Simulation of dynamic loads for marine vessels
The AC75 class yacht – a case study

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BAR Technologies

Presentation Agenda

- General introduction to the Americas Cup
  - Brief history of the AC
  - The AC 75 yacht
  - Loading
- Dynamic loading analysis
- Application to commercial vessels

Agenda

- Step 1 – Introduction to the America's Cup
- Step 2 – Fluid-Structure Interface Validation
- Step 3 – Preliminary Hull Studies
- Step 4 – Refined Hull Studies
- Step 5 – Bustle Optimisation

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The America’s Cup – a brief introduction

- The oldest international competition still operating in any sport (inception 1851)

- The competition is held approximately every three to four years

- The format of the competition is unique in that the rules are effectively reset after every event. This could mean:
  - change to the type of yacht used
  - new race location and conditions
  - new racing format and/or system of scoring

- Leveraging the latest technology has always been at the forefront of each AC campaign

- Rules limit design resources. The timeline limits time to test and develop the race yacht

The AC75 yacht – primary characteristics

- New class of yacht for the 2021 event
- Primary characteristics:
  - monohull
  - 75 ft long
  - total mass of 7.5t
  - 3 hydrofoils (2 main and one rudder)
- Double soft skin mainsail
- Capable of top speeds in excess of 50 knots (93 km/hr)
- Very efficient: boat speed > 2.5 x true wind speed

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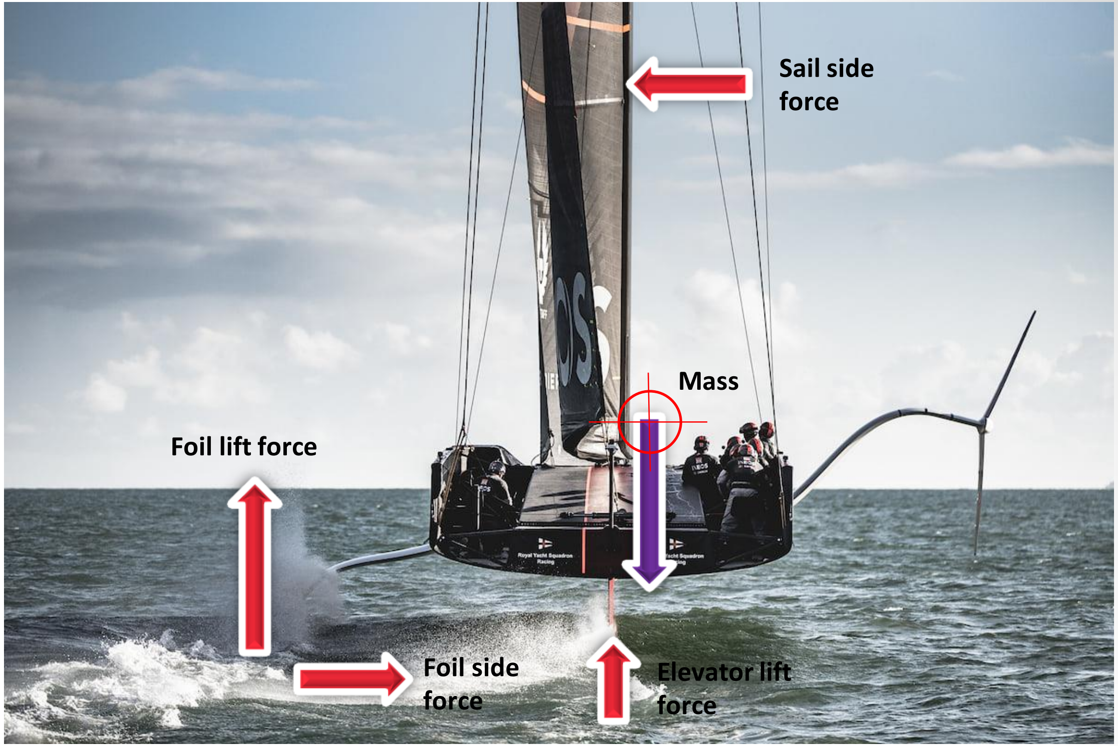
The AC75 yacht – how does it work?



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The AC75 yacht - design and construction

The AC75 yacht - design and construction

- All primary structure constructed using composite materials
- Open design rule for the hull structure
  - minimum panel weight = $2kg/m^2$
  - limited structural testing required
- The primary structure is completely hand-built
- Strict mass budget
- Extensive use made of advanced analysis and simulation techniques
- Highly optimised structure and laminates

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Dynamic loading - typical scenario “splash-down”

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Dynamic loading - typical scenario "stuff"

Entry velocity ≈ 40 knots (75 km/hr)

Total mass ≈ 7.5 tons

Deceleration > 2.5g

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Dynamic loading – analysis aims and methodology

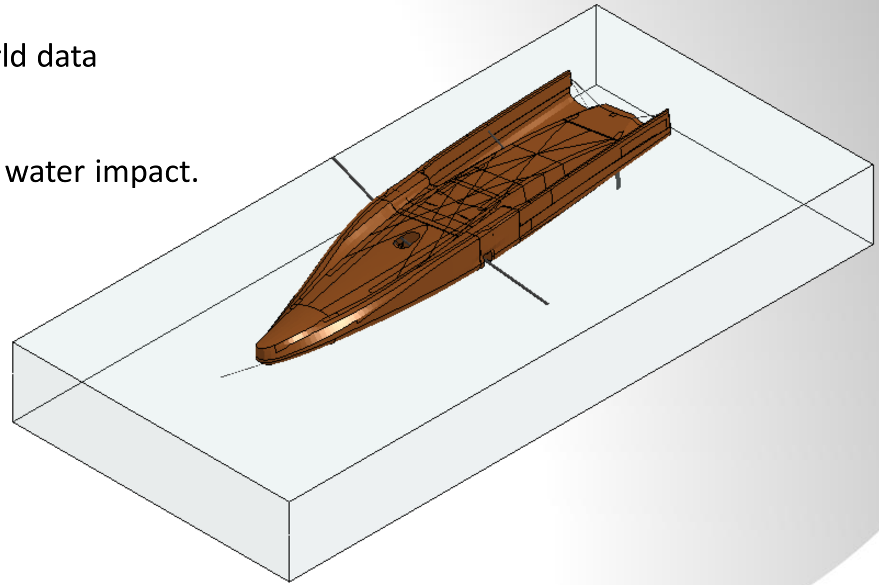
- Aim:
  - To develop confidence in simulation results and prove out the structural concept for an AC75 yacht by:
    - simulating dynamic response and correlate predicated behaviour against real world data
    - understanding how to adjust model parameters to improve accuracy
    - use results as input into the design of the race yacht hull structure

- Methodology:
  - Phased approach:
    - First model to test feasibility by benchmarking an existing hull platform
    - Second model to consider the full platform hull structure
    - Third model to focus on a detailed analysis – the bustle

  - In all cases an explicit solver was used employing fluid-structure interaction capability

FSI Interface Validation - Aims

- Develop the FSI model of the Yacht with the aim of
  - assessing the feasibility of constructing a model that is able to capture a slam type event
  - compare the predicted response with real world data
  - assessing the hull pressure distribution during water impact.



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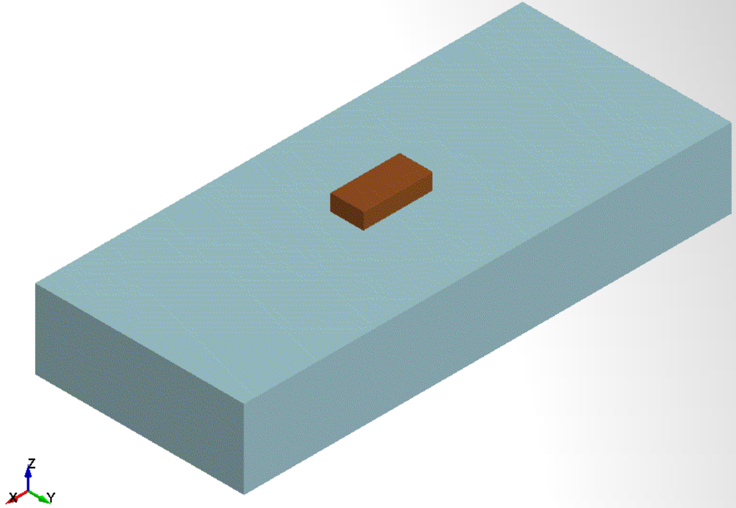
FSI Interface Validation Experimentation

- Drop test - comparing test performed to simulation.

Test



Simulation

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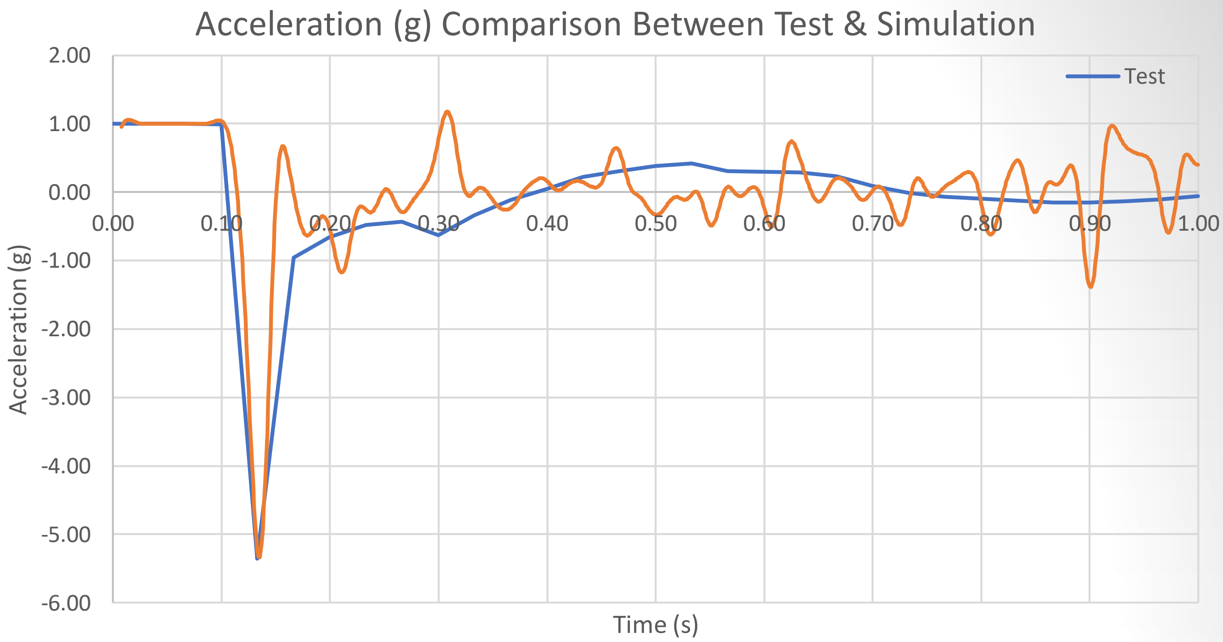
FSI Interface Validation Experimentation

- Drop test - comparing test performed to simulation.



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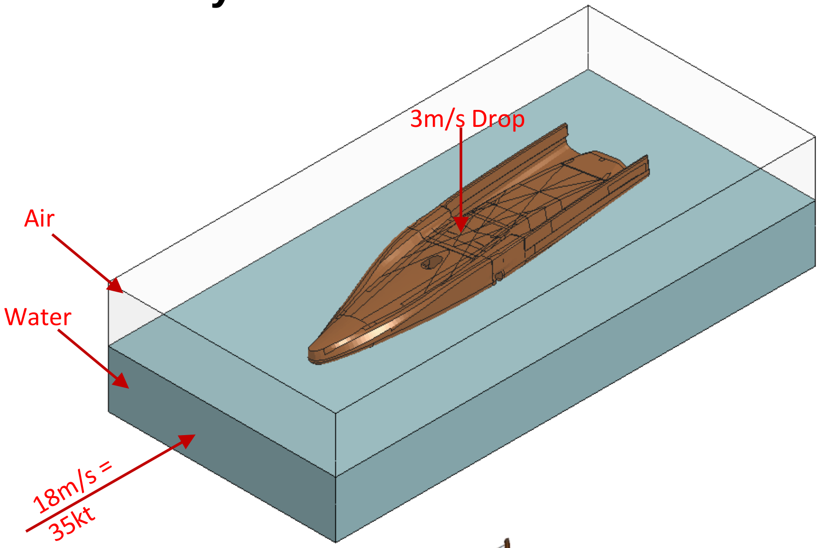
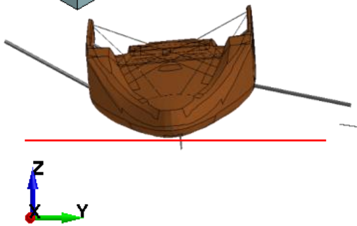
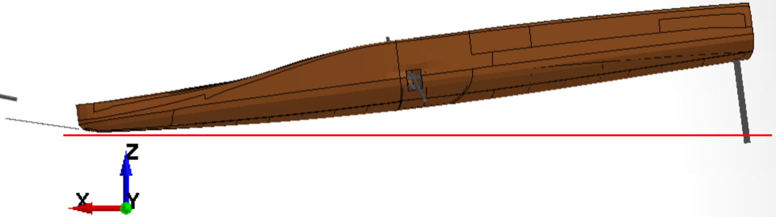
Preliminary Studies Model Build and Setup



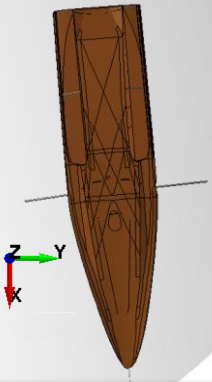
- Composite definitions were taken from existing NASTRAN model
- A constant flow of 35kt was applied to the water, while outer boundaries were constrained in appropriate DOF's.
- The yacht was set to impact the water at a vertical velocity of 3m/s.



Front View
5° Roll



Side View
7° Pitch



Top View
5° Yaw

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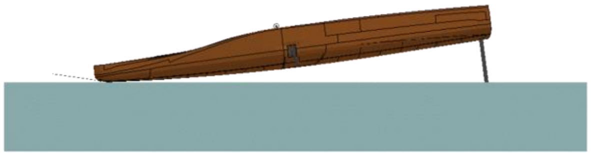
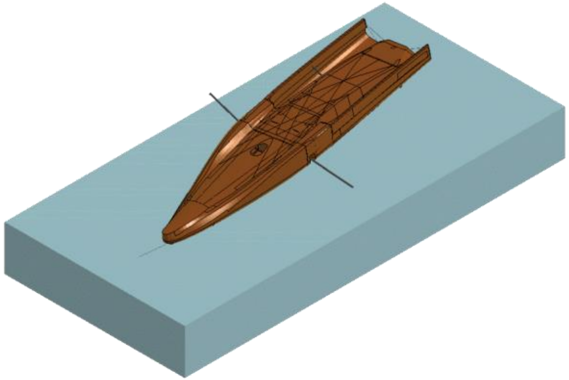
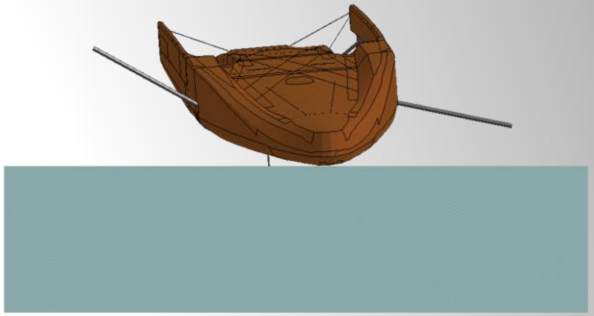
Preliminary Studies - animations of the yacht impacting the water.



Side View



Isometric View



Front View

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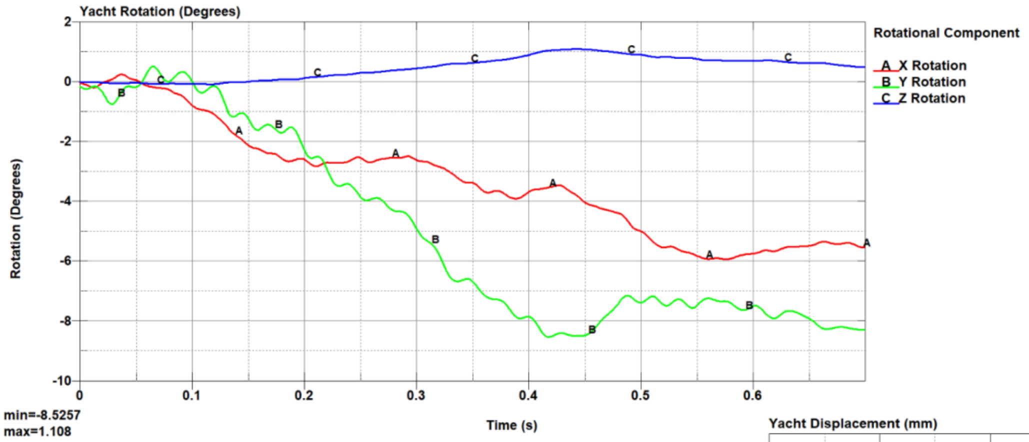
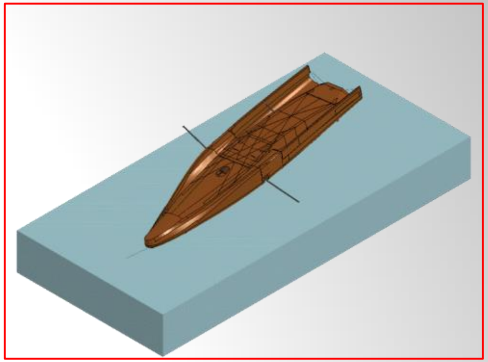
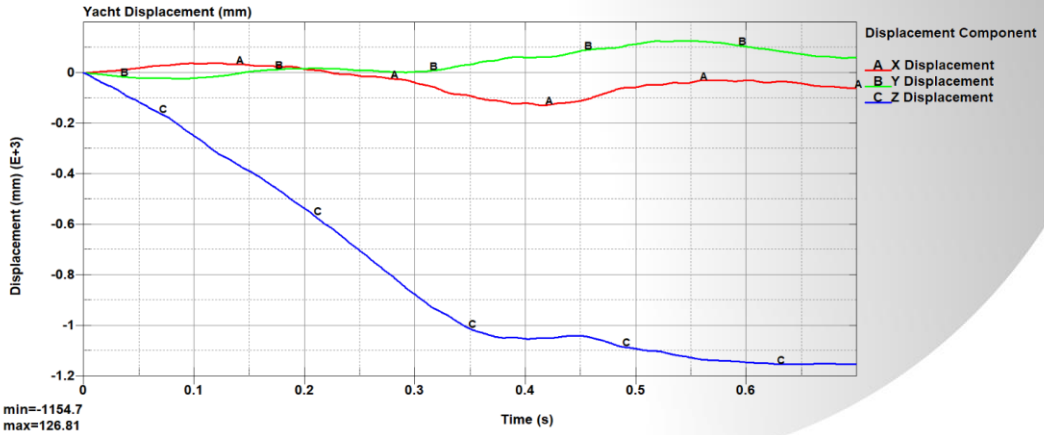
Preliminary Studies Results - rotation and displacement of the yacht CoG







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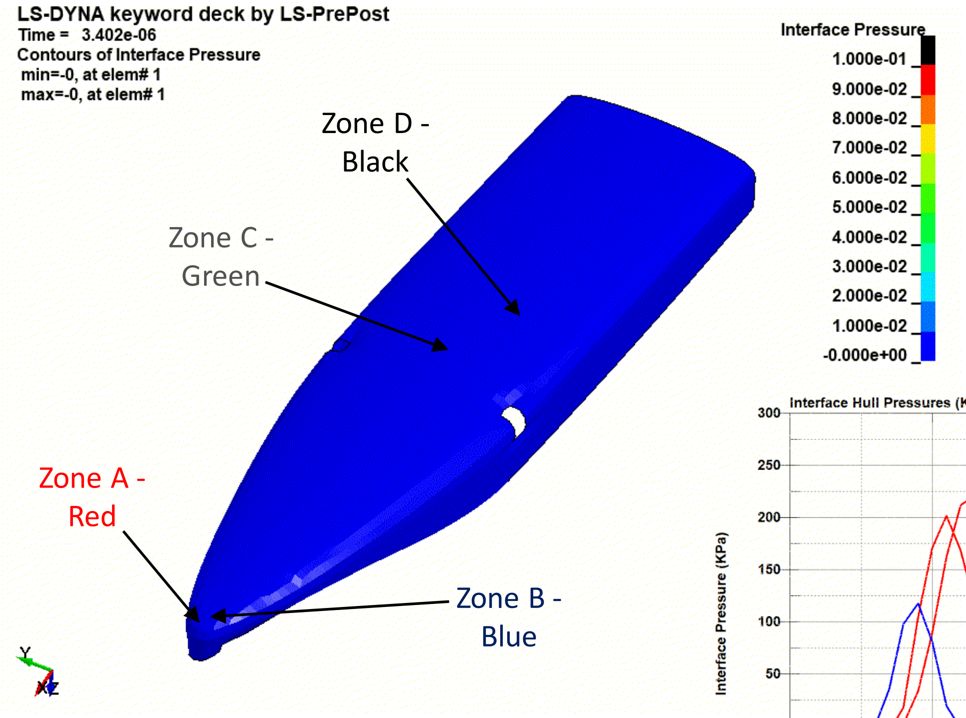
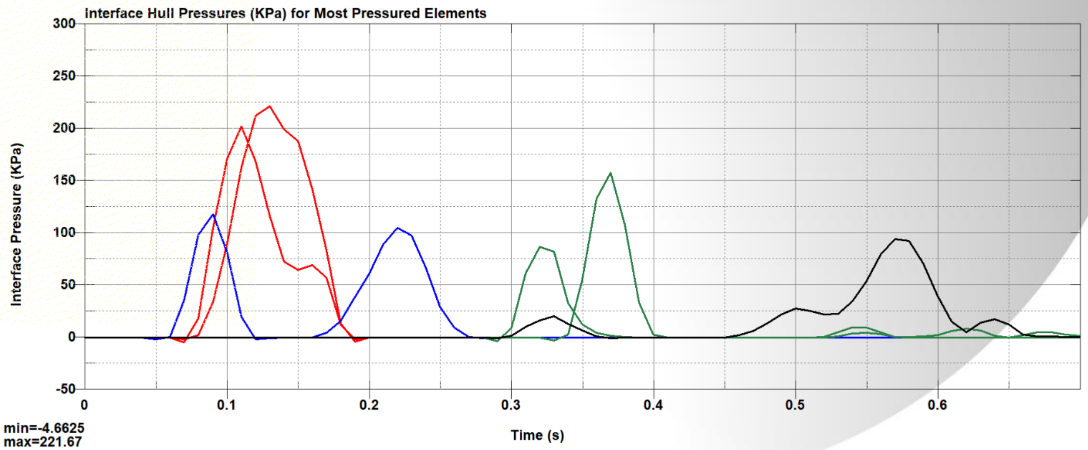
Preliminary Studies Model Results - hull pressure distribution





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Preliminary Hull Studies Summary

- An FSI model was developed to simulate wave slam of an AC75 class yacht.

- Hull pressures were assessed, showing peaks of ~200KPa, however most areas experience pressure much below this value.

- The effect of hull stiffness to pressures suggest that although pressures reduce in some areas with a decrease in stiffness, the peak pressures found during initial impact do not change significantly.

- Certain parameters and modelling methods were found to be important for wave slam simulation in FSI.
    - Output of interface pressures varies significantly to nodal pressures.
    - Penalty factors help in achieving a smoother pressure propagation.

- Although there is confidence in the existing model, there was room to develop the model for improved accuracy.
    - Higher INTFOR file output frequency.
    - COG of the yacht did not perfectly match provided data.
    - Slight leakage was found during simulation. This is a numerical effect where a small percentage of fluid leaks through the hull surface interface.

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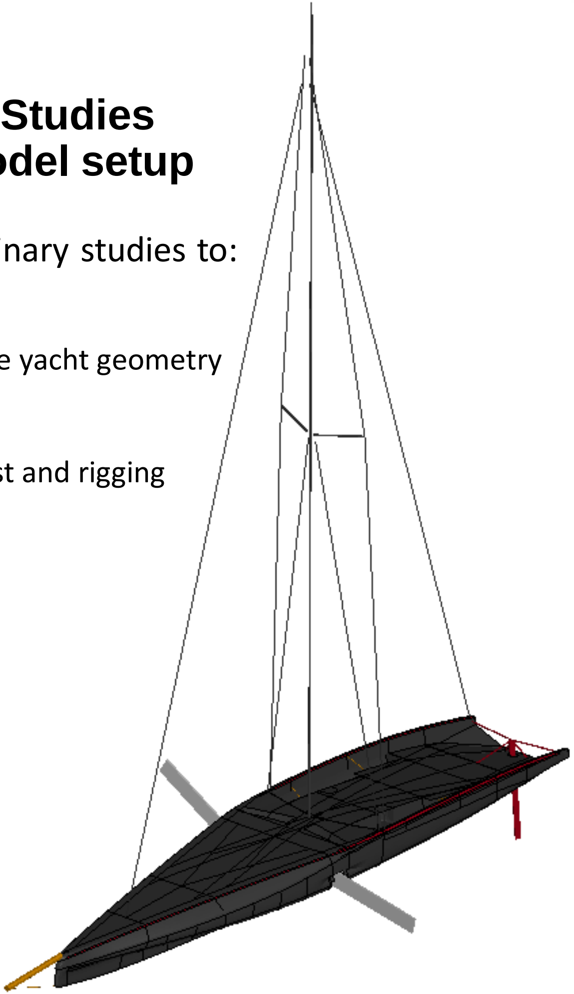
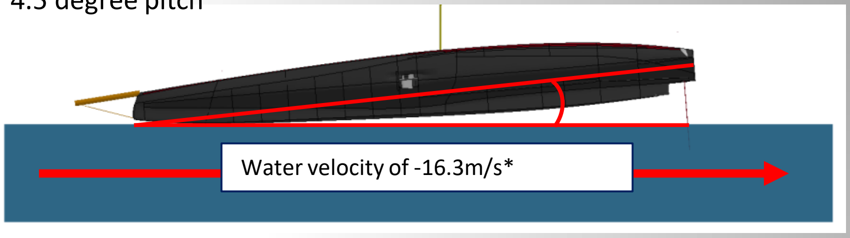
Refined Hull Studies
Aims and model setup

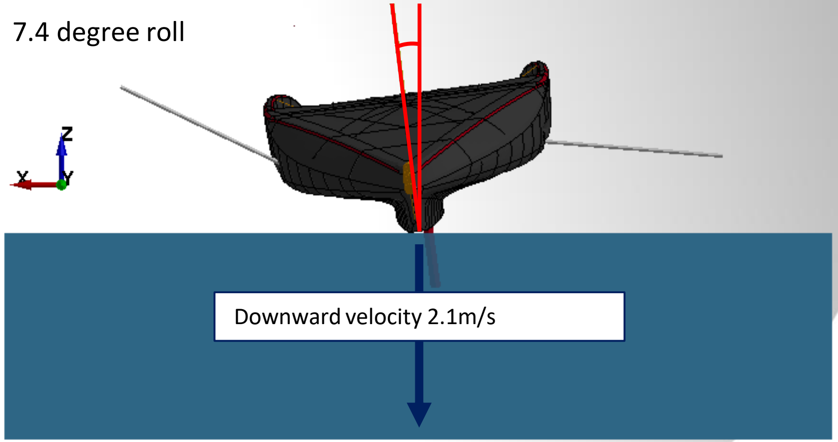
- Extend the preliminary studies to:
  - Analyse the race yacht geometry
  - Include the mast and rigging



4.5 degree pitch



7.4 degree roll



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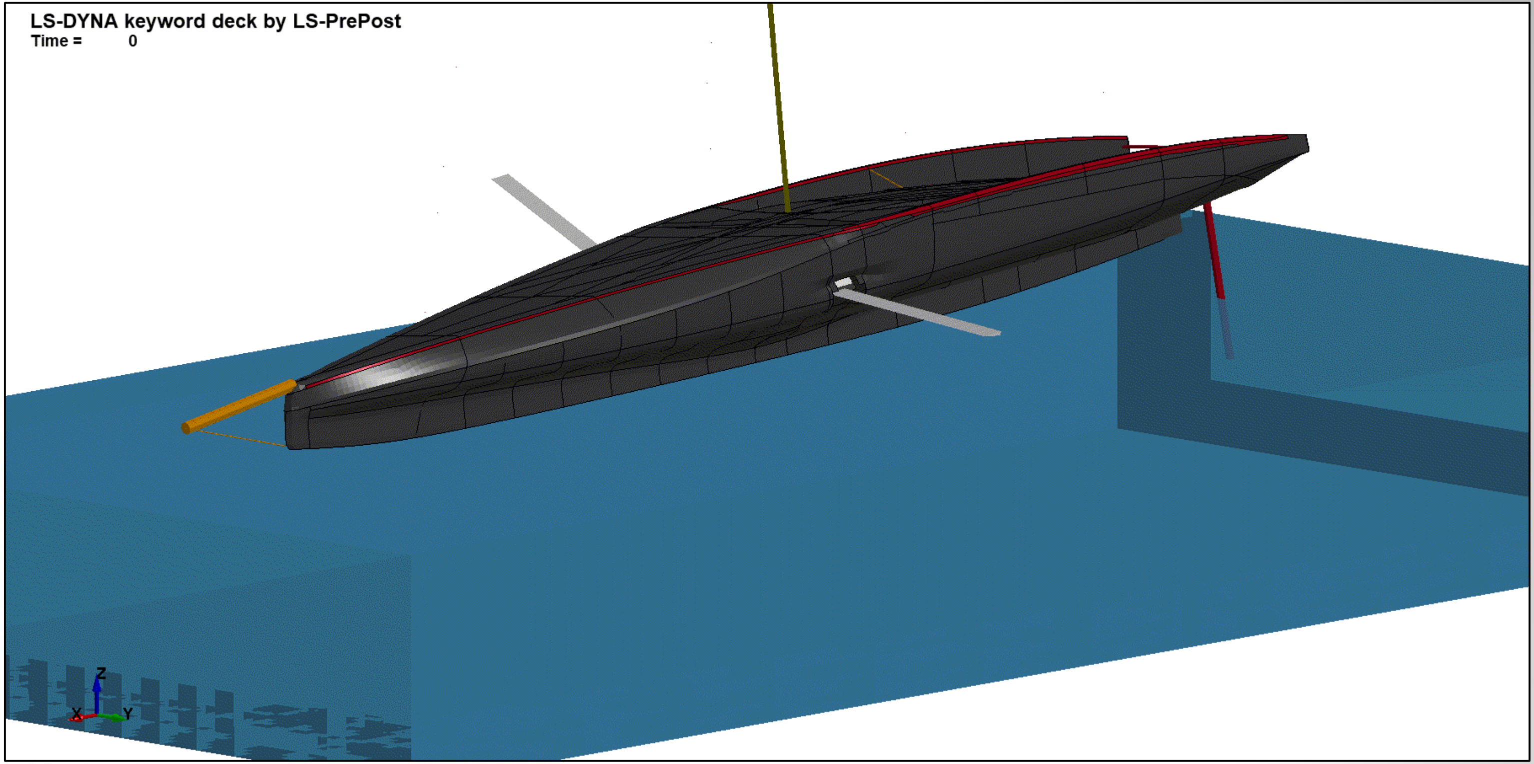
Refined Hull Study Results – Slam ISO View



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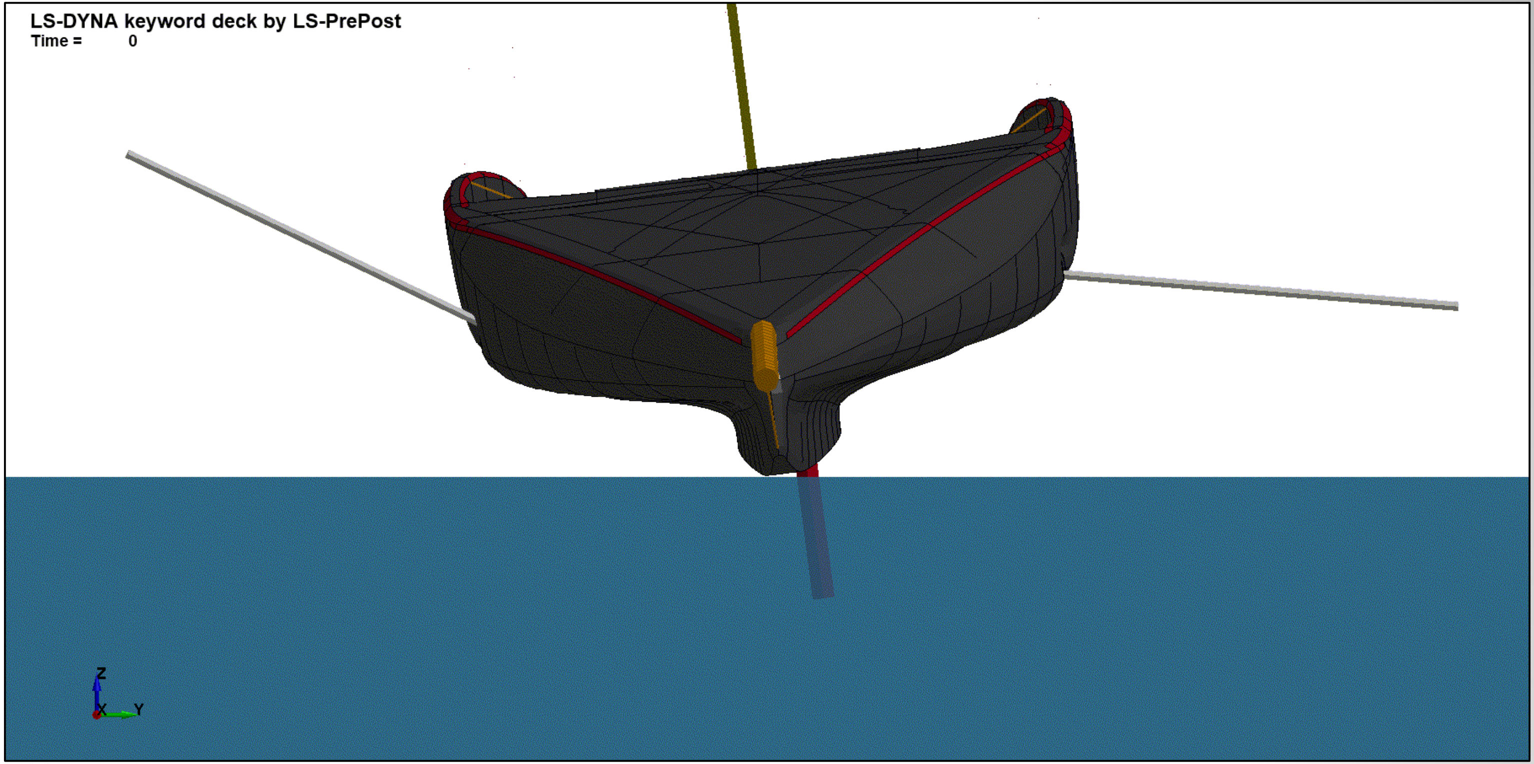
Refined Hull Study - Results – Front View



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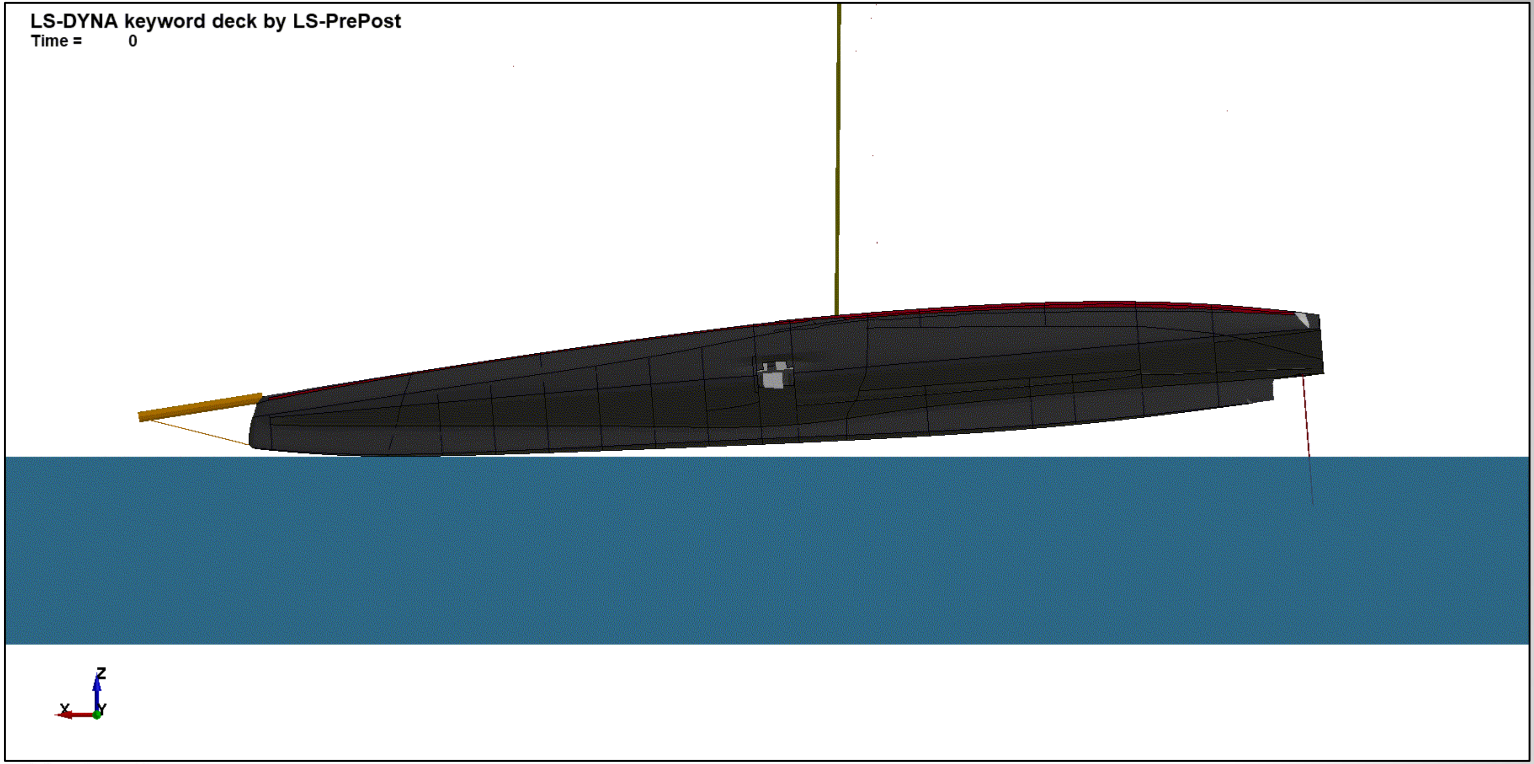
Refined Hull Study - Results – Slam Side View



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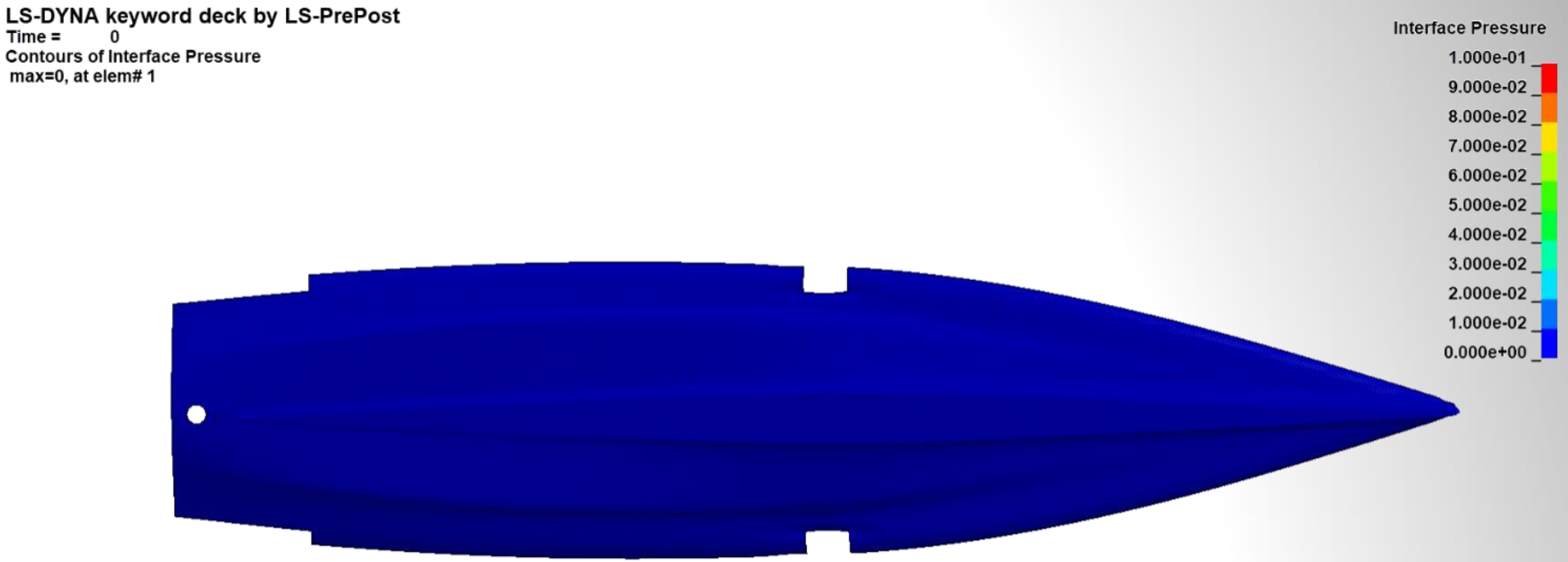
Refined Hull Study - Results – Hull Pressure



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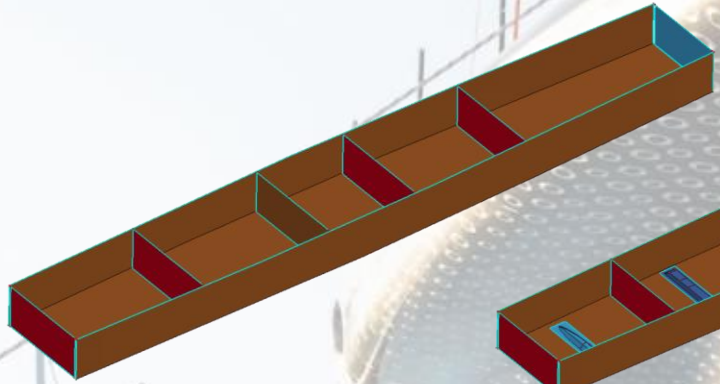
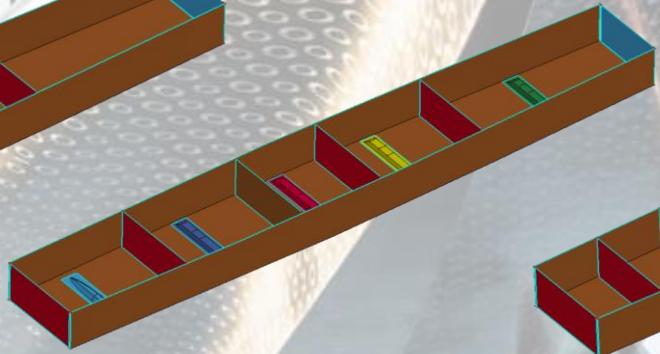
Bustle Optimisation – aims and model setup

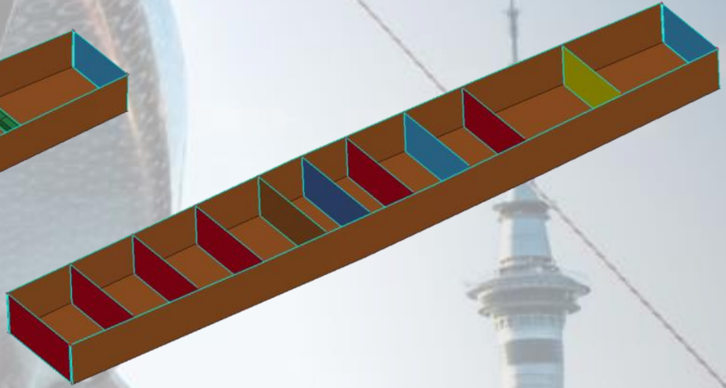
- Extend the previous work to assess the hull bustle in isolation and explore a series of design concepts which would best suit pressure management of the hull pressure.



Initial configuration



Stiffener configuration



Additional bulkhead configuration

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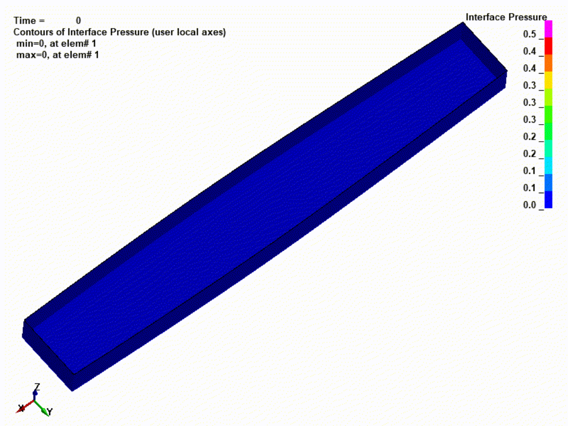
Bustle Optimisation – Pressure Results – Initial Strain, Deceleration

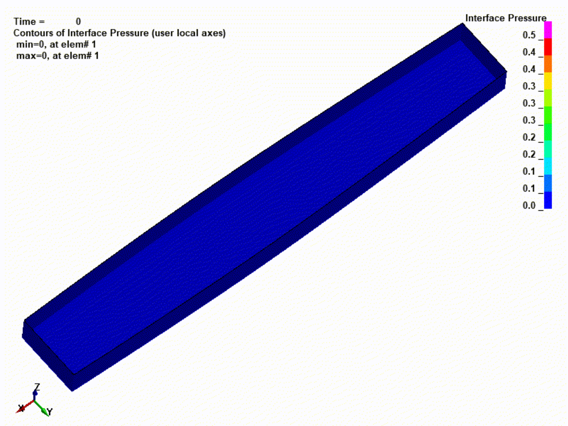
Initial Design

Peak Pressure = 1.09MPa



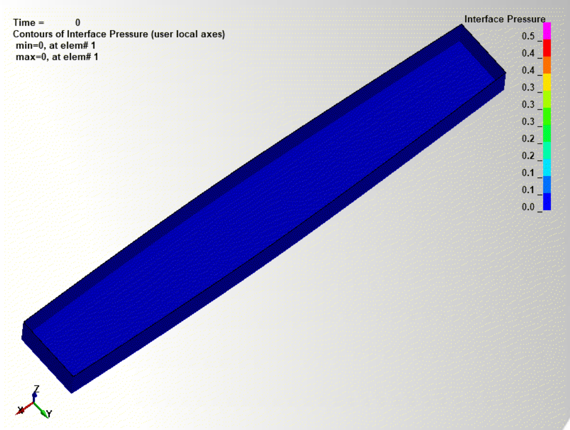
Additional Bulkheads

Peak Pressure = 2.04MPa



Stiffener Design

Peak Pressure = 1.88MPa



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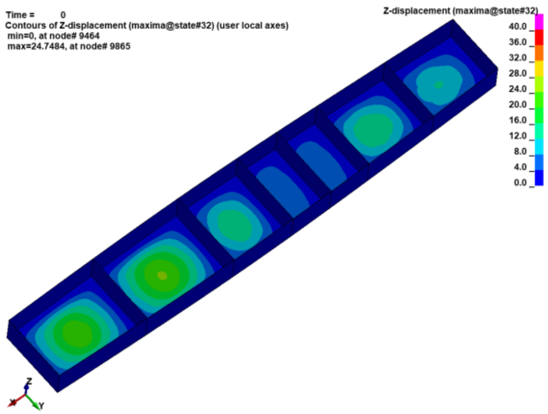
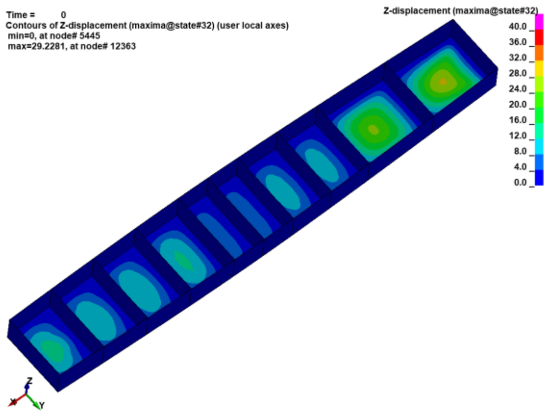
Bustle Optimisation – Initial Strain, Deceleration

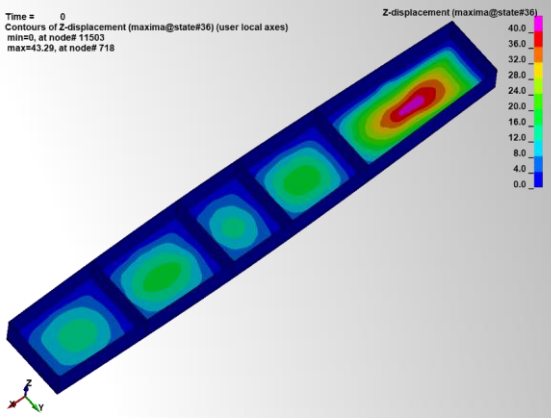
Initial Design



Additional Bulkheads



Stiffener Design



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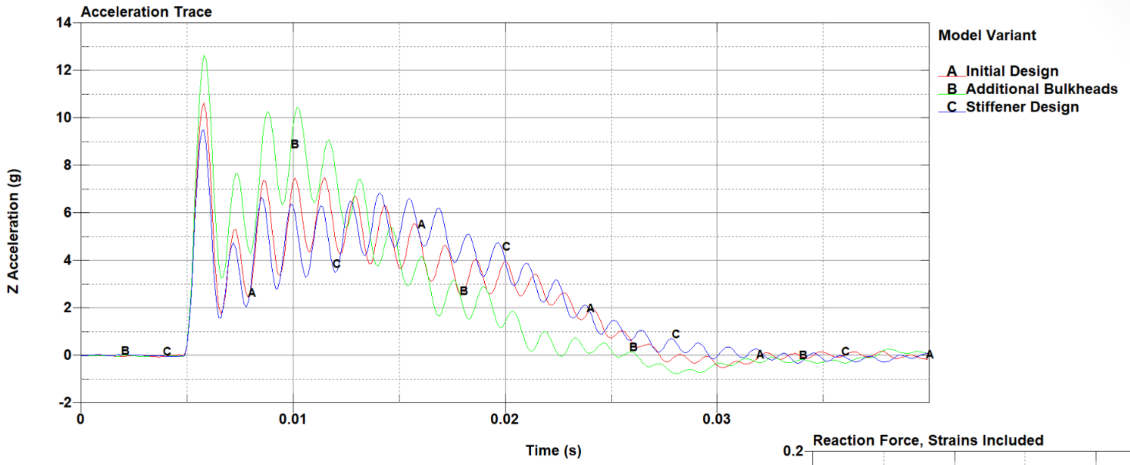
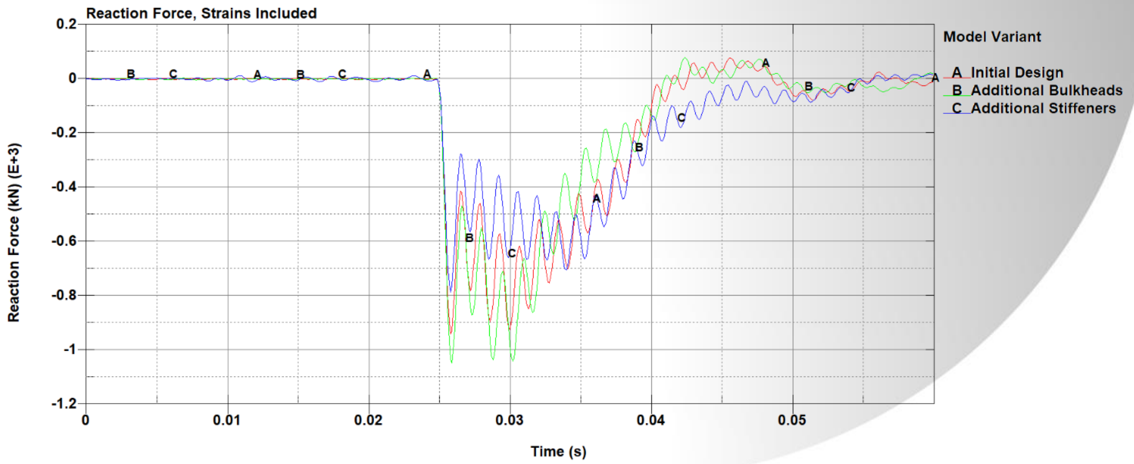
Bustle Optimisation – acceleration and reaction force





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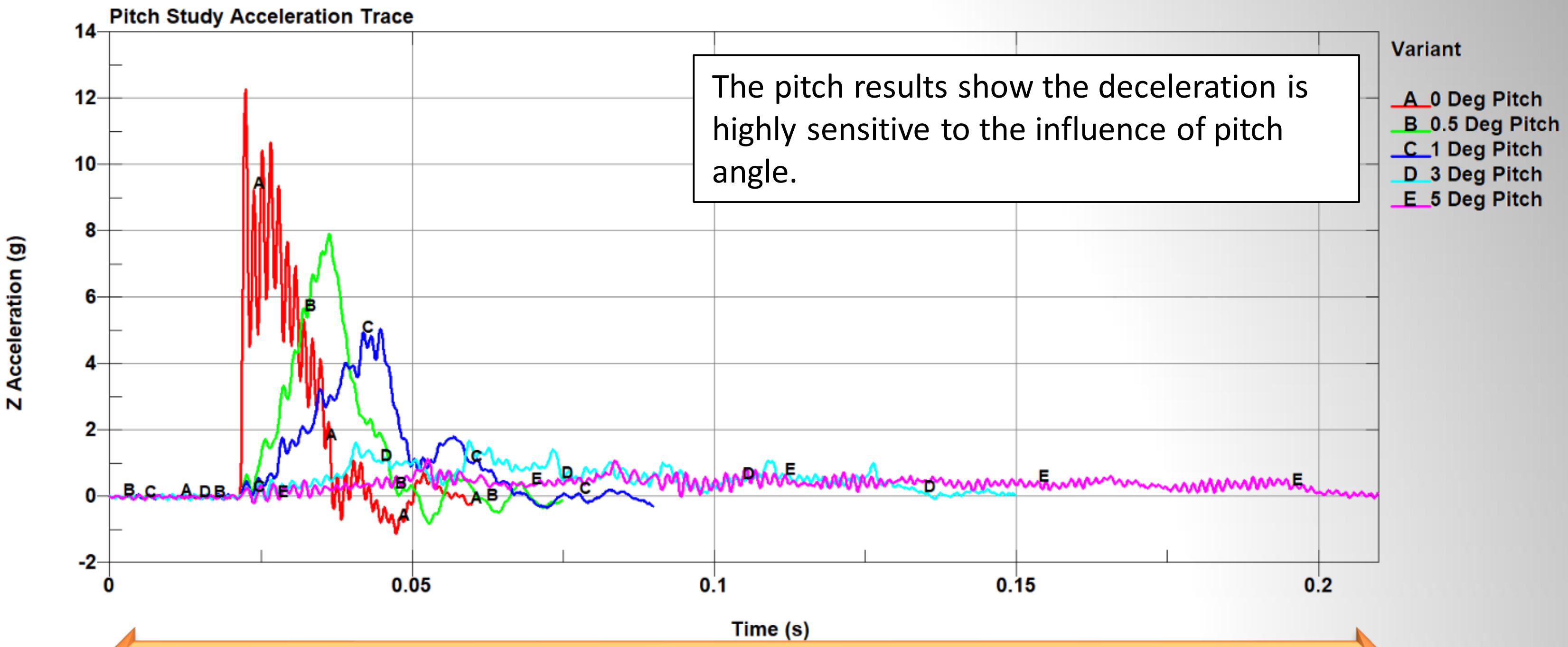
Bustle Optimisation – deceleration vs pitch angle



The pitch results show the deceleration is highly sensitive to the influence of pitch angle.

Longer time duration (200ms) due to larger pitch angle

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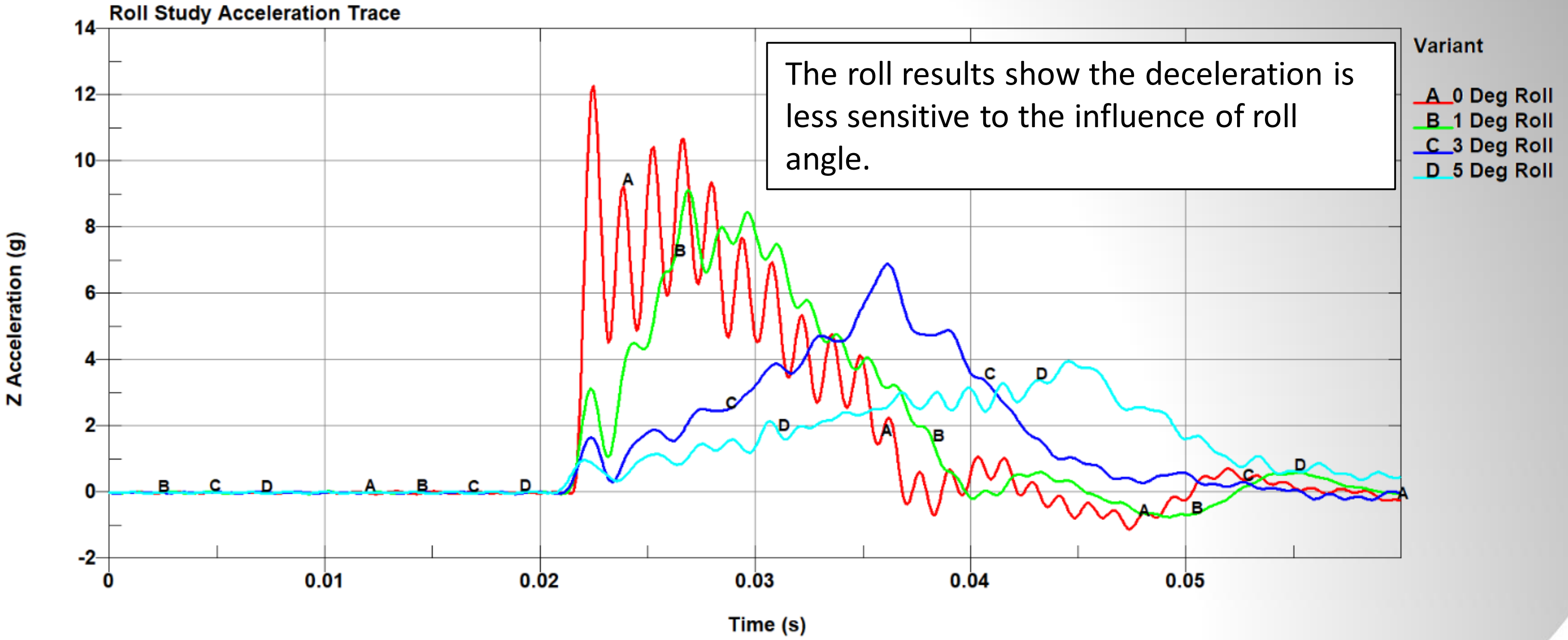
Bustle Optimisation – deceleration versus roll angle



The roll results show the deceleration is less sensitive to the influence of roll angle.

Shorter time duration (60ms)

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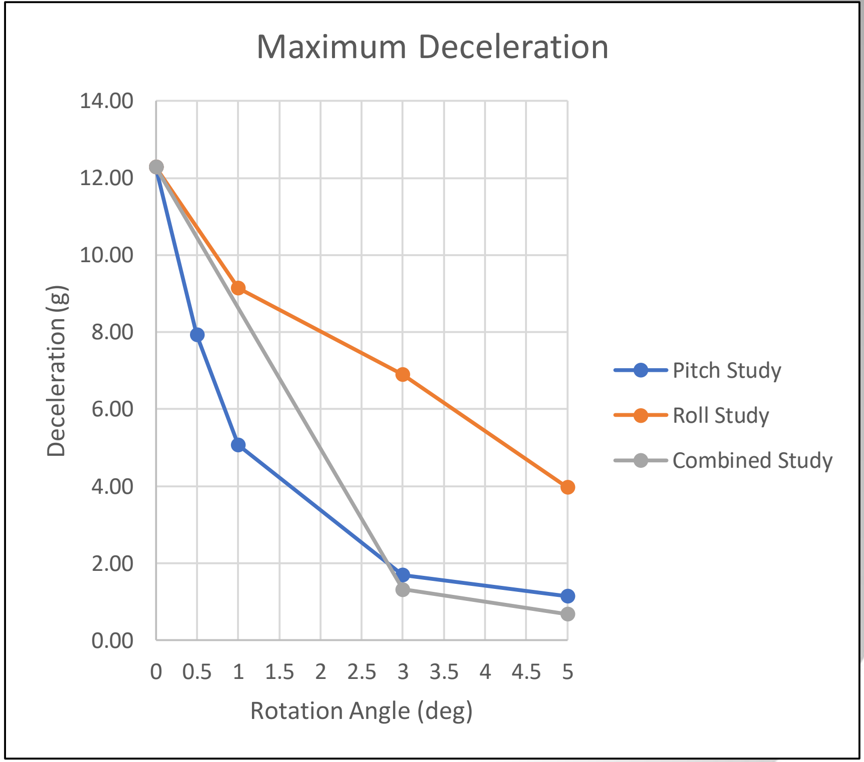
Bustle Optimisation – Maximum Deceleration

- Review of the maximum deceleration observed from each simulation highlights that both the pitch and roll angles have a very significant influence.
- Pitch is observed to have the strongest influence, which is to be expected.
- The angle of impact strongly governs the amount of bustle surface that impacts the water at the same time, therefore, controlling the instantaneous peak force applied.



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Bustle Optimisation – Pitch Sensitivity Pressure Animations

MPa

0° 0.5° 1° 3° 5°

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Application to commercial vessels

- BAR Technologies – Crew Transfer Vessel (CTV)

  - Foil assisted – efficient with enhanced stability (active roll control)
  - Proa concept – non-traditional, minimal in-service experience/data
  - Enhanced seas keeping allows for higher speeds for given conditions than regular vessels
  - Weight reduction is a key driver
  - Limited choice of materials

  - Larger dynamic loads – essential to understand the impact of these loads
  - Ideal opportunity to leverage advanced analysis techniques to develop a better understanding of the structural response

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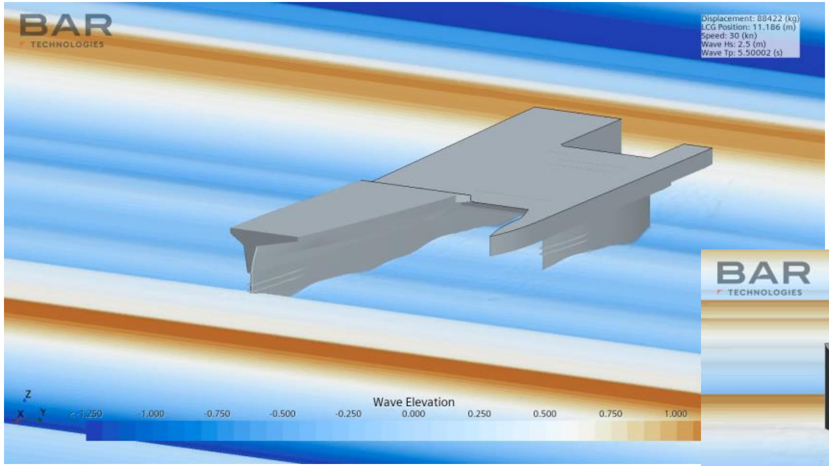
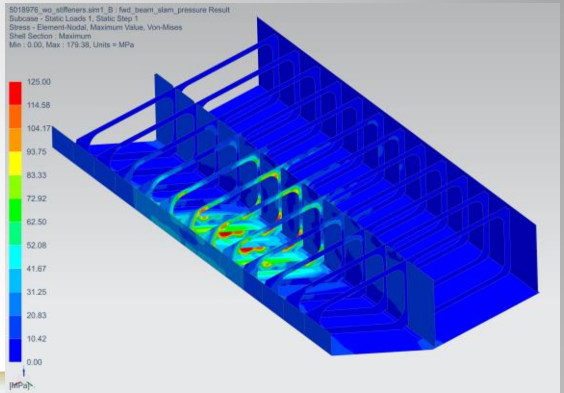
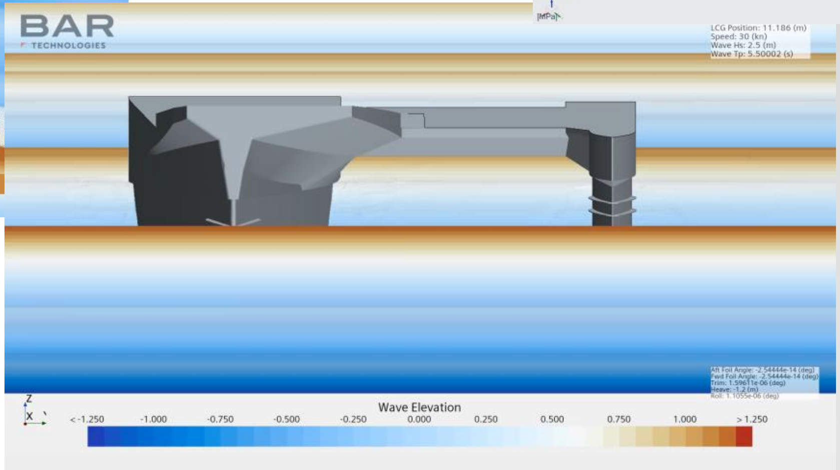
Application to commercial vessels

- typical seakeeping simulations - show potential for slamming loads







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Conclusions

- The use of simulation for predicting the response of hull structure to highly dynamic loading was investigated
- The analysis methodology is computationally demanding and requires experimentation and time to develop confidence
- Ultimately it was found that the methodology provided valuable inputs into the design of the hull structure
- The approach was successfully used to design key aspects of INOES Team UK’s race yacht for AC 36 enabling a light weight solution leading to the benefit of performance
- The methodology and learning are now being applied to commercial vessels to benefit new technologies leading to improved efficiency and performance

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Thank You

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