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(4)

2D MODEL FOR TRIM OPTIMIZATION OF TUGBOAT DURING BOLLARD PULL

PhD in Marine and Offshore Engineering

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1. INTRODUCTION

The tug boat is used nowadays in many offshore works especially transportation of steel structures, even in ship towing in canals or case of machines breakdown, and the emissions from its sailing are very high for their fast movements and barges pulling to their work locations. It is believed that shipping mobilizes about 90% of the world's trade.
Ships generate 16% of SOX emissions, 15% of NOX emissions, and 3% of world CO2 emissions while transporting such a large volume of cargo [1].
Even though studies employ a variety of approaches, there is strong consensus and ample evidence that a cross all examined global regions, actions to reduce greenhouse gas emissions can have significant health benefits from reduced air pollution. These benefits may even completely offset a sizable portion of the costs associated with mitigation [2].

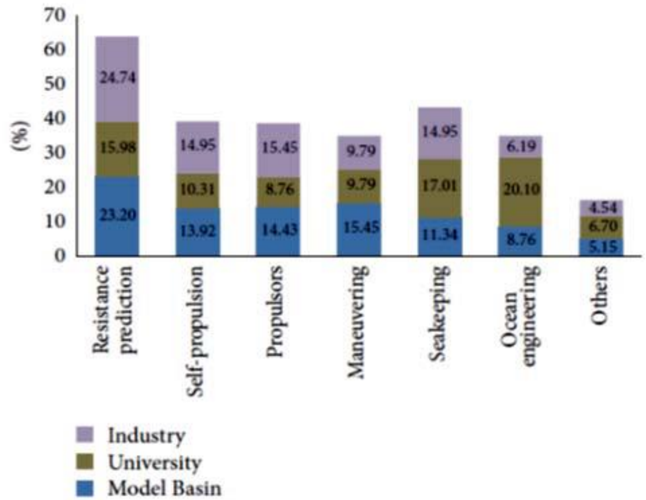

Figure1: Applications of CFD in marine hydrodynamics [3]

- However, the CFD hydrodynamic applications vary from ship resistance, sea-keeping analysis, and self propulsion of ships carried out in commercial and academic research.

3. Literature review :

- Trim optimization resistance prediction outcomes for a KRISO (Korea Research Institute of Ships and Ocean Engineering) Container ship (KCS) model at different trim .

- The best trim angle for the least resistance changes dramatically depending on the draft and speed of the ship. Thus, choosing the ideal trim angle is a dynamic process that, when executed well, may greatly improve voyage economy and save fuel costs [4].

- Trim bow is positive.

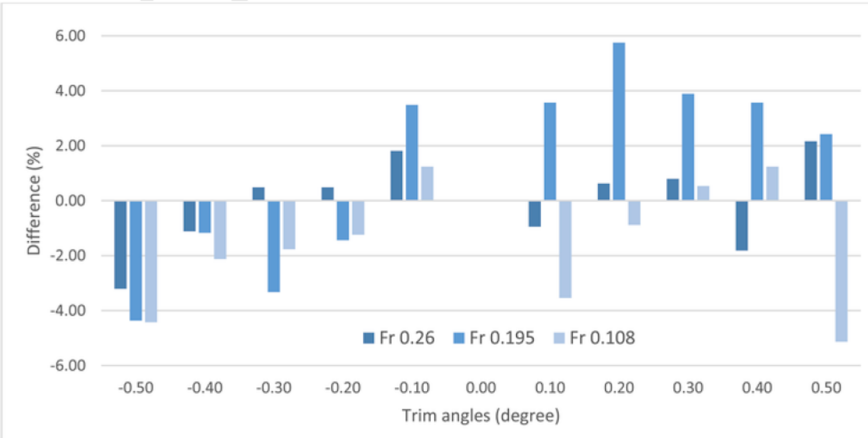

Figure 2: Comparison of calm water resistance of KCS model for different trim angles at different ship speeds

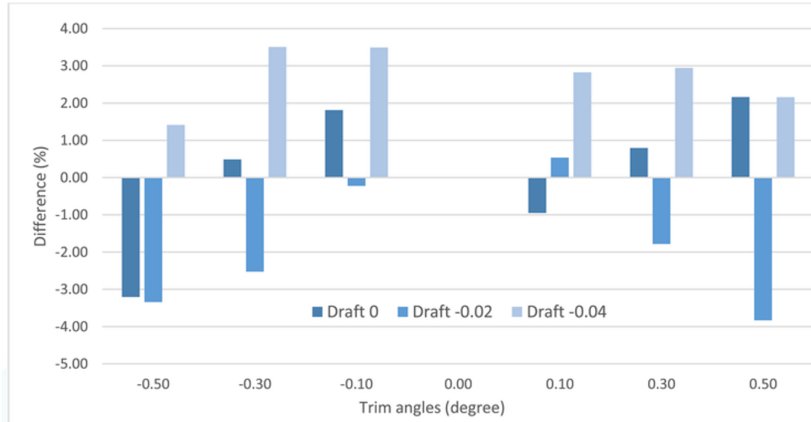

Figure 3: Comparison of calm water resistance of KCS model for different trim angles at different drafts

- The ship that is being studied is a bulk carrier. Three loading scenarios at three different speeds were factored into the computations. Three drafts 8, 9, and 10 m. Three speeds 14, 15, and 16 knots were examined for each draft [5].

- Trim bow is positive.
- Optimum trim at 2 degree aft.

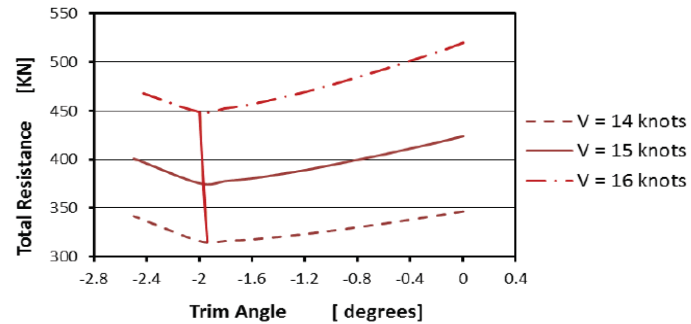

Figure 4: Ship Total Resistance versus Trim Angle for T= 8m

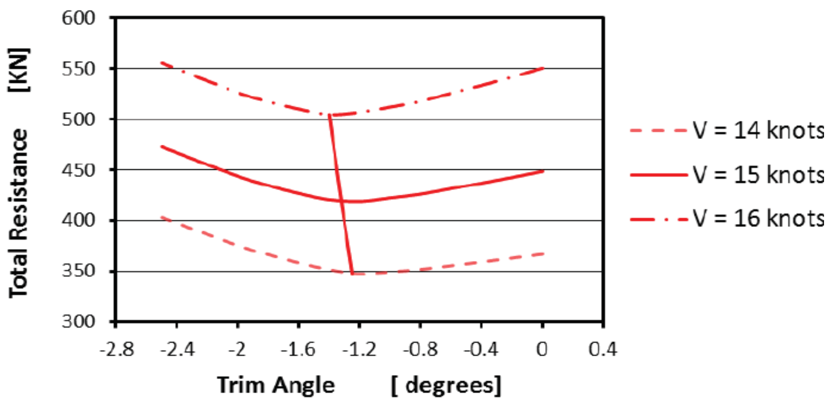

Figure 5: Ship Total Resistance versus Trim Angle for T= 9m

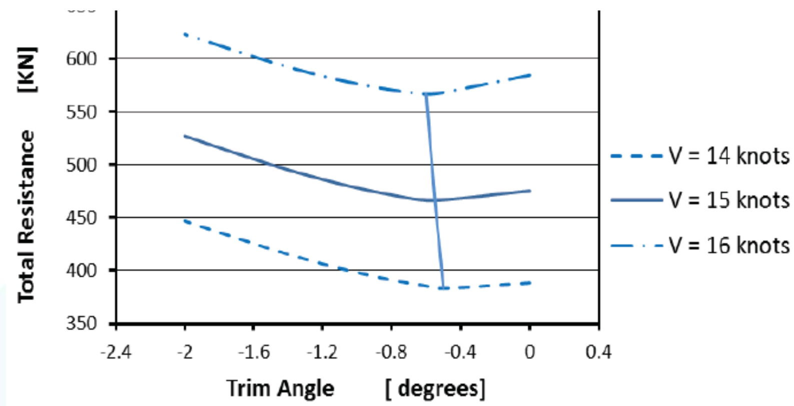

Figure 6: Ship Total Resistance versus Trim Angle for T= 10m

- Oil tanker study according to the findings, fuel savings of 12.30% and 11.70%, respectively, were obtained before and after smoothing in the ballast condition by joint optimization, Under full load circumstances, the fuel savings were 9.47% and 10.18% [6].

- Segments for different weather conditions.

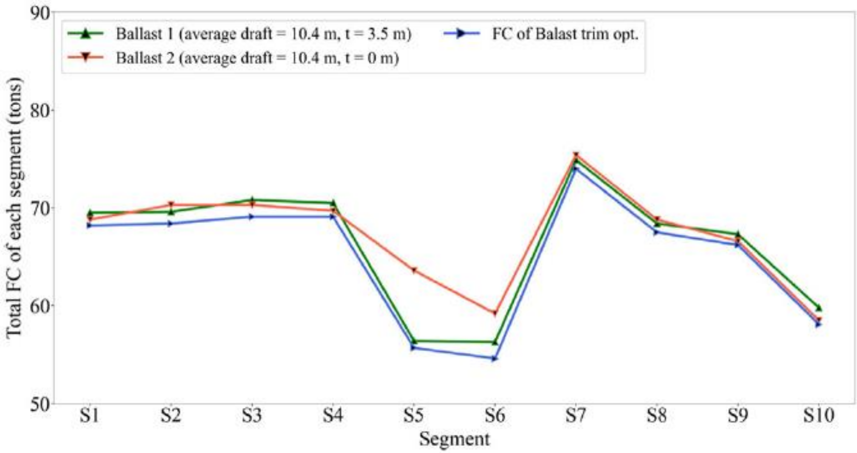

Figure 8: The FC of each segment before and after optimization under Ballast condition

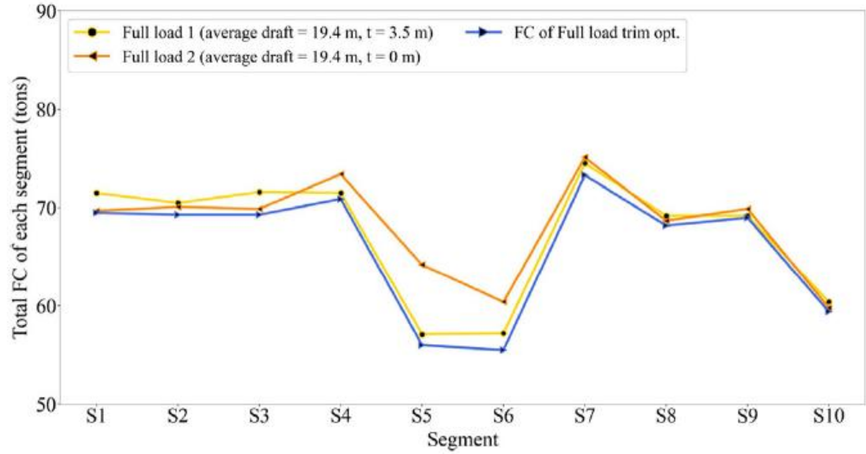

Figure 9: The FC of each segment before and after optimization under full load condition

- The effects of the initial trim and draft, when fully incorporated, on various resistive and hydrodynamic propulsion components of ONR Tumblehome Ship (ONRT).

The findings showed that, in comparison to the level trim, the overall resistance drops by 3.43 and 1.85%, respectively, with a 1.2 trim by fore at Froude numbers of 0.2 and 0.3. On the other hand, the complete resistance expanded by 15.92 and 10.94% at aft Froude numbers of 0.2 and 0.3, respectively, with a 1.2 trim aft [7].

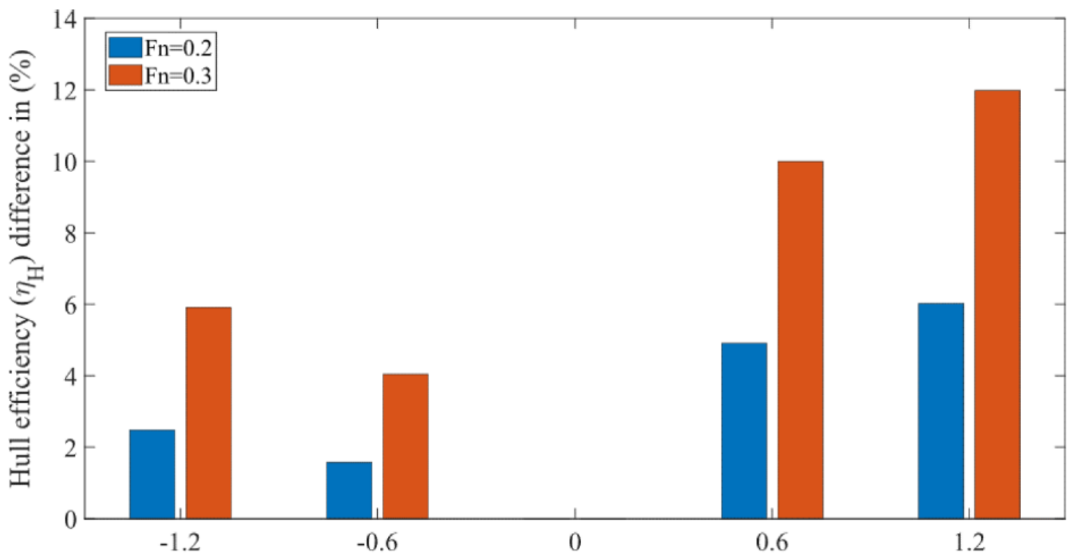

Figure 10: Hull efficiency (η_H) difference compared to level trim condition
Trim by bow is positive

- An analysis of how trim affects the cargo ship's performance, with a displacement of 12,500 DWT. According to the findings, depending on various loading scenarios and ship speeds, operating the ship at ideal trim conditions can reduce the engine power of the ship by 2.5 to 4.5% [8].

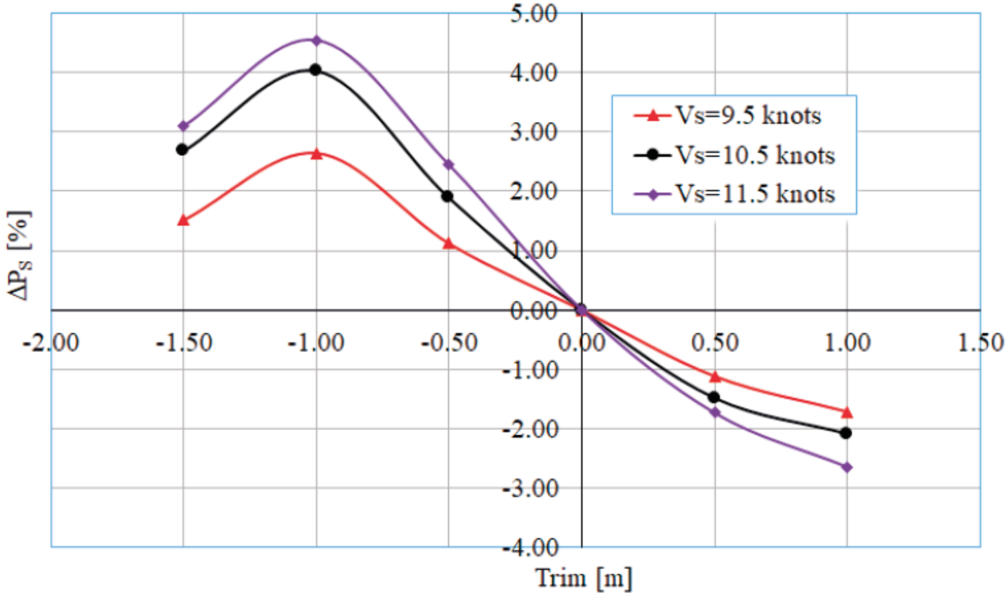

Figure 11: The percentage changes of main engine power at different trims relative to even keel condition

- In relation to the minimal ship engine power, the ship's ideal trim is -1.00 m.

- The S60 hull model is used to validate the numerical method. The ideal trim point for the existing hull shows a significant reduction in wave resistance and overall resistance when compared to the worst trim point and an even keel. The optimization framework's capacity to lower resistance contributes to energy conservation [9].
- Trim by bow is positive

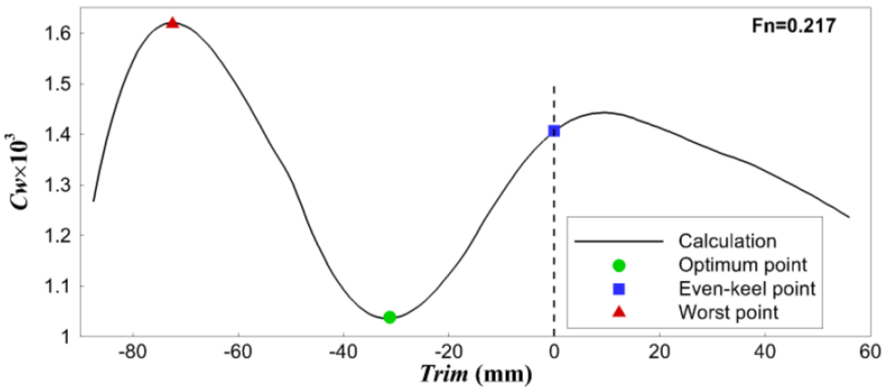

Figure 12: water resistance vs. trim (Fn 0.217)

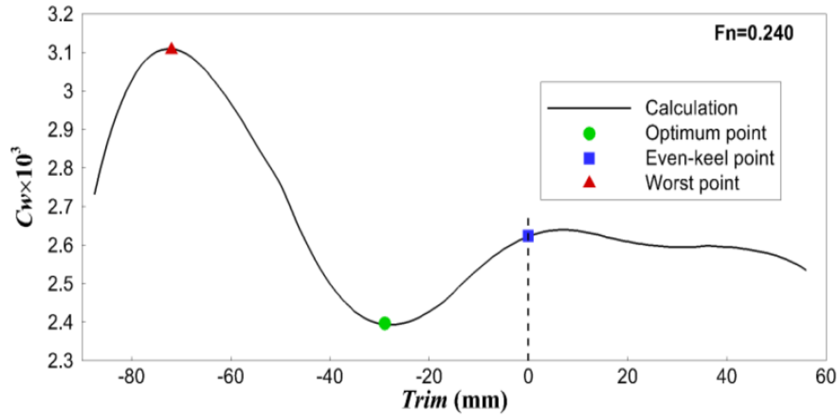

Figure 13: water resistance vs. trim (Fn 0.24)

- The object of study is a container ship. The first step involves using the CFD simulation approach to calculate the model ship resistance in even keel conditions at design draft, illustrating that bow and even keel trim reduce oil consumption more effectively than stern trim [10].
- Trim by bow is negative.

Table 1. Calculation results of ship model resistance

	Fn	0.104	0.146	0.188	0.230	0.256
Draft(m)	Trim(m)			Rt(N)		
0.211	-0.022	8.17	15.51	24.29	34.34	44.12
	0.000	8.35	16.09	25.34	35.38	45.06
	0.025	8.2	16.55	25.68	36.52	46.32
	0.050	8.00	16.65	25.96	37	46.38
	0.075	7.98	16.55	26.15	37.09	47.36
	0.100	7.69	15.89	26.07	36.82	46.21
	0.125	7.92	15.94	26.16	37.15	46.2
0.263	-0.075	8.29	15.74	25.4	37.7	49.81
	-0.050	8.07	15.62	25.12	37.61	47.77
	-0.025	8.35	15.86	25.45	37.49	48.4
	0	8.46	16.11	25.46	37.26	47.54
	0.025	9.14	17.54	27.6	38.85	48.54
	0.06	9.63	18.33	27.73	39.89	51.4
	0.1	9.23	18.85	29.3	41.98	52.24
0.315	-0.075	9.33	17.86	28.45	44.21	57.5
	-0.050	9.14	17.78	29.03	43.05	57.33
	-0.025	9.51	17.89	28.32	43.17	56.46
	0	9	17.29	28.41	44.2	56.85
	0.025	9.75	18.15	29.02	45.19	57.57
	0.05	9.8	19.03	29.98	45.27	58.55

- For the best chance of achieving the total fuel consumption decrease, air lubrication and trim optimization research have been coupled, a small forward trim from trim optimization increased the total gain at their maximum, the aforementioned reductions might reach 13.7% under particular operational conditions.[11].

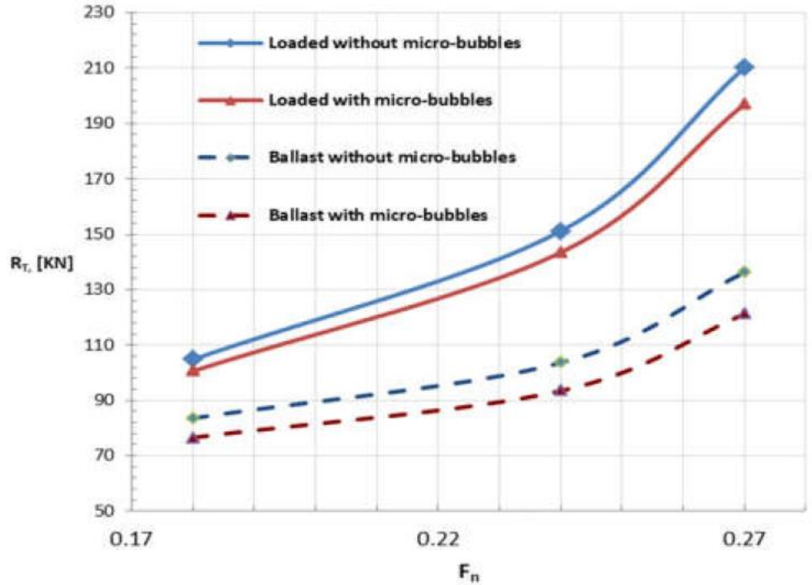

Figure 14: comparison of total resistance in case of optimum trim with and without micro bubbles effect

- Trimming by bow can lower resistance at low Froude numbers on the other hand, when the Froude number increases, trimming by stern usually results in the least resistance [12].

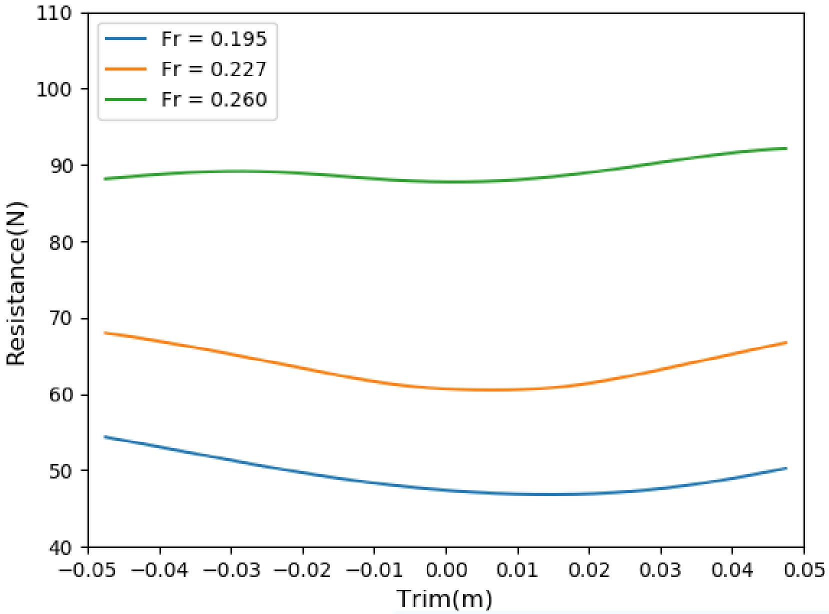

Figure 15: The influence of trim on ship resistance (draft = 0.3418 m)
Trim by bow is positive

- Experimental data from the model test was compared with a numerical study of the resistance data for the KRISO Container Ship (KCS) with an even keel. Subsequently, the ideal trim values were estimated for different service speeds using the calculated resistances. It has been shown that trim optimization at various speeds is a workable and effective way for boats to reduce total drag force, which reduces fuel consumption, and emissions of harmful substances, and enhances energy efficiency. [13].

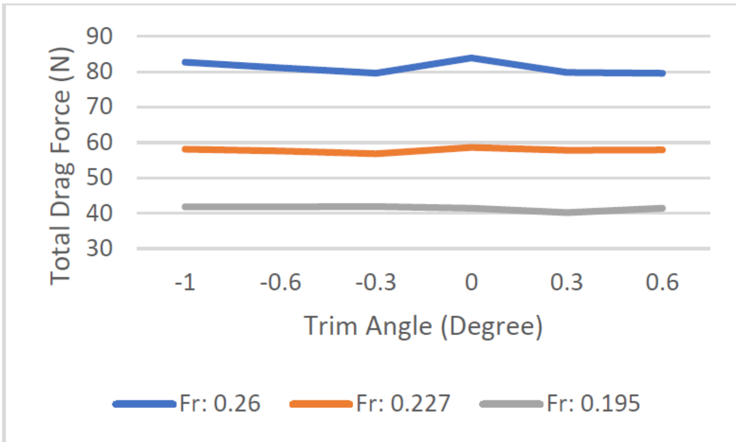

Figure 16: Drag force versus trim angle

Trim by bow is positive

- The resistance may be more or lower under stern trim conditions than in even keel conditions. Nonetheless, 0.06m bow trim is the best trim condition during design drafts. When the ship reaches its maximum draft, bow and stern trim are more beneficial than even keel circumstances. [14].
- Trim by bow is negative

Table 2: Comparison of ship model resistance at design speed between CFD and experiment

Mean darft(m)	Trim(m)	R_m(N)	R_s (N)	Error of CFD Method (%)	Energy-saving efficiency (%)
ballast draft=0.217	-0.03	10.28	10.53	2.43	2.14
	-0.01	10.22	10.49	2.64	2.51
	0.00	10.58	10.76	1.70	0.00
	0.01	10.91	11.33	3.85	-5.30
	0.03	11.13	11.37	2.16	-5.67
	0.05	11.29	11.45	1.42	-6.41
	0.07	11.34	11.77	3.79	-9.39
	0.08	11.46	11.69	2.01	-8.64
design draft=0.283	-0.06	12.26	12.65	3.18	6.02
	-0.04	12.52	12.89	2.96	4.23
	-0.02	12.61	12.97	2.85	3.64
	0.00	13.04	13.46	3.22	0.00
	0.02	13.39	13.64	1.87	-1.34
	0.04	12.63	12.85	1.74	4.53
	0.07	12.87	12.98	0.85	3.57
	0.08	13.08	13.46	2.91	0.00
fully load draft=0.319	-0.06	12.82	13.31	3.82	15.65
	-0.04	12.74	13.42	5.34	14.96
	-0.02	12.62	13.18	4.44	16.48
	0.00	14.88	15.78	6.05	0.00
	0.02	14.38	15.26	6.12	3.30
	0.04	14.00	14.41	2.93	8.68
	0.07	14.06	14.65	4.20	7.16
	0.08	14.10	14.90	5.67	5.58

- Through the use of three different ship types—tanker, container, and bulk carrier ships—it is possible to determine that trim optimization may significantly lower fuel consumption and exhaust gas emissions. Based on the data, it may be concluded that there is no one golden ratio for ship trim and that each ship's hull form varies from the next [15].
-Trim by bow is negative.

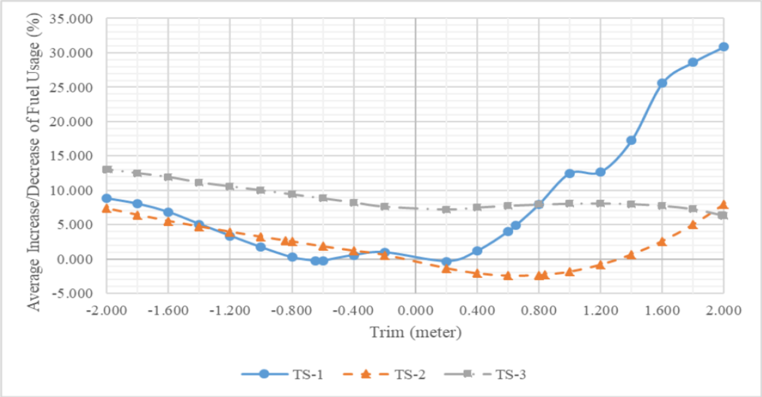

Figure 17: Effect of Trim on Fuel Consumption for Tanker Ships

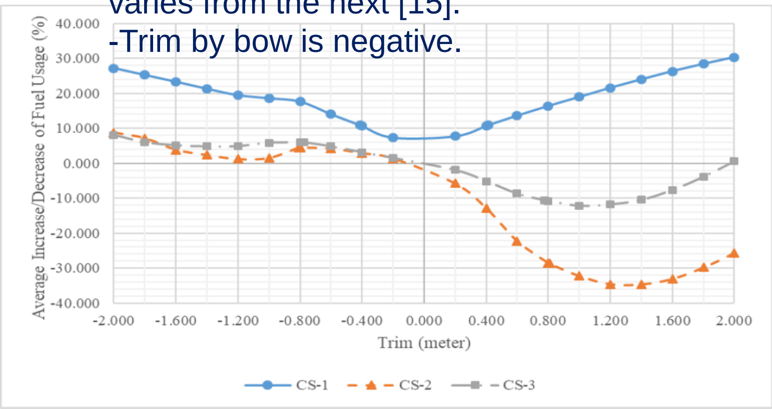

Figure 18: Effect of Trim on Fuel Consumption for Container Ships

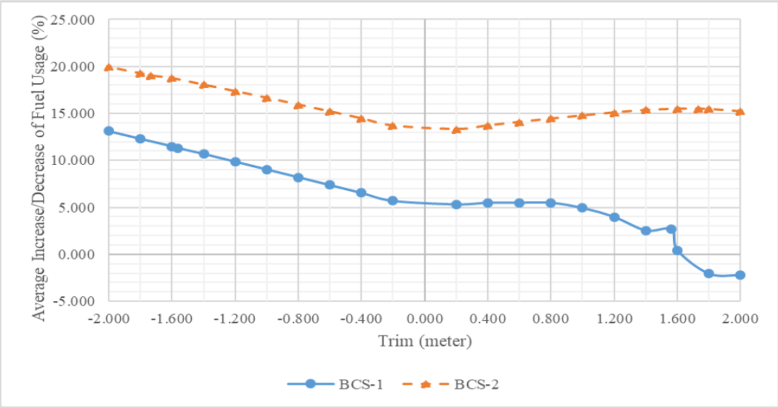

Figure 19: Effect of Trim on Fuel Consumption for Bulk Carrier Ships

3. Research Methodology:

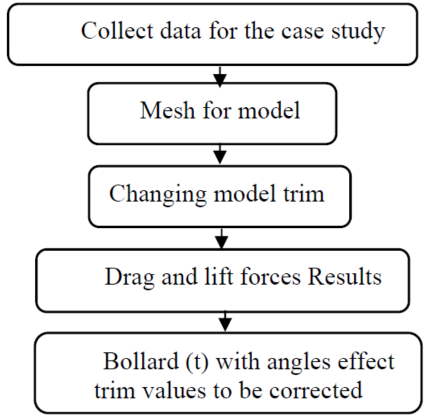

Figure 20: Research Steps

- In this study, a 1:18 scale model of Ajax without a tug appendage was used to create a full-size model of the Escort tug. Table 3 contains the model's primary characteristics.

A speed of (0.2, 0.4, 0.6, 0.8, 1, 1.2, 1.4) m/s was employed in the current study.

Table 2. Particulars of Voith Tractor Escort Tug, Ajax (Hull only)

L.O.A	40.0 m
LWL	38.19 m
BWL,	14.2 m
T (max)	3.8 m
Displacement, tonnes S.W.	1276 t
Lateral area	125.4 m^2

Table 3. Summary of model particulars Length

L.O.A	2.22 m
Waterline	2.122 m
Beam, Waterline	0.789 m
Draft, hull	0.211 m
Displacement, tonnes S.W.	213.3 kg
Nominal scale	1:18

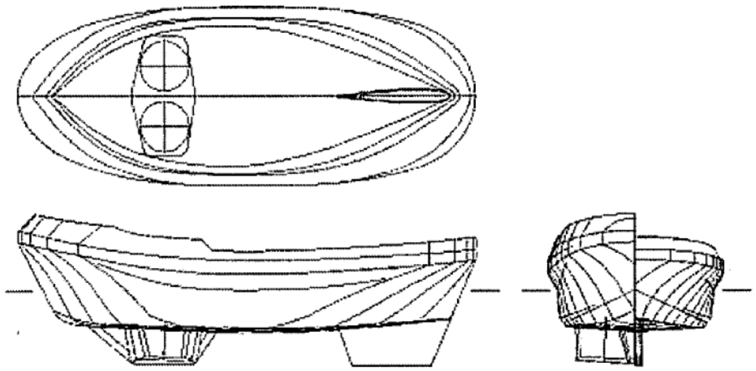

Figure 21: Lines of AJAX hull

Boundary condition of the simulation model:
Turbulence Model: k-omega
Min size:0.022
Max size:0.022
Growth rate:1
Minimum edge length: 7.0142e-003 m
Verification: Analysis using No., of elements: 312975
(Force for trim 0.5 m forward 1.4m/s is 507.145 N)
No., of elements: 379014
(Force at a trim 0.5 m forward 1.4m/s is 508.7164 N)
Shows minor error = 0.3% reaching optimum mesh results.

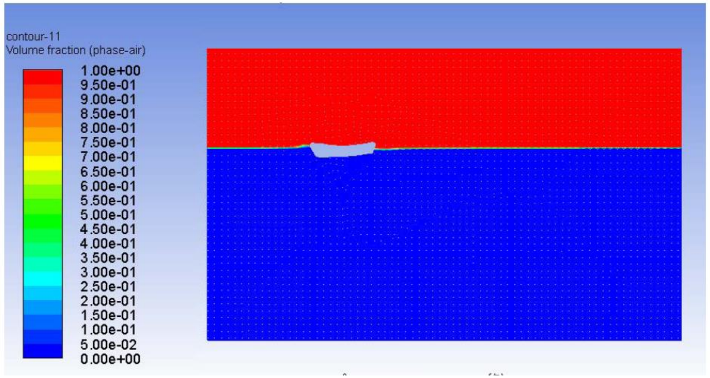

Figure 22: Contour phases (Air-Water) (2D)

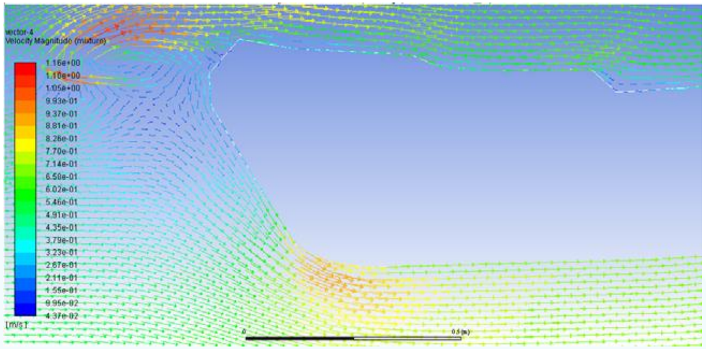

Figure 23: Velocity vectors

4. Results and discussion:

- Speed (m/s)

Model Tug 0.2 0.4 0.6 0.8 1 1.2 1.4

- Trim (-) fwd.

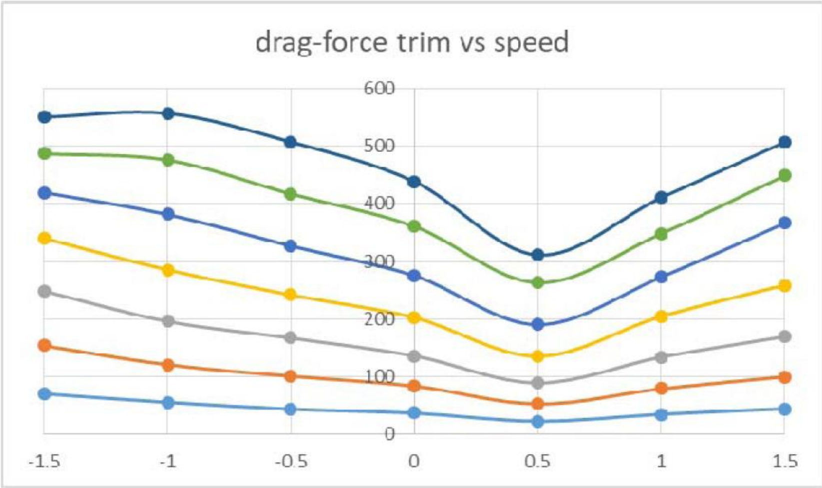

Figure 24: Optimum trims for different trim (m) and forward speed

Model trim in meter

0.083 0.055 0.027 0 -0.027 -0.055 -0.083

- The results shows that the trim (m) of the model versus the speed and it is observed that the resistance force increases with speed also the trim (m) by aft is better in drag results.

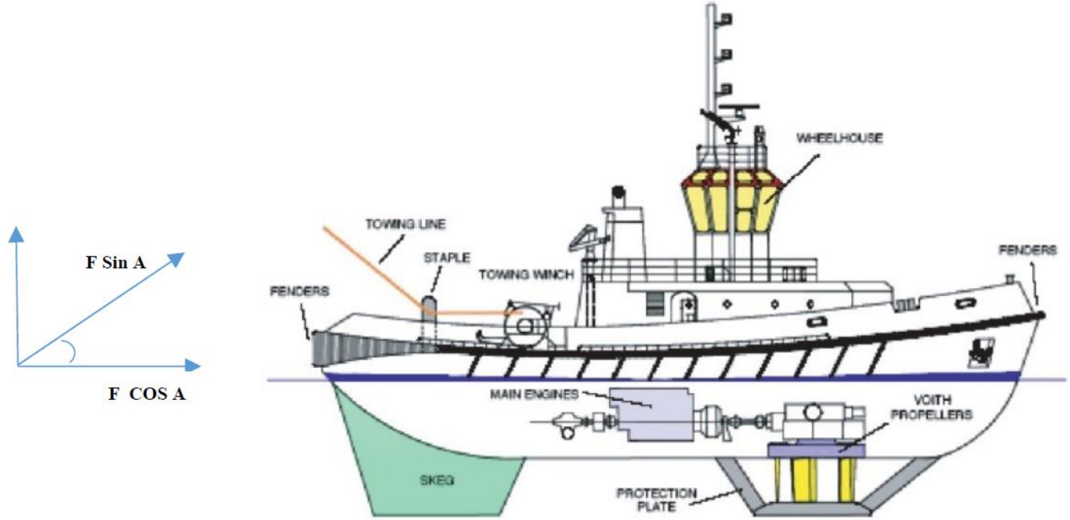

Figure 25: Bollard tension with angle

- As the cosine component is negligible, then the sin force makes a lift, and the change in the trim depends on the component of force and sin of the angle.

Hydrostatic properties from hull model Draft 3.6 m for tug = 0.2 m (study model case)

MCT1cm=10.35

Table 4. Tug trim change tension versus angle

Tension (ton)	*Sin Angles -Tension (N)*												*Even Keel Correction Trim(m)*	
	5	10	15	20	25	30	35	40	45	50	55	60	30	60
10	0.87	1.74	2.59	3.42	4.23	5.00	5.74	6.43	7.07	7.66	8.19	8.66	0.05	0.09
20	1.74	3.47	5.18	6.84	8.45	10.00	11.47	12.86	14.14	15.32	16.38	17.32	0.1	0.18
30	2.61	5.21	7.76	10.26	12.68	15.00	17.21	19.28	21.21	22.98	24.57	25.98	0.15	0.27
40	3.49	6.95	10.3	13.68	16.90	20.00	22.94	25.71	28.28	30.64	32.77	34.64	0.21	0.38
50	4.36	8.68	12.9	17.10	21.13	25.00	28.68	32.14	35.36	38.30	40.96	43.30	0.26	0.44
60	5.23	10.42	15.5	20.52	25.36	30.00	34.41	38.57	42.43	45.96	49.15	51.96	0.31	0.53
70	6.10	12.16	18.1	23.94	29.58	35.00	40.15	45.00	49.50	53.62	57.34	60.62	0.36	0.62
80	6.97	13.89	20.7	27.36	33.81	40.00	45.89	51.42	56.57	61.28	65.53	69.28	0.41	0.7
90	7.84	15.63	23.2	30.78	38.04	45.00	51.62	57.85	63.64	68.94	73.72	77.94	0.46	0.79
100	8.72	17.36	25.8	34.20	42.26	50.00	57.36	64.28	70.71	76.60	81.92	86.60	0.51	0.87

- Referring to Table 4 last column the tension increases with the angle and with the increase in the force the even keel correction trim (m) case shows that tension may increase the trim till a maximum of 0.87 m is added in the stern in case of a maximum tension 100t and angle 60degrees which will change the choose of optimum trim and need to be corrected.

5. Conclusion:

- The tugboat trim optimization during bollard pull operation is considered in this research with different speeds, and wire tension different reaction angles using Computational Fluid Dynamics (CFD) simulations.
The current study for tug model optimum trim, has shown that the velocity and trim have a direct effect on tug drag and lift forces and from hydrostatic properties (even keel) 3.6m (0.2m model draft) founding after tension bollard affect distance about 6.5m from tug stern, the trim range bollard force varies from 10 to 100t.

-The results show that the resistance increases with velocity ,showing better results with trim by aft (stern) and a correction for the optimum trim is needed due to the trim effect by bollard tension angle.
(Angles range from 5 to 60 degrees) observed that greater angles and forces may cause a difference in trim range from 0.5m to nearly 1m at large angles and tension that will make a great changes in optimum trim accordingly ,however larger angles or tensions in addition to different drafts can cause also a different trim condition.

7. References

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