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Computational modelling of squat and resistance optimisation in fully confined water

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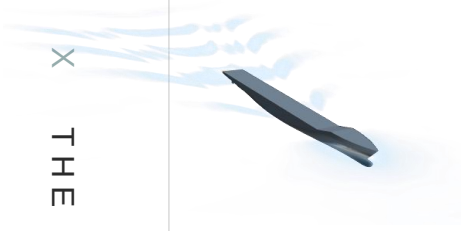


Get to know me at a glance



- **Deputy Editor for Ocean Engineering Journal.**
 - **Editorial Board member of JMSA and EMJT**
 - **Co-author of the Third World Ocean Assessment (United Nations).**
 - **100% green and gold open access research.**
 - **Full datasets available freely or on request.**
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- **Assistant Professor in Naval Architecture at the University of Strathclyde, Glasgow, UK.**
 - **PhD in Naval Architecture, specialising in Computational Fluid Dynamics.**
 - **Teach at University of Strathclyde and at Harbin Institute of Technology, China (Weihai campus).**



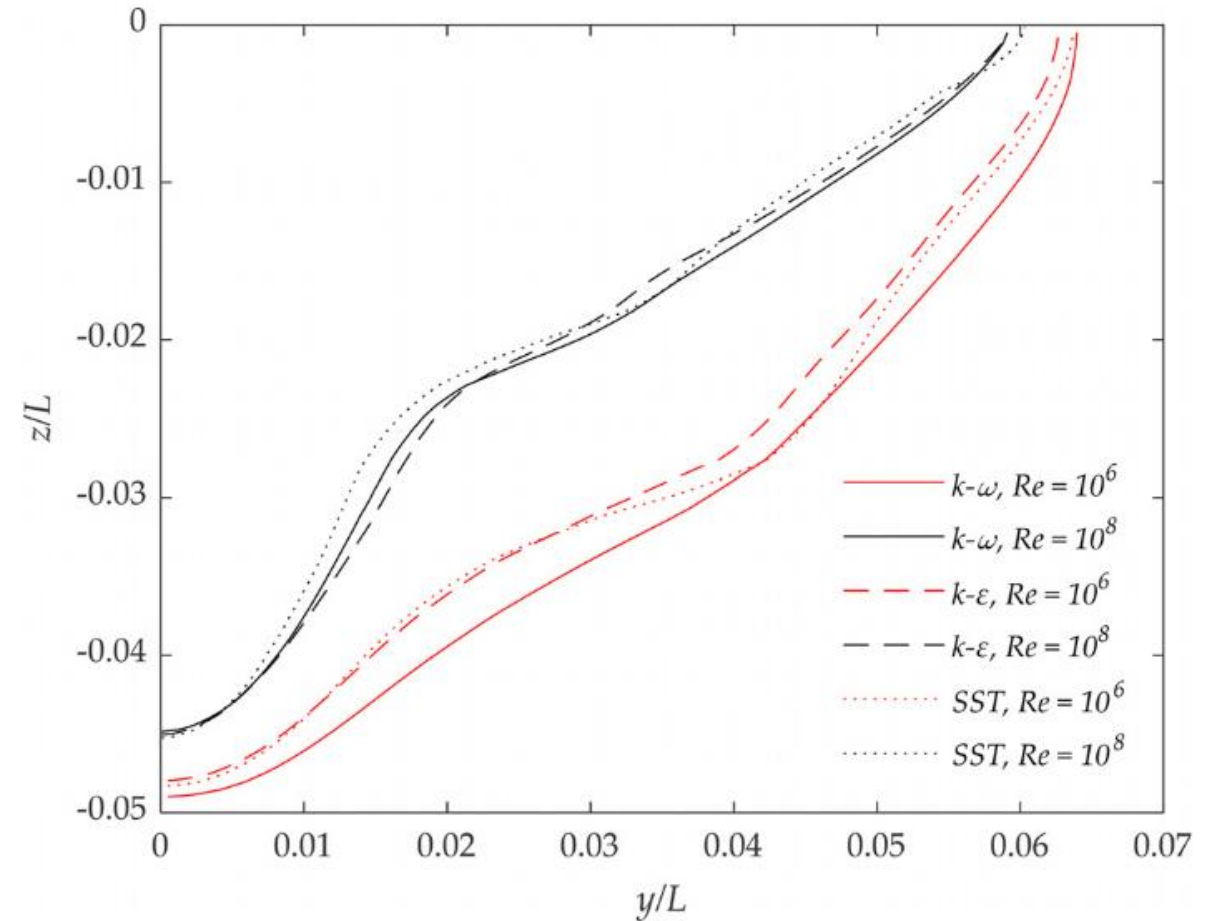


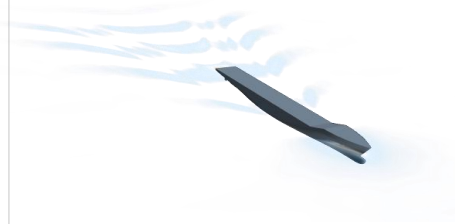
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- Trim optimisation has long been used in deep waters as a technique to improve energy efficiency.
 - Typical savings up to about 5%.
 - Straightforward and well-established procedures based on potential flow.
 - However, our recent work shows that we cannot take for granted the effect of Reynolds number dissimilarities (Le Strat and Terziev, 2025) when trimming a ship (ditto potential flow).
- Viscous effects are magnified in shallow water.

Motivation #1



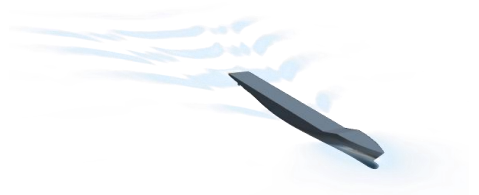


Research questions #1

What does trim optimisation look like in shallow and confined waters?

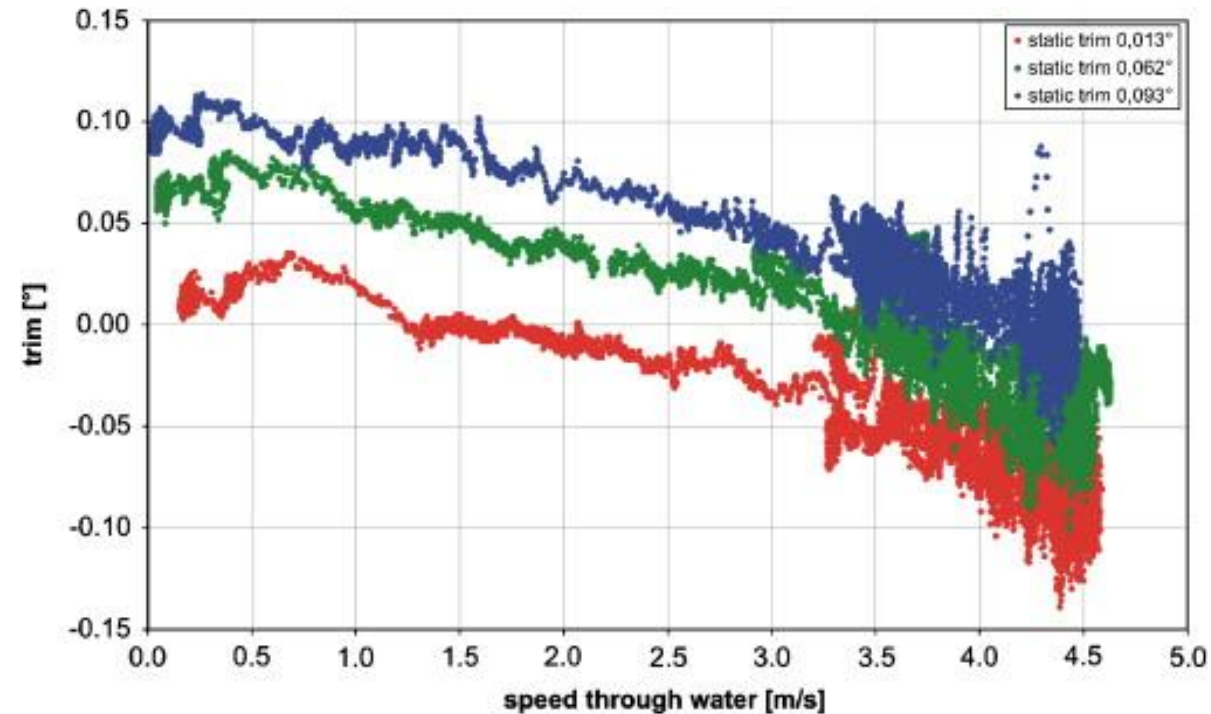
By how much can we expect resistance to reduce?

Are viscous effects really as important as we think and how do we measure this?



- Trim and sinkage or **squat** are generated by the fore-aft imbalance of dynamic pressure.
 - Current practice massively overestimates squat, yet a large number of accident reports mention squat as a contributing factor and many accidents occur in relatively shallow waters.
 - How does initial trim affect squat?

Motivation #2



Research questions #2



What is the interaction between squat and initial trim?

Is the maxim that initial trim is always magnified by squat true?

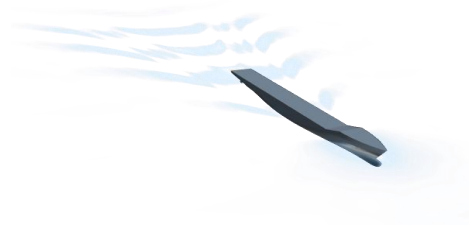
Is it possible to reduce or eliminate squat through initial trim variations?

How much can we influence these dynamic phenomena at low speeds?

What is the interaction between squat and resistance?

Workflow

1. Develop a Computational Fluid Dynamics (**CFD**) model.



2. **Verify and validate** a CFD model of a ship operating in confined waters against experimental data.

3. **Vary the position of the CoG** systematically and re-run simulations.

4. **Vary the blockage** through variations in the depth and width for a constant F_h .

5. **Construct a mathematical model** of the response and use a response surface methodology to find the trade-off between squat and resistance.

6. Begin answering research questions discussed above

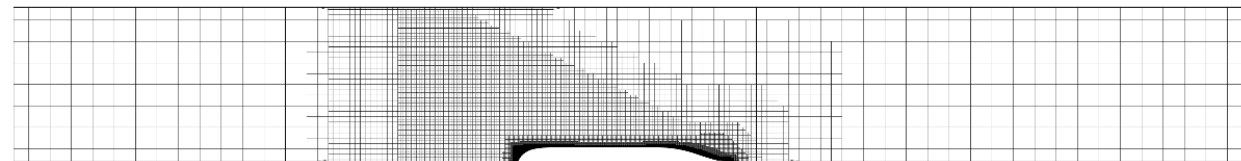
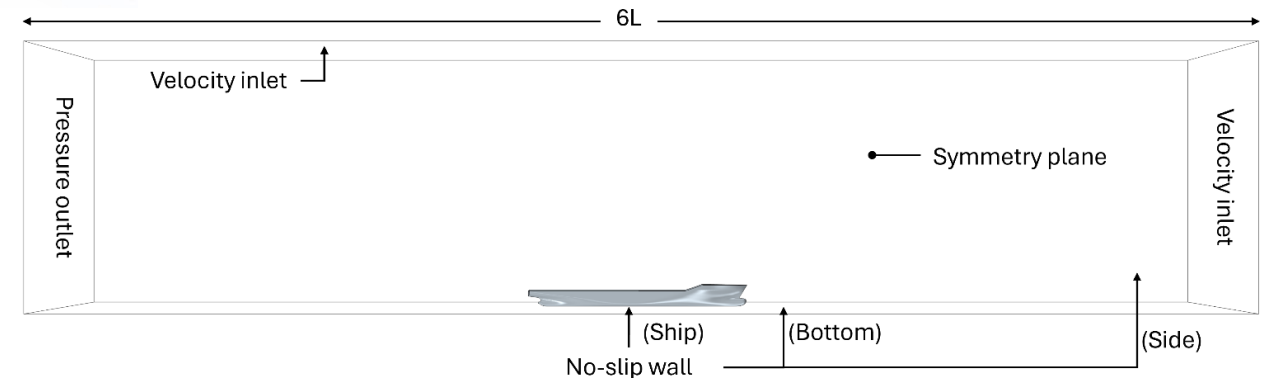
Methodology

1. Develop a Computational Fluid Dynamics (**CFD**) model: *key points for reproducibility*

- High y^+ strategy (50~33), achieved using the methodology set out in Terziev et al. (2022):

$$dy = y^+ \nu / \sqrt{\tau_w / \rho} \text{ and } n = \log[1 - \delta(1 - S)/2dy] / \log(S)$$

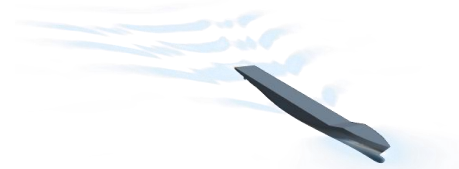
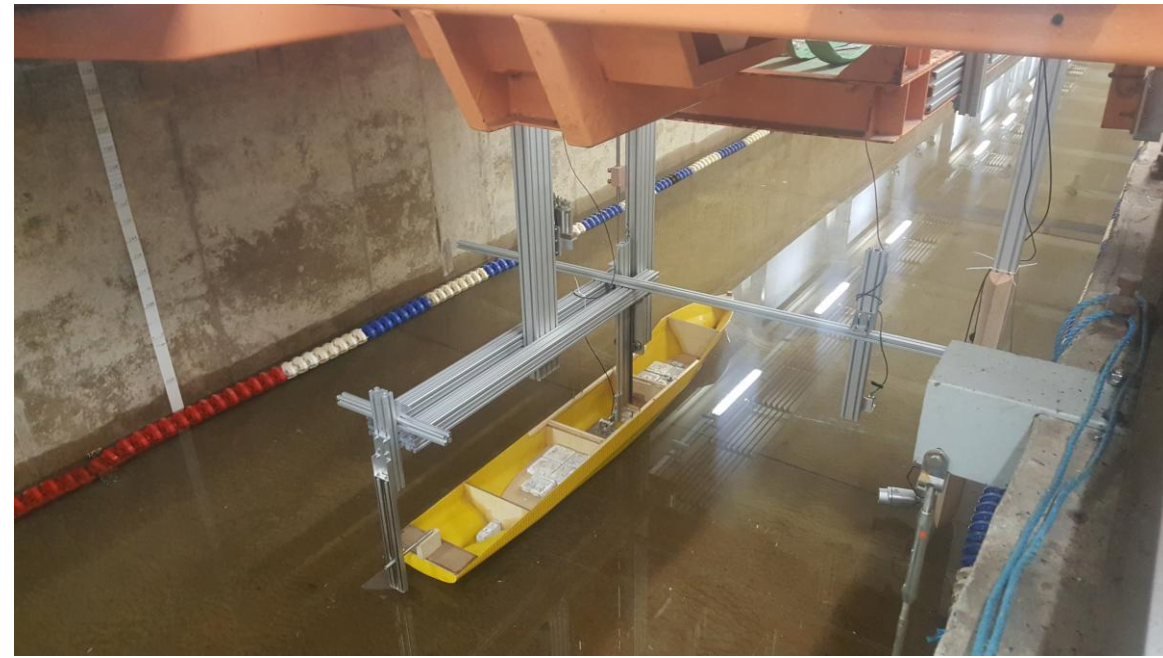
- Standard k - ω turbulence model
- Motion modelled through mesh morphing
- Approximately 10 cells per wavelength on the free surface
- Target ship: KCS
- Replicating experiments by Elsherbiny et al. (2019)



Case studies (1)

- Key features of the Elsherbiny et al. (2019) experiments and CFD implementation:

Elsherbiny, K., Tezdogan, T., Kotb, M., Incecik, A., & Day, S. (2019). Experimental analysis of the squat of ships advancing through the New Suez Canal. *Ocean Engineering*, 178(November 2018), 331–344. <https://doi.org/10.1016/j.oceaneng.2019.02.078>



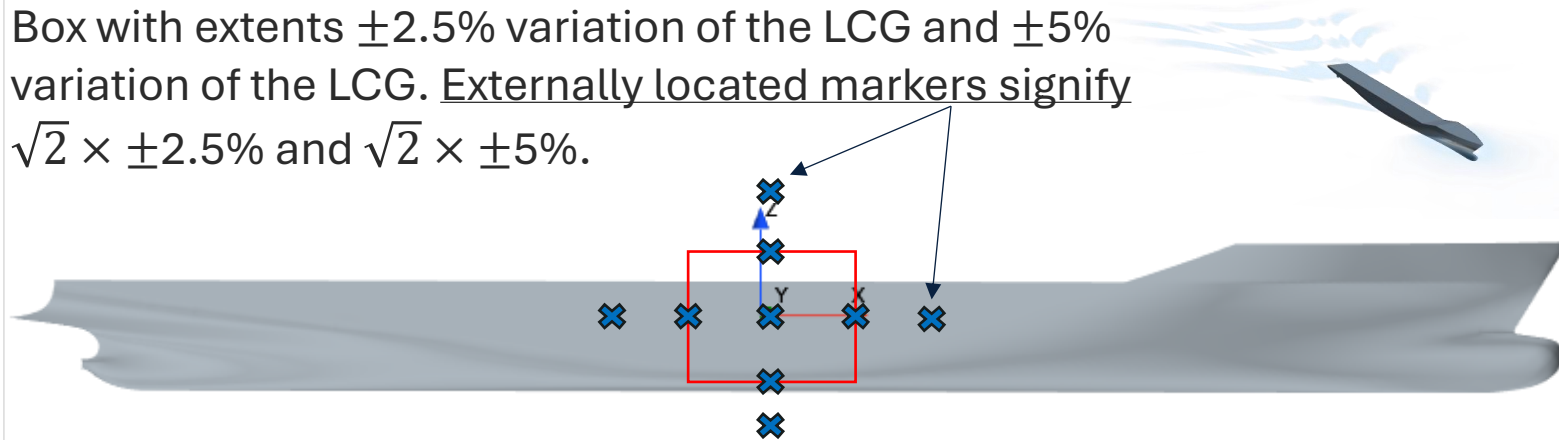
Parameter	Symbol	Full-scale	Model-scale	Units
Scale factor	λ	1	75	-
Ship length	L	230	3.067	m
Beam	B	23.2	0.429	m
Draft	T	10.8	0.144	m
Midship area coefficient	C_M	0.985	0.985	-
Depth-to-draft ratio	h/T	2.22	2.22	-
Width-to-length ratio	w/L	1.5	1.5	-
Depth Froude number	F_h	0.303	0.303	-

Case studies (2)

- Key features of the Elsherbiny et al. (2019) experiments and CFD implementation

LC						Parameter			h/T	w/L	F_h
	LCG (m)	KG (m)	Rx (m)	Ry (m)	Rz (m)	I_{xx} (kgm ²)	I_{yy} (kgm ²)	I_{zz} (kgm ²)			
0*	1.487	0.149	0.134	0.791	0.796	1.099	38.408	38.851	2.22, 2, 1.8	1.5, 1	0.303
1	1.524	0.156	0.135	0.791	0.795	1.111	38.369	38.801			
2	1.524	0.142	0.135	0.791	0.795	1.093	38.351	38.801			
3	1.450	0.156	0.135	0.794	0.798	1.111	38.638	39.070			
4	1.450	0.142	0.135	0.793	0.798	1.093	38.621	39.070			
5	1.434	0.149	0.135	0.795	0.800	1.099	38.773	39.217			
6	1.540	0.149	0.135	0.791	0.796	1.099	38.387	38.831			
7	1.487	0.138	0.133	0.791	0.796	1.092	38.401	38.851			
8	1.487	0.160	0.135	0.791	0.796	1.120	38.429	38.851			

Box with extents $\pm 2.5\%$ variation of the LCG and $\pm 5\%$ variation of the LCG. Externally located markers signify $\sqrt{2} \times \pm 2.5\%$ and $\sqrt{2} \times \pm 5\%$.

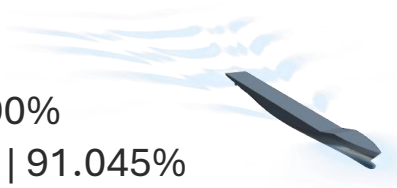


Exaggerated and not to scale

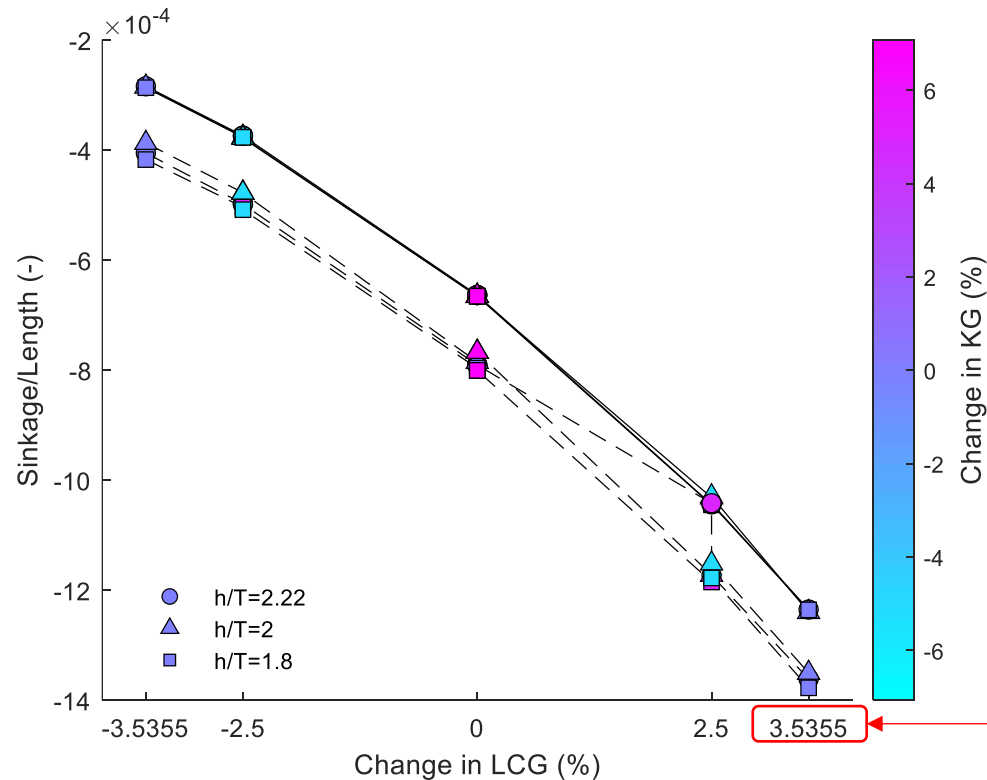
Validation and verification

- Validation and verification was completed following the standard procedures set out by the ITTC.
- The spatio-temporal uncertainty is estimated based on Richardson Extrapolation using the observed order of accuracy which we obtain from a solution triplet.
- Experimental data and uncertainty estimates are from Elsherbiny et al. (2019)

Parameter	Sinkage	Trim	Total resistance
Experimental value	2.09mm	0.022°	1.301N
Fine solution	2.03mm	0.009°	1.278N
Medium solution	2.05mm	0.001°	1.294N
Coarse solution	2.09mm	0.012°	1.317N
Convergence ratio	0.705	0.590	0.443
Observed order of accuracy	2.350	1.52	1.010
Discretisation uncertainty	0.794%	13.752%	3.825%
Experimental uncertainty	3.47% 90%	4.64% 90%	2.2%
Validation uncertainty	3.560% 90.004%	14.514% 91.045%	4.412%
Error (Fine – Experiment)	2.65%	60.02%	1.79%
Validated?	Yes Yes	No Yes	Yes



Results and discussion (1)



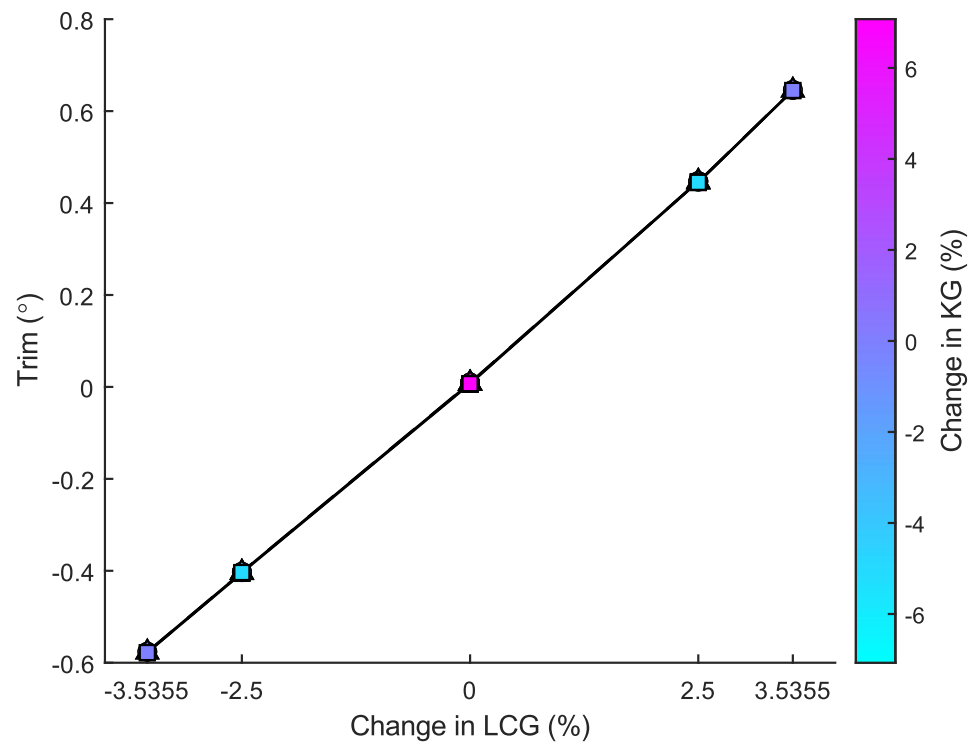
Sinkage is affected **weakly** by changes in KG *if at all*: changes are within 1.5% which is only 2x the discretisation uncertainty and within the experimental uncertainty. We therefore believe it is equally likely that this is a numerical or real effect. We observe some stronger dependencies on the KG when the CoG is moved by 2.5% forward.

Changes in the position of the LCG modify the fore-aft pressure imbalance causing the sinkage to vary by up to a factor of 7.

Equivalent to $\sqrt{2} \times 2.5\%$

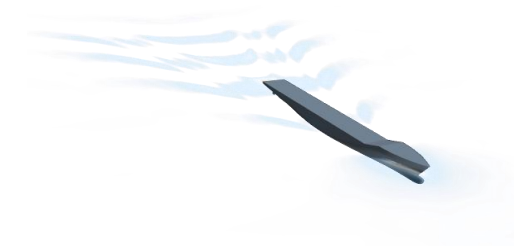


Results and discussion (2)

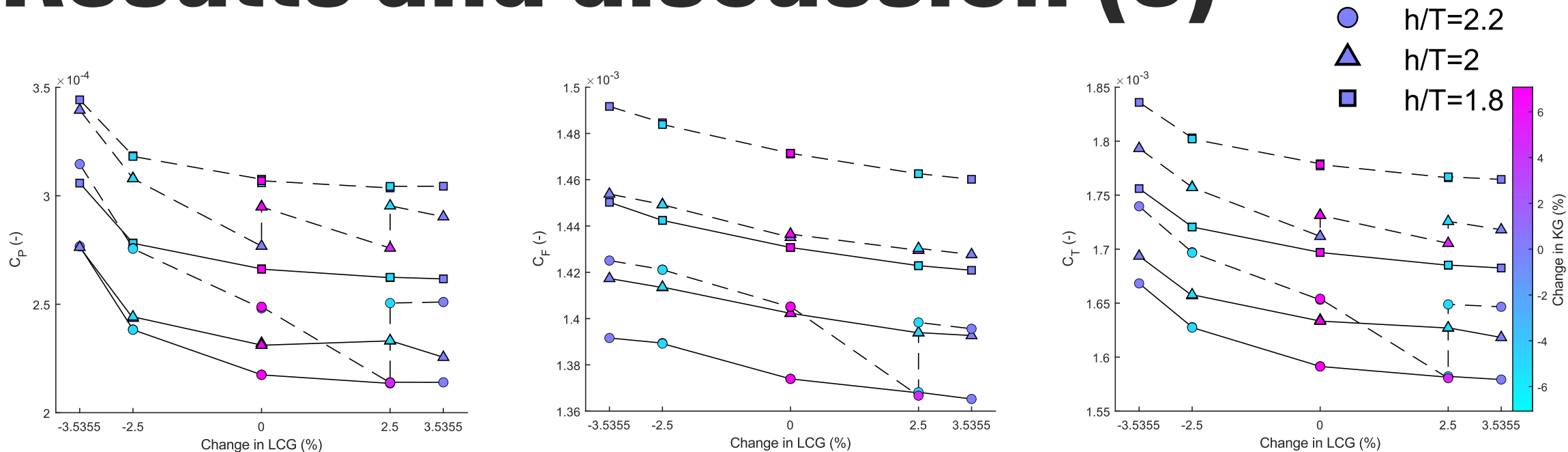


Trim is completely dominated by changes in the position of the CoG. The fore-aft pressure imbalance is insufficiently strong to cause a noticeable change. For reference, the dynamic trim for the basis condition is 0.022° .

The difference due to blockage is in all cases less than 0.2% across all case studies – a value smaller than the discretisation uncertainty ($\approx 13\%$) and experimental uncertainty (90%). It is therefore assumed that the trim is essentially controlled solely by hydrostatics in these cases.



Results and discussion (3)



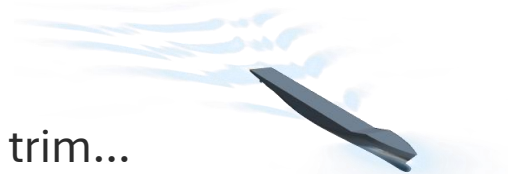
Across the case studies, resistance is always greater when trimmed by stern. The change of the coefficients in that region is predicted to be smooth and relatively simple. As further changes are implemented on the LCG, the KG appears to become more important.

When the CoG is moved forward, the KG becomes a key factor. With higher KGs being better at +2.5% LCG.

Where are these effects coming from if the trim is basically the same?

We postulate that sinkage has more to do with the variation than trim.

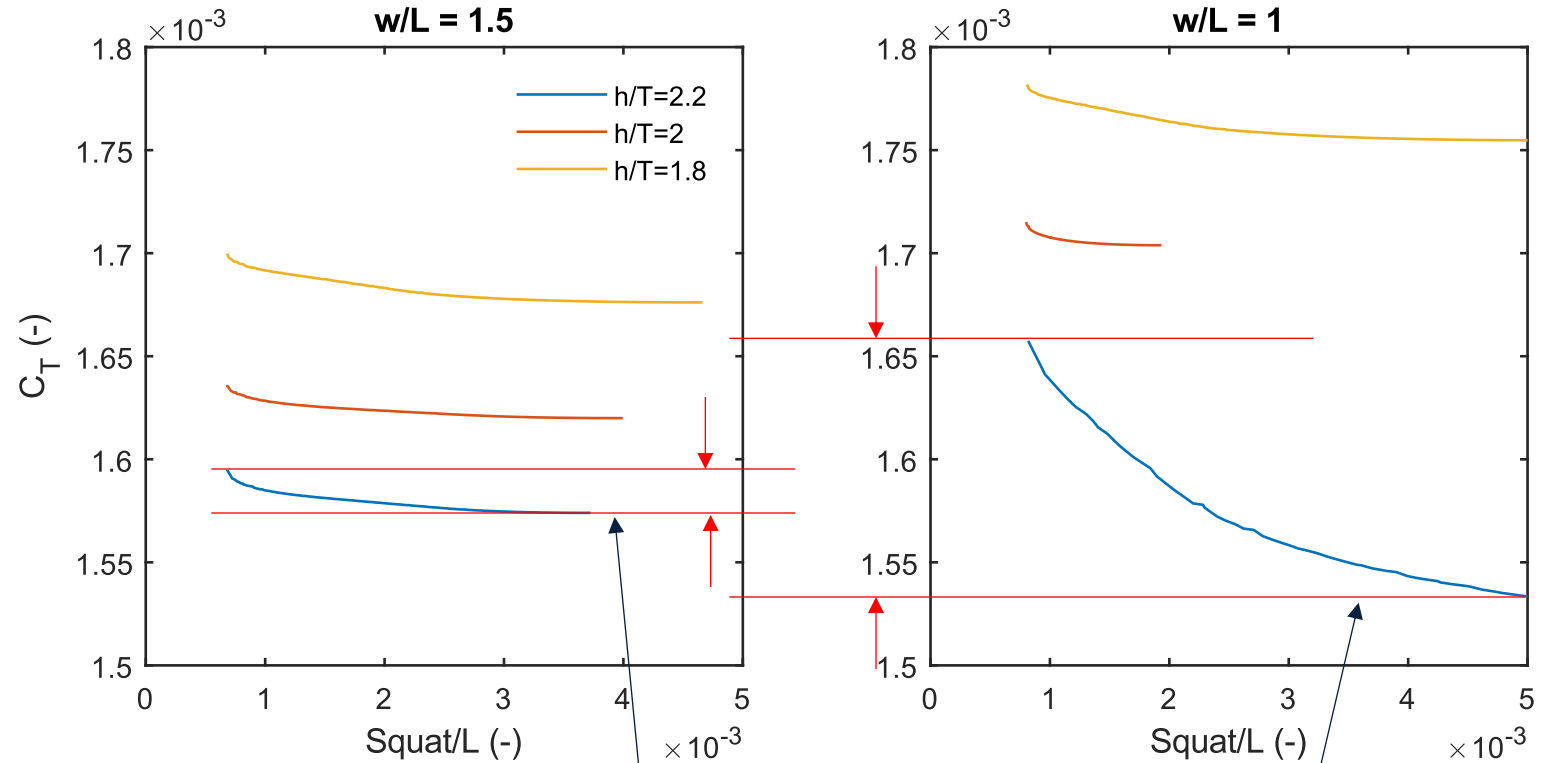
So, we did trim optimisation to find that sinkage has a greater importance than trim...



Results and discussion (4)

Next, we fed all our data into a response surface algorithm which was used as input for a genetic optimiser. We used that to construct pareto fronts of the ship squat vs total resistance. The pareto front gives us the set best achievable trade-offs between the two parameters. This shows us that squat and resistance are inversely related.

An increase in blockage or causes the trade-off to be considerably sharper, particularly when the **velocity** is large even for the same Froude number.



Interestingly, we also predict there are opportunities for savings **if we increase squat** even when the blockage is greater!



Conclusions and future work (1)

Let's recap on the research questions

What does trim optimisation look like in shallow and confined waters?

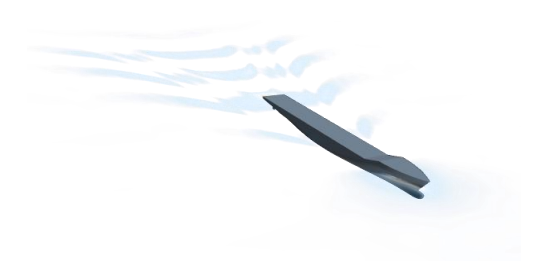
It is much more complicated due to the effects of velocity, depth Froude number, depth, and width

By how much can we expect resistance to reduce?

We predict significant reductions are possible, driven by a combination of sinkage and trim

Are viscous effects really as important as we think and how do we measure this?

Changes in friction are significant, then so are viscous effects.



Conclusions and future work (2)

Let's recap on the research questions

What is the interaction between squat and initial trim?

At low speeds: negligible for trim but not so for sinkage.

Is the maxim that initial trim is always magnified by squat true?

Currently running simulations to determine this.

Is it possible to reduce or eliminate squat through initial trim variations?

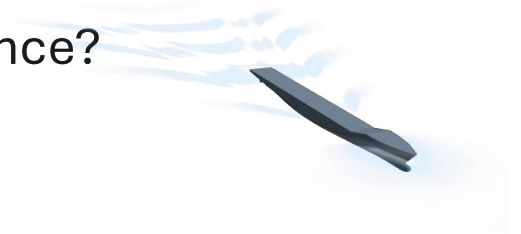
Currently running simulations to determine this.

How much can we influence these dynamic phenomena at low speeds?

We can influence sinkage significantly, but not trim.

What is the interaction between squat and resistance?

It is a trade-off.





Thank you very
much for your
attention

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