Validation of Flow-3D against Experimental Data for an Axi-Symmetric Point Absorber WEC

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Motivation

- **Validation is defined as** "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" (SCS Technical Committee on Model Credibility (1979)

- More specifically we wish to establish that the Flow-3D CFD code is capable of providing useful results in a useful time frame for the specific case of an axi-symmetric point absorber WEC operating in both operational and survival waves.

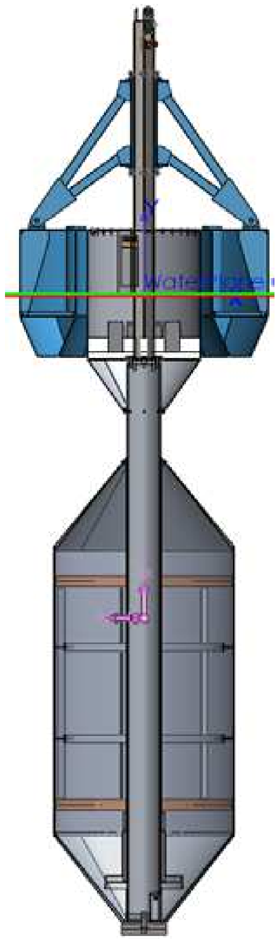
- The criteria against which this will be judged are the accuracy of the motion response, connecting and mooring forces compared to tank tests data and the CPU time required to attain this answer.

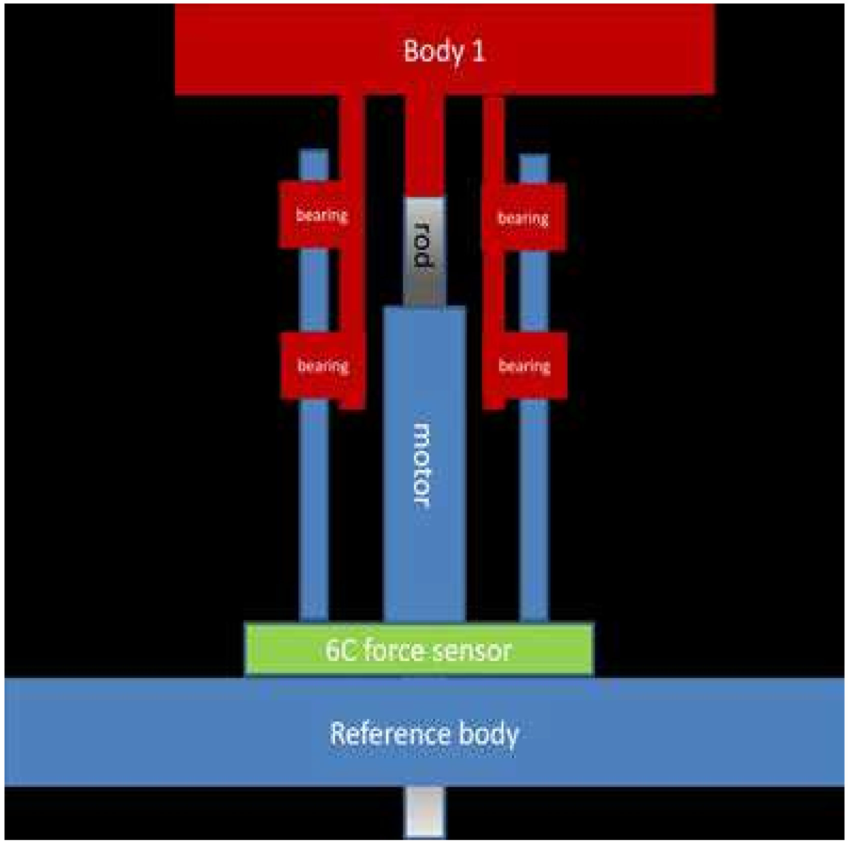
Uses of CFD at Wavebob ;

- Calculate a matrix of Drag Coefficients to supplement a BEM based time domain solver for the surge, heave and pitch dof's and their non-symmetric off diagonal terms.

$$\begin{vmatrix} C_{ss} & C_{hs} & C_{ps} \\ C_{sh} & C_{hh} & C_{ph} \\ C_{sp} & C_{hp} & C_{pp} \end{vmatrix} \quad \begin{vmatrix} V_s^{\,2} \\ V_h^{\,2} \\ V_p^{\,2} \end{vmatrix}$$

Estimate connecting forces between bodies, inertial and mooring forces during operation and in survival mode





Predict the onset of parametric pitching /rolling due to heaving at half the natural pitch period

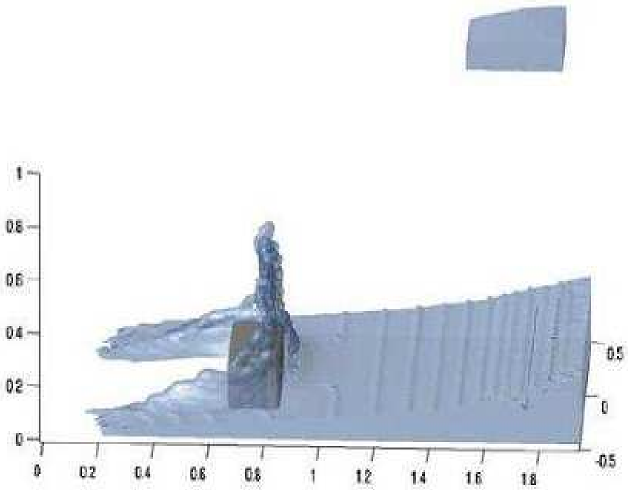
$$\frac{d^2x}{dt^2} + b\omega_0 \frac{dx}{dt} + \omega_0^2 \left[1 + h_0 \sin 2\omega_0 t\right] x = E_0 \sin \omega_0 t$$

$$x(t) = \frac{2E_0}{\omega_0^2 \left(2b - h_0\right)} \cos \omega_0 t.$$

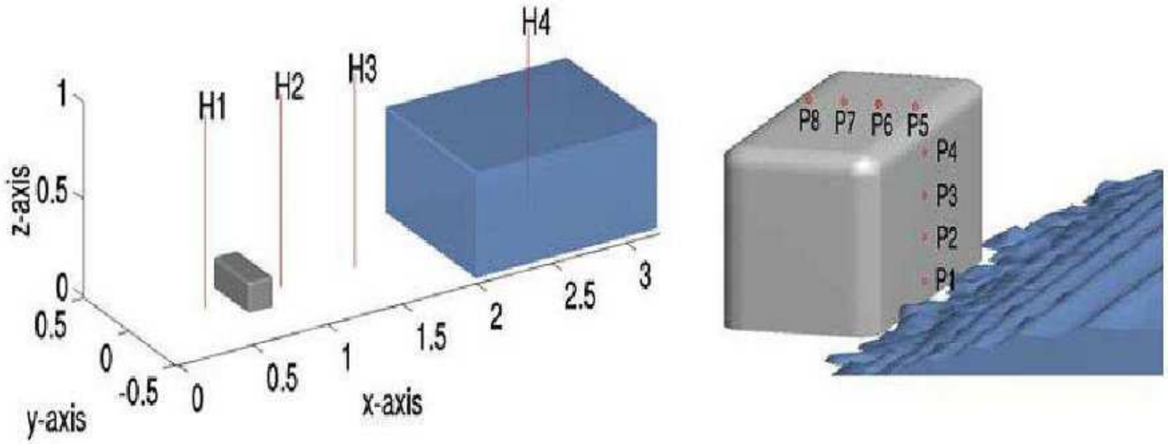
Validation Road Map

- **Free surface flow** with no moving objects (Dam Break Problem)
- **Heave and Pitch Decay Tests** (Wavebob experimental Data at 19^{th} and 35^{th} scale)
- **Regular Wave** Undamped Tests (Wavebob experimental Dataat 19^{th} scale)
- **Irregular Wave** Undamped Tests (Wavebob experimental Data at 19^{th} scale)
- **Survival Wave** Locked Body Tests (Wavebob experimental Data at 35^{th} scale)

Dam Break Problem using data from ERCOFTAC database



Dam Break Problem

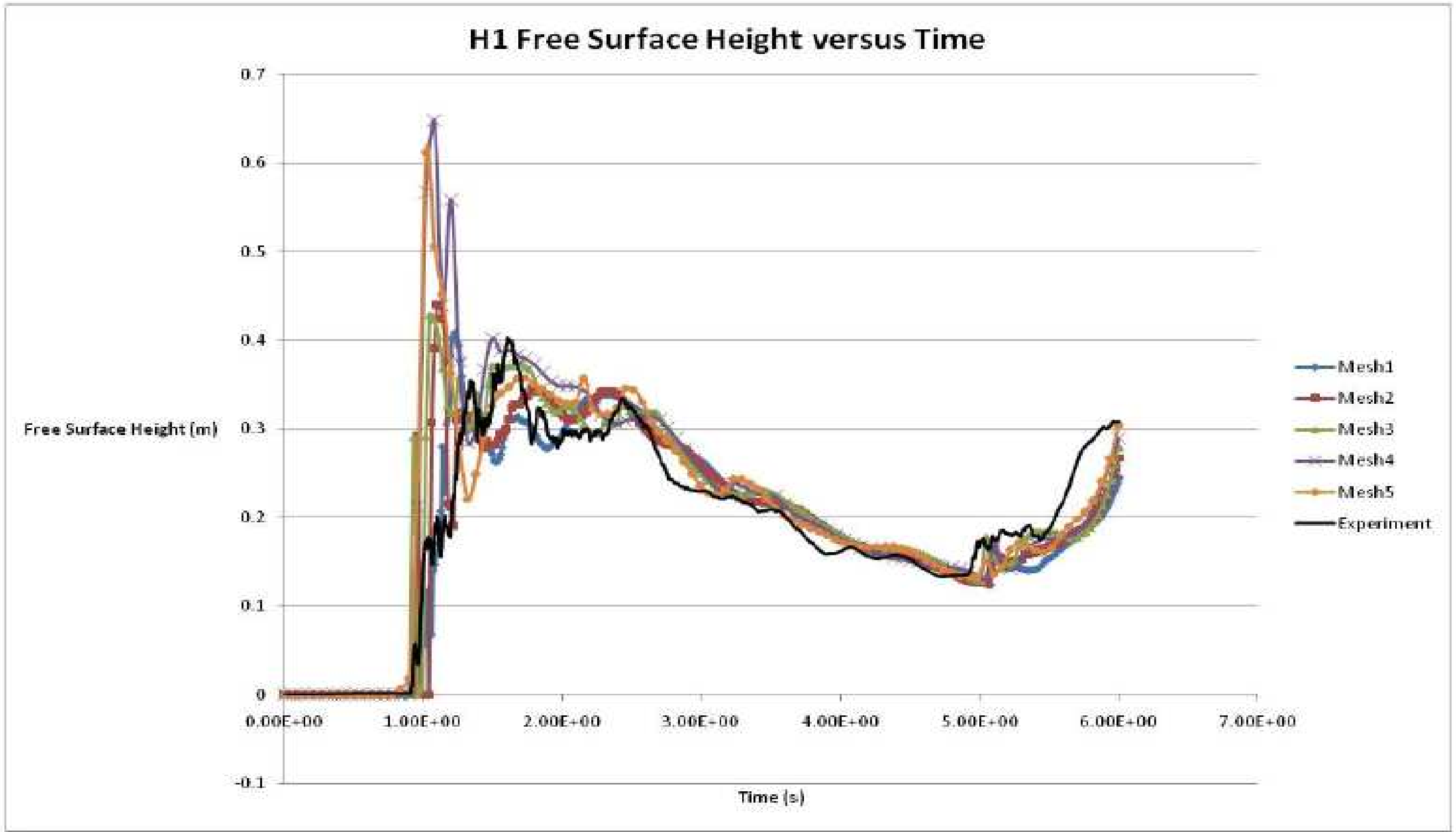


Dam Break Problem

Table 1 CPU and Elapsed Times for Each mesh and Method

Mesh	Number of Cells	Momentum Advection	Single / Double Precision	Turbulence Model	Elapsed Time of Four Processors (secs)	CPU Time (secs)
Mesh 1	6.03×10^{5}	Ist Order	Single	Laminar	971	3389
Mesh2	1.22×10^{6}	Ist Order	Single	Laminar	2227	8223
Mesh3	2.39×10^{6}	Ist Order	Single	Laminar	7951	30710
Mesh4	4.84×10^{6}	Ist Order	Single	Laminar	19330	72780
Mesh 5	2.73×10^{6}	Ist Order	Single	Laminar	32780	130200
Mesh1	6.03×10^{5}	2^{nd} Order	Single	Laminar	1168	4186
Mesh1	6.03×10^{5}	3^{rd} Order	Single	Laminar	1232	4456
Mesh1	6.03×10^{5}	Ist Order	Double	Laminar	1039	3646
Mesh1	6.03×10^{5}	2^{nd} Order	Single	RNG	2004	7538
Mesh1	6.03×10^{5}	2^{nd} Order	Single	LES	1253	4539

Dam Break Problem



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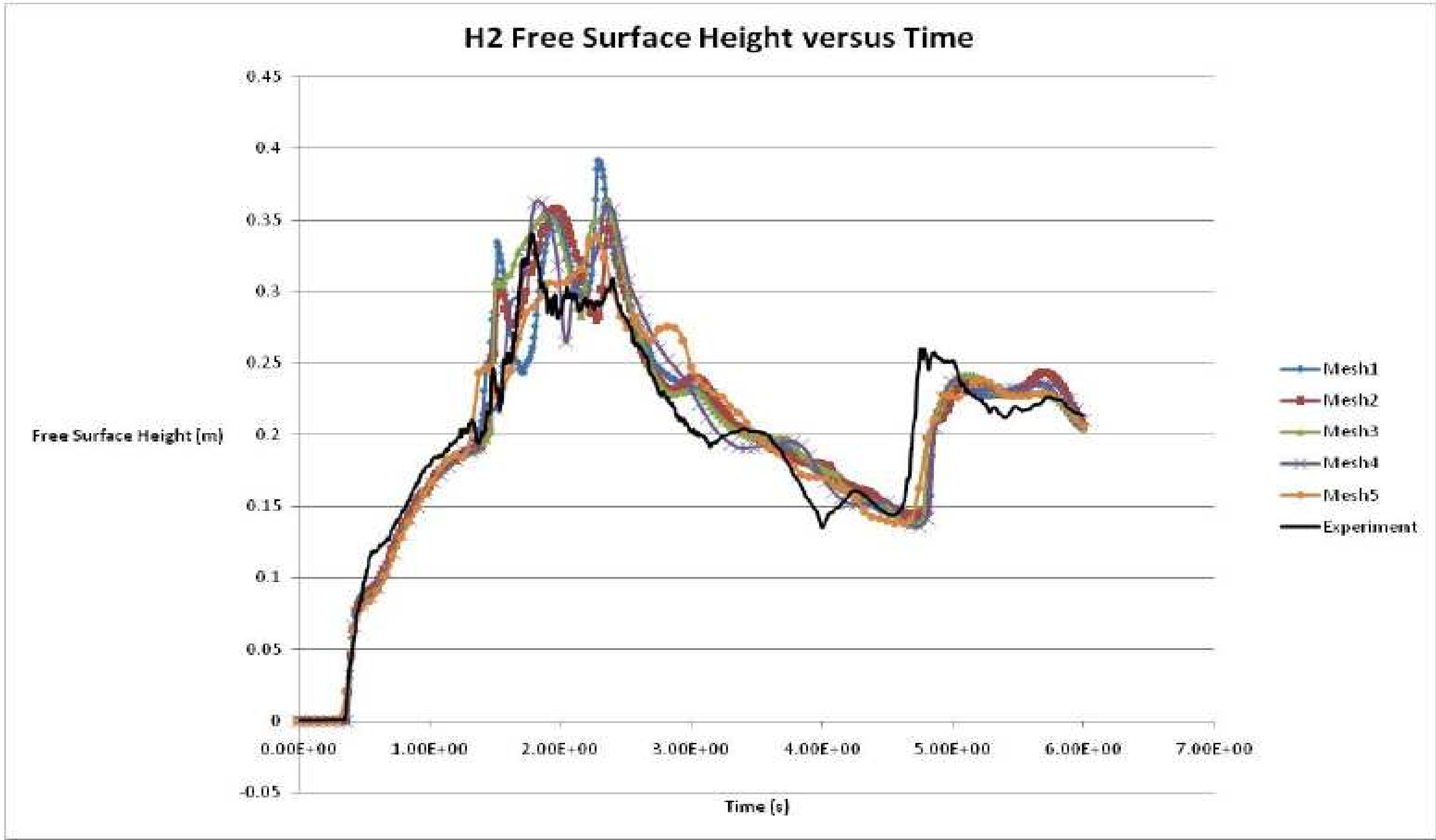

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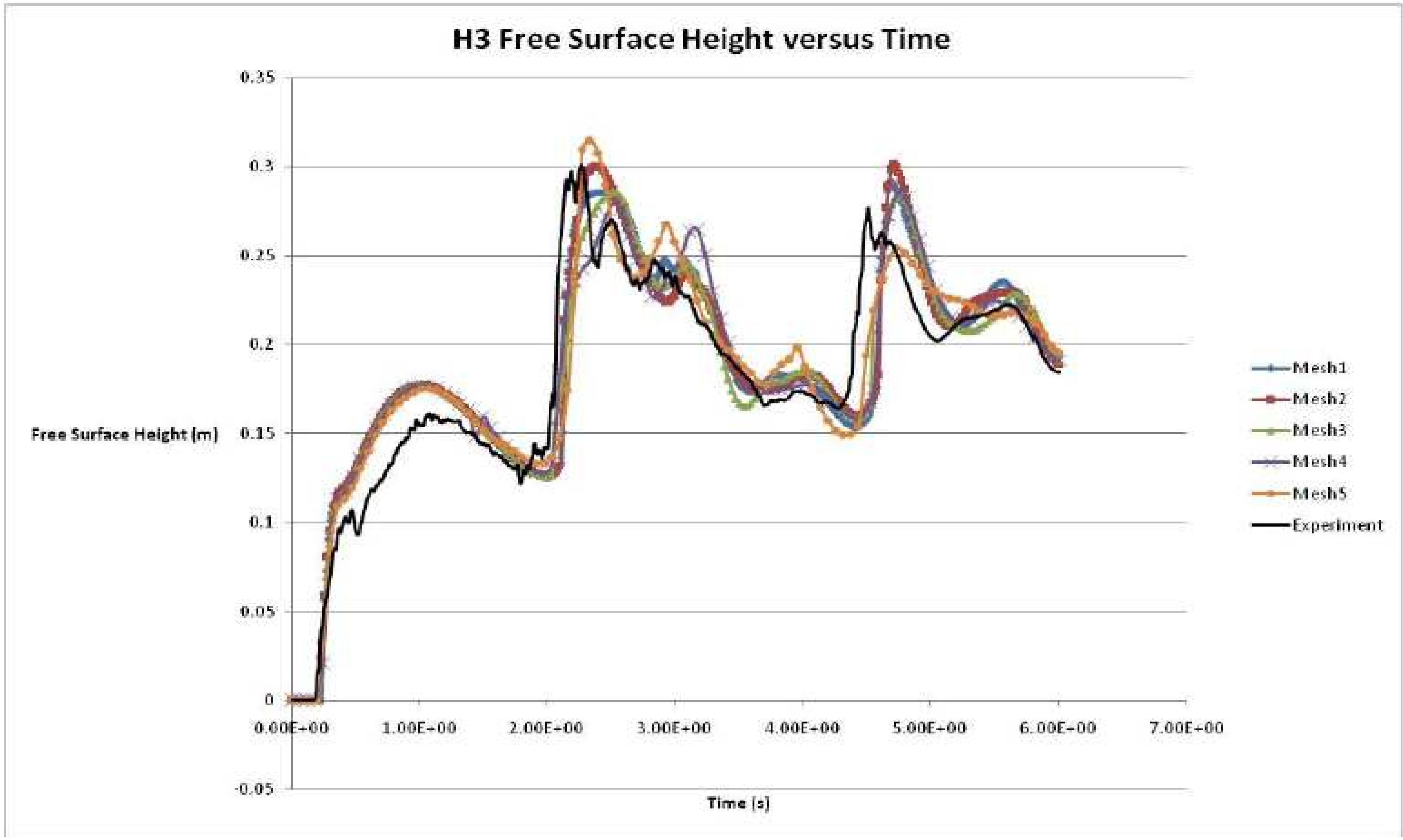

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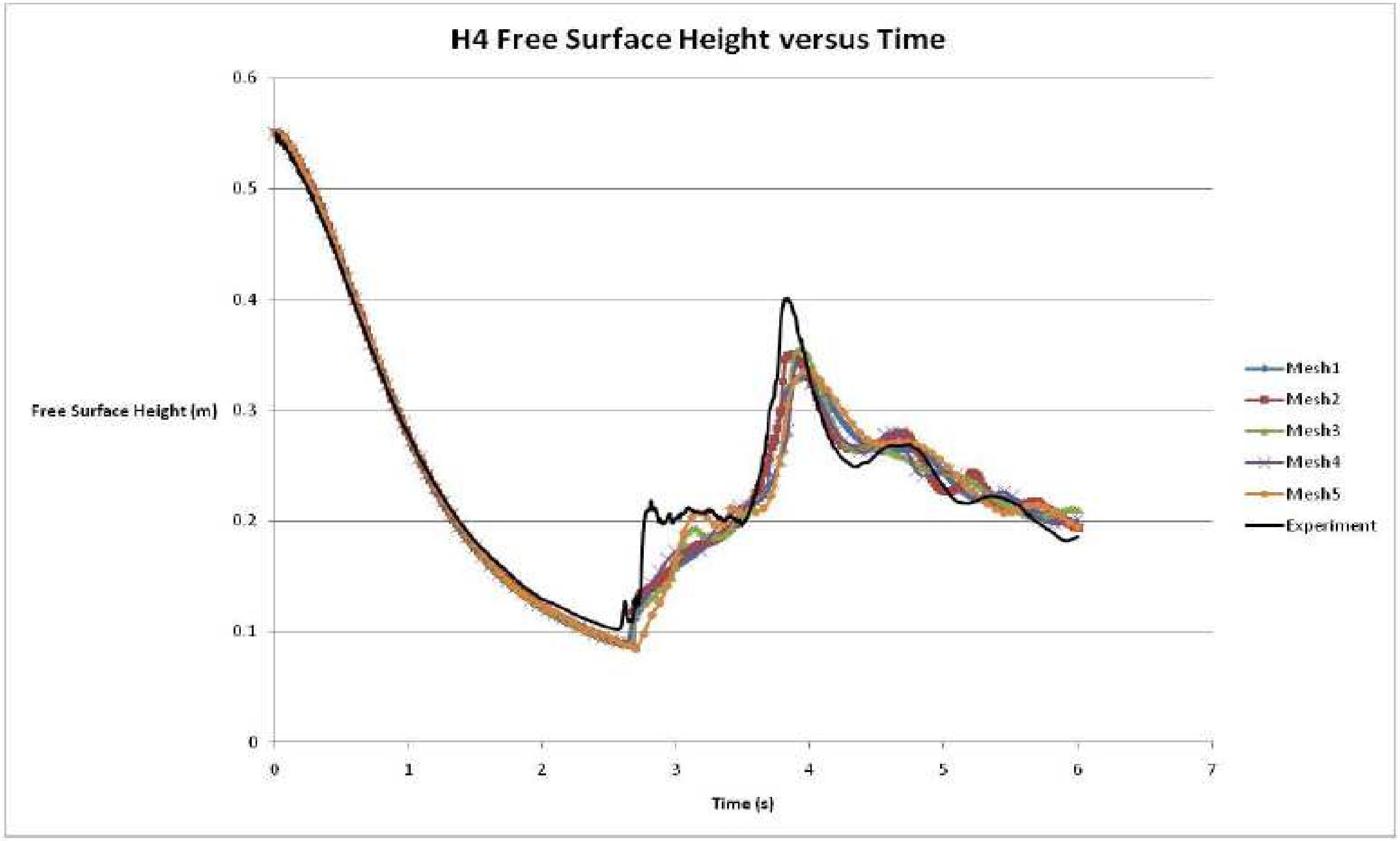
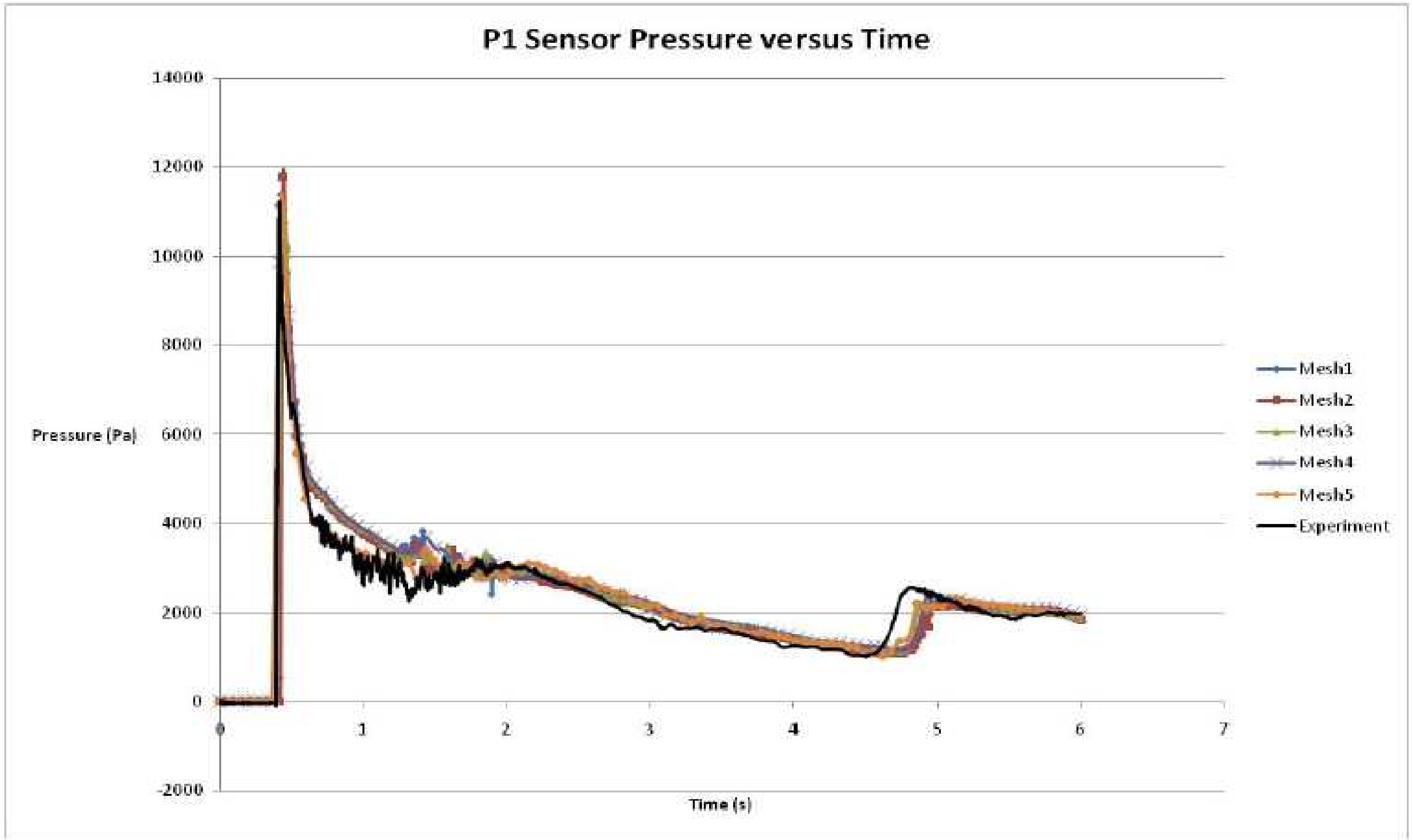


Dam Break Problem



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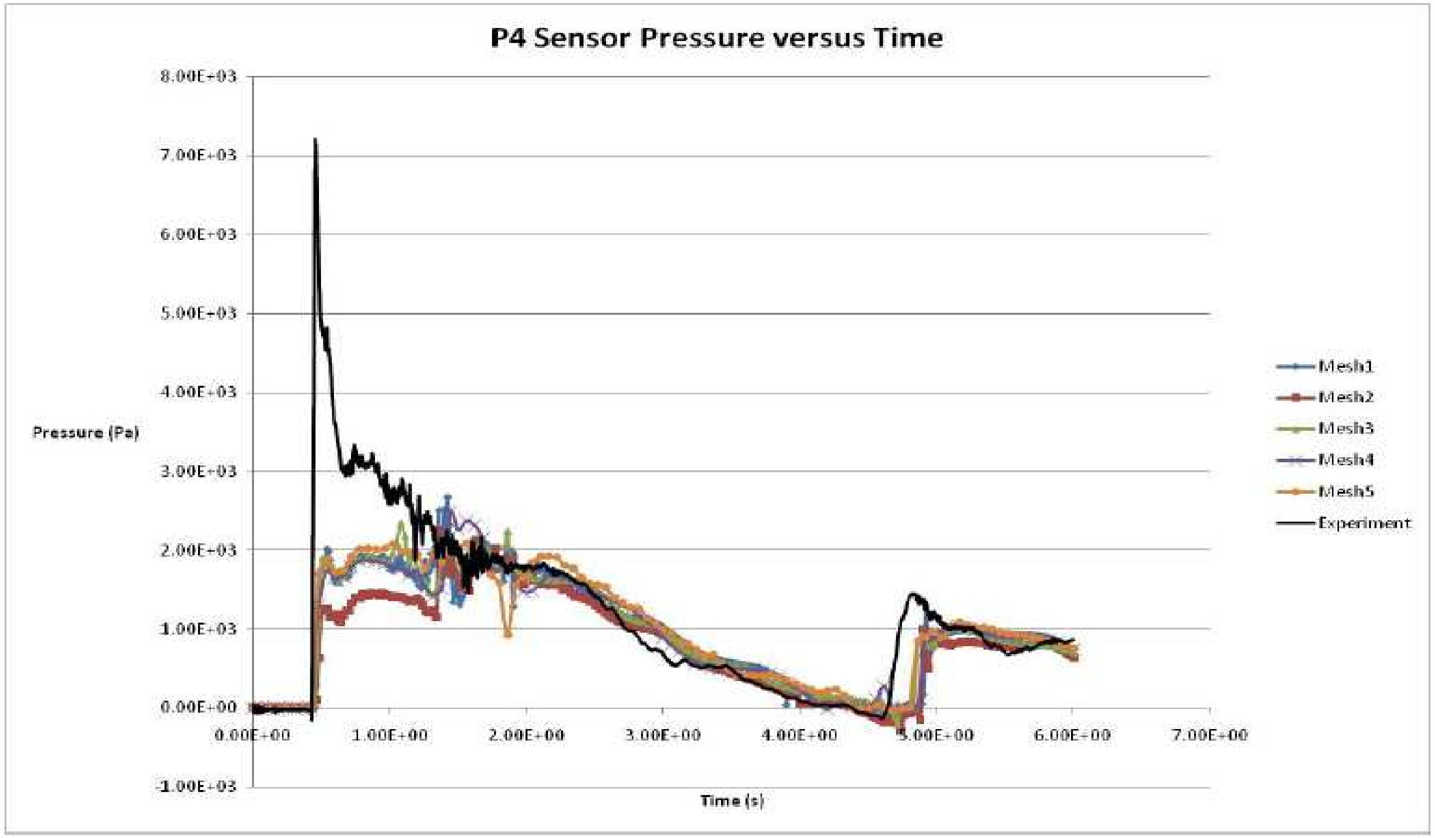

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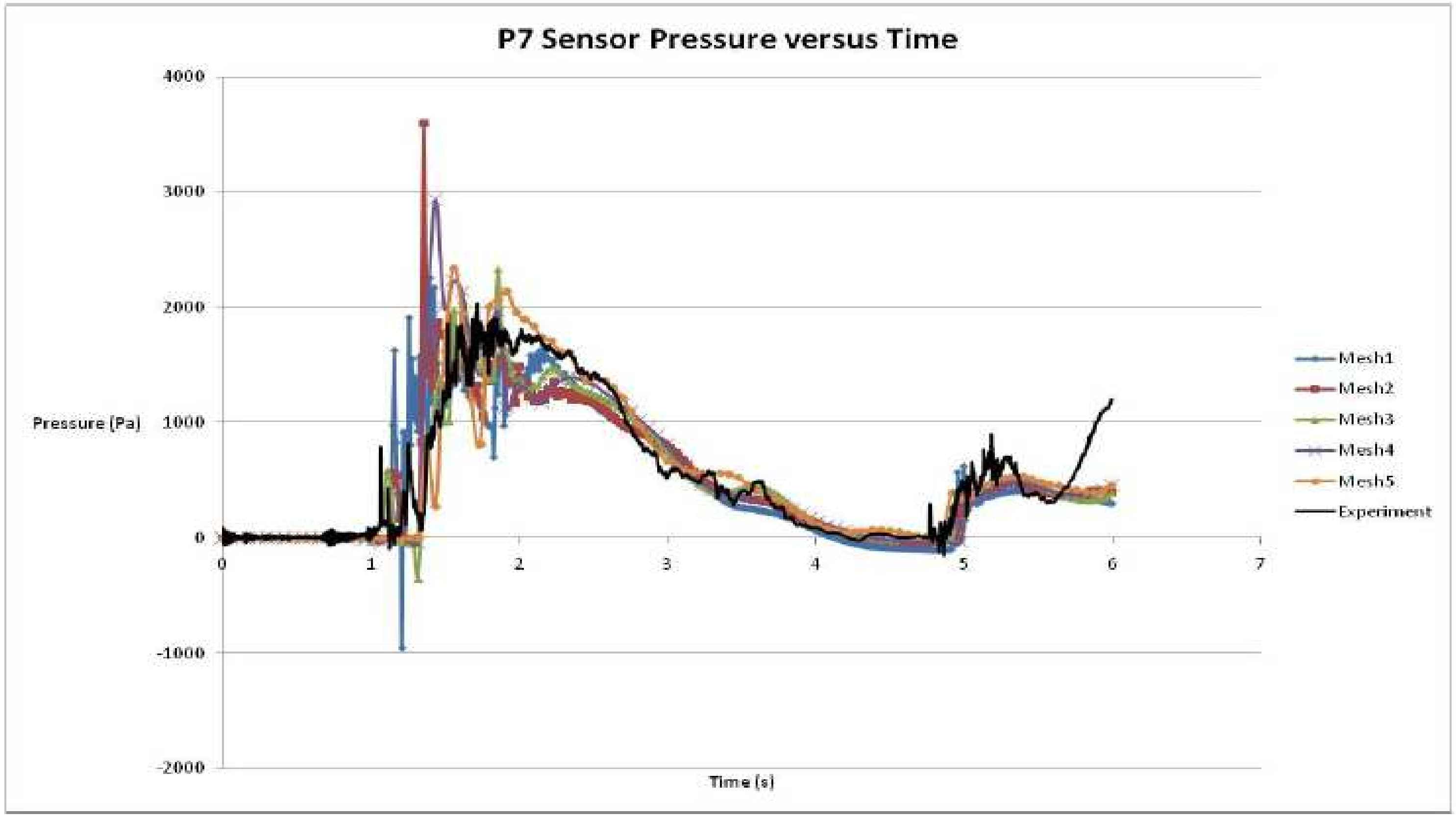


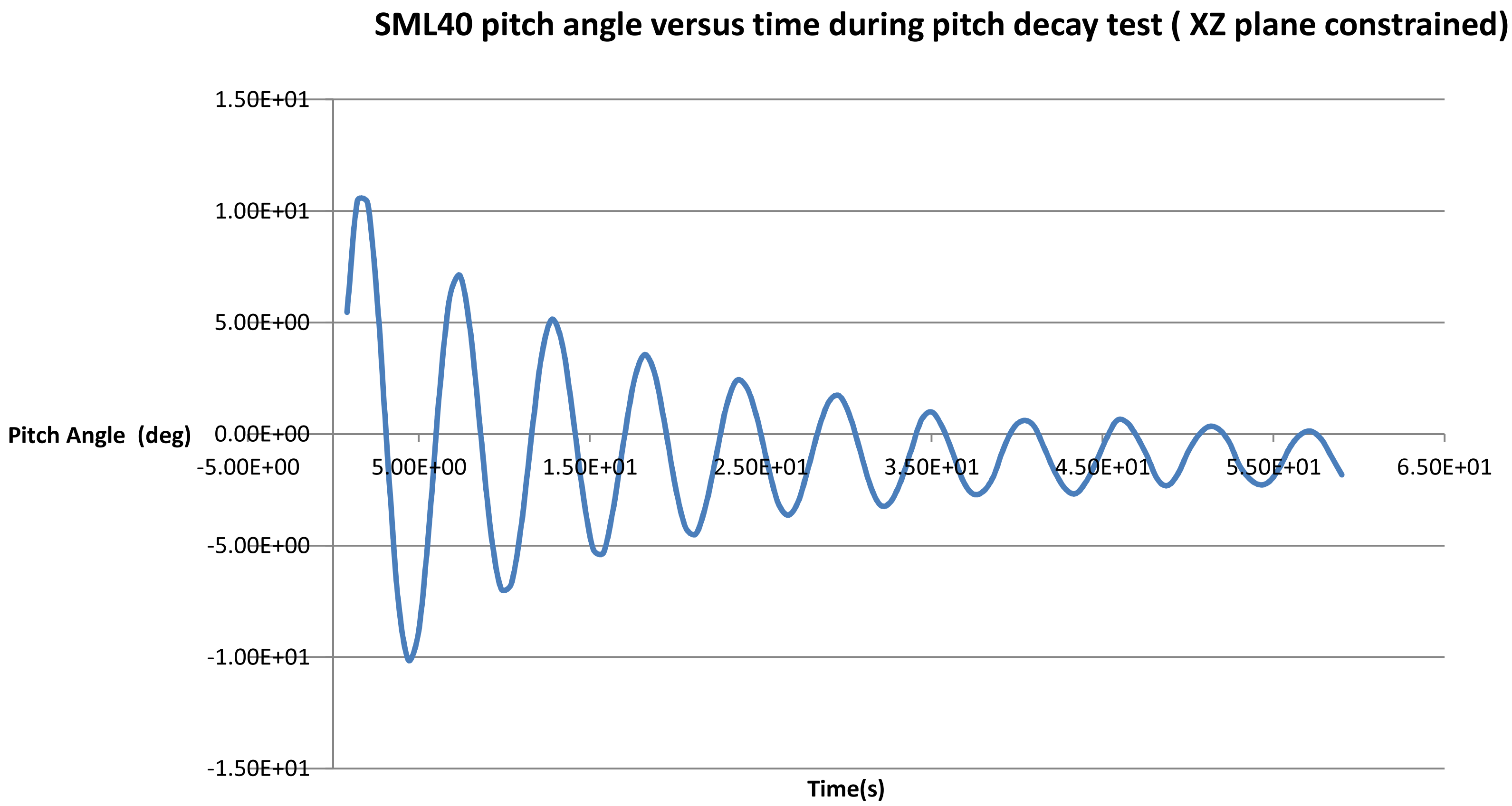
Dam Break Problem Conclusions

- The Flow-3D code has been used to simulate a very challenging free surface flow problem and has in produced good qualitative and quantitative agreement with the experimental data. The main discrepancies could easily be due to problems measuring the free surface elevation and the repeatability of the experimental measurements.
- The prediction of pressure on the surface of an obstacle on which the flow impinges are also generally in good agreement with the experimental measurement, the main deviation being again where there is a significant amount of fluctuation in the experimental measurements.
- The solution can be adequately obtained on a relatively coarse mesh using Ist order differencing with no turbulence model in around 15 minutes on a shared memory configuration over four processors. The lack of need for a turbulence model suggests that the turbulent structures which dominate the resulting flow are resolvable at this level of mesh refinement.

Pitch Decay of Unmoored 35th Scale Survival Model

- Objective is to ensure Locked Body Survival model had correct pitch stiffness and thus pitch period prior to Survival testing.
- Model has 0.39cm Diameter
- 8m X 8m X 5m depth Wave Tank
- 4 levels of mesh refinement with inner mesh size = 0.015m
- Outflow Boundaries on sides of tank to remove reflections

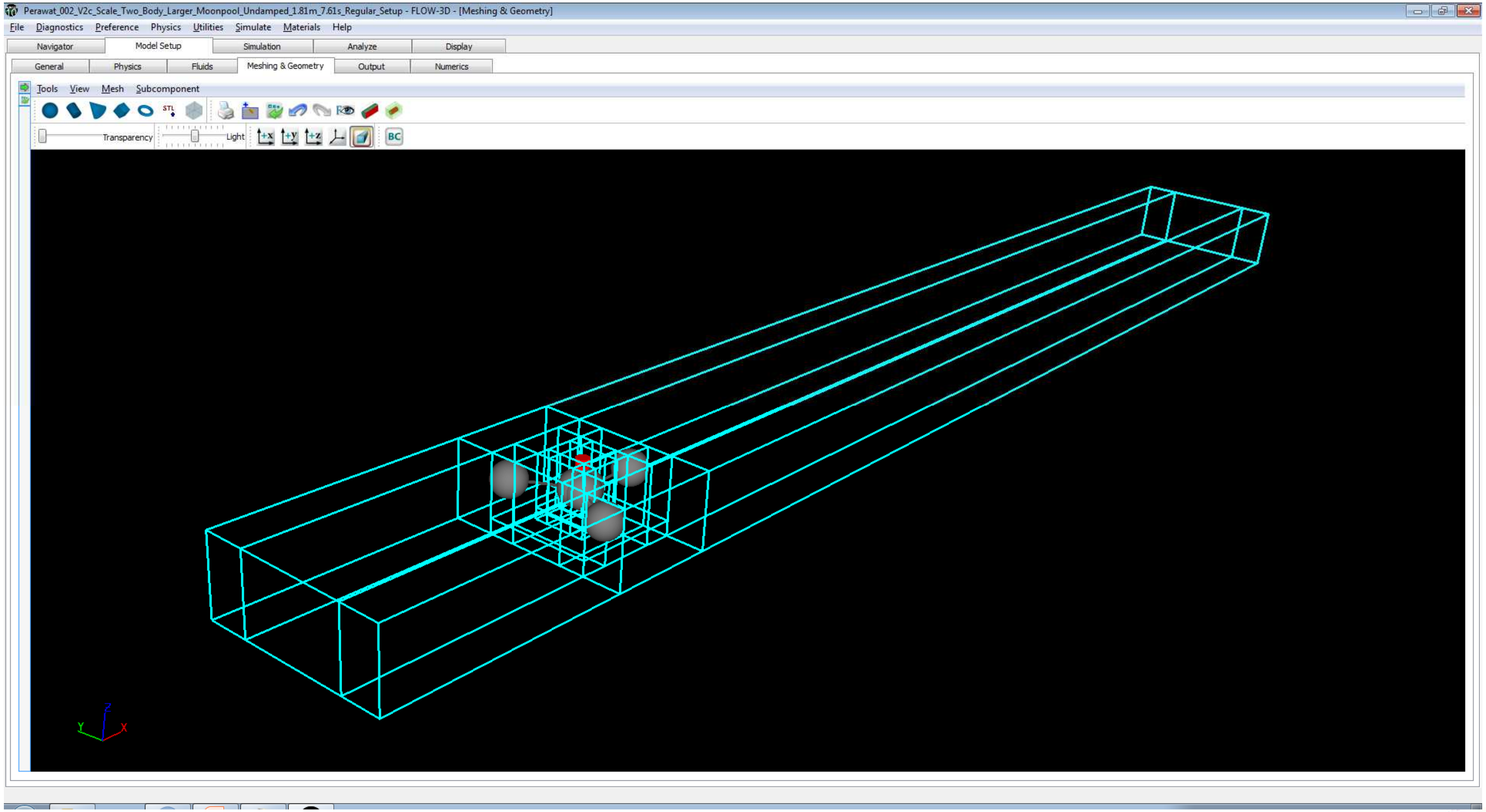
CFD Pitch Decay Response



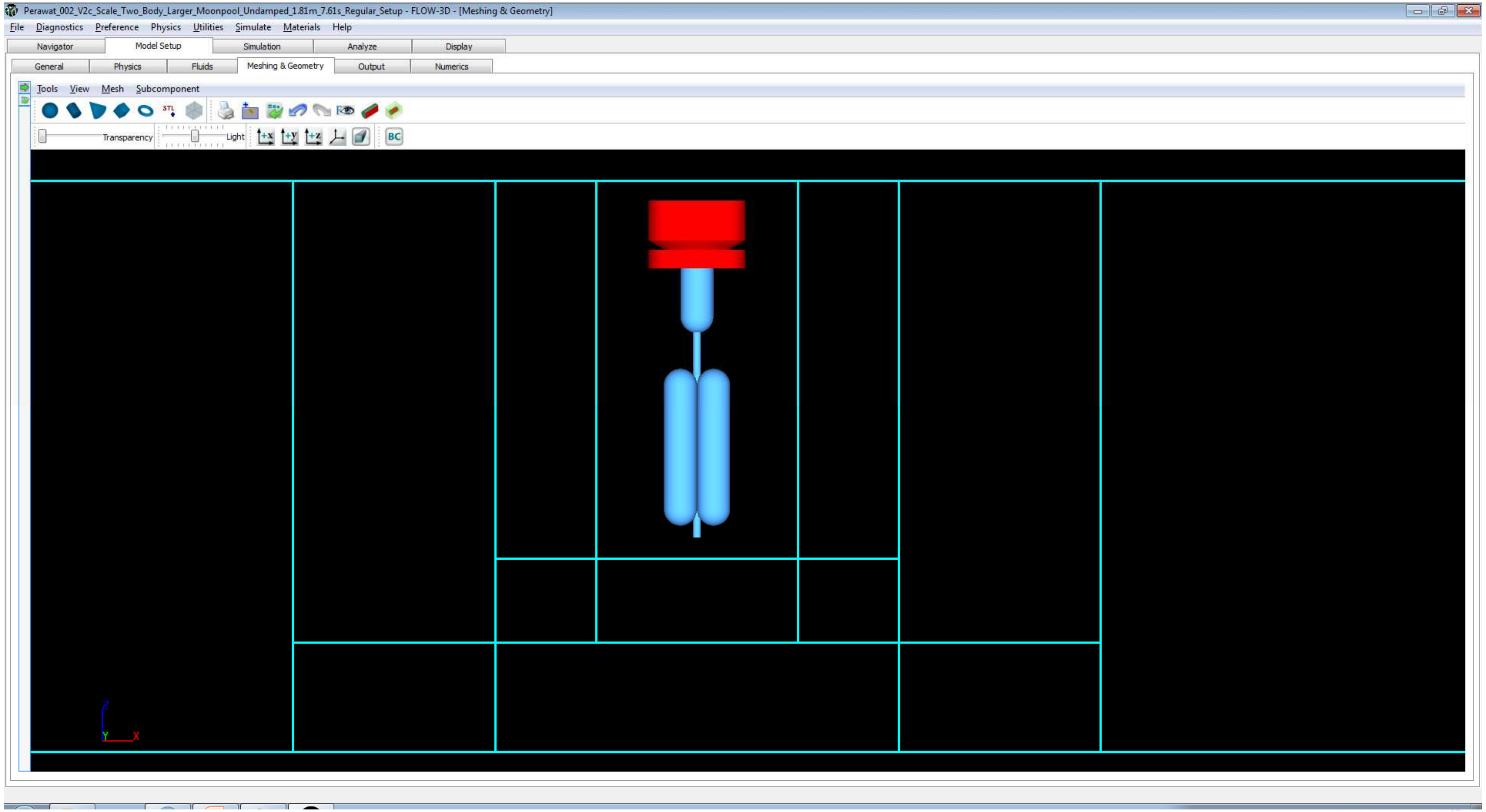
CFD Pitch Period

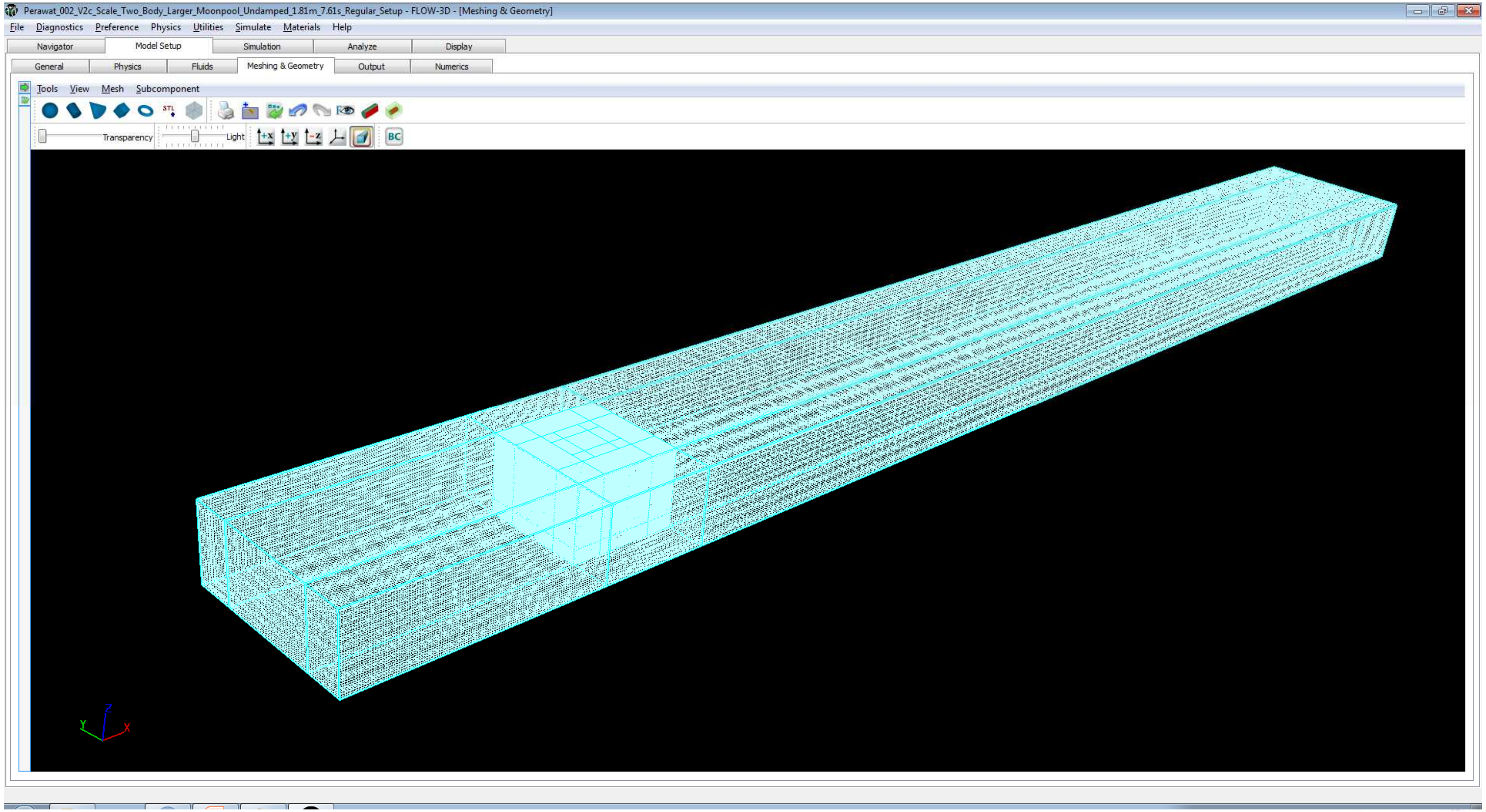
- Experimentally measured pitch period = 5.52 secs
- Pitch Period from simulation is 5.51 secs (0.2% error)
- 21 hours to solve for 60 secs of simulation time on a 2.3 million cell mesh.

Numerical Wave Tank Mesh Blocks



Numetrical Wave Tank Mesh Blocks




Perawat_002_V2c_Scale_Two_Body_Larger_Moonpool_Undamped_1.81m_7.61s_Regular_Setup - FLOW-3D - [Meshing & Geometry]
File Diagnostics Preference Physics Utilities Simulate Materials Help
Navigator Model Setup Simulation Analyze Display
General Physics Fluids Meshing & Geometry Output Numerics
Tools View Mesh Subcomponent
Transparency
Light
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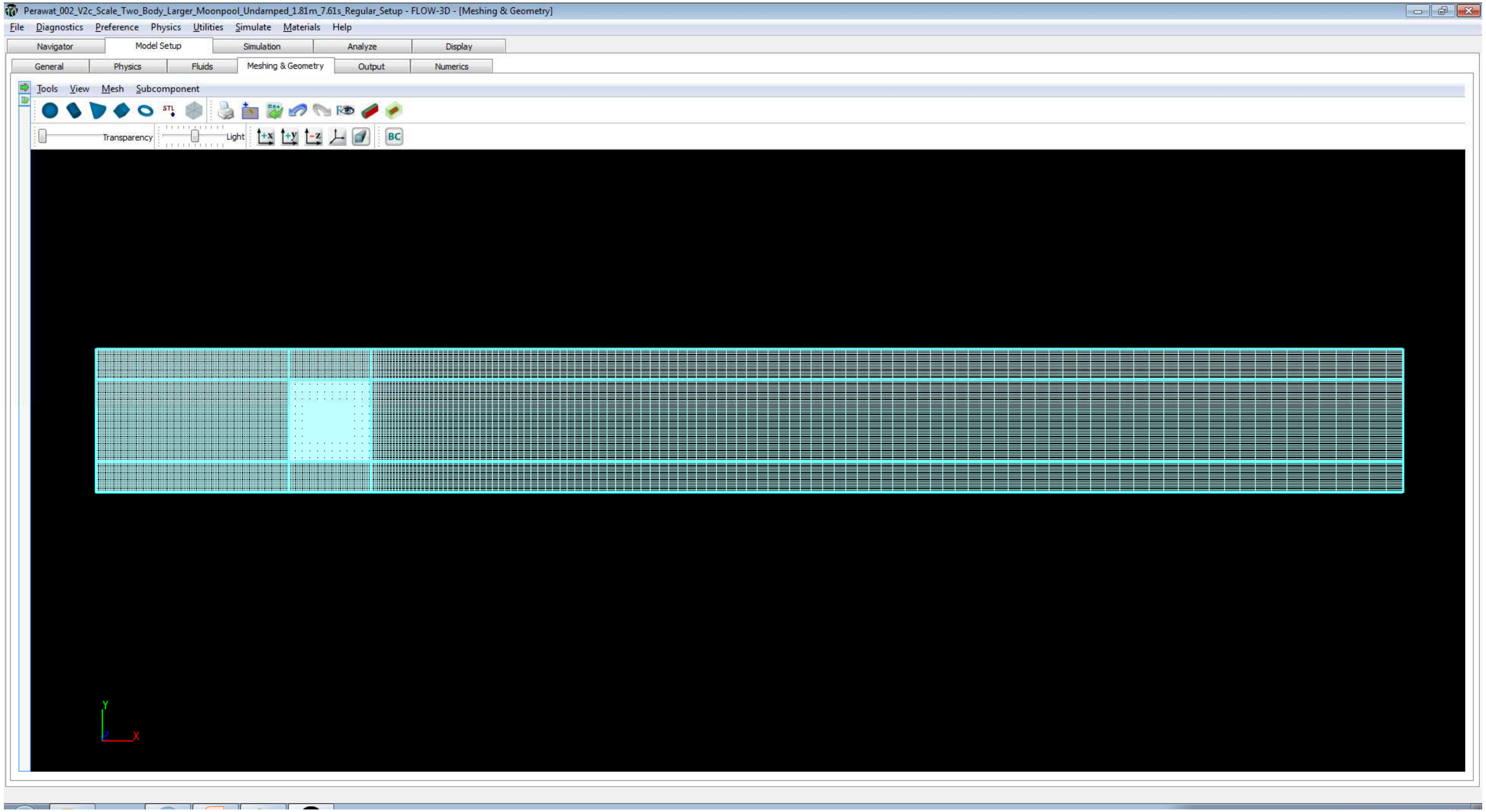
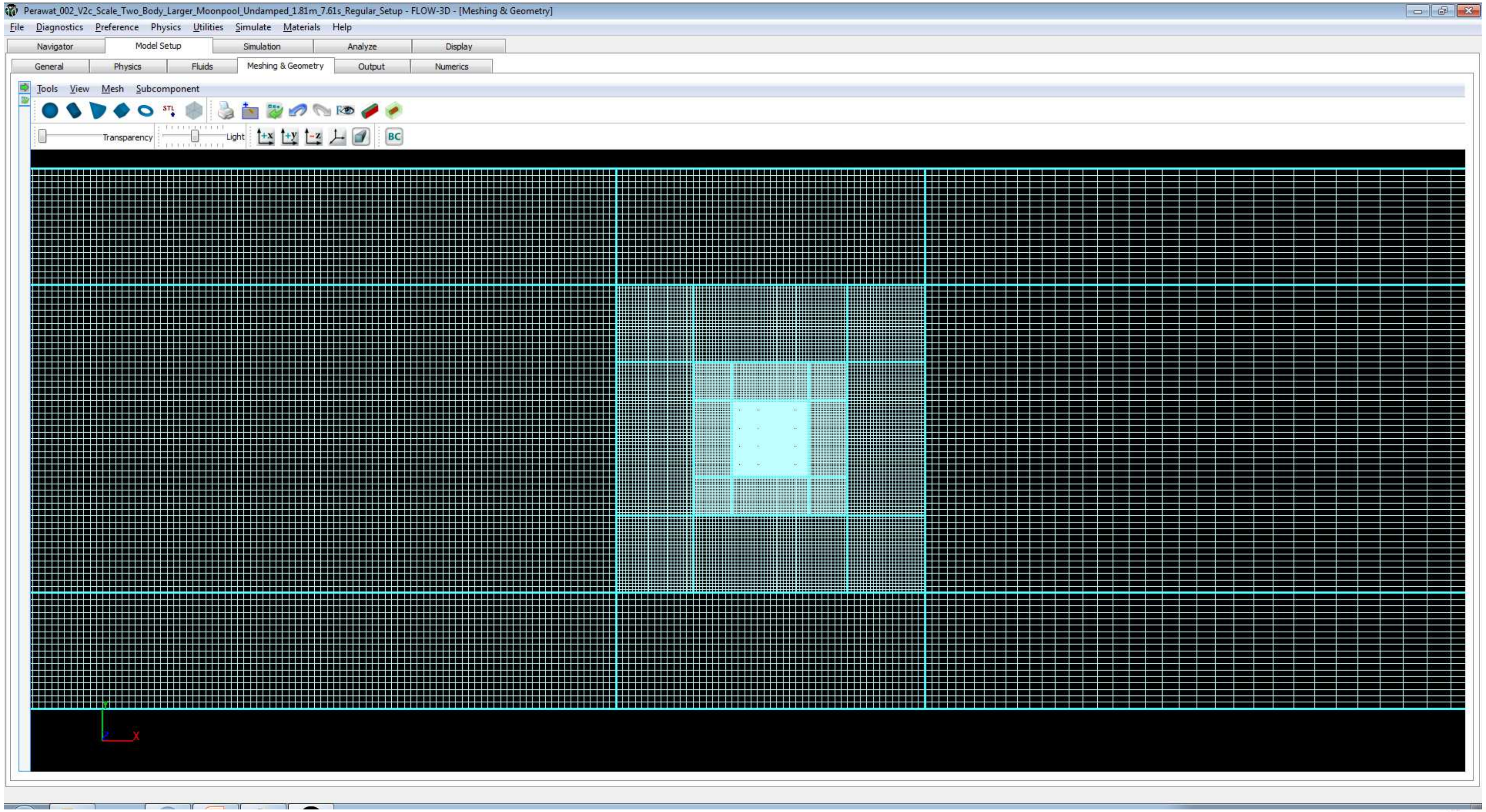
Numerical Wave Tank Mesh



Numerical Wave Tank Mesh



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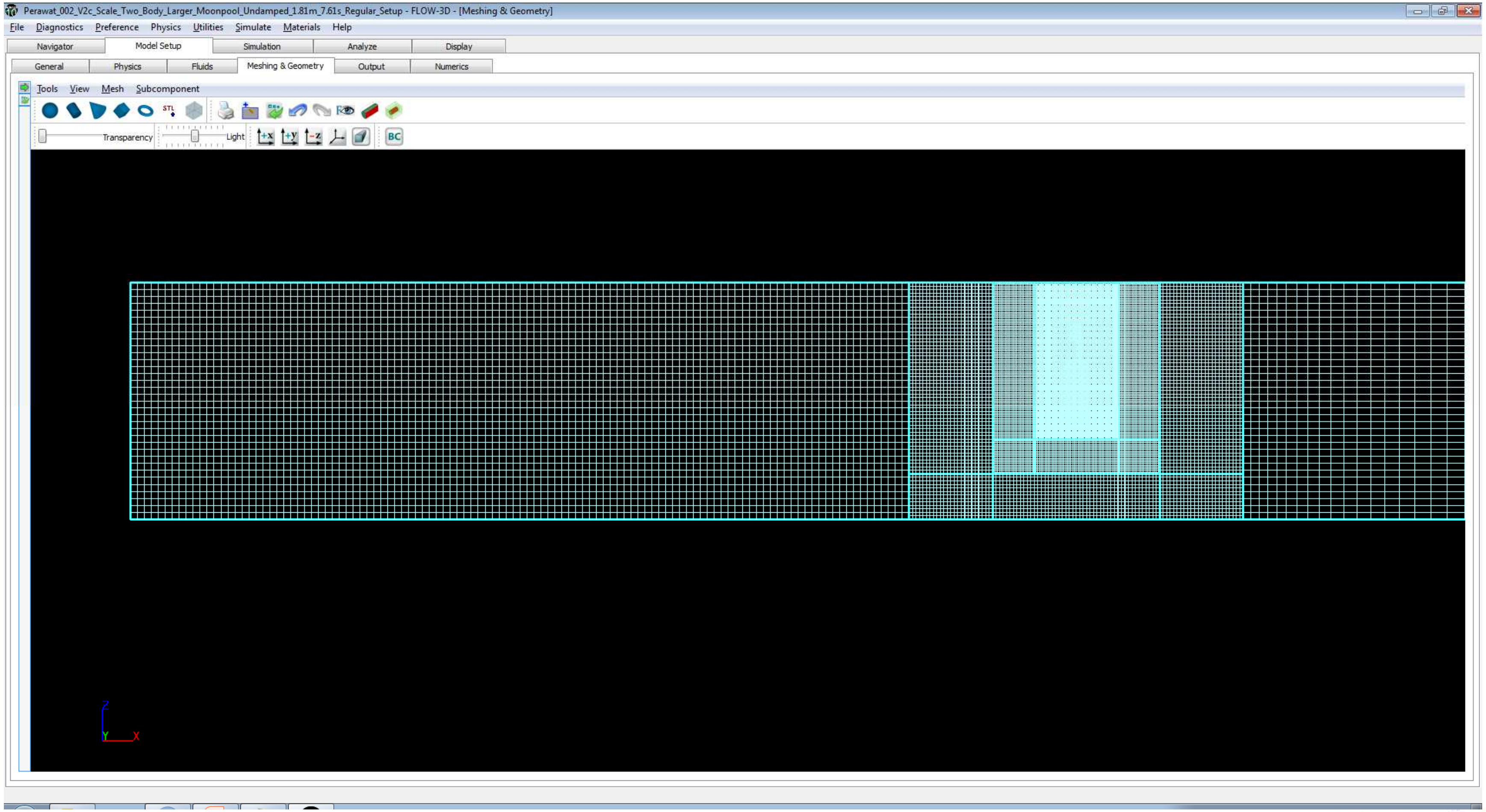

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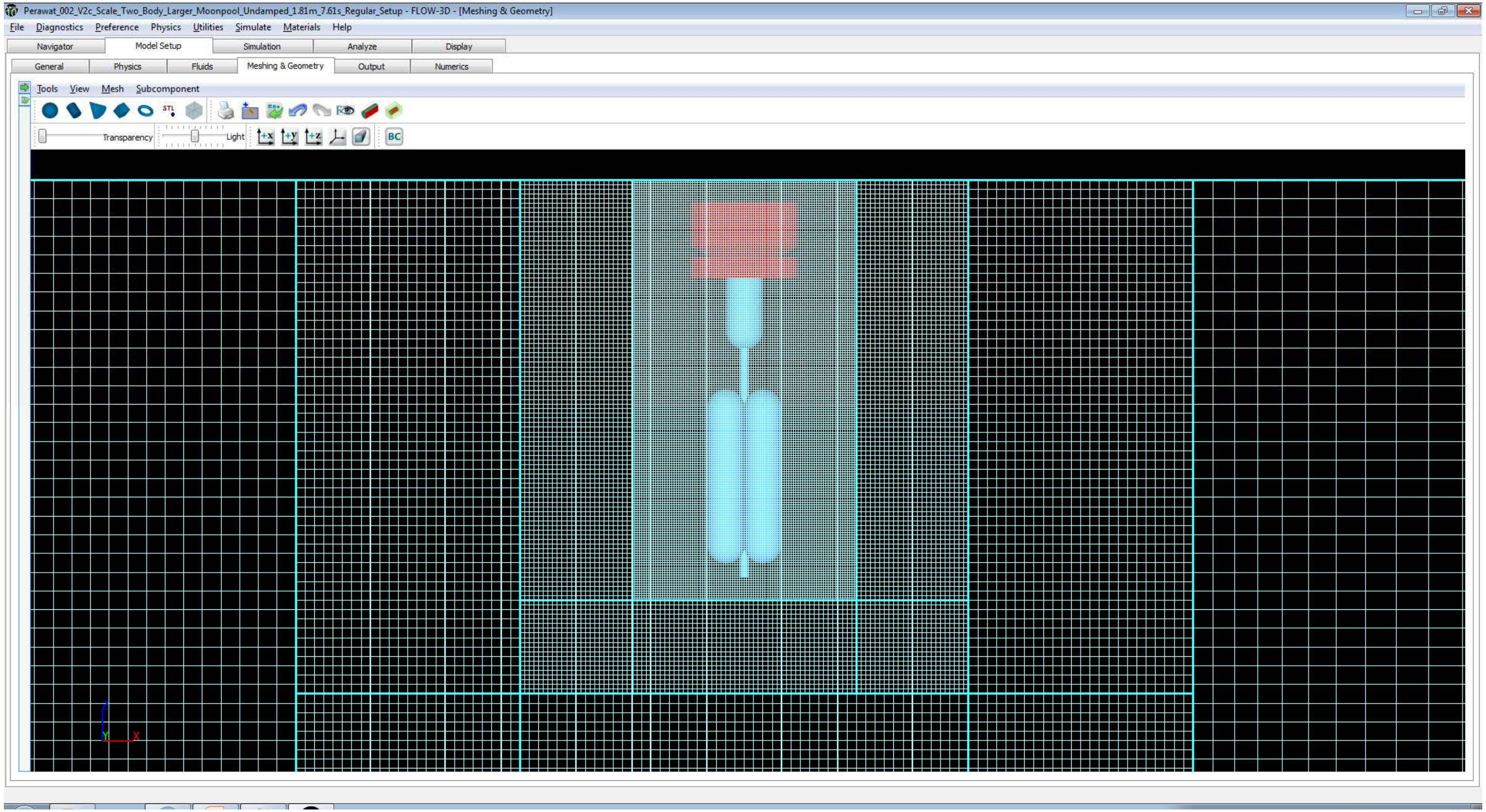

Mesh Characteristics

- Use cubic cells except in damping zone
- Smallest cell size determined by sufficient resolution of WEC
- Not less than 50 cells per wave length
- Not less than one cell per wave height
- Distance from wave maker to target at least 1 wavelength
- Distance from target to start of damping zone at least half a wavelength.
- Damping zone at least 8 wavelengths
- Tank width at least one length.
- At least 1 million cells but not more than 4 million.

Run times

- Decay Tests 24 hours
- 20 regular waves with two moving bodies 2-4 days.
- Irregular waves with 100 frequency components 4-10 days
- 4 Processor twin core machine, 3 years old.
- Latest machines costing less that 8,000 Euros and code would reduce run times by 50% -80% .

Results and Conclusions

- Decay tests results are very good provided mass properties correct.
- Regular wave and irregular wave results are currently poor to satisfactory , due to alignment with experiment setup and insufficient mesh resolution.
- Prediction of parametric pitching is good.
- Survival wave results are surprisingly good.
- Mesh size determined by geometry not wave, consequently stepper waves are better resolved.
- Use CFD for decay and survival tests and leave the power production to the drag coefficient supplemented BEM codes which prefer shallower waves.

Dam Break Problem References

1. SPH European Research Interest Community SIG, Test-Case 2 3D dambreaking, R.Issa and D. Violeau. http://wiki.manchester.ac.uk/spheric/index.php/Test2
2. K.M.T Kleefsman, G. Fekken, A.E P Veldman, B. Iwanowski, and B. Buchner. A volume of fluid based simulation method for wave impact problems. J Comp Phs, 206: 363-393, 2005.

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