



# WEC-Sim Technical Training Course



*PRESENTED BY*

WEC-Sim Development Team





# Advanced Features – Nonlinear Hydrodynamics

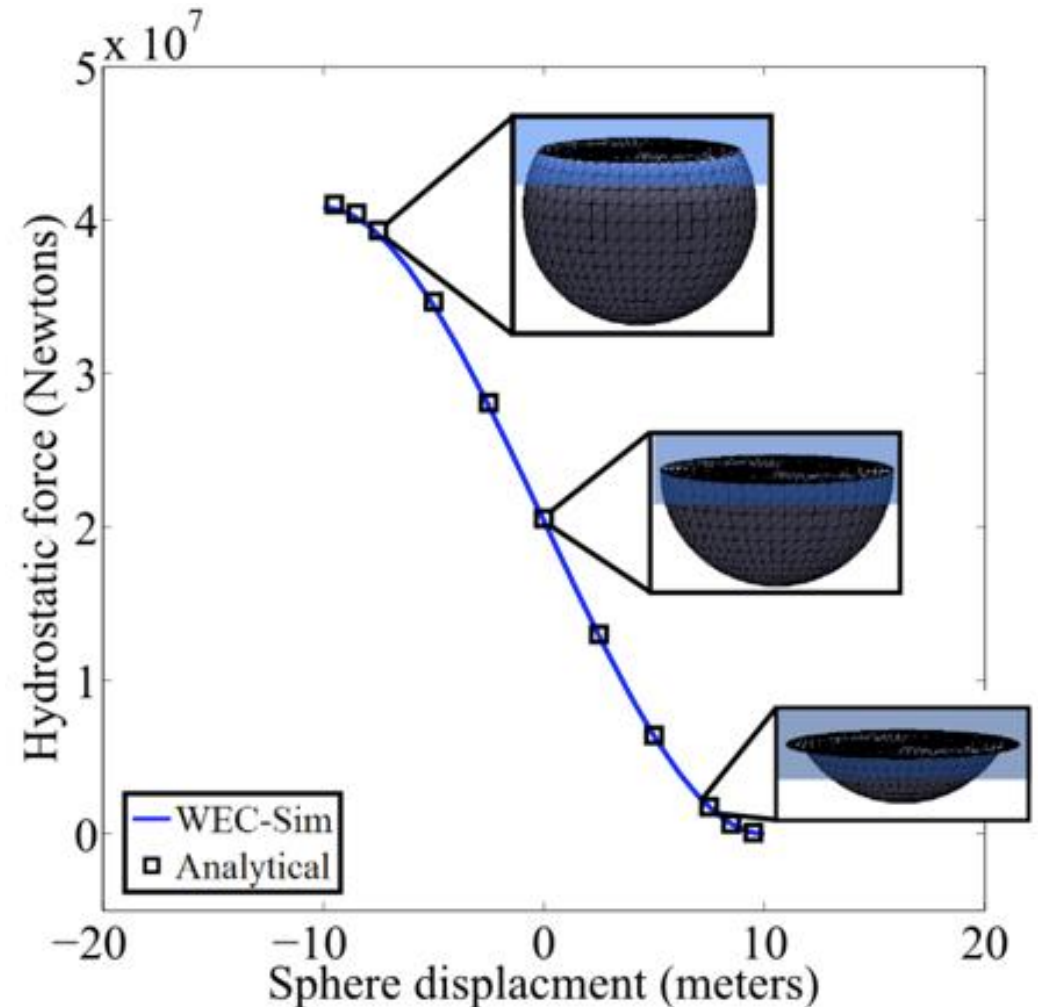


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# Nonlinear Hydrodynamics

- WEC-Sim has the option to include the two **nonlinear hydrodynamic forcing terms** when solving the system dynamics of WECs:
  - Nonlinear hydrostatic restoring forces.
  - Nonlinear Froude-Krylov forces
    - Based upon the incident wave and not the diffracted wave
- A weakly nonlinear approach is applied to account for the nonlinear hydrodynamic forces induced by the instantaneous **water surface elevation, body position, and geometry** of the floating body.



## 4 Nonlinear Hydrodynamics

- Because linear wave theory is used to determine the flow velocity and pressure field, the values become unrealistically large for wetted panels that are above the mean water level.
- To correct this, the **Wheeler stretching method** is used, which forces the water column (based on the instantaneous wave elevation) to have a height that equals the water depth when calculating the flow velocity:

$$z^* = \frac{D(D + z)}{D + \eta} - D = \frac{D(z - \eta)}{D + \eta}$$

- The method is not intended to model highly nonlinear hydrodynamic events, such as wave slamming and wave breaking.
- For the nonlinear hydrostatics calculation, the pressure on the wetted surface is calculated based on the mean free surface. This ensures the wave amplitude is not double counted in the summation of hydrostatic and Froude-Krylov pressures.

## Nonlinear Settings

- The nonlinear hydrodynamics option can be used by setting `body(#).nonlinearHydro = 1` or `2`

### %% Body Data

```
body(1) = bodyClass('../../hydroData/ellipsoid.h5');  
body(1).mass = 'equilibrium';  
body(1).inertia = [1.375264e6 1.375264e6 1.341721e6];  
body(1).geometryFile = '../../geometry/elipsoid.stl' ;  
body(1).quadDrag.cd=[1 0 1 0 1 0];  
body(1).quadDrag.area=[25 0 pi*5^2 0 pi*5^5 0];  
body(1).nonlinearHydro = 2; % Non-linear hydro on/off
```

- Typically, `body.nonlinearHydro = 2` is recommended if nonlinear hydrodynamic effects need to be used.
- Note that `body.nonlinearHydro = 1` only considers the nonlinear restoring and Froude-Krylov forces based on the instantaneous body position and mean wave elevation.

## Nonlinear Settings

- An option is available to reduce the nonlinear simulation time is to specify a nonlinear time step:
  - $\text{simu.nonlinearDt} = N * \text{simu.dt}$ , where  $N$  is number of increment steps.

### %% Simulation Data

```
simu = simulationClass();  
simu.simMechanicsFile = 'ellipsoid.slx';  
simu.solver = 'ode45';  
simu.mode = 'normal';  
simu.explorer = 'off';  
simu.startTime = 0;  
simu.rampTime = 50;  
simu.endTime = 150;  
simu.dt = 0.05;  
simu.rho = 1025;  
simu.nonlinearDt = 3*simu.dt;
```

- As the ratio of the nonlinear to system time step increases the computation time is reduced, but at the expense of the simulation accuracy.

## Nonlinear Settings

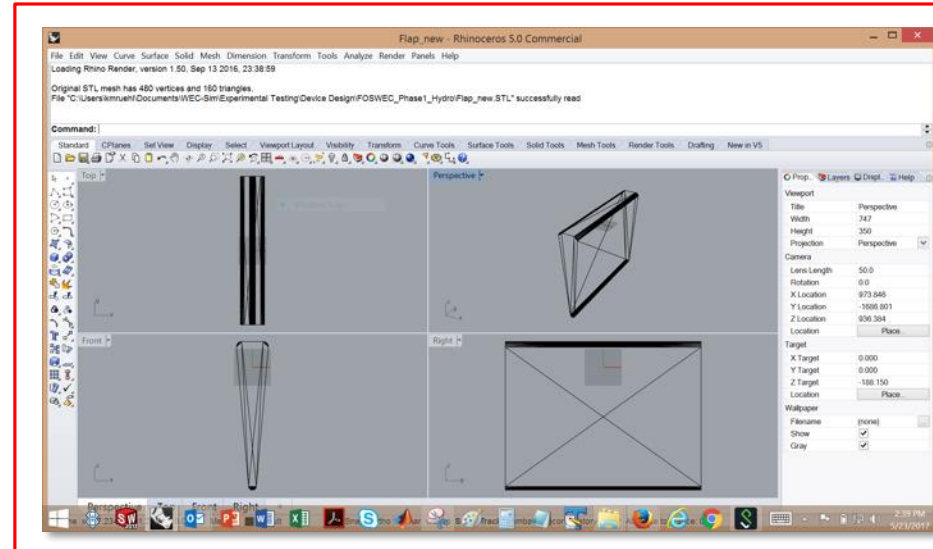
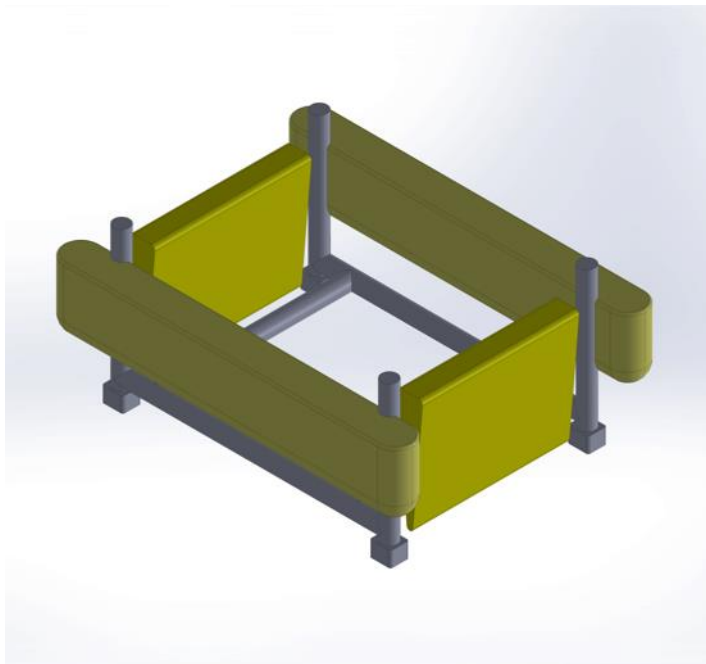
- WEC-Sim's nonlinear hydrodynamic option may be used for regular or irregular waves, but not with user-defined waves utilizing the *elevationImport* wave type.
- To use nonlinear hydrodynamic option for user-defined waves, the user has to first use FFT to compute the spectrum and the corresponding phases for the waves. Then the user will utilize the *spectrumImport* wave type.
- The reason for this method of implementation is that the individual wave components (wave amplitudes, wave frequencies, and wave numbers) that comprise the user-defined wave needs to be known in order to estimate the incident wave pressure on the wetted surface of the hydrodynamic body.
  - For more information please refer to the **Developer Manual** section on WEC-Sim's documentation page.

- When the nonlinear option is turned on, the geometry file (\*.stl) (previously only used for visualization purposes in linear simulations) is used as the discretized body surface on which the non-linear pressure forces are integrated.
- STL (STereoLithography) is a file format native to the stereolithography CAD software created by 3D Systems.
- It is widely used for rapid prototyping, 3D printing and computer-aided manufacturing.
- The STL format specifies both ASCII and binary representations. WEC-Sim accepts both formats.

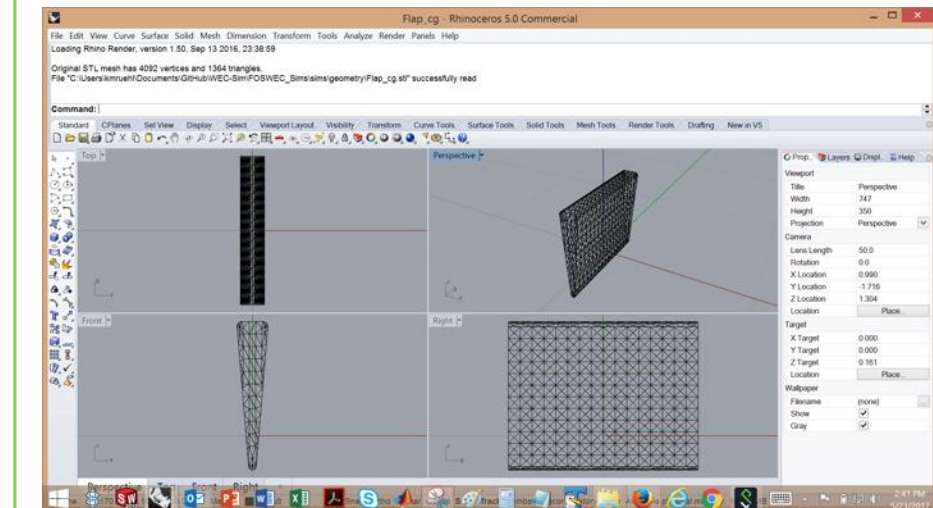


# STL File Generation

- A higher resolution STL mesh is required compared to just visualization.



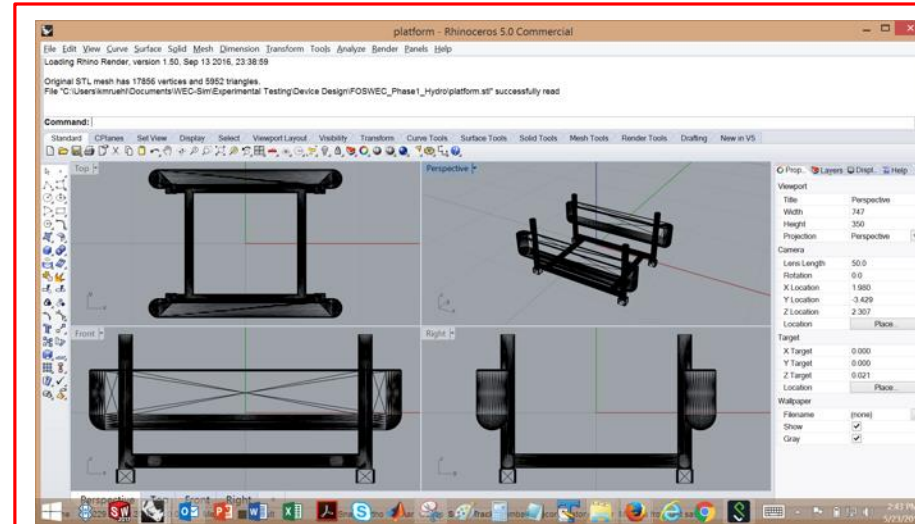
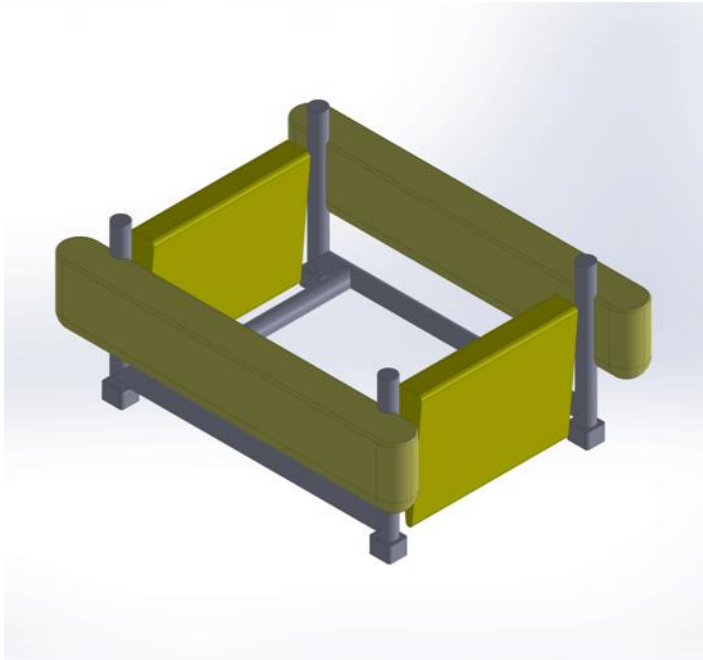
Poor  
Resolution



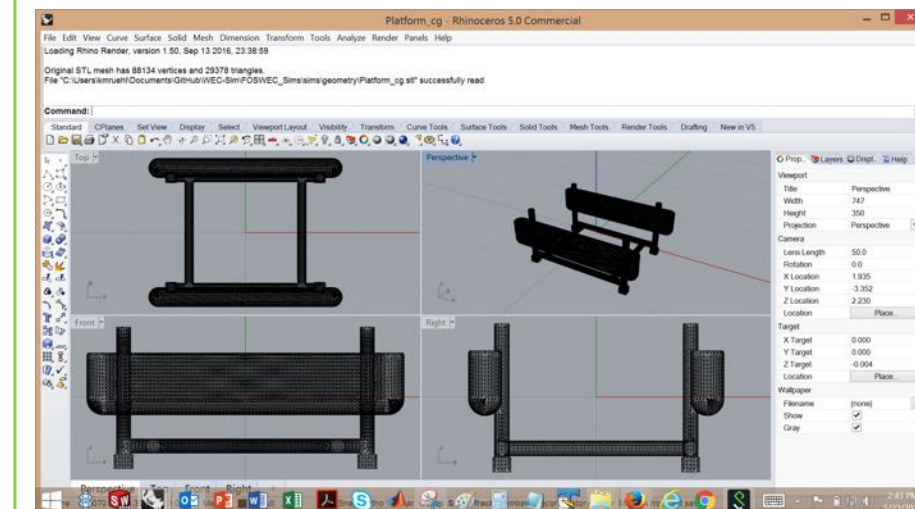
Better  
Resolution

# STL File Generation

- Reiterating that STL mesh resolution is key for a stable and accurate model.



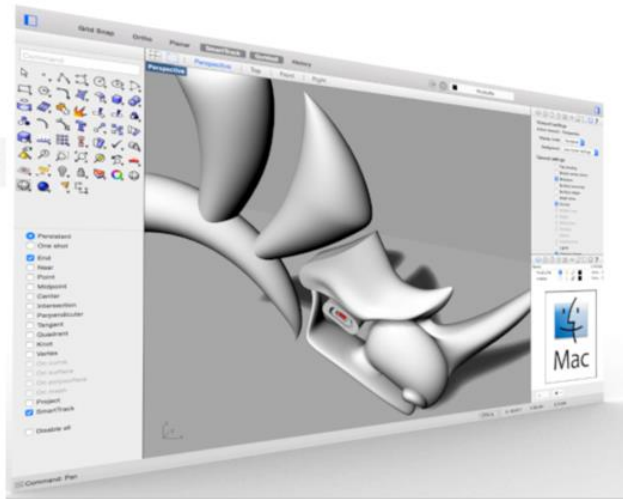
Poor  
Resolution



Better  
Resolution

## II STL File Generation

- The simulation accuracy will increase with increased surface resolution (i.e. the number of discretized surface panels specified in the .stl file), but the computation time will also increase.
- There are many ways to generate an STL file, however it is important to verify the quality of the mesh before running WEC-Sim with nonlinear hydrodynamics.
- An STL file can be exported from most CAD programs, but few allow adequate mesh refinement.
  - A good program to perform STL mesh refinement is Rhino.

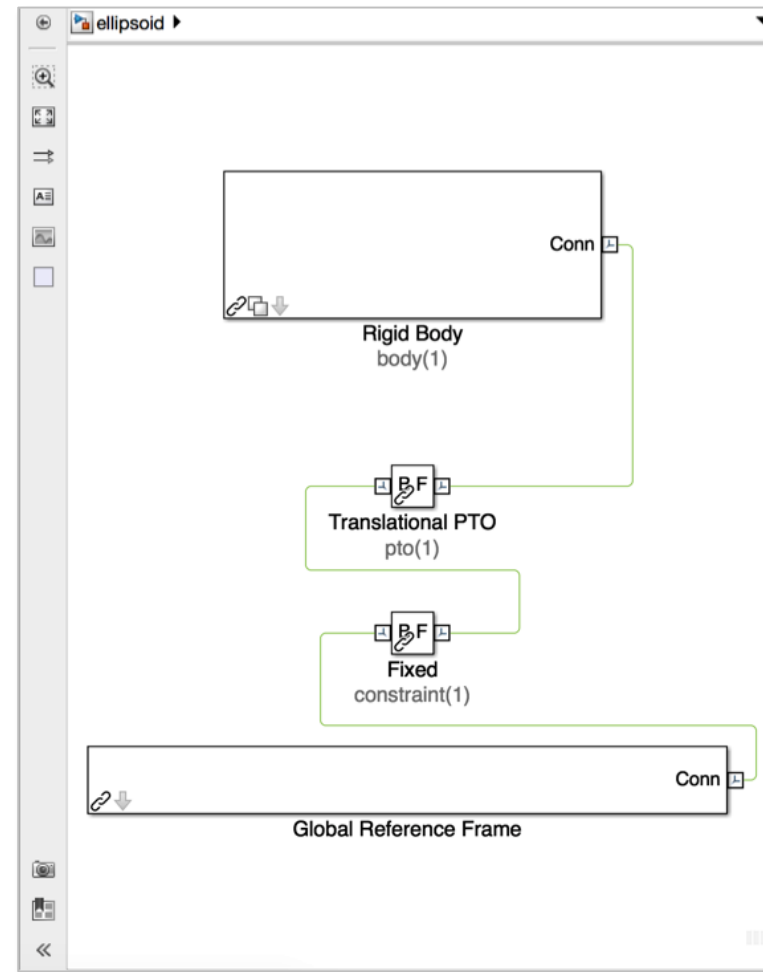
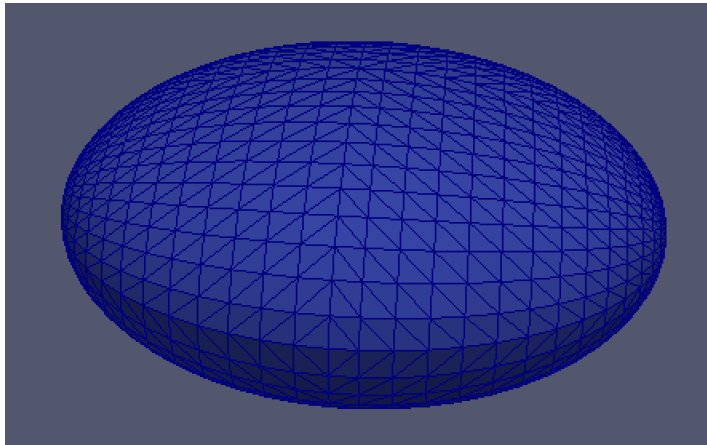
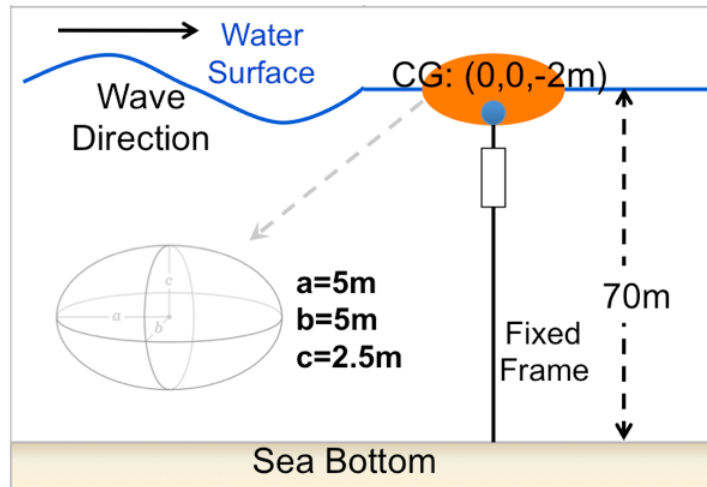


<https://www.rhino3d.com/>

- Some helpful resources explaining how to generate and refine an STL mesh in Rhino3d are:
  - <https://wiki.mcneel.com/rhino/meshfaqdetails>
  - <https://vimeo.com/80925936>

## Tutorial - Heaving Ellipsoid

- An example is provided in the WEC-Sim Application repository
  - [https://github.com/WEC-Sim/WEC-Sim\\_Applications/tree/master/Nonlinear\\_Hydro](https://github.com/WEC-Sim/WEC-Sim_Applications/tree/master/Nonlinear_Hydro)



## Tutorial - Heaving Ellipsoid

- Example `wecSimInputFile.m` to run the heaving ellipsoid applications case with `nonlinearHydro` active.

### %% Simulation Data

```

simu = simulationClass();
simu.simMechanicsFile = 'ellipsoid.slx';
simu.solver = 'ode45';           % 'ode4' for fixed step or 'ode45' for variable step
simu.mode = 'normal';          % Specify Simulation Mode ('normal','accelerator','rapid-accelerator')
simu.explorer = 'off';         % Turn SimMechanics Explorer (on/off)
simu.startTime = 0;
simu.rampTime = 50;
simu.endTime = 150;
simu.dt = 0.05;
simu.rho = 1025;
simu.nonlinearDt = 3*simu.dt;

```

### %% Wave Information

#### % Regular Waves

```

waves = waveClass('regular');
waves.height = 4;
waves.period = 6;

```

### %% Body Data

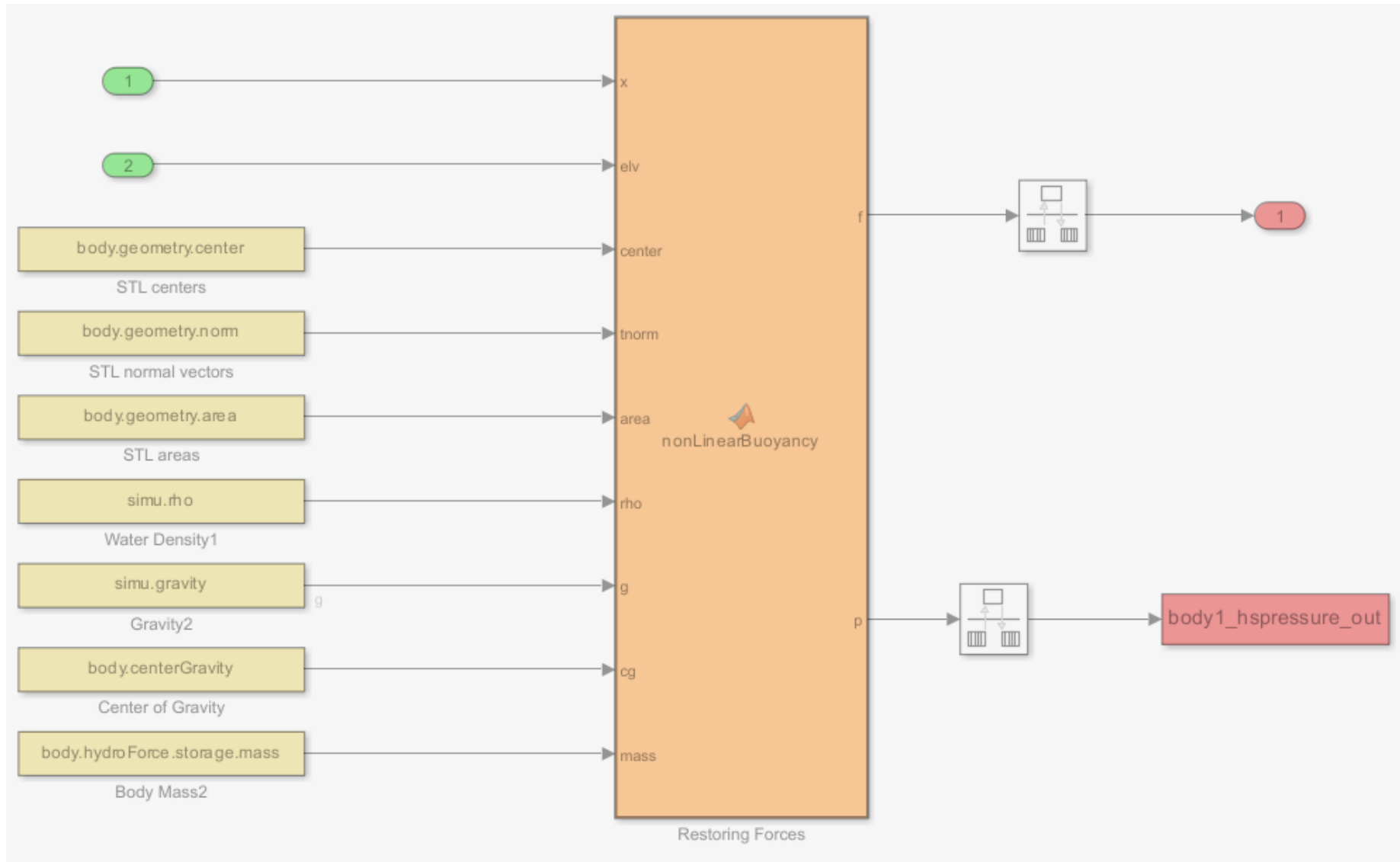
```

body(1) = bodyClass('../hydroData/ellipsoid.h5');
body(1).mass = 'equilibrium';
body(1).inertia = [1.375264e6 1.375264e6 1.341721e6];
body(1).geometryFile = '../geometry/ellipsoid.stl' ;
body(1).quadDrag.cd=[1 0 1 0 1 0];
body(1).quadDrag.area=[25 0 pi*5^2 0 pi*5^5 0];
body(1).nonlinearHydro = 2;      % Non-linear hydro on/off

```

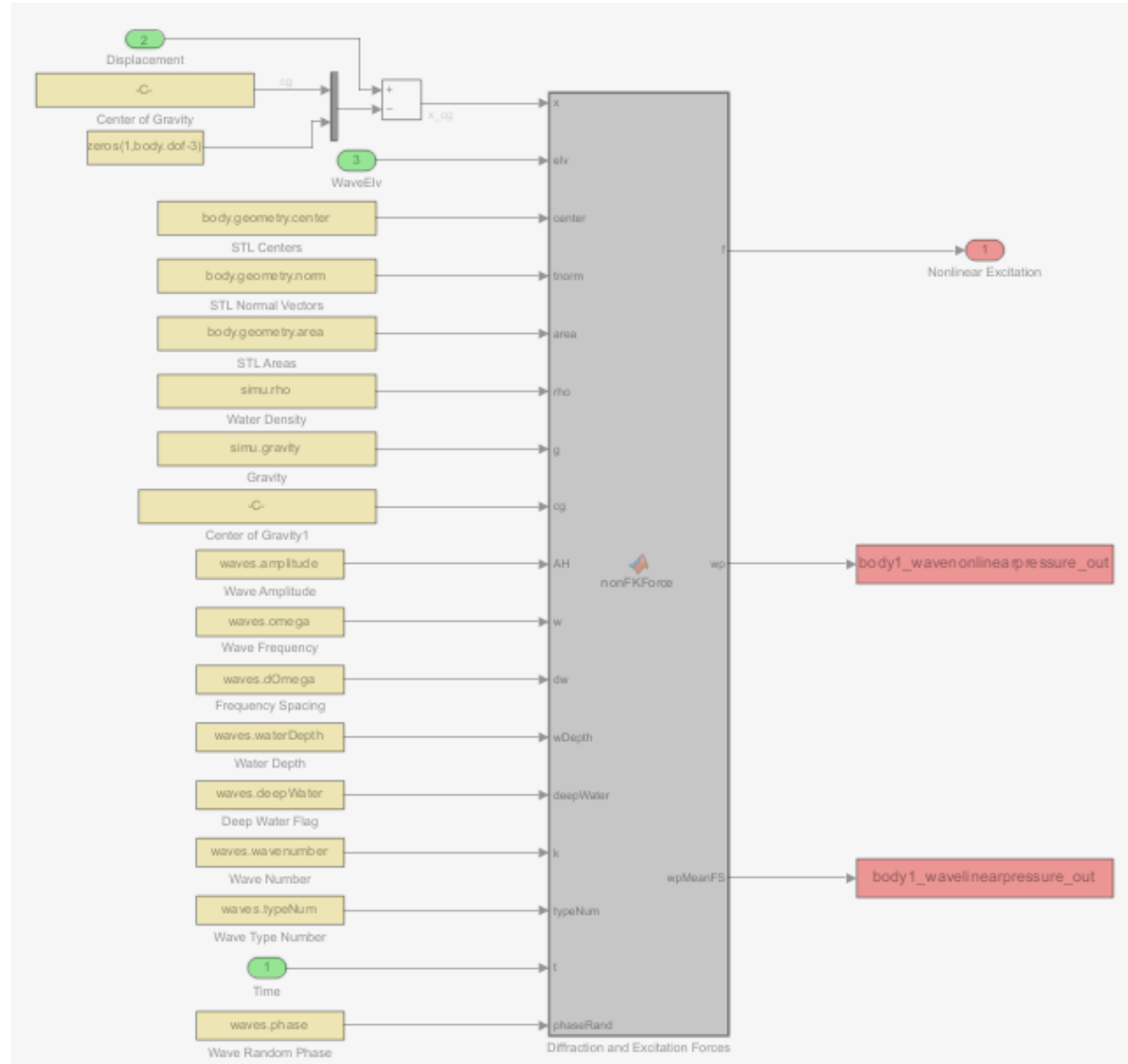
# Code Structure

- Simulink block for calculating nonlinear hydrostatic restoring forces



# Code Structure

- Simulink block for calculating nonlinear Froude-Krylov forces



## WEC-Sim Updates and Notes

- To reduce the output file size for the nonlinear hydro runs, the pressure distribution from nonlinear hydrodynamics calculation should NOT be saved in the .mat file as default.
- For multiple condition runs, it is recommended to save the SELECTED data from each simulation with different names using the “userDefinedFunctionsMCR.m” file
- If the body geometry is symmetric along the incoming wave direction, it is recommended to use 3DOF (instead of 6DOF) to reduce potential numerical instability, particularly when nonlinear hydrodynamics option is used.



# Thank you!



All previous webinar materials and recordings are available online:

<http://wec-sim.github.io/WEC-Sim/webinars.html>

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