Resistance Decomposition of a Self-propelled Ship in Full Scale

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Motivation

- Simulations of self-propelled ships at full scale are a main goal for CFD;
- These flows involve multiple complex physics such as turbulent flow, free-surface and cavitation,making them numerically challenging;
- Very little data at full scale exists for comparison/validation;

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Overview and goals

- To perform a full scale simulation of a self propelled ship, and corresponding simplifications, i.e, no propeller and double-body setup;
- How is the resistance affected by
  1. the inclusion of the free-surface?
  2. the propeller?
  3. hull roughness?
- How do these effects affect each other?

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Overview and goals

- Top-down approach with reference case being the self-propelled* simulation, with free trim and sink and hull/propeller roughness.

- The remaining simulations are progressive simplifications of the reference case:
  1. no ship motion (fixed trim and sink);
  2. no propeller (resistance test);
  3. no free surface - double body setup:
     - with/without roughness;
     - with/without propeller;

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JoRes Project

- "Development of an industry recognised benchmark for Ship Energy Efficiency Solutions";
- Provides a data base of sea trial data, useful for full scale CFD validation, with several workshops being organised on this topic;
- Over 50 participating organisations, project conclusion in 2023.

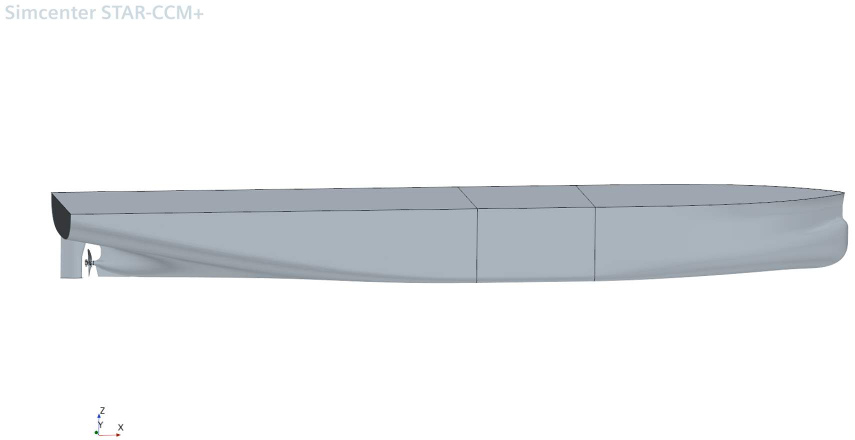
Test Case

- The JoRes tanker, one of the vessels studied in the JoRes project;
- Geometry given in the project, along with sea trial data and roughness measurements;

L_{pp}	178.50 m	D_p	6.5m
B	32.26 m	$\frac{P_{0.7R}}{D}$	0.7947
T_M	10.47 m	$\frac{A_E}{A_0}$	0.445
		$\frac{D_H}{D_P}$	0.15
		Z	4

Table: JoRes 1 tanker dimensions

Test Case



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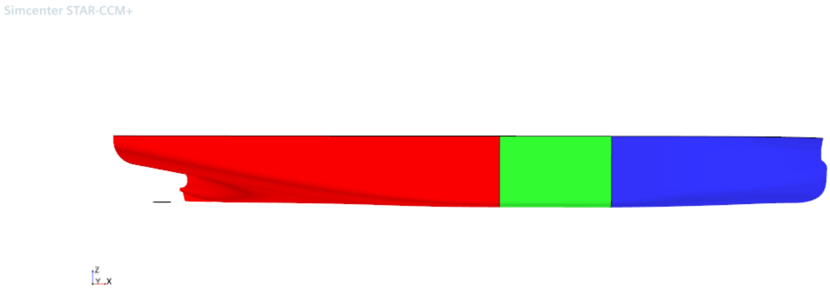
Test Case



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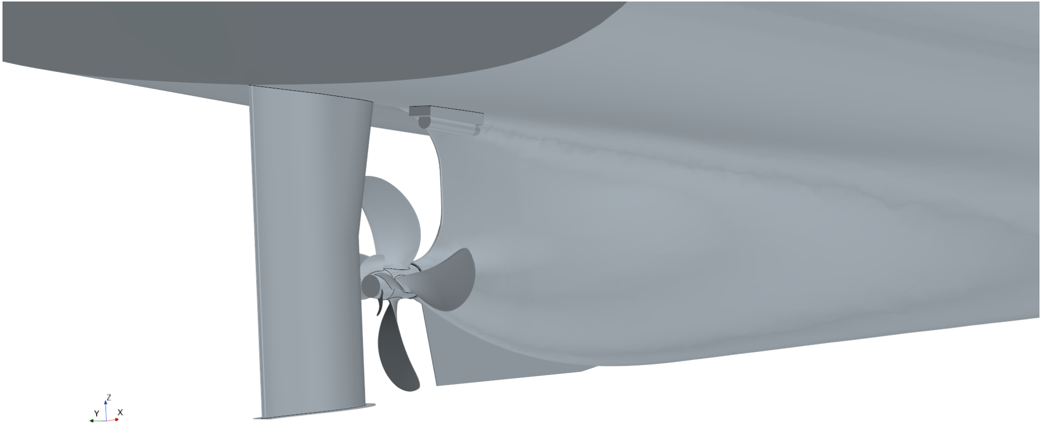

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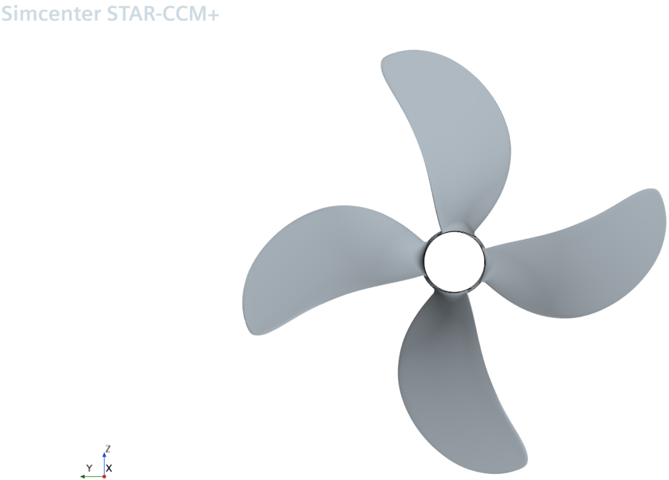
Test Case



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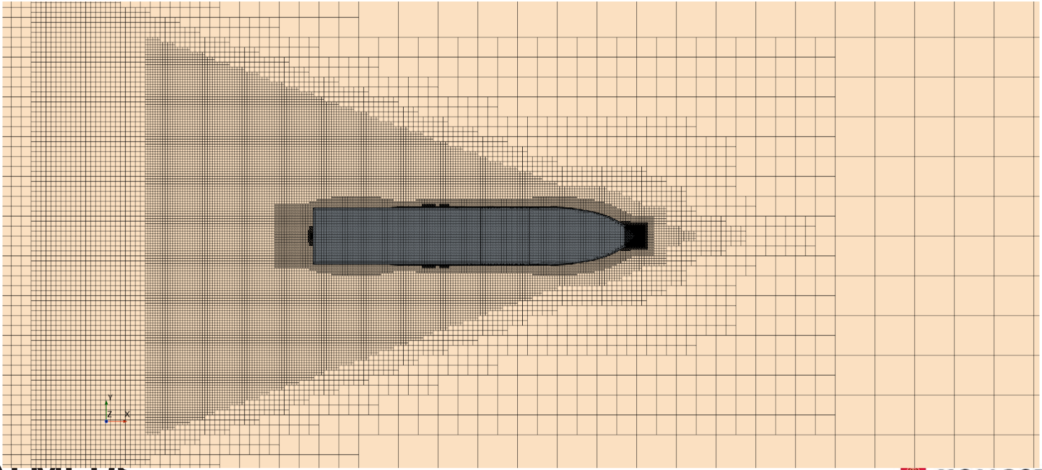

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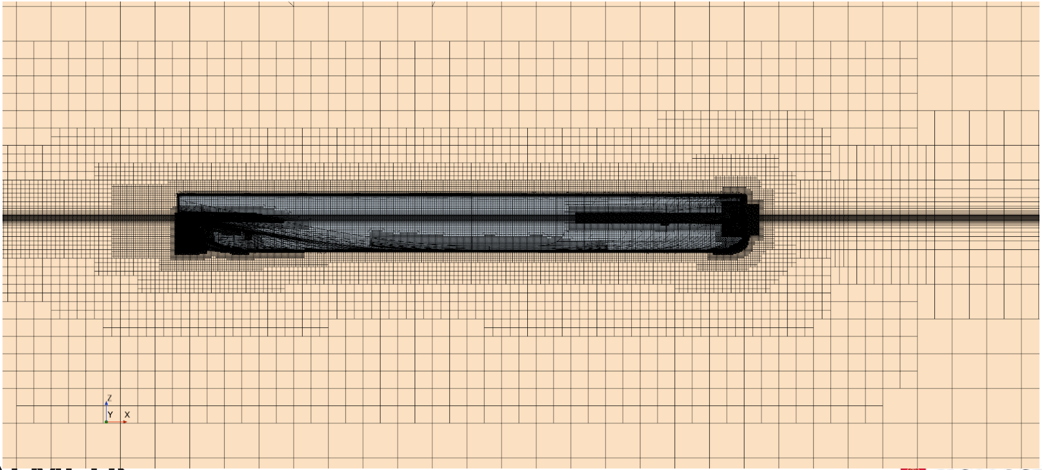
Test Case



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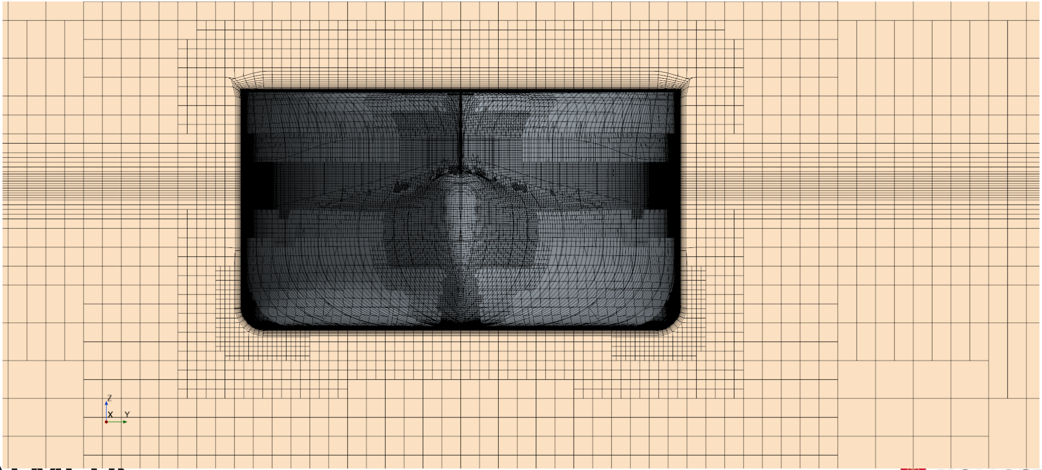

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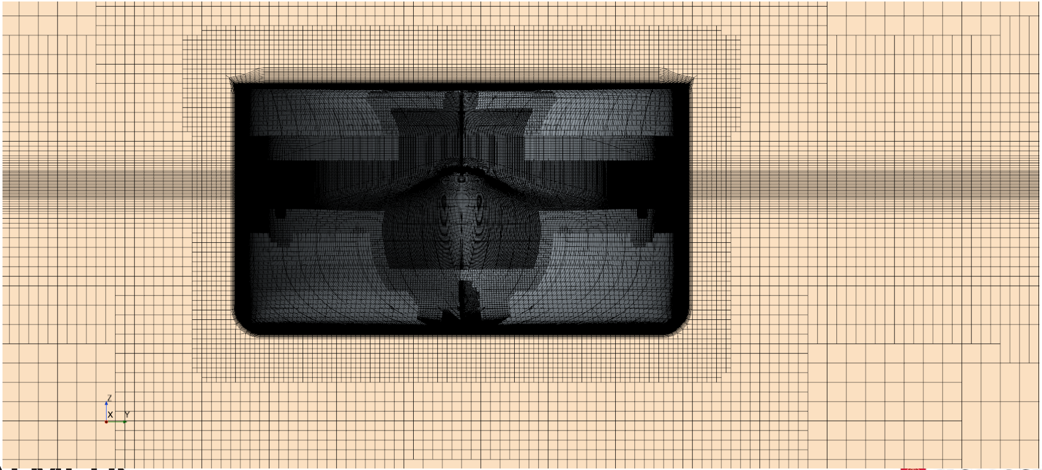

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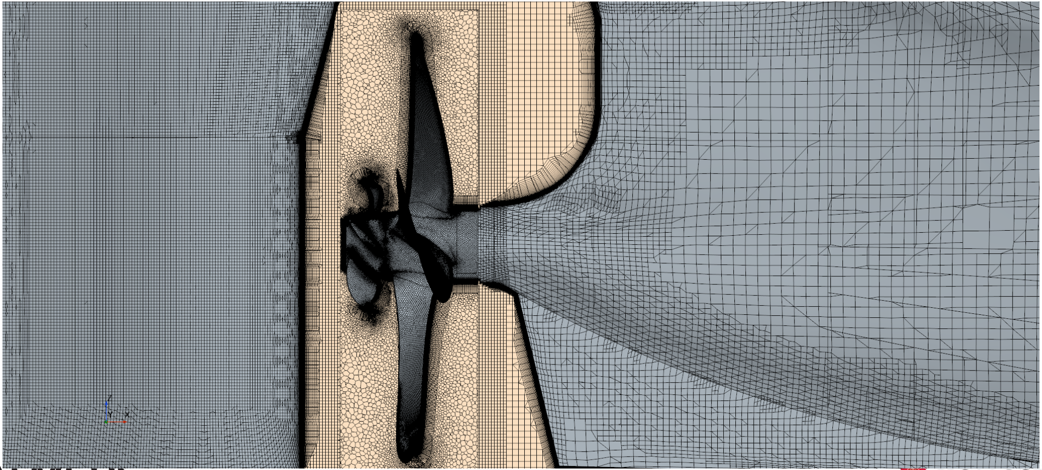
Test Case



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Grid settings

Designation	Grid 5	Grid 4	Grid 3	Grid 2	Grid 1
# of prism layers	20	25	30	35	40
Expansion ratio	1.2	1.157	1.129	1.110	1.095
Growth Layers	4	5	6	7	8
Design refinement ratio	2.0	1.6	1.33	1.14	1.0

Table: Grid settings

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Grid settings

Designation	Grid 5	Grid 4	Grid 3	Grid 2	Grid 1
# of surface faces	150,442	234,286	295,508	396,177	499,010
# of volume cells	3,812,535	7,201,525	10,918,634	17,022,359	24,107,080
Design refinement ratio	2.0	1.6	1.33	1.14	1.0
Surface refinement ratio	1.82	1.46	1.30	1.12	1.0
Volume refinement ratio	1.85	1.50	1.30	1.12	1.0

Table: Double Body without Propeller

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Grid settings

Designation	Grid 5	Grid 4	Grid 3	Grid 2	Grid 1
# of surface faces	239,240	349,212	439,947	574,421	697,023
# of volume cells	5,583,304	10,106,176	15,213,482	23,522,579	32,535,742
Design refinement ratio	2.0	1.6	1.33	1.14	1.0
Surface refinement ratio	1.71	1.41	1.26	1.10	1.0
Volume refinement ratio	1.80	1.48	1.29	1.11	1.0

Table: Double Body with Propeller

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Grid settings

Designation	Grid 5	Grid 4	Grid 3	Grid 2	Grid 1
# of surface faces	208,936	331,928	424,922	576,462	723,545
# of volume cells	6,264,248	12,133,854	18,950,116	29,773,509	42,243,195
Design refinement ratio	2.0	1.6	1.33	1.14	1.0
Surface refinement ratio	1.86	1.48	1.30	1.12	1.0
Volume refinement ratio	1.89	1.52	1.31	1.12	1.0

Table: Free Surface without Propeller

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Numerical Settings

- Simulations performed in STAR-CCM+ 17.02.008-r8;
- $k - \omega$ Shear Stress Transport (SST) turbulence model with wall functions and all y+ approach;
- Total prism layer thickness selected such that y^+_{avg} ranges from 60 to 120, depending on the grid.
- Second order schemes for space discretisation. Time step selected such that propeller rotation ranges from 1° to 0.5°, depending on the grid, keeping Courant number constant.

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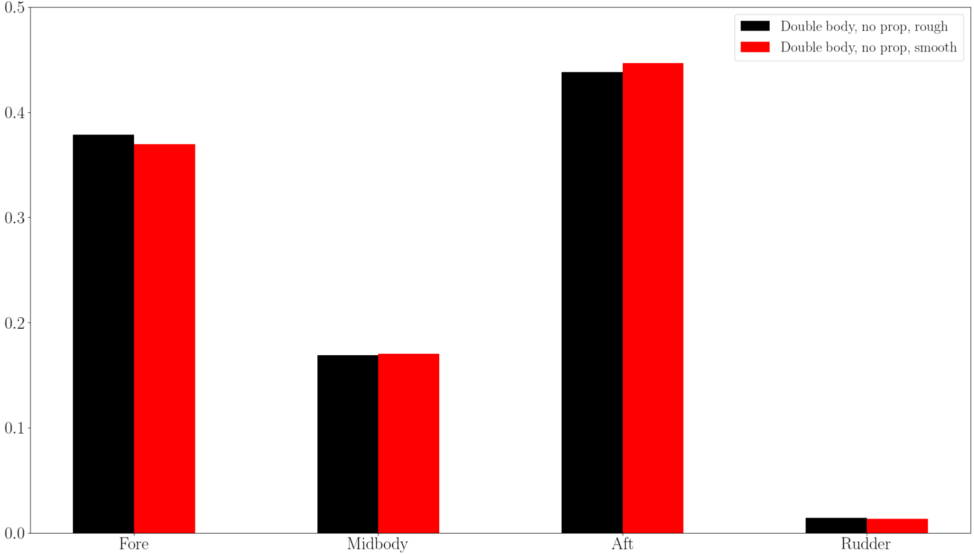
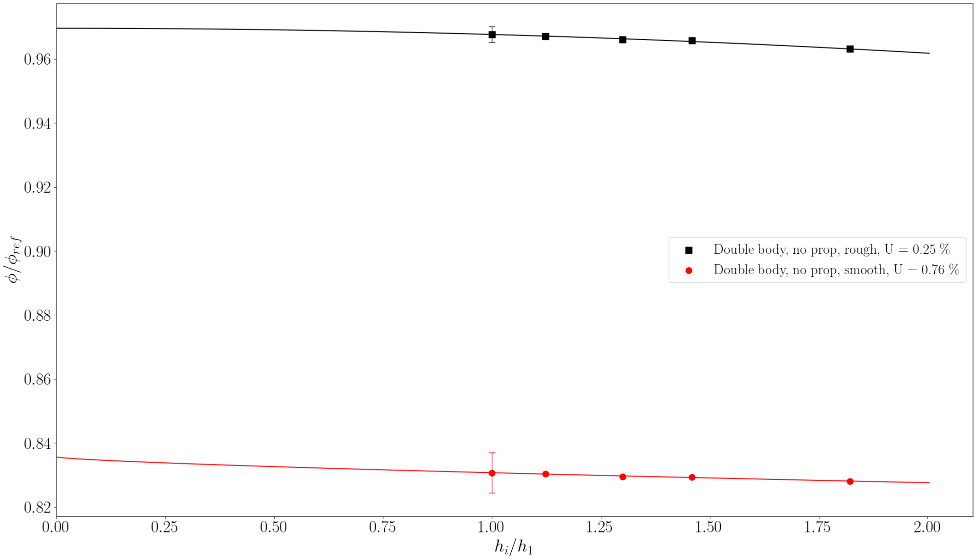
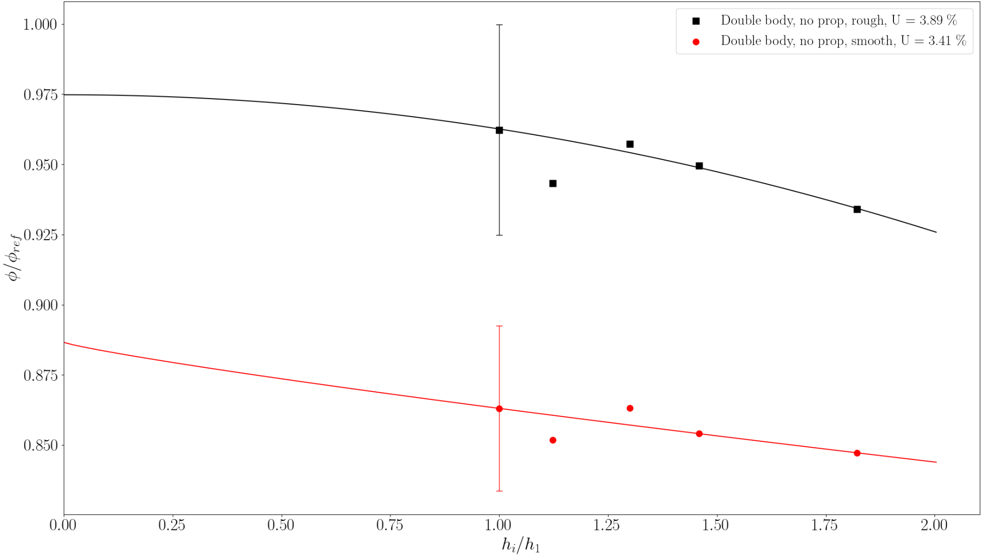
Friction Resistance Split



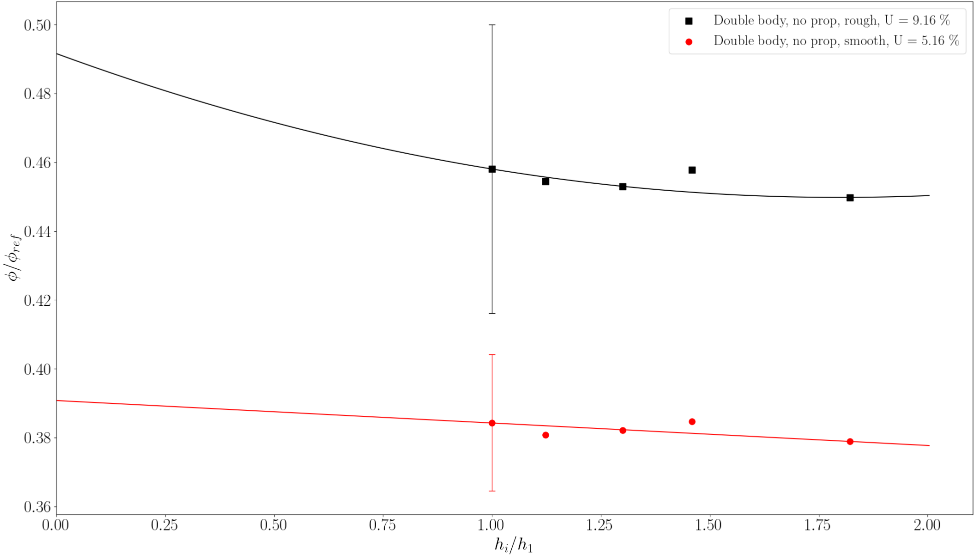
Friction Resistance - Fore



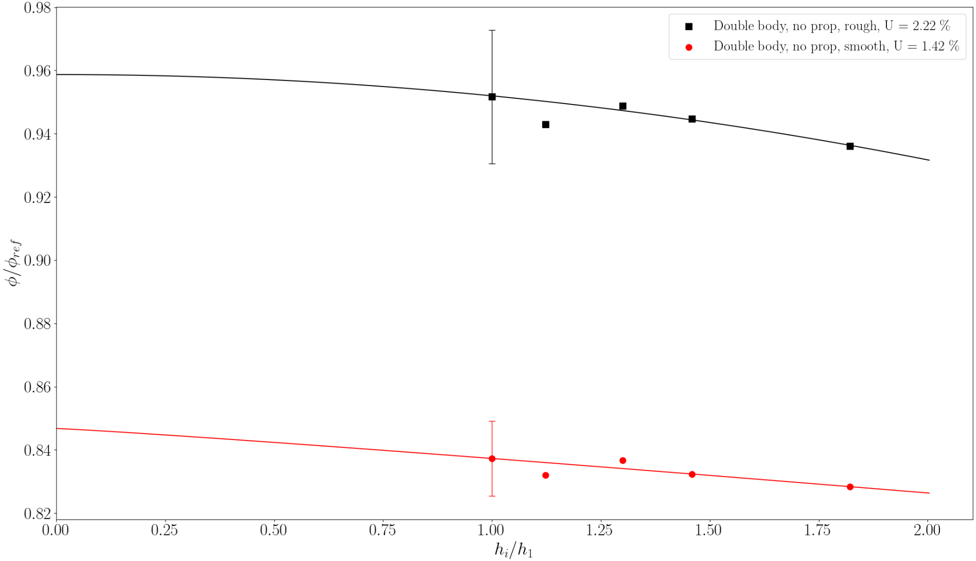
Friction Resistance - Aft



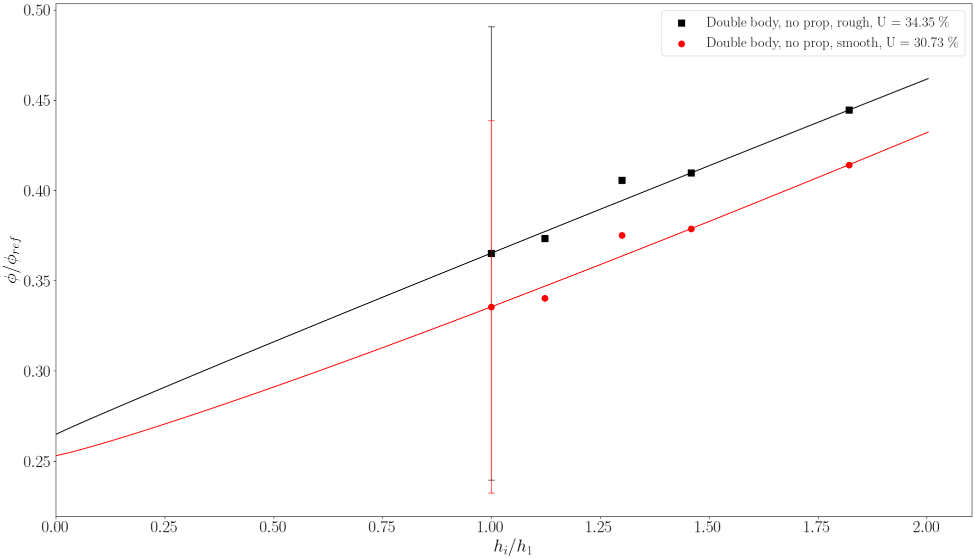
Friction Resistance - Rudder



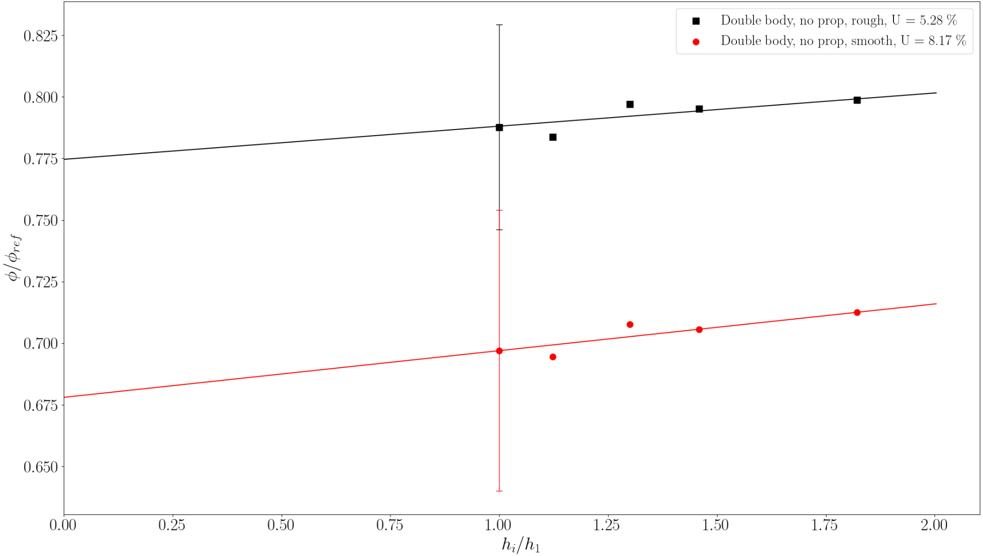
Friction Resistance - Hull



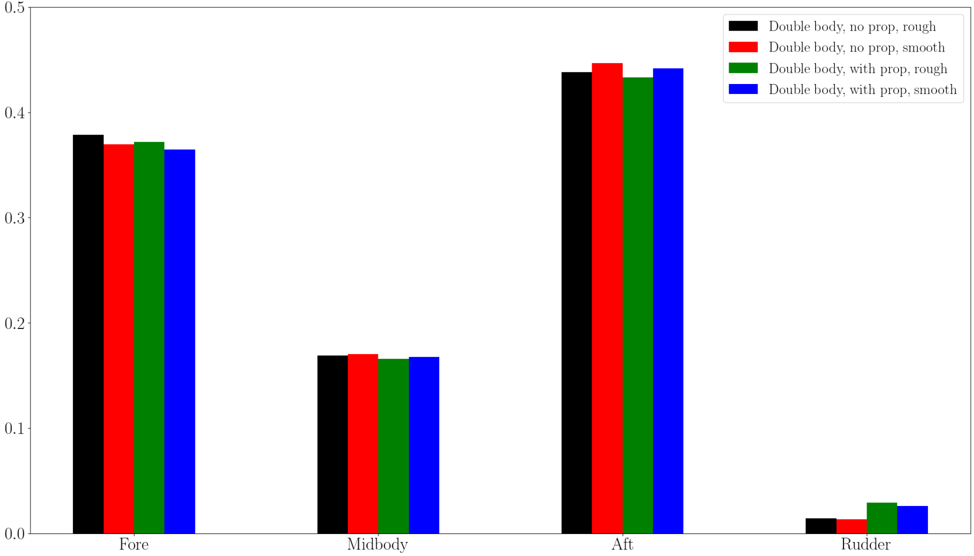
Pressure Resistance - Hull



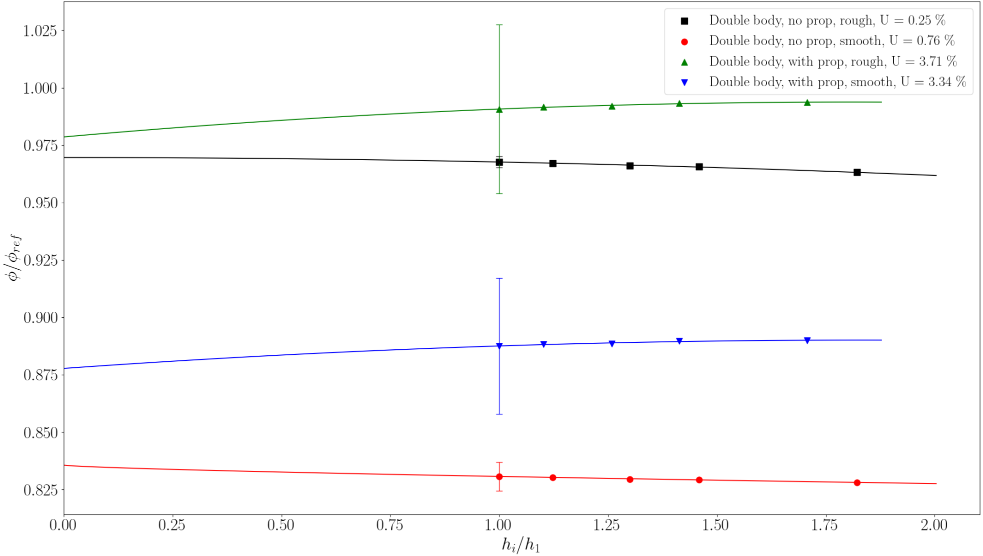
Total Resistance - Hull



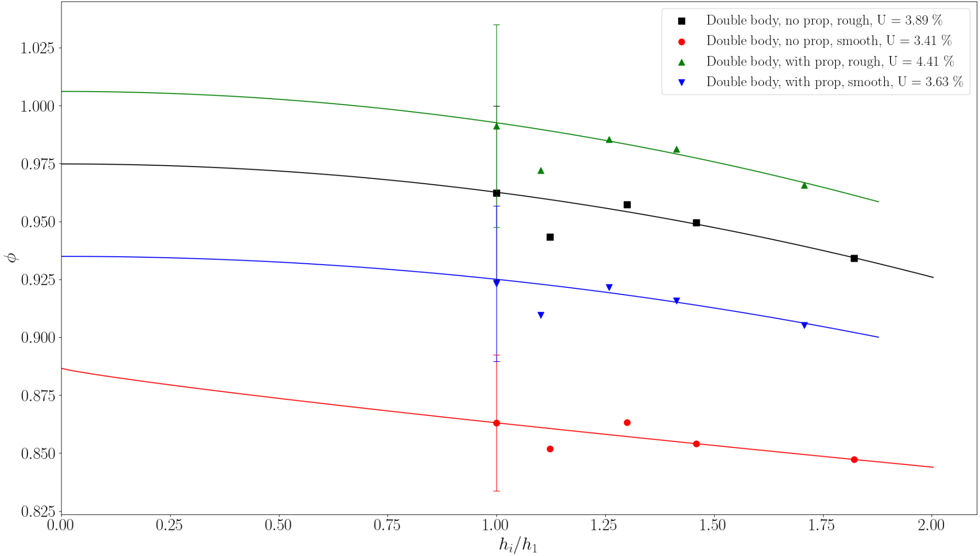
Friction Resistance Split



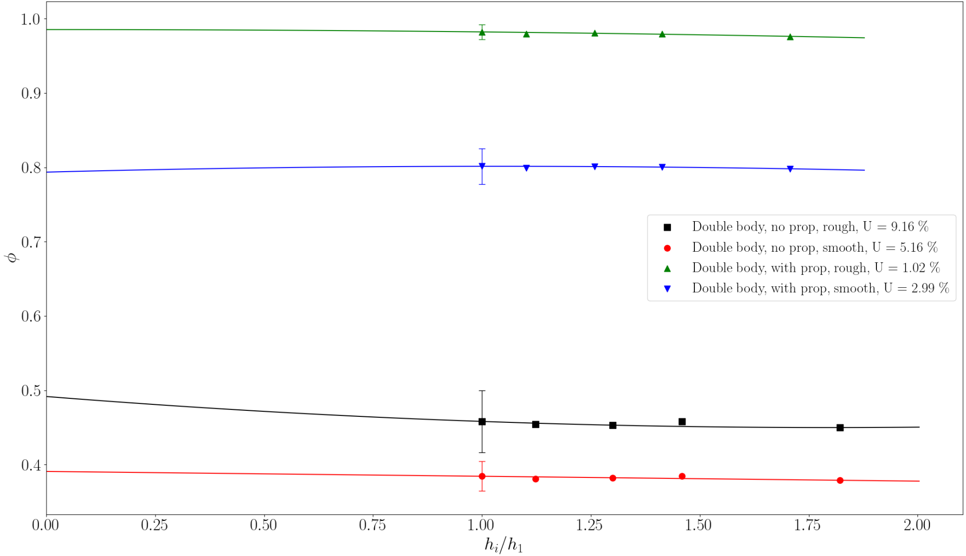
Friction Resistance - Fore



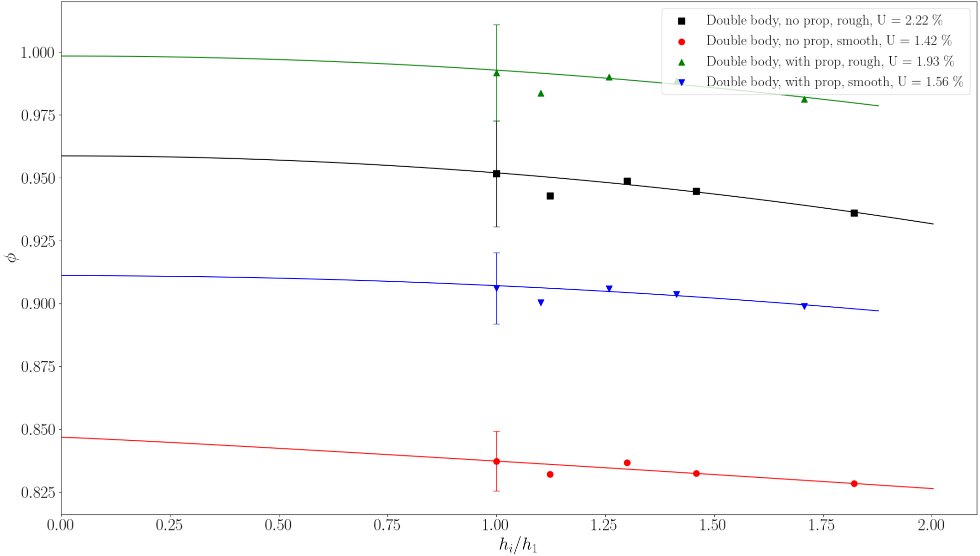
Friction Resistance - Aft



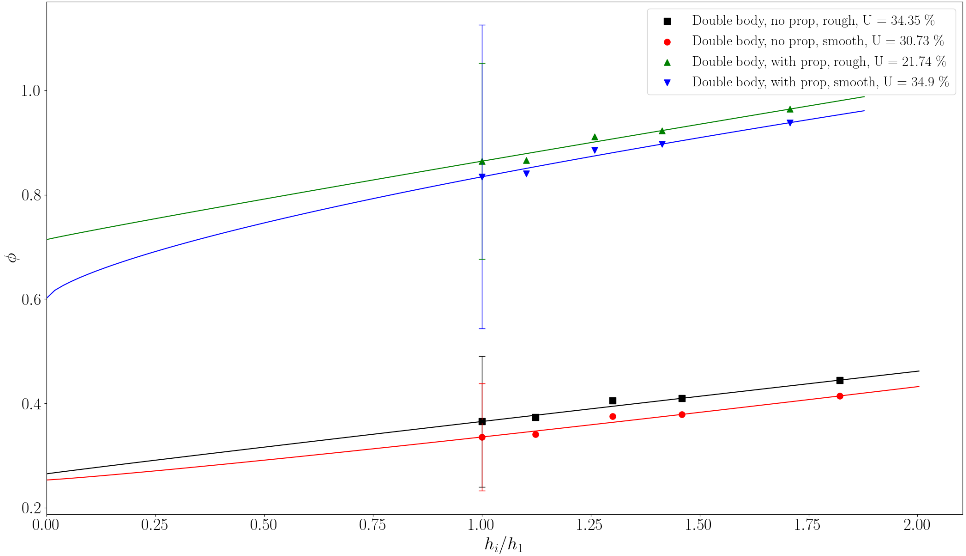
Friction Resistance - Rudder



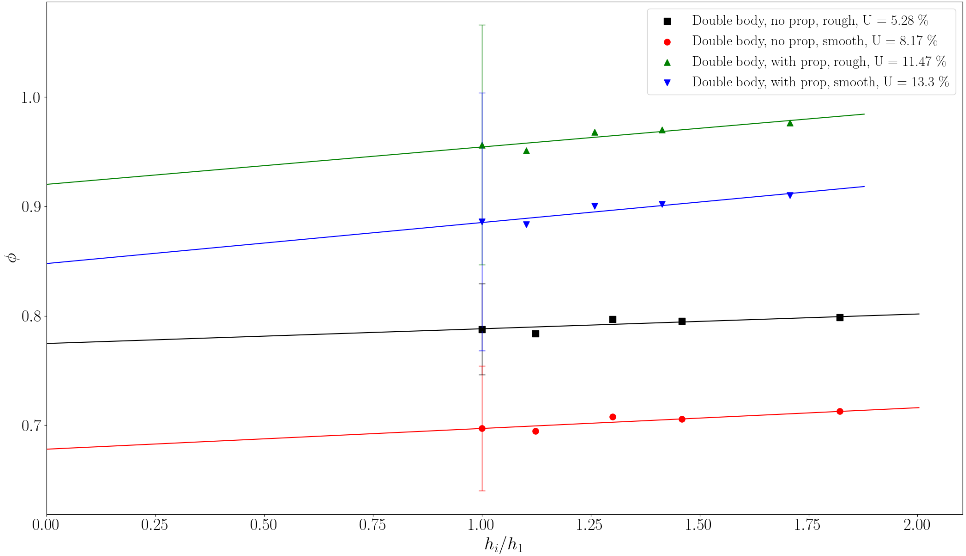
Friction Resistance - Hull



Pressure Resistance - Hull



Total Resistance - Hull



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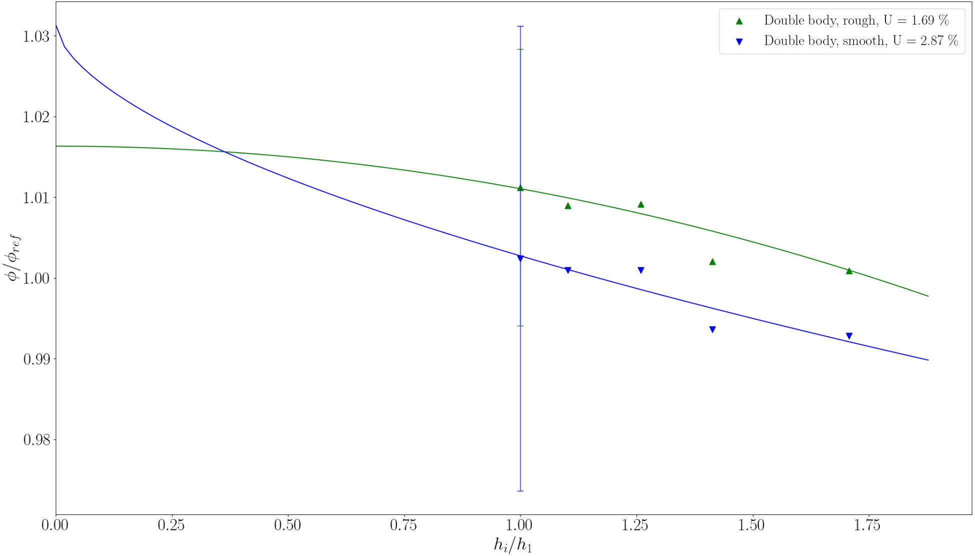
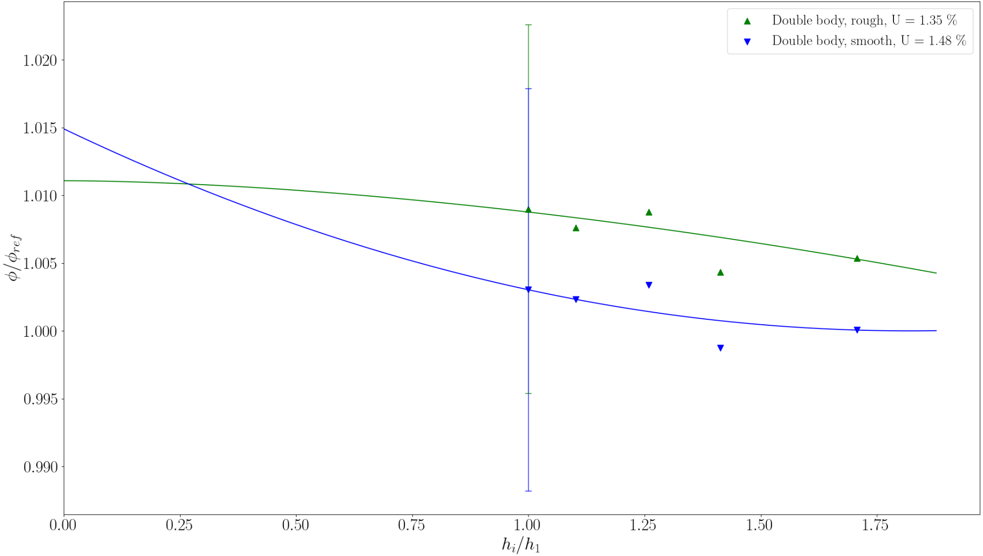
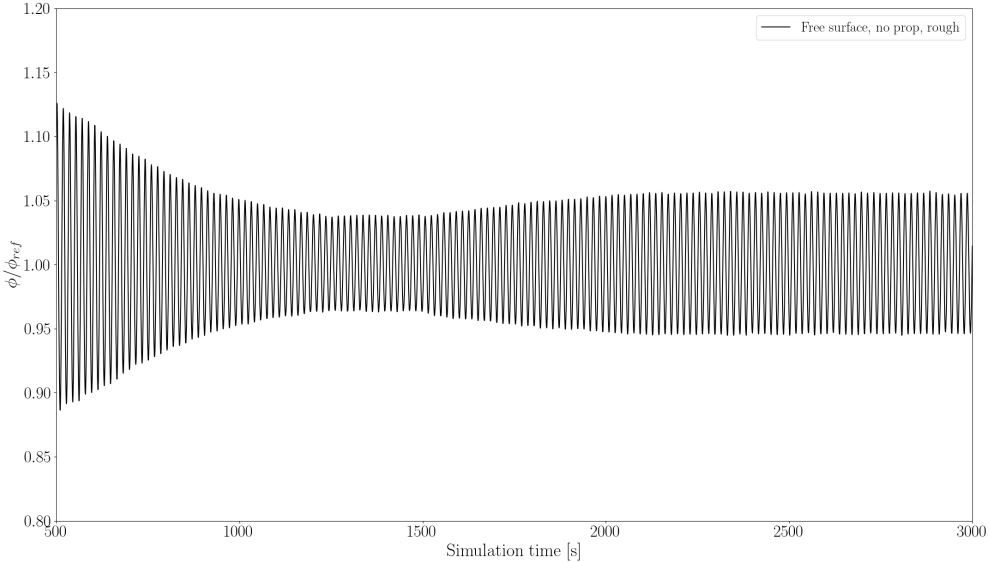
Propeller Thrust



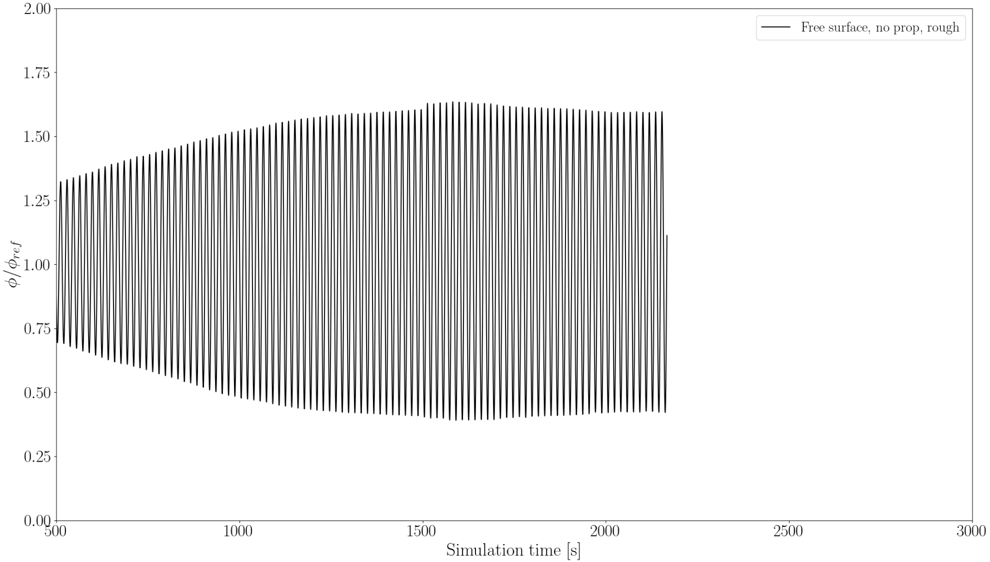
Propeller Torque



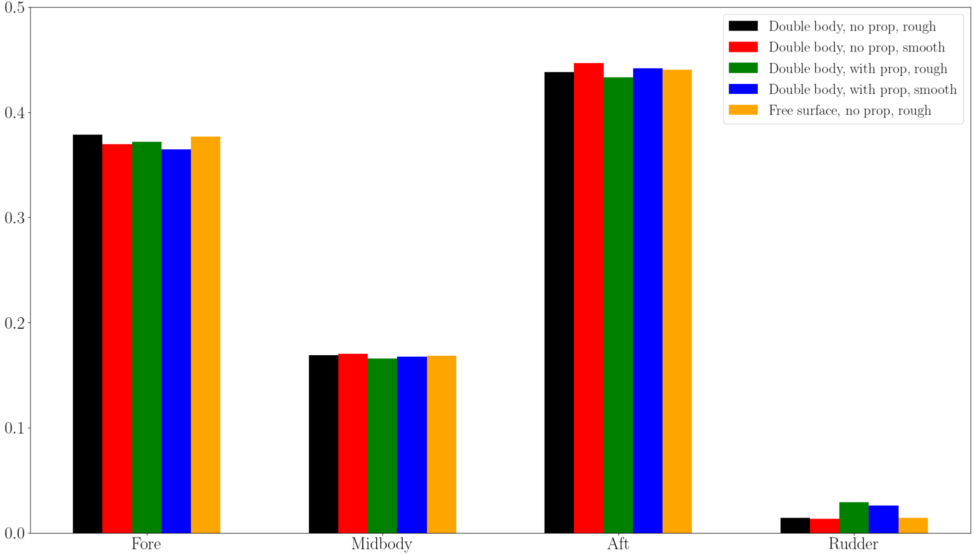
Total Resistance - Hull - grid5



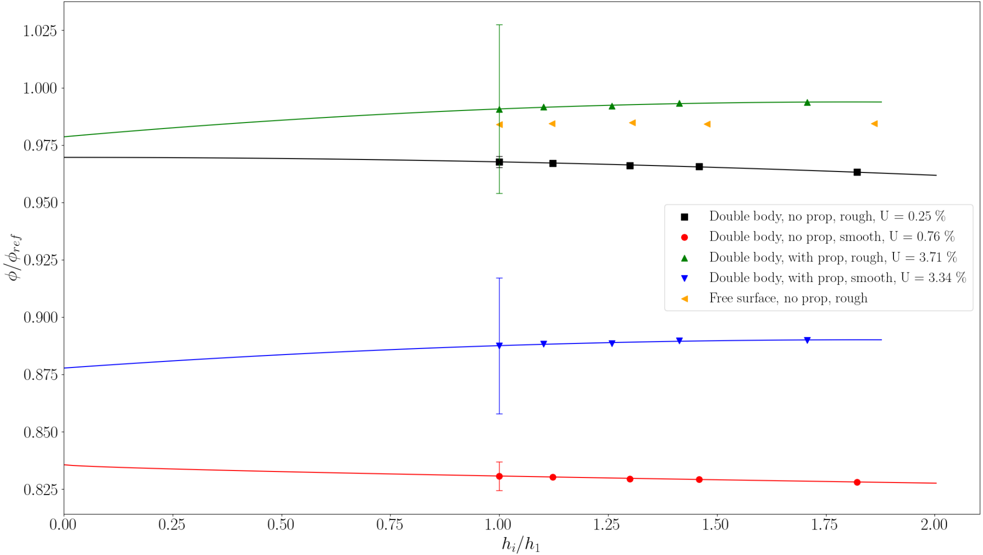
Total Resistance - Hull - grid3



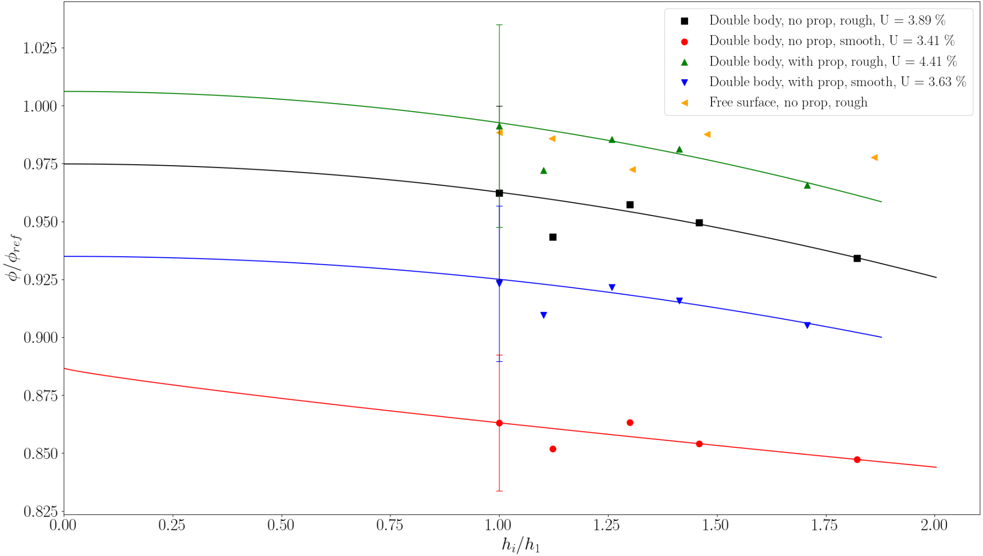
Friction Resistance Split



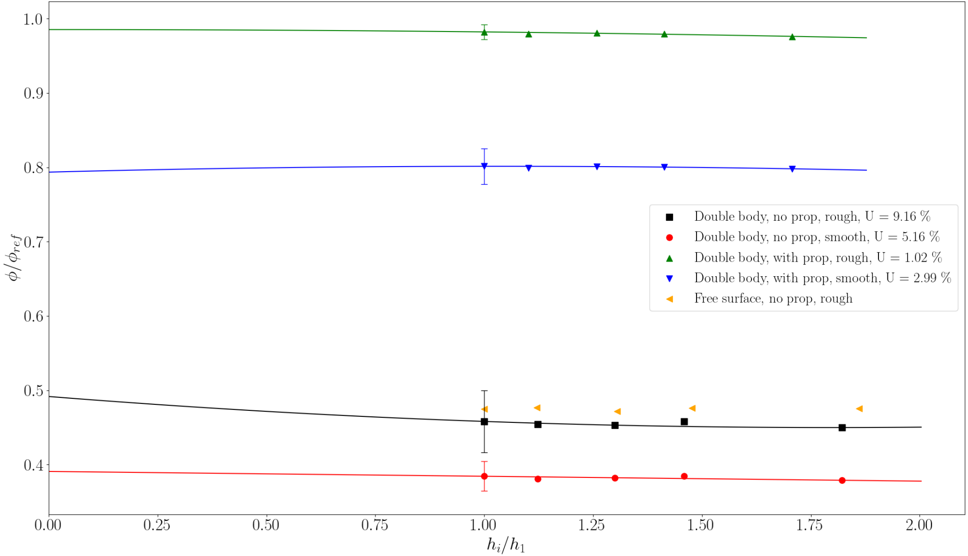
Friction Resistance - Fore



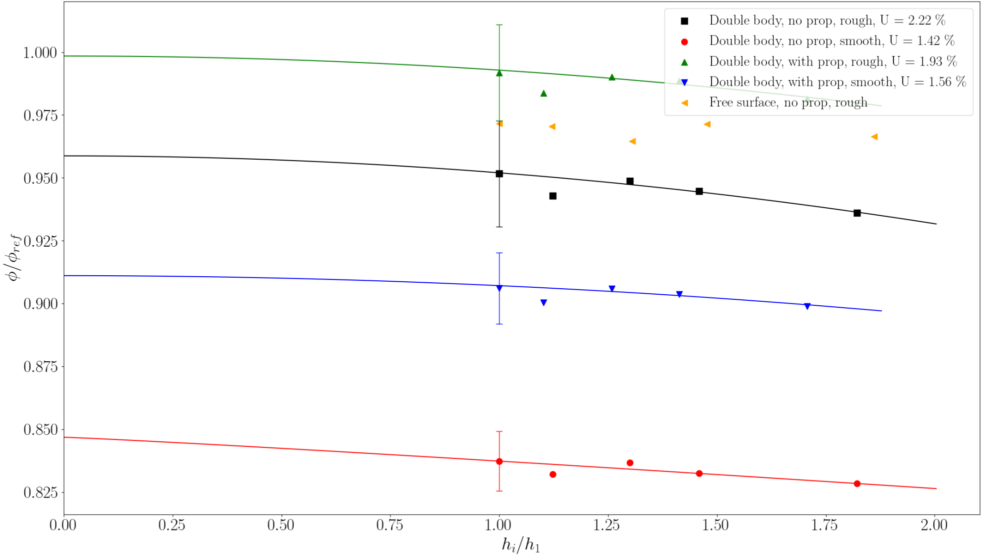
Friction Resistance - Aft



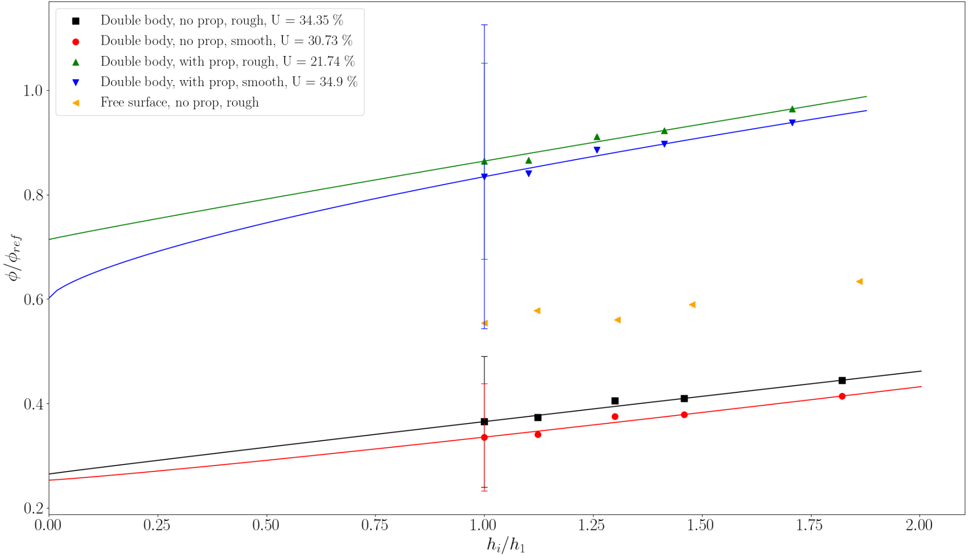
Friction Resistance - Rudder



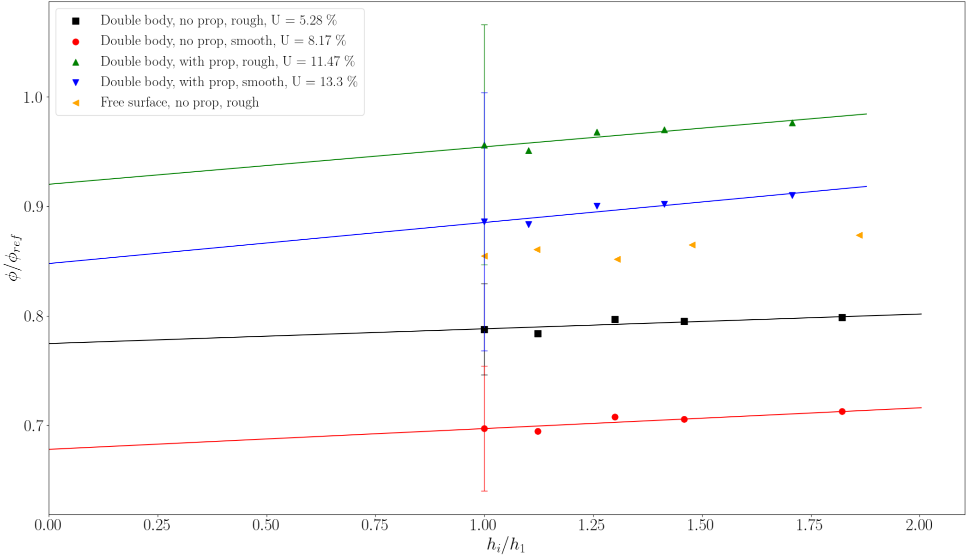
Friction Resistance - Hull



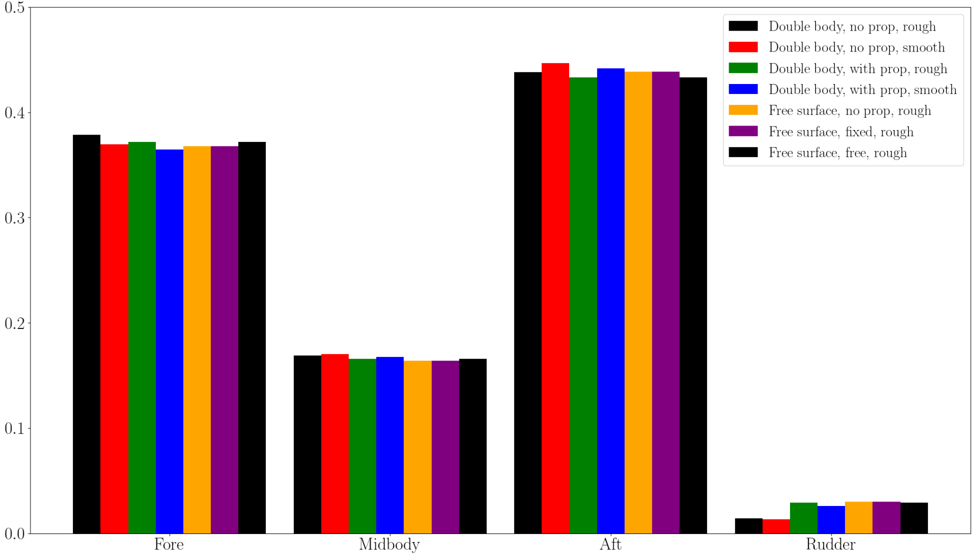
Pressure Resistance - Hull



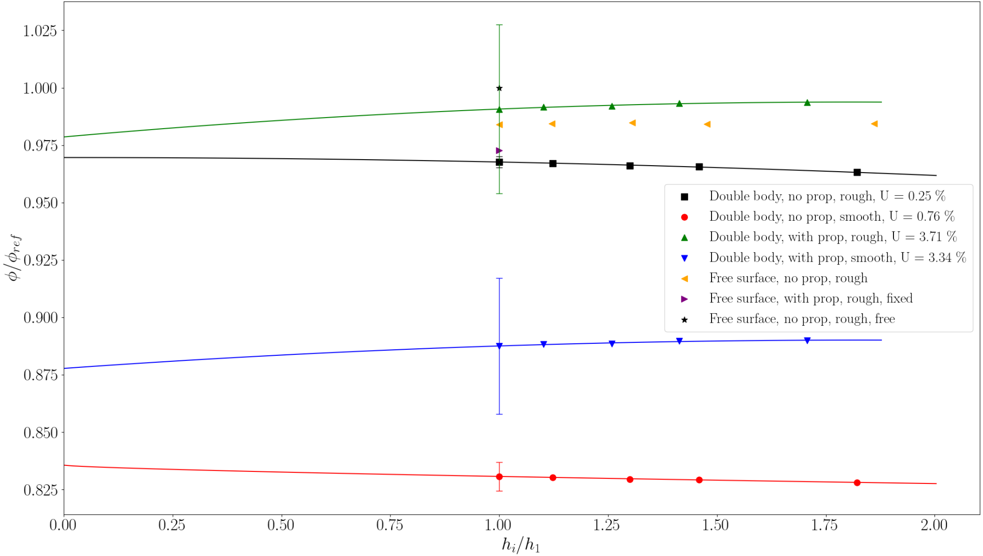
Total Resistance - Hull



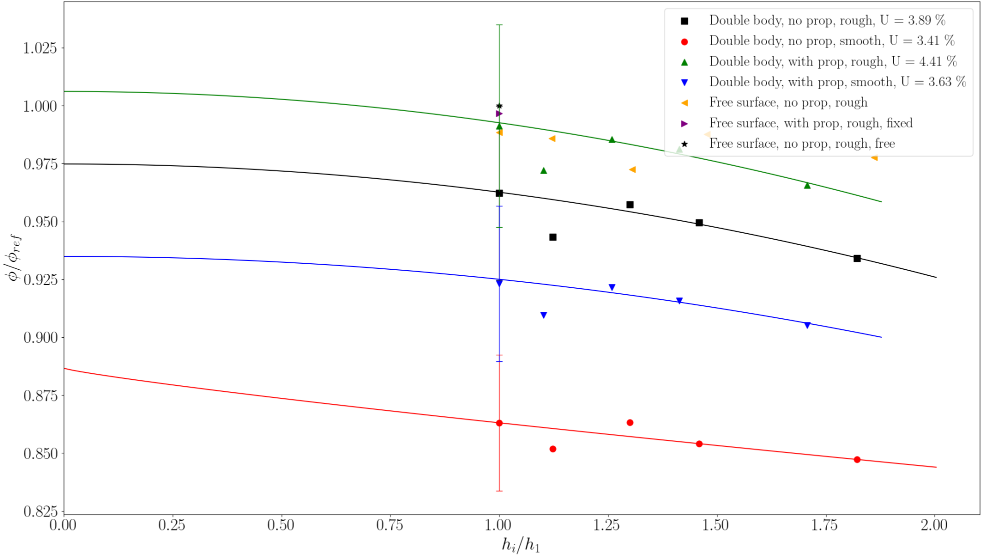
Friction Resistance Split



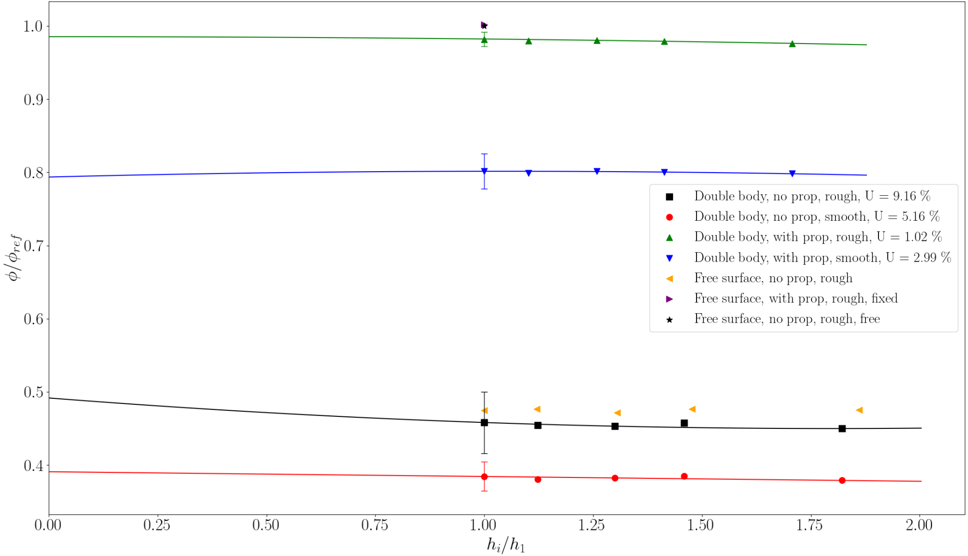
Friction Resistance - Fore



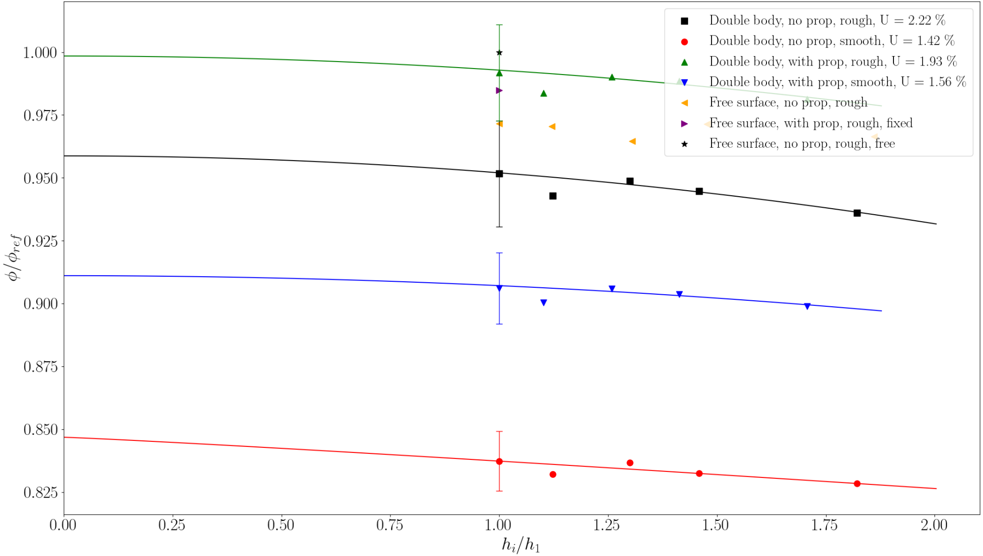
Friction Resistance - Aft



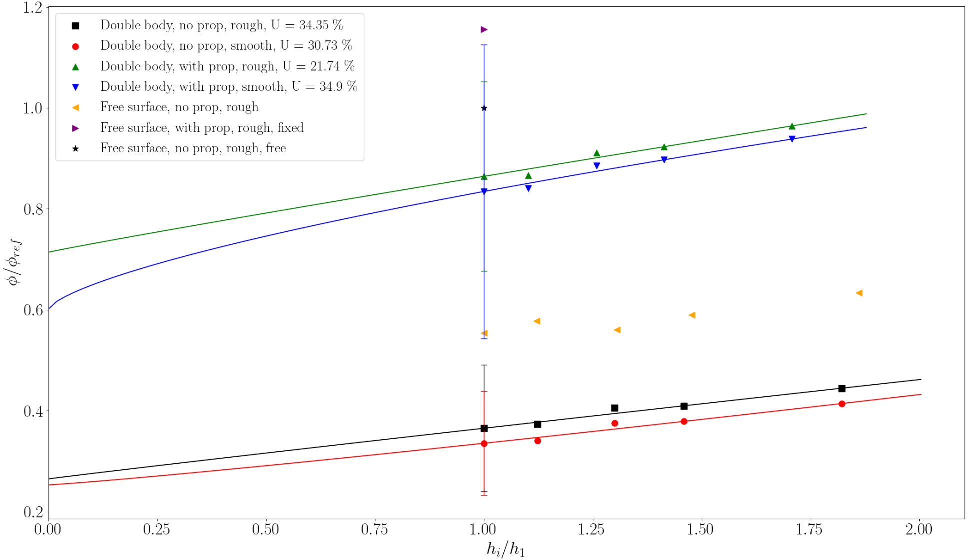
Friction Resistance - Rudder



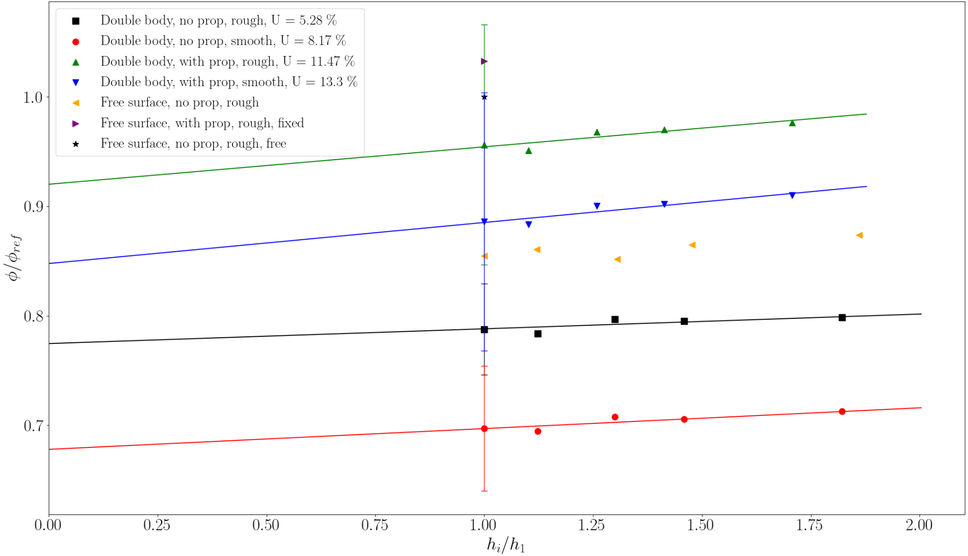
Friction Resistance - Hull



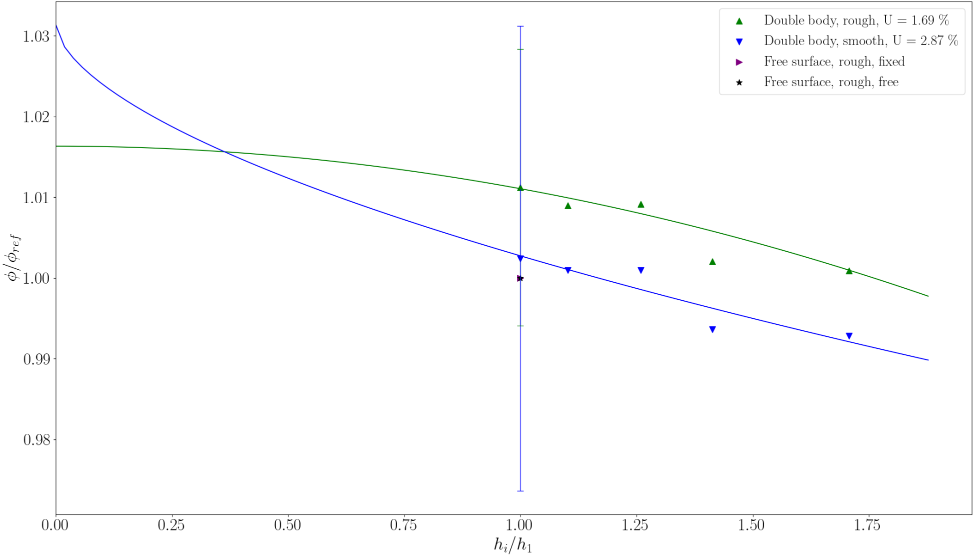
Pressure Resistance - Hull



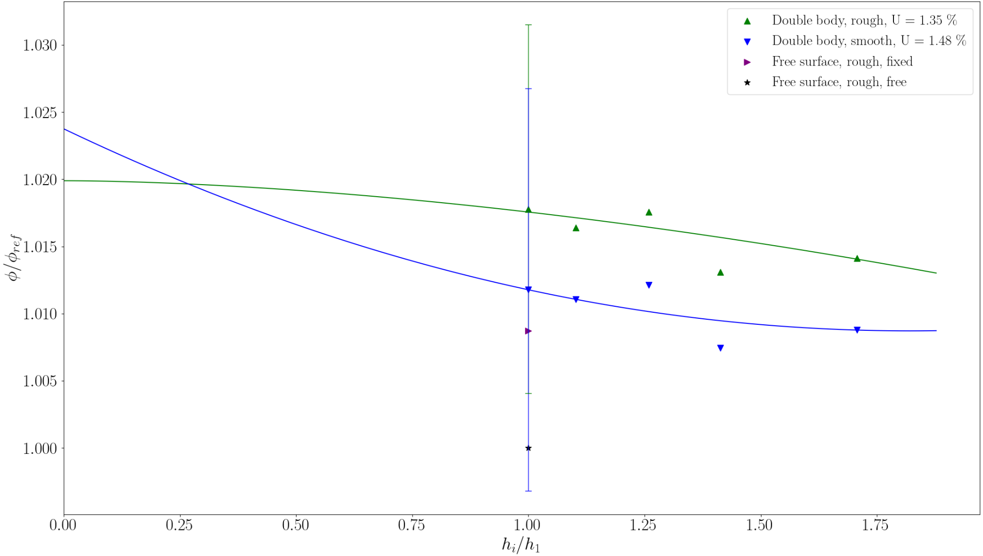
Total Resistance - Hull



Propeller Thrust



Propeller Torque



Conclusions

- Very good friction resistance predictions with double-body setup. Roughness accounts for over 10% of friction resistance;
- Propeller influence on friction resistance is not limited to the aft of the ship. Including the propeller in double-body setup significantly improves pressure resistance prediction.
- Pressure resistance oscillations make statistical convergence extremely difficult when free surface is included. Results seem to indicate that the effect of the free-surface on the resistance is comparable or smaller than the effect of including the propeller.

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Future Work

- Understand mechanism behind pressure oscillations. Is it physical, is it numerical?

- Reliable data for setup with free surface and propeller. Challenging if pressure oscillations are a physical behaviour due to different time scales.

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- The computations were enabled by resources provided by Chalmers e-Commons at Chalmers.
- The WASP-FS project within the Kongsberg UTC at Chalmers is acknowledged as well.

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Thank you for watching

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