2D MODEL FOR TRIM OPTIMIZATION OF TUGBOAT DURING BOLLARD PULL

Emad Elsayed [(1)i], Ahmed Mehanna [(2) ii], Elsayed H. Hegazy [(3)], Ahmed S. Shehata [(4)]

Department of Marine and Offshore Engineering, Arab Academy for Science and Technology, Alexandria, Egypt

Keywords: Marlog 13, Trim Optimization, Bollard Pull, Tugboat, Alexandria.

1. **ABSTRACT**: Trim optimization is one of the finest strategies to reduce fuel consumption. The trim merely has to be modified for changes in ballast or weight distribution and even both together. To ascertain how bollard pull forces affect trim optimization, which needs to be checked and considered, the study employs a tug hull model in its numerical simulation. However, high angles with tensions significantly change the trim angle, so tug trim needs to be adjusted to obtain the appropriate different trim measurements are used in the forward and stern to get the optimum trim.

Nonetheless, the study aims to demonstrate the significant impact of bollard pull angles since bollard effects are noted when a combination of high tension and angle alters the trim and correction required in the selection the appropriate trim optimization.

2. 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].

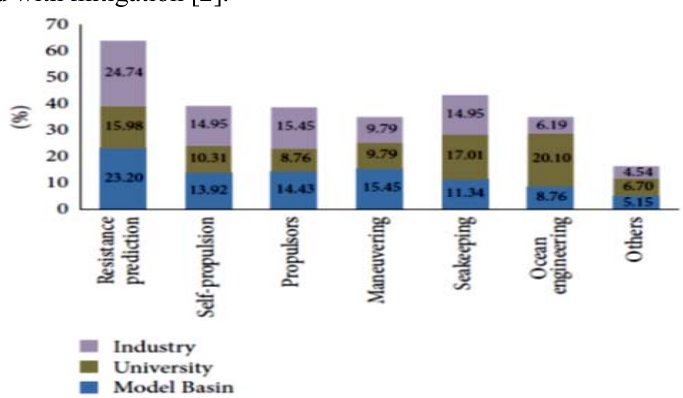

Figure1: Applications of CFD in marine hydrodynamics [3]

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

Trim optimization resistance prediction outcomes for a KRISO (Korea Research Institute of Ships and Ocean Engineering) Container ship (KCS) model at different trim settings have been tested in several research. Three distinct ship speeds and drafts were simulated, together with varied trim angles, and the resistance the ship met was estimated. The study found that choosing the best trim angle for that specific voyage scenario might result in a notable decrease in ship-encountered resistance. 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].

Additional research to optimize the trim for the least amount of resistance 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, The relationship is linear and gets smaller as the draft gets bigger. The rate of decrease increases with speed. The speed of 16 knots at 8 m draft results in the largest reduction in resistance, nearly reaching 14%. [5].

Reduced power reduction and fuel consumption are the main goals of trim optimization, as mandated by the new IMO regulations for the reduction of greenhouse gas emissions. That measure's cost-benefit analysis is presented in (ABS, Ship energy efficiency, 2013):

- Savings: an average of 1 to 2 percent less propulsion fuel used.
- Applicability to Ship Type: All ships, however, long-haul ships benefit the most.
- Cost: Using model testing, the data development cost ranges from $50,000 to $100,000 (total for all ships of comparable design). Effective data utilization requires $500–5,000 in shipboard software tools. Energy expenditures for pumping ballast and cargo planning time for cargo distribution optimization are the only in-service costs [6].

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%. Show how combined optimization may improve the fuel-saving rate and get beyond the drawbacks of single-parameter optimization [7].

The effects of the initial trim and draft, when fully incorporated, on various resistive and hydrodynamic propulsion components of ONR Tumblehome Ship (ONRT) model. In the computational fluid dynamics (CFD) environment, a comprehensive set of double-body, self-propulsion, and resistance tests were simulated for different trim and draft conditions in continuous displacement. The investigation revealed that advancing the propellers increased their thrust, which increased the hydrodynamic propulsive efficiency of the model [8].

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% [9].

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. [10].

Because it is more flexible and easier to operate in practice than a standard hull form refit, ship trim optimization has gained importance as an energy-saving tactic in recent years. 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. [11].

For the best chance of achieving the total fuel consumption decrease, air lubrication and trim optimization research have been coupled. Overall, the findings demonstrated that microbubbles had a significant impact on the loading condition and a very positive impact on the ballast condition. Under loaded and ballast situations, the reduction of ship overall resistance might be as high as 6.3% and 11%, respectively. With just the suggested modest front cut, these savings might be increased to 7.8% and 13.7% [12].

The sample points' defined requirements are followed when doing Reynolds averaged Navier-Stokes (RANS) simulations. 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. [13].

Utilizing a computational fluid dynamic with the help of the commercial package Star-CCM+. First, to confirm the results, 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. [14].

In comparison to other conditions, the ship faces the most resistance, and the optimal trim state is at 0.01m bow trim. As the stern trim value rises, there is an overall increase in resistance. Stern trim should so be declined. 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. [15].

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 [16].

The dynamic trim optimizer is a useful tool that can help with that by offering important information. Choosing the optimal trim for sailing instead of the level trim will enhance efficiency by 8.7%. The potential savings under different operating conditions may be considerably greater, depending on several variables like the vessel's hull shape, displacement, mean draft, speed, route, and depth [17].

Three methods studied optimum trim, the optimum trim was found to be 1.7 m for the constant form factor and constant thrust deduction fraction, 1.6 m for the actual form factor and actual thrust deduction fraction, and the optimum trim for the direct power method was found to be approximately 1.5 m. [18].

The impact of bollard pull on the move from corrected to ideal trim has not been extensively explored, even though prior trim optimization has been extensively researched.

3. Research Methodology

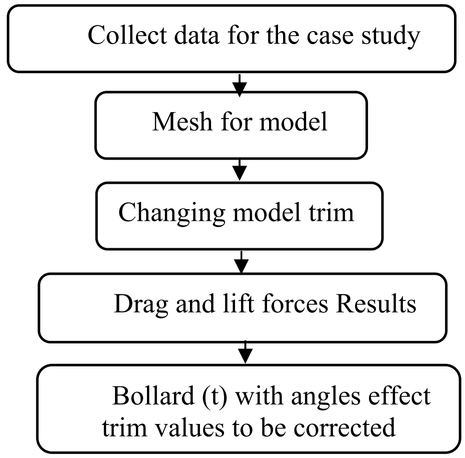

Figure2: Research Steps

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 1 (4) 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 1. 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 2. 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

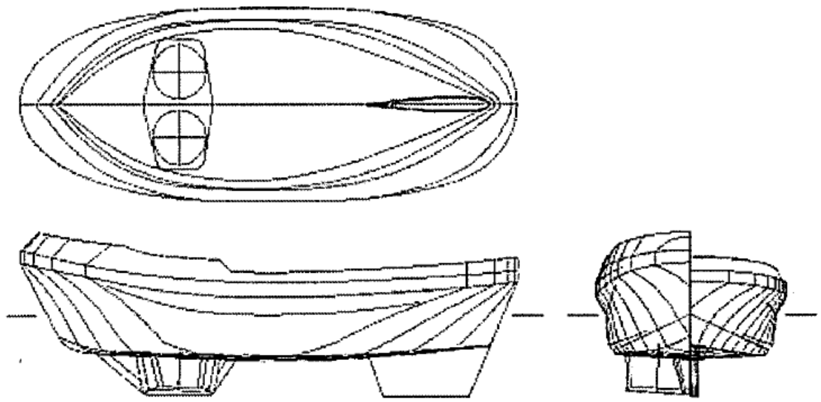

Figure 3: Lines of AJAX hull

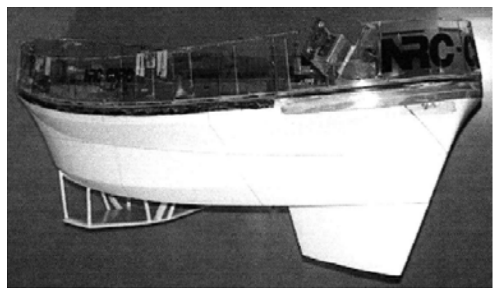

Figure 4: Photo of AJAX hull [19]

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.

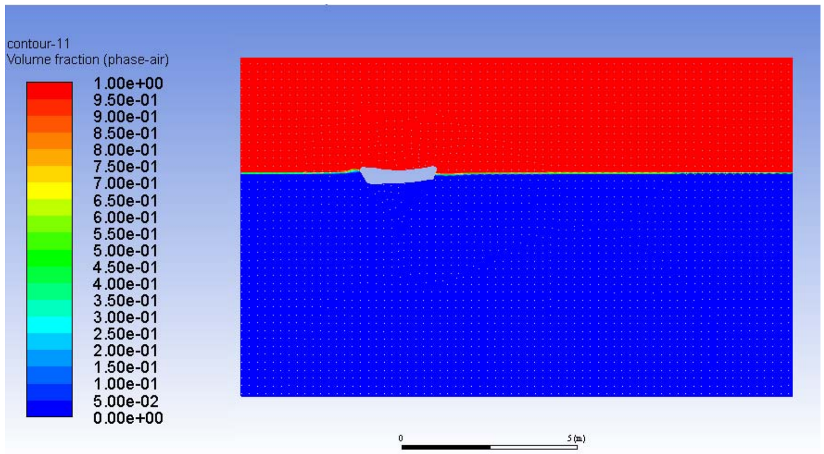

Figure 5: Contour phases (Air-Water) (2D)

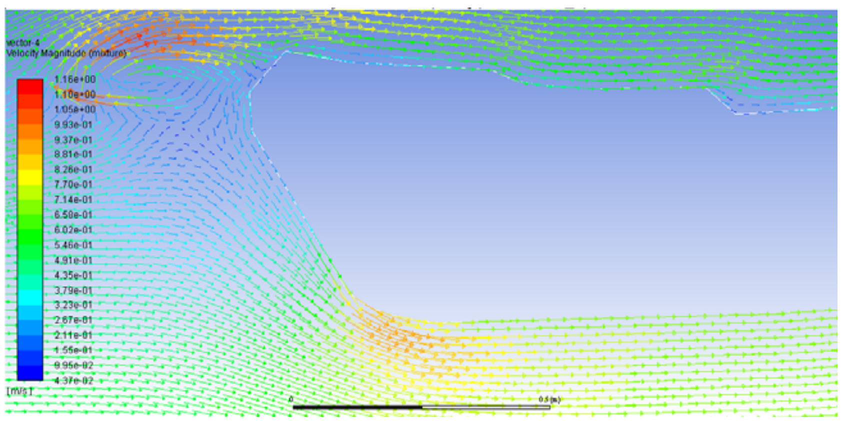

Figure 6: Velocity vectors

As shown in Figure 5 for water air phase changing trim values also figure 6 shows the fluid velocity around the model hull.

Table 3. In the cases to which the CFD model is applied, drag force

Drag Force (N)								
Trim (m)		*Speed (m/s)*						
Model	*Tug*	0.2	0.4	0.6	0.8	1	1.2	1.4
0.083	1.5	44.780	100.143	169.884	258.995	366.350	448.710	506.823
0.055	1	35.262	79.375	134.284	204.753	273.0233	348.249	410.633
0.027	0.5	23.190	52.970	89.441	135.702	190.495	263.348	311.292
0	0	37.254	83.930	136.468	202.736	275.340	360.878	438.676
-0.027	-0.5	44.043	101.159	167.272	241.899	326.957	417.167	507.145
-0.055	-1	55.909	121.013	196.213	285.519	381.514	475.769	556.841
-0.083	-1.5	70.738	153.885	248.681	340.228	419.573	486.885	550.388

4. Results and discussion

The results show 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.
Trim (-) fwd.
All Dimensions in meters (m)

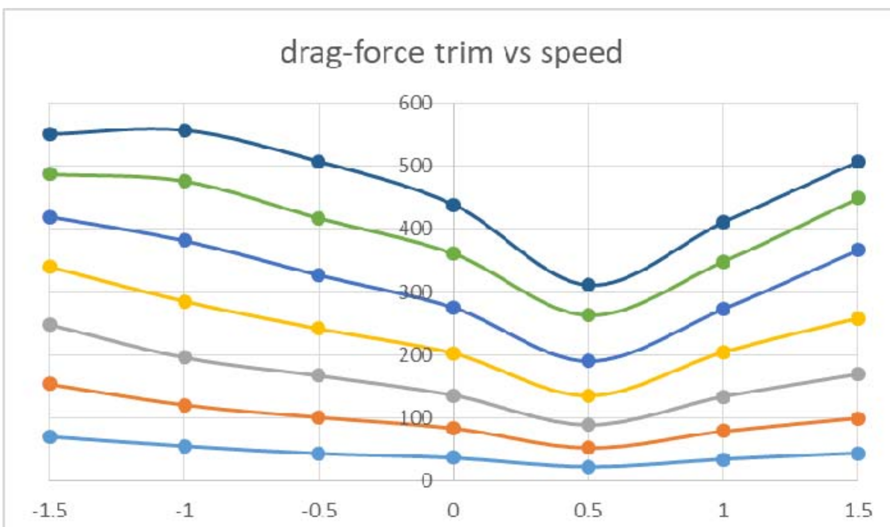

Figure 7: Optimum trims for different trim (m) and forward speed

$FD=0.5C\rho Av^2$,

Where A is the area of the item confronting the fluid, ρ is the fluid's density, v is the flow velocity, C is the drag coefficient.

Table 4. The cases to which the CFD model is applied lift force

Lift Force (N)								
Trim (m)		*Speed (m/s)*						
Model	*Tug*	*0.2*	*0.4*	*0.6*	*0.8*	*1*	*1.2*	*1.4*
0.083	1.5	-975.143	-1040.97	-1138.58	-1254.39	-1387.29	-1505.05	-1539.88
0.055	1	-1554.95	-1615.13	-1704.83	-1808.54	-1908.04	-1985.06	-2148.16
0.027	0.5	-2387.01	-2435.46	-2511.03	-2594.41	-2692.64	-2810.98	-3030.55
0	0	-1363.06	-1418.45	-1510.45	-1621.21	-1745.27	-1899.01	-2124.18
-0.027	-0.5	-634.354	-699.549	-803.193	-938.18	-1096.77	-1304.31	-1579.92
-0.055	-1	-132.996	-202.234	-313.904	-468.839	-675.041	-940.011	-1262.22
-0.083	-1.5	548.3367	464.7614	311.5614	87.04341	-205.249	-549.777	-930.854

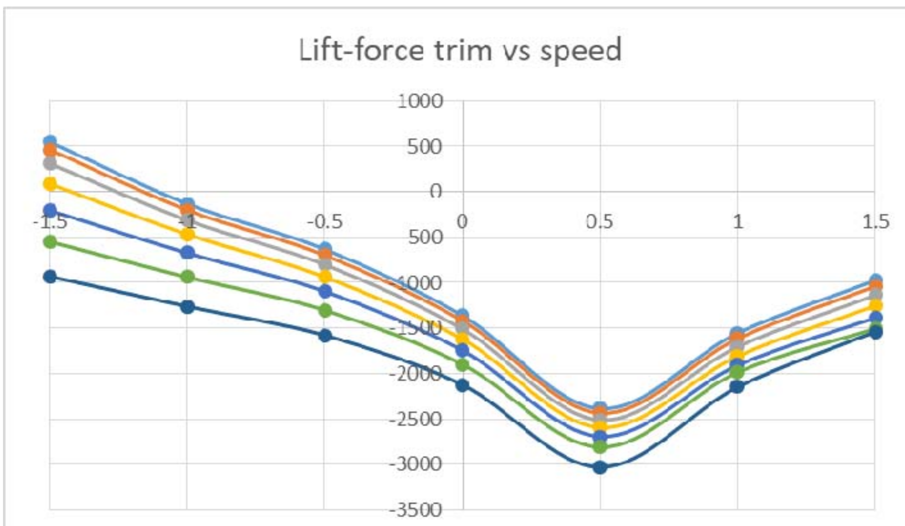

Figure 8: Optimum trims for different trim (m) and forward speed lift force

The lift force is better in the forward trim as shown in Table (4), and shown on figure 8

5. EQUATIONS

MCT 1 cm = W x GML/100L (1)

Where W is the displacement of the vessel in tons

GML is the length-mean-centric height expressed in meters.

The length of the tug in meters is L.

Calculation of trim: -

*Change in trim = (displacement *(LCG-LCB)) / 100*MCT CM* (2)

*Change in draft = Change in trim * (LCF/length)* (3)

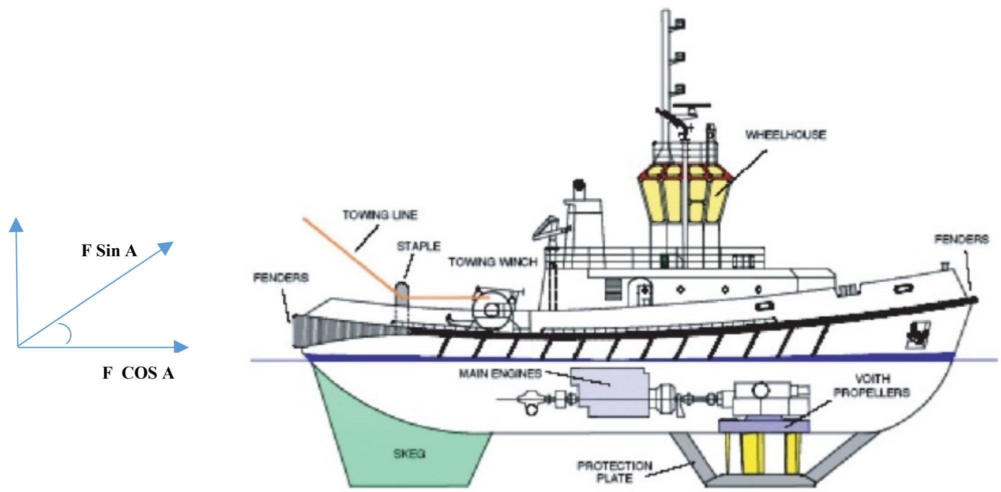

Figure 9: Bollard tension with angle [20]

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 5. Tug trim change from tension vs 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 5 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.

Using Auto-hydro software to obtain hydrostatic results for the tug.

6. Conclusion

Trim optimization leads to a decrease the ship resistance, which means the reduction of fuel consumption and limits harmful emissions without any need for external machines or technologies, which means that it is a cheap method of decreasing fuel consumption.

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 from 10 to 100t.

The results show that the resistance increases with velocity showing better results by 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 6o degrees) observed that greater angles and forces may cause a difference in trim from 0.5m to nearly 1m at large angles and tension that will make a great change in optimum trim accordingly however larger angles or tensions in addition to different drafts can cause also a different trim condition.

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