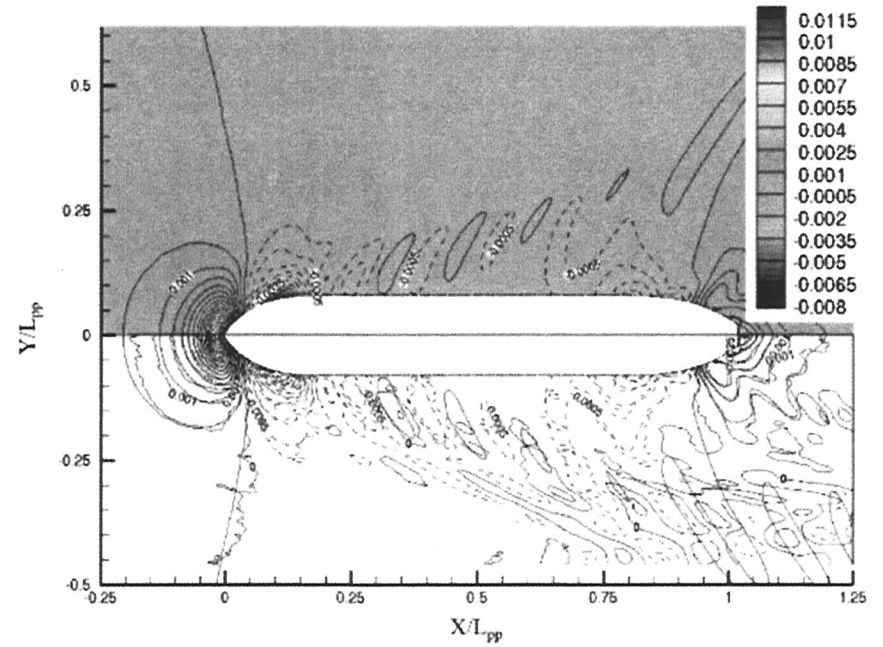
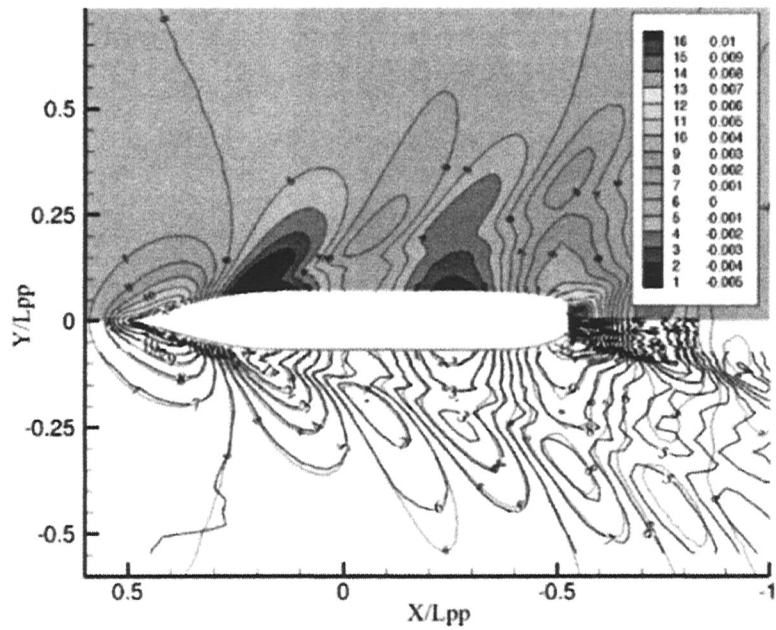
➤ Verification results

▪ Resistance



	KCS			JBC		
	Exp.[3]	Present	Error	Exp.[5]	Present	Error
Total resistance (N)	41.170	41.847	1.64%	18.206	18.500	1.62%
Frictional resistance (N)	32.777	33.346	1.74%	13.409	13.691	2.10%
Pressure resistance (N)	8.393	8.501	1.28%	4.797	4.809	0.26%
Wake fraction	0.208	0.224	7.80%	0.61	0.59	-2.81%
Sinkage (%Lpp)	-	-	-	-0.086	-0.0908	-5.58%
Trim (%Lpp)	-	-	-	-0.180	-0.190	-5.39%

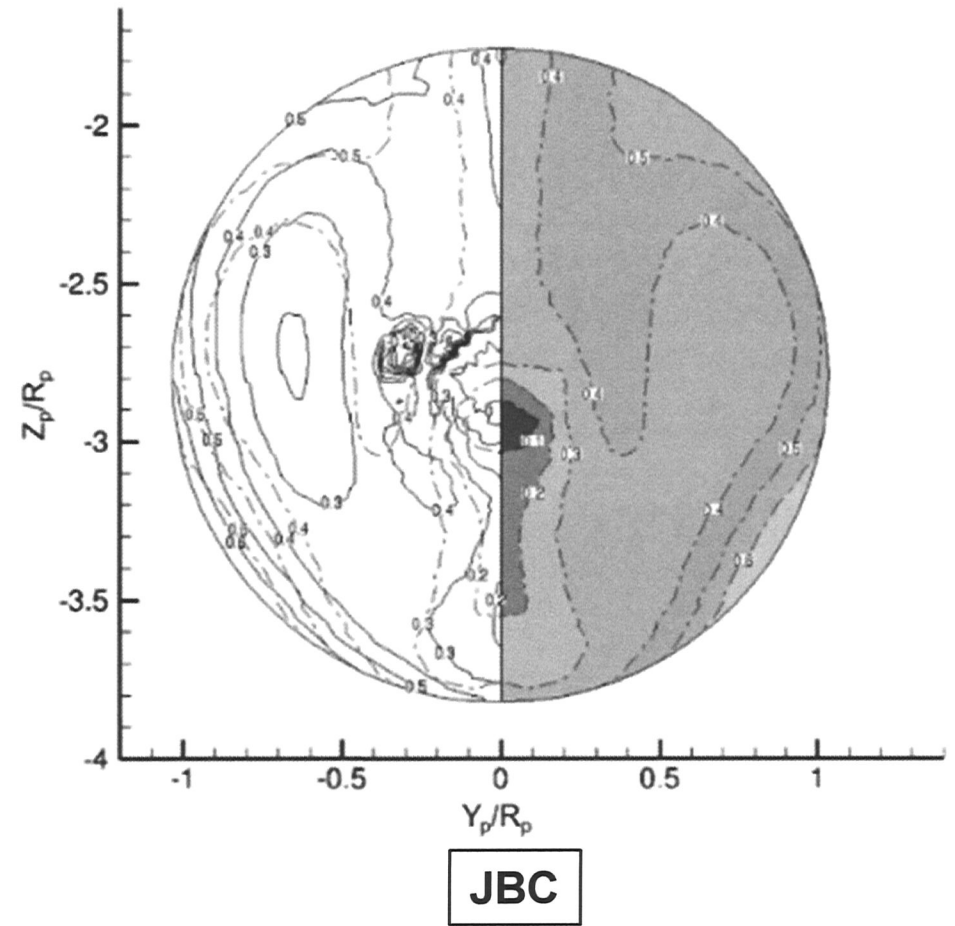
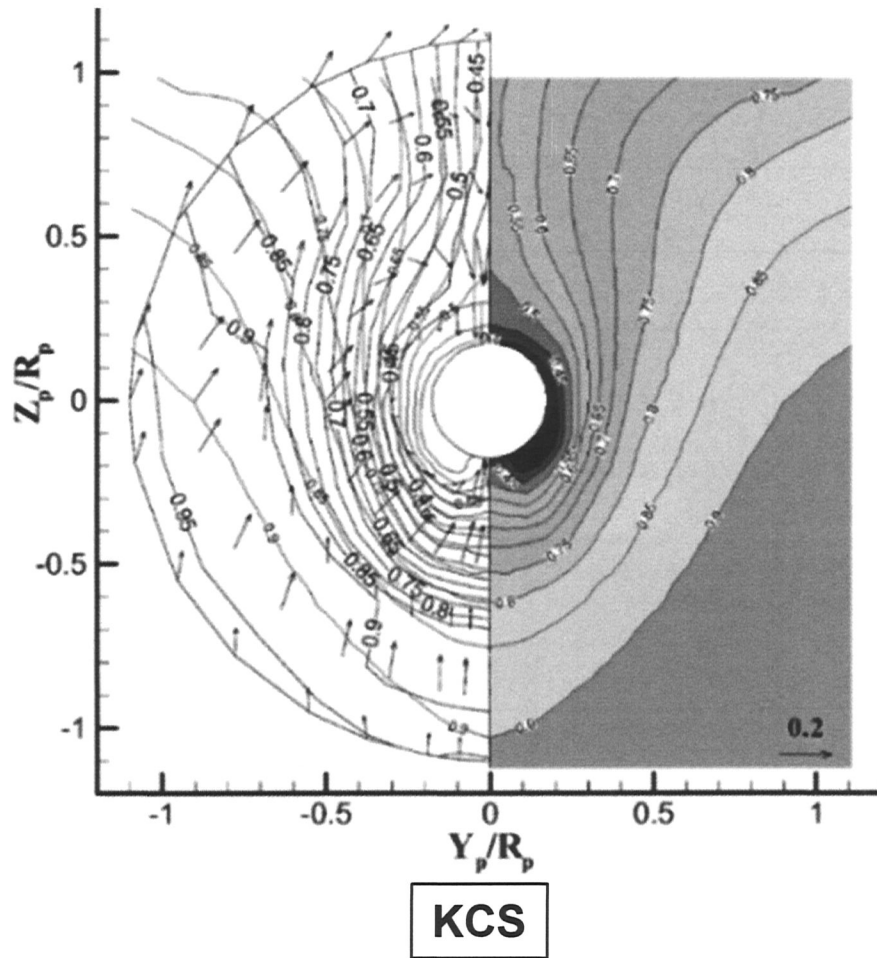
- Wave pattern and Wave height along the hull surface



KCS

JBC

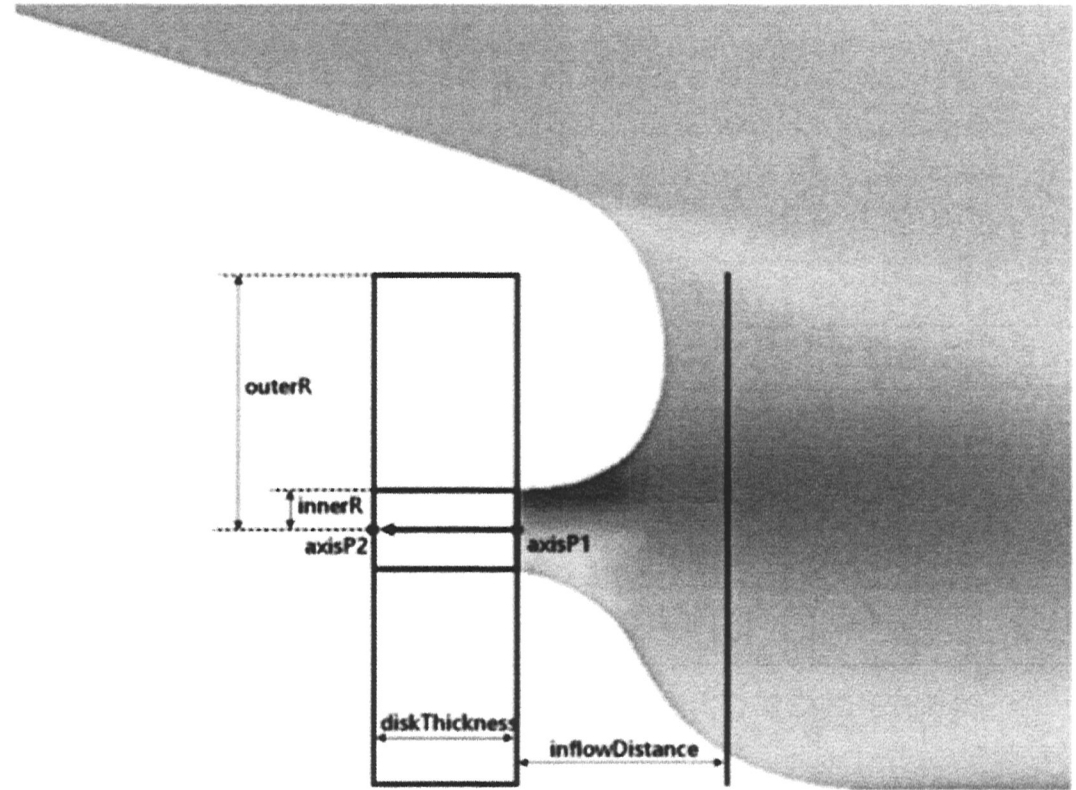
- Wake distribution at propeller plane [KCS, $X/L_{pp} = -0.4825$] (left), [JBC, $X/L_{pp} = -0.4843$](right)



수치해석 검증 – Self propulsion [JBC]

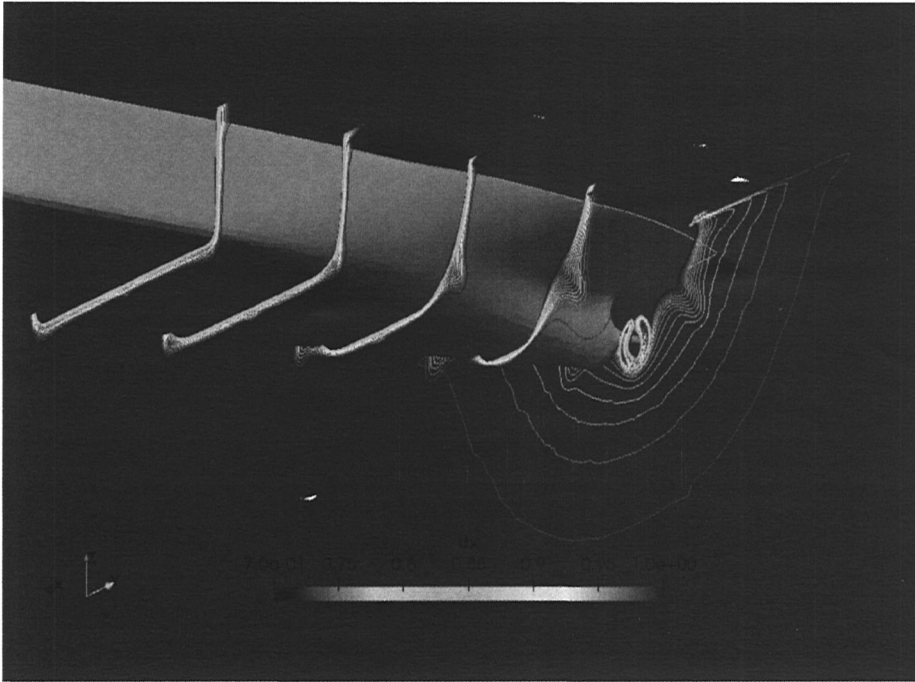
➤ Simulation conditions

- Target ships
 - JBC (항주자세 유동)
- Mesh
 - The number of prism layers : 6
 - Total number of grid : 4 million
- Solving
 - Actuation disk model
 - Kt, Kq form POW data
- Froude Number : 0.142
- Reynolds Number : 7.46×10^6



<Definition sketch for virtual propeller>

➤ Verification results



Velocity contour around the stern of ship

Resistance and propulsion coefficients

	Exp.[5]	Present	Error
Total resistance (N)	40.844	41.344	1.22%
Frictional resistance (N)	26.818	26.783	-0.13%
Pressure resistance (N)	14.025	14.561	3.82%
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%

결론 및 향후연구

➤ 결론

- 상용 저항해석 프로그램을 대체할 수 있을 것으로 판단됨
 - 추력과 토크 계수 오차 1%이내 (전진비 0.6 이하)
 - 저항 오차 2% 이내
 - 항주자세 오차 6% 이내(JBC)

➤ 향후연구

- Sliding 기법과 Body-force 기법을 통한 저항해석 비교 검토
- PMM 해석을 위한 기능개발 및 검증
- 파도 중 저항/자항 해석 기능개발 및 검증

감사합니다