



*FLOW-3D*®

*- Maritime -*



Connect & Development  
**주식회사 에스티아이 C&D**  
창조적 지식기반 전문엔지니어그룹

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1. Introduction to (주)에스티아이C&D

2. Introduction to FLOW-3D®

3. FLOW-3D® Maritime Application



# Introduction to (주)에스티아이C&D

# 에스티아이C&D 연혁

- ❖ **설립일 : 1997년 11월**
- ❖ **위치**
  - ◆ 서울시 금천구 가산동 우림라이온스밸리 B동 301호
  - ◆ 미국 Seattle
- ❖ **업무영역**
  - ◆ FLOW-3D® 한국 내 공급 및 유지보수
  - ◆ 구조, 열유체 관련 컨설팅 및 용역
  - ◆ 구조분야 해석 및 금형 개발
  - ◆ 협업 및 PDM 관련 소프트웨어 개발
- ❖ **연구인력구성**
  - ◆ 19명 : 박사 2인, 석사 8인
- ❖ **주요 컨설팅 업체**
  - ◆ 현대/기아자동차, 현대모비스, 삼성종합기술원, LG전자, 대림기업, KAIST, KIST, POSCO, 인지 AMT, 신창전기, 동남공업 등
  - ◆ 한국수자원공사, 한국전력공사, 삼성건설, 대우건설, GS건설, SK건설, 등



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*Introduction to **FLOW-3D**®*

# FLOW-3D® 개발 연혁

## ❖ 개발 연혁

- ◆ 1960년대 미국 Los Alamos Lab에서 자유표면 연구 시작
- ◆ VOF method 창시 (B.Nichols, C.W.Hirt)
- ◆ 1980년 Flow Science 설립 (C.W.Hirt)
- ◆ 1985년 Version 1.0 Release
- ◆ 현재 Version **10.0.2** Release

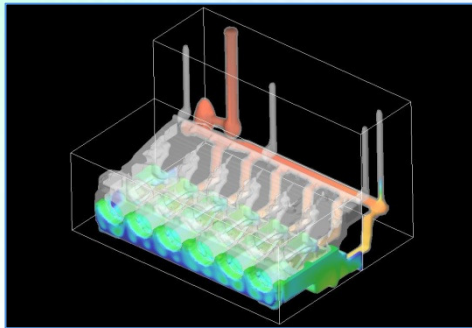


## ❖ 특성

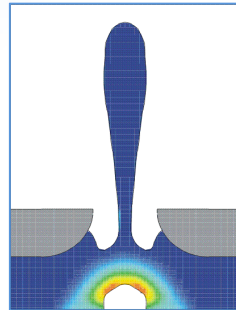
- ◆ 세계 최초 VOF, FAVOR method 개발 및 적용
- ◆ 자유표면, 열전달, 응고의 정확성으로 명성
- ◆ 기체-액체, 고체-액체 interaction 해석 기능 탁월

# FLOW-3D<sup>®</sup>'s Main Application Areas

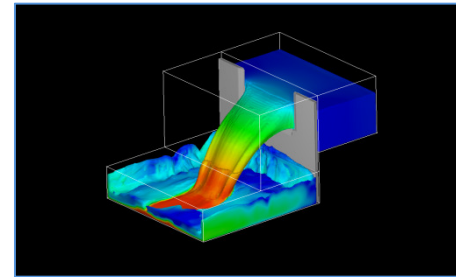
*The same solver for all applications!*



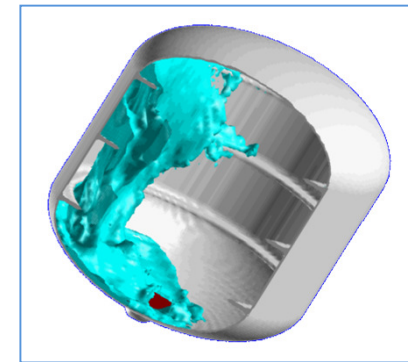
Metal Casting



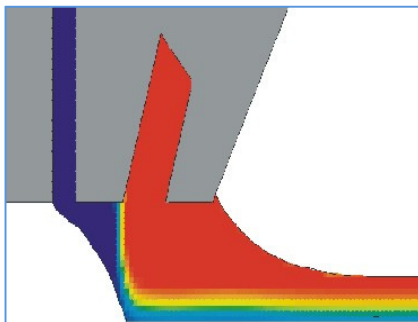
Inkjets



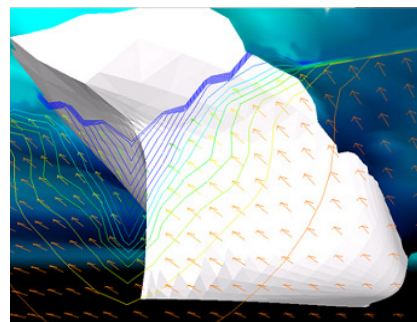
Water &  
Environmental  
Engineering



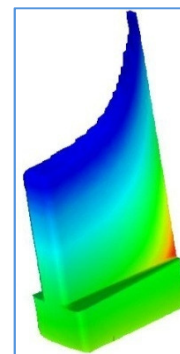
Aerospace



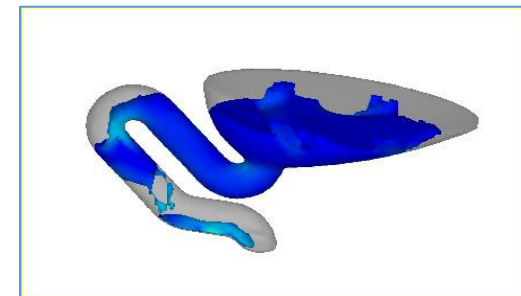
Coating



Marine



MEMS



Consumer Products

# FLOW-3D<sup>®</sup> 의 구성

- ❖ Pre-processor (전처리 기능)
  - ◆ GUI, Text mode
  - ◆ Initial condition, boundary condition, mesh generation, physical option, ...
  - ◆ CAD interface
- ❖ Solver
  - ◆ 계산 수행
  - ◆ Solver monitoring
  - ◆ User subroutine 작성
  - ◆ Single & Double precision version, Parallel processing version
- ❖ Post-processor (후처리 기능)
  - ◆ Animation, 3D, 2D, graph, ASCII, ...
  - ◆ Post 전용프로그램 interface
- ❖ Hardware
  - ◆ PC, Unix, Super computer, ...

# FLOW-3D<sup>®</sup>의 기능

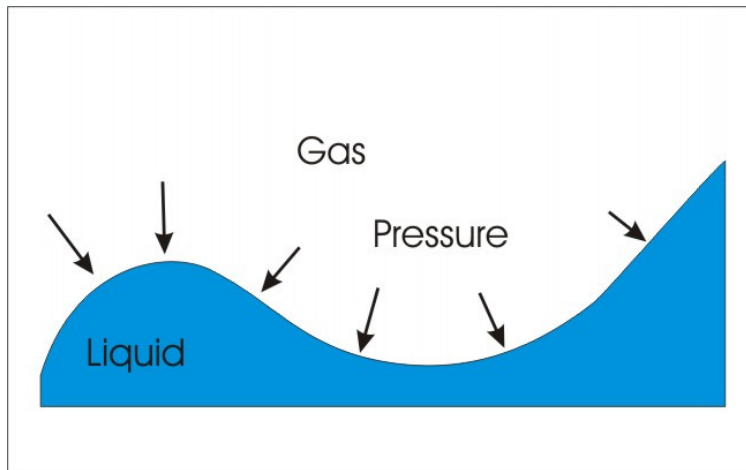
- ❖ 자유표면 예측
- ❖ 곡면 표현
- ❖ 유한체적법 격자
- ❖ 관수로, 개수로 유동
- ❖ 포텐셜 유동
- ❖ 운동계 내의 유동현상
- ❖ 입자추적
- ❖ 물질의 확산
- ❖ 2상 유동
- ❖ 압축성 유동
- ❖ 자연대류, 강제대류
- ❖ 열전달 (대류, 복사, 전도)
- ❖ FSI(Fluid Structure Interaction)
- ❖ TSE(Thermal Stress Evolution)
- ❖ Moisture Drying
- ❖ 전기장
- ❖ 생성항 (열, 질량, 운동에너지)
- ❖ 점성발열
- ❖ 공동현상
- ❖ 상변화
- ❖ 표면장력
- ❖ 기포 추적
- ❖ 비뉴턴 유체
- ❖ 틱소트로피
- ❖ 난류모델
- ❖ 다공성매질
- ❖ 회전체정의
- ❖ CAD interface
- ❖ GMO(General Moving Object)
- ❖ Granular Flow
- ❖ 증착

# 이론적배경 : Free Surface Modeling

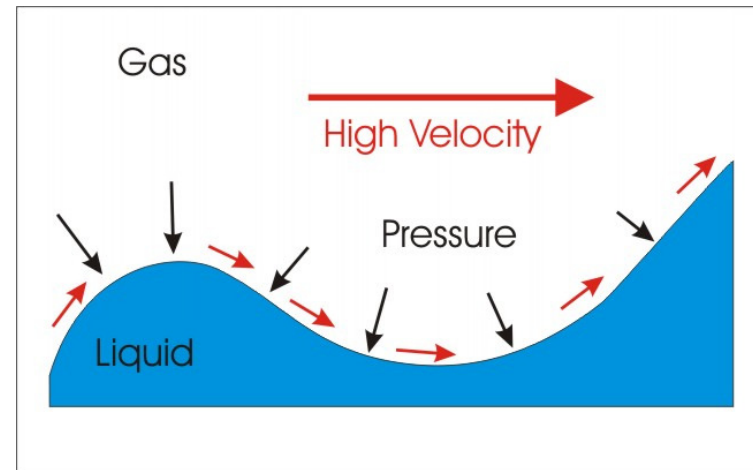
- ❖ **What is a “free surface”**
  - ◆ Liquid/gas interface
  - ◆ Gas only applies a normal force (pressure) to liquid
  - ◆ Usually applicable when density ratio  $\sim 1000:1$
  
- ❖ **Density and viscosity in gas  $\ll$  liquid**
  - ◆ Pressure variations in gas much smaller than liquid
  - ◆ Frictional forces also small in gas

# 이론적배경 : Possible Interface Scenarios

- ❖ Scenario on the left embodies a **“free surface”**
  - ◆ Low gas velocities, and very small shear forces
- ❖ If the gas has high velocity, as on the right, shear may be significant.  
Can't model that scenario as a free surface.
- ❖ Engineer must decide when to use VOF



Free Surface

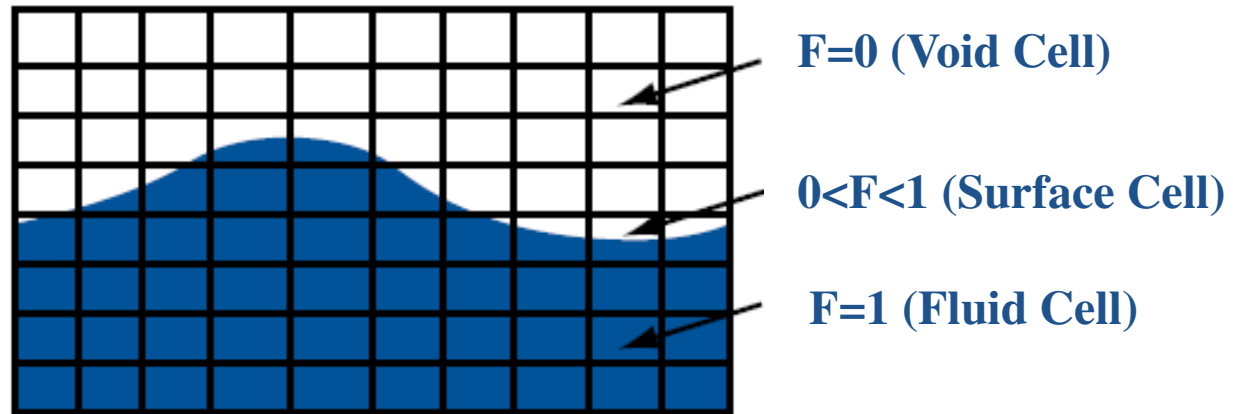


Not a Free Surface

# 이론적 배경(1) : VOF (Volume of Fluid)

- ❖ 자유표면을 정의하는 방법
- ❖ 가정 : Void Pressure = Constant

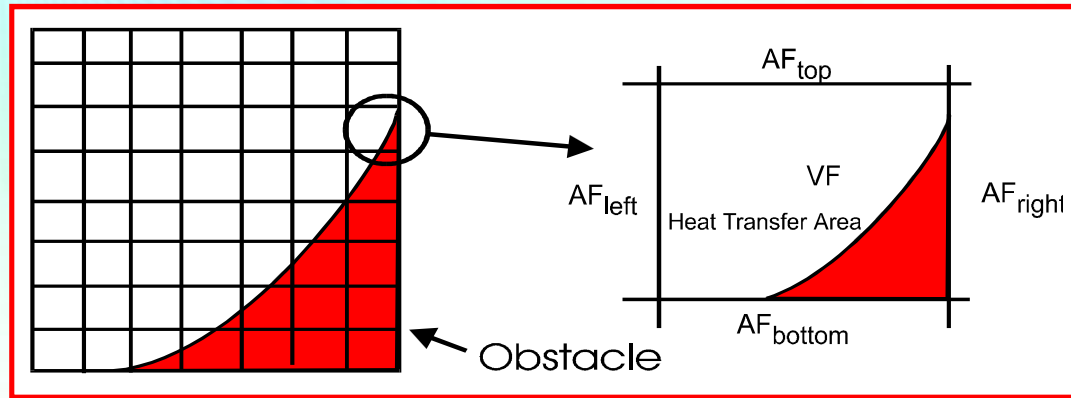
Pressure = constant  
(or  $PV^\gamma = \text{constant}$ )



Method for the definition of free surface

- ➔ 비산 및 Wave breaking같은 복잡한 자유표면운동 기술하는 방법  
: 고정 Eulerian 격자를 사용하는 VOF 방법 이용
- ➔ 정확한 압력 및 운동학적 경계조건을 sharp interface(상이 경계면)에서 적용  
: 특별 수치차분법 사용

## 이론적 배경(2) : FAVOR™



### Quantities Stored

*AFR* - right

*AFB* - back

*AFT* - top

*VF* - Heat Transfer Area

$$VF = \frac{\text{open volume}}{\text{volume of cell}} \quad AF = \frac{\text{open area}}{\text{cell edge area}}$$

### ❖ *Integrated into conservation equations*

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} + w \frac{\partial C}{\partial z} \rightarrow \frac{1}{V_f} \frac{\partial C}{\partial t} + u A_x \frac{\partial C}{\partial x} + v A_y \frac{\partial C}{\partial y} + w A_z \frac{\partial C}{\partial z}$$

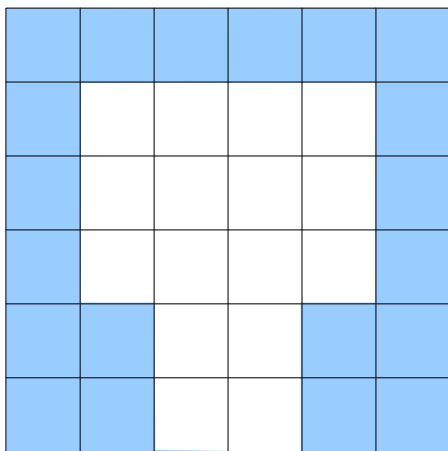
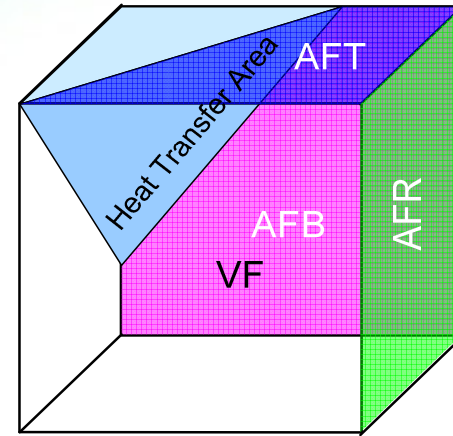
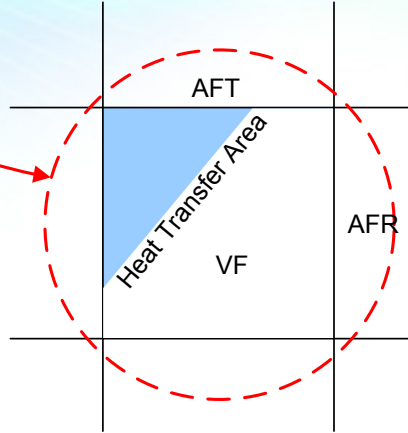
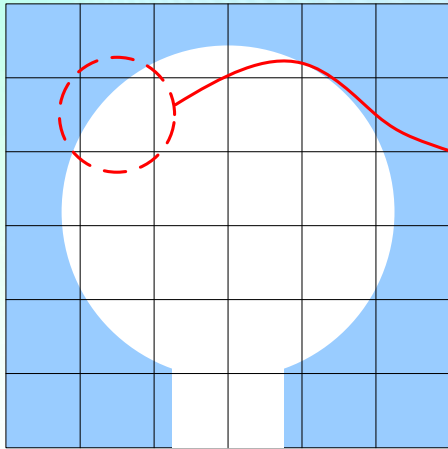
### ❖ **FAVOR : Fractional Area/Volume Representation**

### ❖ **신속하고 정확한 곡면 표현 (Direct CAD Interface)**

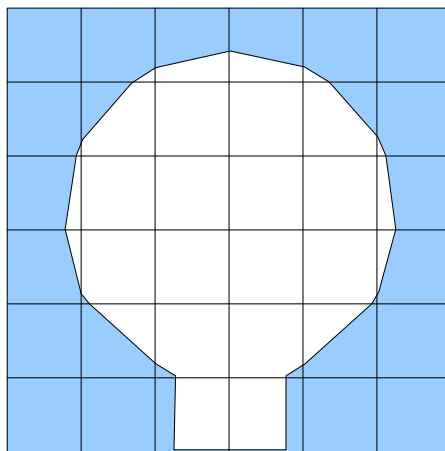
**➔ 유동 및 열전달 계산의 정확성 확보**

# 이론적배경 : FAVOR™

실제 형상



일반 육면체 격자



FLOW-3D® : FAVOR



FAVOR™

Direct CAD Interface  
신속하고 정확한 곡면표현



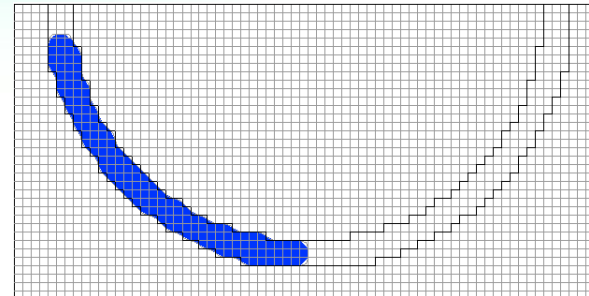
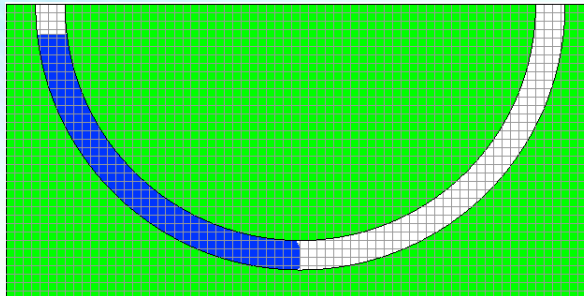
유동/열전달 정확성 확보

# FLOW-3D® (FAVOR™) vs. 육면체격자

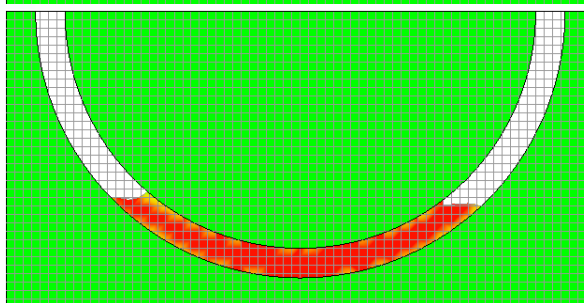
FLOW-3D : FAVOR

육면체격자

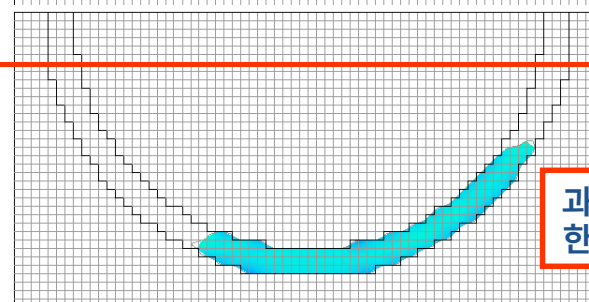
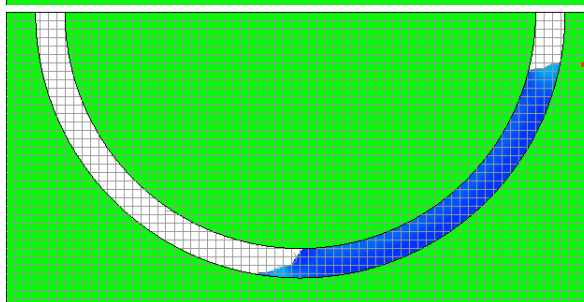
t = 0.0 sec



t = 0.5 sec



t = 1.0 sec



정확한 곡면 표현



실제와 동일한 결과

부정확한 곡면 표현



실제와 상이한 결과

# 타 유동해석 프로그램과의 차이점

- ❖ 기상의 유체와 액상의 유체를 모두 해석
  - 일반 2 fluid 해석시 기상과 액상사이에 운동량 확산(momentum diffusion)이 존재하므로 해석의 정확성 감소.
  - 계산 시간의 증가
    - ➡ FLOW-3D : 액상의 유체만을 해석함.
  
- ❖ Cell 표면에서의 부정확한 유체속도
  - Cell 중심위치에서의 유체속도를 사용하므로 Cell 표면의 속도를 구하기 위하여 보간(interpolation)을 수행함.
  - 일반 VOF 방법은 Cell 중심에서의 속도를 사용하므로 부정확한 해석이 됨.
    - ➡ FLOW-3D : Cell 표면에서 유체의 속도를 사용 ; 보간 불필요, 정확한 값

# 수치해석의 배경

## ❖ 기술 선진화의 요구

- ◆ 선진국 : 3차원 유동해석의 적용 증가
- ◆ 사전 점검을 통한 수치리 구조물 효율 증대
- ◆ 최적 운영조건 확보를 위한 기초 자료 수집
- ◆ 수리 구조물 흐름 및 확산 등 유동현상에 대한 이해 확대
- ◆ 데이터화된 결과 분석을 통한 기술력 증진

# 수치해석과 실험 비교

구 분	실 험	수 치 해 석
비 용	모델 제작비	소프트웨어, 컴퓨터
소요시간	모델 제작 및 실험 시간	모델링 시간, 계산 시간
정 확 성	정확	정량적 결과 : 보정 필요 정성적 결과 : 정확
다 양 성	모델 수정이 어려움	자유로운 모델 수정
Data수집	조건에 따라 측정이 어려움	모든 영역에서 가능
가 시 화	Video 촬영을 통한 가시화	다양한 방법의 시각화
재 현 성	모형 제거 시 재현 불가능	언제나 재현 가능

# 수치해석을 통해 얻을 수 있는 DATA

- ❖ 압력 (Pressure)
- ❖ 속도 (Velocity)
- ❖ 운동에너지 (Kinetic Energy)
- ❖ 난류 관련 정보 (에너지, 점도 변화 등)
- ❖ 특정부위를 지나는 유량, 구조물이 받는 힘, 등
- ❖ 혼합, 확산 (Mixing, Diffusion)
- ❖ Particle Movement
- ❖ 기타 열적 정보 (온도, 밀도, heat flow rate 등)



결과 자료들을 종합하여 목적하는 현상에 대한 정보를 수집하고  
문제점 발생시 원인 및 대책을 수립함.

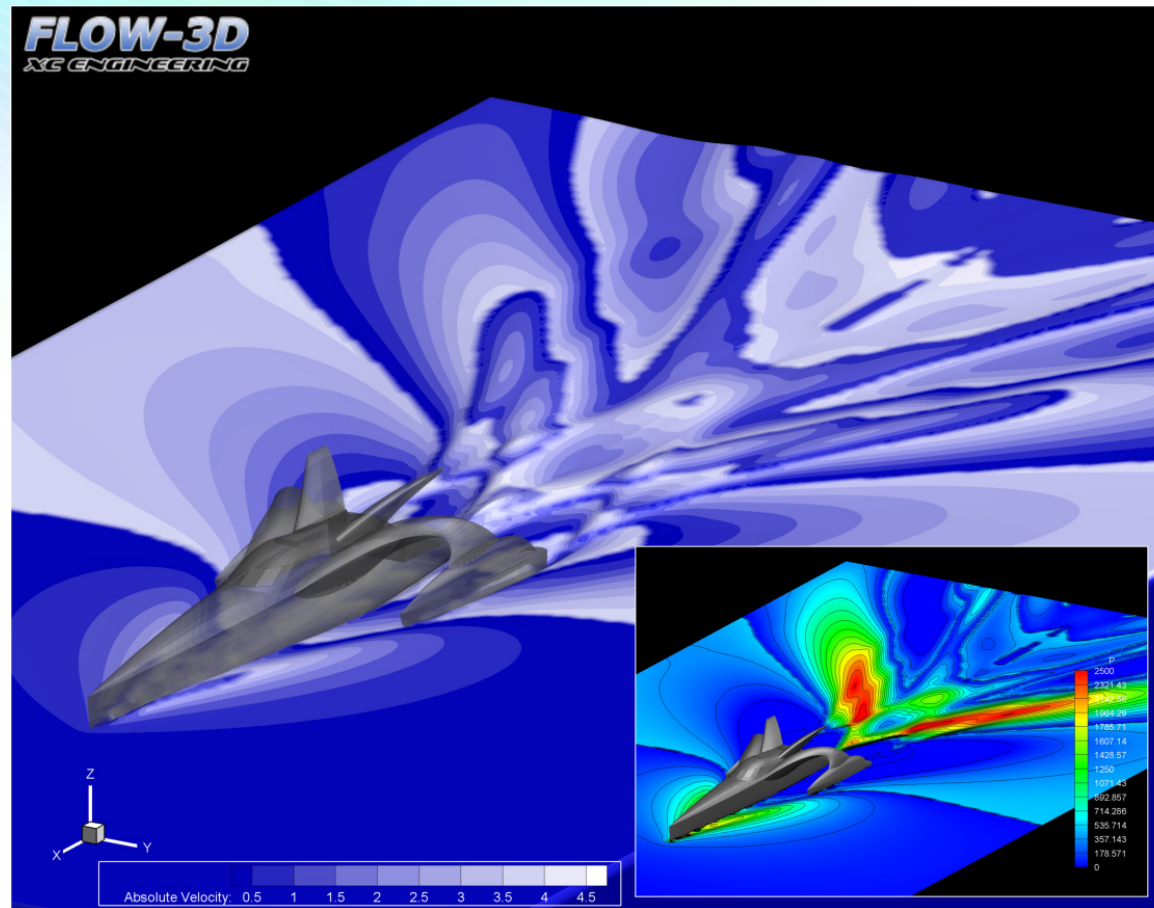


**FLOW-3D®**

**Maritime Application**

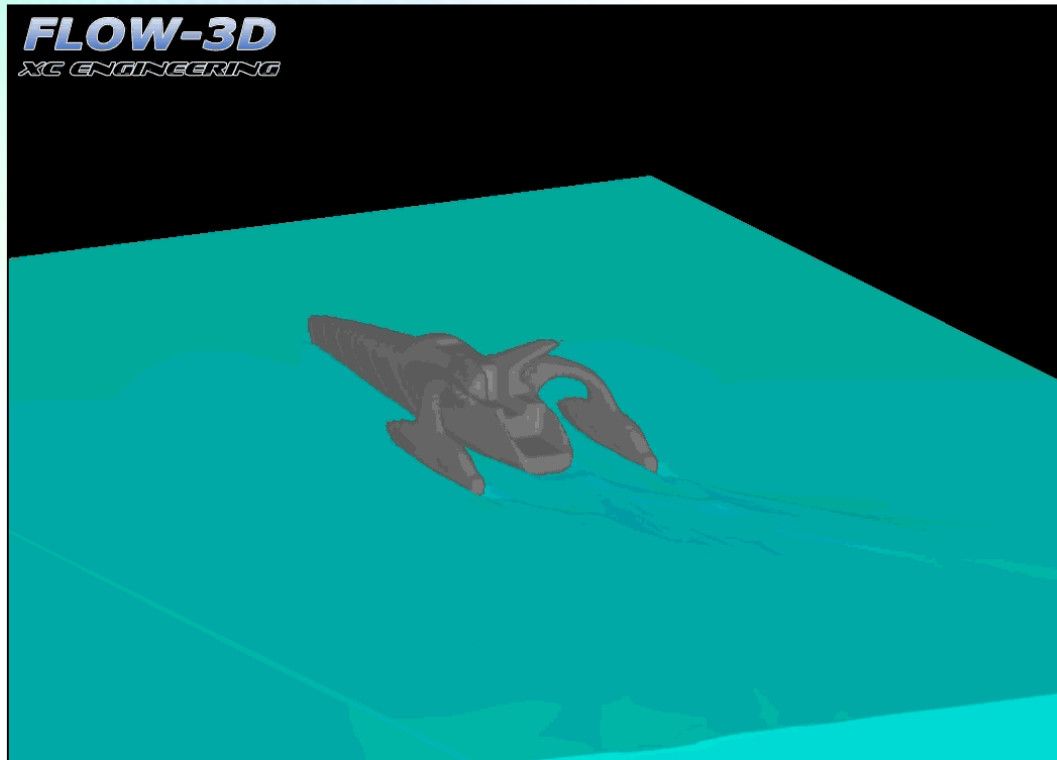


# Velocity and Pressure Field in Calm Water

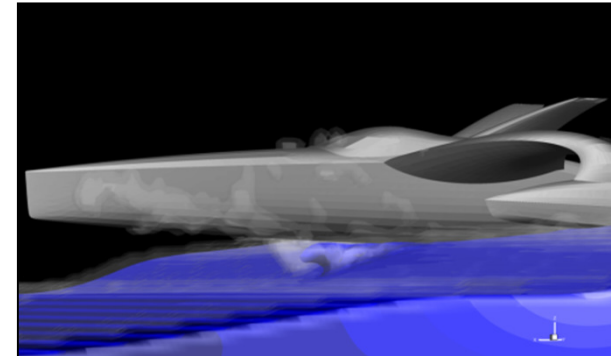


2008 World Earth Race Champion

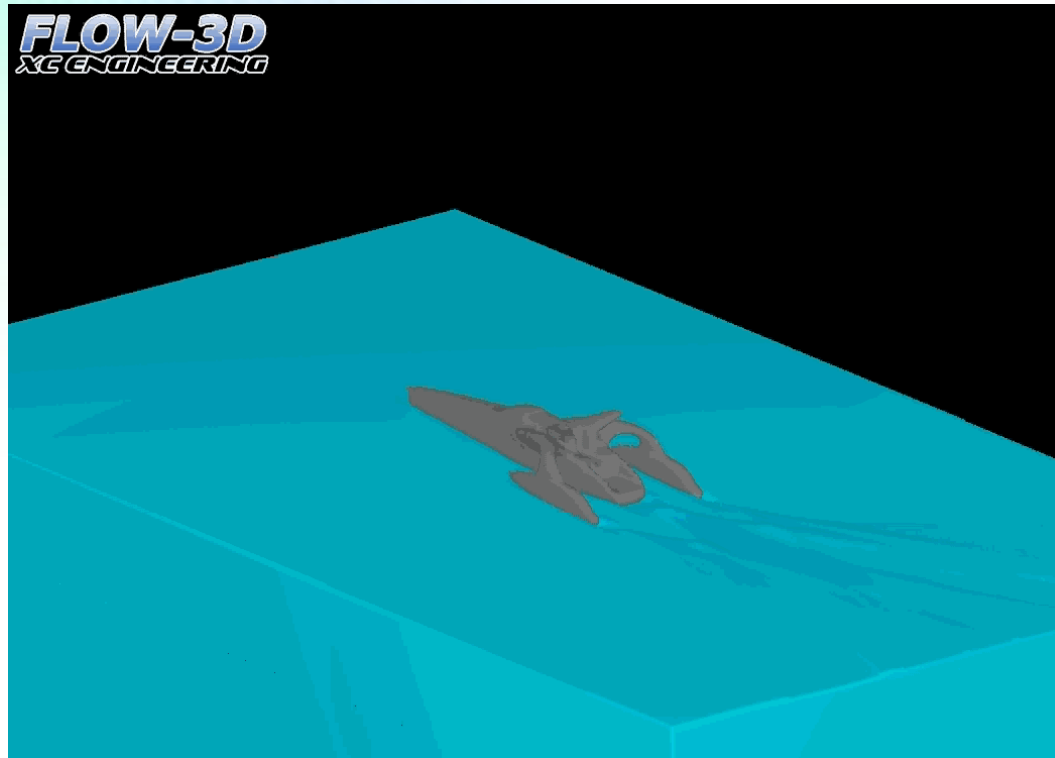
# 4meter Waves Simulation



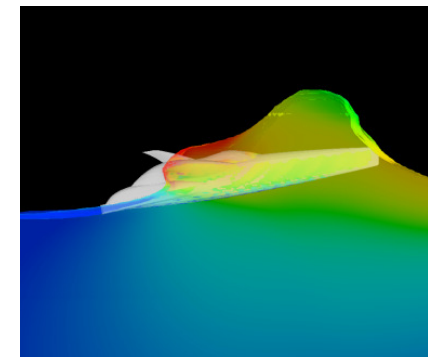
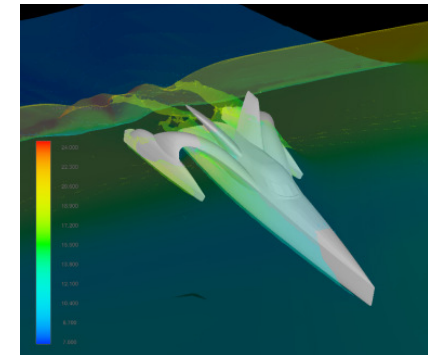
2008 World Earth Race Champion (avi)



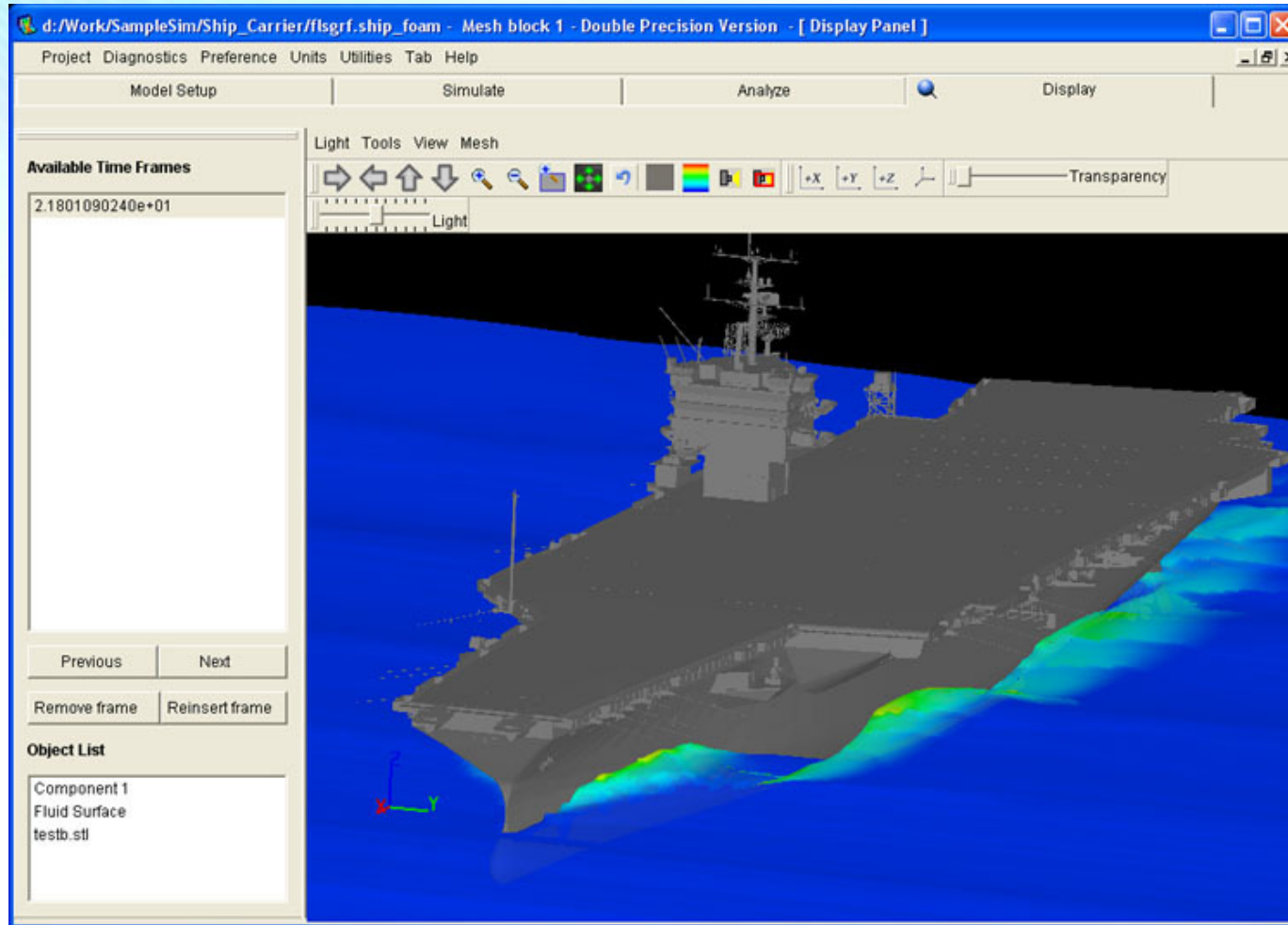
# 12meter Waves Simulation



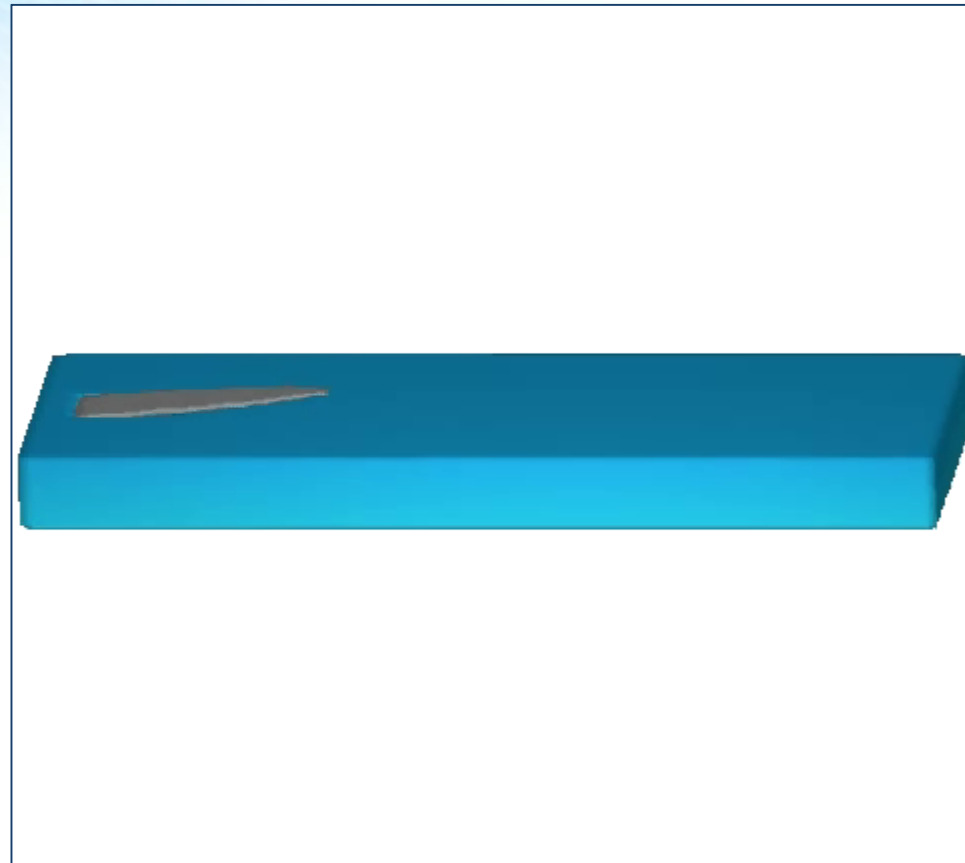
2008 World Earth Race Champion (avi)



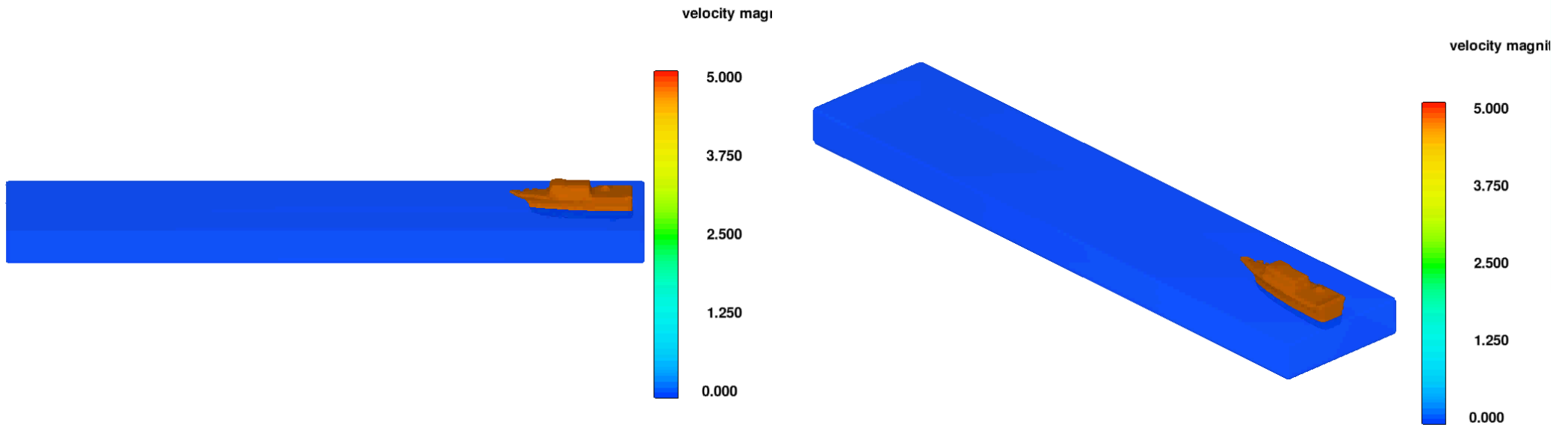
# Hull Design



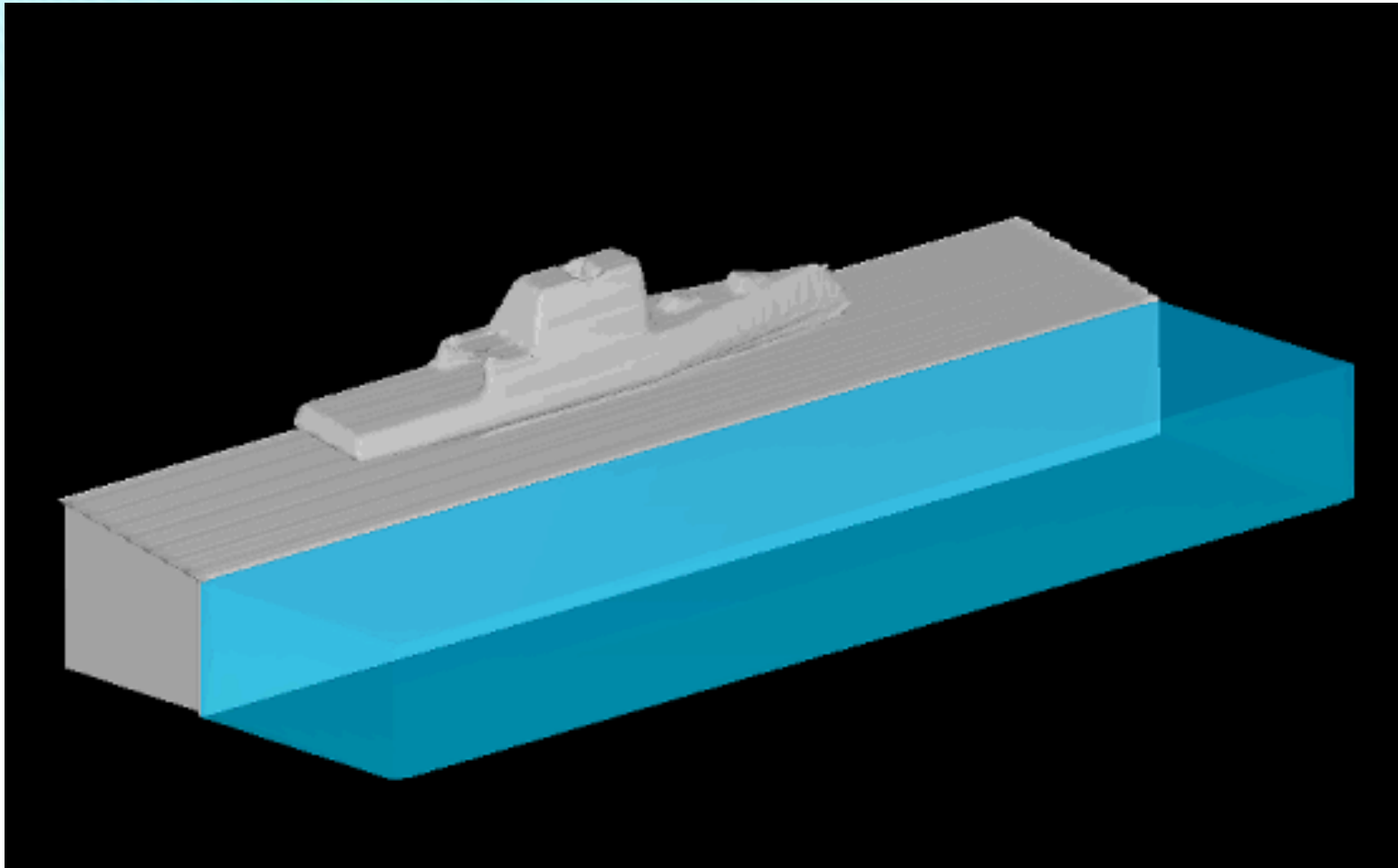
# Tracking the Wake of a Boat



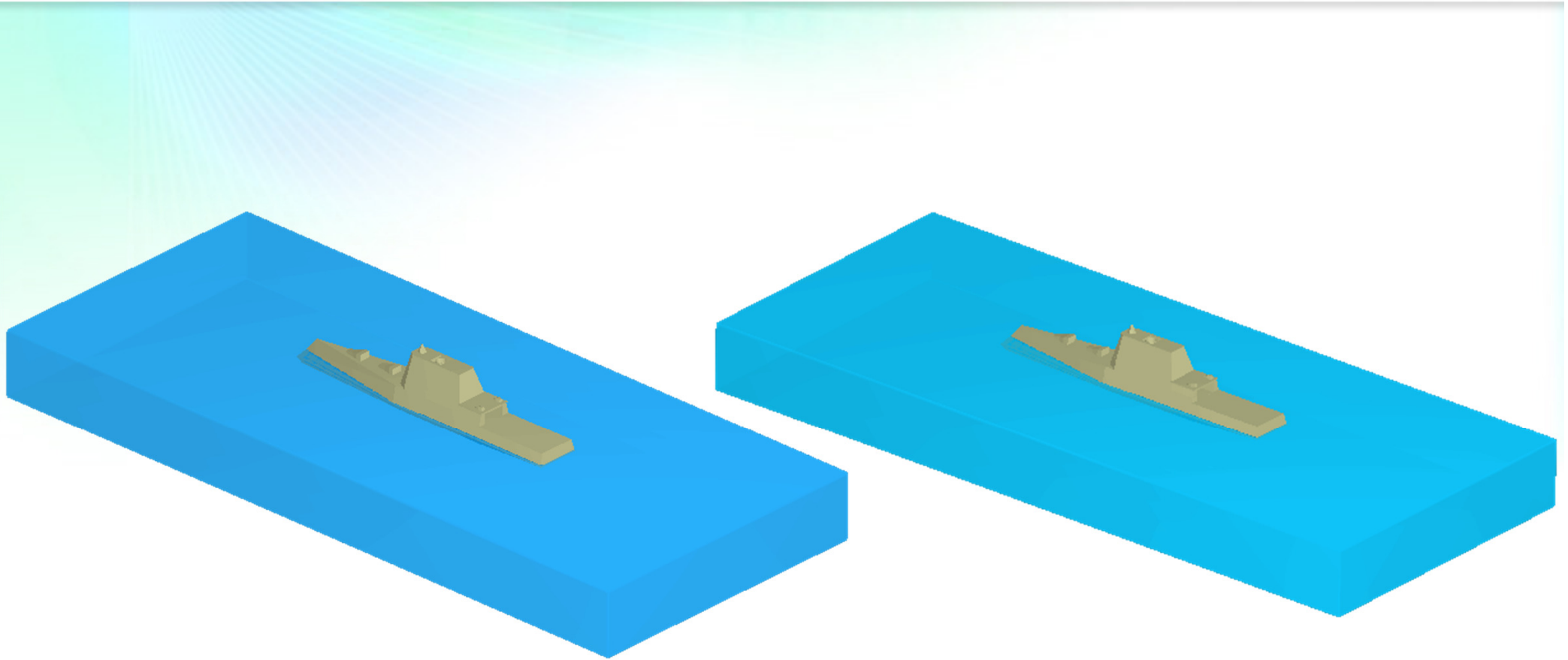
# Tracking the Wake of a Boat



# Launch Ship



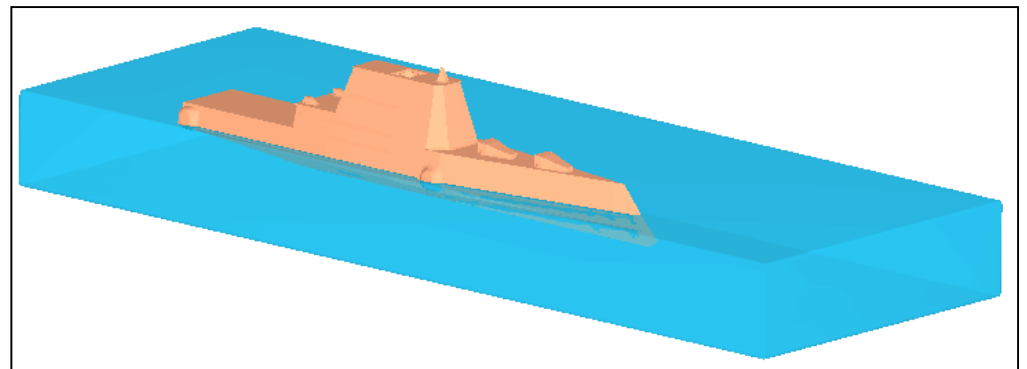
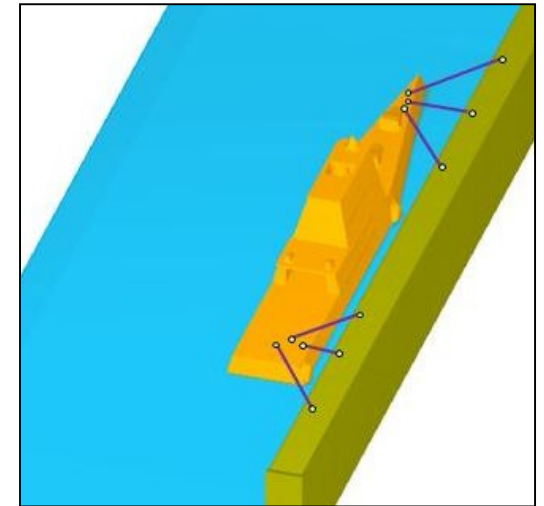
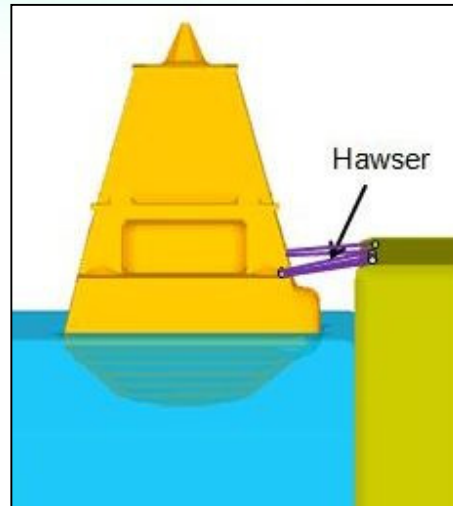
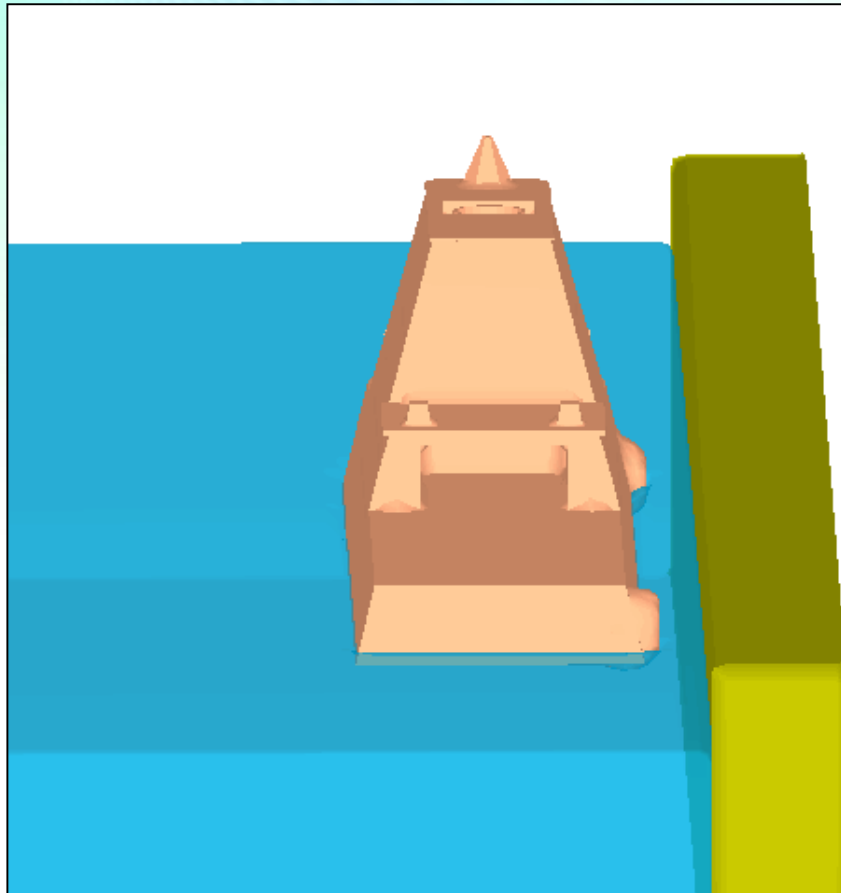
# Modeling Unstability vs. Stability



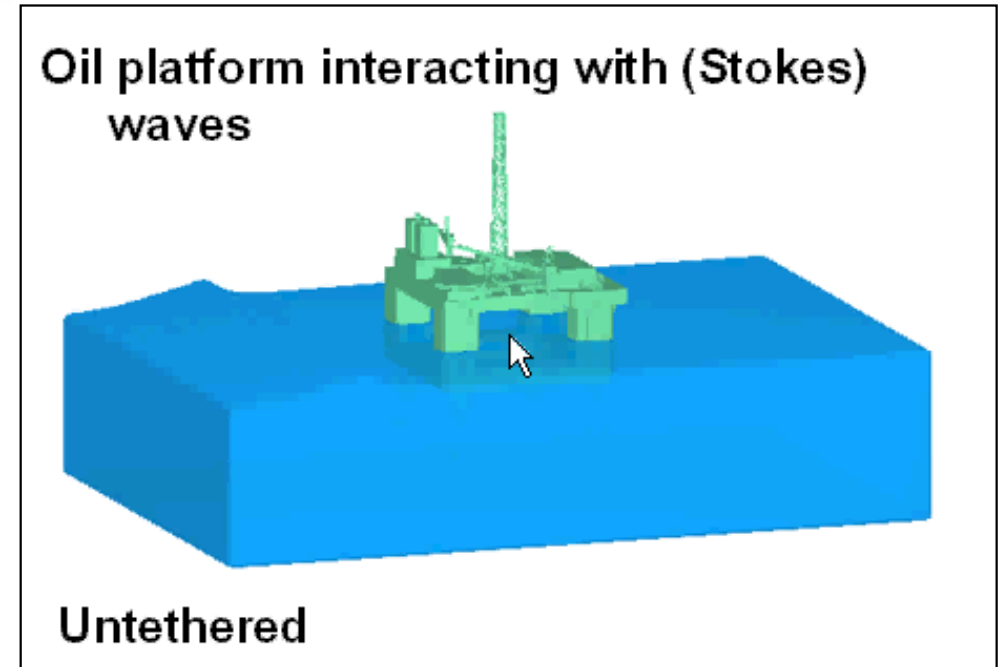
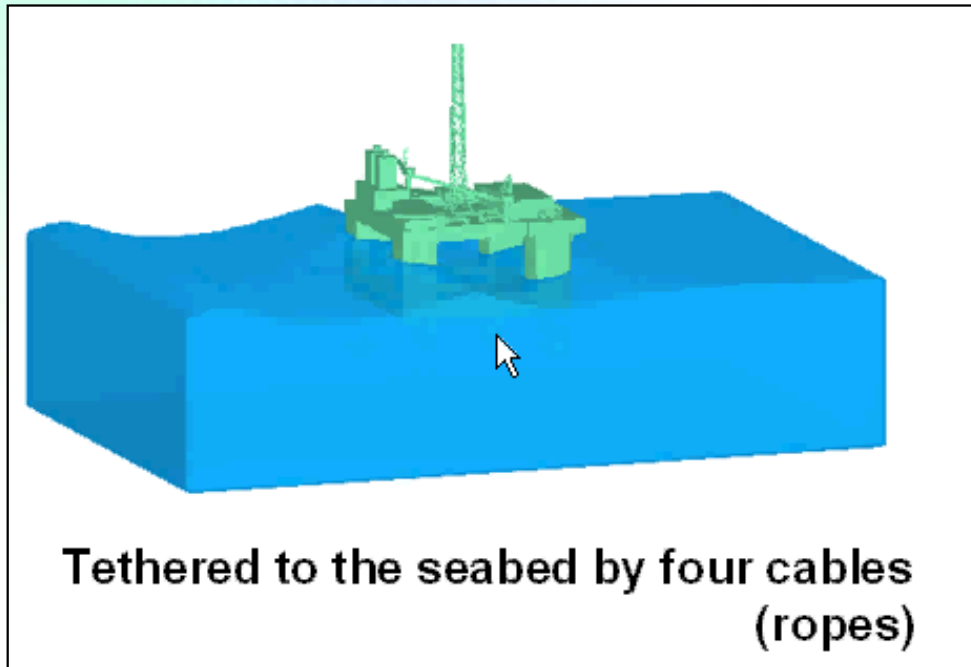
**Unstability**

**Stability**

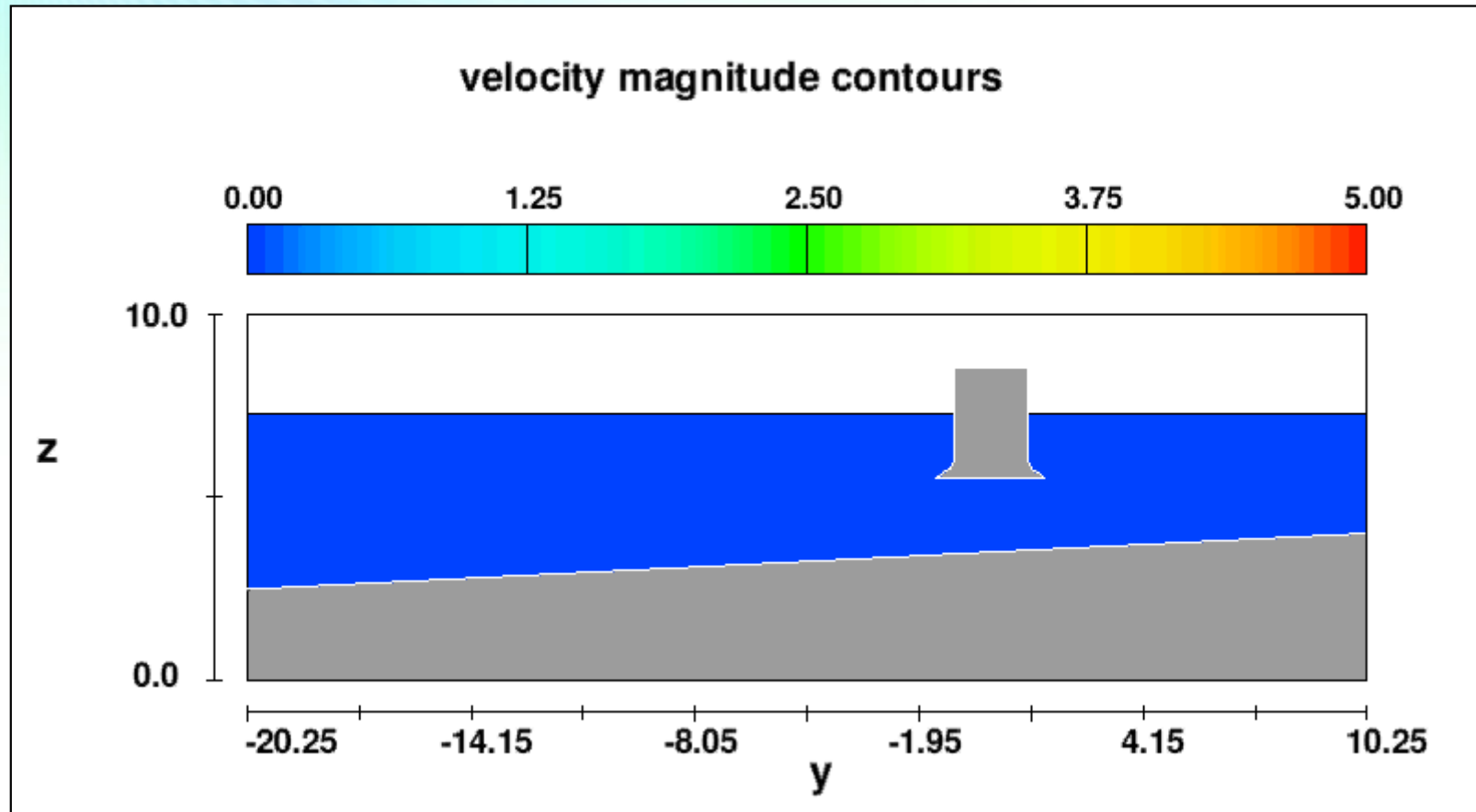
# Moored Ship Using Springs & Ropes



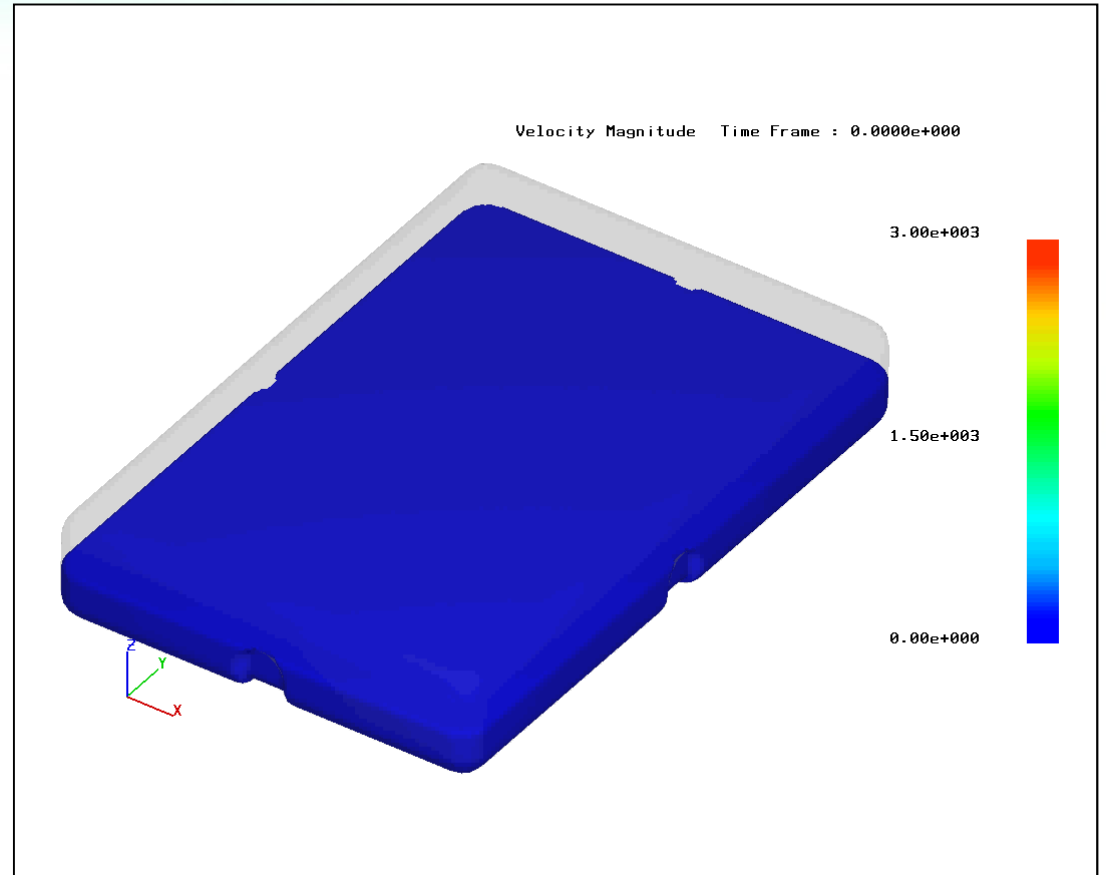
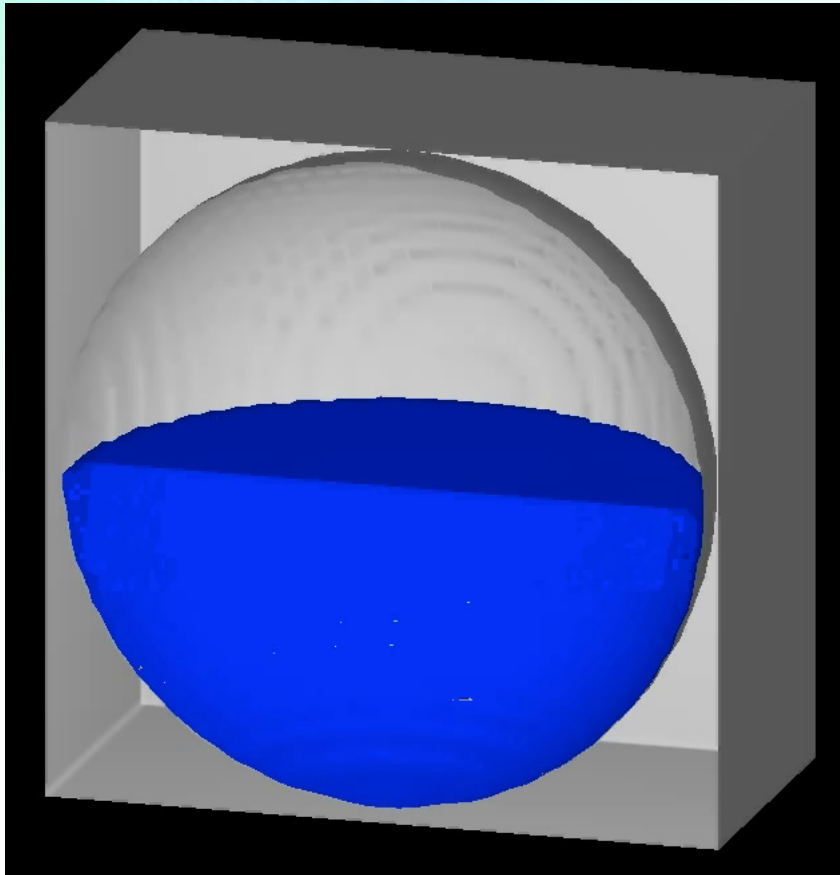
# Moored Ship Using Springs & Ropes



# Floating Breakwater



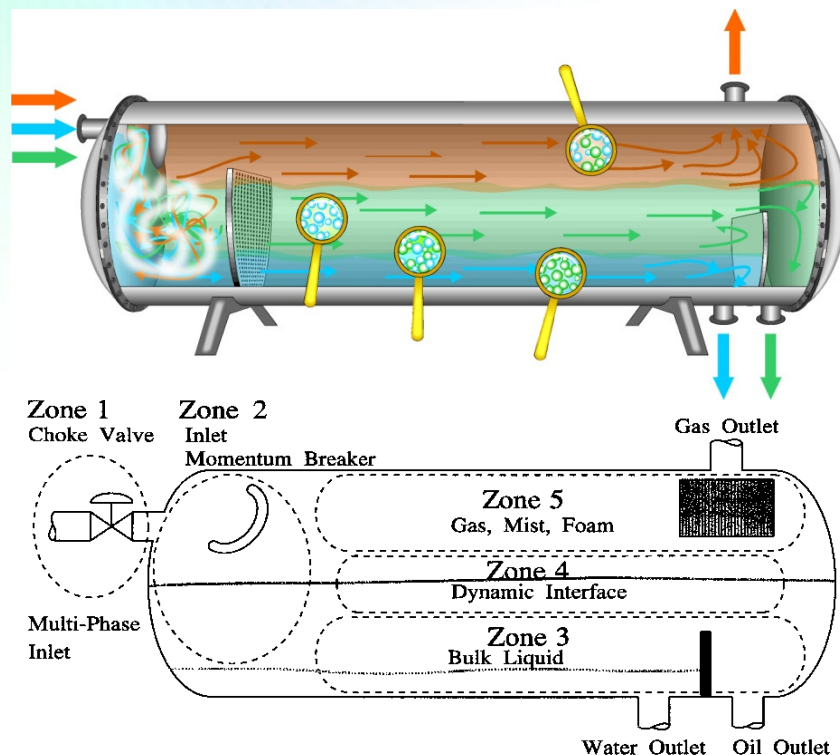
# Sloshing



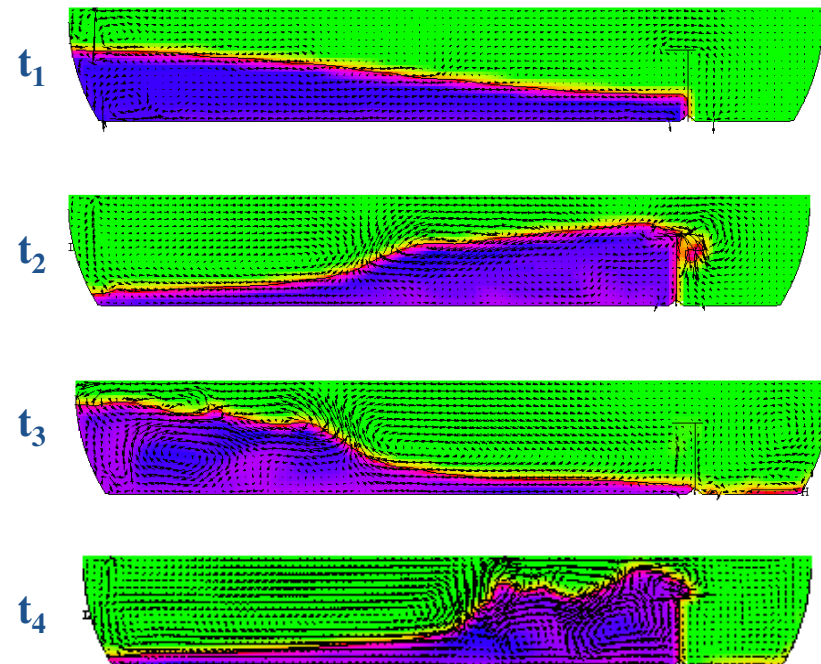
# Three Phase Separator Sloshing

- ❖ Modeling and simulation of a dense dispersion
- ❖ Flow and separation in oil/water/gas gravity separators

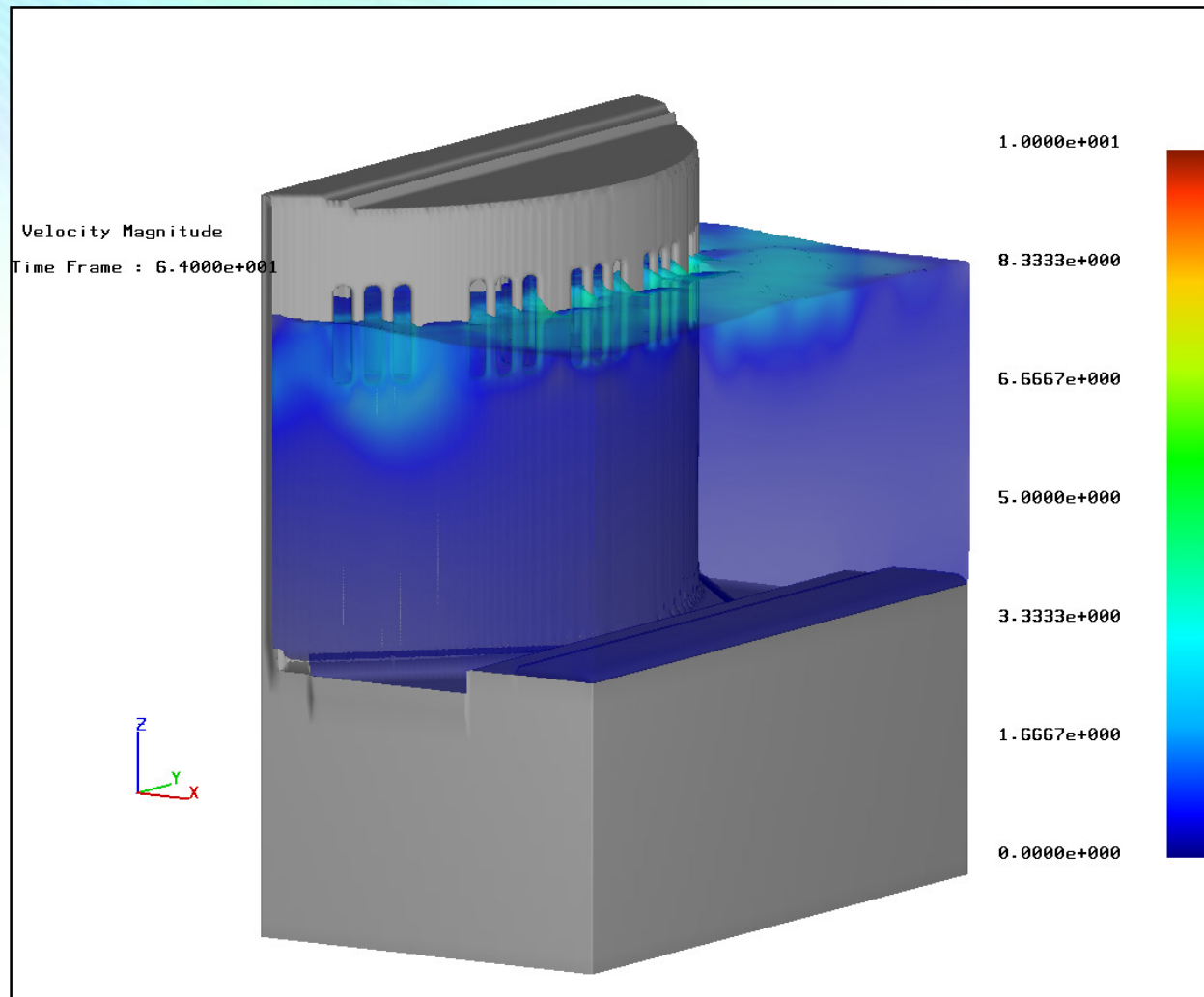
By SINTEF



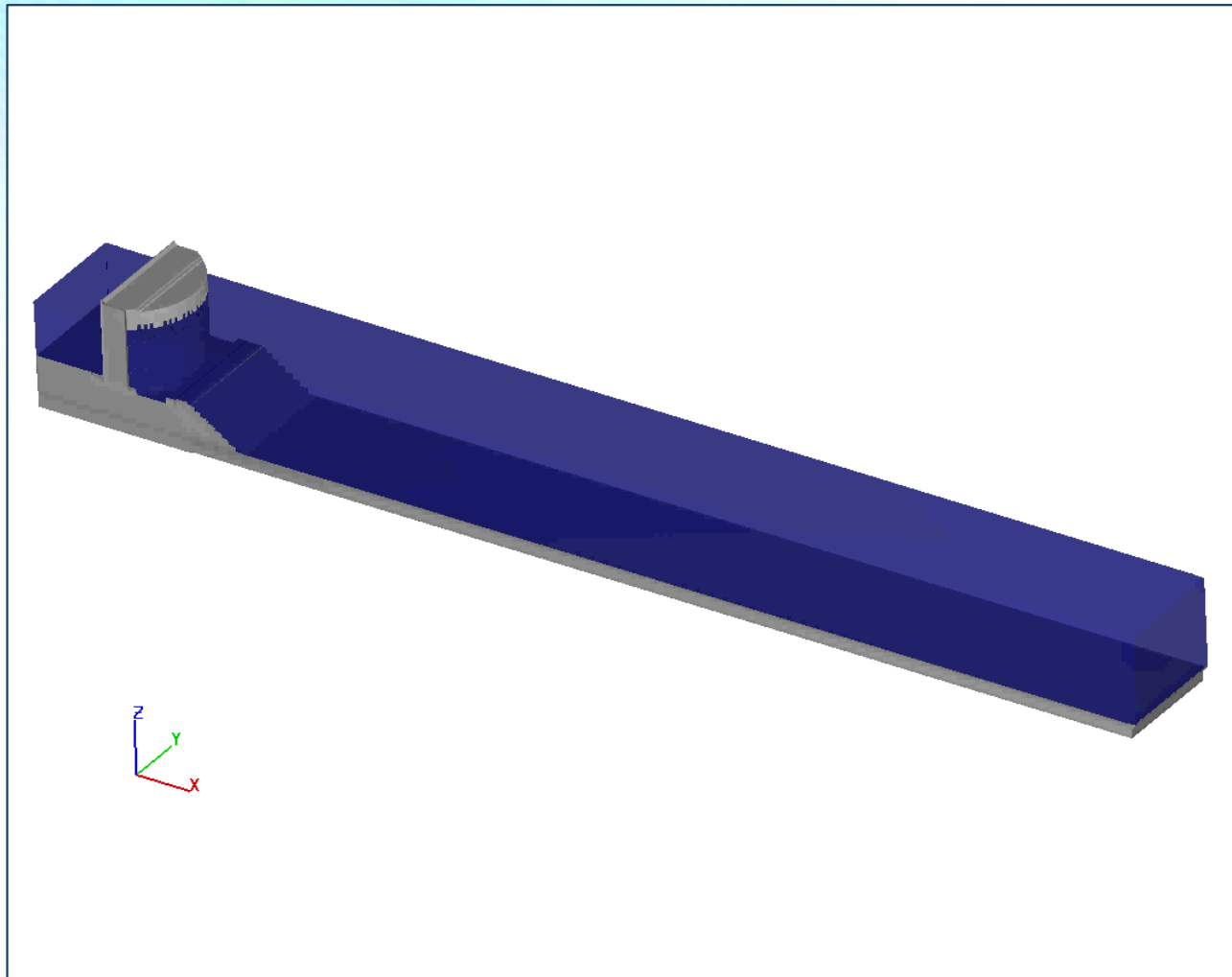
Drift Flow Model



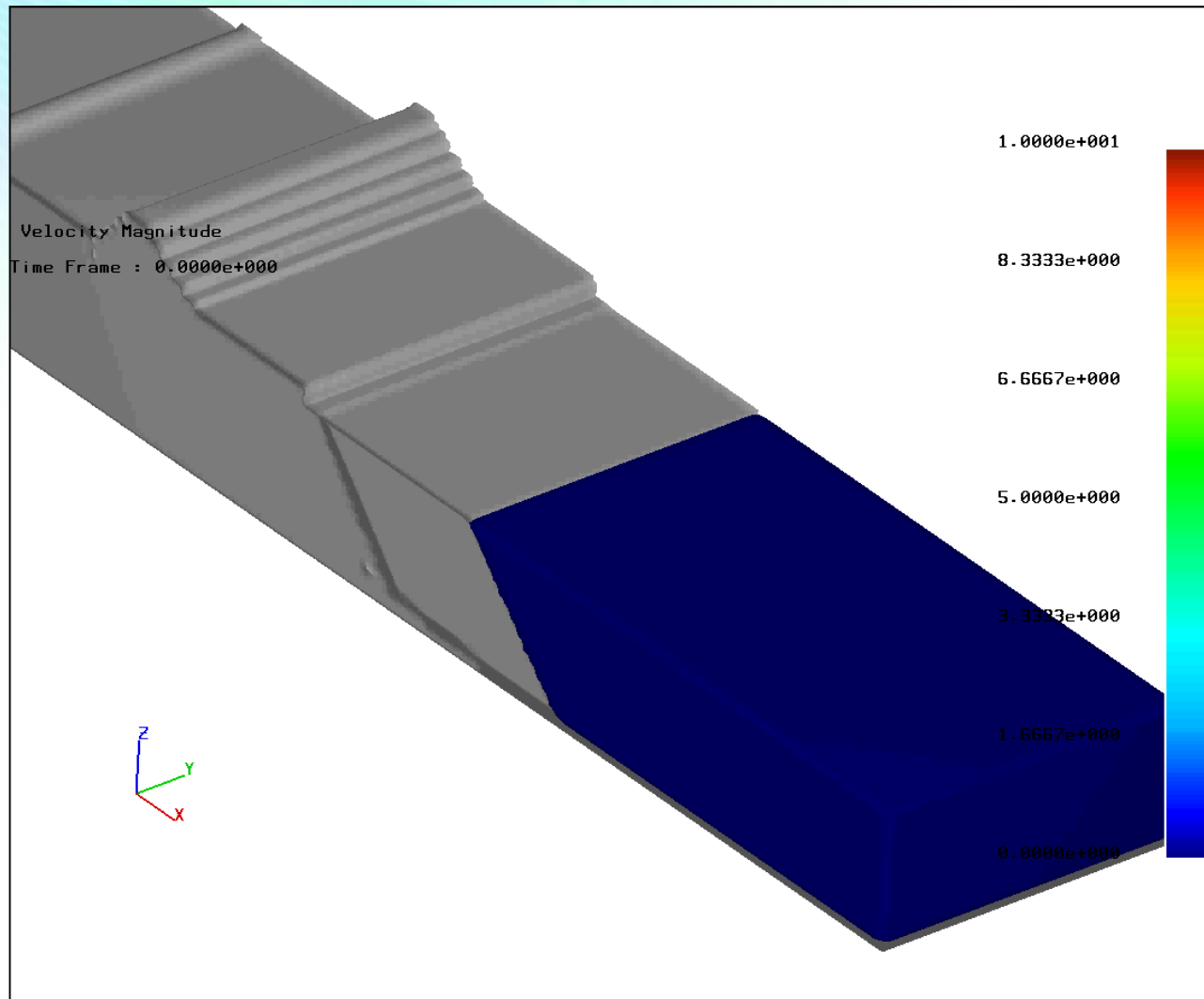
# Wave & Cassion



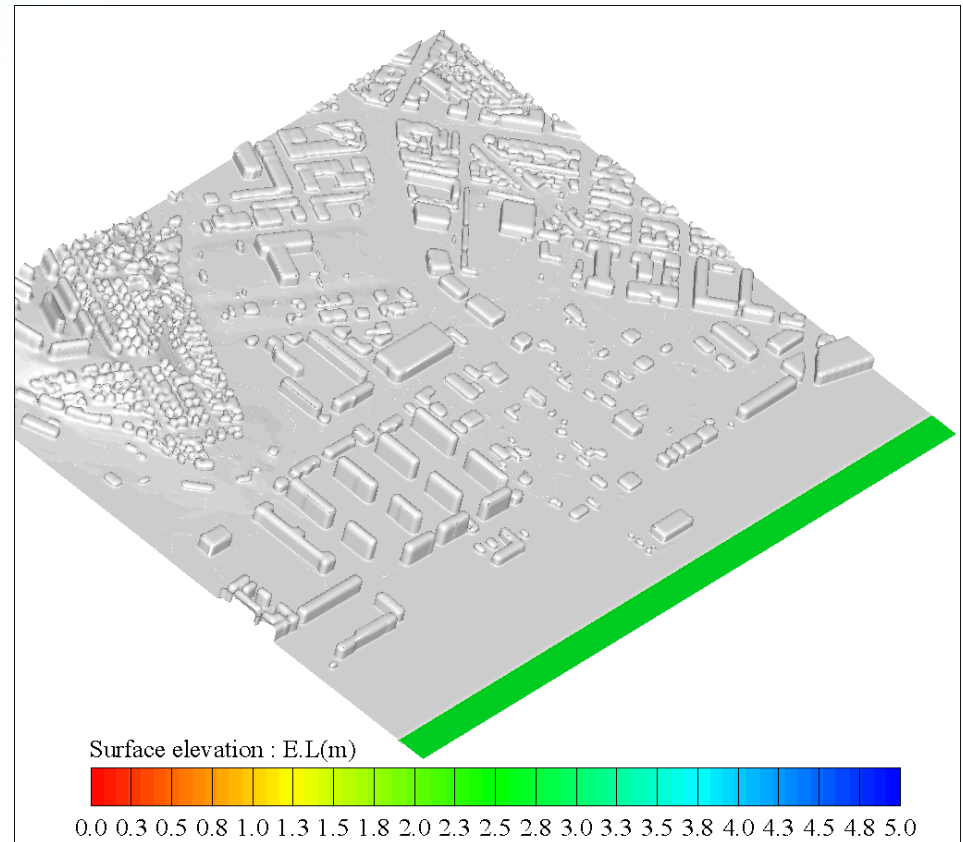
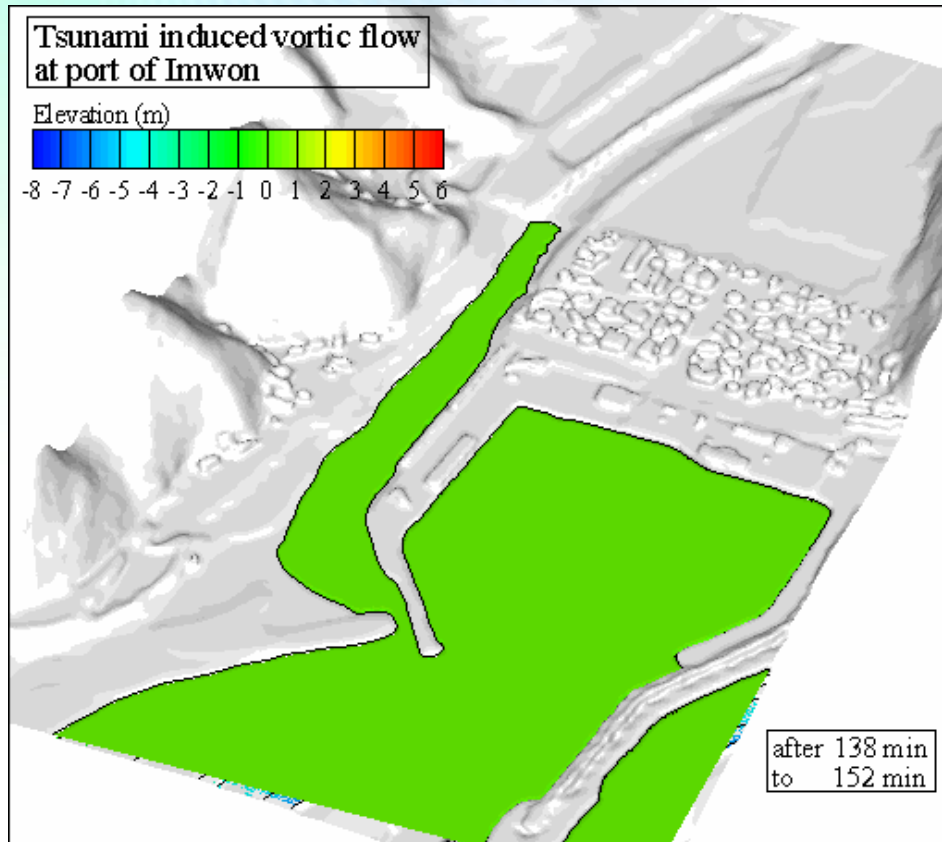
# Wave : Cassion



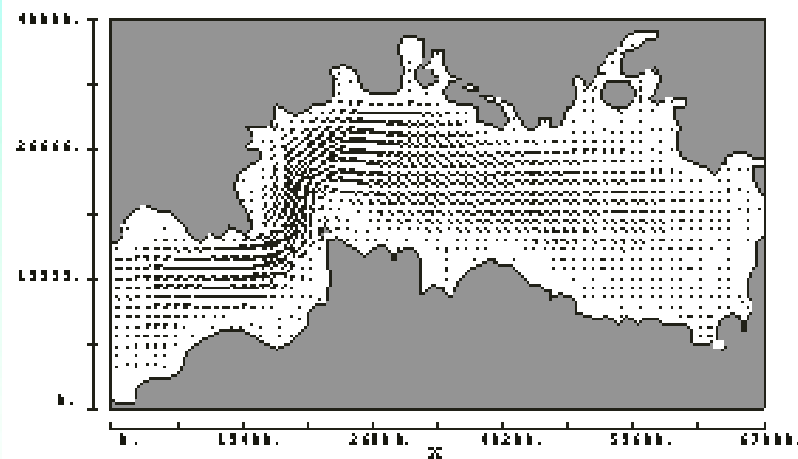
# Wave : Cassion



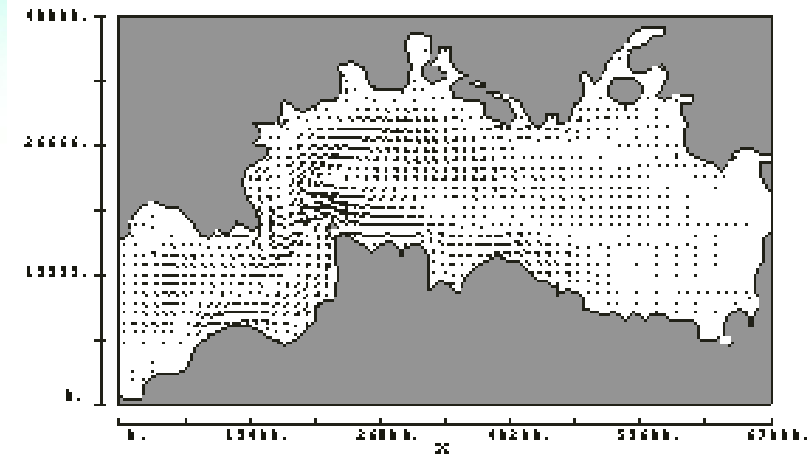
# Tsunami Induced Vortical Flow at Port of Imwon



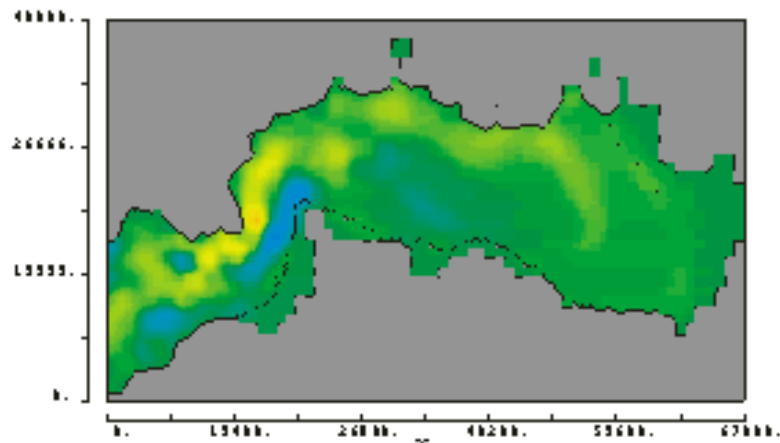
# Tidal Current In Tokyo Bay



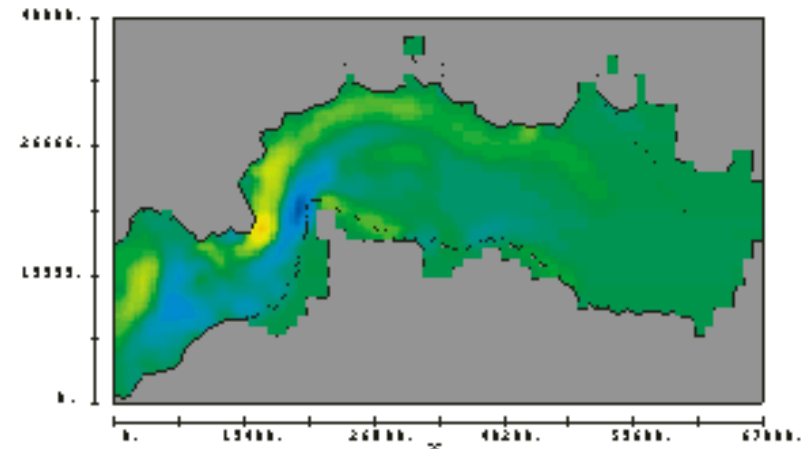
Tidal Current of high tide at 3m depth (51h)



Tidal Current of high tide( 1 hour later ) at 3m depth (52h)

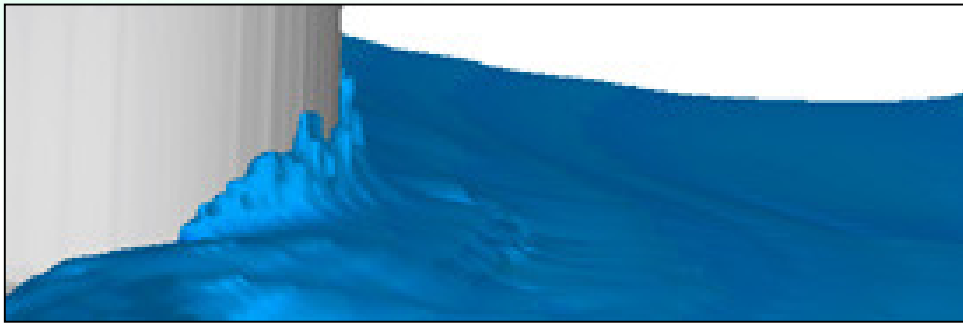


Vertical velocity at 9m depth at high tide (51h)

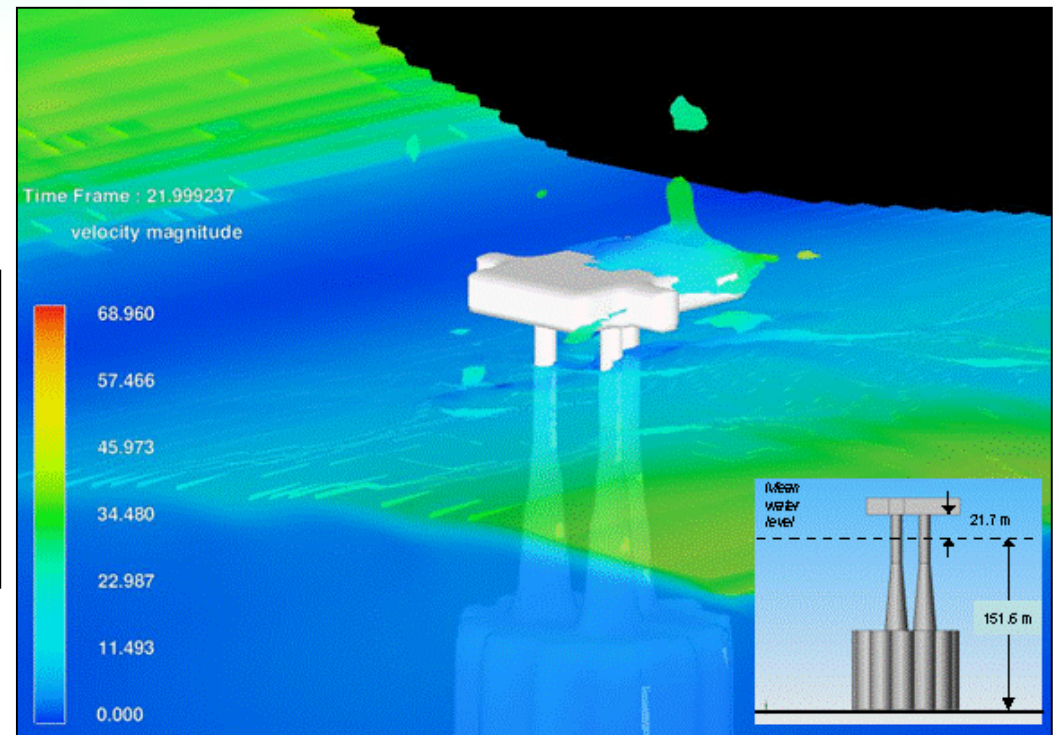


Vertical velocity at 9m depth at high tide( 1 hour later ) (52h)

# Wave Impacts

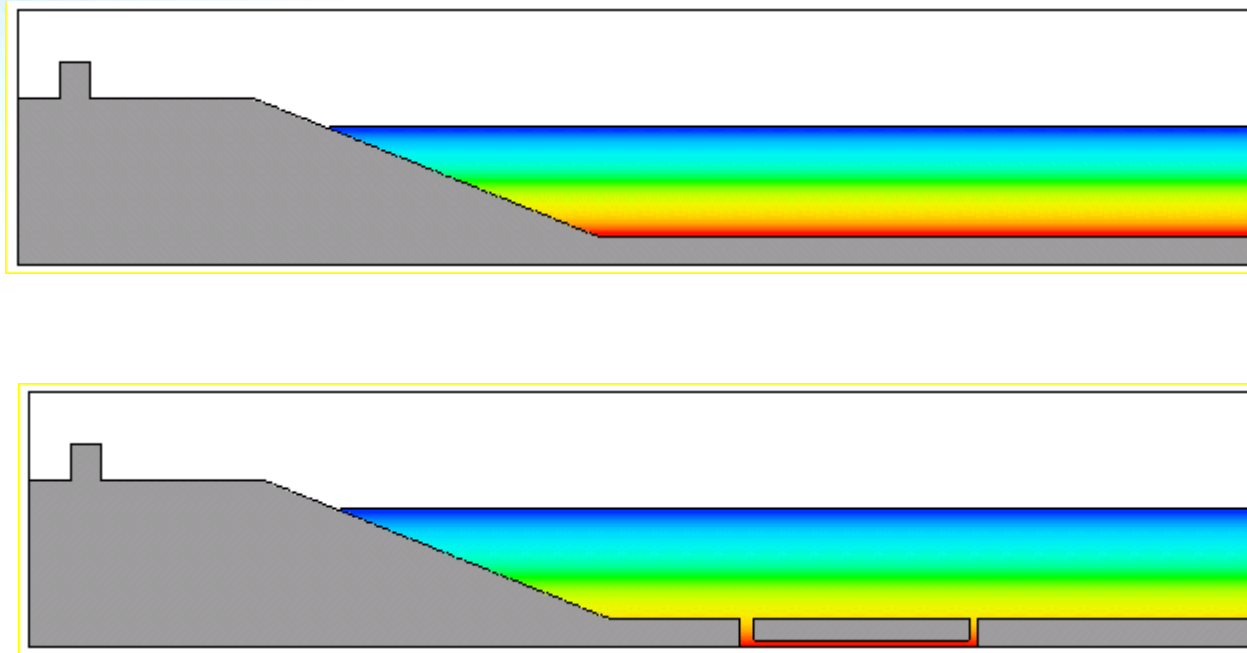


Wave impact on sea structure



Wave impact on a gravity-based structure

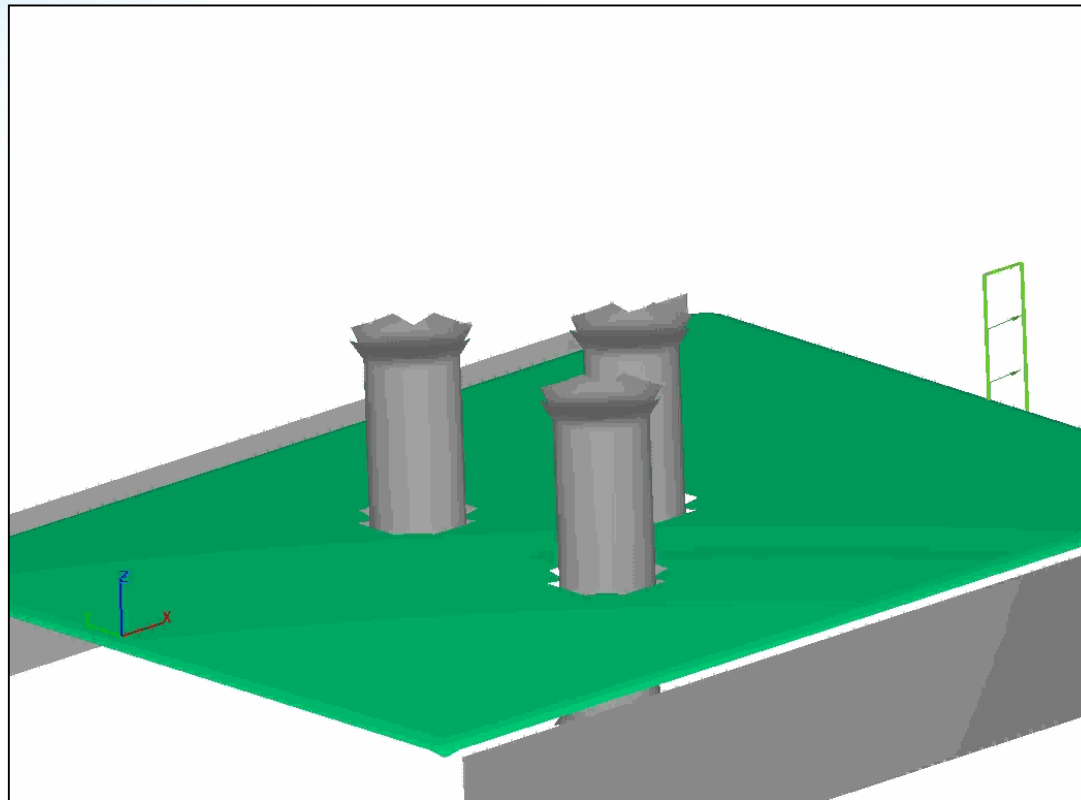
# Protection from Surge Waves



**Submerged flap is filled with air after a surge warning**

# Sediment Scour Pier

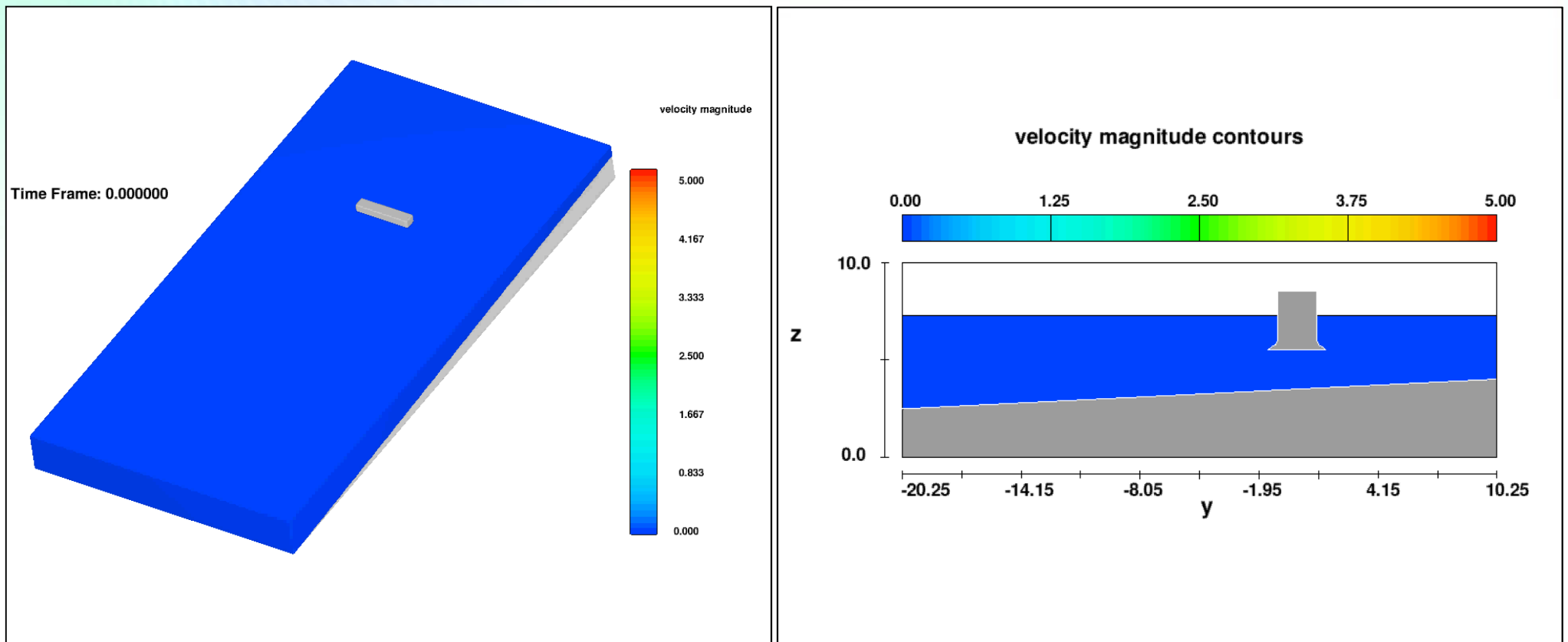
- ❖ The erosion occurs around a group of three 2.4 m diameter piers as river water flows past at 1.5 m/s.
- ❖ River depth : 15.8 m, mean sediment size 0.35 mm.



Simulation of erosion around complex piers.

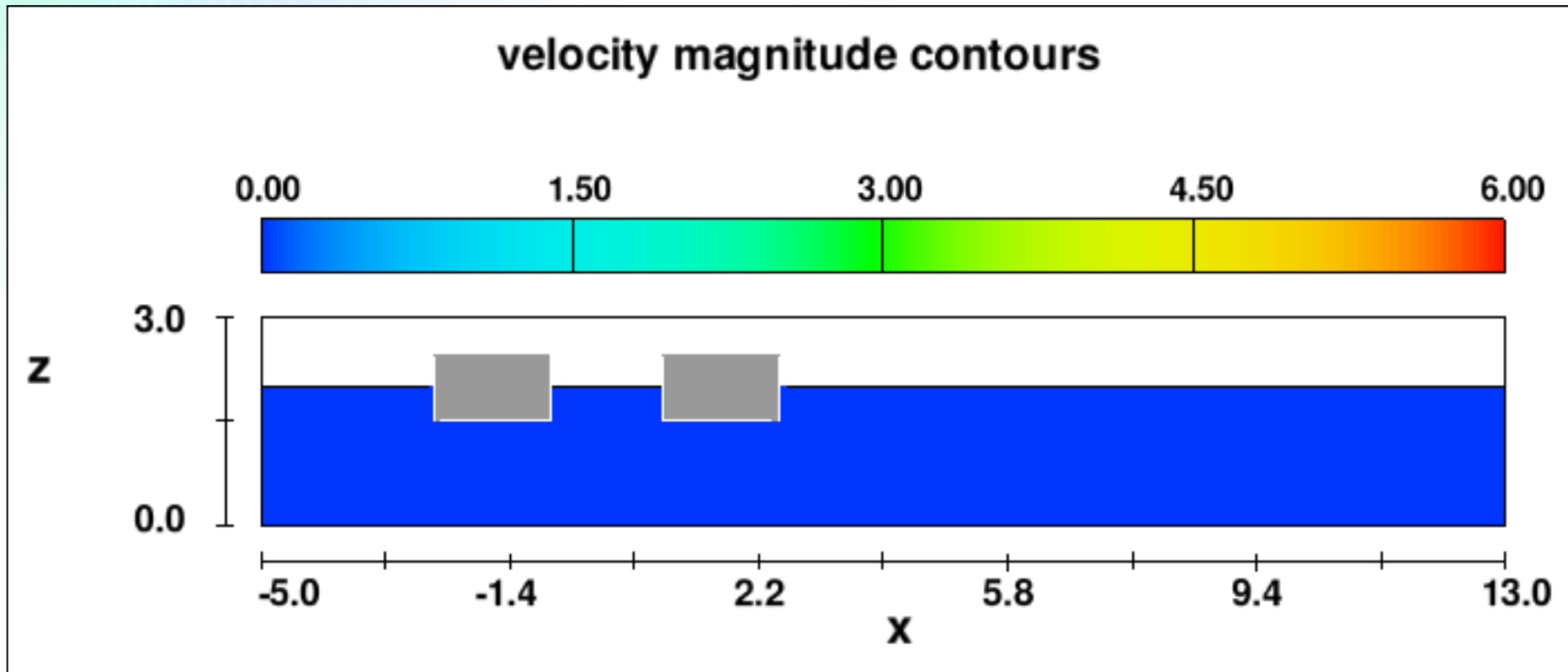
# Floating Breakwater

## ❖ Wave model & GMO



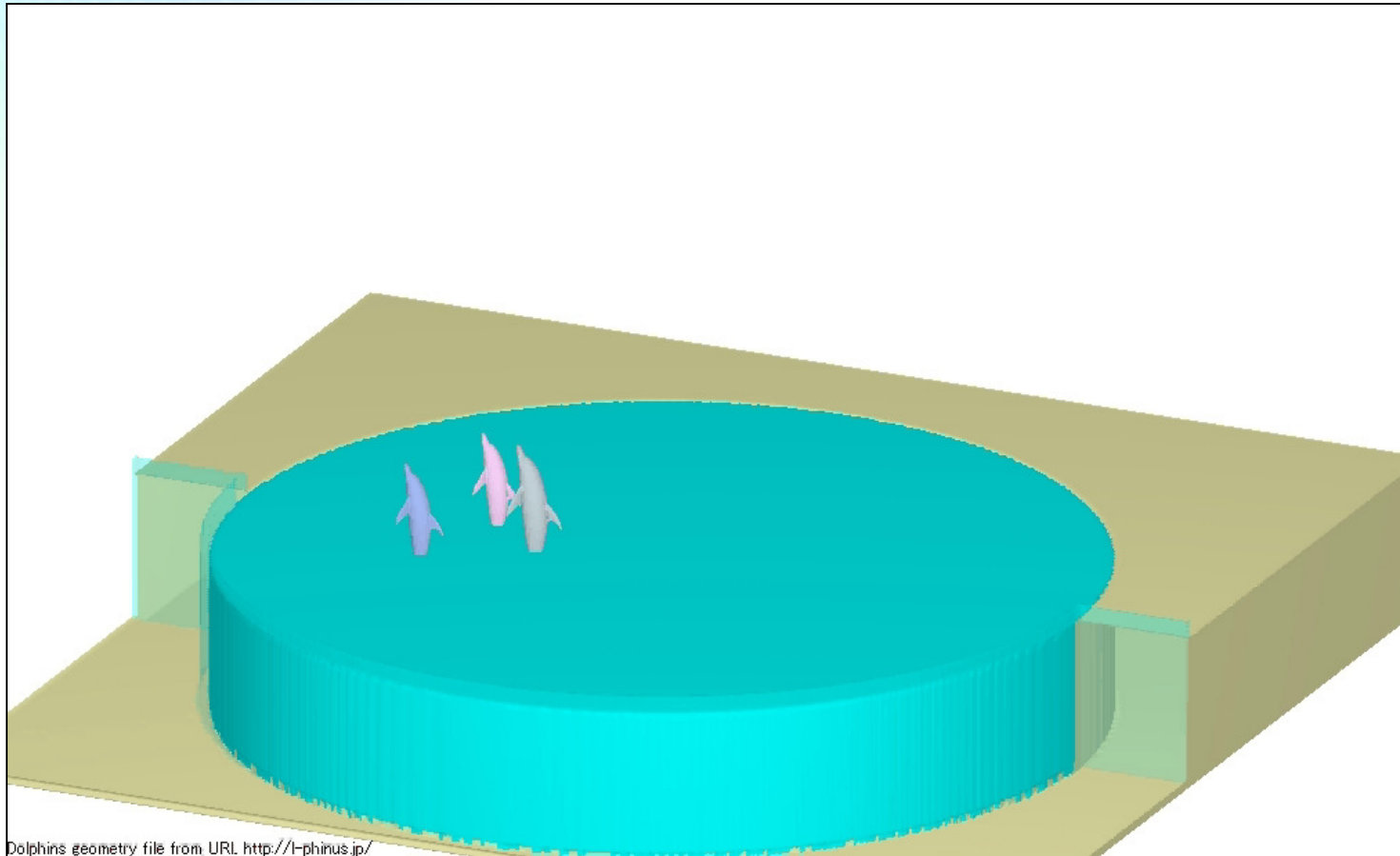
# Ropes & Springs

## ❖ Tugging a boat



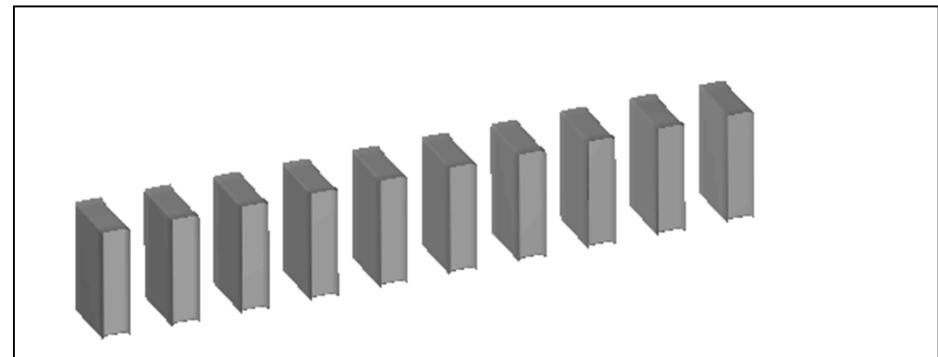
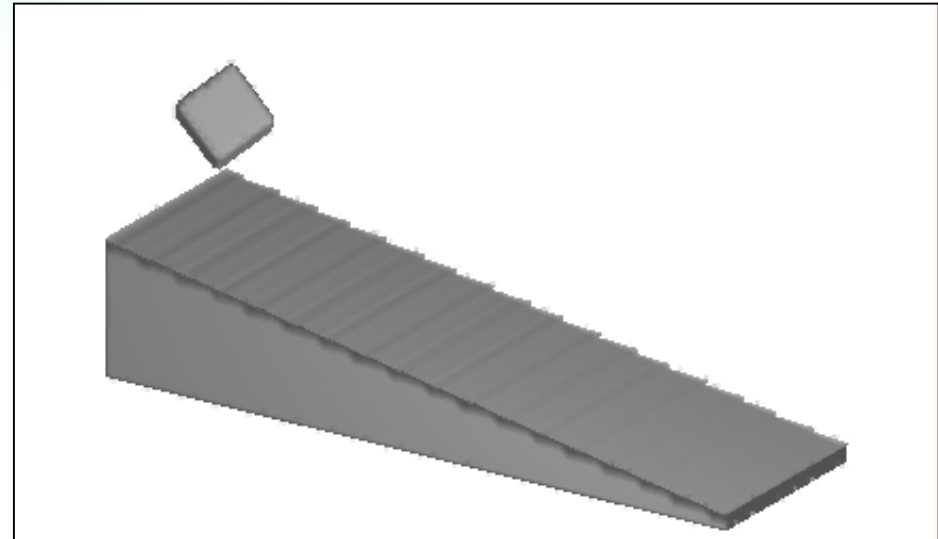
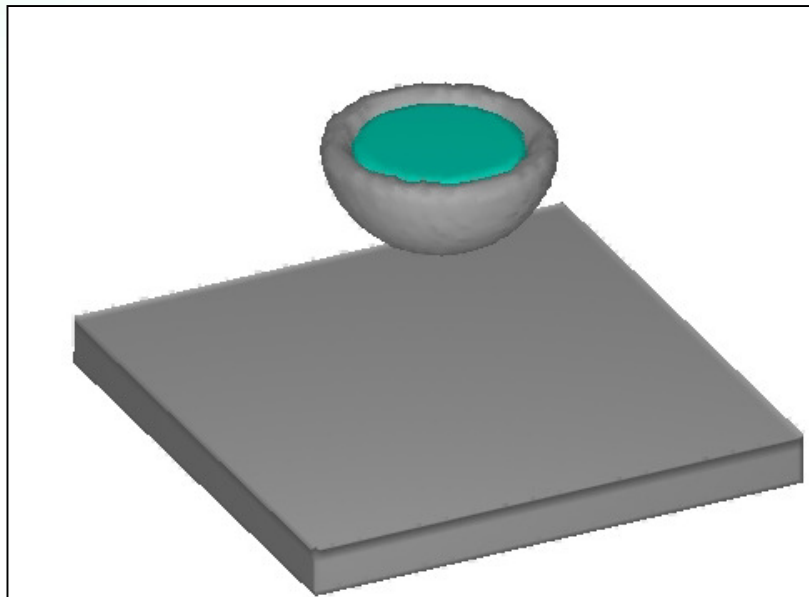
# General Moving Obstacles

## ❖ Swimming Dolphins



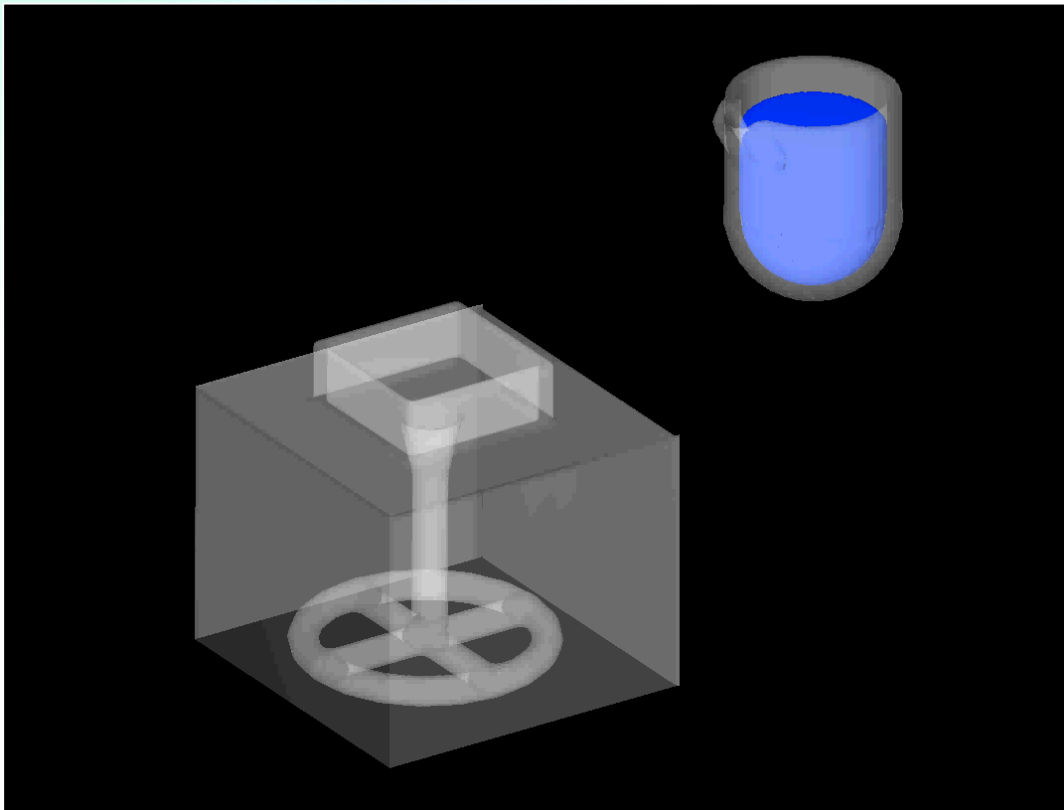
# Collision Control

- ❖ Elastic/inelastic collisions
- ❖ Friction effects
- ❖ Multiple object/walls/baffles

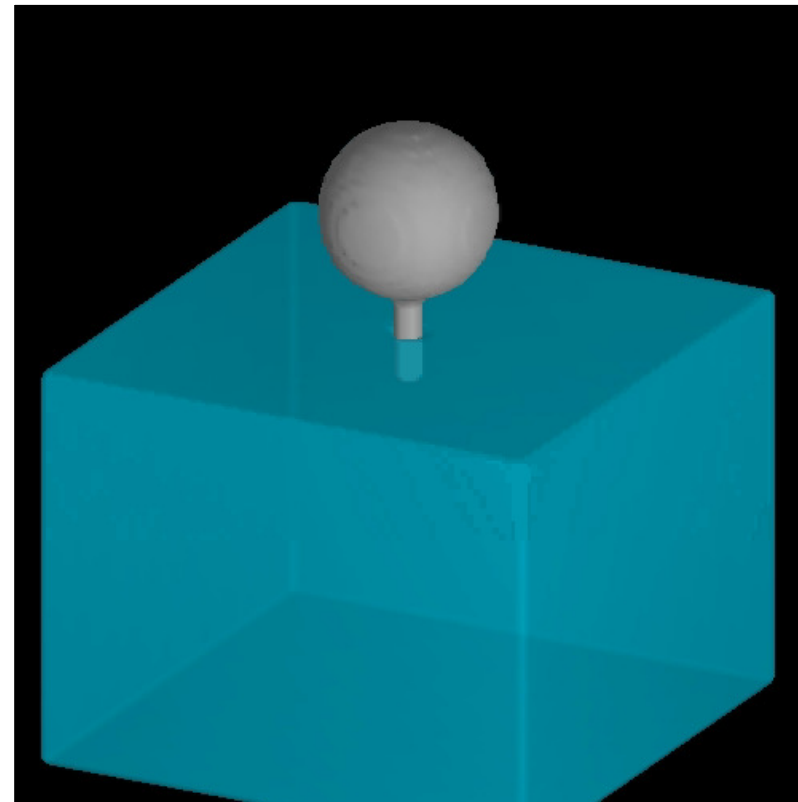


# General Moving Obstacles

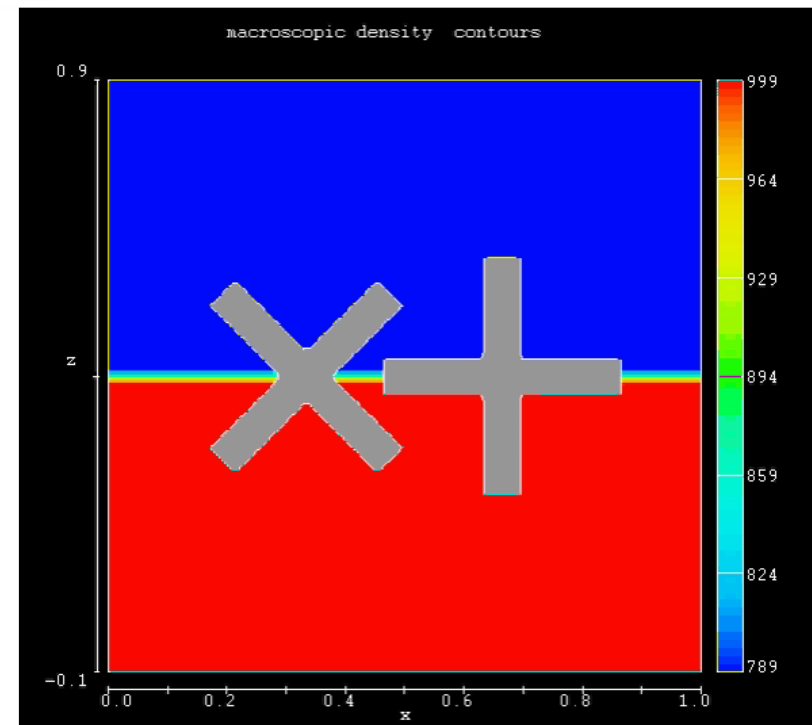
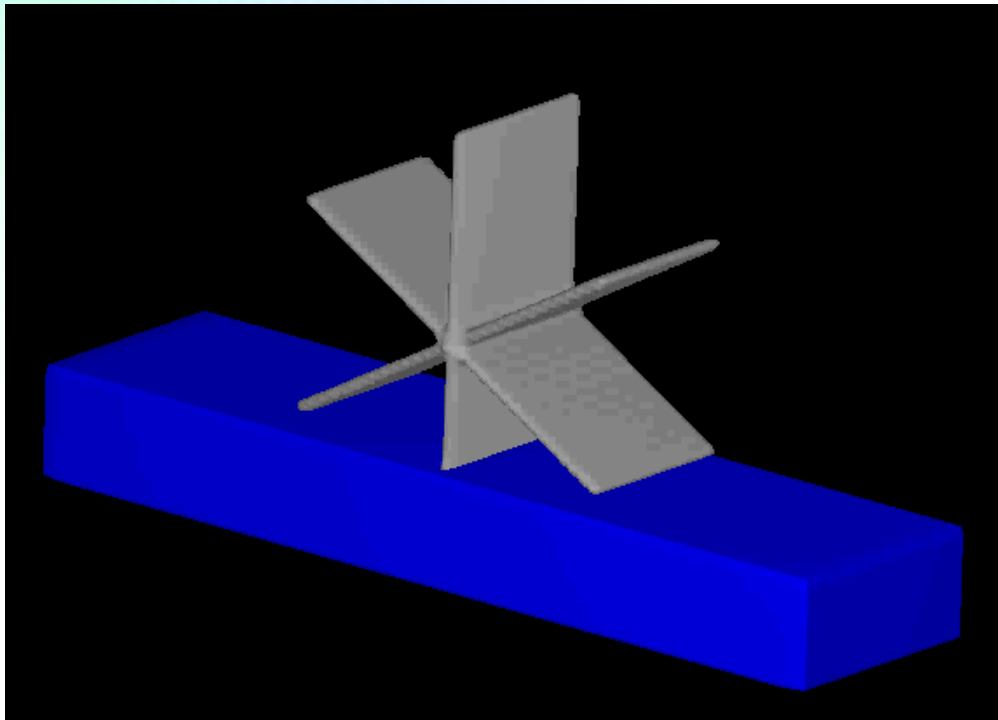
Prescribed GMO motion



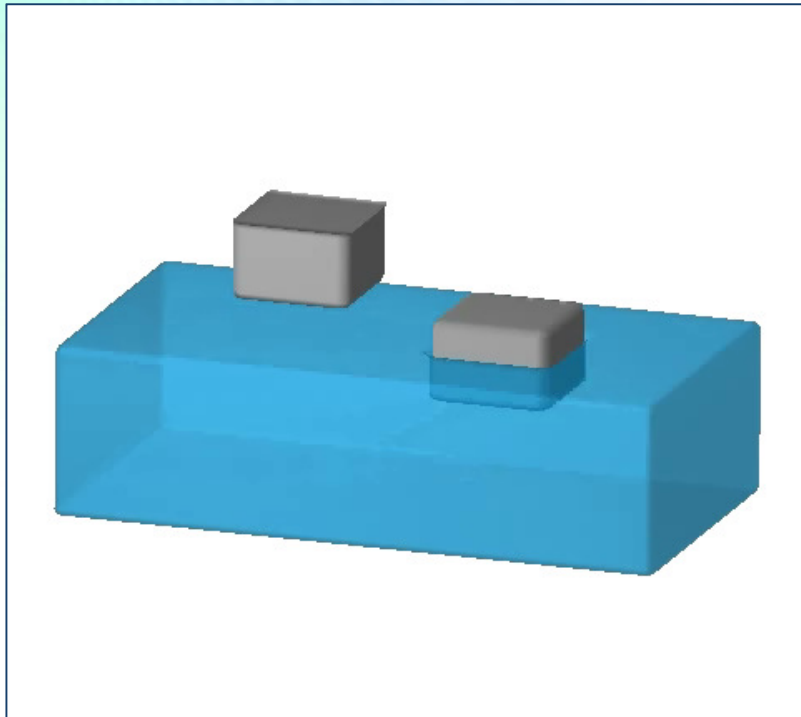
Coupled GMO motion



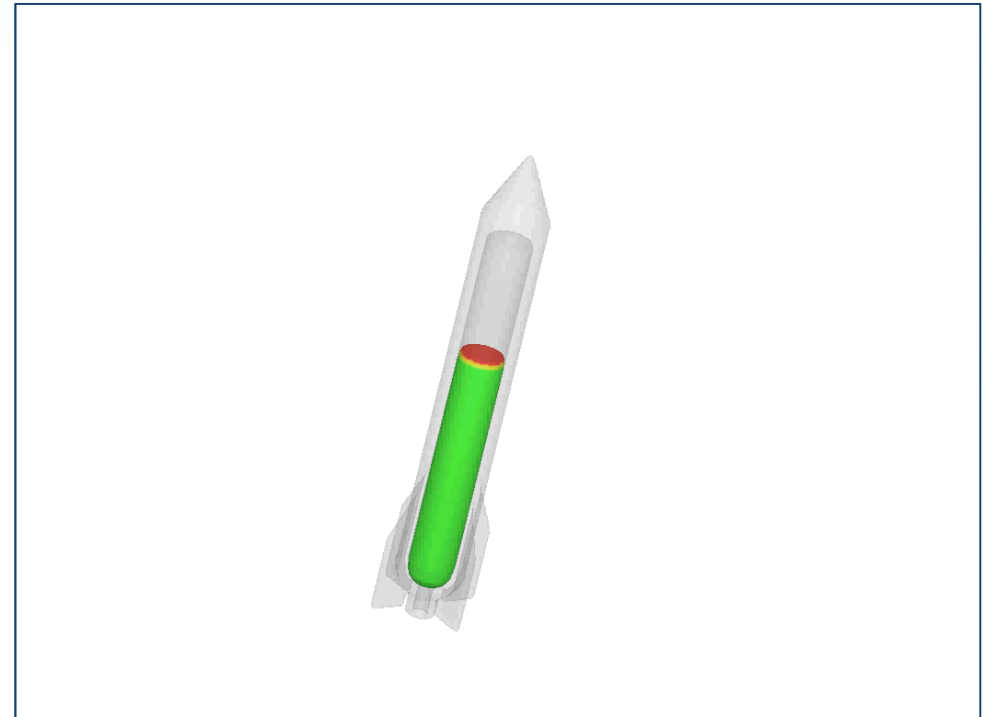
# General Moving Obstacles



# General Moving Obstacles

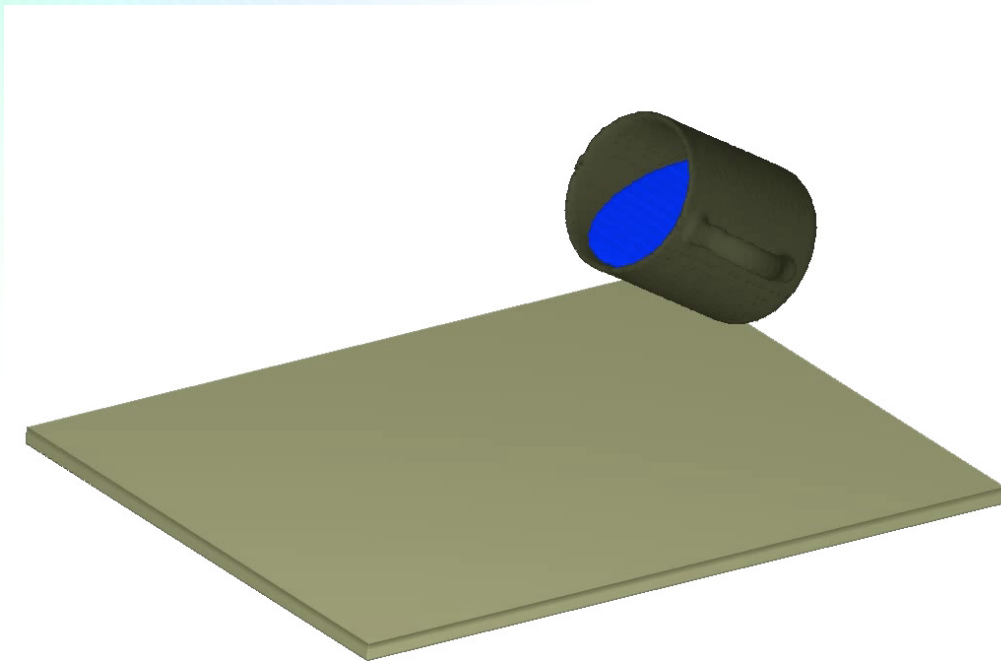


**Bouncing Ice Cubes**



**Launch of a water-propelled model rocket**

# General Moving Obstacles

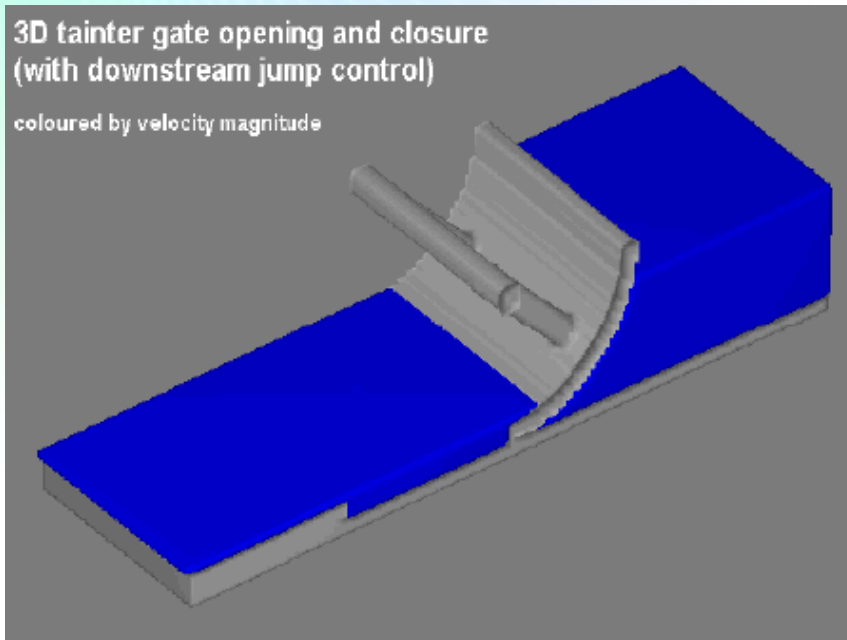


Coffee Spill

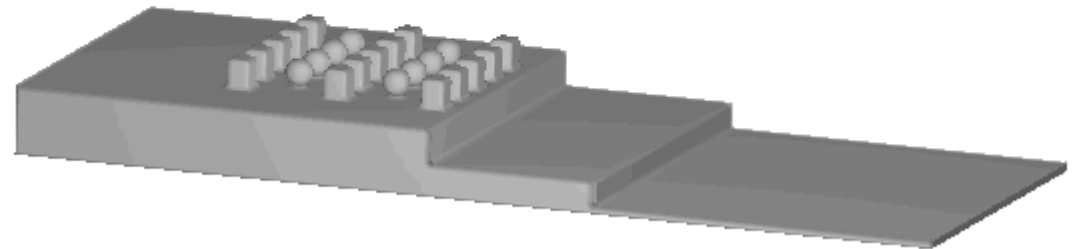


Ice Cream Cone

# General Moving Obstacles



**Tainter Gate**

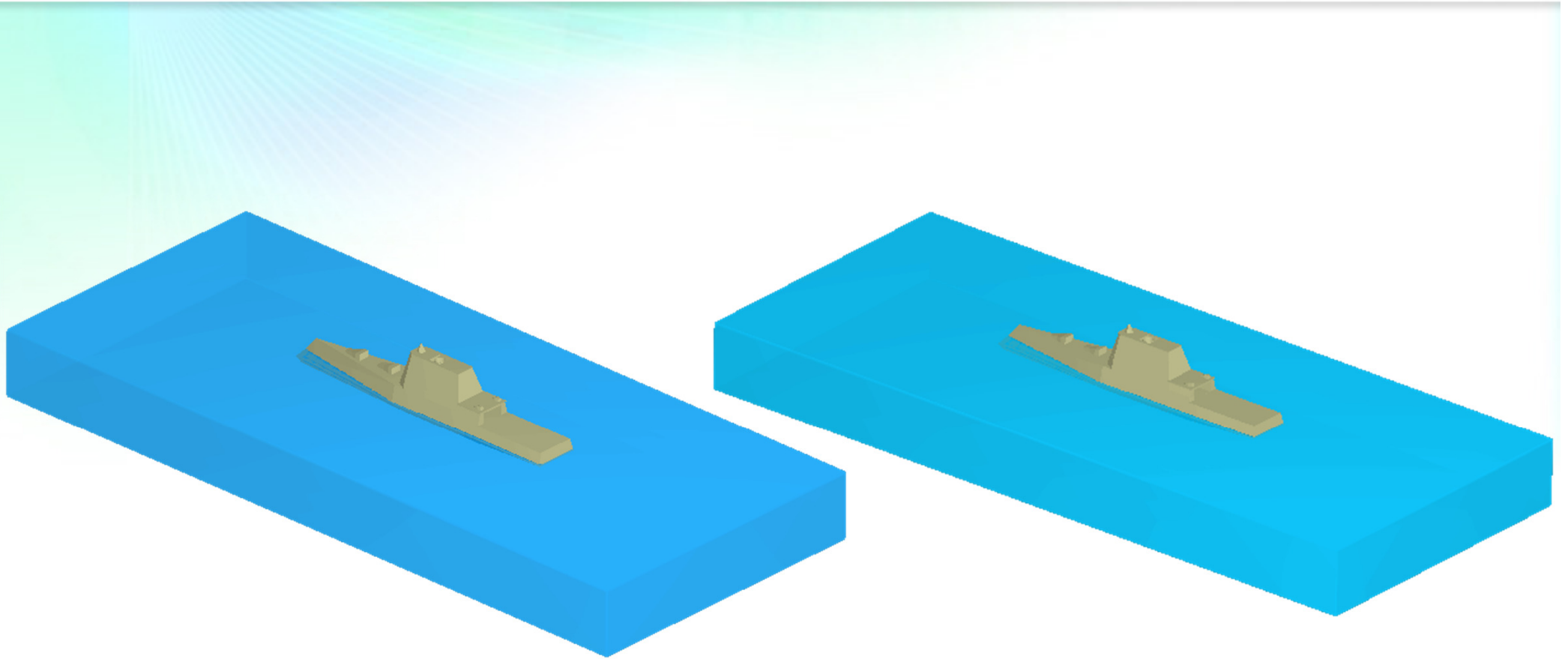


**Debris Flow**



# Stability of a Floating Object

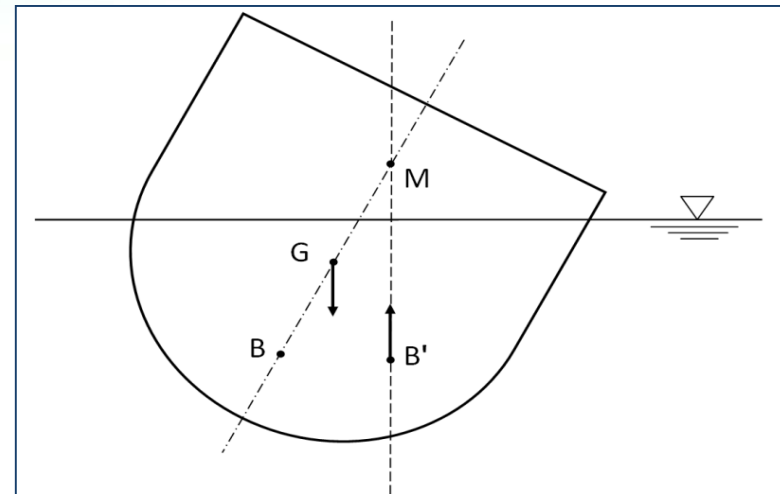
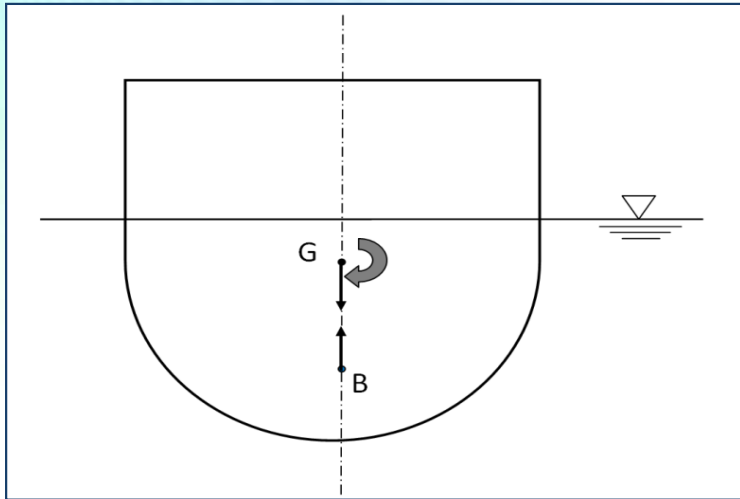
# Modeling Unstability vs. Stability



**Unstability**

**Stability**

# Metacenter & Metacentric Height



**G:** gravity center

**B:** buoyancy center

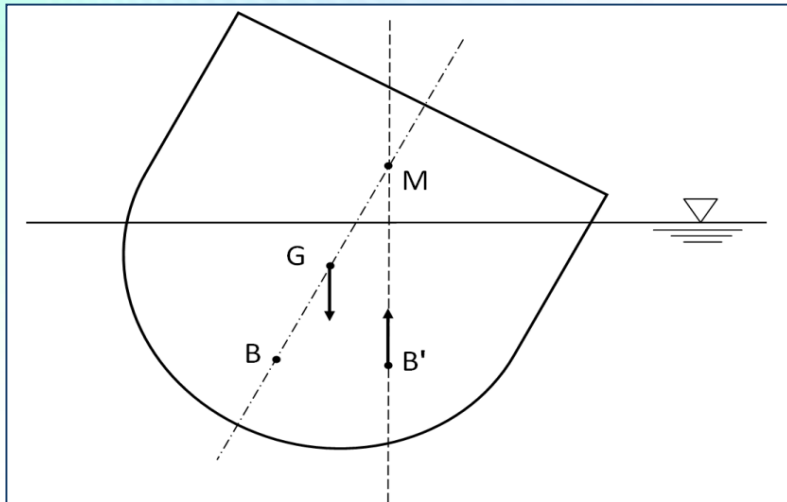
**M:** metacenter

- ◆ Buoyancy center (B or B'): mass center of displaced fluid volume
- ◆ Metacenter (M)
- ◆ Metacentric height (GM): distance from G to M.

If M is above G, then  $GM > 0$ .

If G is above M, then  $GM < 0$ .

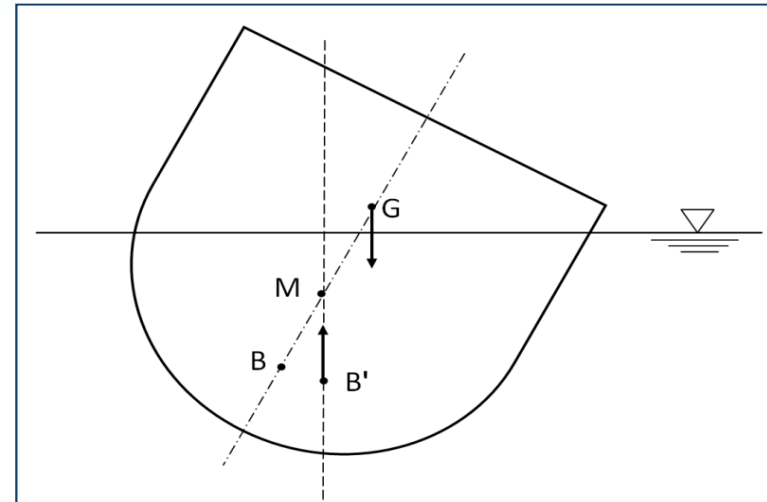
# Stable and Unstable Conditions



**M is above G,**

**$GM > 0$ ,**

**The buoyancy torque restores equilibrium,  
object is unstable, object is stable.**



**G is above M,**

**$GM < 0$ ,**

**The buoyancy torque does not restore  
equilibrium, object is unstable.**

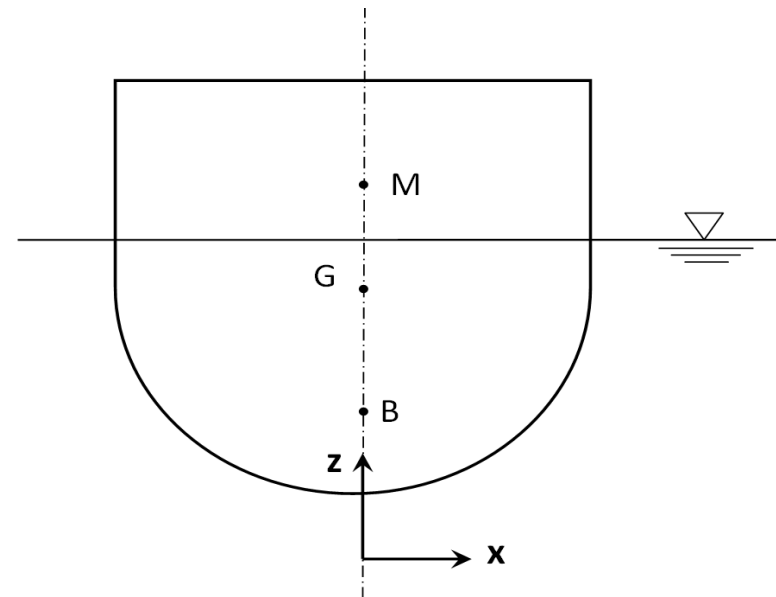
**$GM \uparrow$ , then stability  $\uparrow$**

# Calculation of Metacentric Height GM

$$BM = \frac{I_x}{V_w}$$

$$GM = BM - BG$$

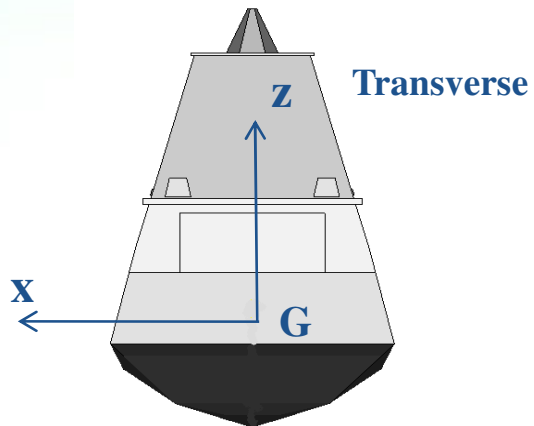
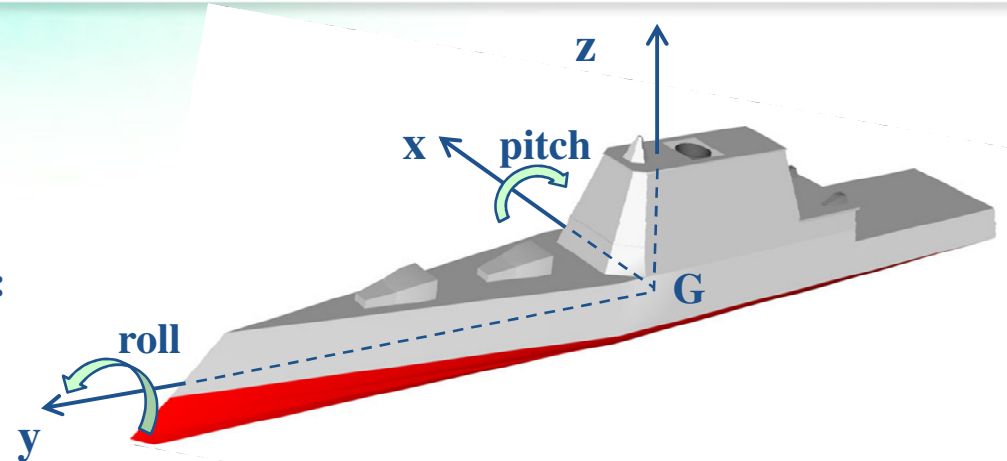
- **BM: distance from B to M.**
- **$I_x$  : moment of inertia about z,  $I_x = \int x^2 dV$**
- **$V_w$  : displaced fluid volume**
- **BG: distance from B to G.**



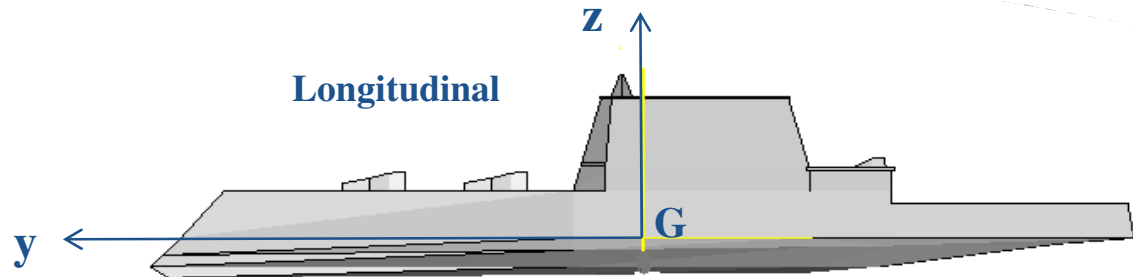
# Stability of a Ship

❖ Two metacentric heights exist:

- ◆ Transverse metacentric heights ( $GM_T$ ):  
for transverse rolling motion
- ◆ Longitudinal metacentric height ( $GM_L$ ):  
for longitudinal pitch motion



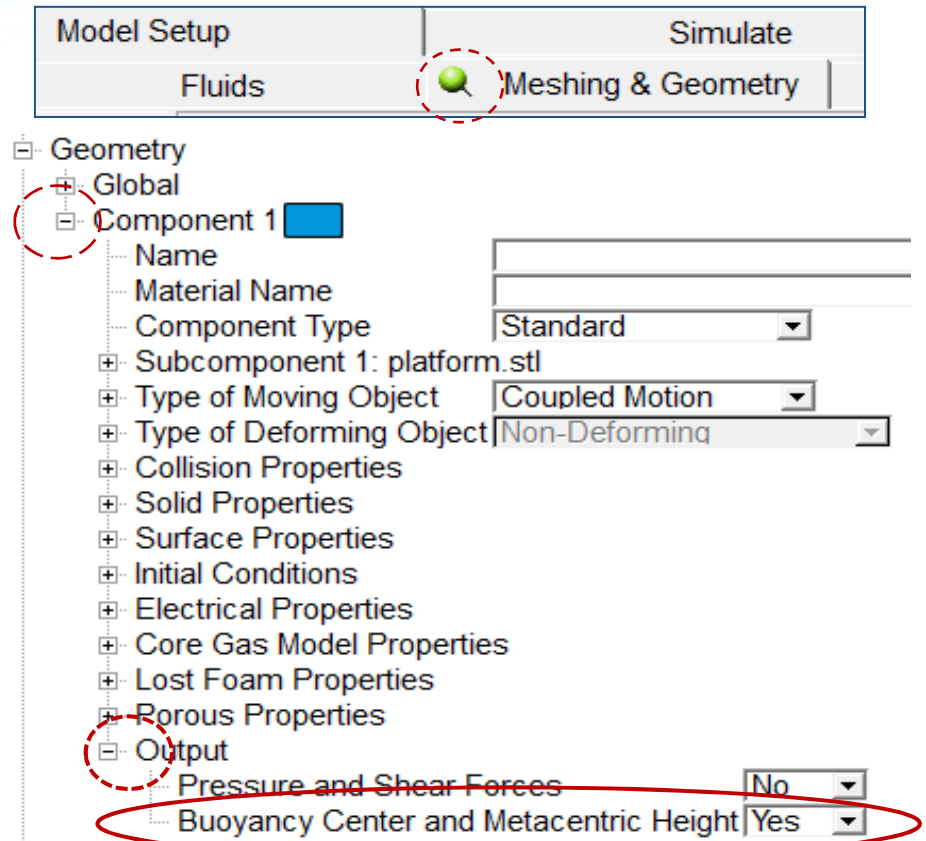
$$BM_T = \frac{I_x}{V_w}, \quad GM_T = BM_T - BG$$



$$BM_L = \frac{I_y}{V_w}, \quad GM_L = BM_L - BG$$

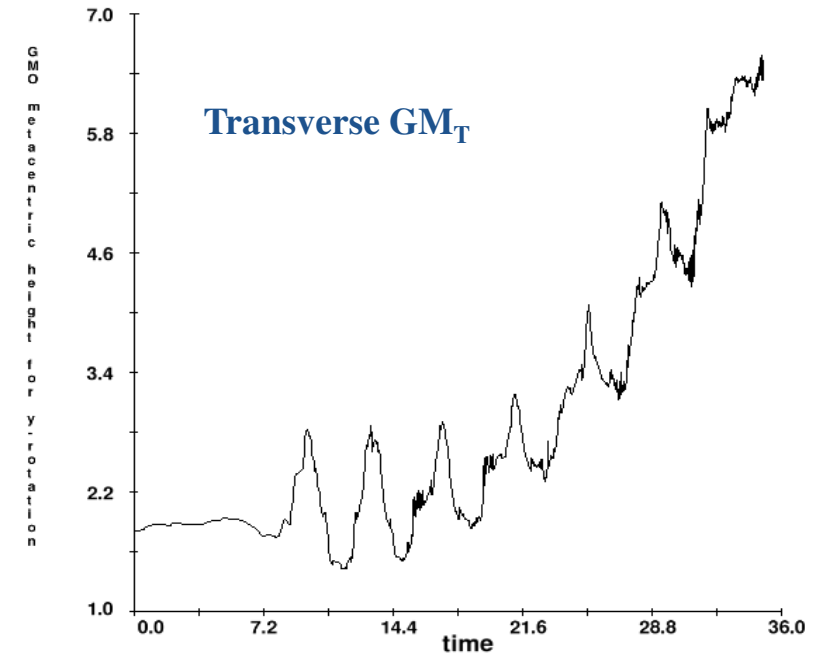
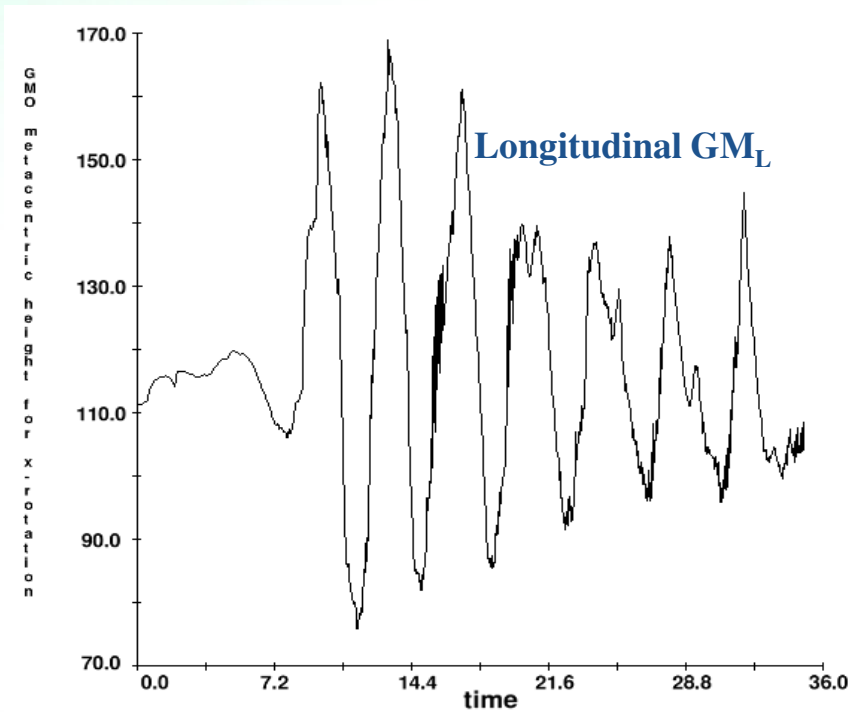
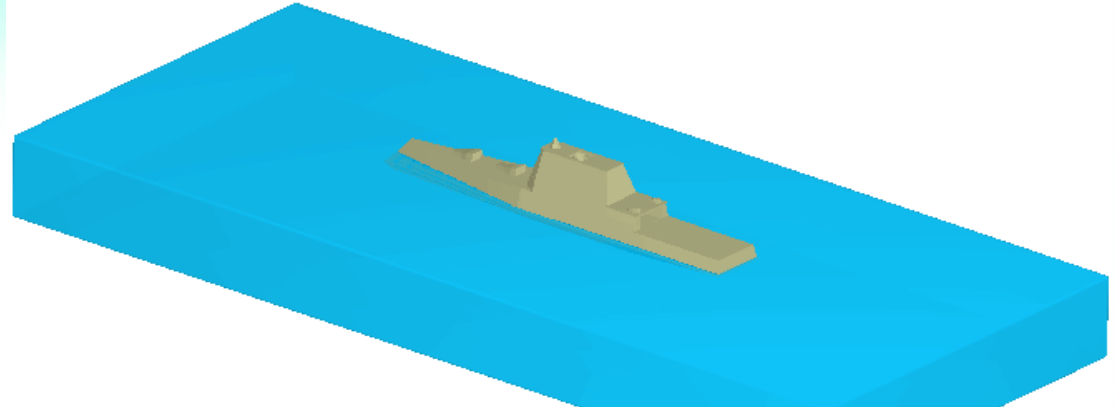
# Stability Analysis

- ❖ For a GMO, history data output:
  - ◆ Buoyancy center (B) vs. time
  - ◆ Gravity center (mass center, G) vs. time
  - ◆ Metacentric heights (GM) vs. time:
    - GM for rotation around  $x$ -axis
    - GM for rotation around  $y$ -axis
- ❖ Data interpretation
  - ◆ Floating object:
    - If  $GM > 0$ , object is stable.
    - If  $GM < 0$ , object is unstable.
    - $GM \uparrow$ , stability  $\uparrow$
  - ◆ Submerged object:
    - If G is below B, object is stable
    - If G is above B, object is unstable



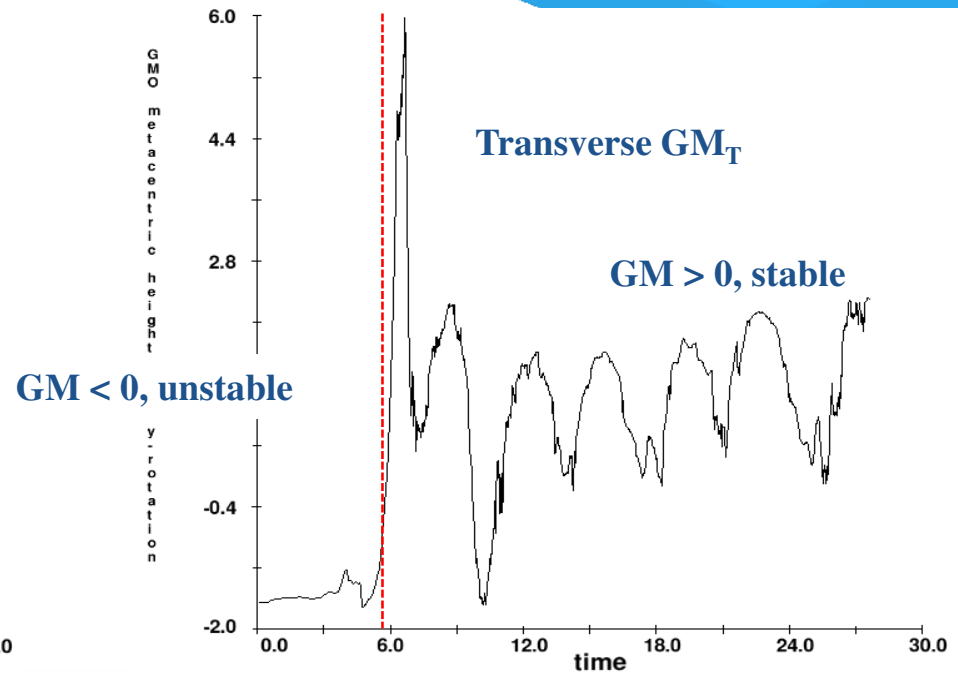
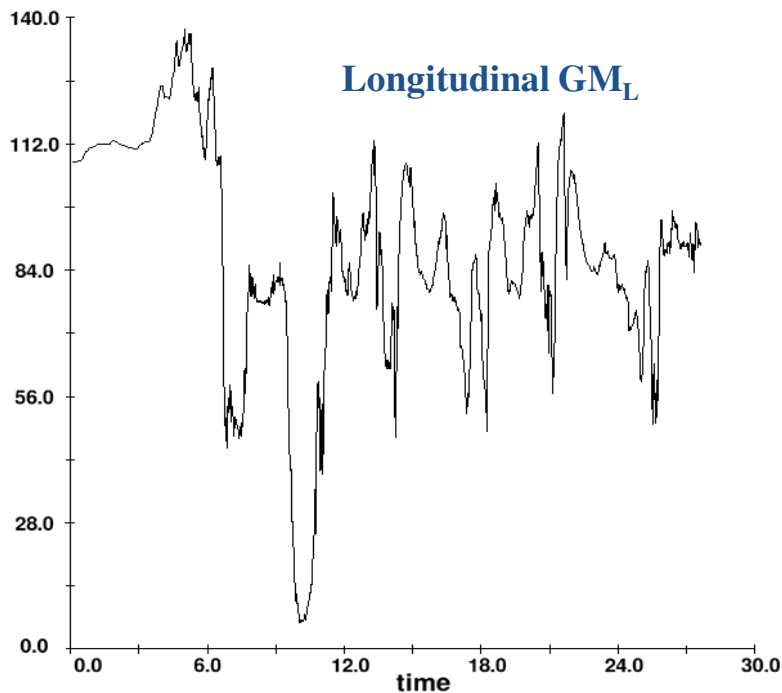
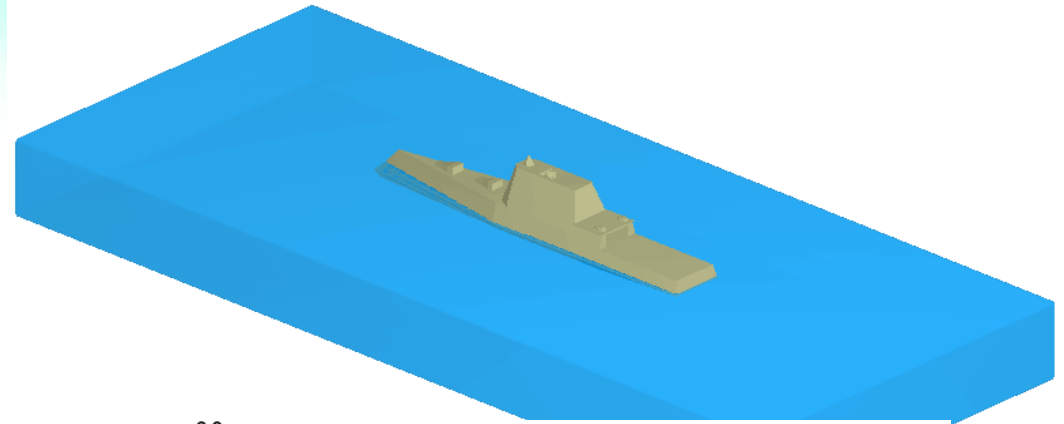
# Examples #1 : Stable

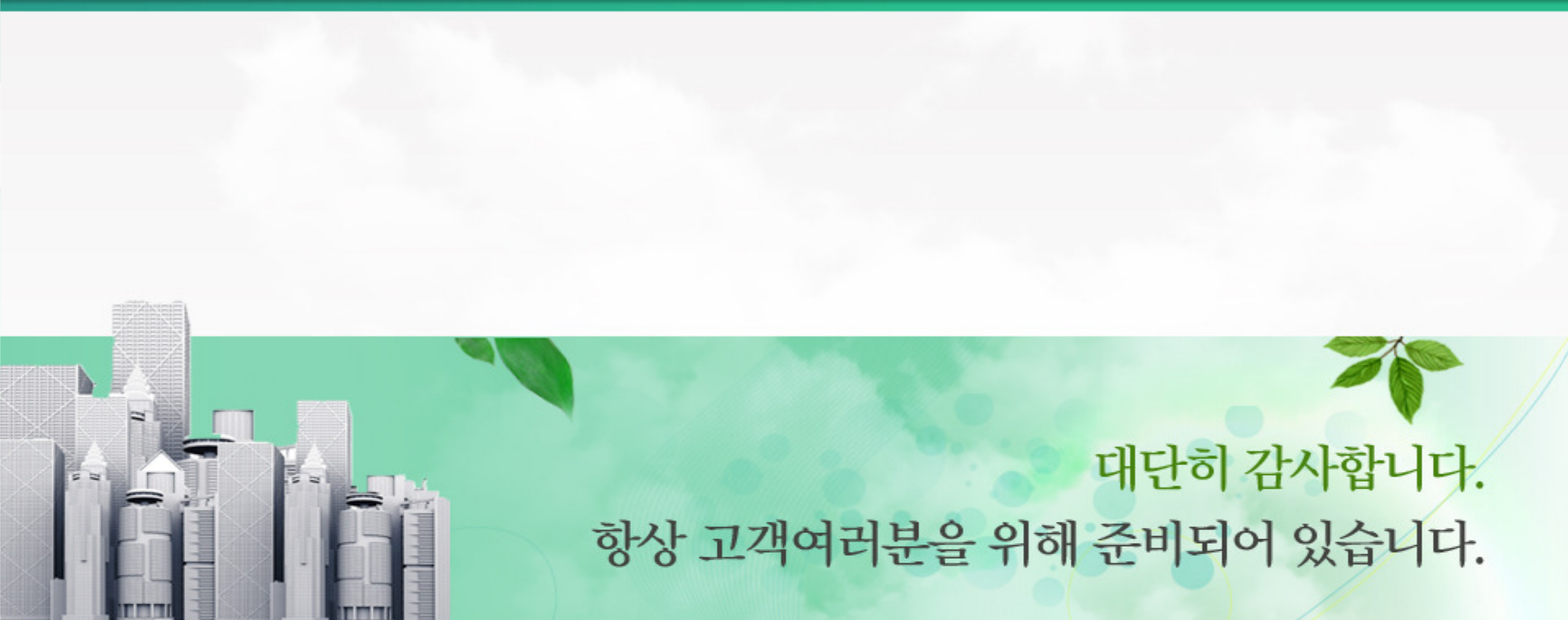
$$GM_L \gg GM_T > 0$$



# Example #2: Unstable

$GM_L > 0, GM_T < 0$





대단히 감사합니다.  
항상 고객여러분을 위해 준비되어 있습니다.