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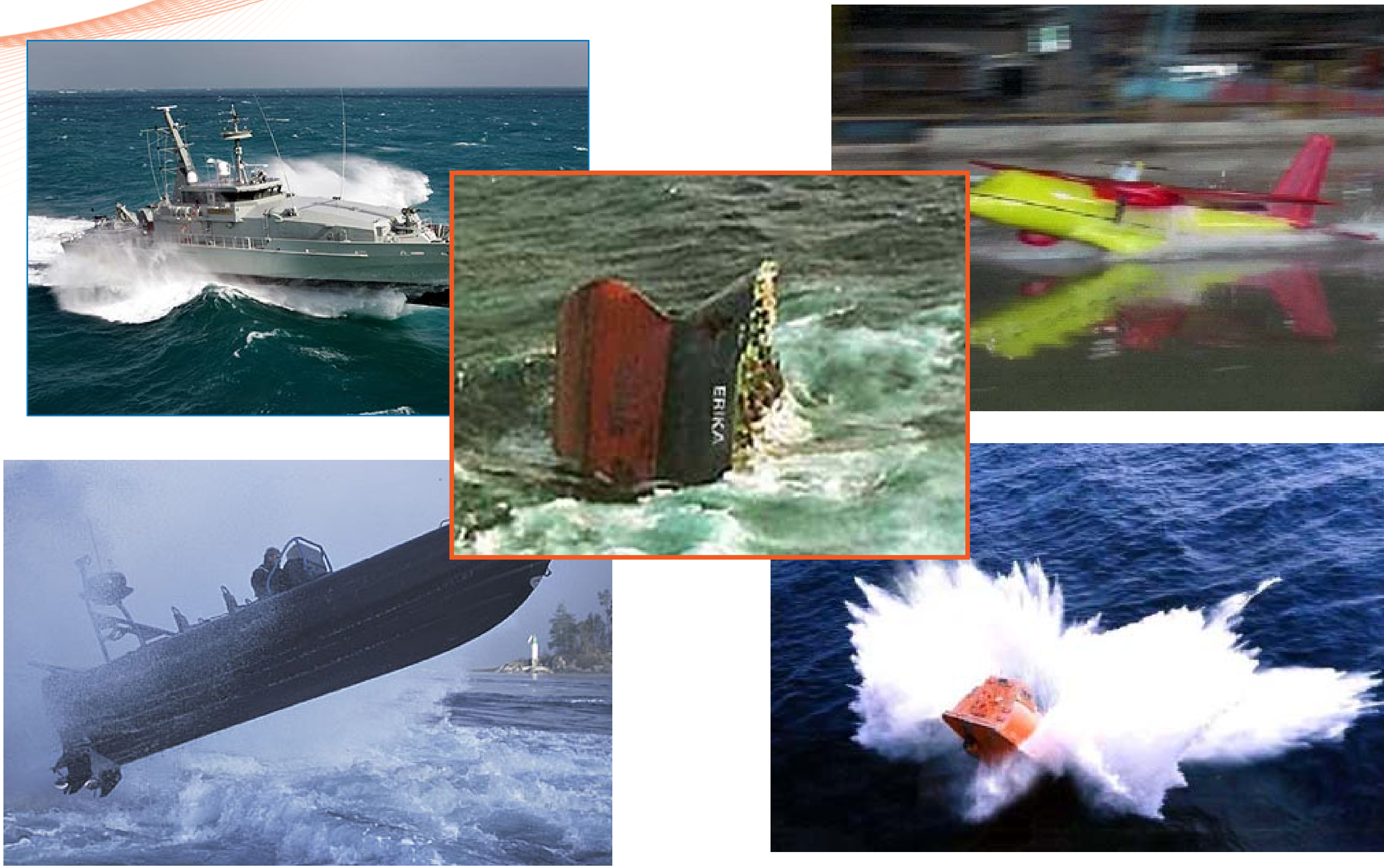
Maritime phenomena of interest



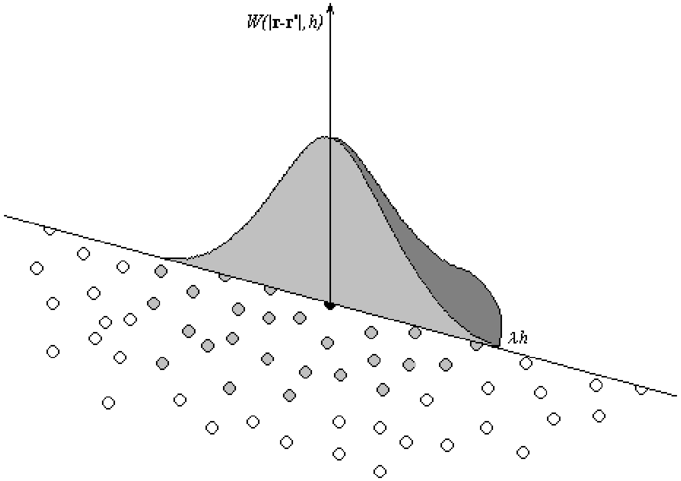
Realistic Simulation through HPC: Application to Risk at Sea

A. Kamoulakos, P. Groenenboom
ESI Group

B. Cartwright
Pacific ESI

Particle Method SPH

- Smoothed Particle Hydrodynamics (SPH)
- Meshless method for continuum mechanics
- Origins in modelling of cosmic physics
  - Gingold and Monaghan (1971)
- Proven in hypervelocity impact applications
- ESI version significantly enhanced for fluid-flow applications
  - Handles free-surface and other interfaces



Special “interpolation” functions used called “smoothing functions”

Normalization

$$\int W(\mathbf{x}-\mathbf{x}',h)\,d\mathbf{x}'=1$$

Compact support

$$W(\mathbf{x}-\mathbf{x}')=0 \qquad |\mathbf{x}-\mathbf{x}'|>\kappa h$$

Delta function property

$$\lim_{h\to 0} W(\mathbf{x}-\mathbf{x}',h)=\delta(\mathbf{x}-\mathbf{x}')$$

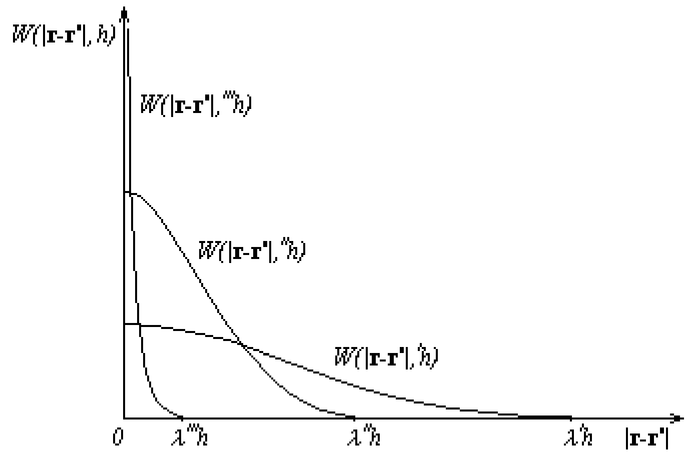
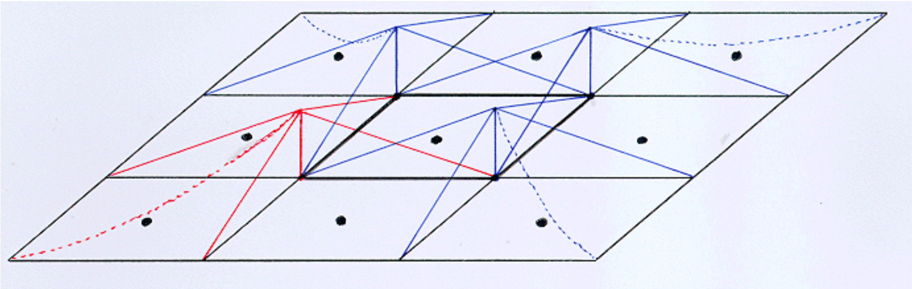
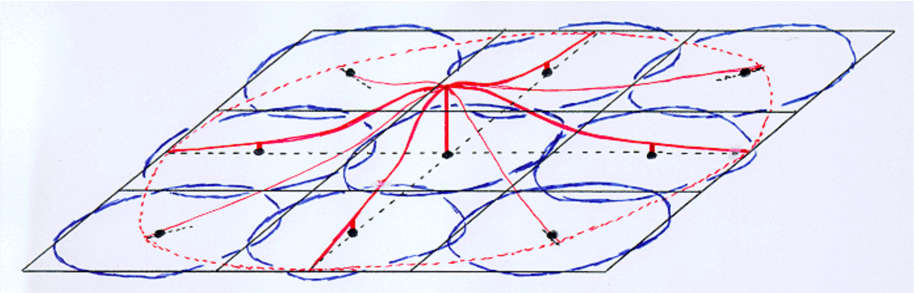


Illustration of smoothing functions



FE interpolation functions



SPH smoothing function

SPH - basic concepts

- Properties (eg. density) can be interpolated within a certain range.

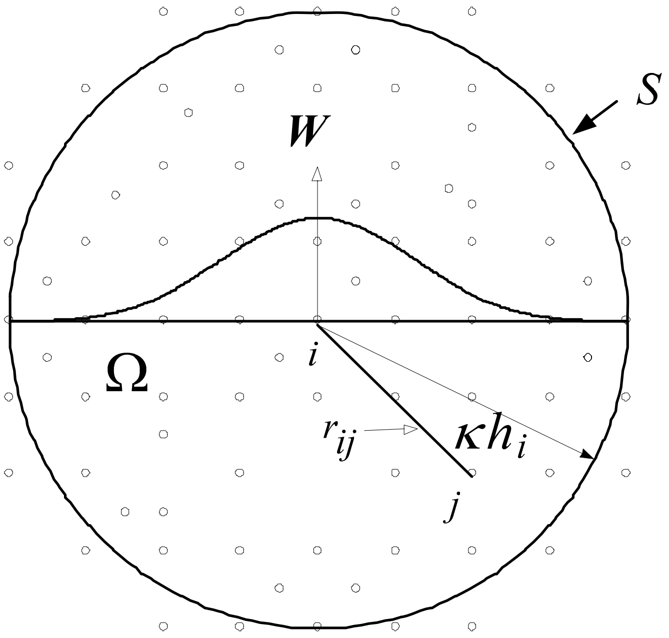
h – Smoothing length

W – Smoothing function

✓ **Kernel approximation**

$$f(x) = \int f(x')W(x-x',h)dx'$$

$$\nabla f(x) = \int f(x')\nabla W(x-x',h)dx'$$



SPH - basic concepts

- The interpolation points are identified with particles of a specified mass.

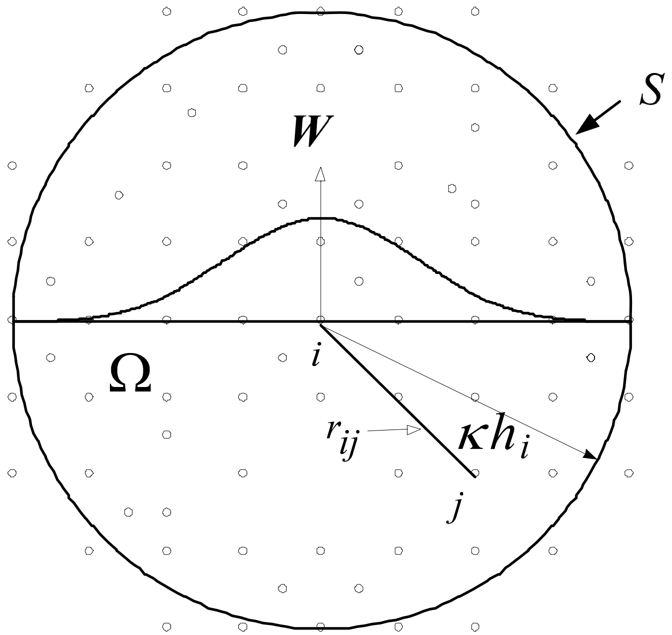
***h* – Smoothing length**

***W* – Smoothing function**

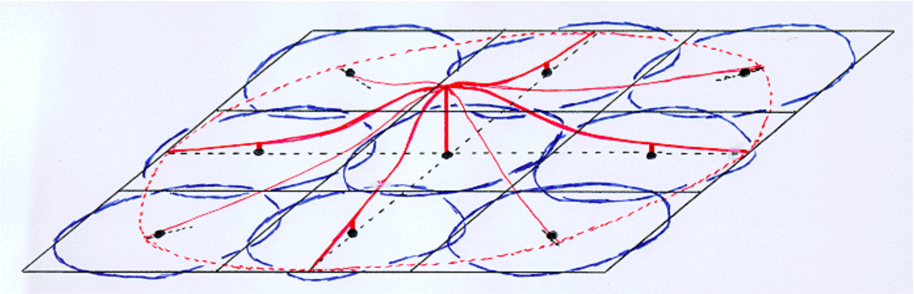
✓ **Particle approximation**

$$f_i = \sum_{j=1}^{N} \left(\frac{m_j}{\rho_j} \right) f_j W(x_i - x_j, h)$$

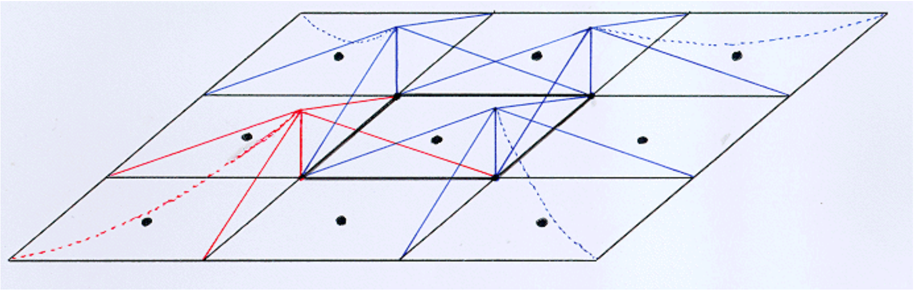
$$\nabla f_i = \sum_{j=1}^{N} \left(\frac{m_j}{\rho_j} \right) f_j \nabla_i W(x_i - x_j, h)$$



- The FE connectivity is replaced by a dynamic nearest neighbor search.



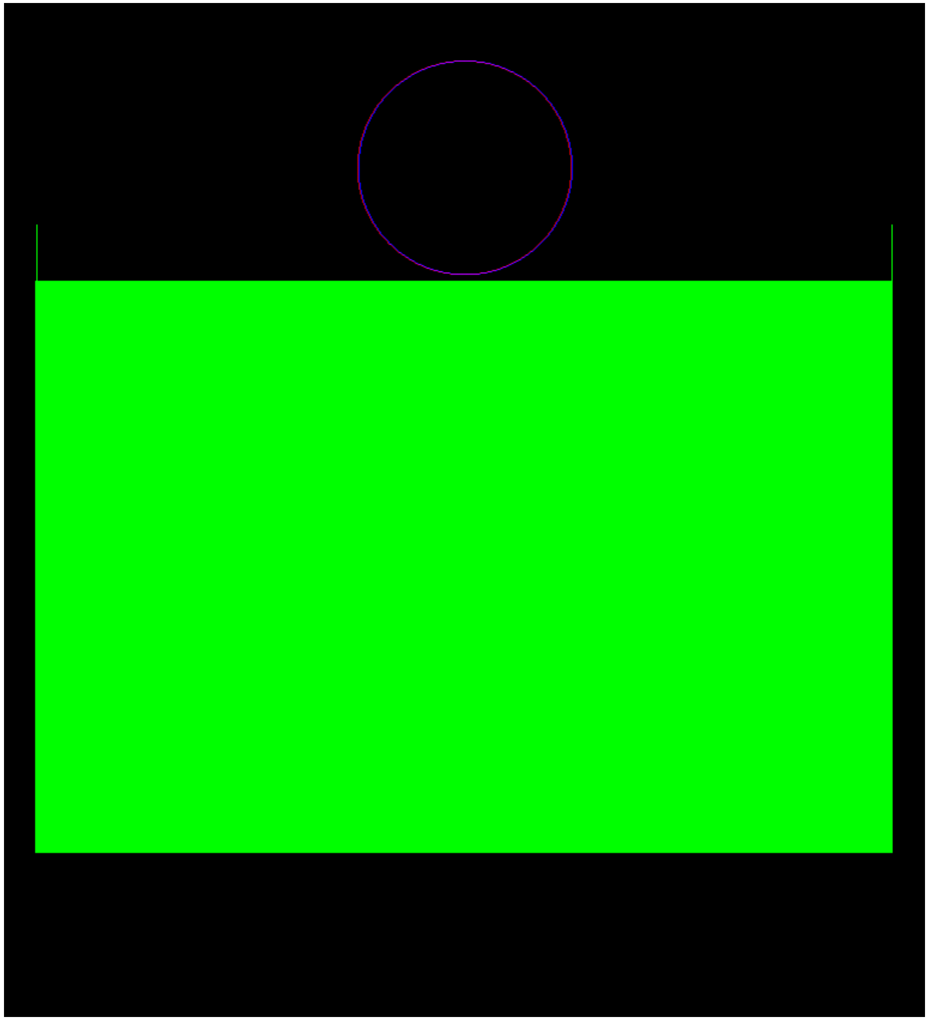
SPH neighborhood



FE connectivity

Cylinder impacting fluid at constant speed

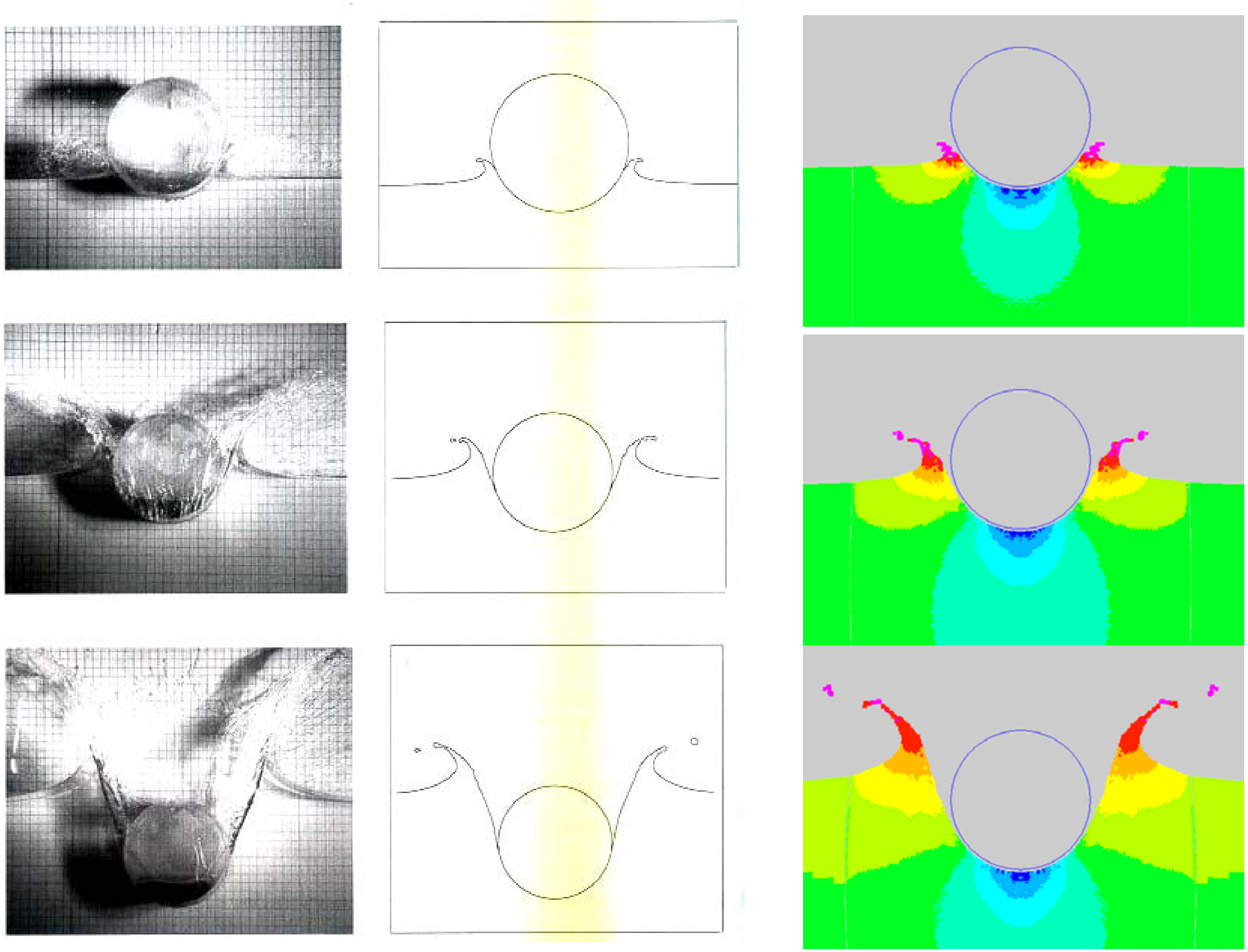
- The SPH method is fully integrated in the explicit finite element, crashworthiness code PAM-CRASH.
- A coupling between FE and SPH allows an interactive treatment of fluid-structure interaction.
- For regions with limited fluid displacements it is possible to use finite elements for the water.
  - See aircraft splashdown later on



Contours represent velocity magnitude

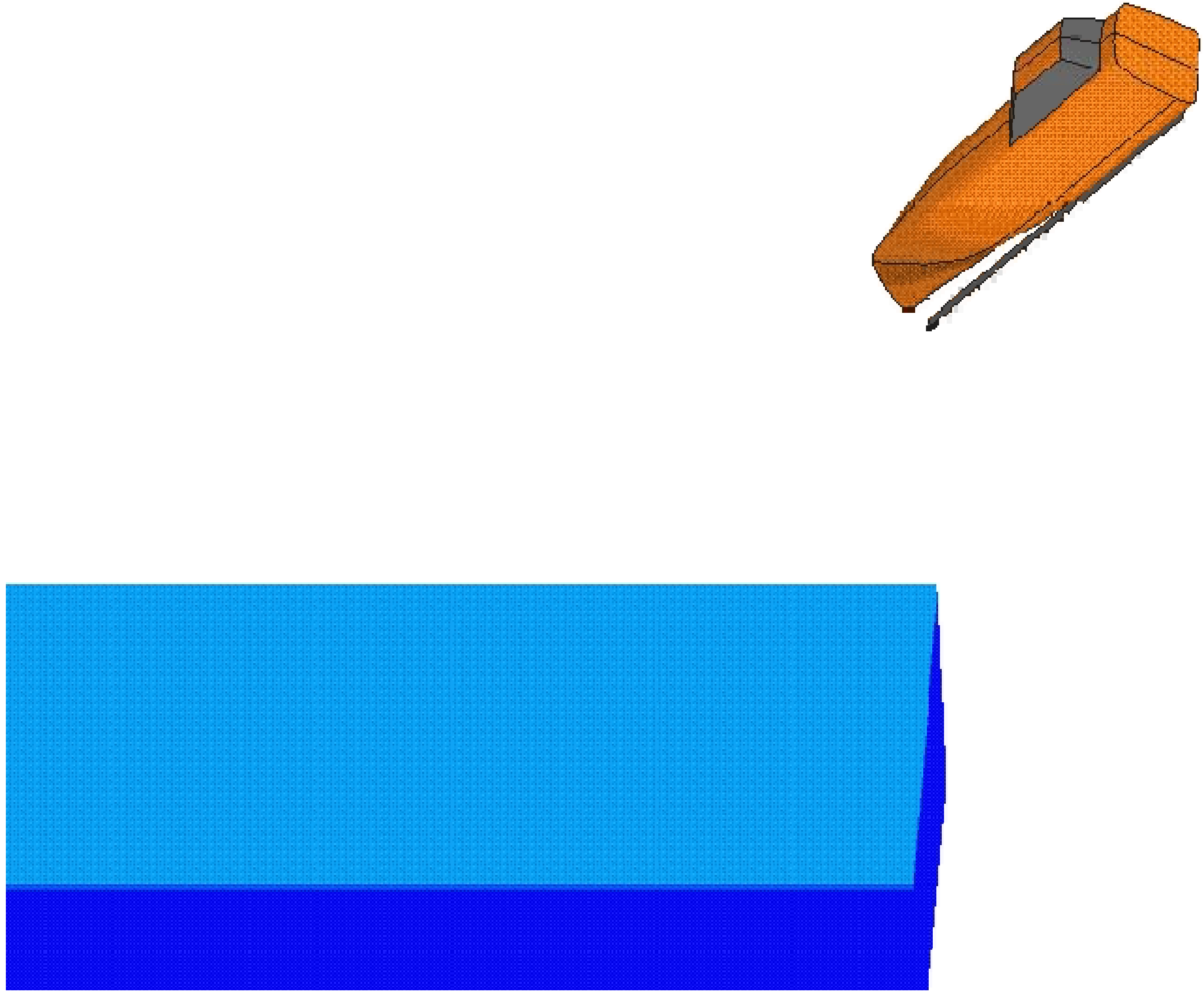
Cylinder impacting fluid at constant speed

Free-surface deformation from Fekken (left) and for PAM-CRASH SPH/FE simulation with the contours of the velocity

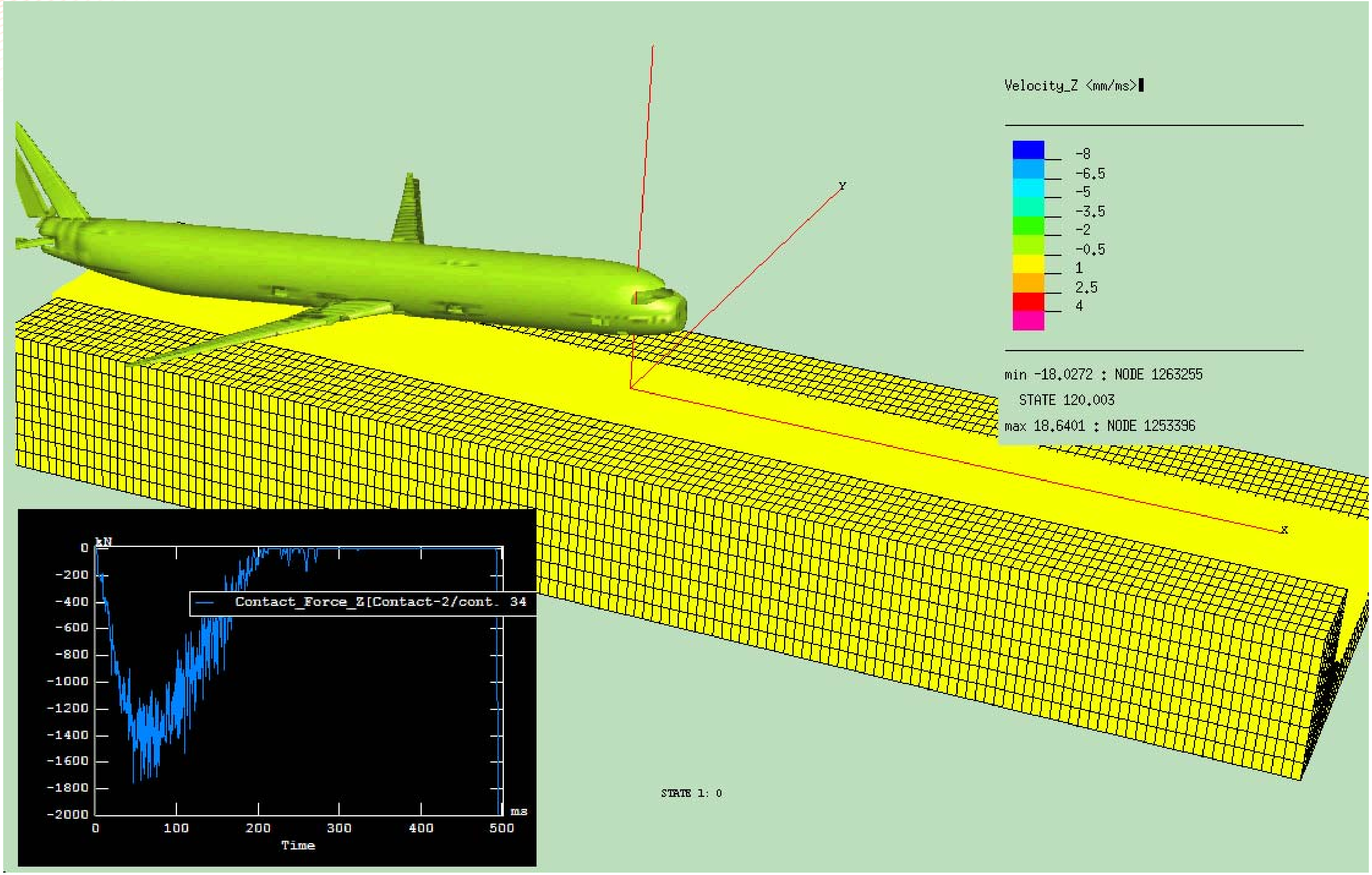


Free fall of a lifeboat
Limiting scenario

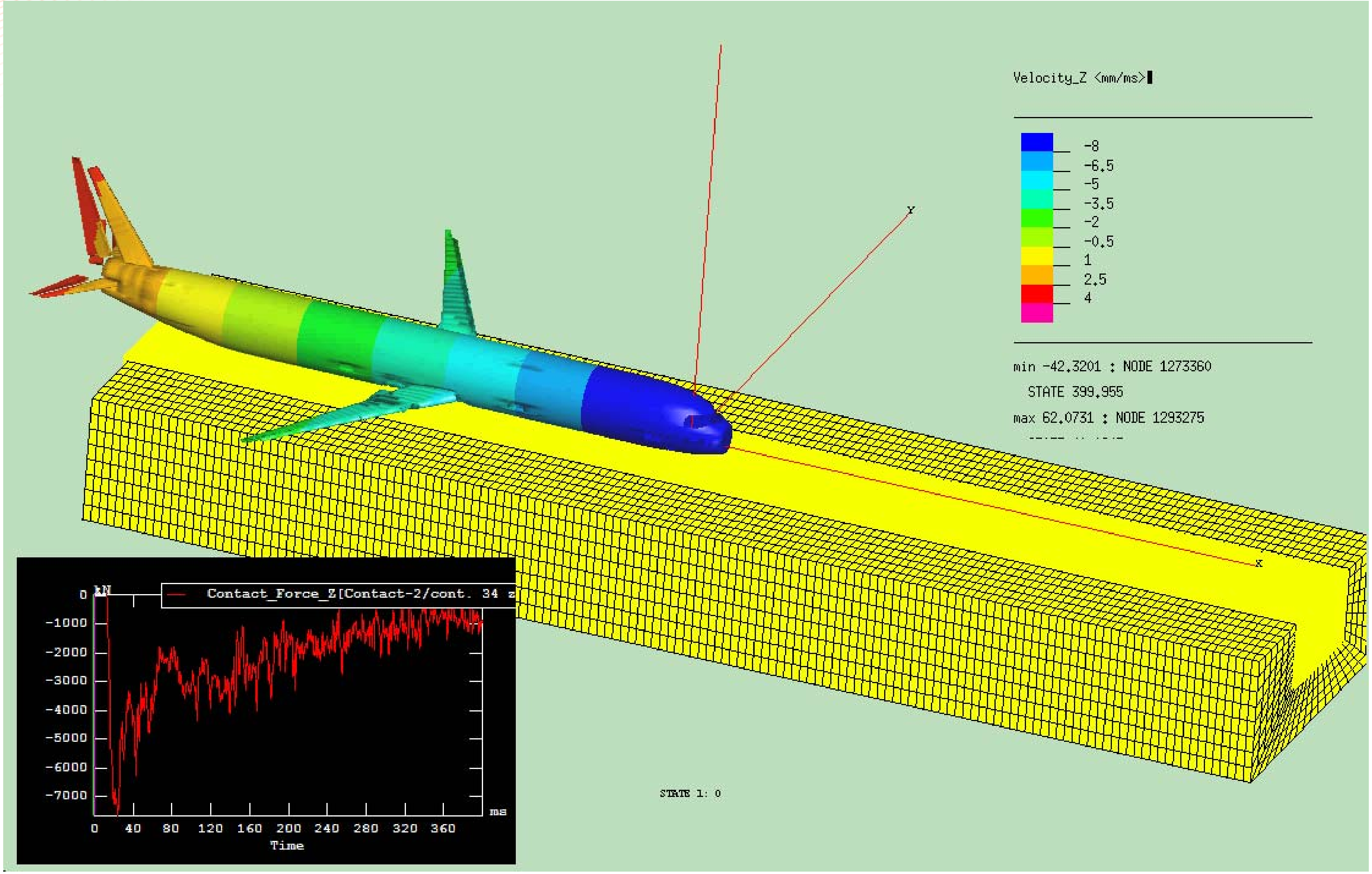
A commercial application



(EC research project CRAHVI)
Airbus 321 ditching (Courtesy of DLR)

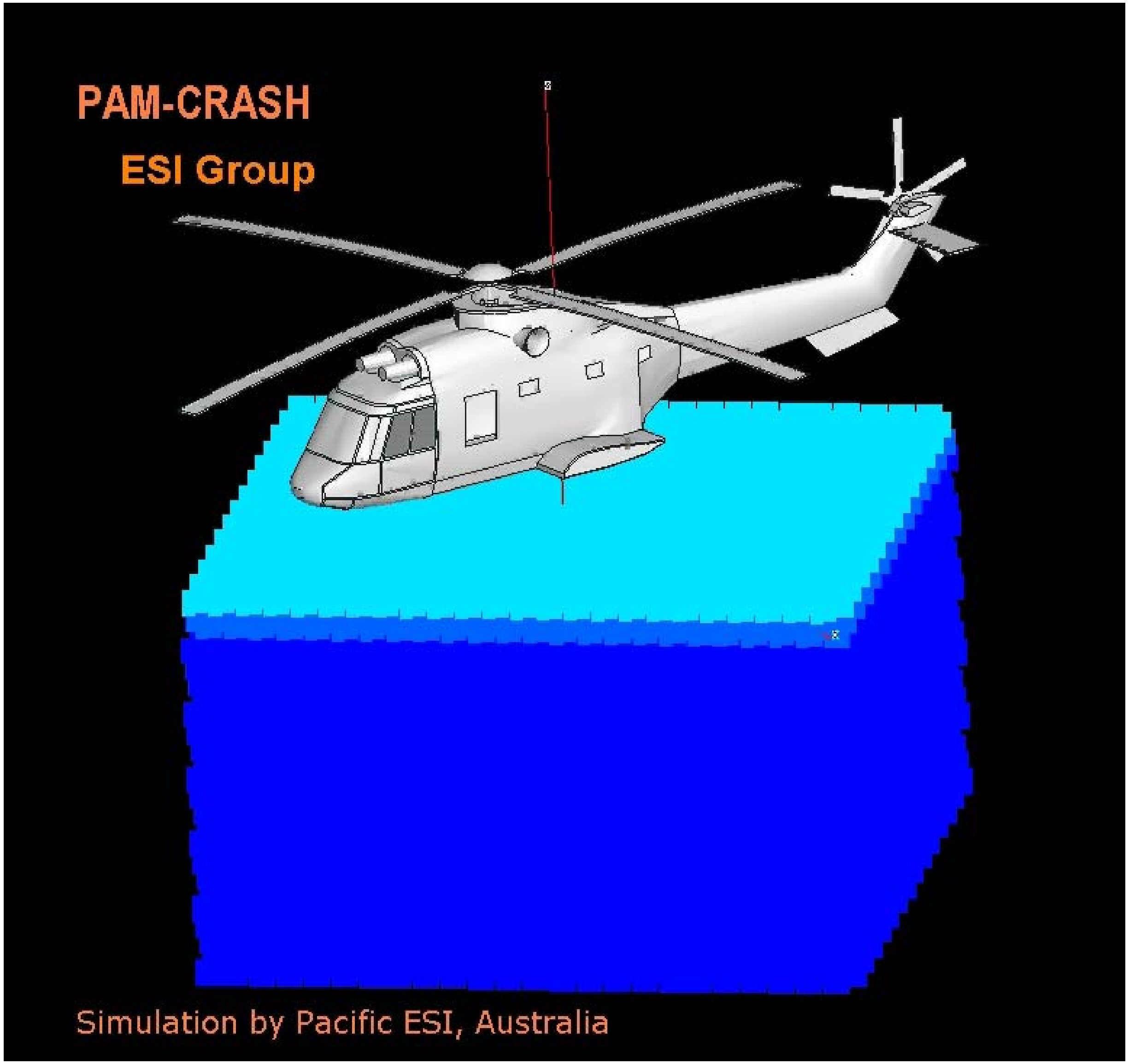


(EC research project CRAHVI)
Airbus 321 ditching (Courtesy of DLR)



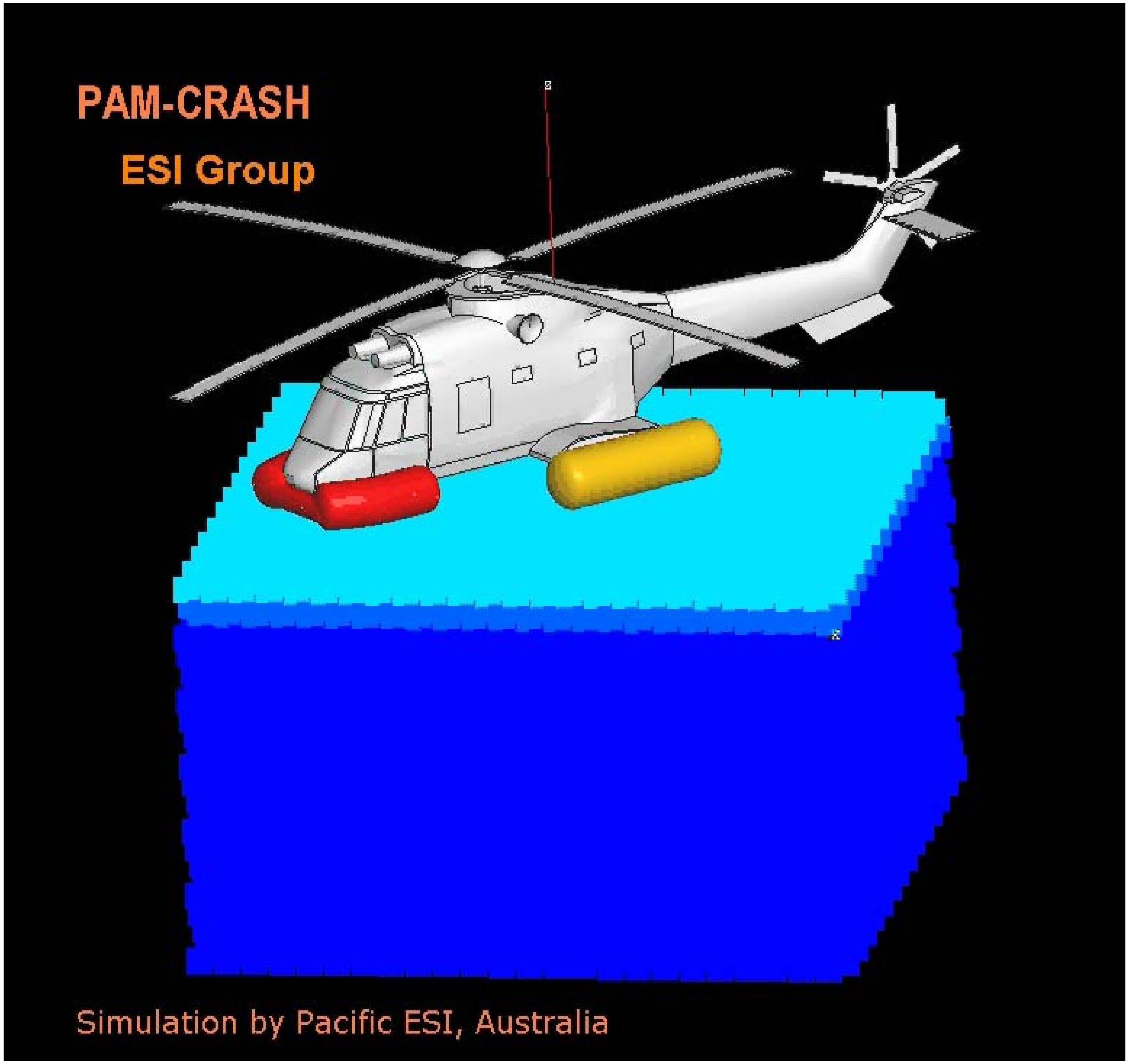
Capsizing phase of splashdown of helicopter

Capsizing of Puma without airbags



Capsizing prevention mechanisms

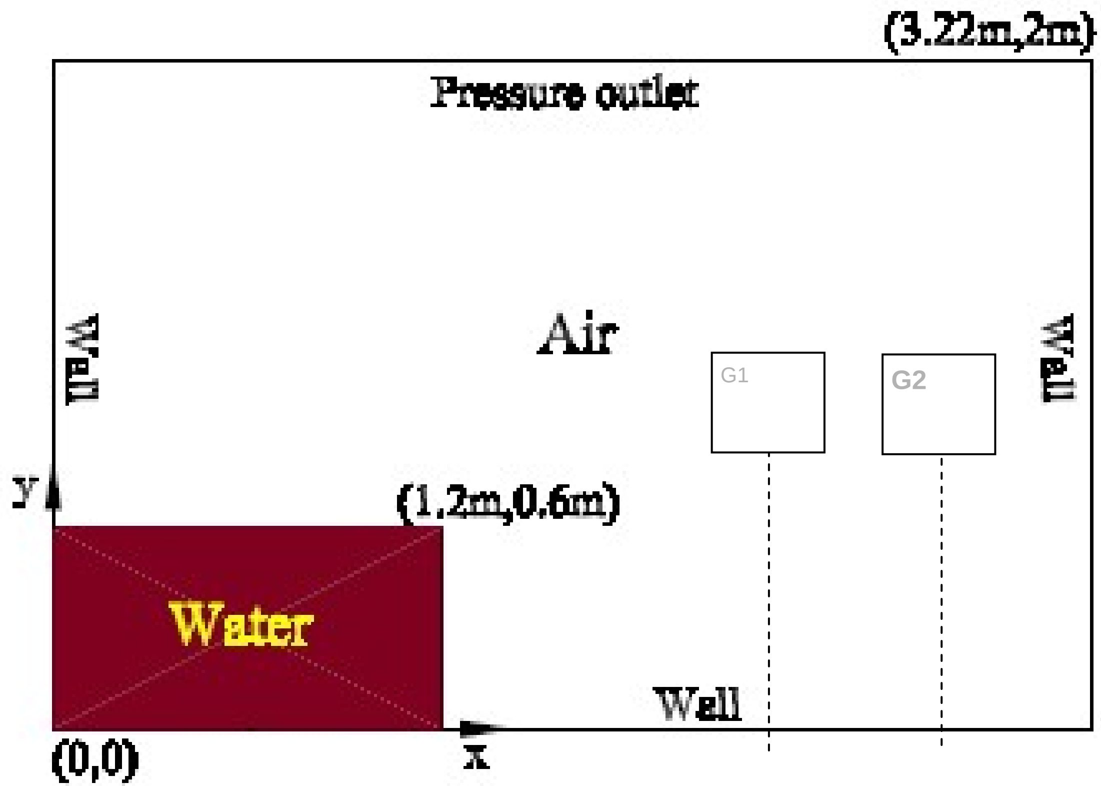
Effect of airbags



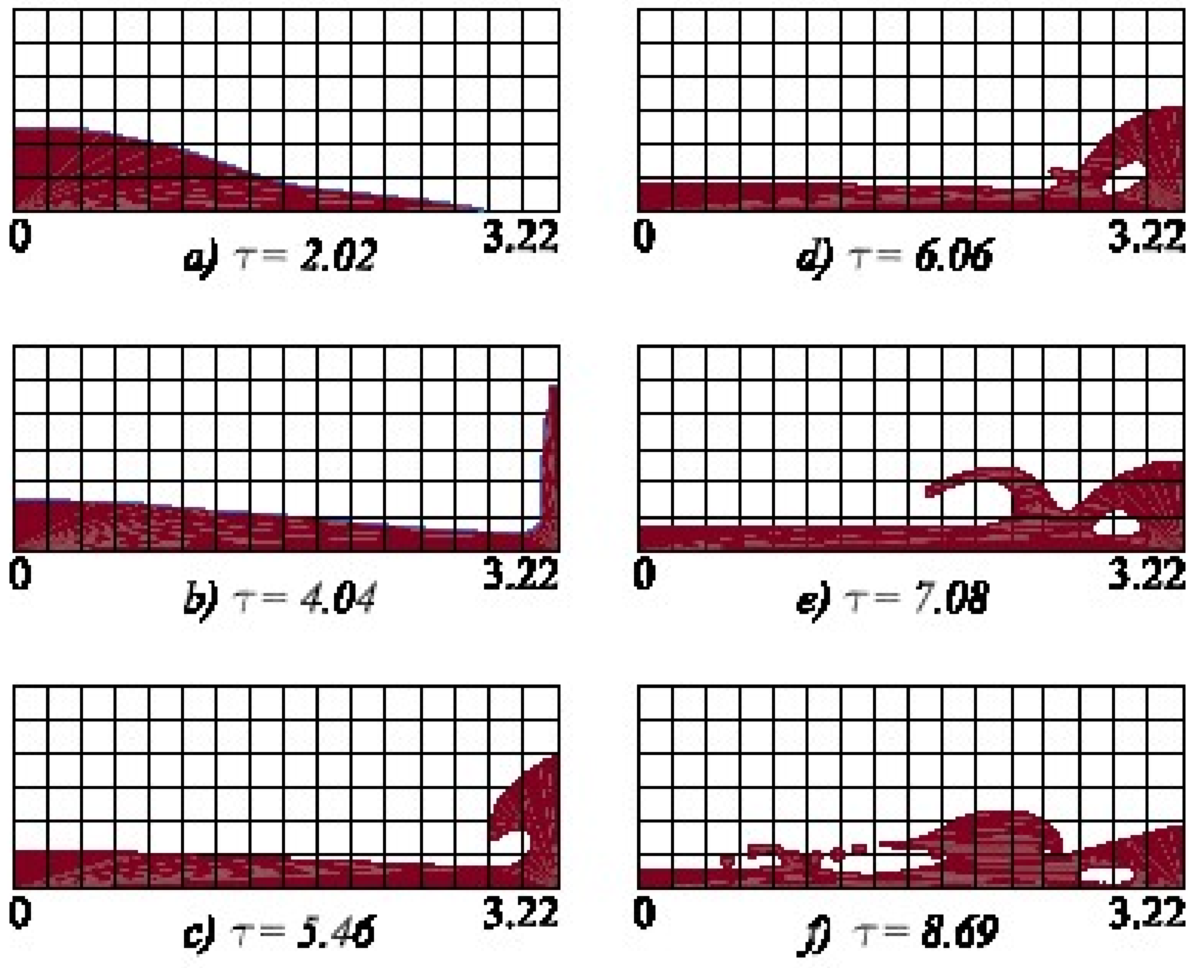
Dam Break Benchmark

TEST: dam-break as described by Abdolmaleki, Thiagarajan and Morris-Thomas from the University of Western Australia at Crawley (2004) has been selected.

Important validation case and for particle size and SPH parameters.

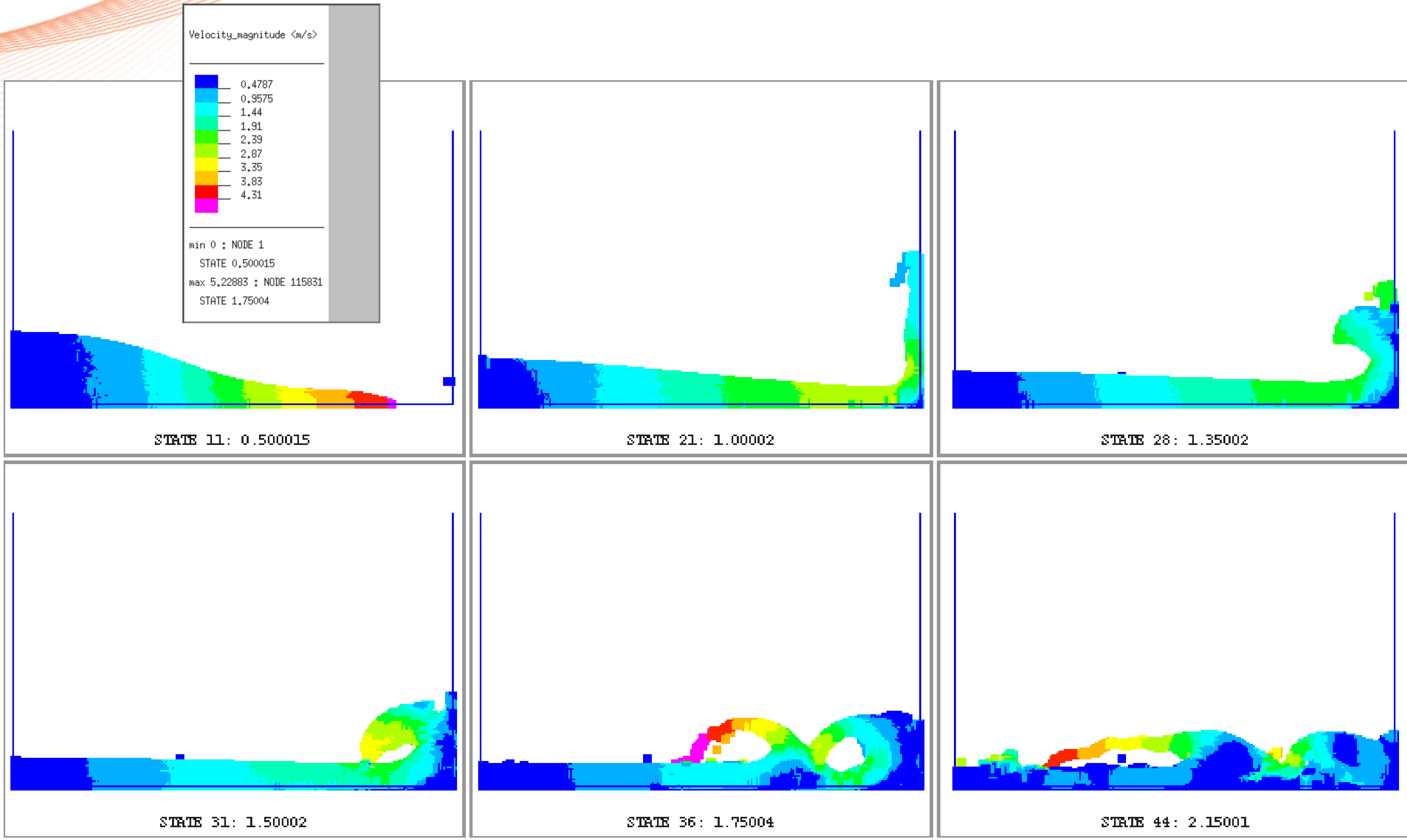


Published Results



water contours as computed by FLUENT from Abdolmaleki et al.

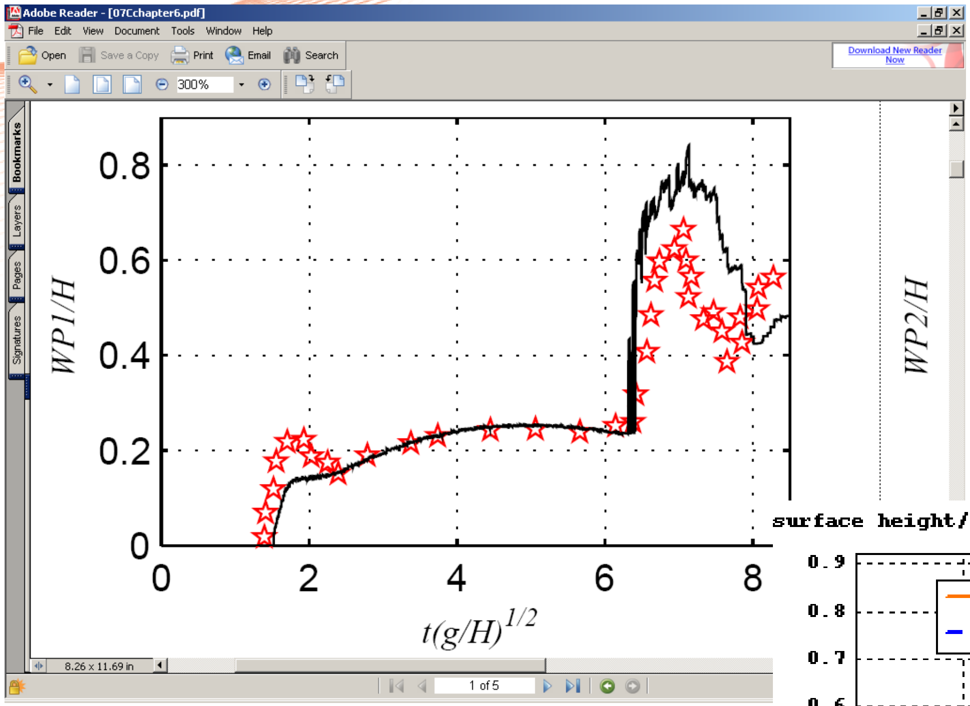
DAM Break Simulation results

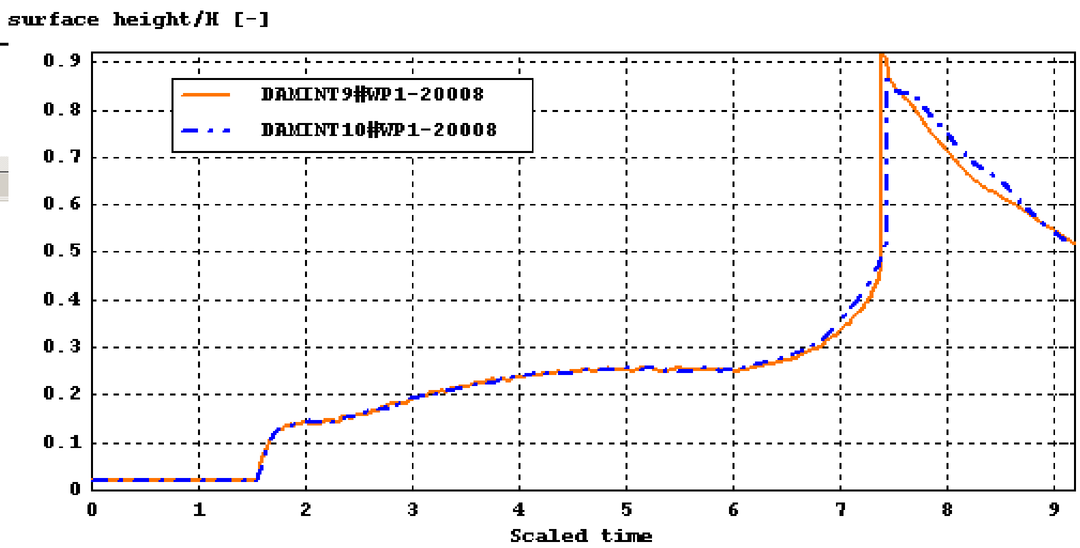


contour of the velocity at dimensionless time of 2.02, 4.04, 5.46, 6.06, 7.08 and 8.69

Comparison of SPH with CFD

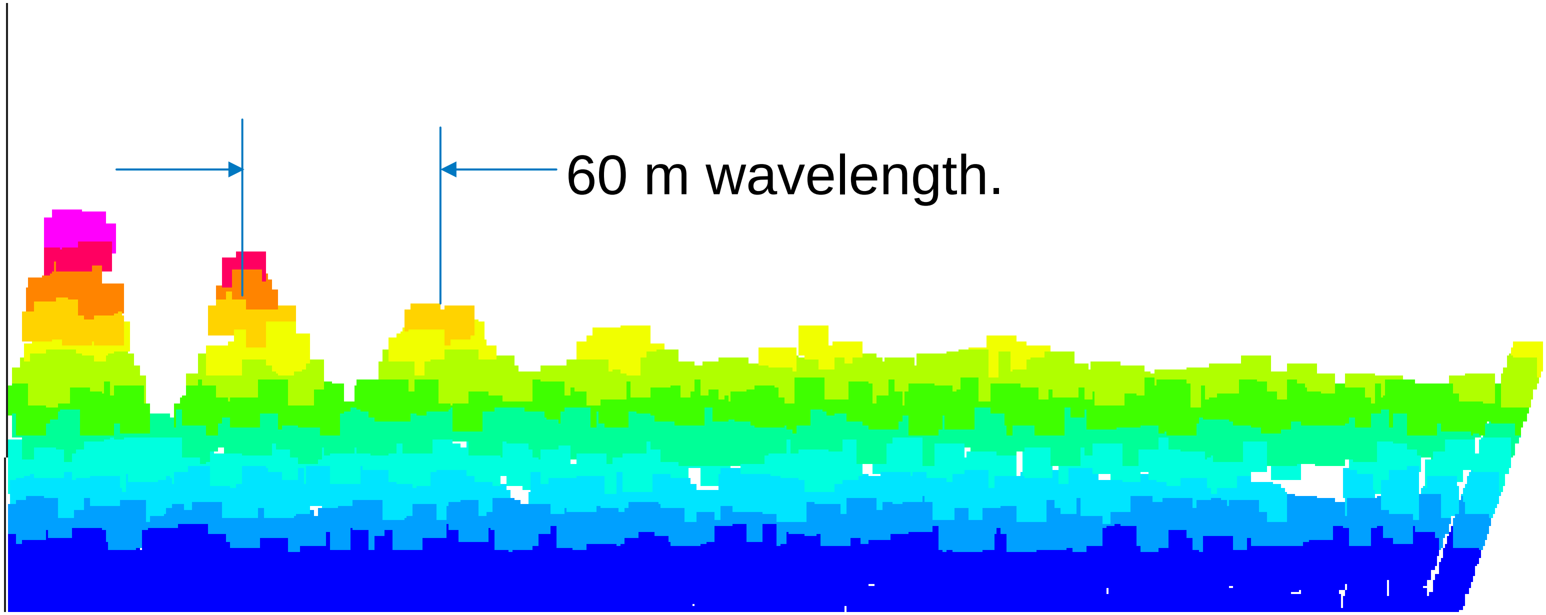
Free surface elevation (scaled) gauge 1 for two intermediate simulations.





Making Waves !

Regular Wave Trials – not good



Colour represents vertical height

(Exaggerated vertical displacements)

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Wave Generation issues

- For numerical solutions, modelling the wave to a depth where no motion occurs is costly, so we'd like to avoid it.
- If the modelling depth is less than half a wavelength, the solution for deep water waves will require special treatment of the sea-floor boundary.
- Rigid wall boundary conditions at this boundary are inconsistent with wave solutions for deep water.
- Moving the floor according to the motions of the wave theory has been found to reproduce the surface wave.

Australian Government
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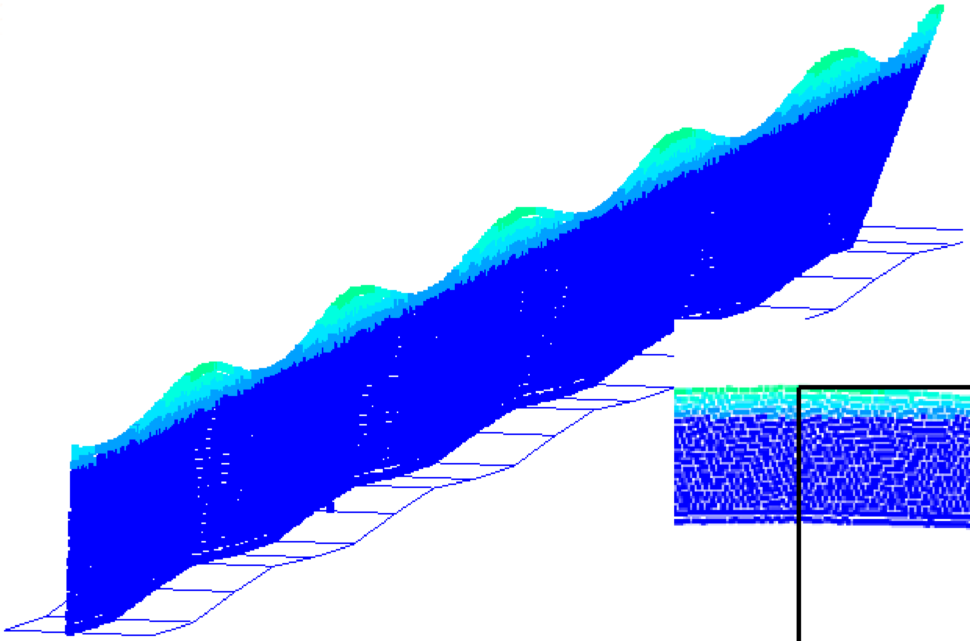
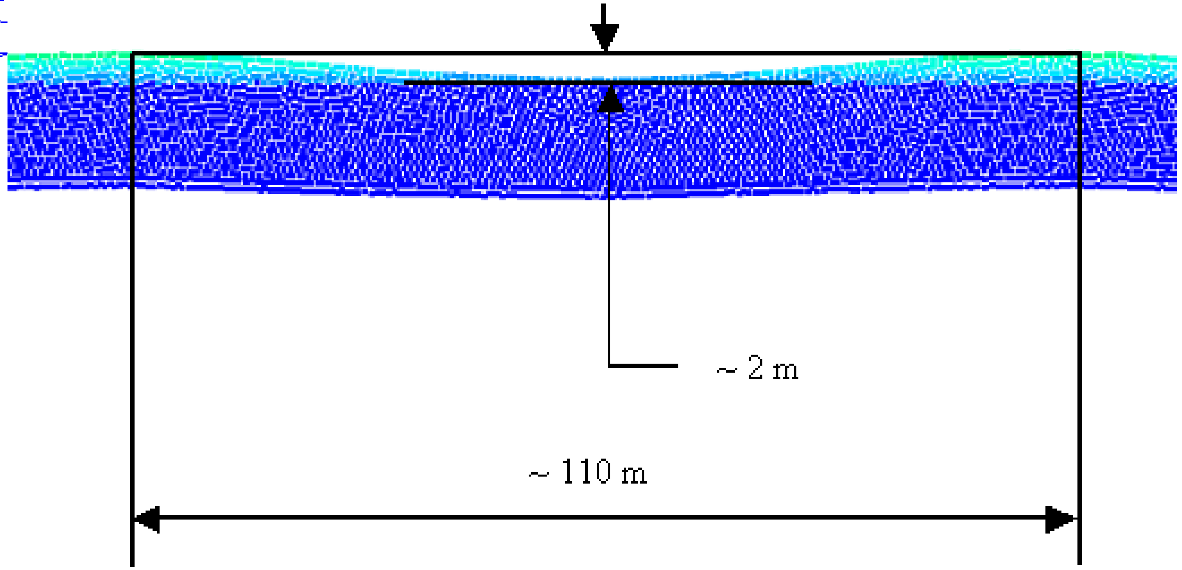
Regular Wave Trials – Practical solution developed



Wavelength = 110 metres

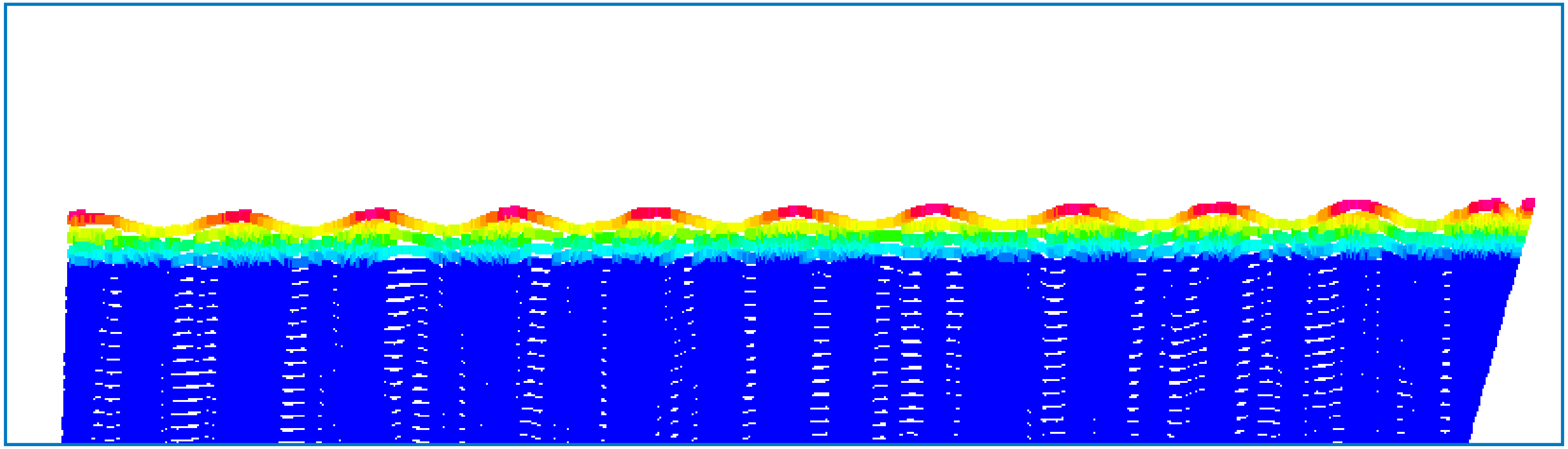
Depth = 15 metres



Wave Generation

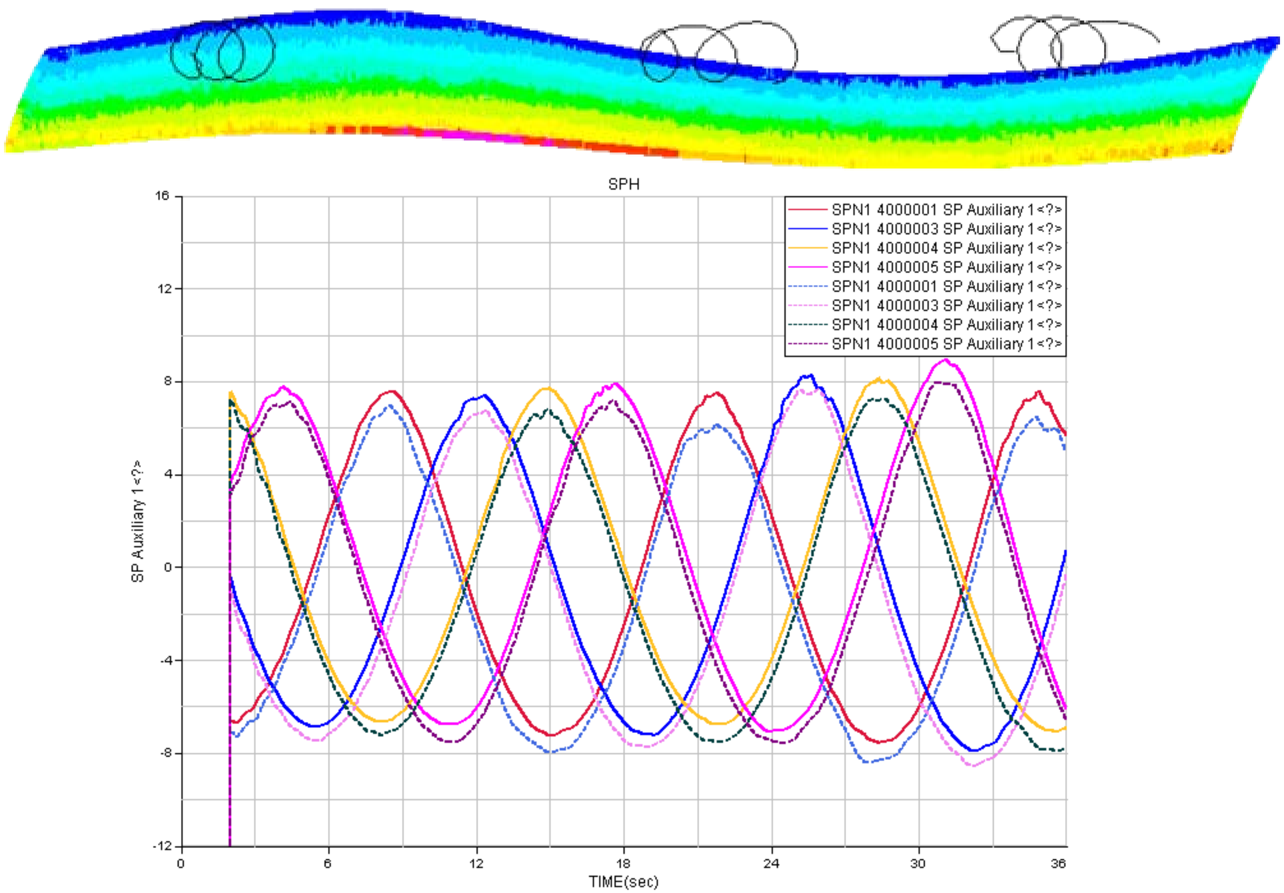
This concept permits a wave in a shallow tank to behave like a deep water wave. This allows a more CPU-efficient solution than the simple solution of modelling the complete depth.

Below is an example of 1km of a 1m amplitude wave of 100m wavelength in 15 metres of water. *(The view is oblique, to reveal the 1m amplitude, colour representing height.)*

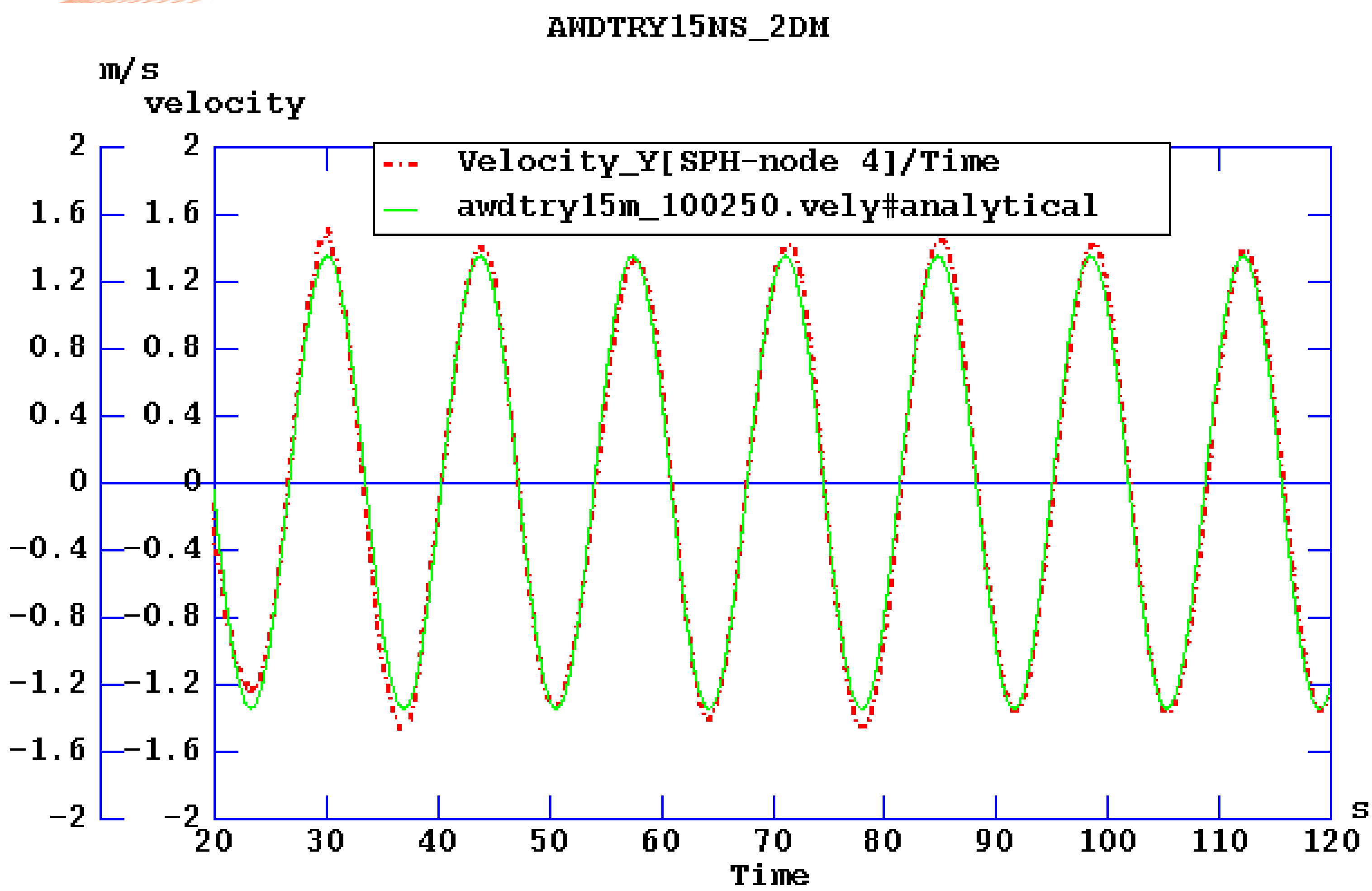


Wave Generation

- Applicable to a full size ship, by implementing second order Airy displacements on the boundaries, we can generate a wave of 8 metres waveheight and 294m wavelength.

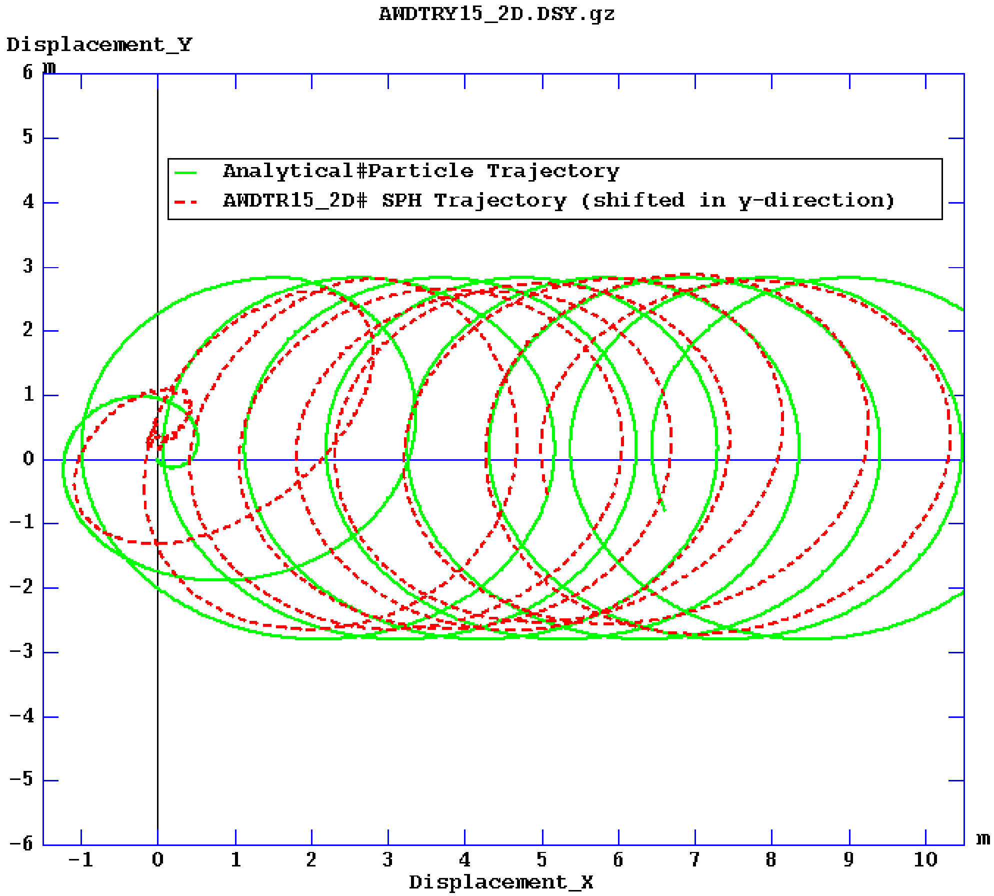


Wave Generation



History of the vertical velocity of a selected particle compared to the analytical solution.

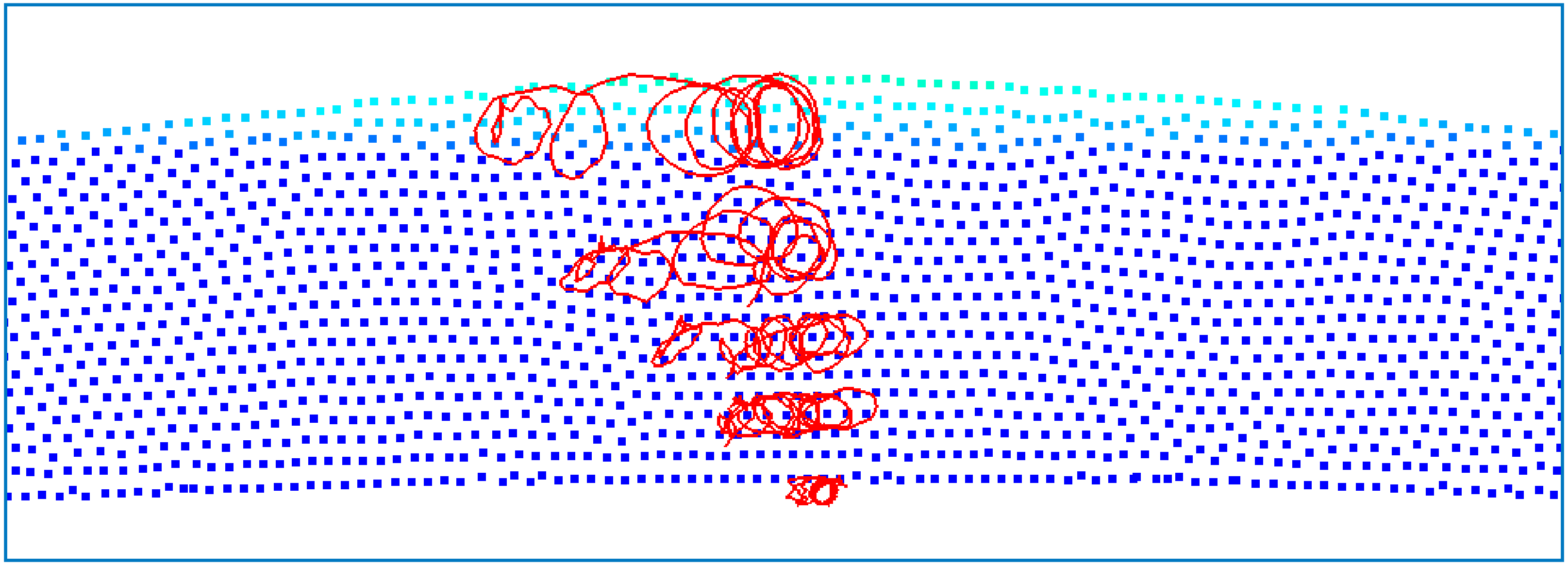
Wave Generation



Trajectory of a selected particle compared to the analytical results. Since the particles tend to sink due to gravity there will not be a perfect match

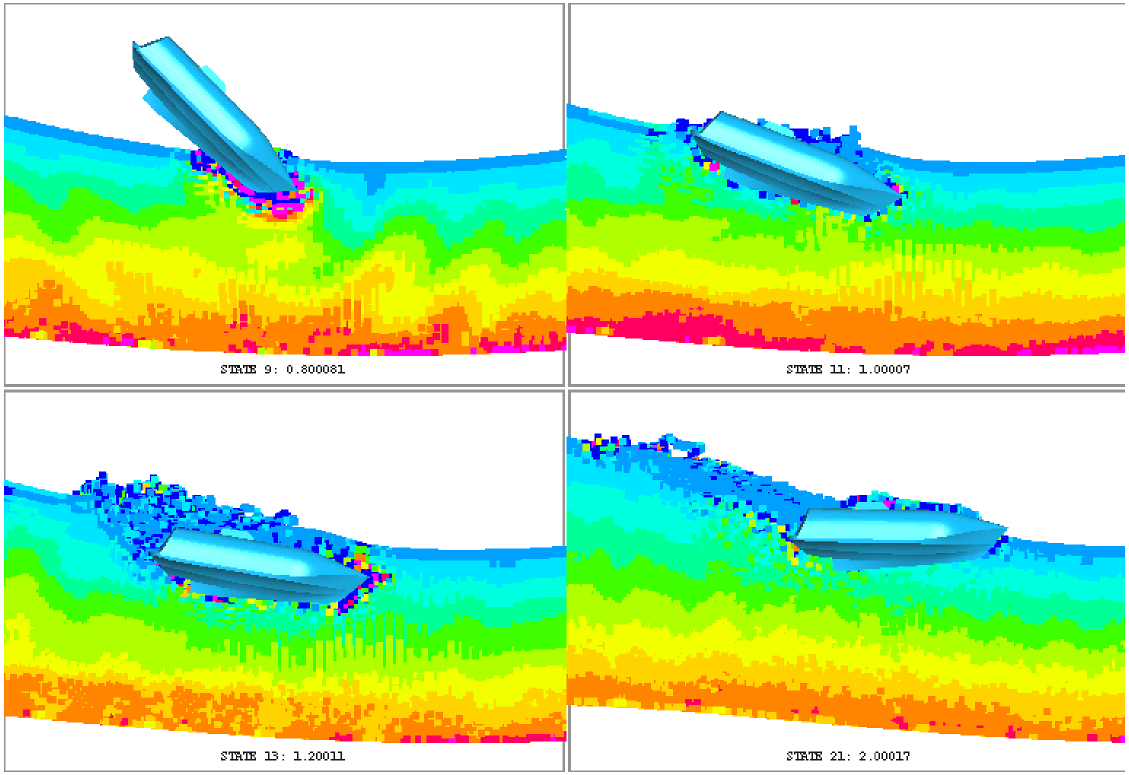
Deep Water Waves

Orbits of discrete particles within a wave illustrate that the particles at the junction of the SPH and the novel sea-floor interface have a circular motion, indicating that these deepest SPH particles are behaving as though they were in a deeper body of water



Life Boat Water Entry

- Combination of waves with boat slaming



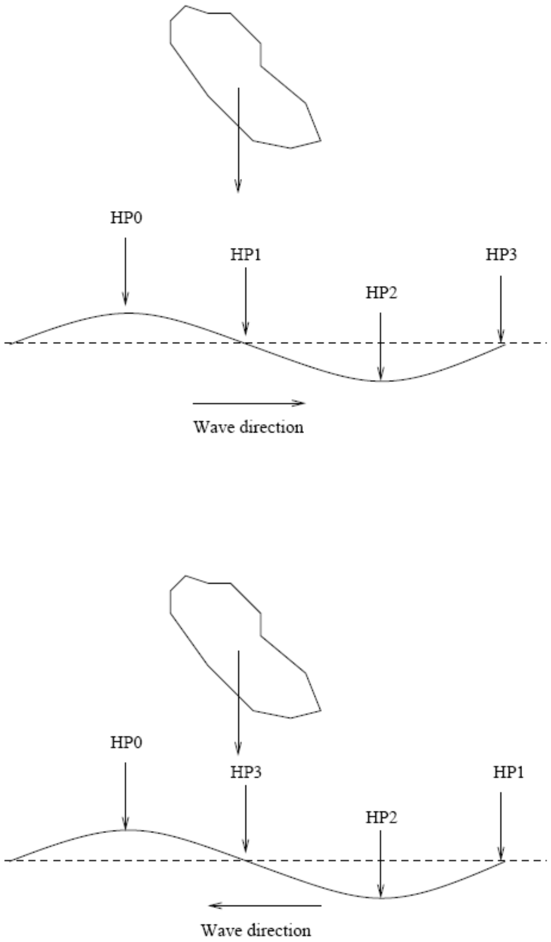
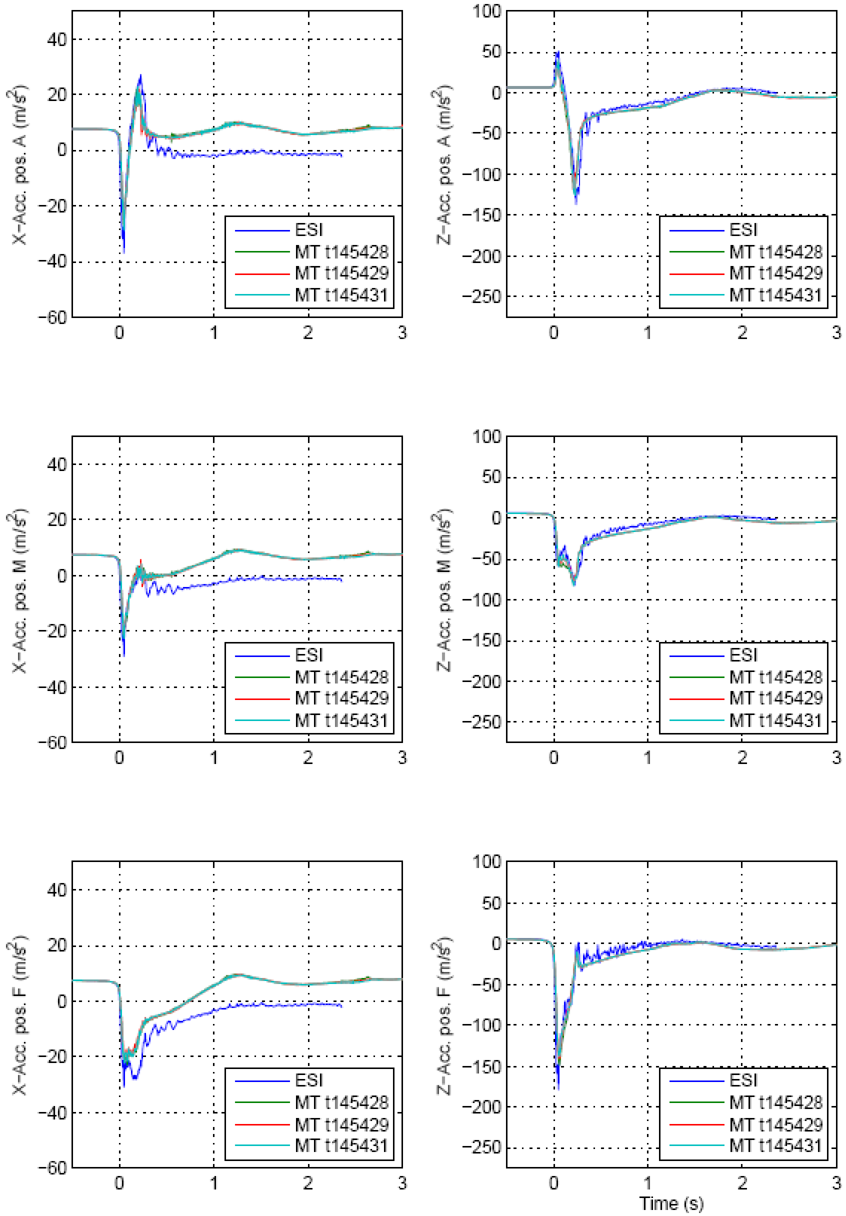


Figure 1.1: Hip point definition.

Life Boat Water Entry

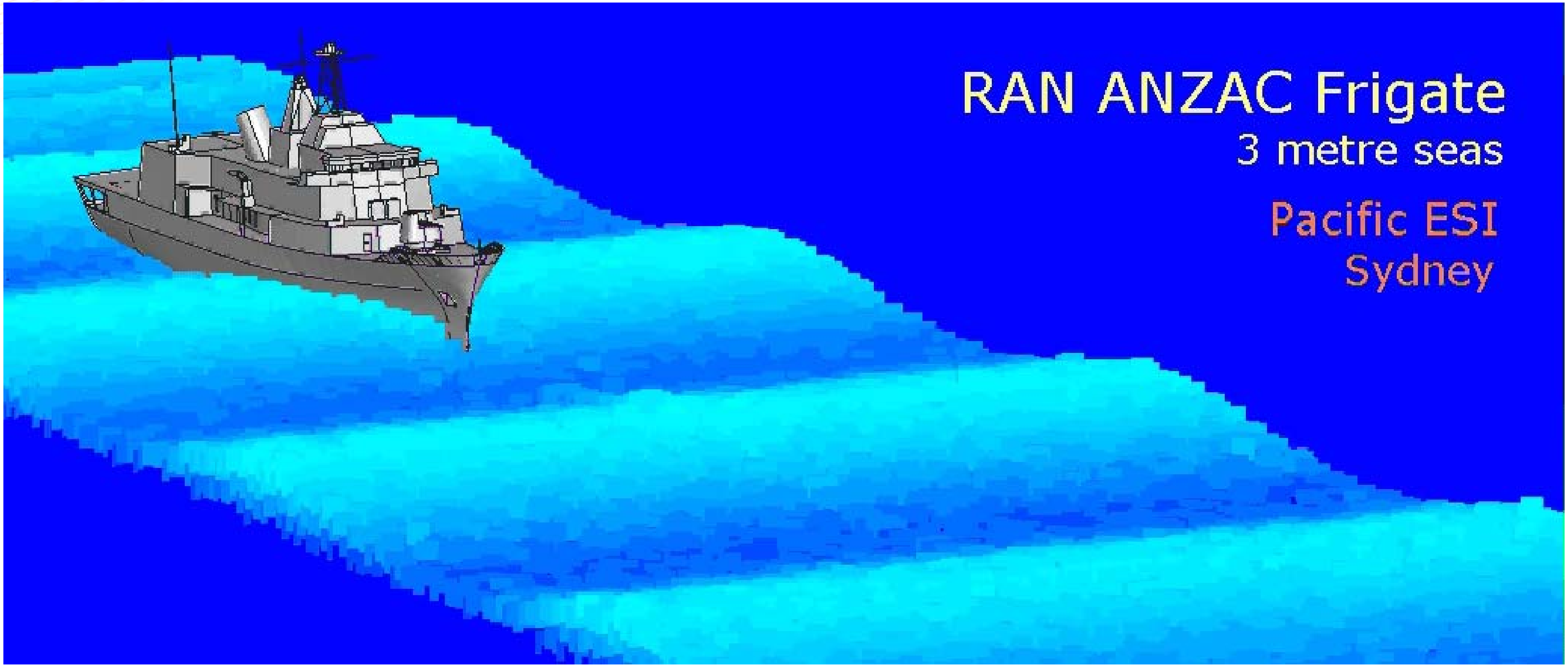
Drop height : 30m , Initial pitch : 50deg. Hit point : HP3 Wave dir. : Head



- The (x- and z-) accelerations from the PAM-CRASH simulations at 3 different locations at the hull of the LB have been compared to the results from 3 scale tests.

Monohull in waves

Monohull in Head Seas



A generic monohull is accelerated forward by a velocity boundary condition.

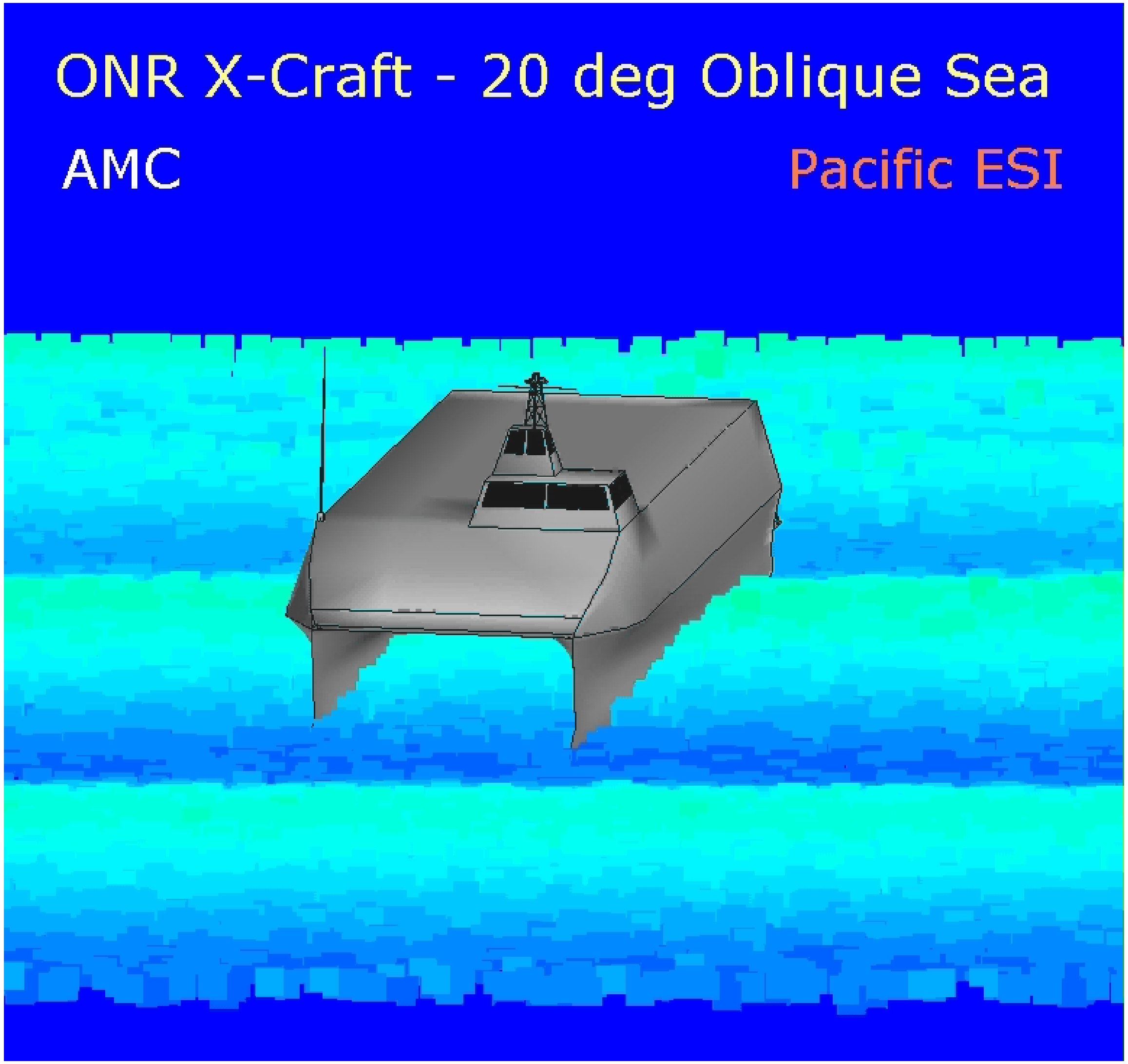
Cartwright, 2005.

Multihull in oblique waves

A generic catamaran is propelled forwards at an angle to the waves.

Response of the vessel demonstrates pitch, yaw, heave and roll.

Cartwright et al, HPYD, 2006.



Amphibious Transport Ship

Waves in the well dock

JP 2048 - Amphibious Capability

Australian Government
Department of Defence
Defence Science and Technology Organisation

Phase 4A/B (acquisition of Landing Helicopter Docking Ship)

Purpose of Study

1. Need to minimise risk associated with well docks
2. Define operational constraints of well dock operations
3. Develop numerical tools for landing craft tender evaluation

Australian Government
Department of Defence
Defence Science and Technology Organisation

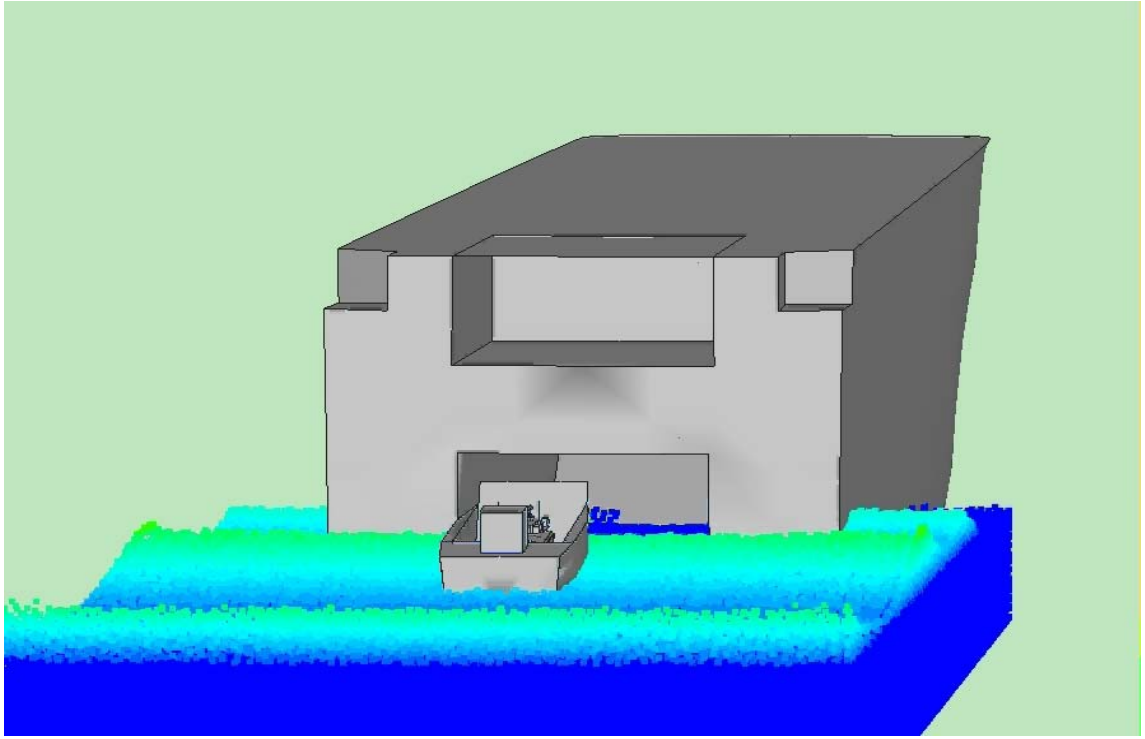
Amphibious Transport Ship

Waves in the well dock

An Amphibious Transport Ship (ATS), or Landing Helicopter Dock (LHD) ship, is a multi-purpose naval vessel to transport troops and equipment from sea to shore by a landing craft via a flooded well dock in the aft end of the ATS. The landing craft are subject to waves produced by the ATS motion and external waves.

Landing craft with 6 DOF.

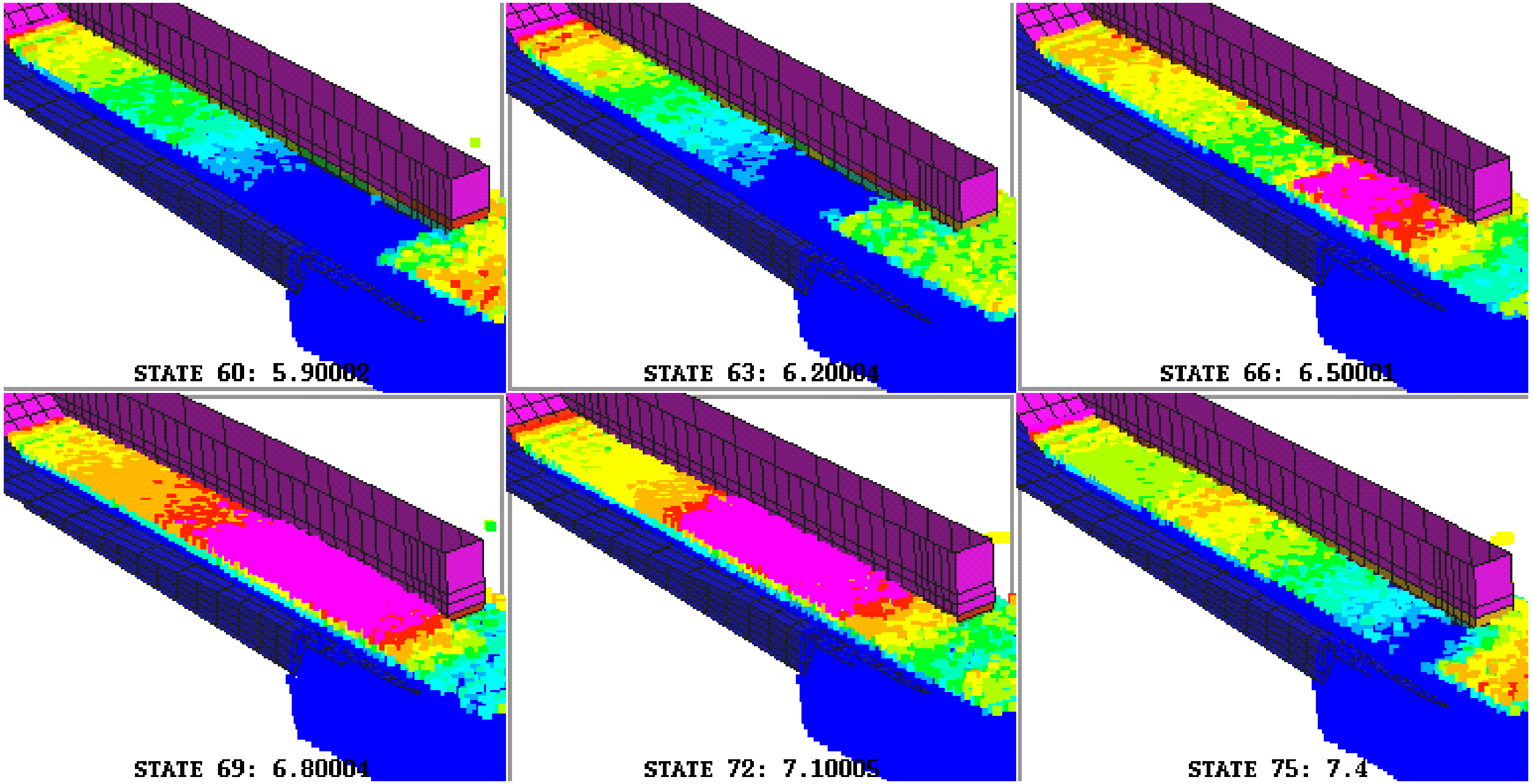
Asymmetric thrust on entering well dock produces a collision with wall. Large peak forces result.



Amphibious Transport Ship

Waves in the well dock

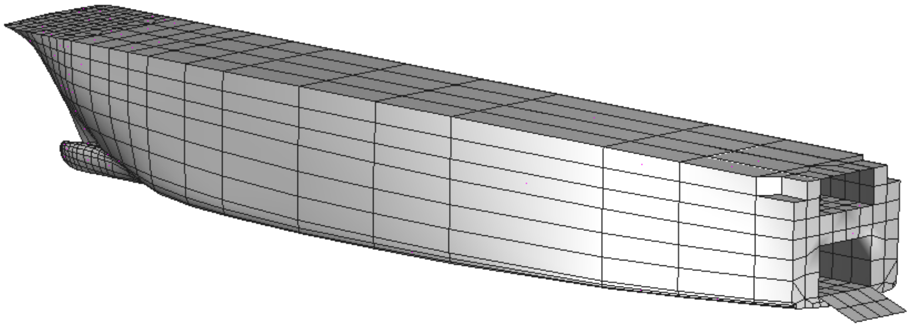
A perspective aerial view into the cut-away section of the well dock at the aft end of the ATS model. (Deck removed for clarity) Colour contour represent wave height (range -0.01 .. 0.03 m).



Numerical Analysis Setup Overview

LHD Model

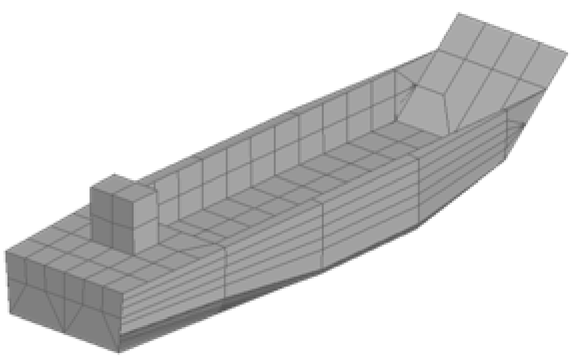
Length overall (LOA) (m)	210
Beam (m)	33
Draft at COG (m) **(with flooded well dock)**	7.6
Trim angle when flooded	Trim by stern 1.8 m
Well Dock Dimensions **Length (m)** **Width (m)**	 70.0 14.8
Mass (tonnes)	26000

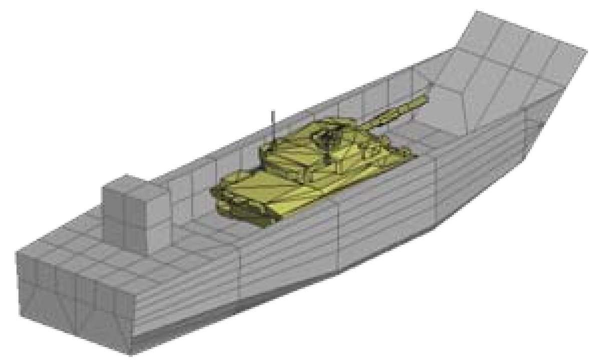


Numerical Analysis Setup Overview

Landing Craft Models

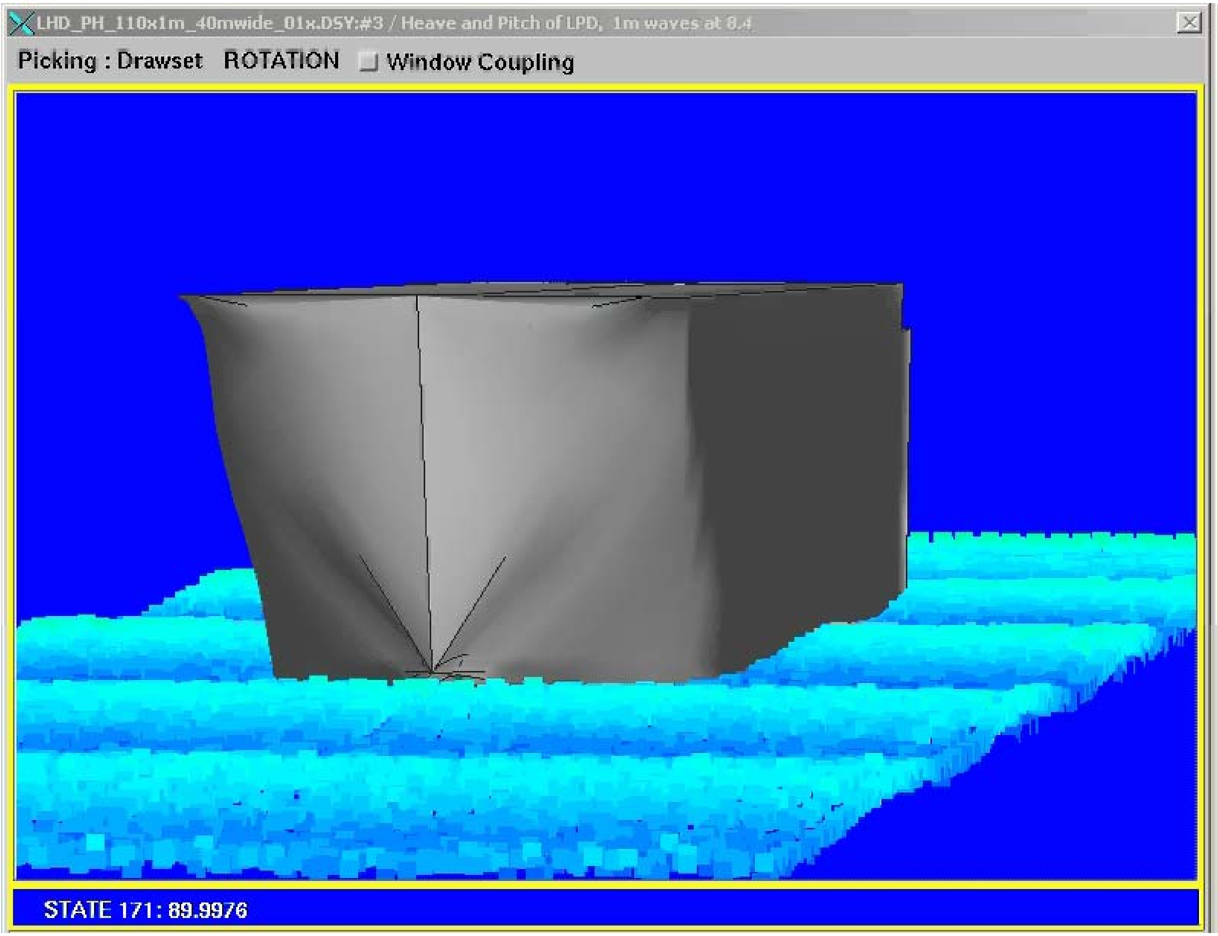
Length overall (LOA) (m)	24.5	
Beam (m)	6.4	
Mass (tonnes)	**Model 1 (Light)** 42.8	**Model 2 (Heavy)** 90.4
Longitudinal COG from FP (m)	11.1	9.6
KG at midships (m)	1.366	1.852
Draft at Midships (m)	1.14	1.68

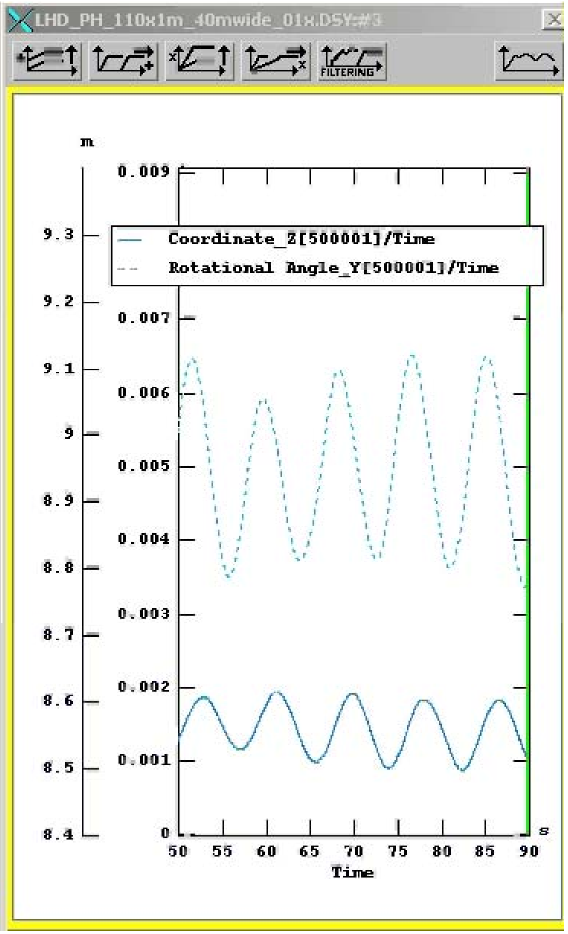




Results and Observations

LHD Motions – Pitch and Heave in 1m sea





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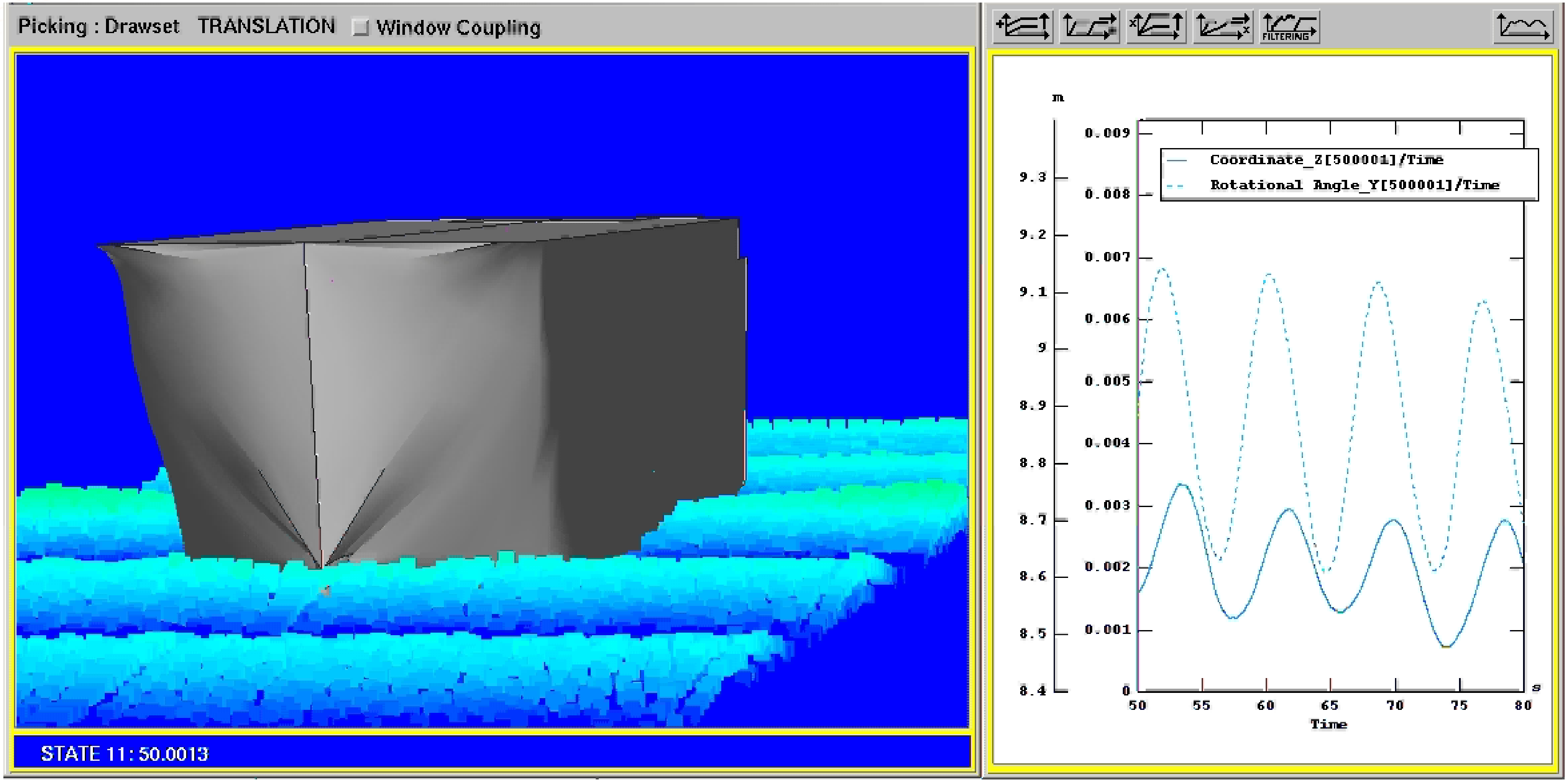
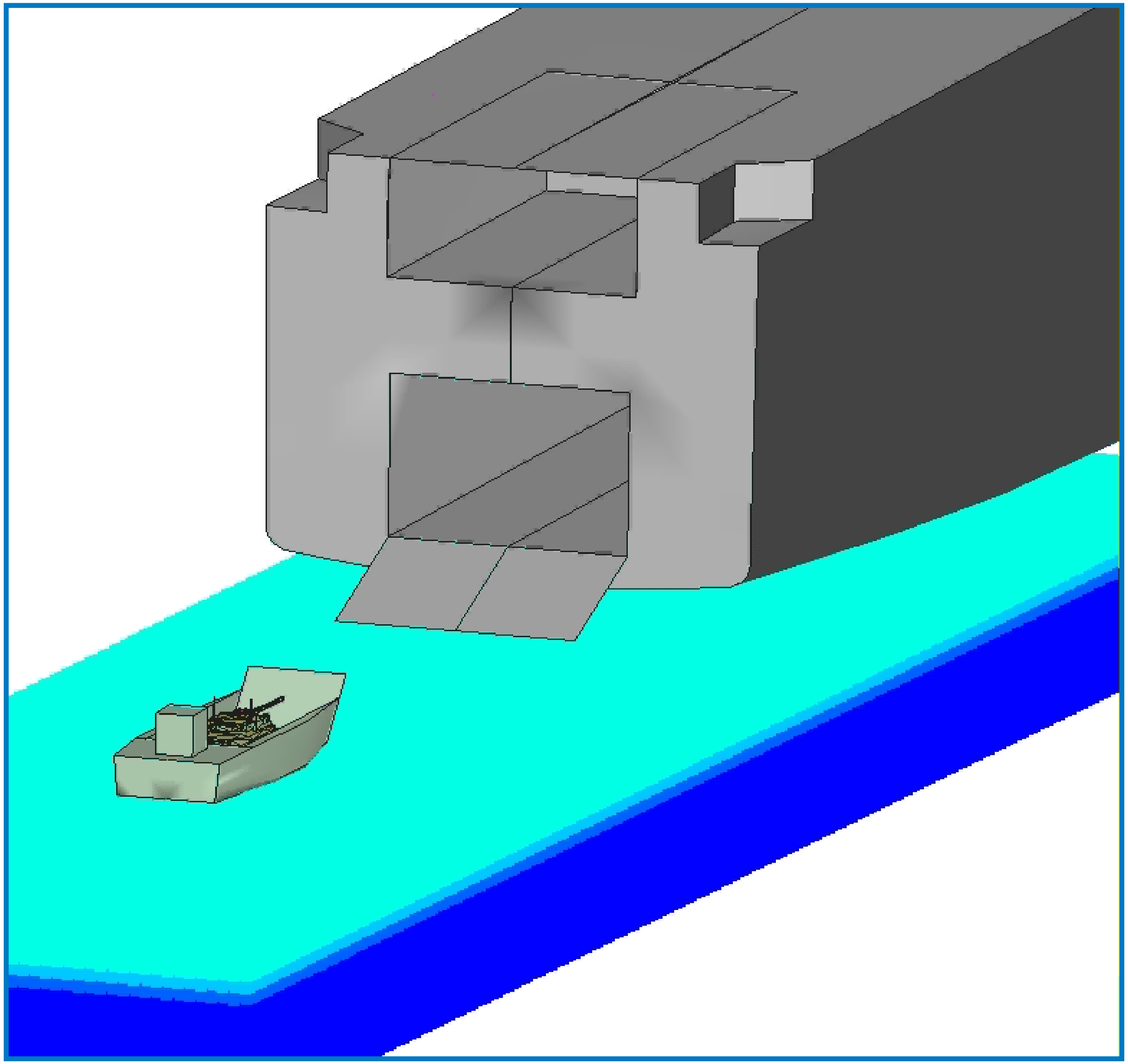
Results and Observations

LHD Motions – Pitch and Heave in 2m sea

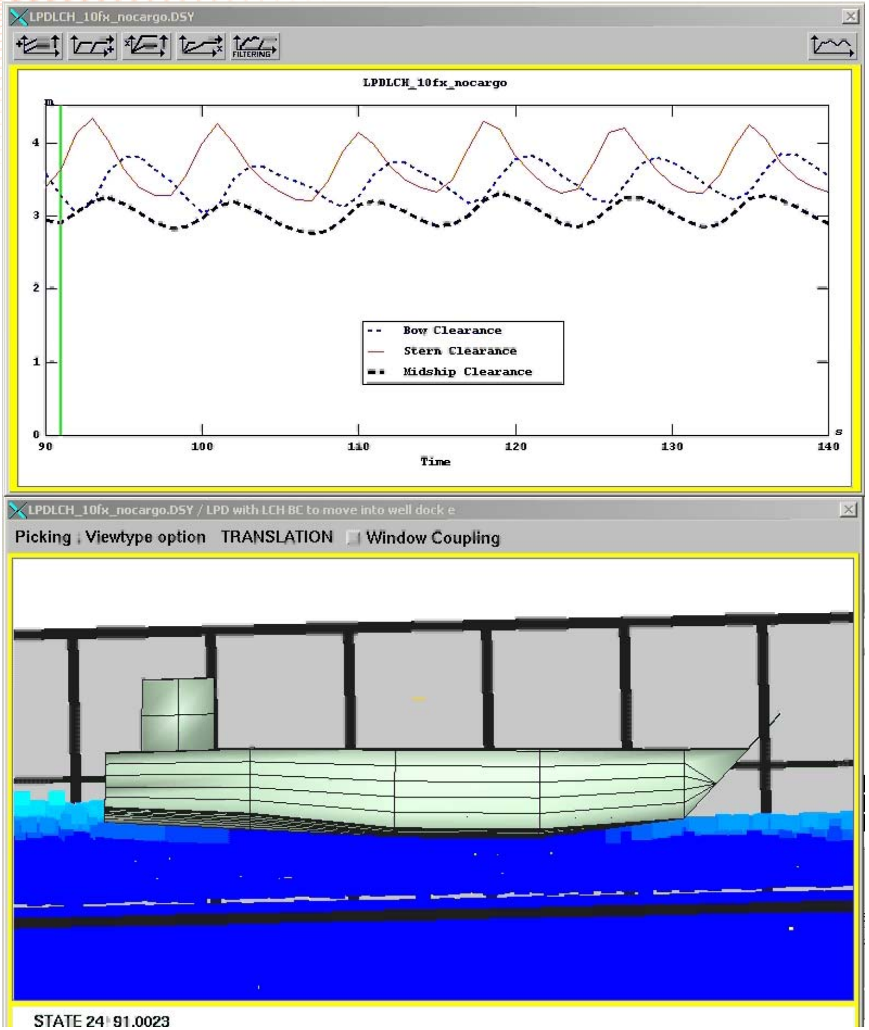


Landing Craft Motions

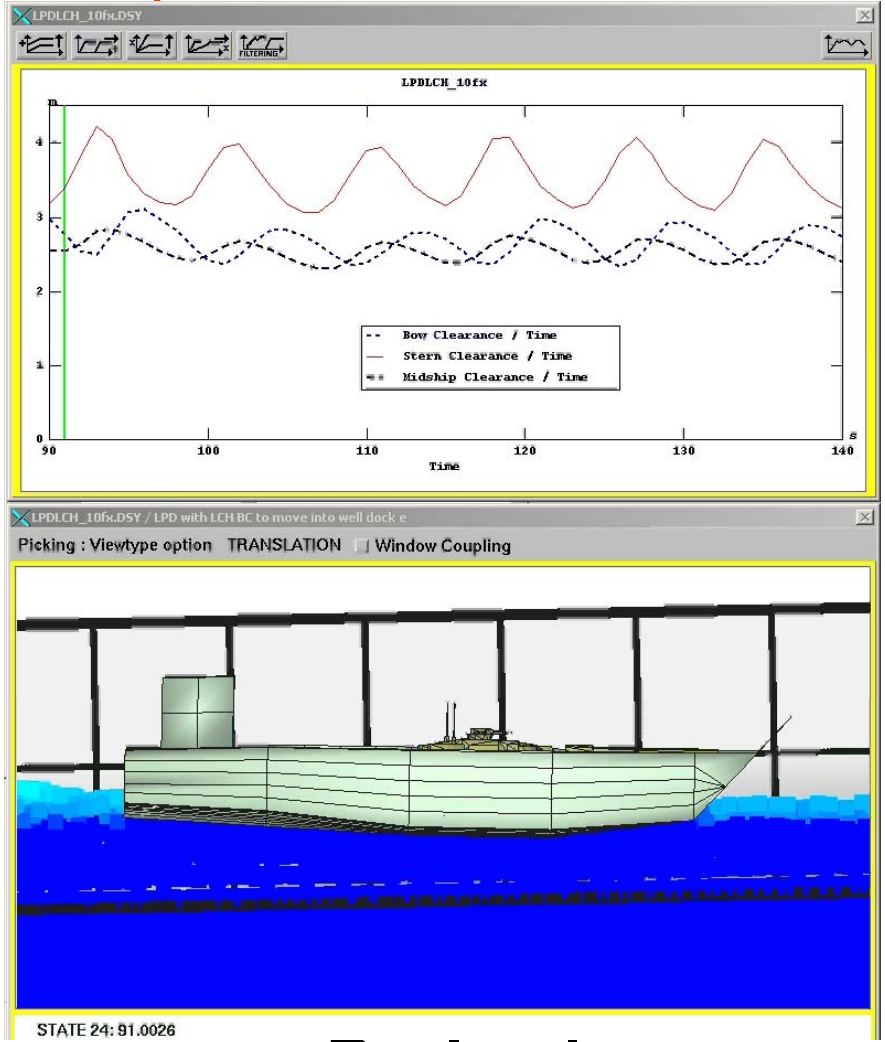


Results and Observations

Clearance Under the Landing Craft at Mid-Dock



No Payload



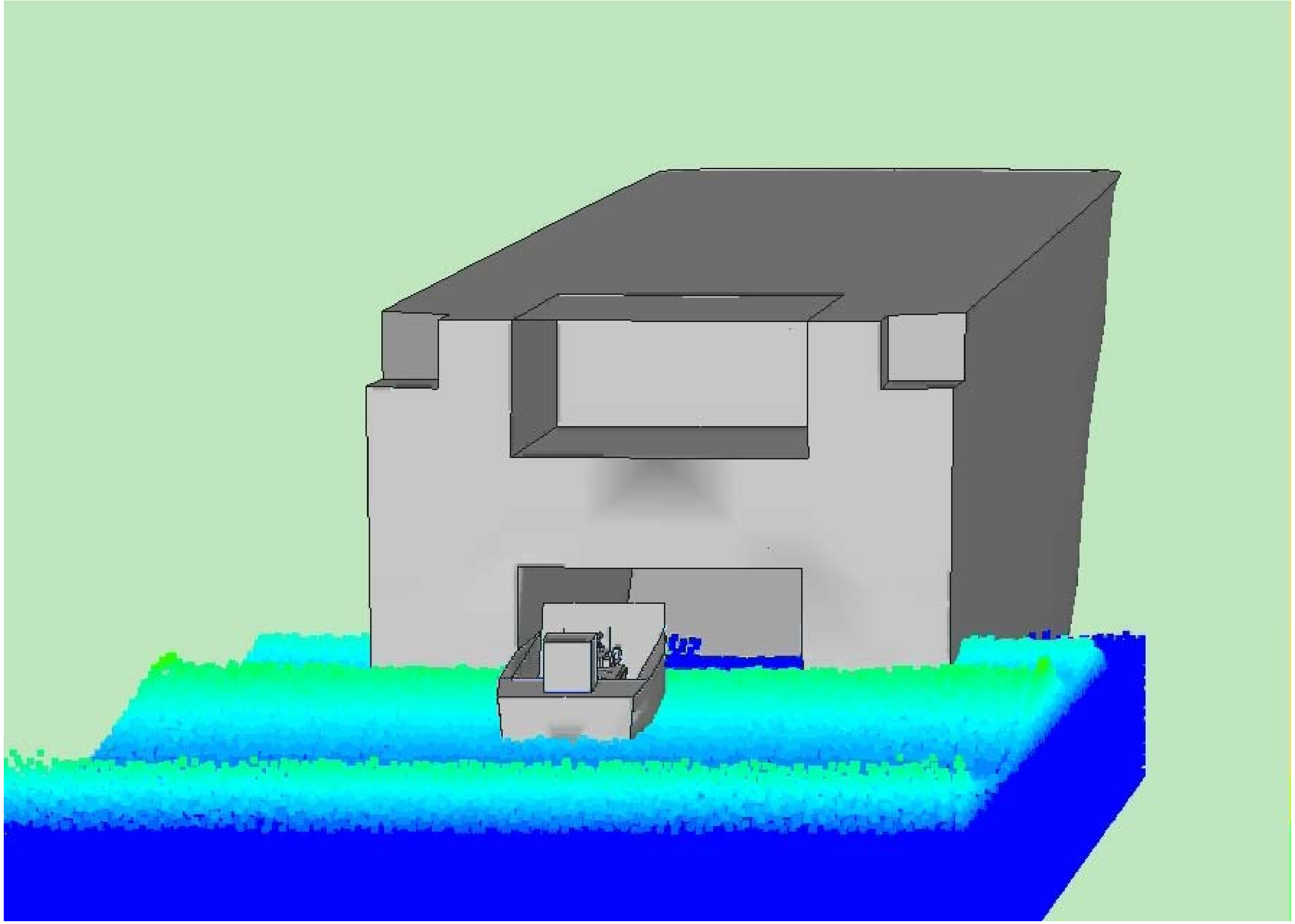
Payload

Results and Observations

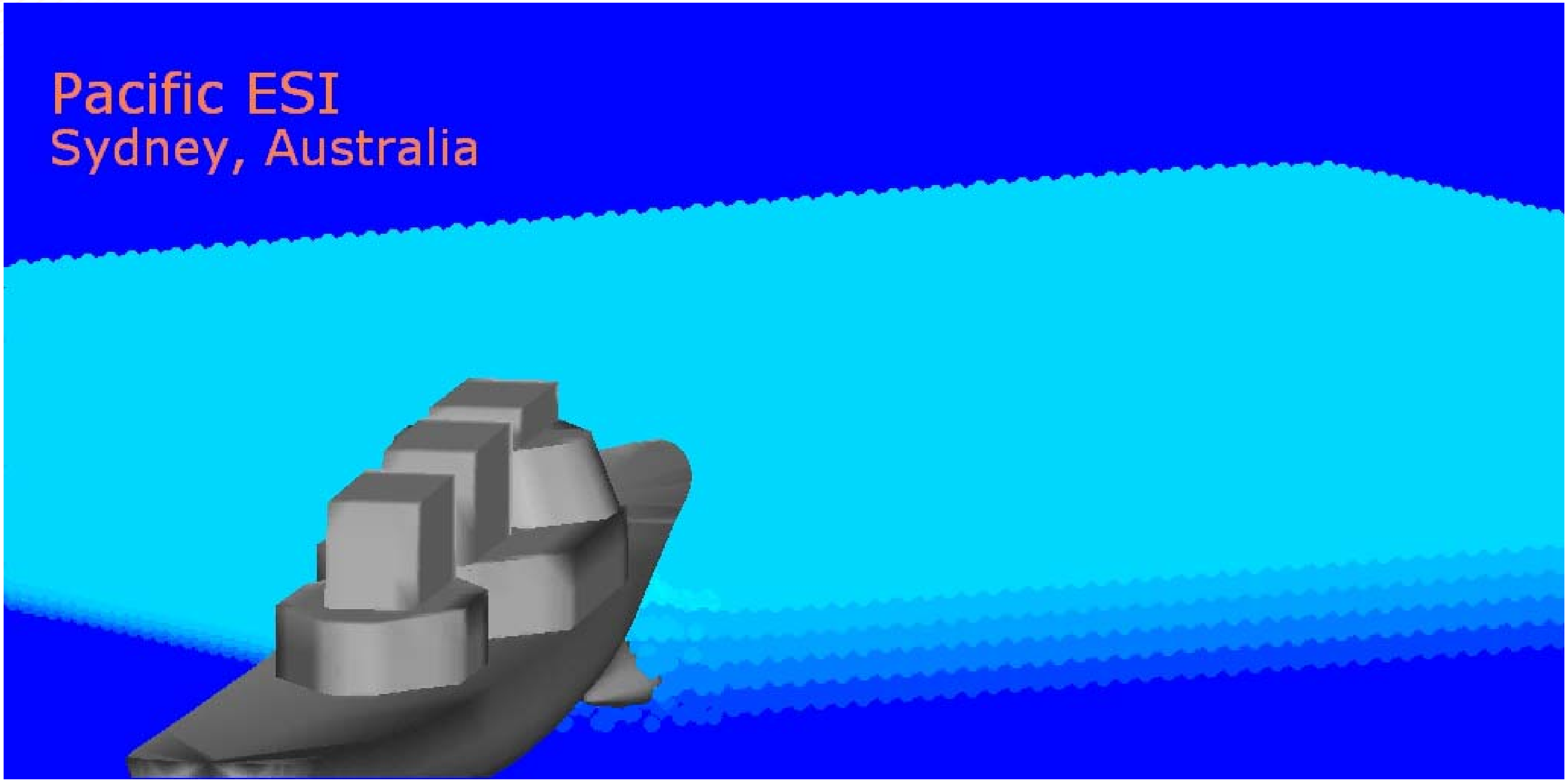
Rough Landing Scenario

Landing craft with 6 DOF.

Asymmetric thrust on entering well dock produces a collision with wall. Large peak forces result.

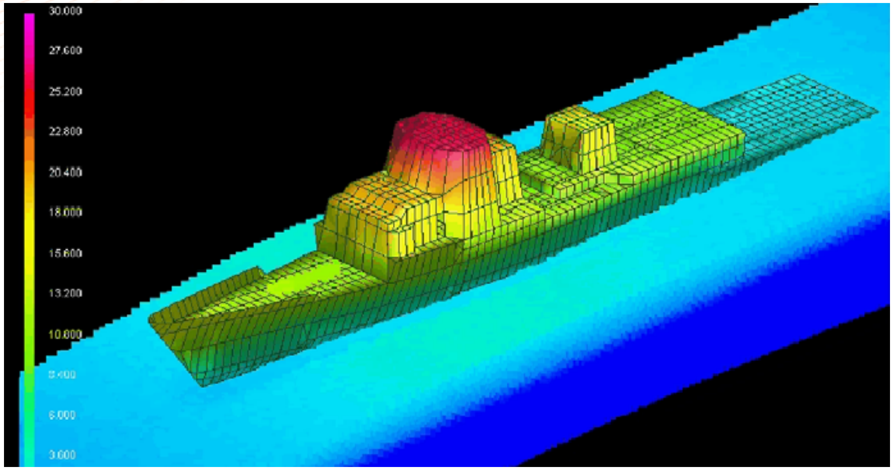


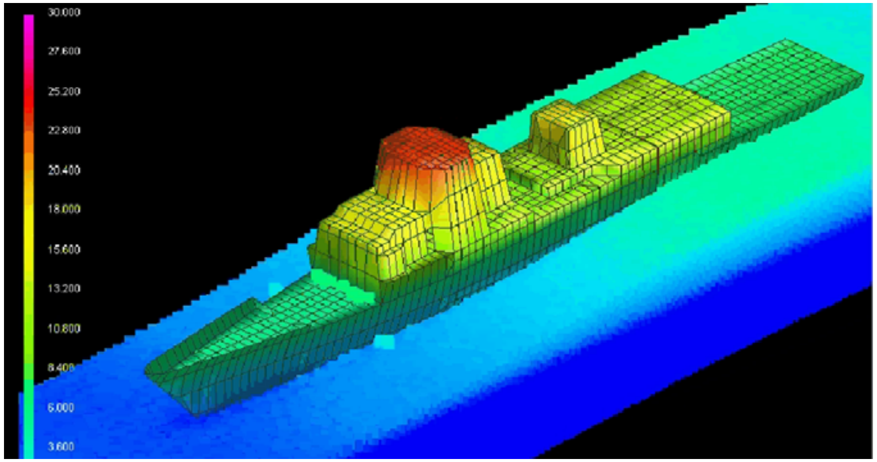
Fast frigate in heavy seas

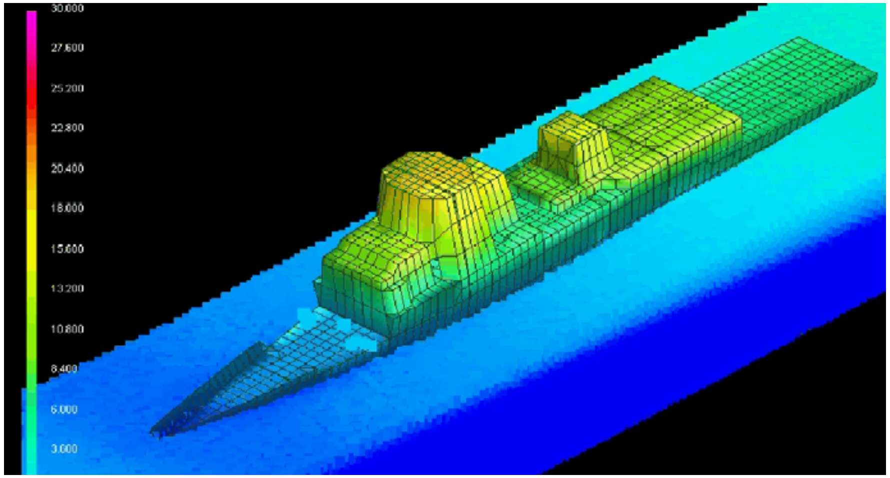


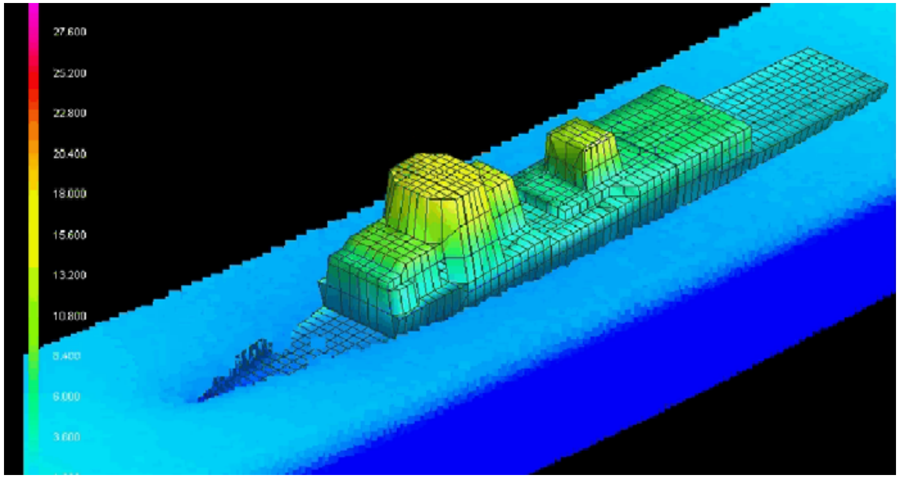
Motion in Waves

Regular head waves of 8 meter height and a wave length of 294 meter



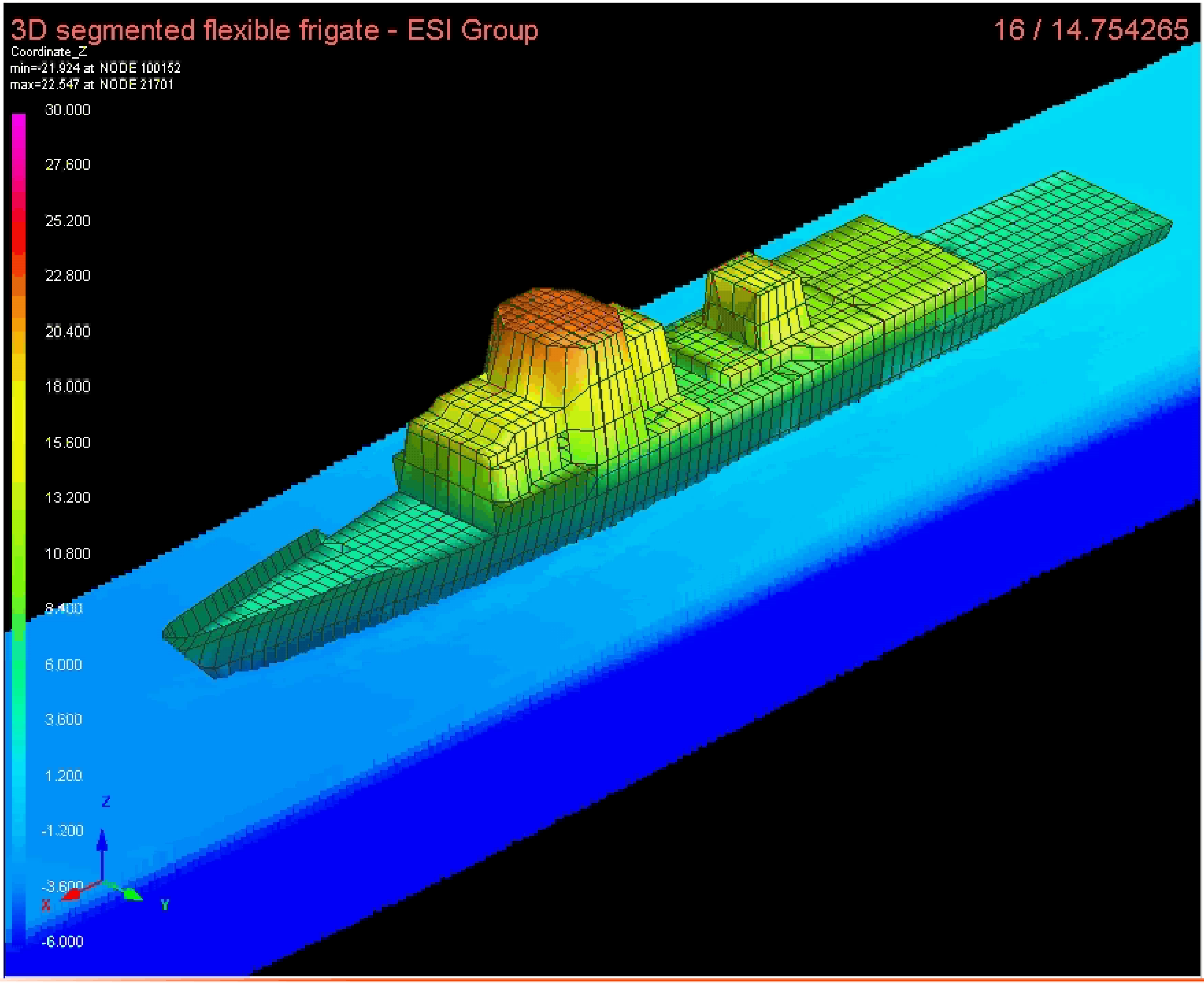




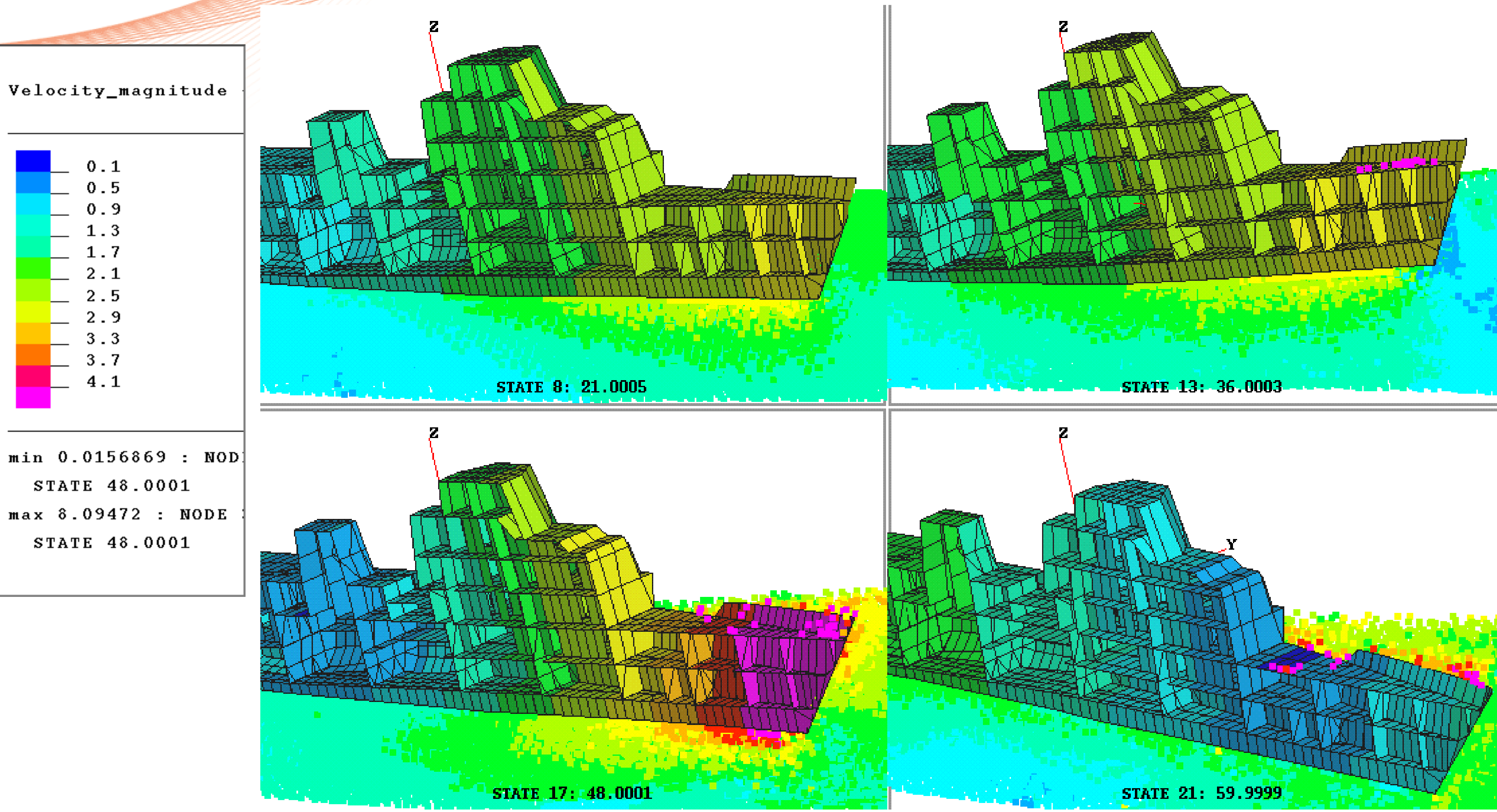


Generic Frigate Model

Vertical/bending moment/velocity for flexible model

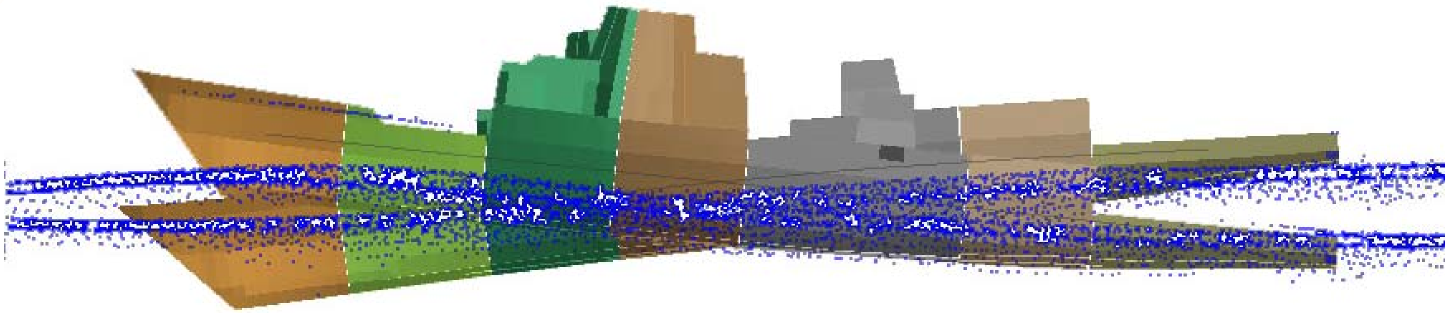


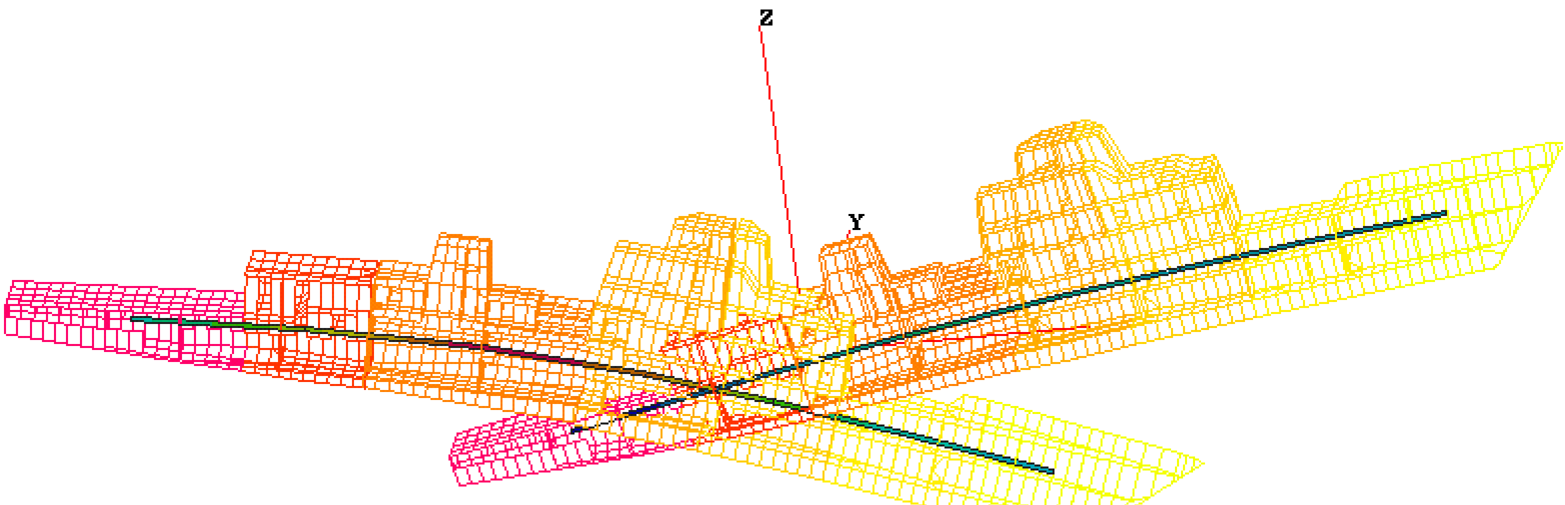
Motion in Waves



Display of the velocity magnitude for the flexible model in waves.

Motion in Waves

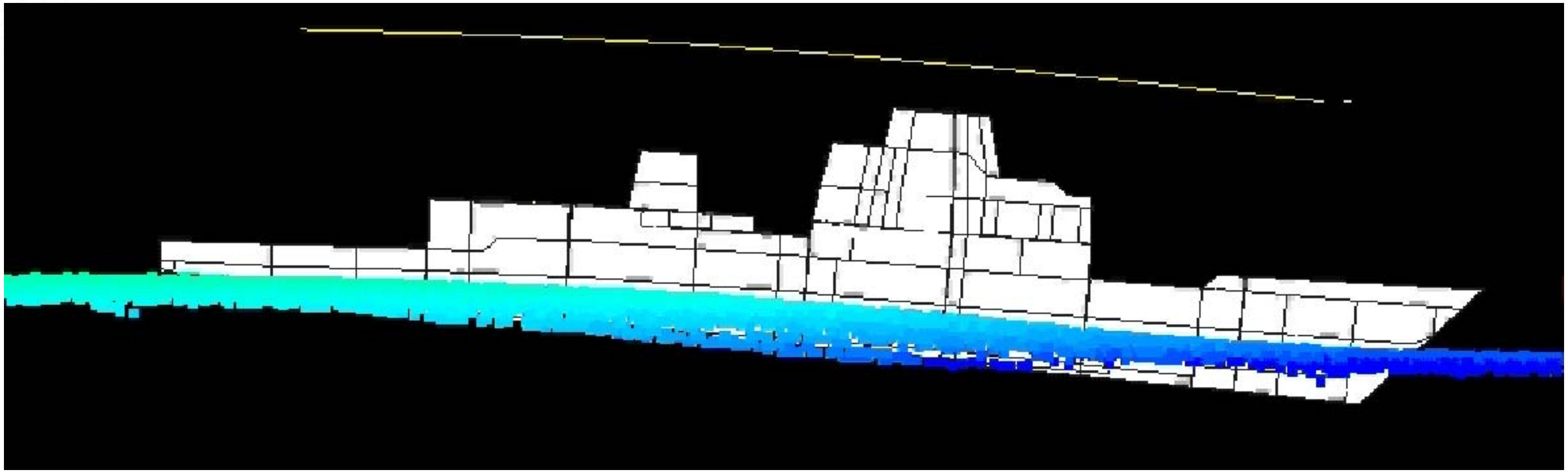


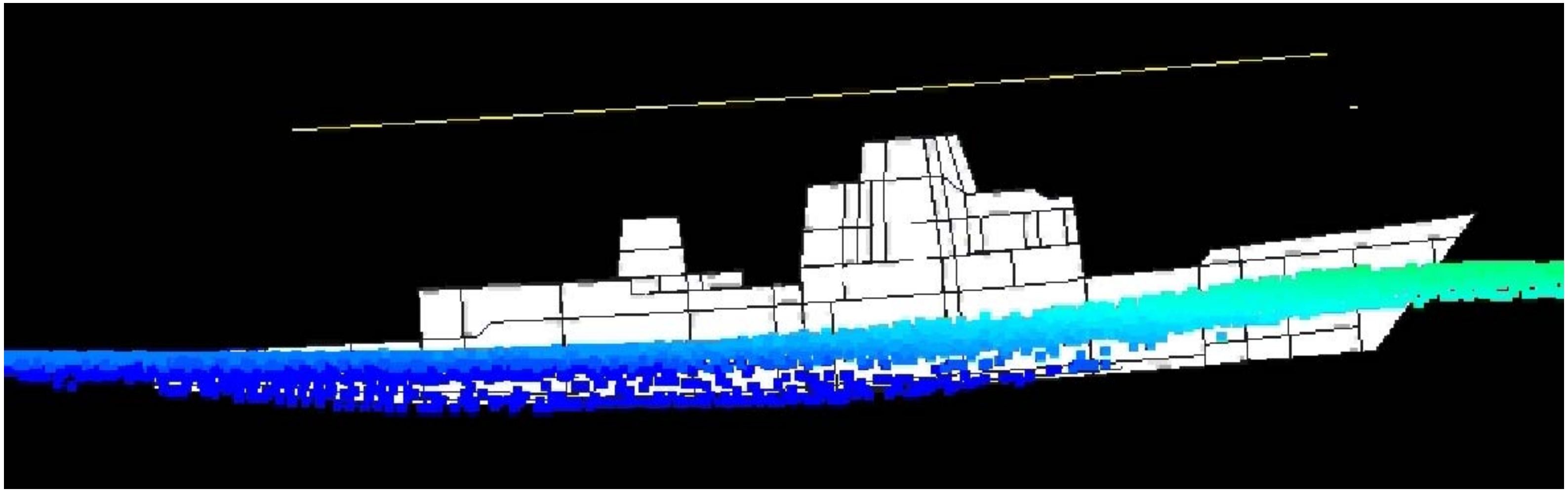


Overlaid plot of ship with backbone stresses for the stiff model at 2 moments showing the motion and bending at 21 and 60 seconds (displacements scaled by a factor of 4).

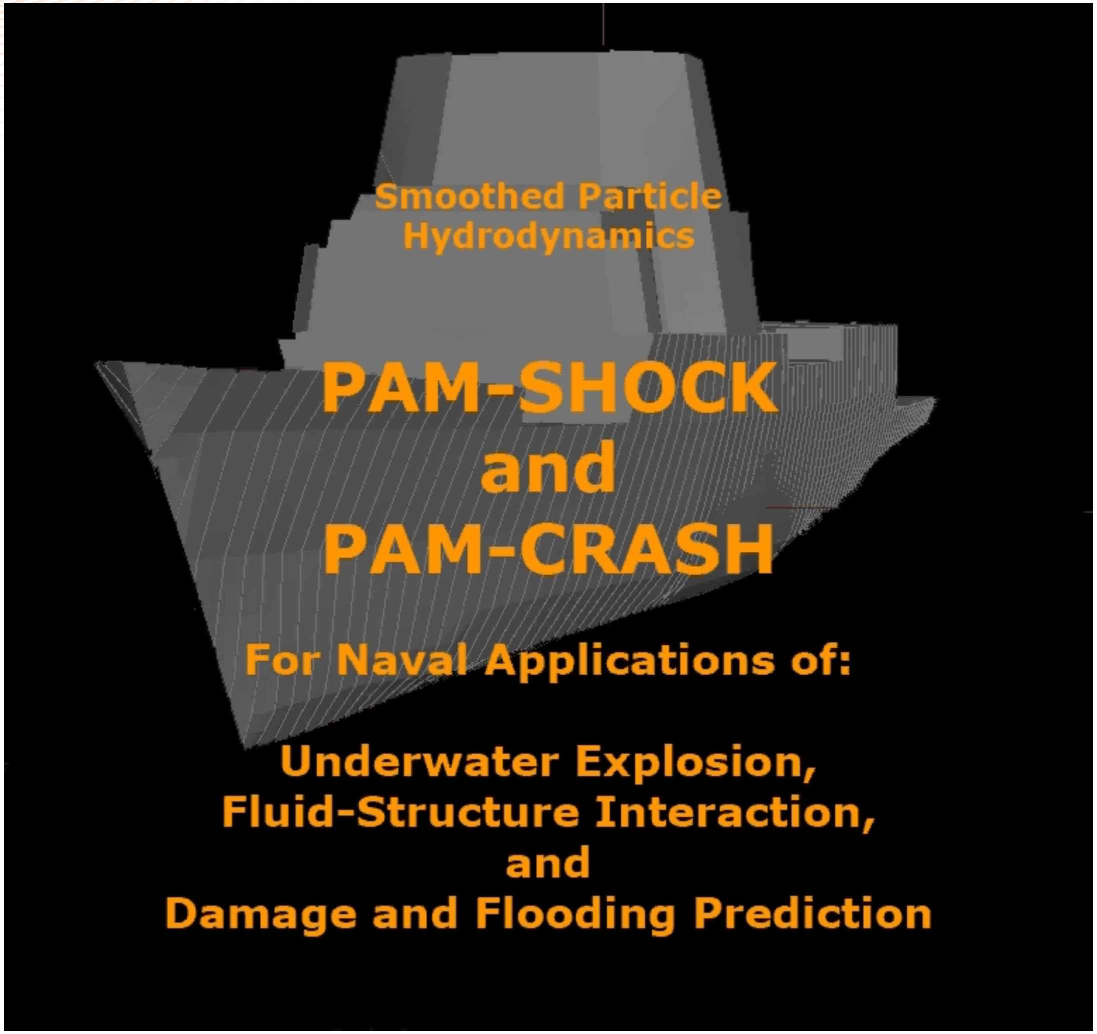
Generic Frigate Model

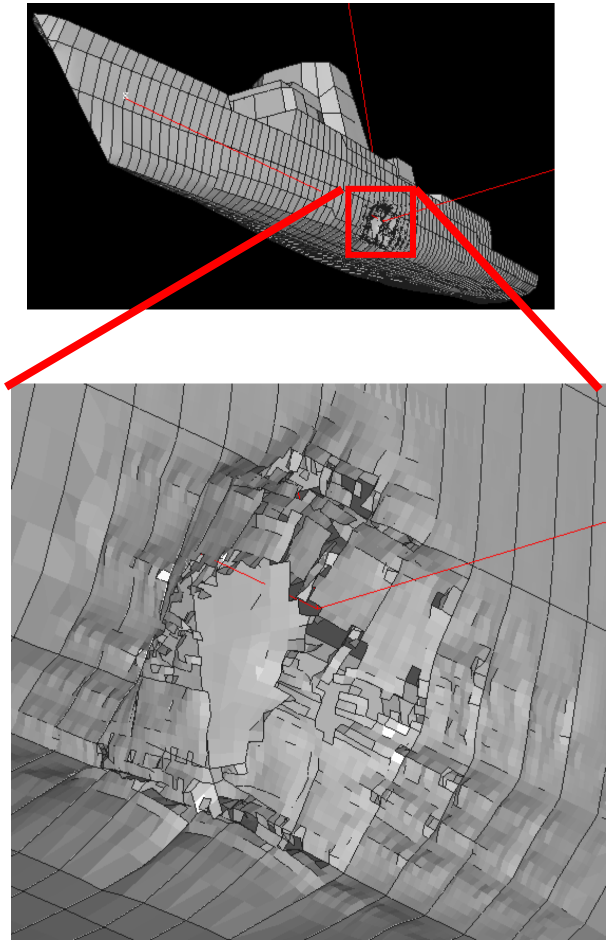
Side view of the backbone deformations



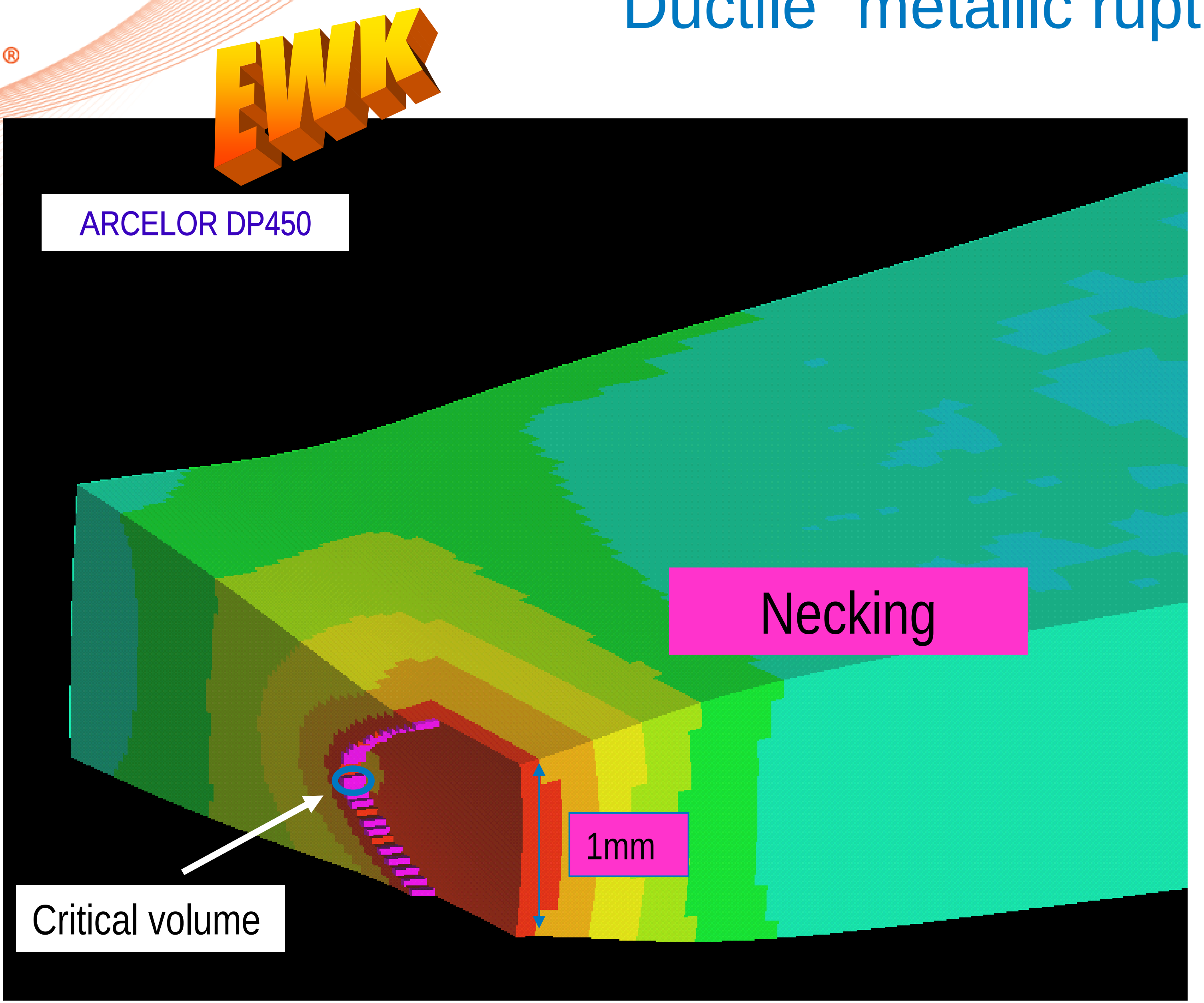


Vessel subject to UNDEX

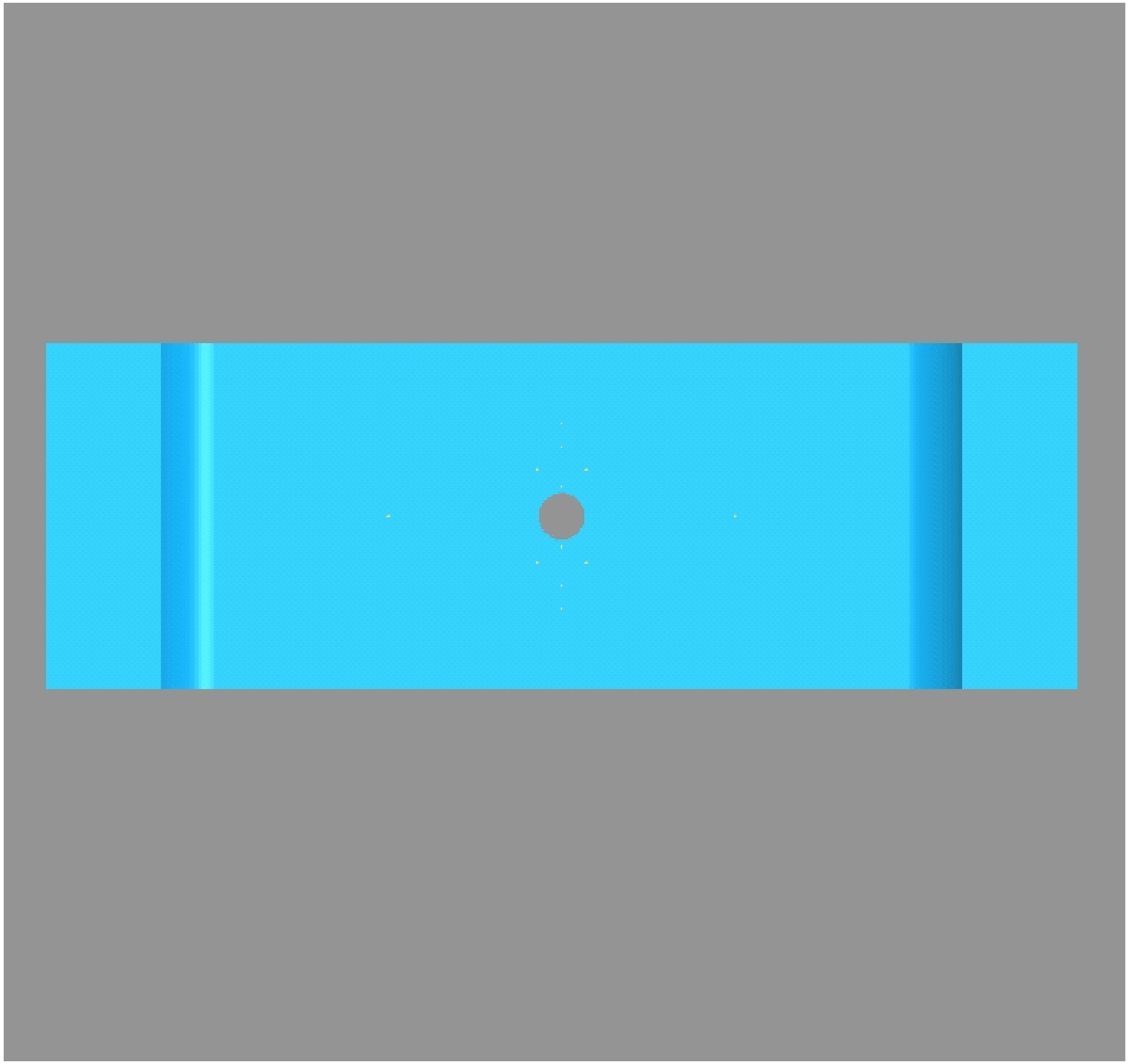




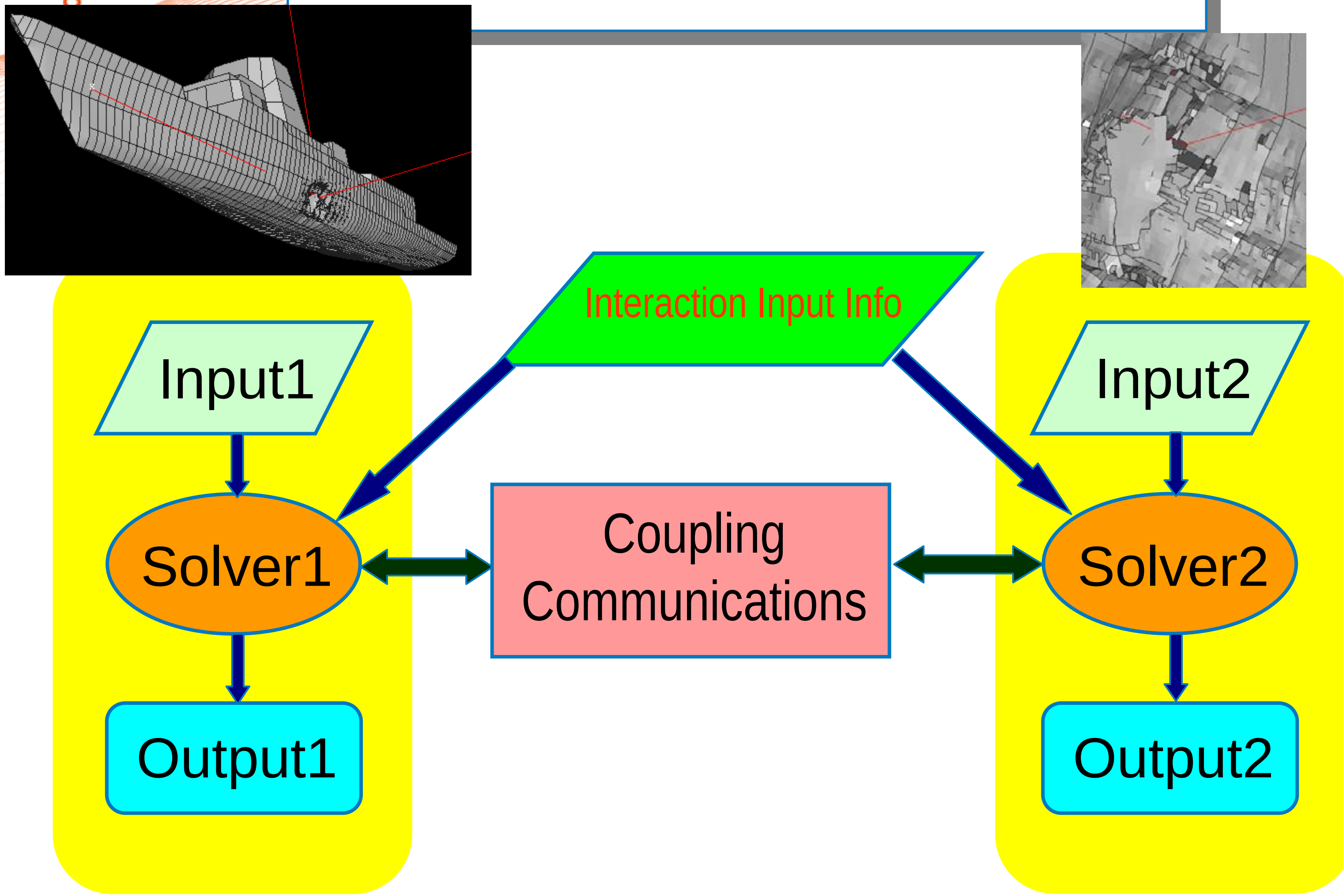
“Ductile” metallic rupture



Effect of stress concentration



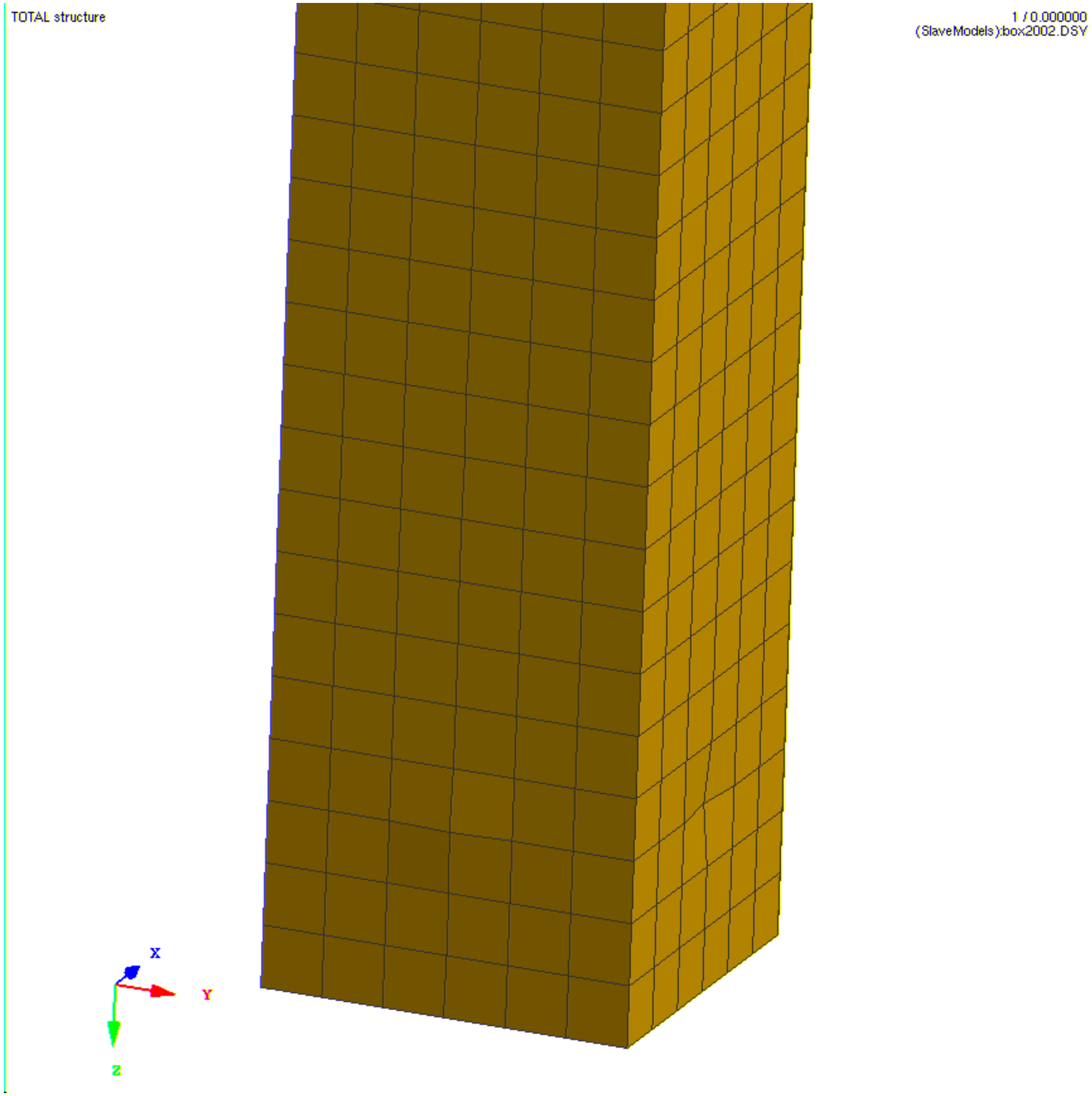
Multi–Model Coupling
for Multi-Scale calculations



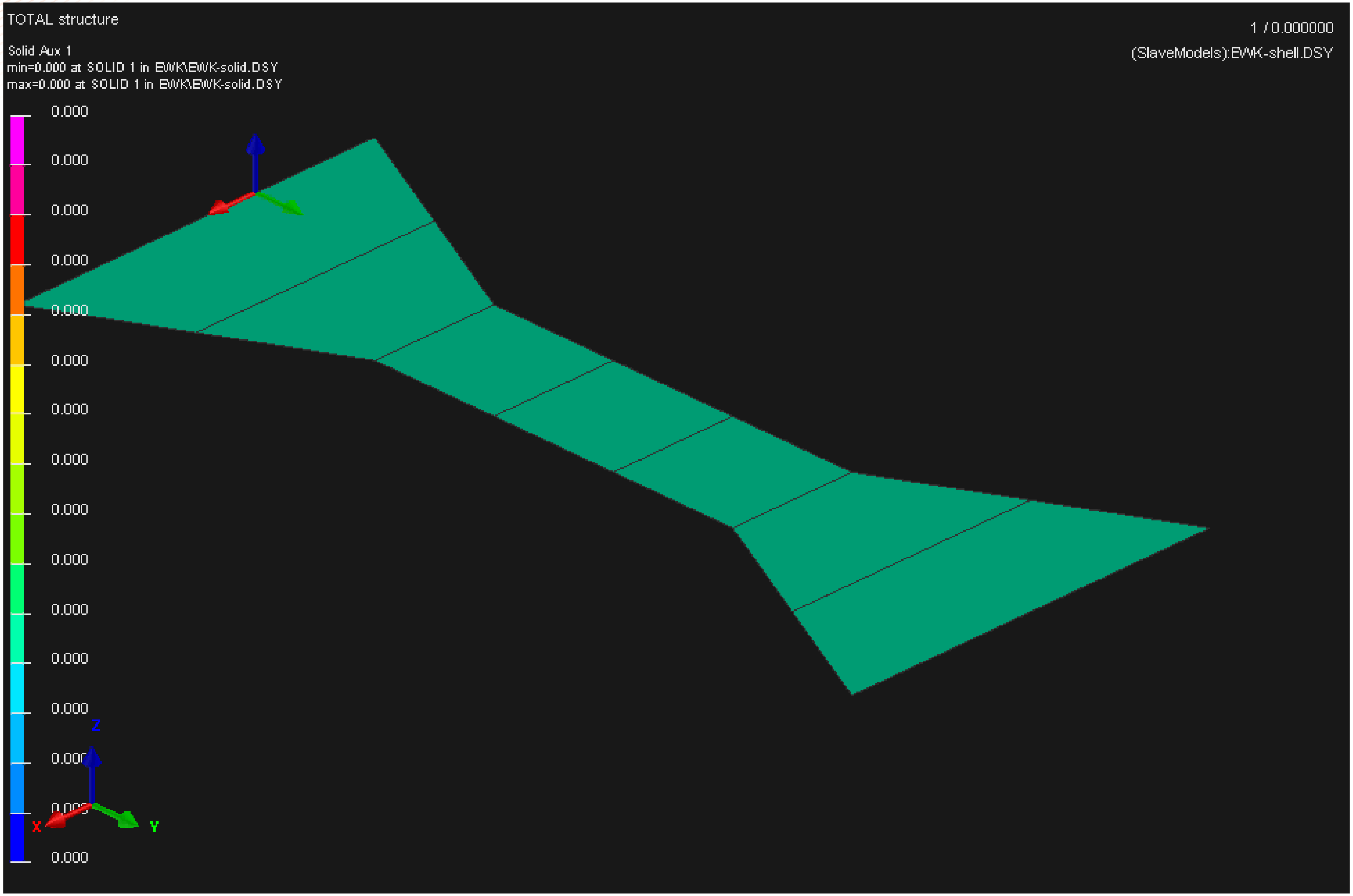
Model 1
32 processes

Model 2
128 processes

Automatic shell to solid transition

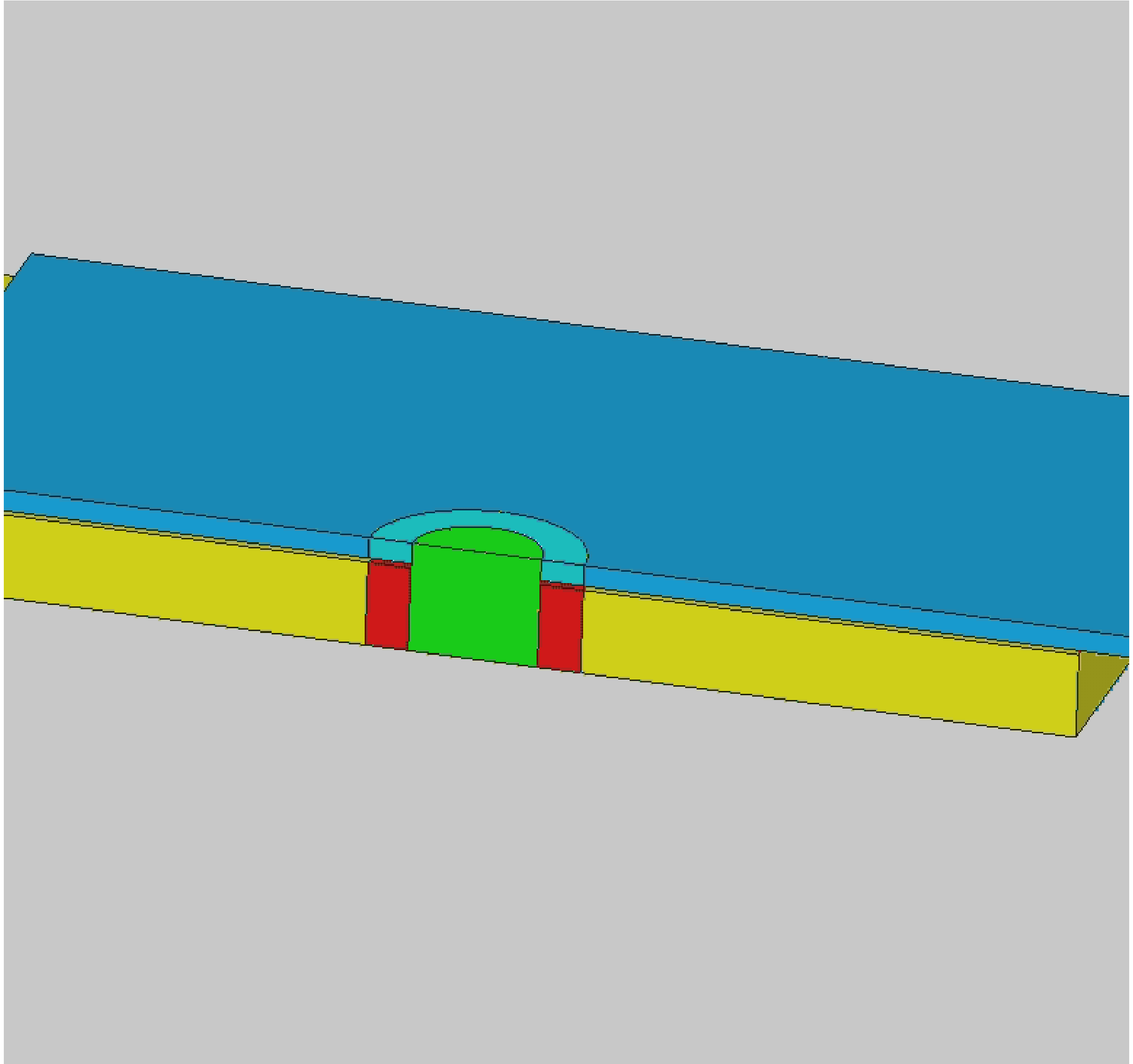


Automatic shell to solid transition

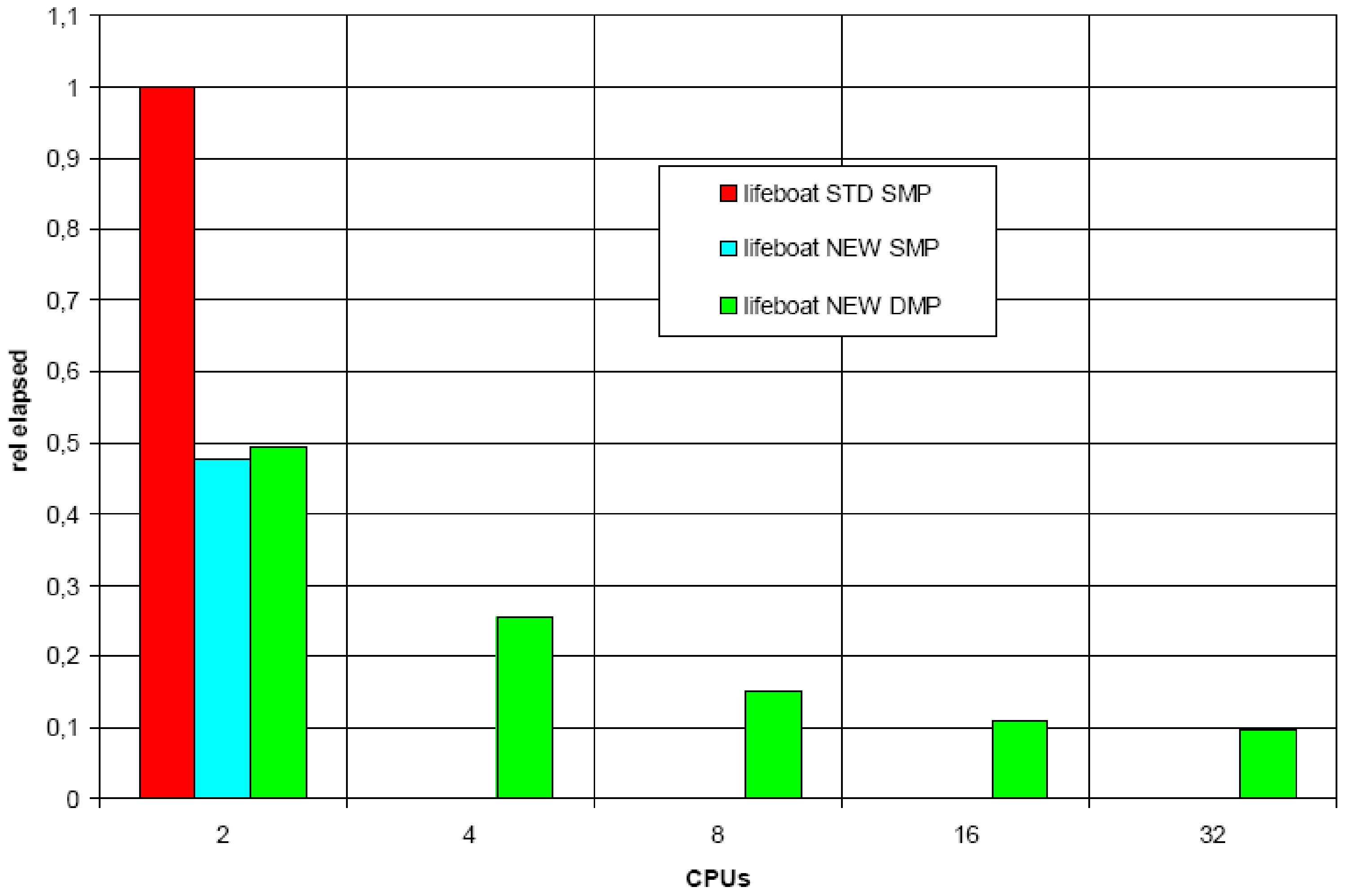


EWK model for efficiently predicting connectors

And either calibrate macro elements for efficient handling of hybrid FE large models, or perform intrinsic and predictive calculations through the Multi-Model Coupling option



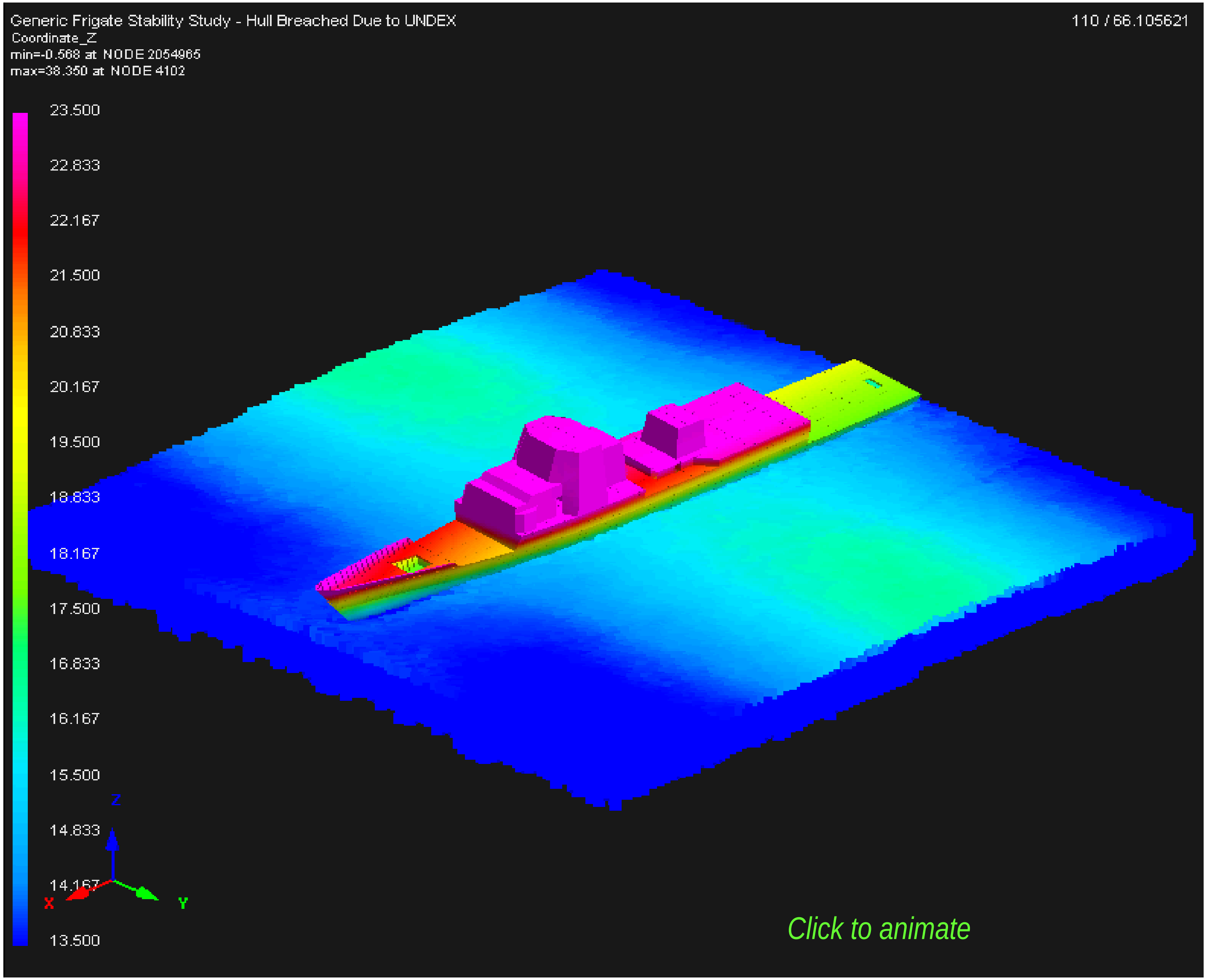
SPH DMP scalability



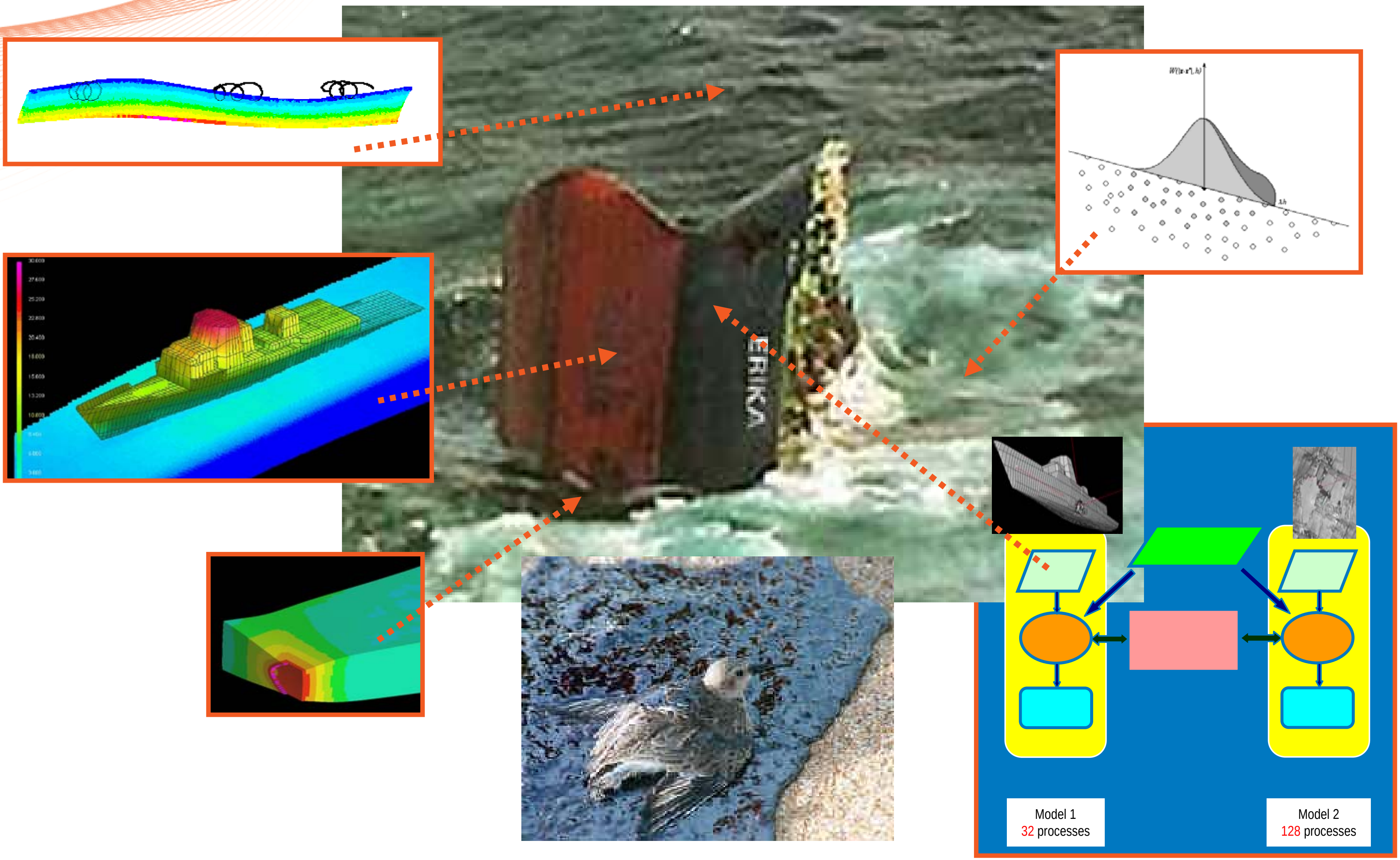
Effect of flooding !

Response of damaged vessel

Note the initial list to port indicating flooding



Designing for Erika disaster prevention



Thank you !