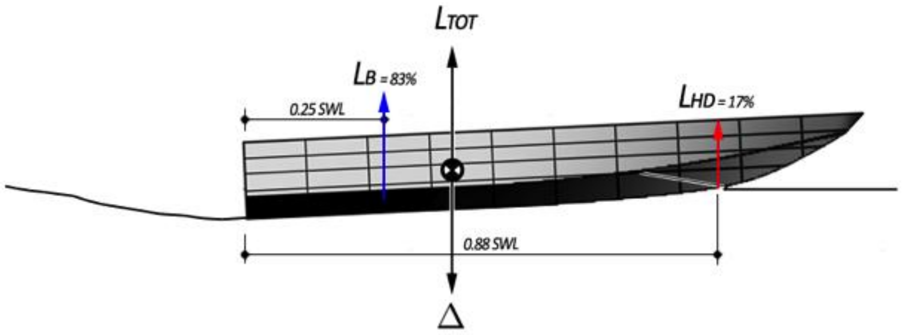
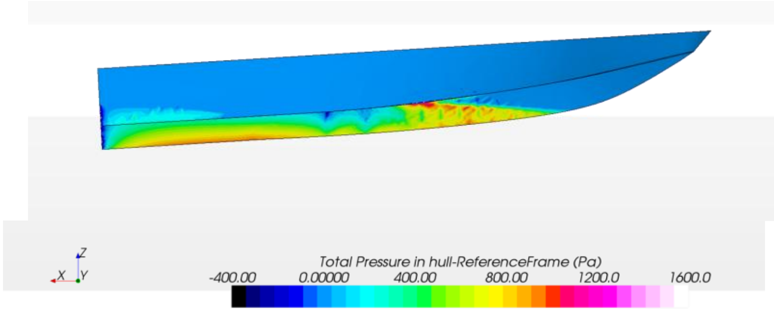
THE PERFORMANCE OF PLANING HULLS IN TRANSITION SPEEDS

BY DOYOON KIM

UNIVERSITY OF SOUTHAMPTON

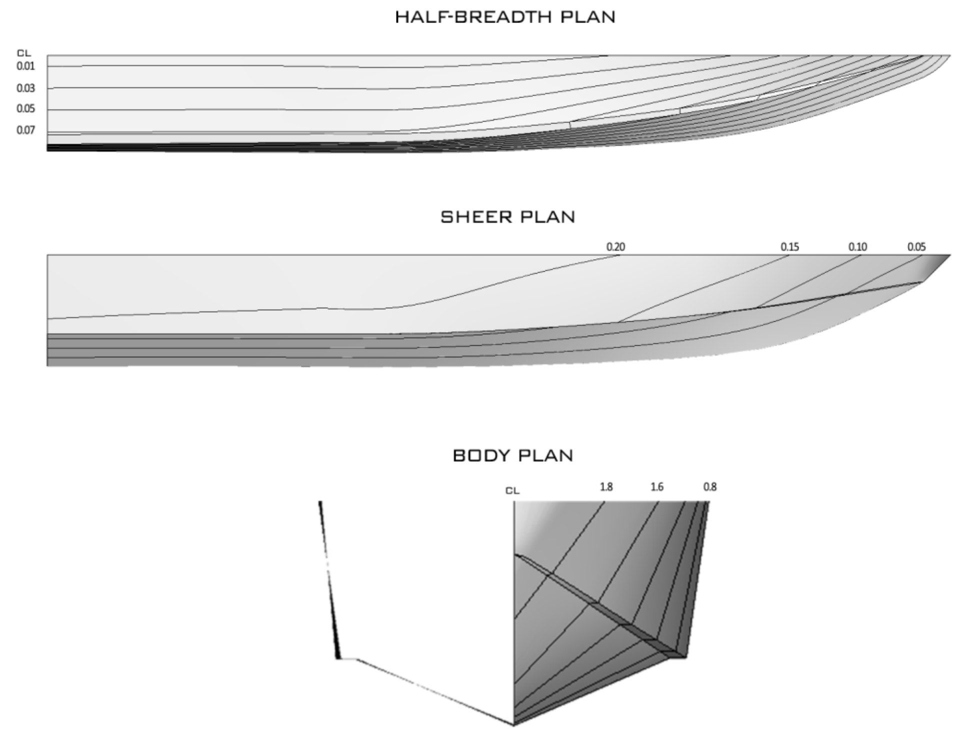
LIST OF CONTENTS





AIM & OBJECTIVE

- INVESTIGATE TRADE-OFF PHENOMENA OF PLANING HULLS IN TRANSITION SPEEDS
  - Resistance, pitch and heave motions
  - TRADE-OFF between HYDROSTATIC & HYDRODYNAMIC support
- IMPROVE EXISTING NUMERICAL MODEL TO ESTIMATE PERFORMANCE OF PLANING HULLS
  - Better prediction of hull motions in intermediate speed regions
- Hull used for the present work
  - Simplified & averaged version of high speed planing craft: removed step and spray rails
  - Racing craft with surface piercing propeller
  - Design max. speed: over 70 knots
  - Prismatic section shape



Hydrodynamic phenomena of planing hulls

C_V	Manoeuvring mode	Note
$\simeq 0$	Displacement mode - Entire lift is by buoyant force	Hydrostatic state
~ 0.50	Hydrodynamic effects visualised - Immersed bow: trims up due to the development of the transverse wave system - Negative hydrodynamic lift	
$0.50 \sim 1.50$	Positive contribution to lift by hydrodynamic effects - Only slightly separated flow from the forward part of chine - Significant side wetting with immersed bow - At $C_V \simeq 1.0$ total planing lift is approximately equal to hypothetical buoyant force - Above $C_V > 1.0$ positive dynamic reaction increases rapidly	Measured resistance is considerably larger than that predicted by Savitsky's planing performance prediction method
$1.50 \sim 2.00$	Sufficiently large dynamic lift force observed - Hump trim: maximum trim occurs - Separation of the flow from the hard chine Significant rise of COF, positive trim and emergence of the bow	Good agreement between measured result and Savitsky's method
$2.00 \sim$	Bow may immerse again but little effect to total drag - Trim decreases again	Savitsky's method provides realistic results

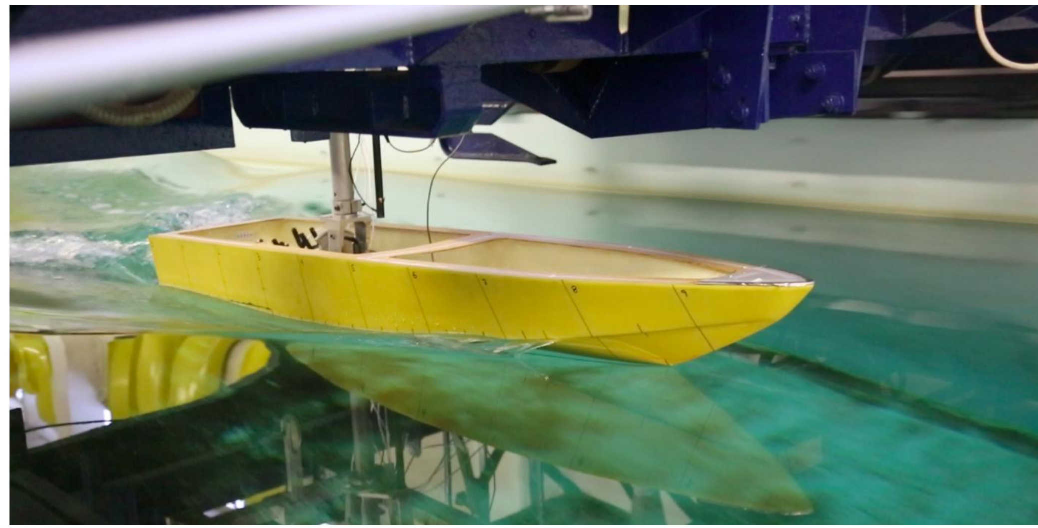
$$C_{L0} = \tau^{1.1}\left[0.0120\,\lambda^{1/2} + \frac{0.0055\,\lambda^{5/2}}{{C_V}^2}\right]$$

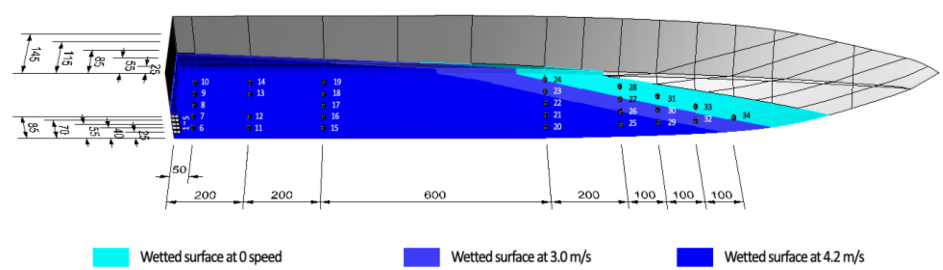
$$C_{L\beta} = C_{L0} - 0.0065\,\beta\,{C_{L0}}^{0.60}$$

$$C_p = \frac{l_p}{\lambda B} = 0.75 - \frac{1}{5.21\,\frac{{C_V}^2}{\lambda^2} + 2.39}$$

TOWING TANK TEST

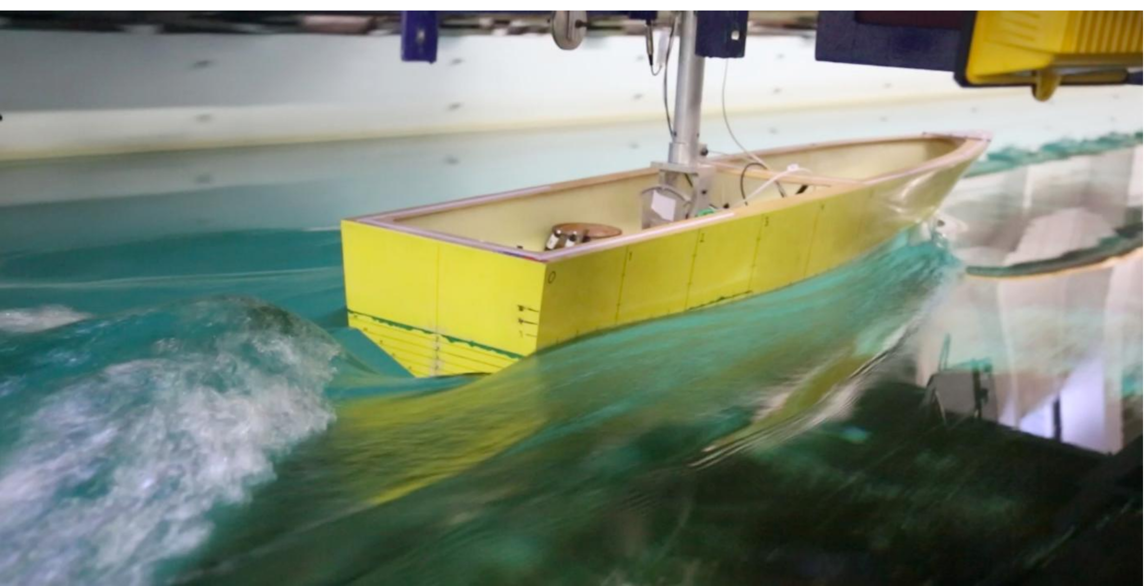
- OBJECTIVE: Primary means to investigate the performance of planing hulls
- Conducted in Solent towing tank in Southampton Solent University for three days
- Model
  - LOA 2.0 metre
  - Displacement 24.5 kg
  - GRP sandwich structure
- Measured: Speeds, Heave, Pitch, Resistance, Sideforce and Pressure on the hull
- Speed range: 1.0 m/s to 4.2 m/s (Froude Number 0.26 to 1.12)
- Speed interval: 0.4 m/s

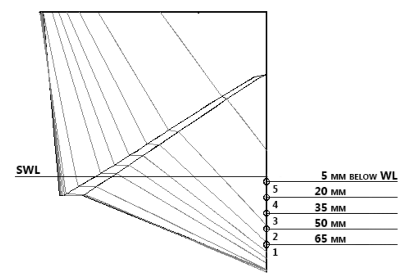


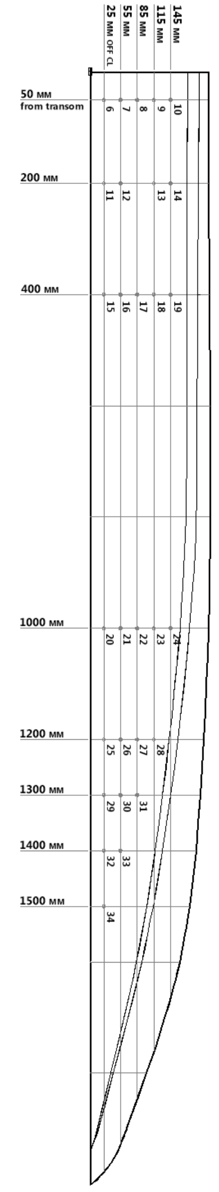


TOWING TANK TEST

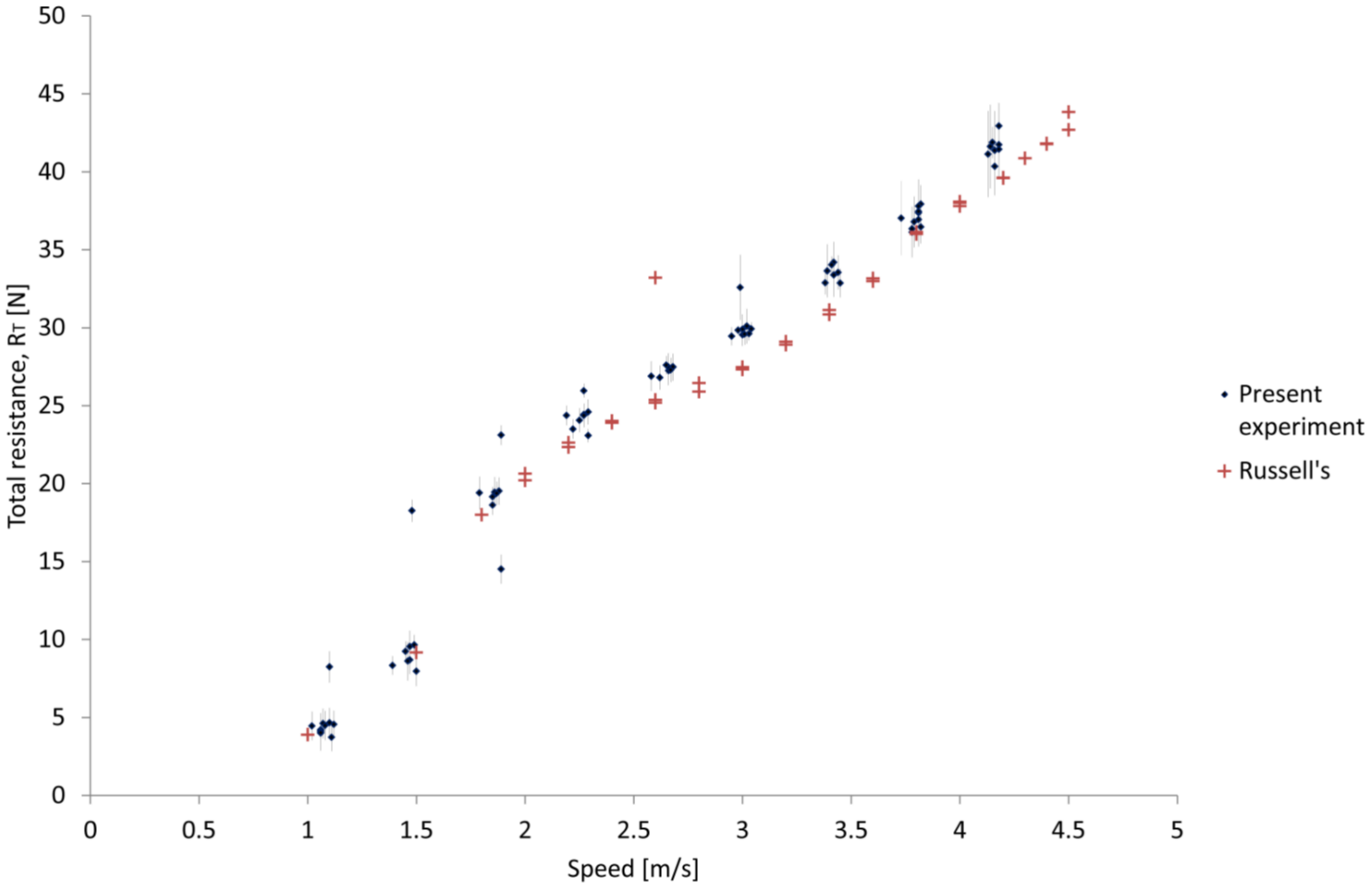
- Pressure measurement
  - 34 pressure tappings
  - 3 major regions: based on existing experimental data
    - 5 at transom
    - 14 at stern region
    - 15 at bow region
  - Pressure transducers (range: 0~5kPa)





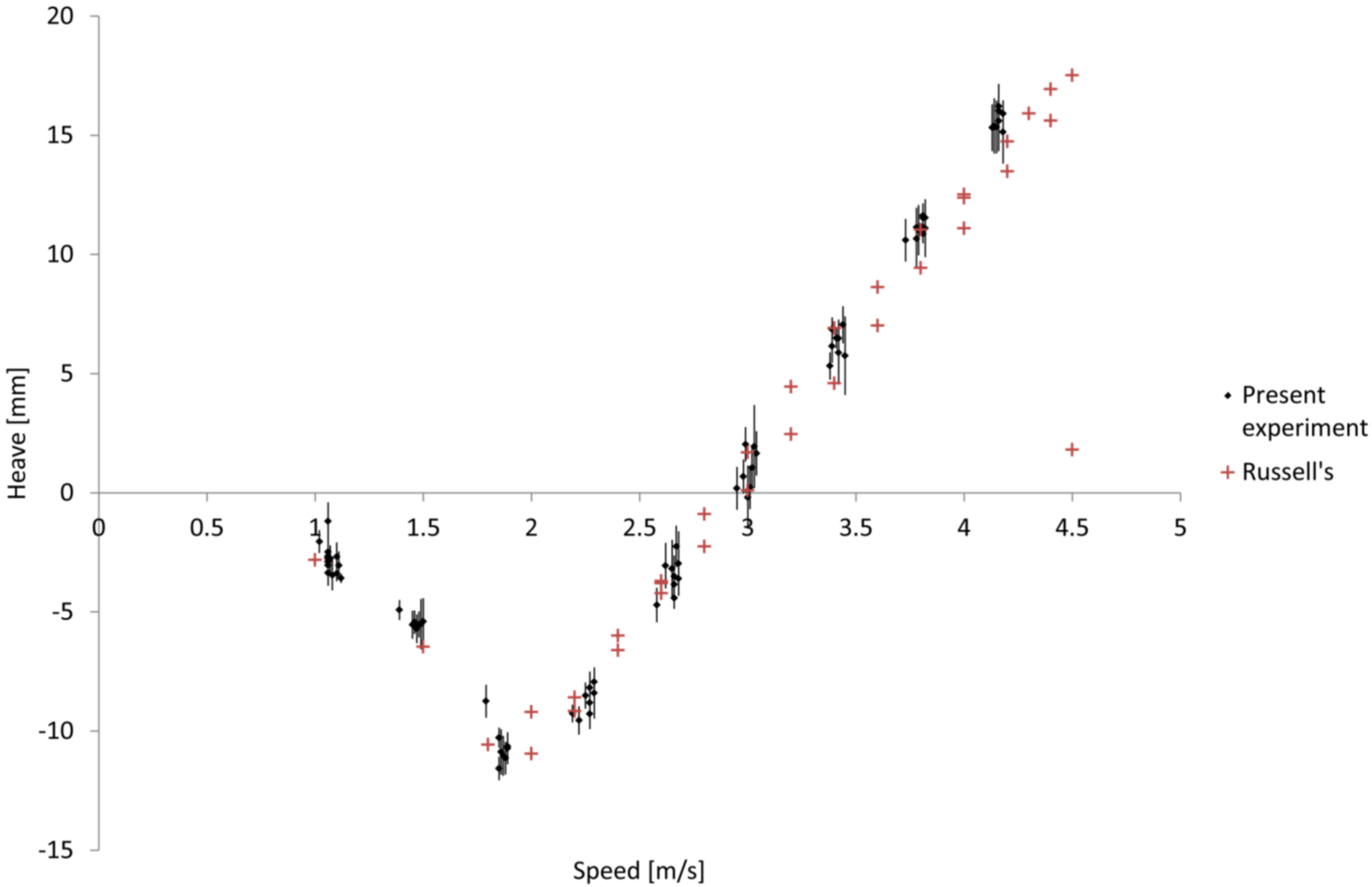


Results: Total resistance



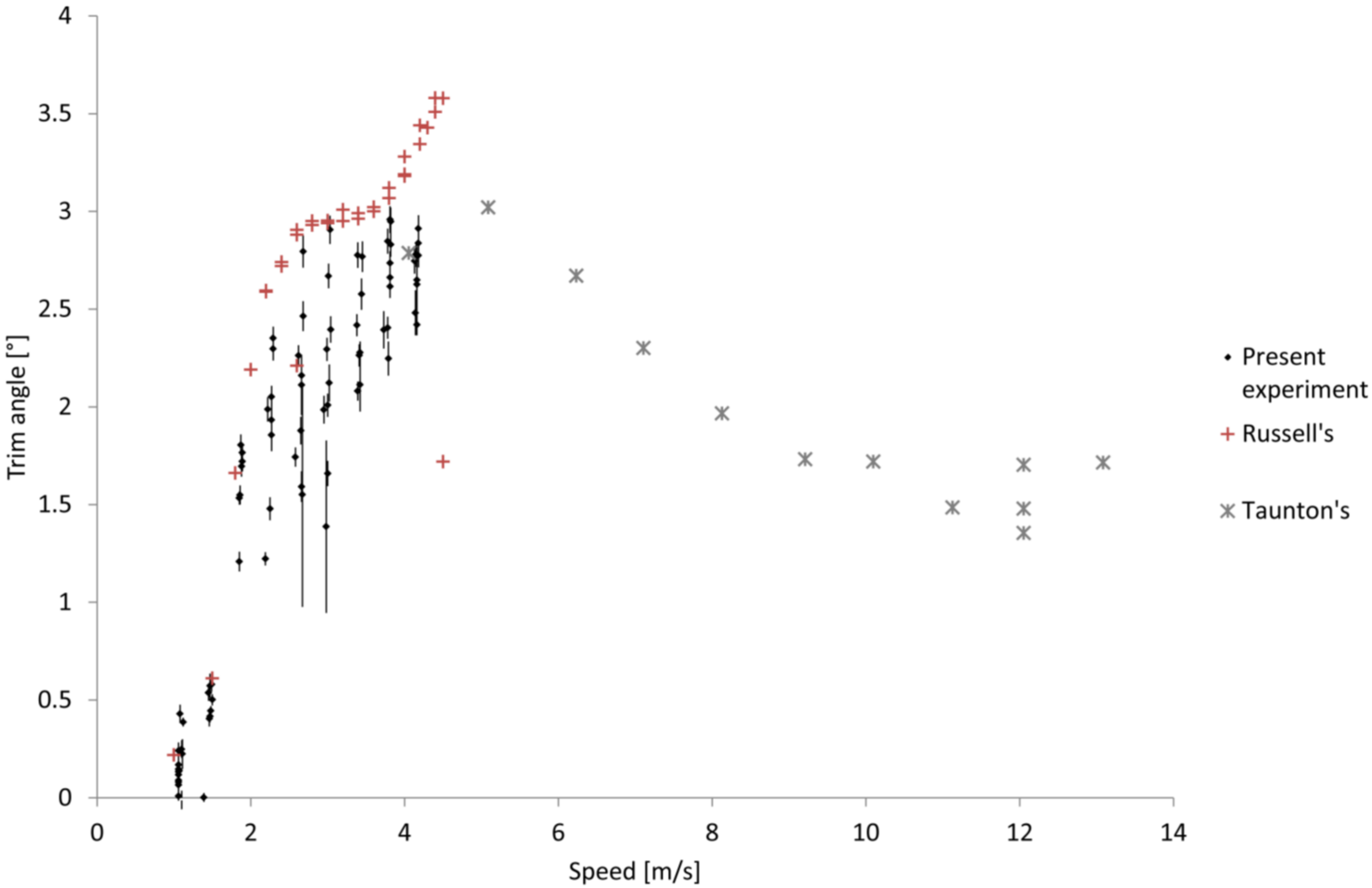
- Total resistance
  - Slightly higher resistance
  - assumed due to existance of pressure tappings and hydroelasticity of the hull model, i.e. hydroaging

Results: Heave (negative dynamic sinkage)



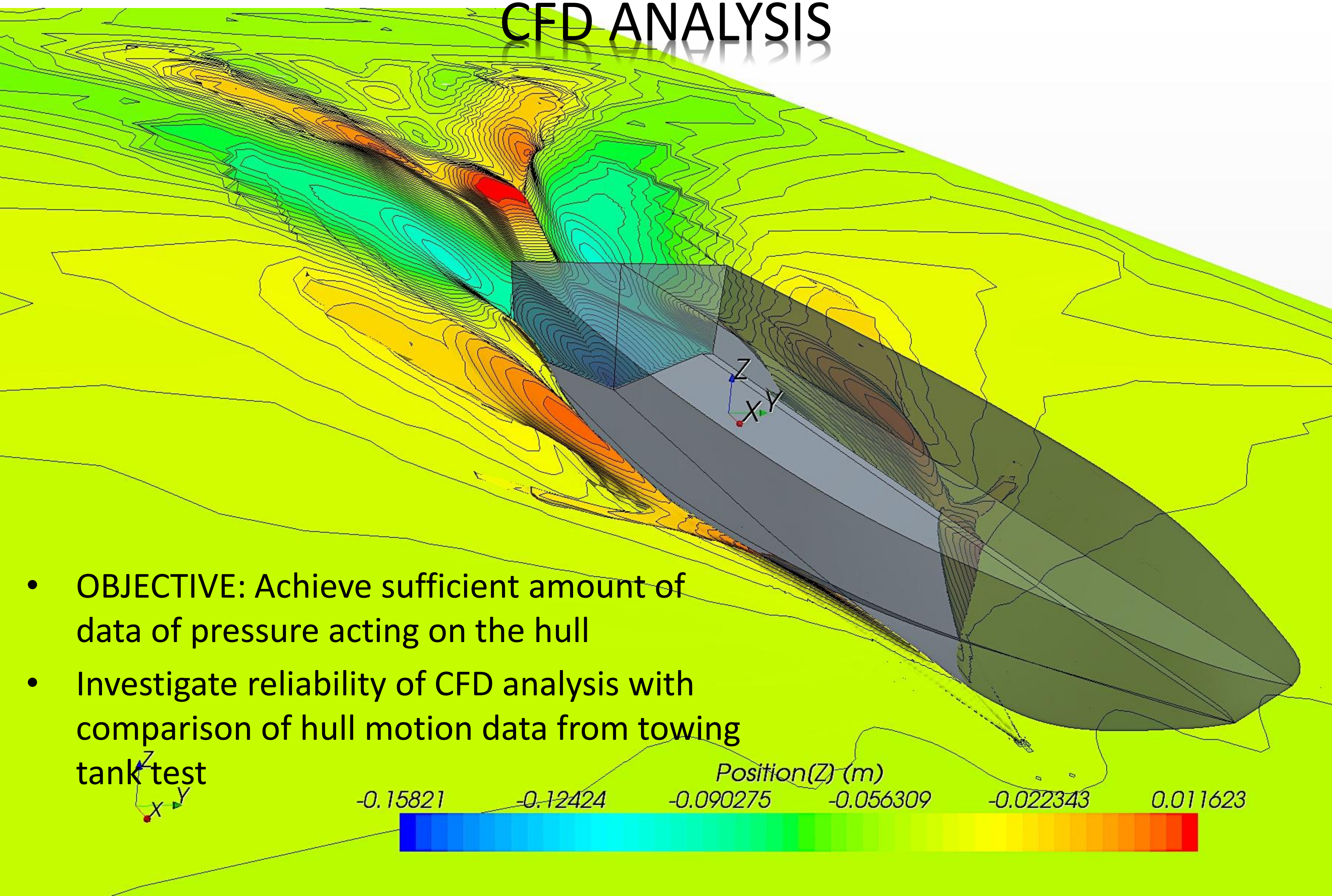
- Heave
  - Positive / negative sinkage lie in the range of uncertainty in measurement

Results: Trim



- Trim (or pitch)
  - Underestimation of trim in transition speeds
  - Assumed due to hydroelasticity and pressure tappings

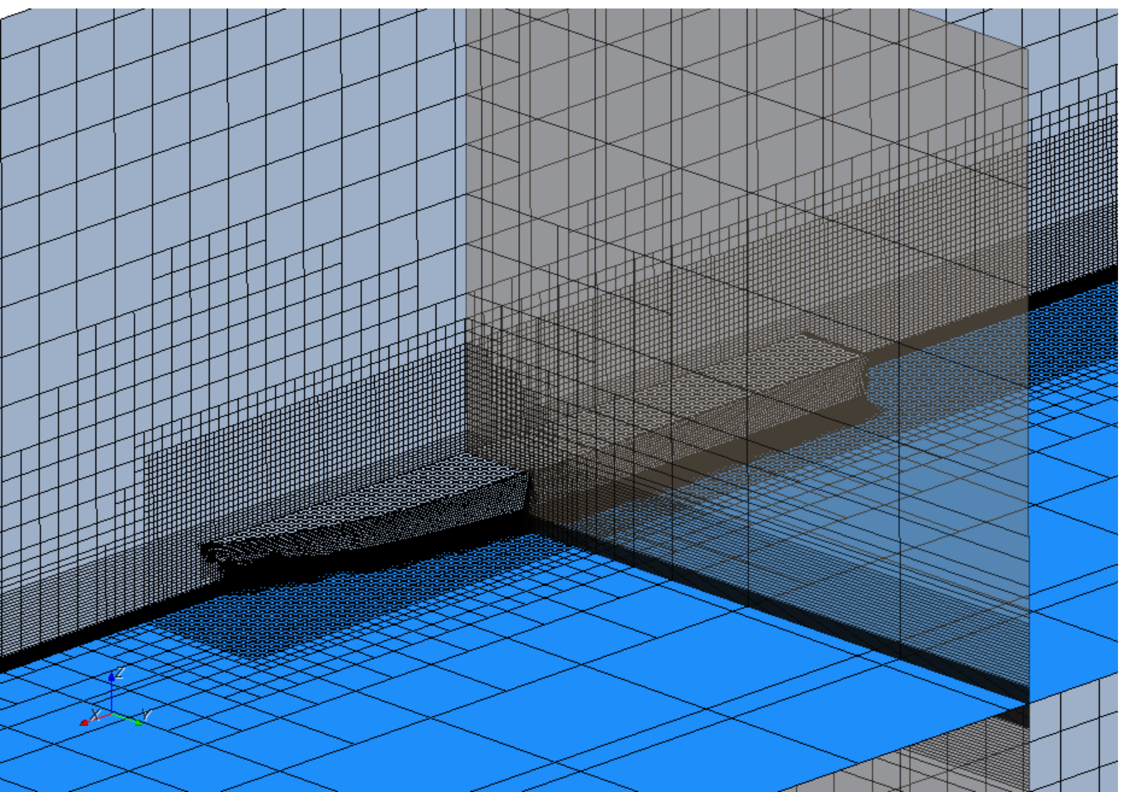
CFD ANALYSIS



- OBJECTIVE: Achieve sufficient amount of data of pressure acting on the hull
- Investigate reliability of CFD analysis with comparison of hull motion data from towing tank test

Mesh generation

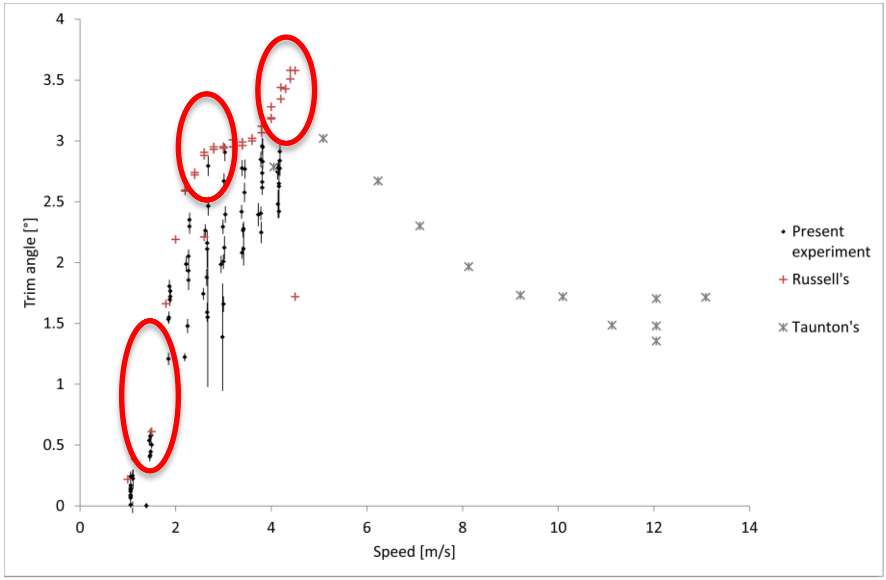
- Trimmer mesh with anisotropic density control
- Three grid conditions set: 0.5, 1.0 and 2.0 million
  - Parameter refinement ratio √2
- y+ setting: equivalent to 60 in three speeds respectively



Physics setting

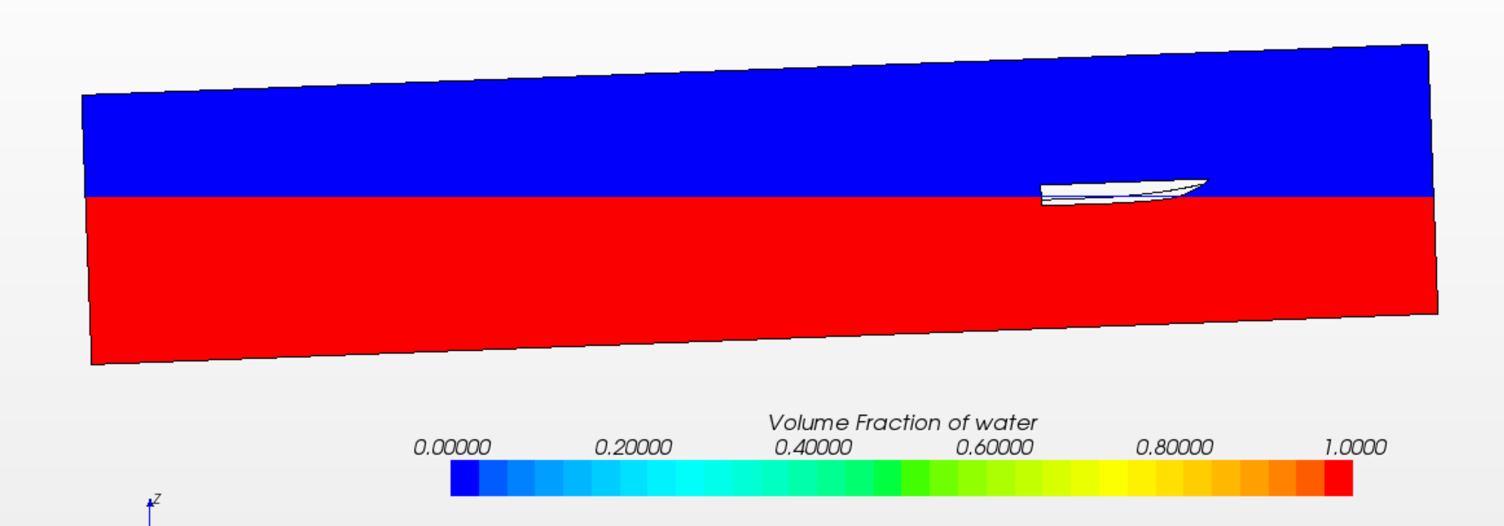
- Speed conditions: three distinct modes of planing hull's motions, i.e.
  - Lowest dynamic sinkage in displacement mode
  - Initiate planing in semi-displacement mode
  - Maximum trim angle in planing mode

V [m/s]	Cv	Fn_vol	Trim [degree]	Sinkage [mm]	R_T [N]
1.86	0.94	1.09	1.39	8.65	15.83
3.00	1.52	1.77	2.86	-3.68	25.67
4.16	2.11	2.45	3.31	-21.17	32.22



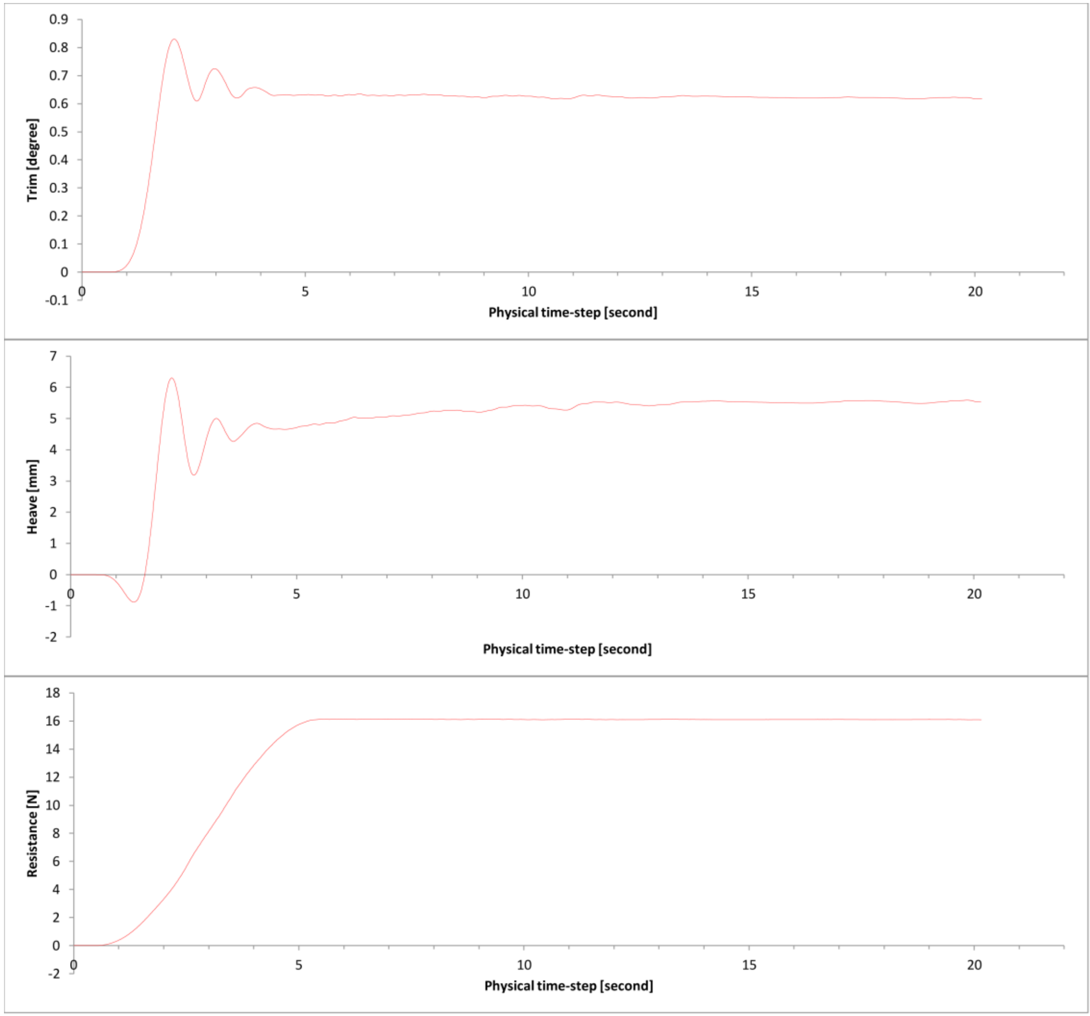
Physics setting

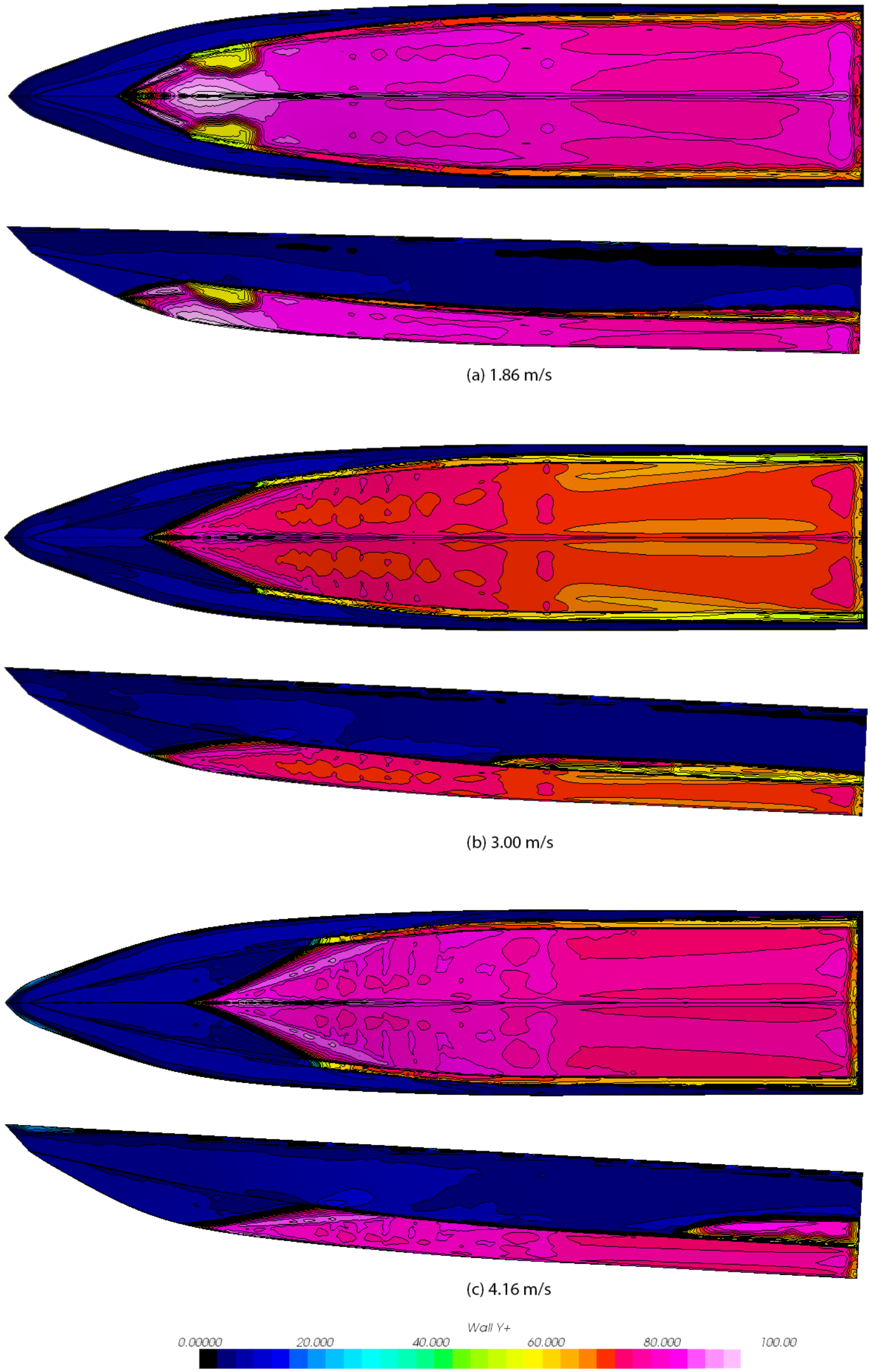
- Turbulent model : κ−ω Shear Stress Transport (SST)
- 2 DOF - pitch & heave, unsteady transient simulation
- Dynamic Fluid Body Interaction (DFBI) module applied
- Multi-phase volume of fluid method
- Each speed case was set in experimental trim & heave condition
  - For faster convergence



Physics setting

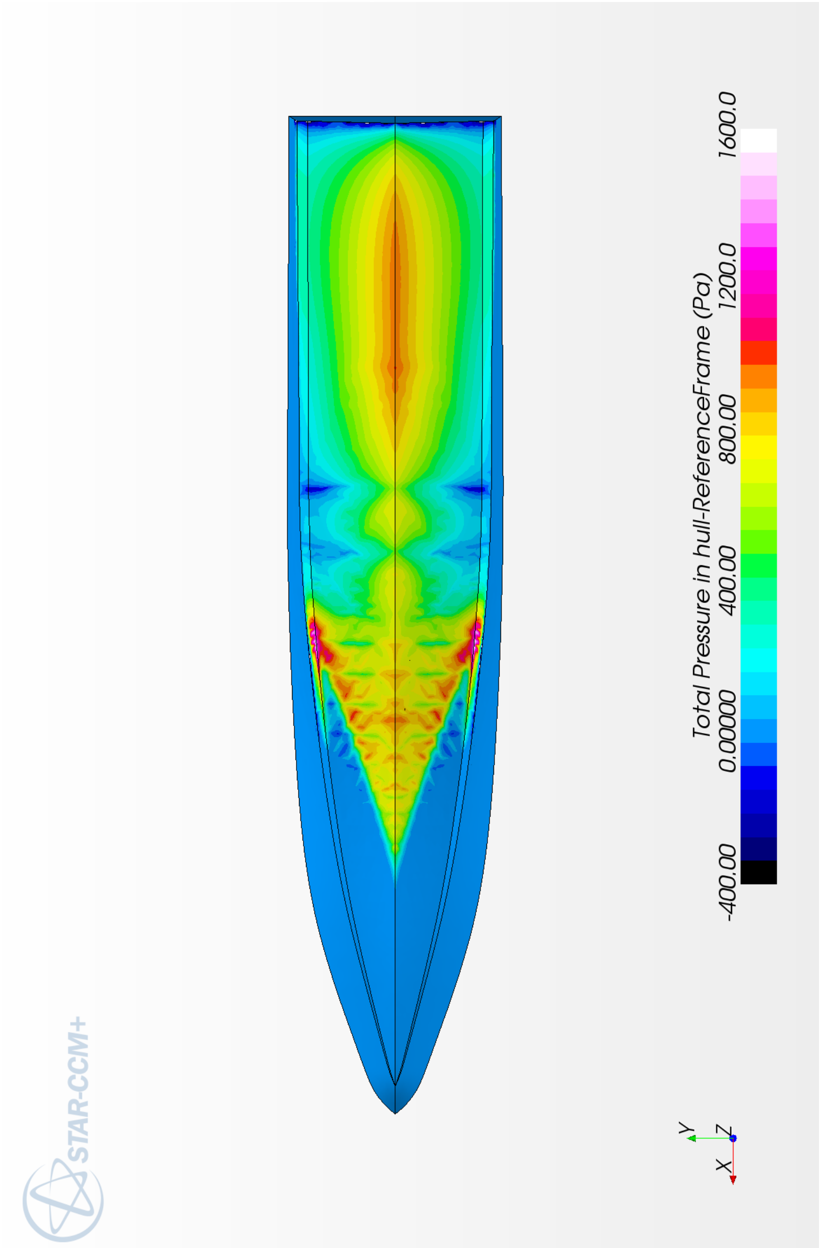
- Constant flow speeds
- Courant number below 1.0
  - Although CD-adapco suggests free from Courant number in implicit transient simulation
- Ramp function applied
  - Fixed motions for initial 0.5 second
  - Fully released after 5 seconds
  - Generally stabilised after 10 physical time-steps





Results: y+ report

- Higher y+ value compared to the expected (up to 80)
- Still within reliable range of y+
- Highly depends on flow speeds on local hull surfaces



Results: total pressure

Cv ≈ 1.0:

- Hydrostatic characteristics
- Negligible hydrodynamic effect

Cv ≈ 1.5:

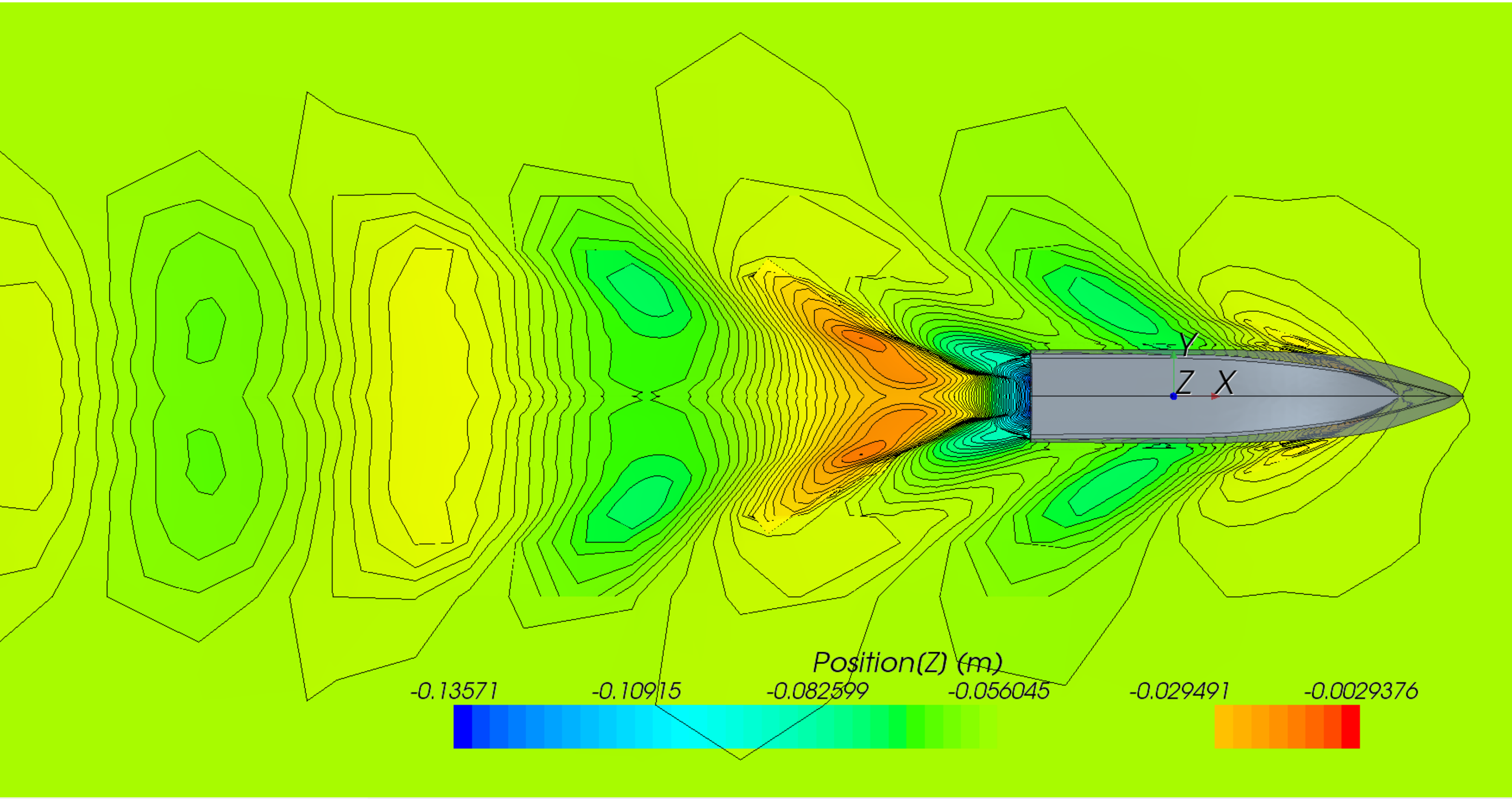
- Stagnation line detected
- Hydrodynamic effect initiating

Cv ≈ 2.0:

- Obvious hydrodynamic effect
- ‘Hump’ region immerse

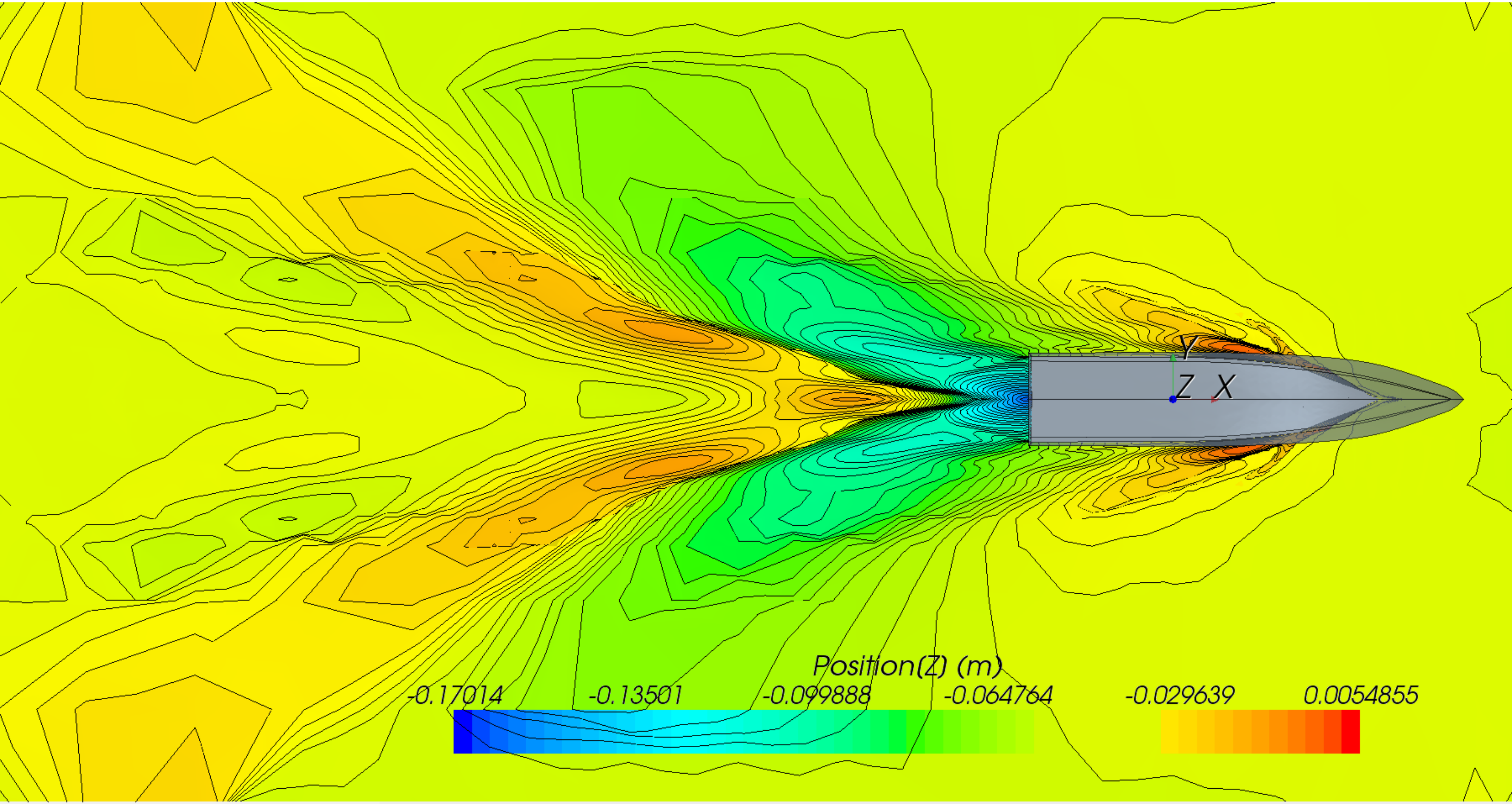
Wave elevation in 1.86 m/s

- Well developed wave system



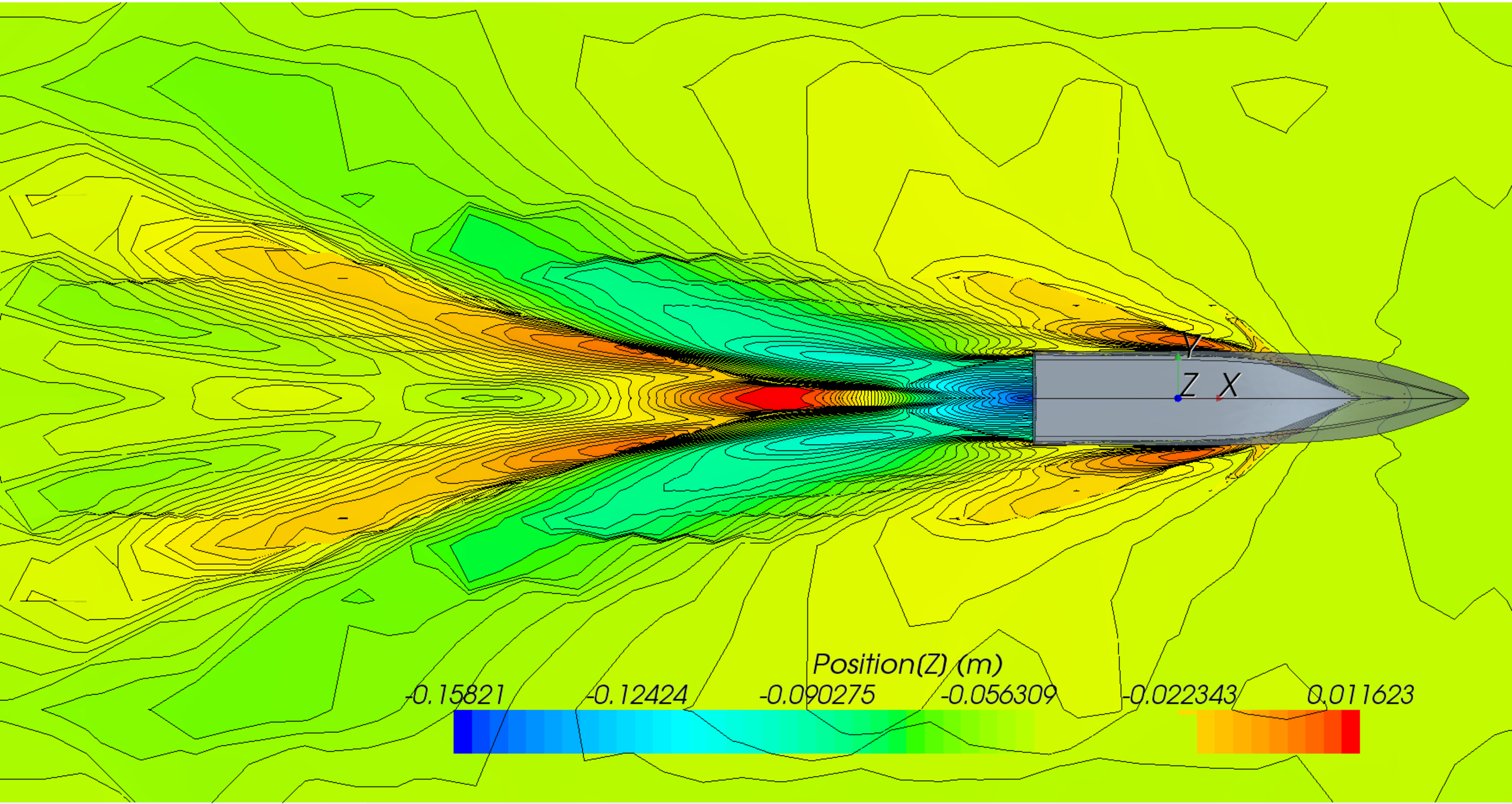
Wave elevation in 3.00 m/s

- Hydrodynamic effects visualised



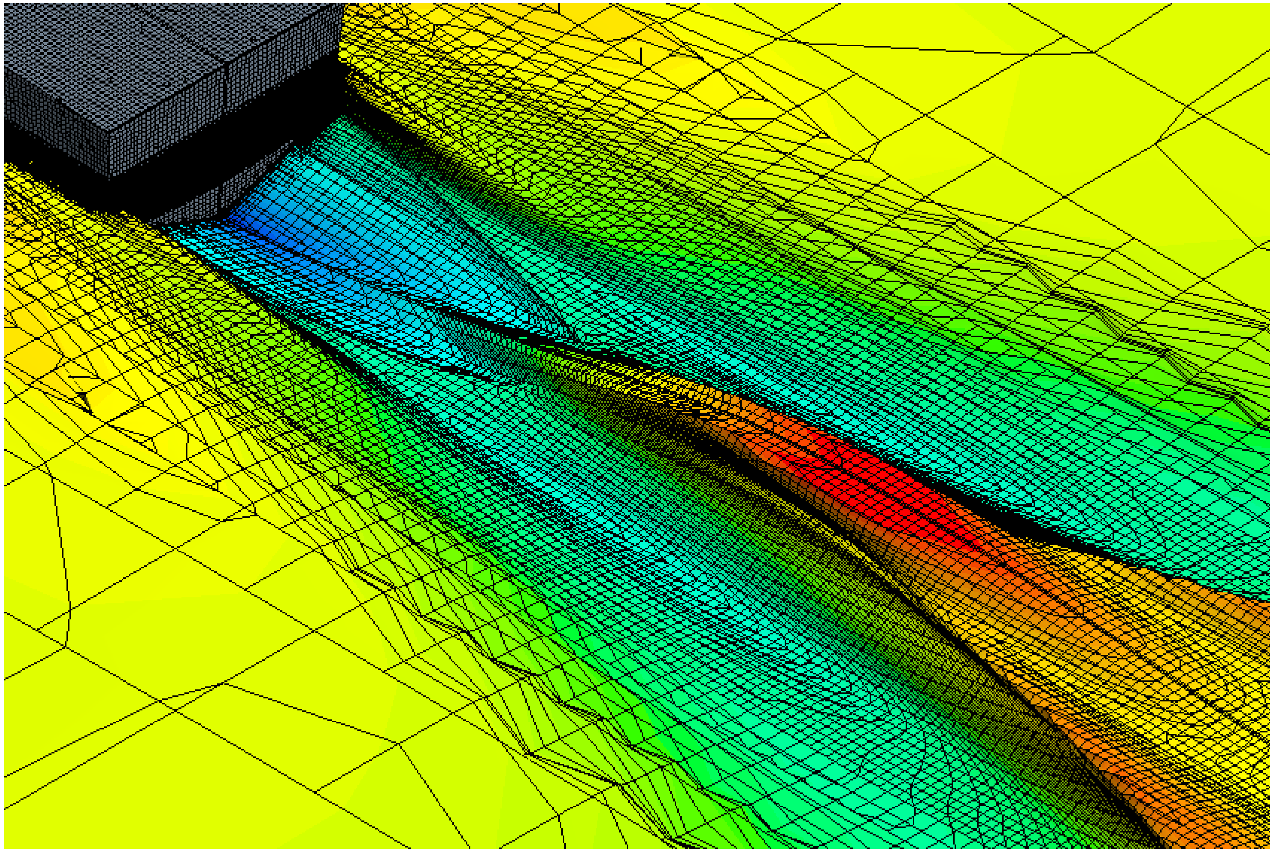
Wave elevation in 4.16 m/s

- Violent separation & spray generation



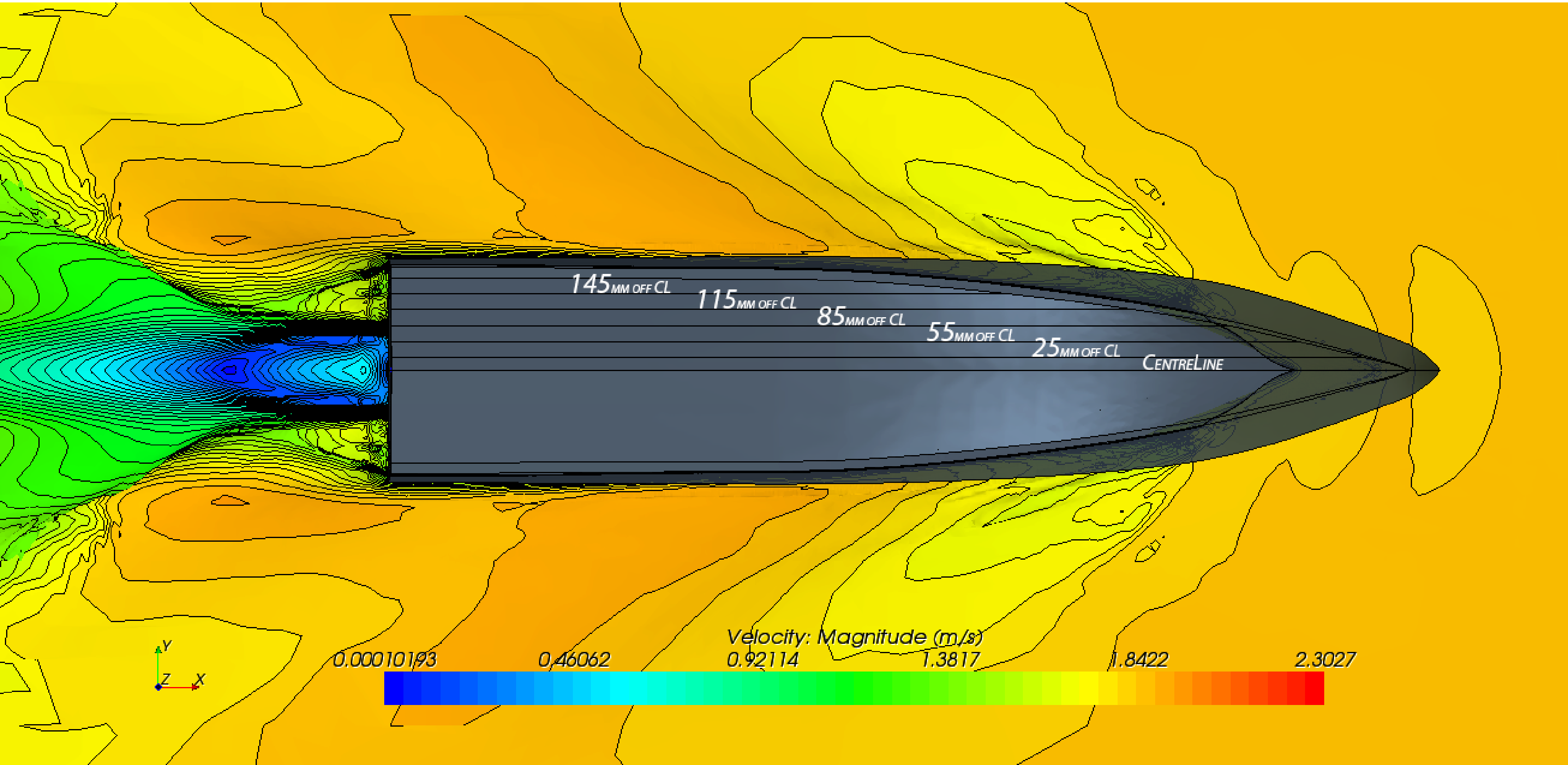
Wake

- Reasonable expression of wake generation could be observed
- Well agreed with existing numerical model by Faltinsen
- Limitation: expression of spray by Volume of Fluid method with multi-phase model

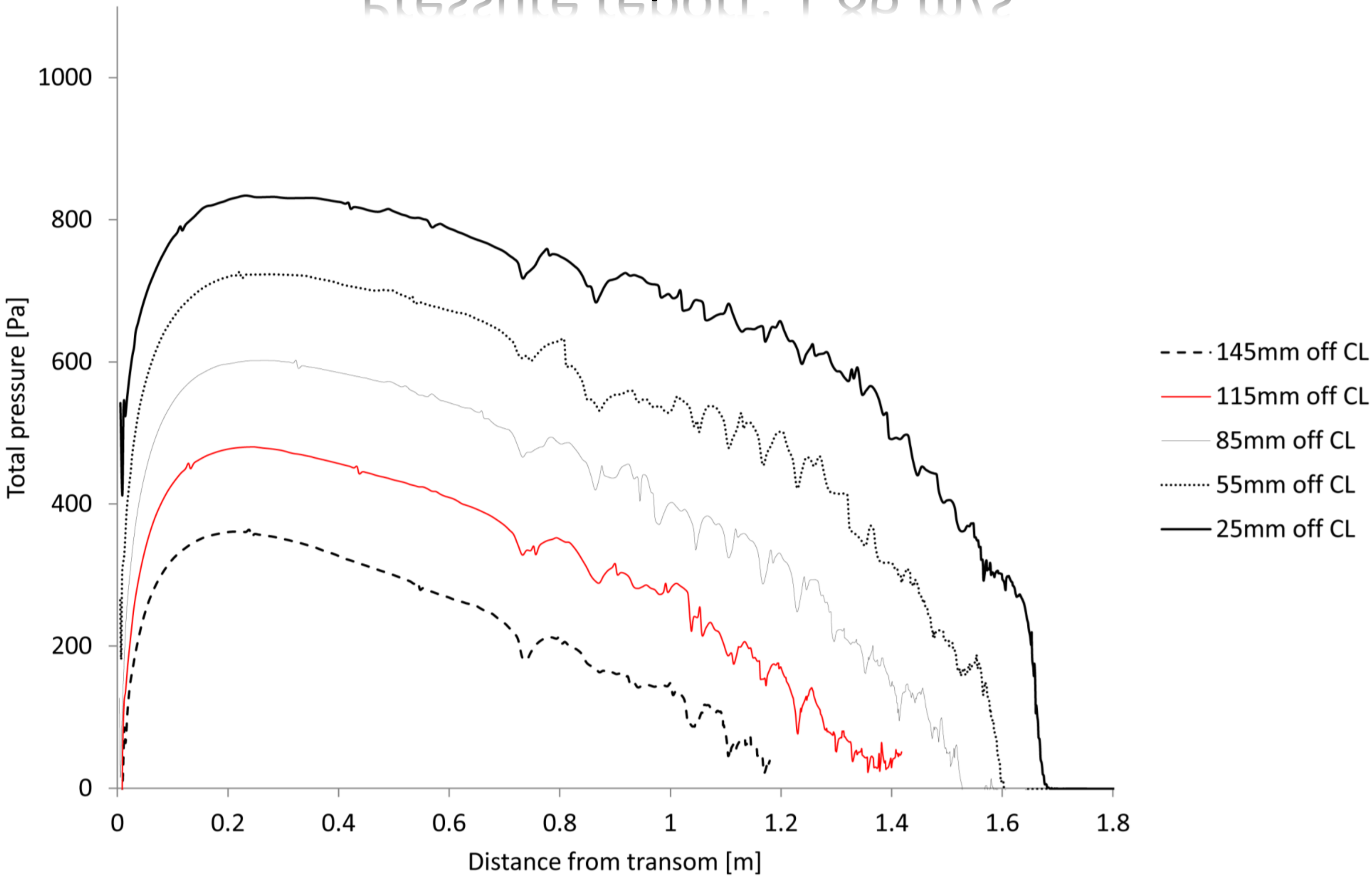


Pressure report: longitudinal direction

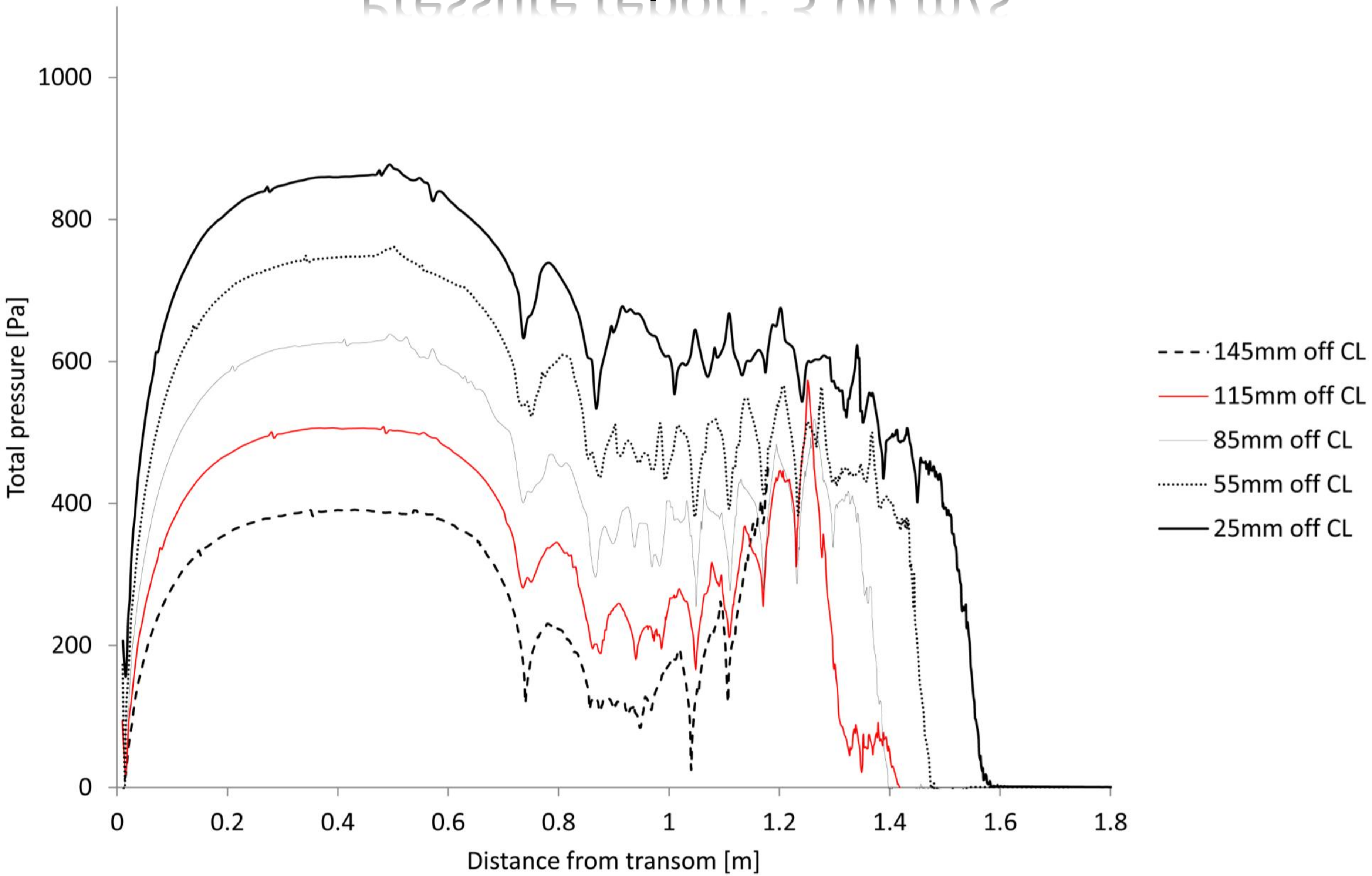
- 5 longitudinal planes along x-axis
- Same distance from centreline with experiments



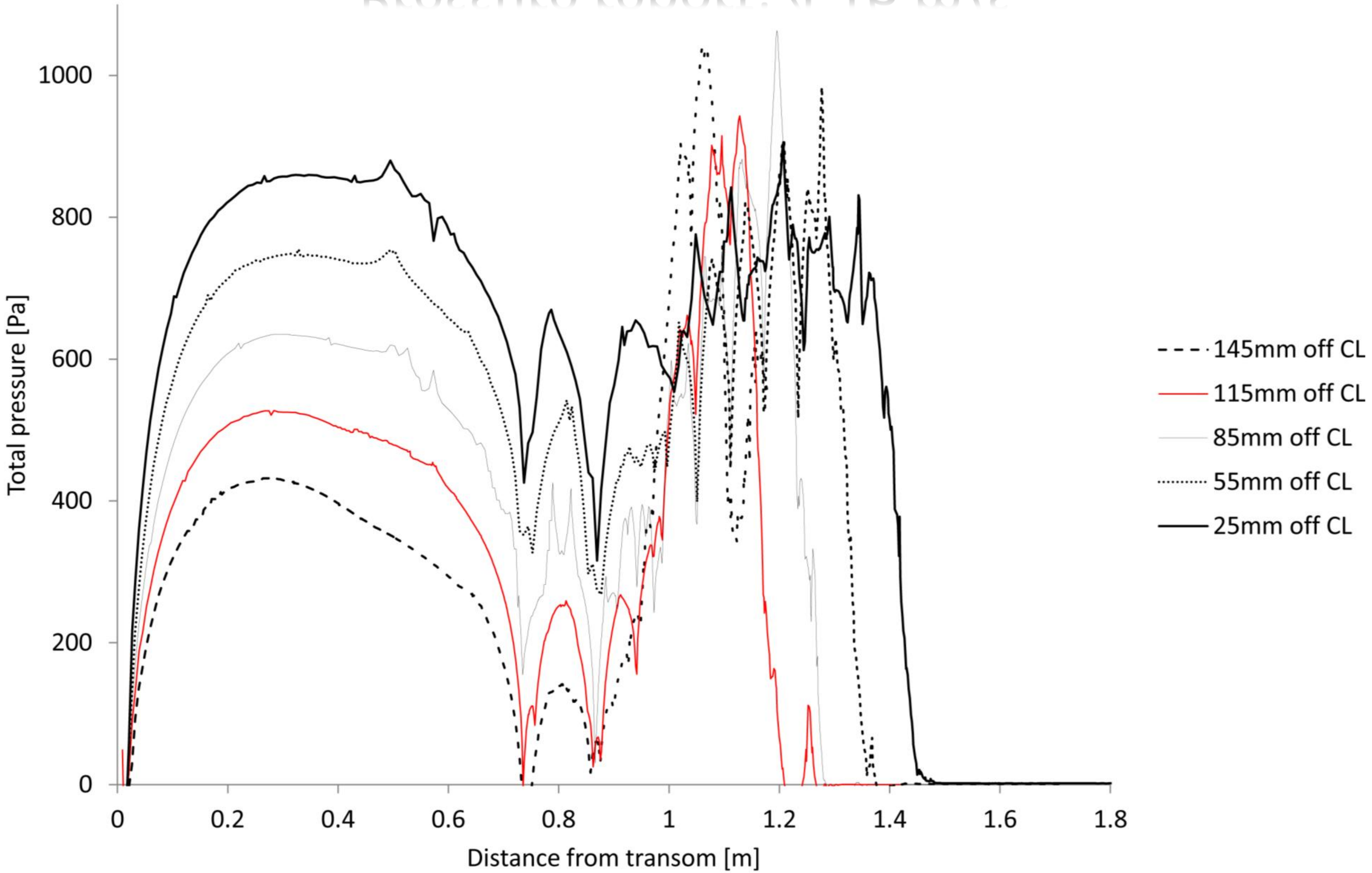
Pressure report: 1.86 m/s



Pressure report: 3.00 m/s

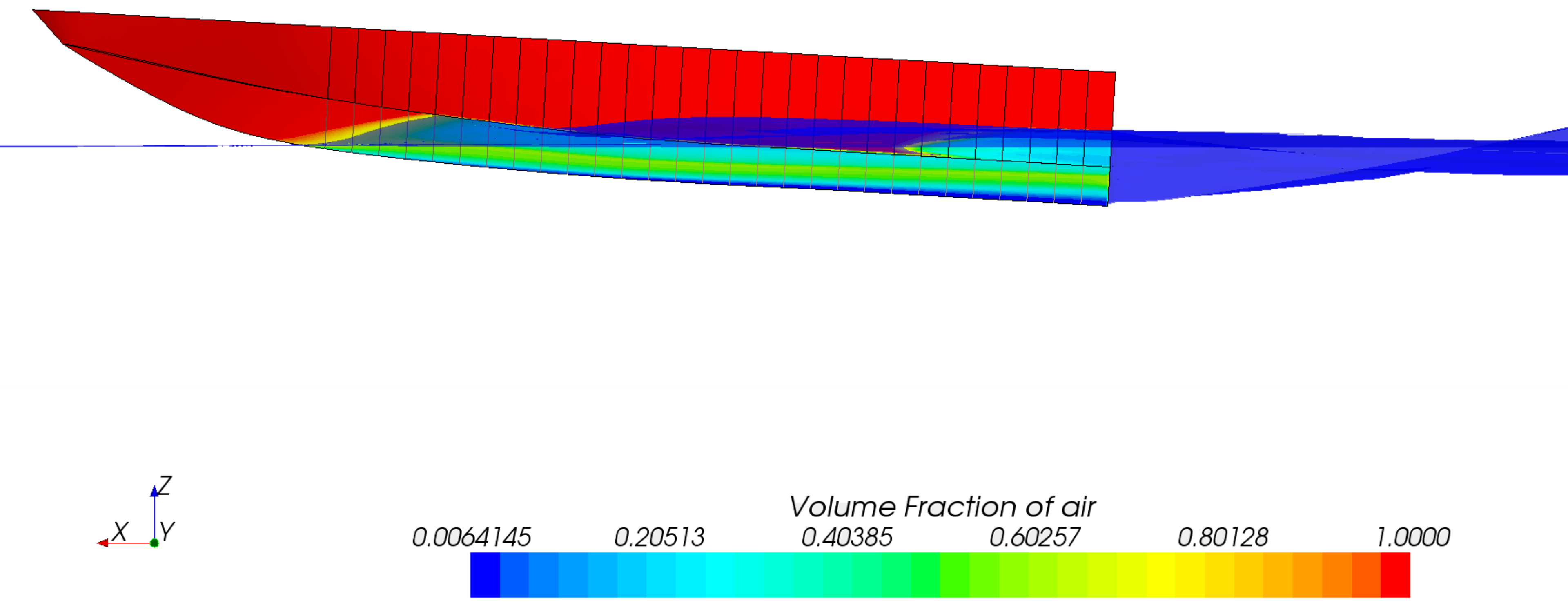


Pressure report: 4.16 m/s

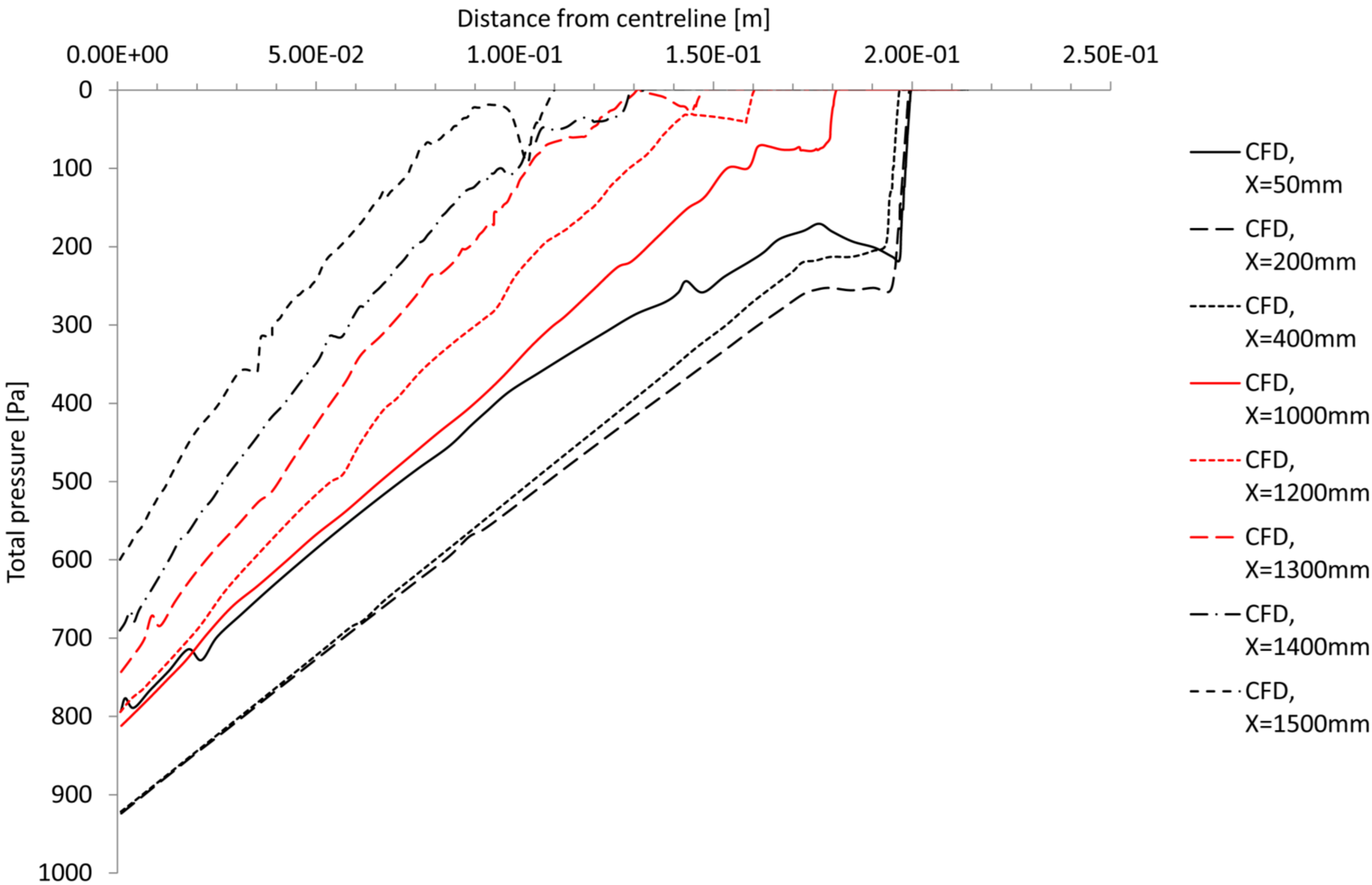


Pressure report: transverse direction

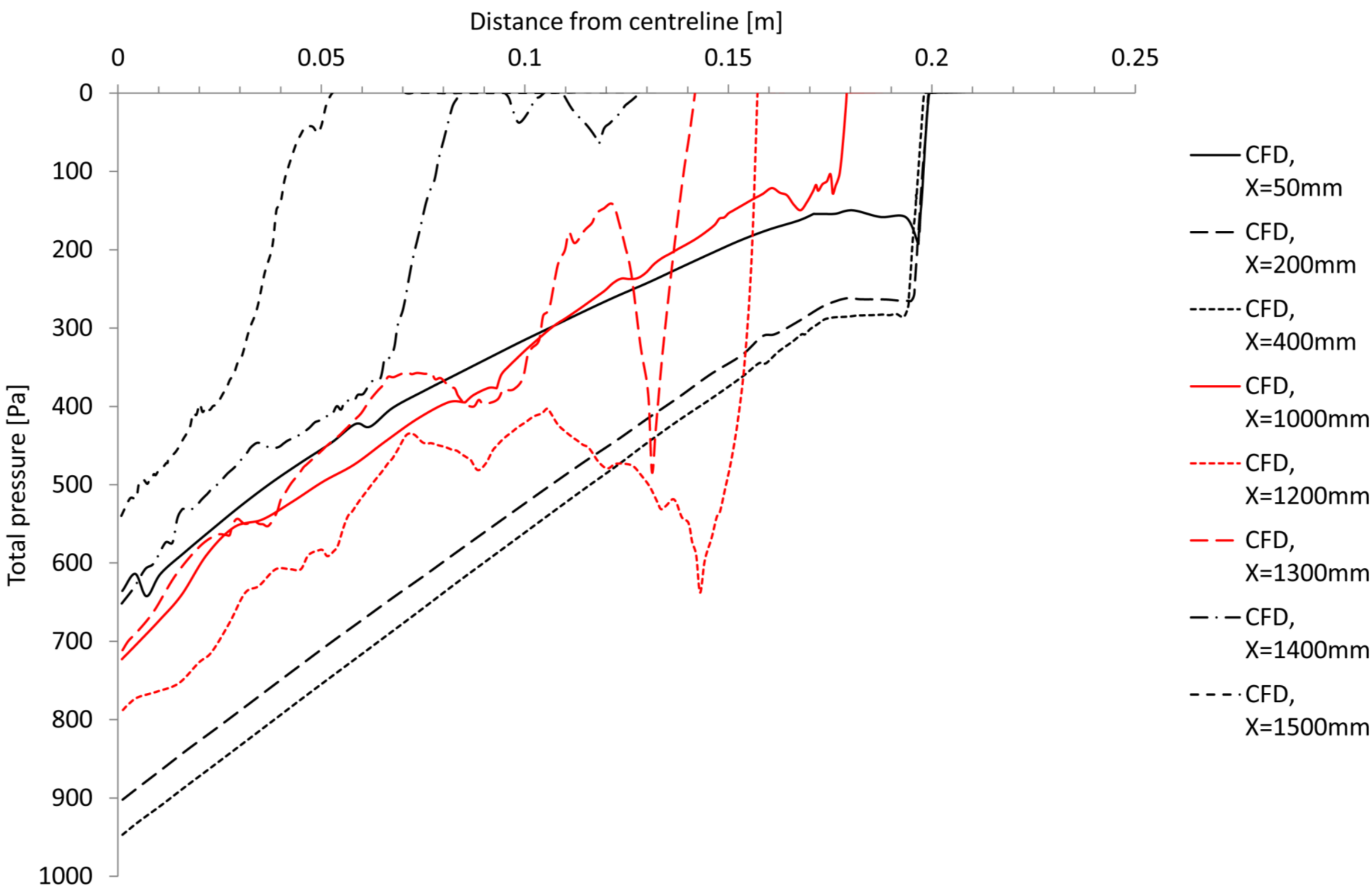
- Over 30 transverse sections with 50mm interval
- Same distance from transom stern with experiments



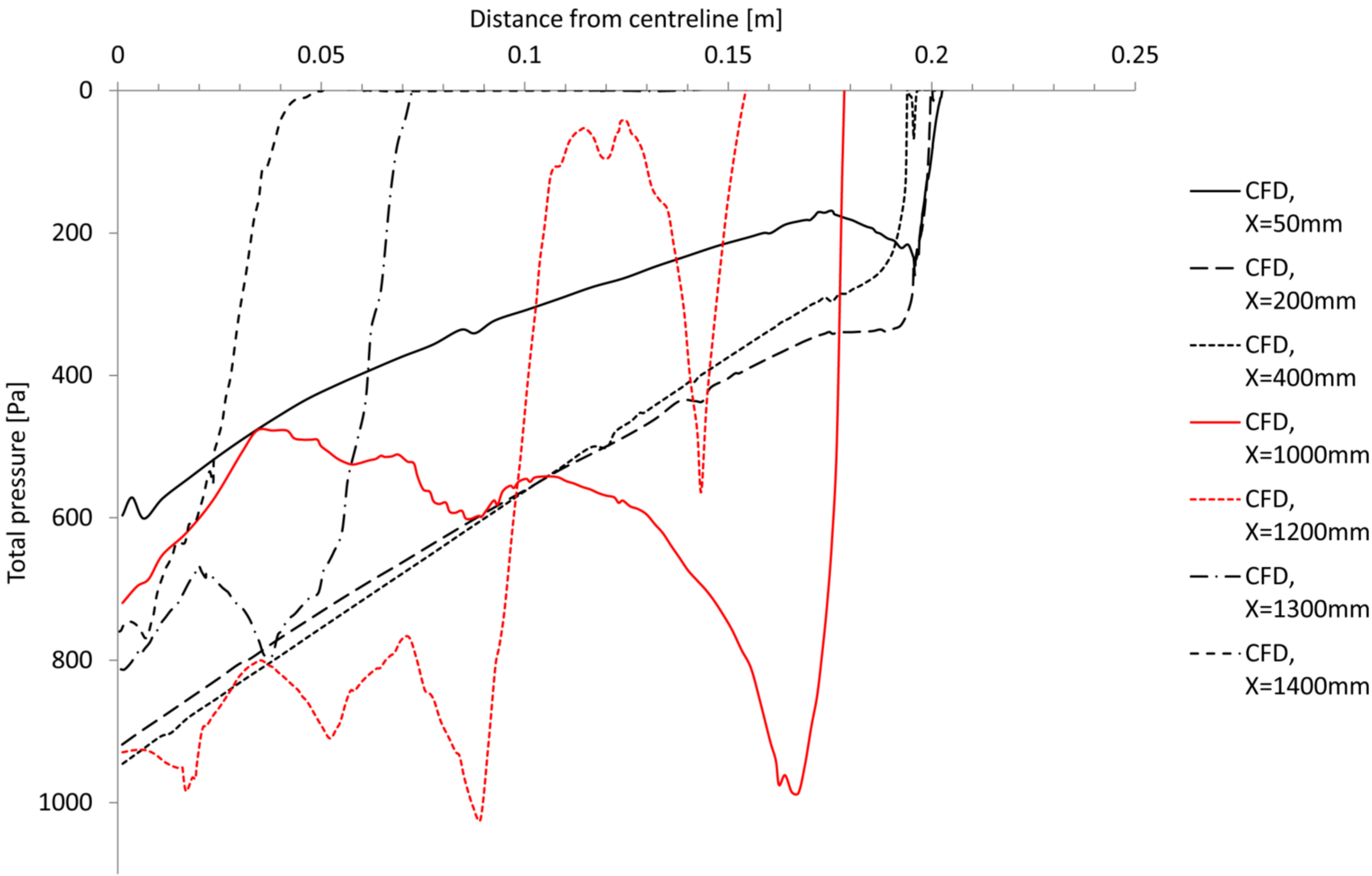
Pressure report: 1.86 m/s



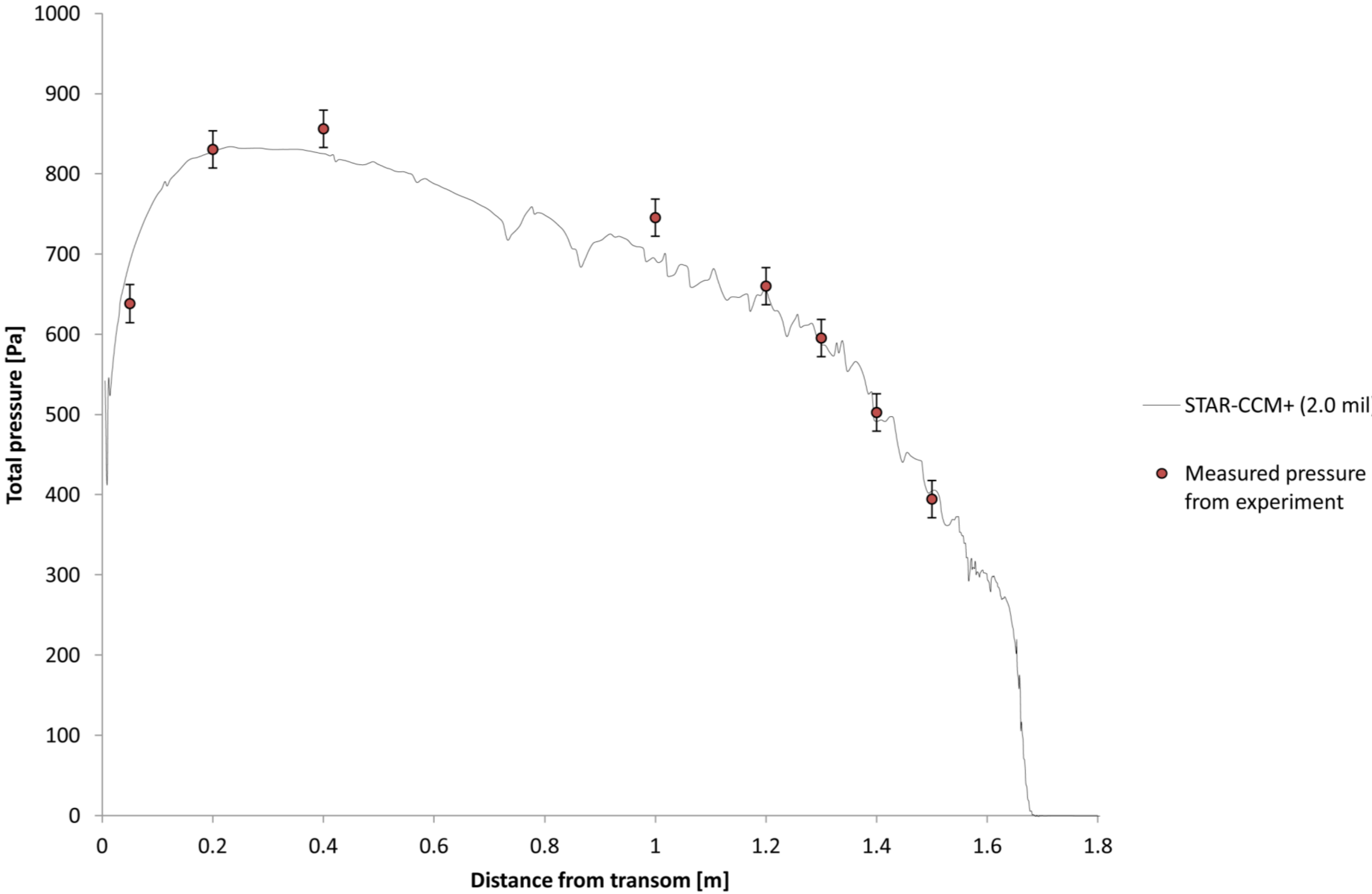
Pressure report: 3.00 m/s



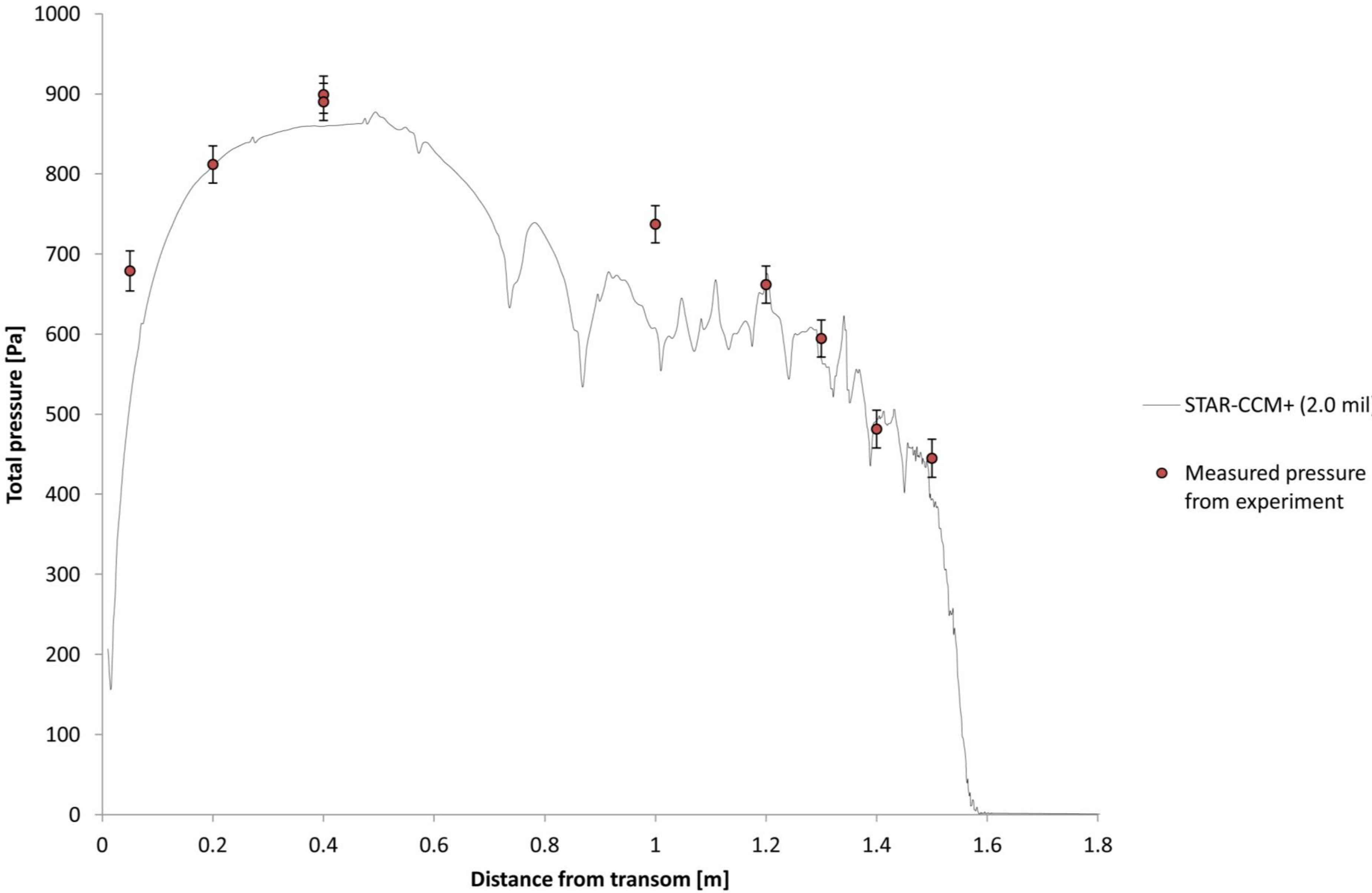
Pressure report: 4.16 m/s



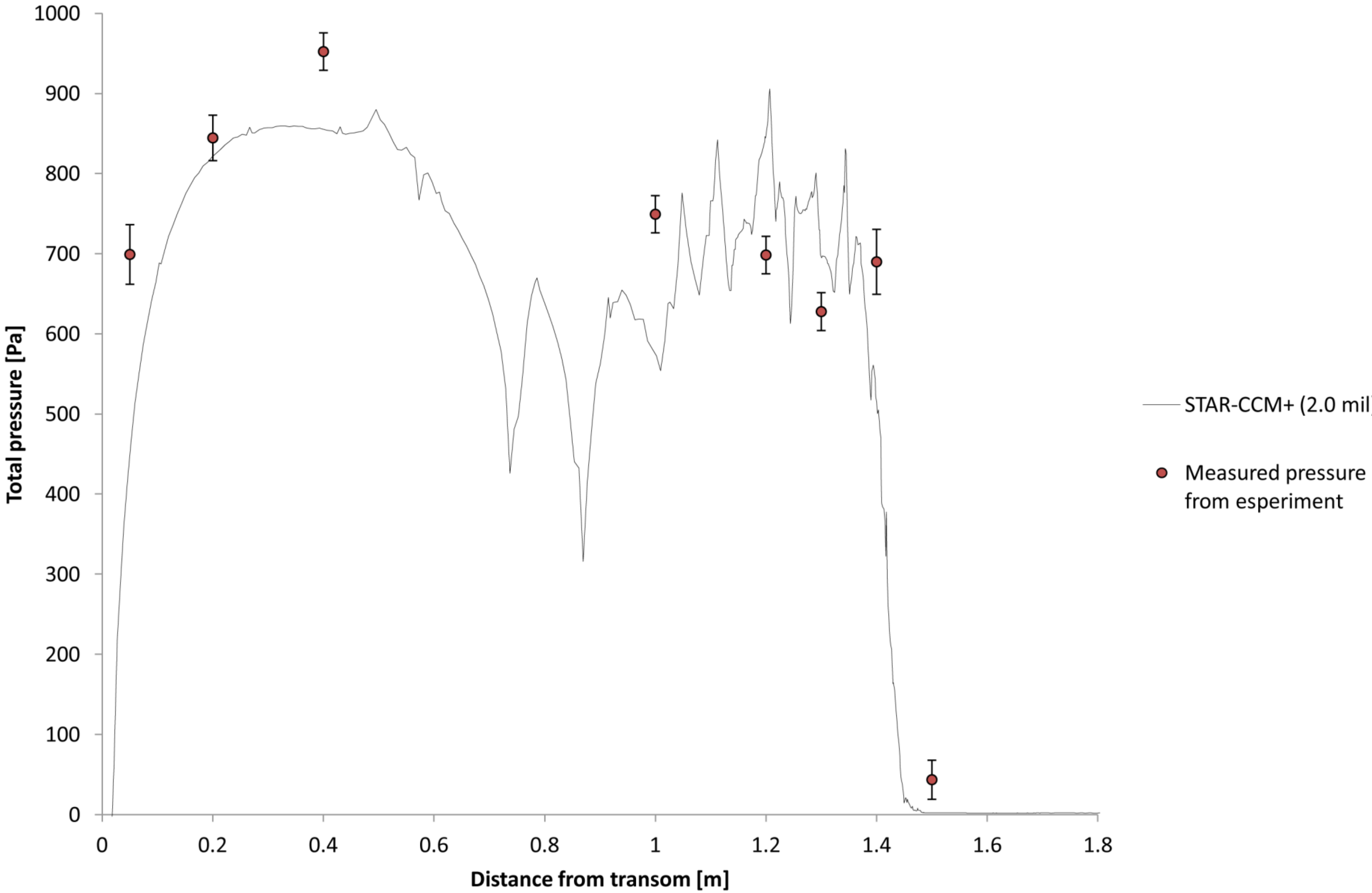
Comparison: 1.86 m/s



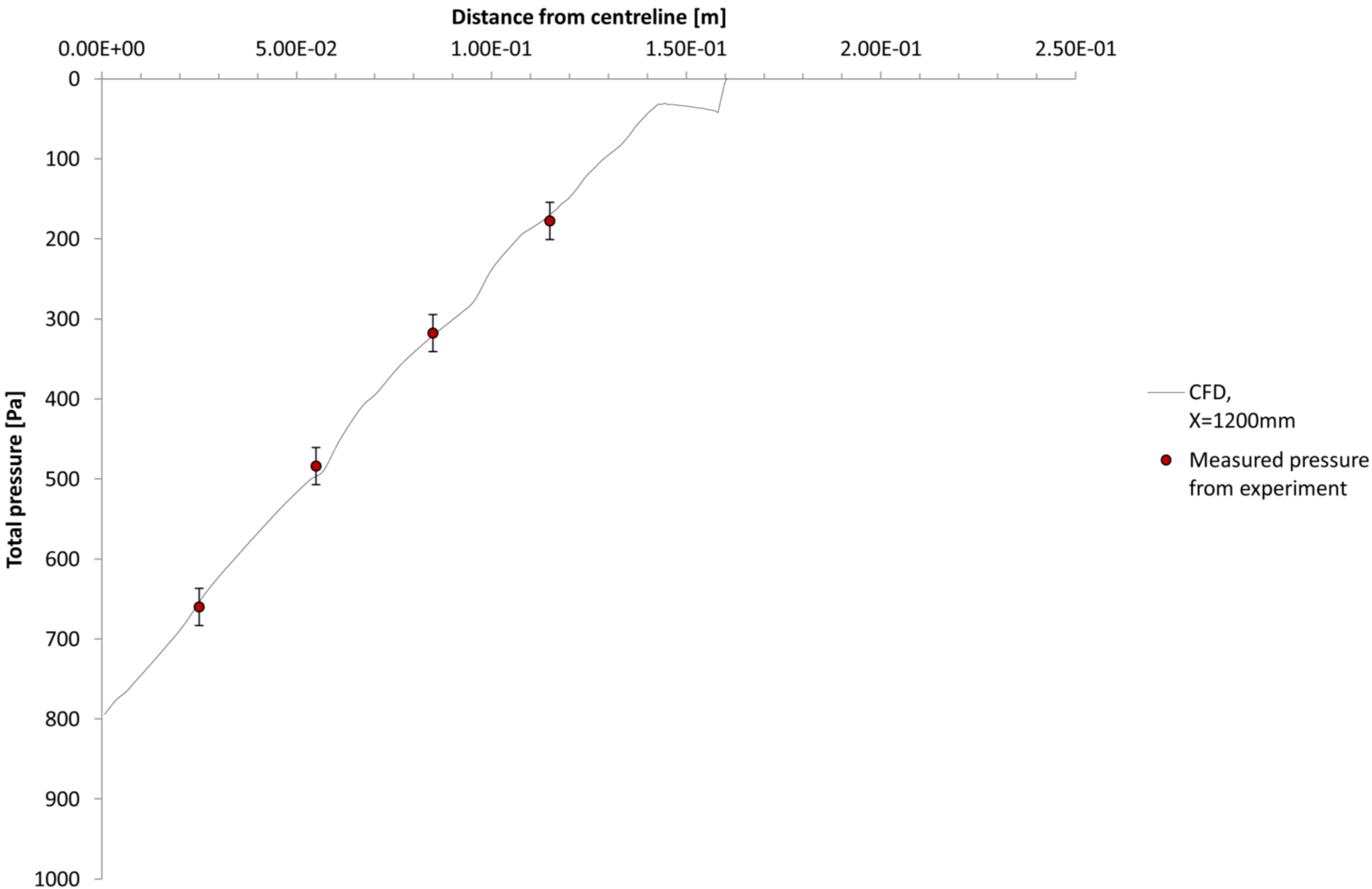
Comparison: 3.00 m/s



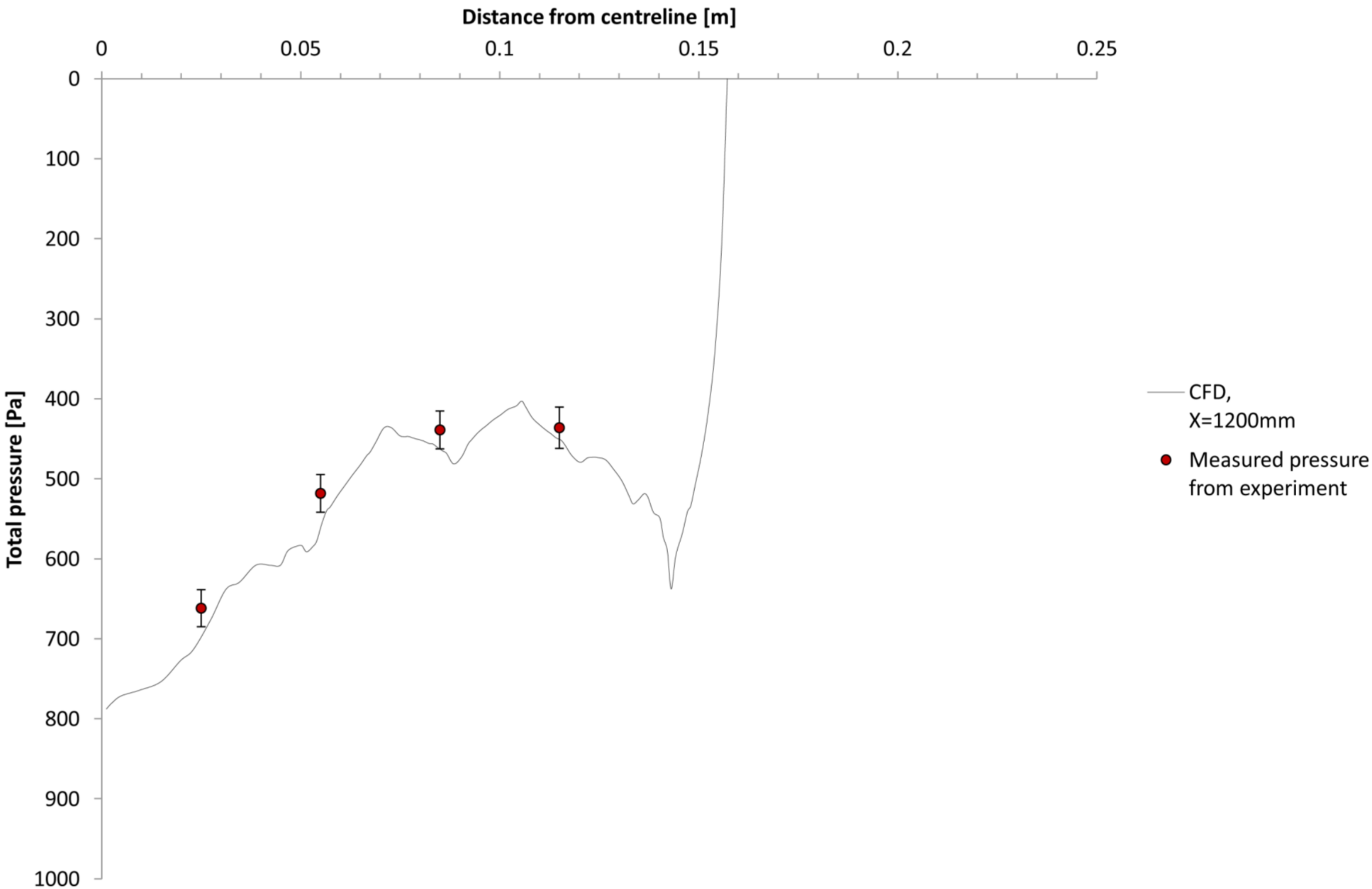
Comparison: 4.16 m/s



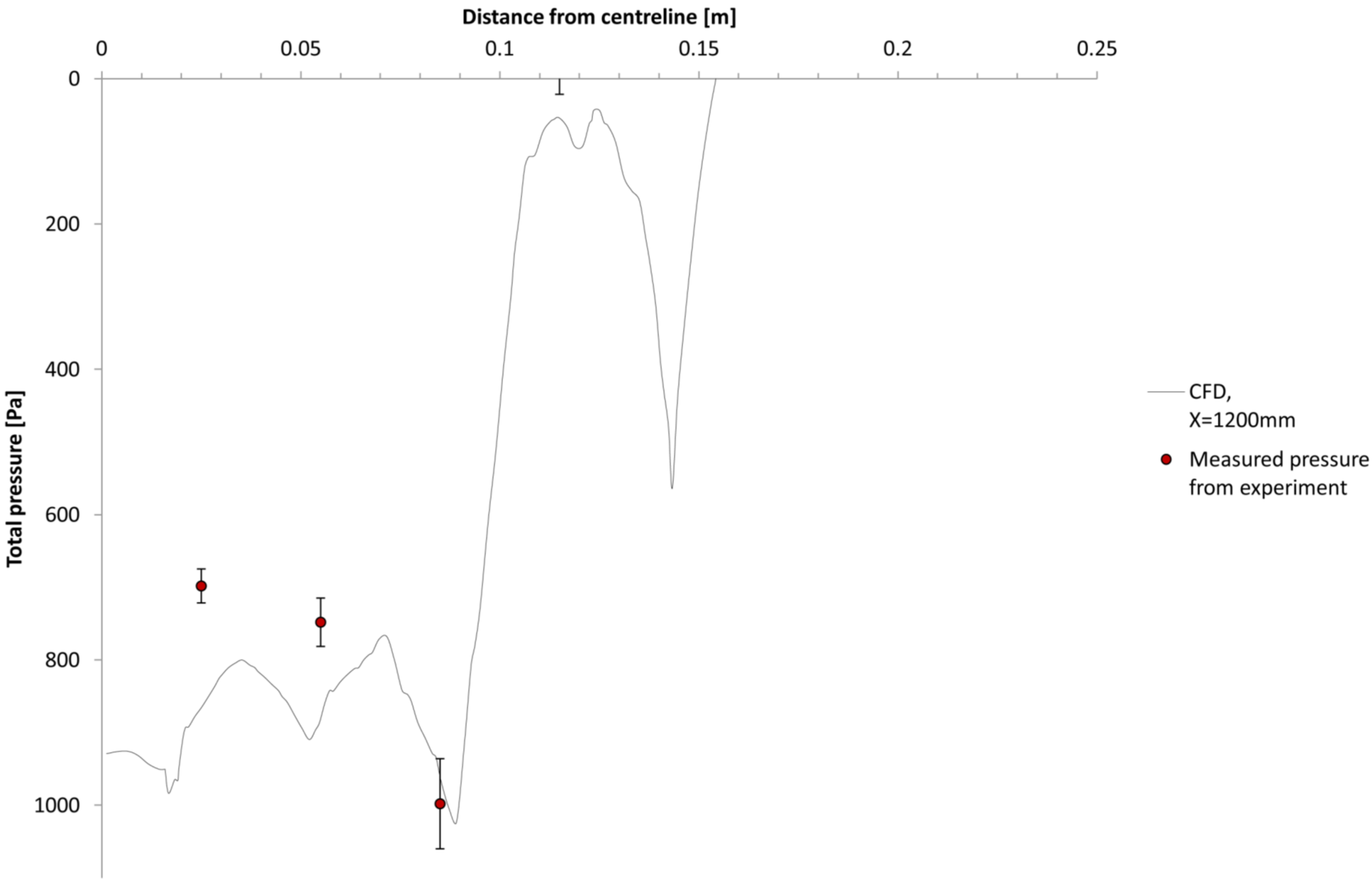
Comparison: 1.86 m/s



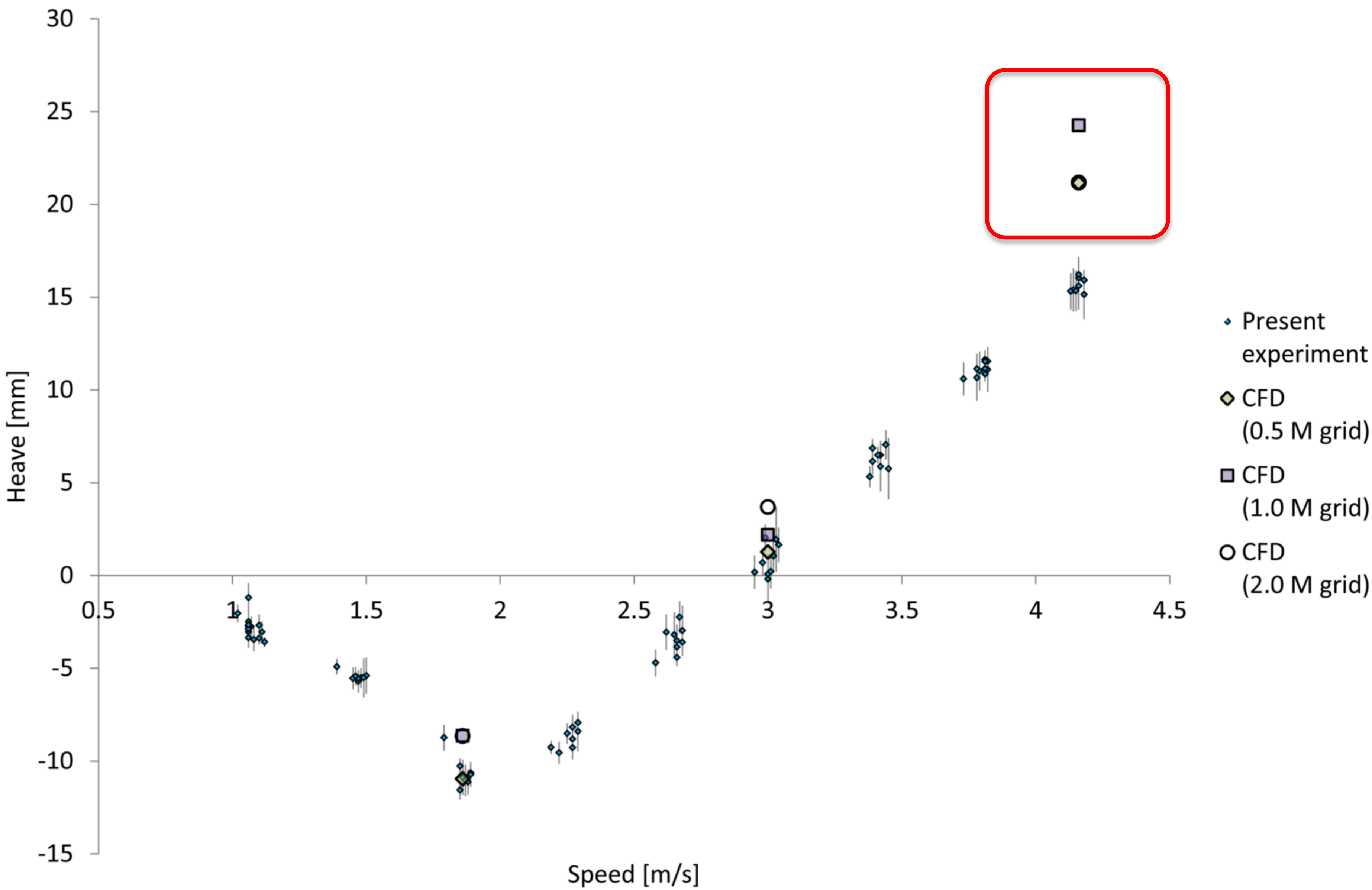
Comparison: 3.00 m/s



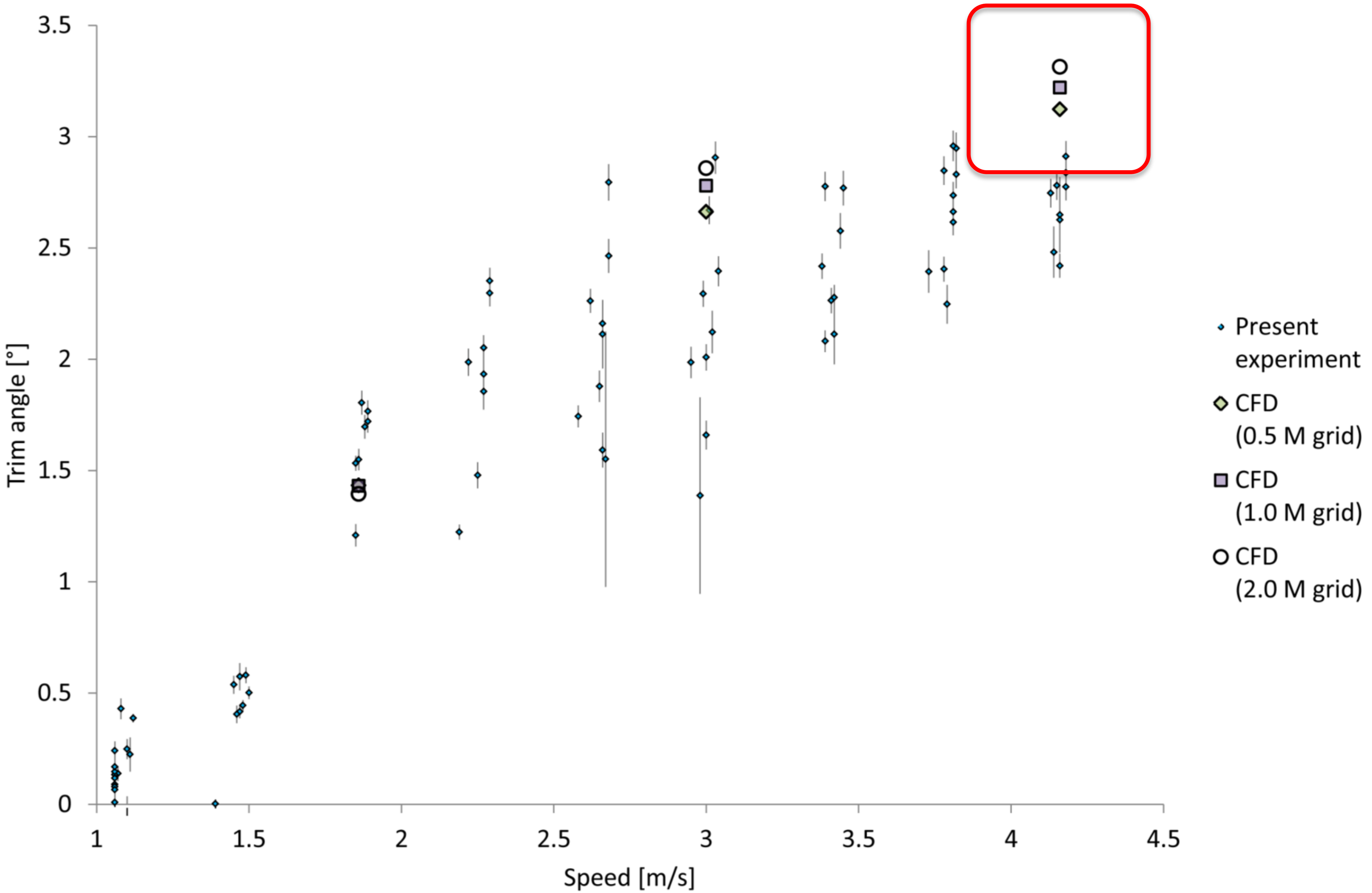
Comparison: 4.16 m/s



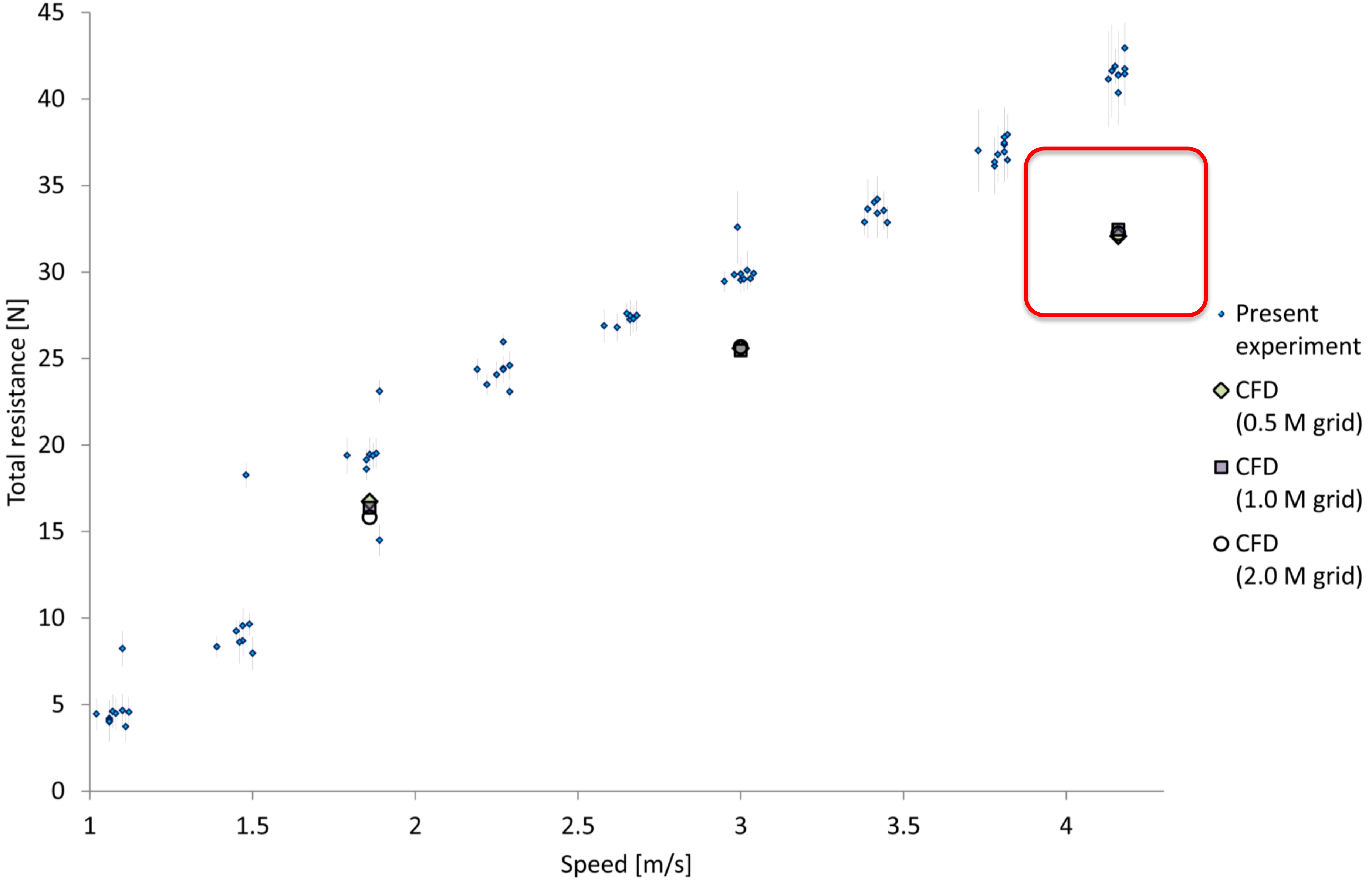
Comparison: Heave (negative dynamic sinkage)



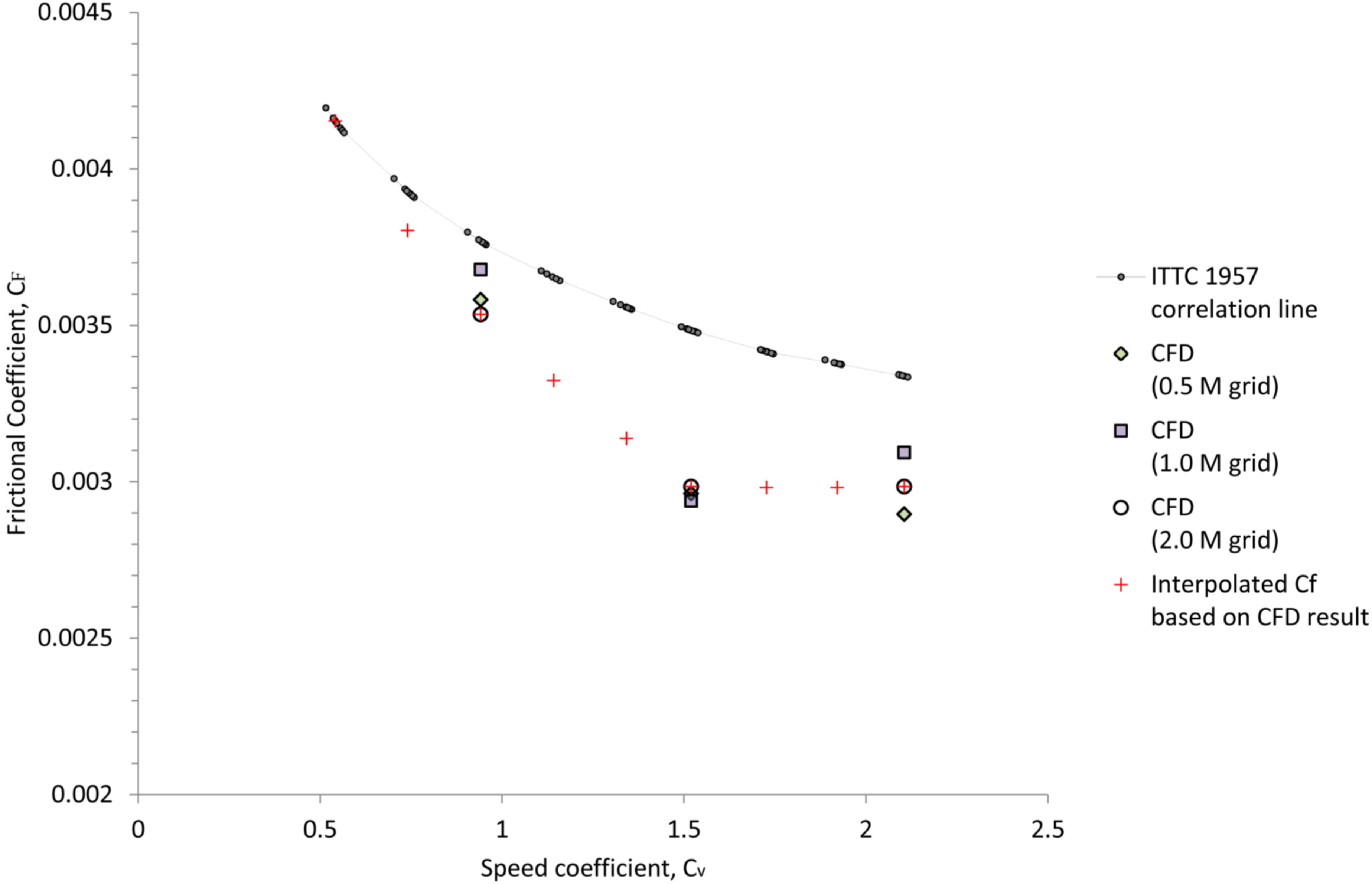
Comparison: Trim



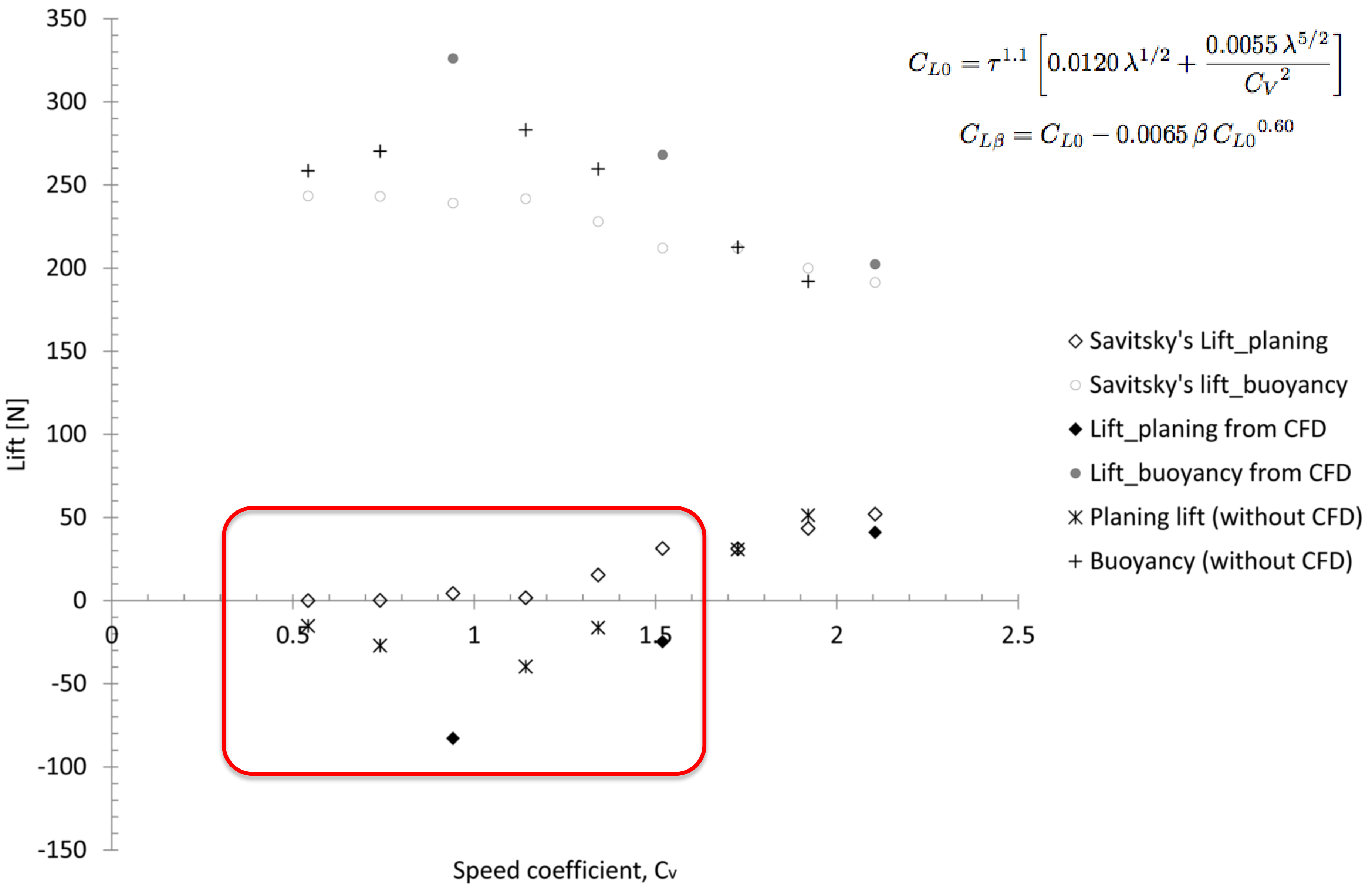
Comparison: Total resistance



Comparison: Frictional coefficient



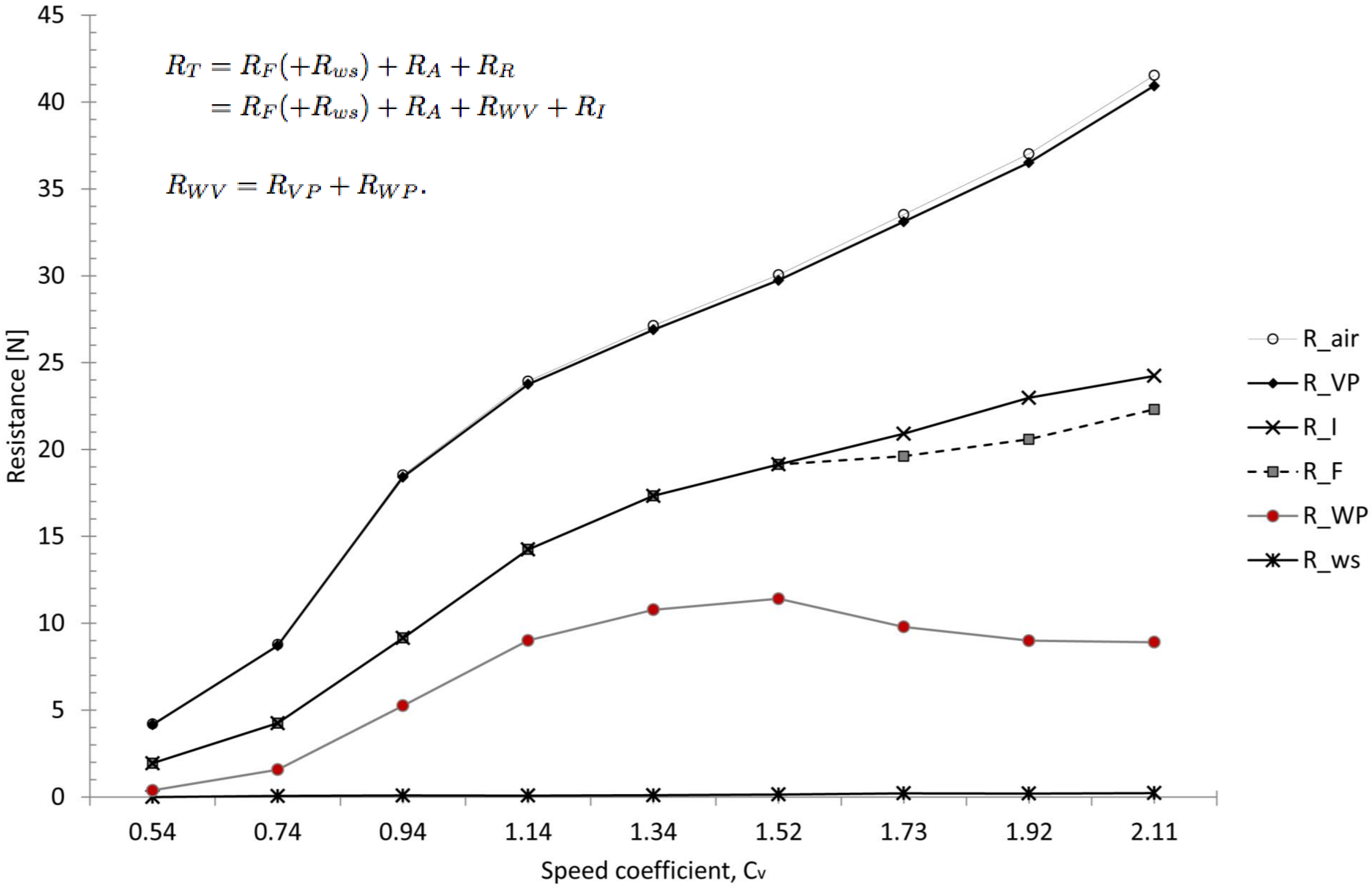
Comparison: Lift trade-off



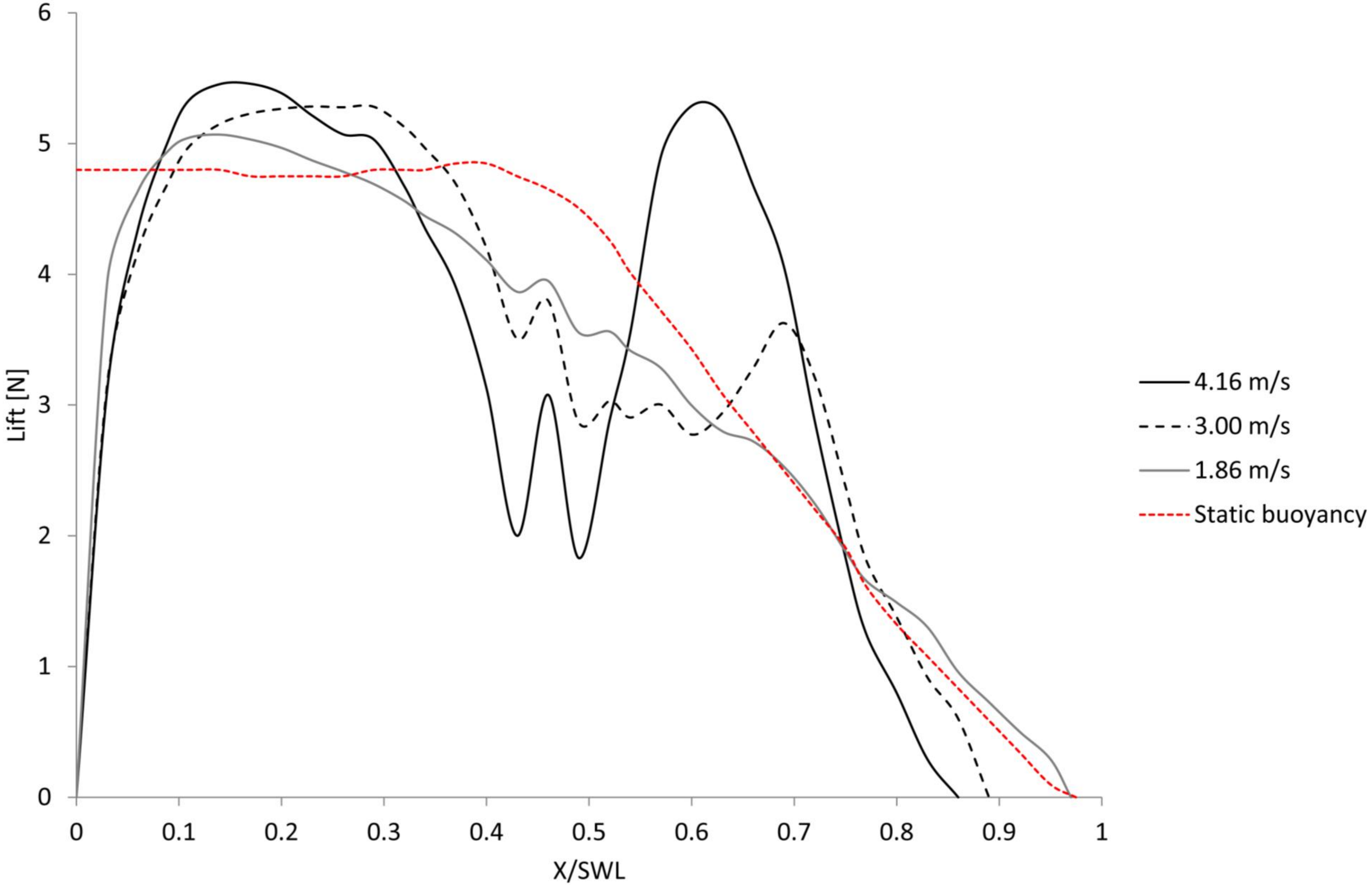
Results: Resistance break-down

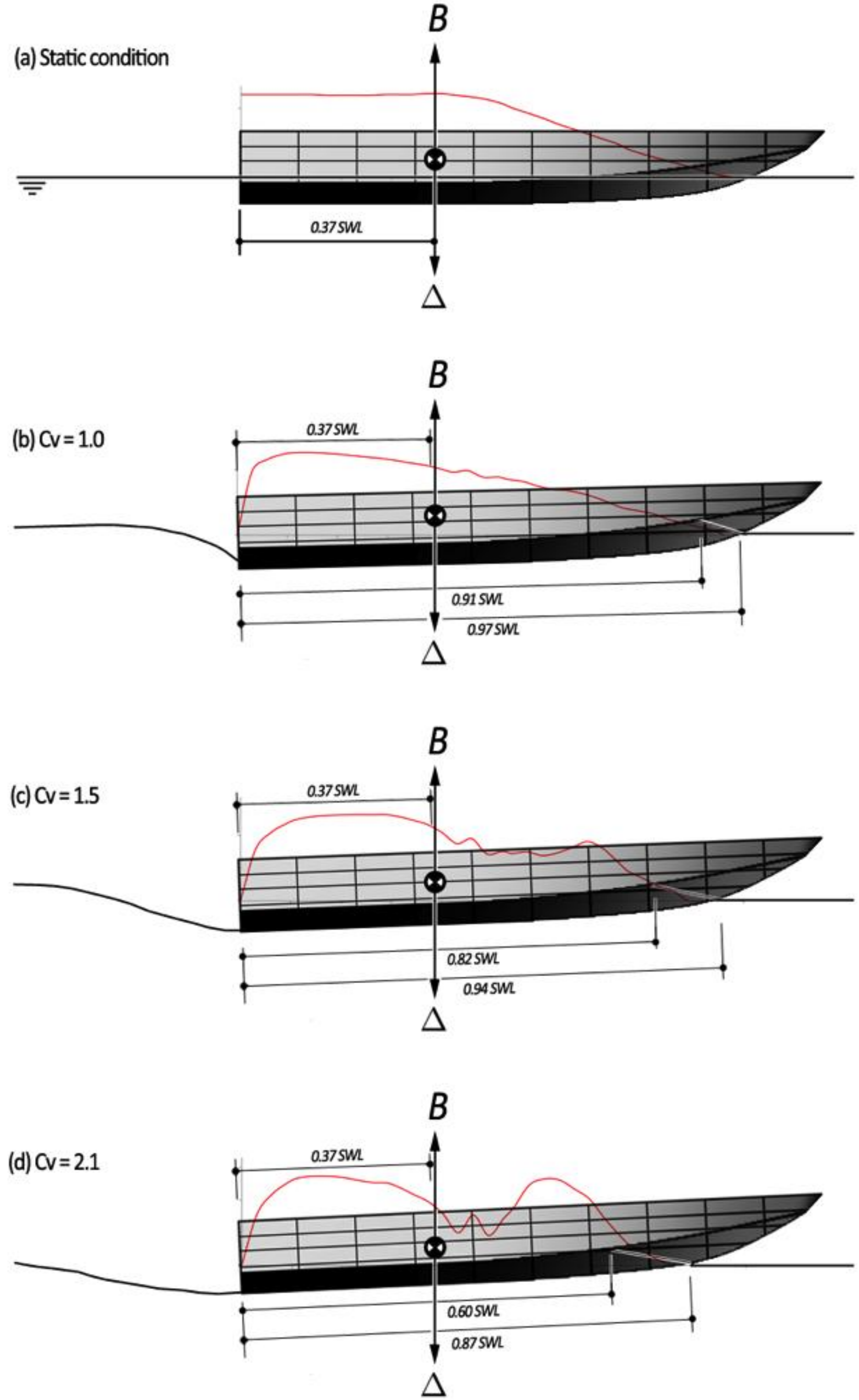
$$R_T = R_F(+R_{ws}) + R_A + R_R$$
$$= R_F(+R_{ws}) + R_A + R_{WV} + R_I$$

$$R_{WV} = R_{VP} + R_{WP}.$$



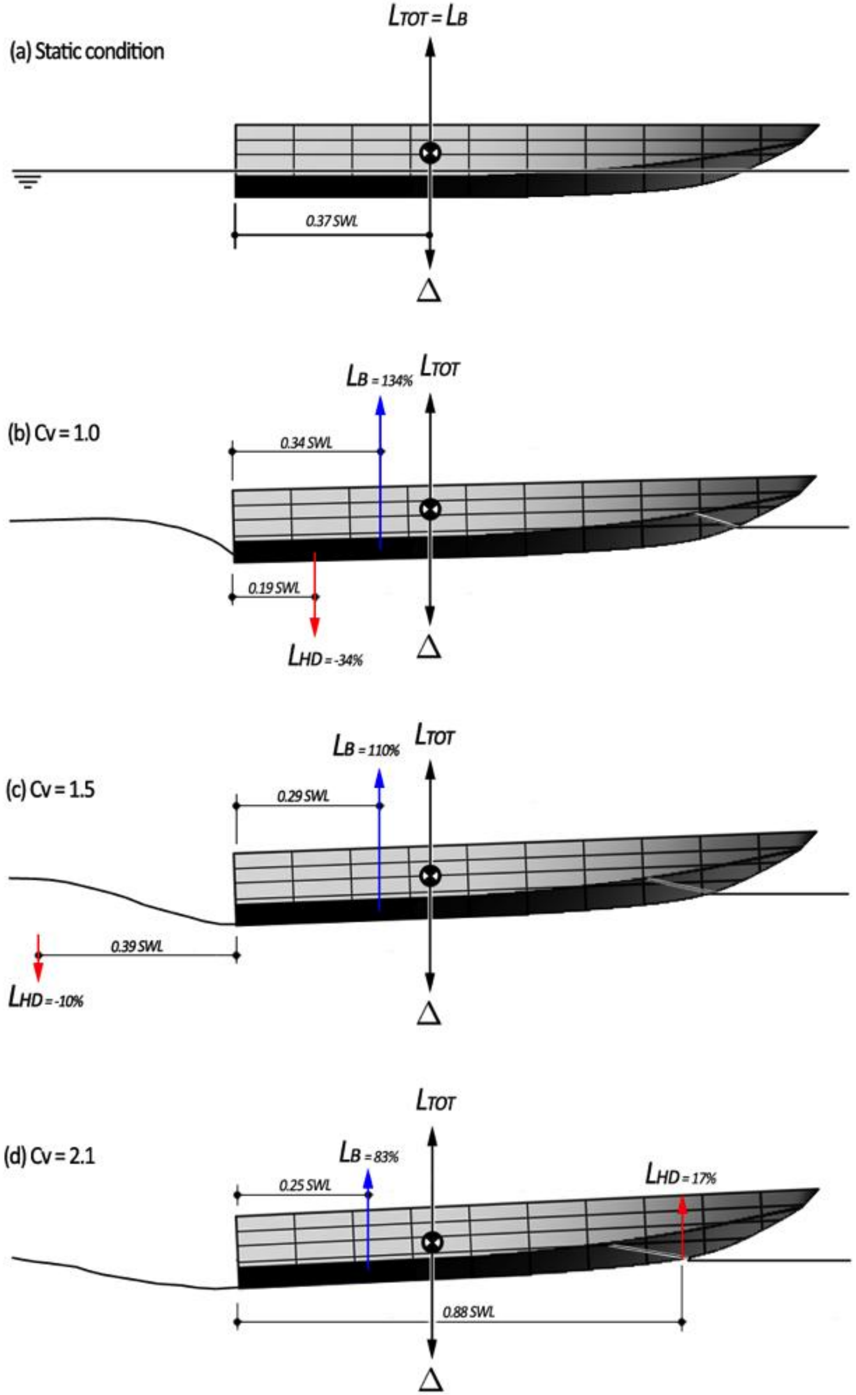
Results: Lift trade-off





Results: Lift distribution

- Cv ≈ 1.0:
  - Hydrostatic characteristics
  - Slightly trim
- Cv ≈ 1.5:
  - Stagnation line detected
  - Hydrodynamic effect initiating
- Cv ≈ 2.0:
  - Obvious hydrodynamic effect
  - ‘Hump’ region immerse



Results: Lift distribution

- Cv ≈ 1.0:
  - Trim due to negative hydrodynamic suction pressure
- Cv ≈ 1.5:
  - Centre of Buoyancy retreats due to trim angle
  - High suction pressure around transom
- Cv ≈ 2.1:
  - Centre of Buoyancy further backward
  - Centre of Hydrodynamic lift comes near COG
  - Indicating further speed increase resulting in stabilised attitude

Conclusion: Pressure & attitudes

- At low speed well conformed pressure reports
- Slight overestimation of hydrodynamic effects in high speeds
- Reasons:
  - Hydroelasticity of towing tank model: absorbing hydrodynamic lift
  - Existence of pressure tappings on towing tank model: reduced hydrodynamic effect
  - Limitation of k-w SST turbulent model: transom separation

Conclusion: Resistance

- At low speed in good accordance with experimental data
- Growth in underestimation of total resistance as speed increases
- Reasons:
  - Hydroelasticity of towing tank model: absorbing hydrodynamic lift hence higher wetted surface area in the experiment
  - Existence of pressure tappings on towing tank model: reduced hydrodynamic effect hence additional resistance incurred
  - Limitation of k-w SST turbulent model: transom separation