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Abstract

This study presents the results of a workshop conducted within the JoRes framework, focusing on self-propulsion CFD simulation of the full-scale bulk carrier vessel, JoRes5 GRIP. This vessel serves as an ideal validation case, having undergone sea trials both with and without an Energy-Saving Device (ESD)—specifically, pre-swirl stators (PSS). The sea trials were performed at comparable draught conditions (TM = 7.7 m) and across multiple speeds, providing a robust comparative dataset. The vessel, with a length between perpendiculars (LPP) of 182 m, was tested at speeds of 13.65, 15.25, 16.02, and 16.32 kn. These conditions were replicated in the CFD simulations conducted during the workshop, providing insights into the influence of PSS on propulsion performance and enabling validation against full-scale measurement.

1. Introduction

Continuous advancements in computational fluid dynamics (CFD) have equipped researchers with increasingly accurate tools for predicting the performance of full-scale vessels. However, to ensure reliability, these computational predictions must be validated against high-quality sea trial data. Within the JoRes Joint Research Project, https://jores.net/, a comprehensive dataset of sea trials has been developed to benchmark various vessel types and support efforts to improve energy efficiency in maritime transport.

This study presents the outcome of a workshop conducted under the JoRes framework, focusing on the self-propulsion CFD simulation of the full-scale bulk carrier JoRes5 GRIP. This vessel provides an ideal validation case, having undergone sea trials both with and without an energy-saving device (ESD)—specifically, pre-swirl stators (PSS). The trials were conducted at a consistent draught of TM = 7.7 m and at multiple speeds, offering a robust dataset for comparative analysis. The vessel was tested at speeds of 13.65, 15.25, 16.02, and 16.32 kn, and these conditions were replicated in the CFD simulations performed during the workshop.

The primary objective of the workshop was to numerically simulate the sea trials using CFD for validation purposes. Previous comparative analysis of different CFD codes and numerical approaches used for self-propulsion simulations revealed improvements in the accuracy of power prediction. Nonetheless, further refinement is needed to enhance consistency and reliability. This paper also outlines the evaluation of simulation results, with a particular focus on estimating the power gain associated with the use of ESDs such as PSS.

2. Why is this case unique?

Energy-saving devices have been introduced in the maritime industry for some time, but there are still ongoing debates about whether their installation is worthwhile. The challenge is associated with an explicit confirmation of fuel saving due to the device installation. If the device is installed on a newly built vessel, there is no sea trial record without the device. Hence, it is impossible to understand the contribution of savings made possible by the device. It appears that this challenge can be addressed on a retrofitted vessel, as trials could be performed before entering the dry dock (without an energy-saving device) and then after the dry dock (with an energy-saving device).

In practice, to save costs, the dry-docking opportunity is also used not only for the ESD installation but also for hull cleaning and new paint application. As a result, when the vessel is out of the dock, there are at least two significant alterations (a clean hull with new paint and the ESD) that make it difficult to understand the specific contribution to the savings from ESD. Another opportunity is to compare long-term monitoring data for the vessel with and without ESD; however, if the operational conditions (draughts, speeds, duration of voyages, and idle times) are not the same, it introduces uncertainty into the comparison.

For the JoRes5 GRIP bulker case, the story is different and somewhat unique. The vessel was launched late September (the vessel's identity is anonymous, so the year of launch is not disclosed) and remained alongside the harbour until the beginning of April. Because she was in the water in the winter months, it was expected that not too much marine growth would appear on the hull. By the end of March, the propeller was polished by divers, and the first trials without the ESD were performed. After the first trial, the ship entered dry dock for the installation of the PSS. Upon arrival in dry dock two weeks later, the vessel was inspected immediately, before any cleaning or painting took place. As expected, the hull was found in an immaculate condition, with no visual traces of green weed fouling. Only a thin layer of slime was present in certain areas. The effect of the slime layer is considered minimal; the ship had a very low draught with approximately 5 m aft and 0.1 m fore during the six-month winter period at the yard. Only the bottom surface was exposed to water, where no fouling had developed due to the absence of sunlight.

In the dock, the flat bottom was recoated with a second layer of anti-fouling coating. In theory, this changes the surface roughness of the bottom. However, as the existing paint layer was new and untouched, the effect on frictional resistance, and hence vessel performance, can be considered negligible. This exercise suggests that, unlike many previous attempts, the hull conditions for the trials with and without ESD were almost identical. Roughness measurements were not performed on this vessel; however, comparing the photos of the JoRes5 bulker and JoRes1 tanker in the docks show that they had a similar type of paint and similar paint conditions, so an assumption was suggested to use the tanker's roughness values for the bulker, too. It would also be helpful to develop good comparisons between the JoRes1 tanker and the JoRes5 bulker, which also have similar dimensions.

3. Vessel Description and Sea-Trial Condition

The JoRes 5 GRIP is a 52,000 DWT bulk carrier with a length of 189.9 m and a beam of 32.26 m. The vessel is propelled by a diesel direct configuration using an engine that generates a power of 8,600 kW at 121 RPM. A picture of the vessel is provided in Fig.1. Fig.2 shows the installed Pre-Swirl-Stator (PSS) energy saving device (ESD).

The shaft power was measured using a torsion meter on the propeller shaft, which was based on strain gauges. For both trials, the same instrumentation and strain gauge on the propeller shaft were used to avoid bias errors. Position, course and speed over ground were determined using a DGPS unit, which was installed on the bridge top. The relative wind speed and direction were obtained using a sonic anemometer positioned on the mast on top of the wheelhouse. Data was stored automatically with a sampling frequency of 10 Hz on a PC located on the bridge. Furthermore, a visual recording was made of the draught, observing the draught markings on the hull from a small boat. The depth below the keel was manually recorded from the echo sounder indicator in the wheelhouse. The water depth at the trial location was 110 m. The displacement has been calculated using the visually recorded draught.

Fig.1: JoRes5 GRIP bulker during the sea trials

Fig.2: Pre-Swirl Stator (PSS) installed in the dry dock

To record the wave height, period and direction, a free-floating Datawell Directional Wave Buoy of type DWR G4 was used during trial 1 (without PSS). For trial 2 (with PSS installed), the wave height was estimated visually, as the wave buoy was not deployed due to miscommunication. However, the sea conditions were fair during the trials. Table ITable I presents an overview of the speed trials condition.

Double-speed runs of 10 minutes were conducted at four power settings. The heading of the runs was fixed at 151° and 331° to obtain sufficient space for turning and accelerating the vessel. This deviates from the ISO 15016 standard, which states that the heading of the vessel should be chosen in accordance with and against the dominant wave direction. However, as the waves were low (0.15 m), this had no significant effect on the wave corrections. The uncorrected performance data has been analysed and corrected for the non-ideal weather and environmental conditions according to the ISO 15016 standard.

The analysis has been performed using the STAIMO program version 1.2.0.

Table I: Overview of speed trials condition

Parameter	Trial 1	Trial 2	Unit
	Without PSS	With PSS	-
Length over all	189.9	189.9	*m*
Length between perpendiculars	182.0	182.0	*m*
Breadth	32.26	32.26	*m*
Moulded draught at forward perpendicular	7.70	7.68	*m*
Moulded draught at midship	7.75	7.73	*m*
Moulded draught at aft perpendicular	7.73	7.71	*m*
Moulded displacement	36142	36040	m^3
Midship area coefficient	0.994	0.994	-
Main section area	249	248	m^2
Wetted surface of hull	7173	7165	m^2
Wetted surface of rudder	99	99	m^2
Wetted surface of bilge keels	70	70	m^2
Bow length for wave correction	42	42	*m*
Height of anemometer	38	38	*m*
Transverse wind area	772	773	m^2
Average significant wave height	0.12	0.15	*m*
Average true wind speed	0.90	1.6	*m/s*

It was intended to perform both sets of trials (with and without PSS) under the same loading conditions. The difference in draught between the trials, therefore, was only 20 mm, Table I. Nevertheless, the middle draught is larger than the forward and aft draughts for both trials, and the vessel was sagging, Fig.3.

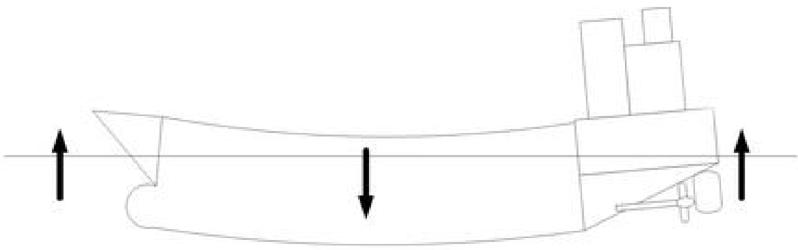

Fig.3: Vessel is sagging

It is normally assumed in CFD that the vessel is rigid and has no sagging or hogging. Uncertainty analysis was performed for this case to understand the effect of different components (including the change in draught) on the vessel performance. The uncertainties can be expressed by a 'Performance Indicator' (PI). The performance indicator 'PI' represents the relative power deviation at a constant speed from the reference speed/power condition. The reference speed/power condition is here taken as the hypothetical 'true' condition without measurement errors. The advantage of this method is that a single indicator can express uncertainties in both speed and power.

As shown in Fig.4, if the draught is estimated with insufficient accuracy (e.g., a 100 mm error at all marks), this will result in a performance difference of approximately 1%. In our case, the deviation between the draughts is only 20 mm, so it is expected that it will have a minor effect on the performance. Therefore, we suggest to use the forward and aft draught values and ignore the midship draught. In this case, there will be a minor deviation in displacement; however, we will ensure a bit more realistic flow behaviour around the bow and stern.

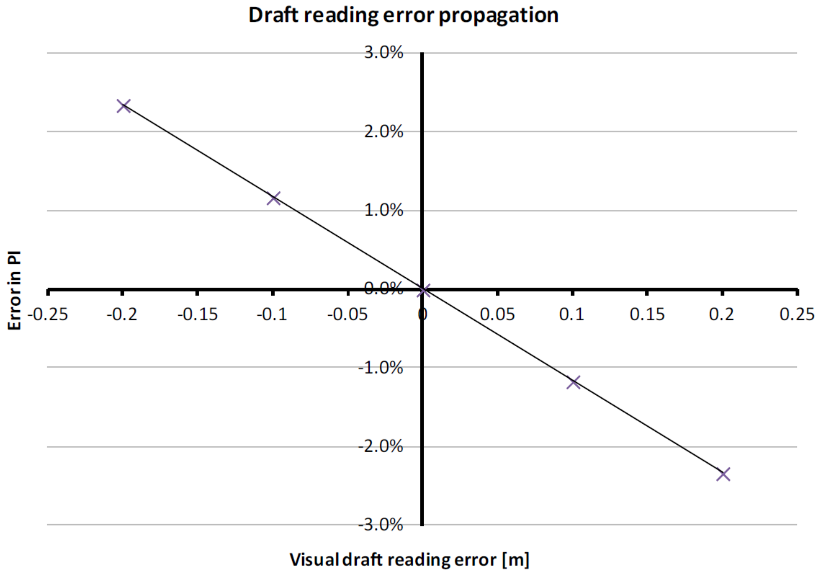

Fig.4: Performance Indicator (PI) error (%) vs draught reading error (m)

3. Sea Trial Result

The results show that to achieve a speed of 16 kn, a shaft power of 7975 kW is required with the PSS in place, which is 6.8% less power compared to the 8558 kW that is required to achieve the same speed without the PSS in place. Taking the uncertainty into account, it can be said that the difference between the trials is 6.8% ± 1%. At equal power, this corresponds to a speed difference of 0.3 knots, which is favourable for the condition with the pre-swirl stator in place.

The required RPM to achieve a shaft power of 7975 kW decreases from 124.0 to 120.3 RPM due to the presence of the PSS, Fig.5. The light running margin without PSS in place is 5.2%. After installation of the PSS, the light running margin has decreased to 2.0%.

The main objective of the ship scale verification was to perform the sea trials without and with PSS at the identical settings. Hence, the target was to keep the shaft RPM as close as possible to both sets of trials. Nevertheless, due to the PSS effect, the vessel speeds differed. Table II shows the speeds for no waves, no current, and no wind conditions after corrections according to ISO 15016.

Table II: Vessel speeds with and without PSS, while operating in similar shaft RPM

	Trials without PSS	Trials with PSS
Vessel speed 1	13.06 kn	13.65 kn
Vessel speed 2	14.61 kn	15.25 kn
Vessel speed 3	15.40 kn	16.02 kn
Vessel speed 4	16.01 kn	16.32 kn

Fig.5 shows the result of measured and corrected shaft power values at different vessel speeds. Fig.6 shows the corresponding shaft rotational speeds plotted against the measured shaft power. In both figures, the measured data have been curve-fitted to establish a reference for comparing power and RPM at given vessel speeds. In CFD self-propulsion simulations, the vessel speed is held constant while the propeller rotational speed (RPM) is adjusted to balance the resistance and thrust forces at the given speed. It may be inconvenient to run the cases with and without PSS at different speeds; so it was recommended to choose the speed in one set of trials and interpolate all the results for the other set to these speeds. Table III presents the corrected power and RPM for the same four speeds to be used in

CFD computations.

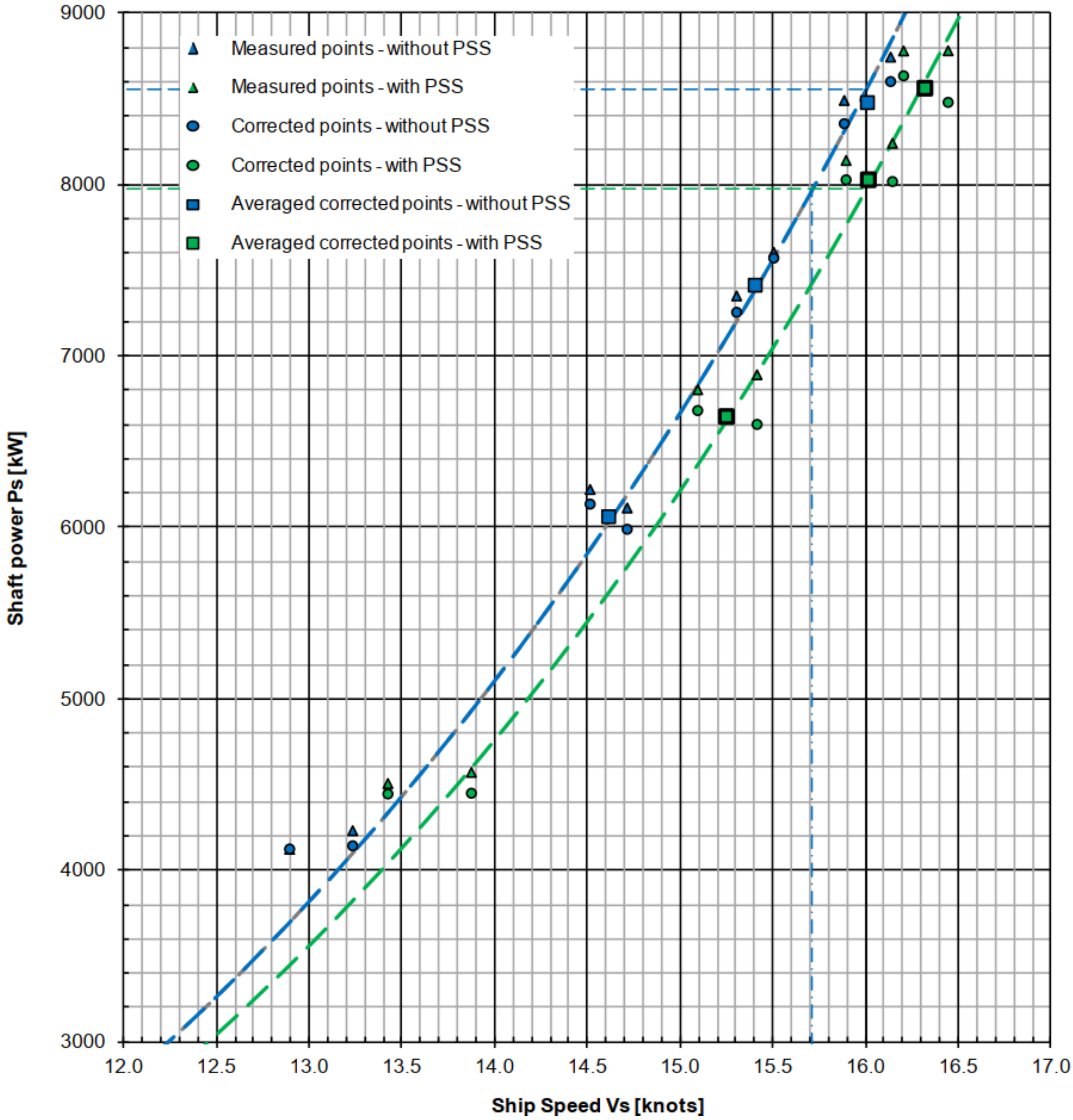

Fig.5: Measured and averaged corrected shaft power for different speeds of vessel at sea trial with and without PSS

Table III: Corrected and curve-fitted results of sea trial for 4 speeds to be used in CFD workshop

Speed [kn]	Power [kW]			RPM		
	Without PSS	With PSS	Diff.	Without PSS	With PSS	Diff.
13.65	4745	4408	-7.1%	105.1	99.8	-5.0%
15.25	7048	6579	-6.7%	119.5	113.4	-5.1%
16.02	8435	7947	-5.8%	126.6	120.5	-4.8%
16.32	9025	8476	-6.1%	129.4	123	-4.9%

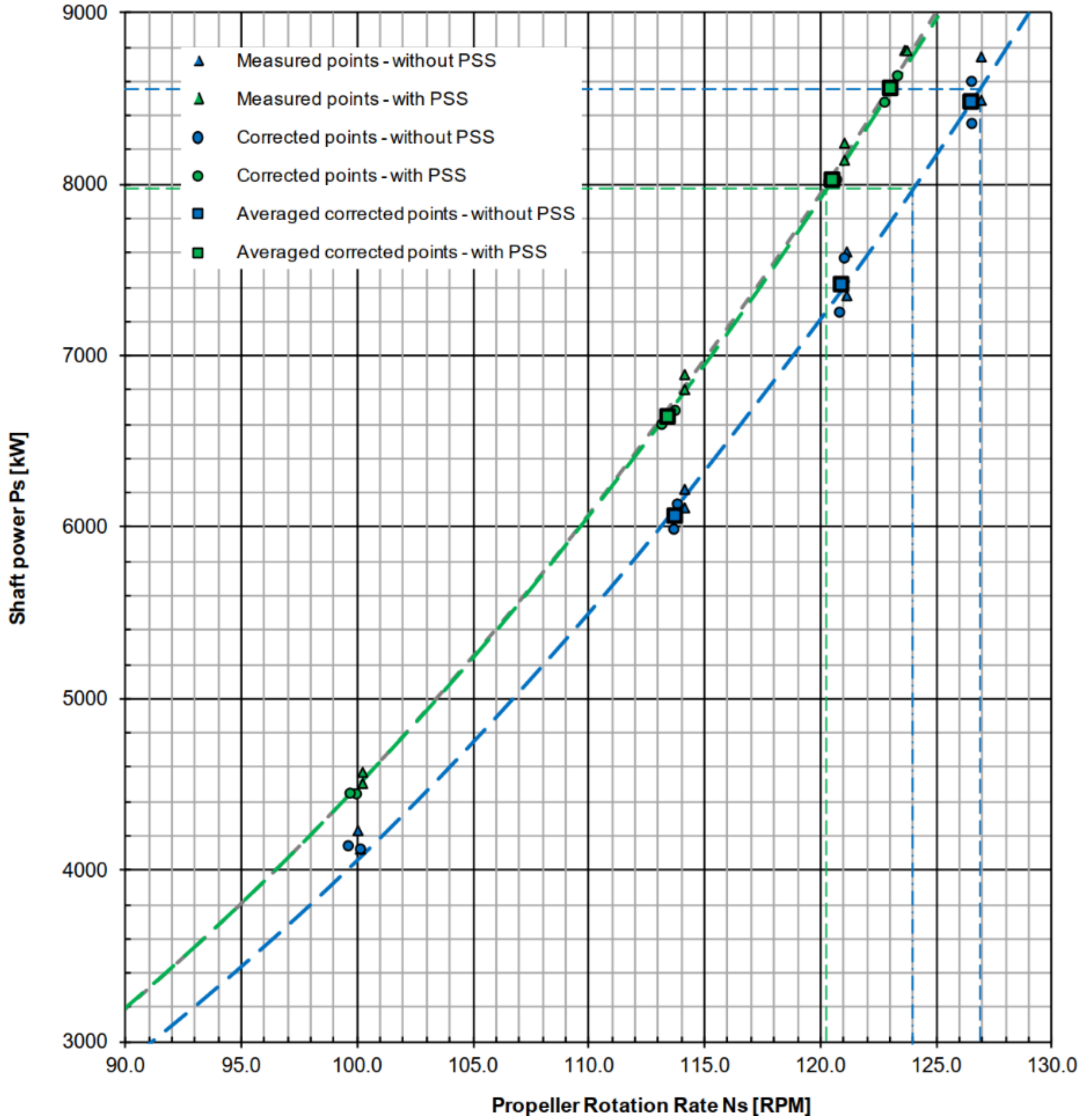

Fig.6: Shaft power vs. propeller rotation speed for vessel at sea trial with and without PSS

4. Self-Propulsion CFD simulation

Based on the sea trial report, a detailed case description was developed, specifying the necessary conditions such as vessel speeds, draughts, and hull surface roughness. To ensure an unbiased comparison, the RPM and shaft power values were not disclosed to participants, enabling a blind CFD validation against the measured data. The geometry files used in the simulations are publicly available on the JoRes website. The provided hull model includes the rudder, propeller hub, propeller blades, and configurations both with and without the pre-swirl stator (PSS). The principal particulars of the hull are listed in Table IV, and the propeller specifications are detailed in Table V.

The superstructure is not considered in the CFD simulation. Based on *ITTC (2008)* procedures, the total ship resistance coefficient could be written as:

$$C_T = \frac{S + S_{BK}}{S}\,[(1+k)C_F + \Delta C_F] + C_R + C_{AA}$$

Table IV: Suggested main particulars of the hull without and with PSS for CFD simulations

Characteristic		W/O PSS	With PSS	Units	Notes
Length between perpendiculars	L_{PP}	182.0	182.0	m	
Length of submerged body	L_{OS}	189.515	189.515	m	
Breadth	B	32.26	32.26	m	
Draught at aft perpendicular	T_{AP}	7.72	7.72	m	
Draught at fore perpendicular	T_{FP}	7.69	7.69	m	
Draught at midship	T_M	7.705	7.705	m	$T_M = \frac{T_{AP} + T_{FP}}{2}$
Static trim angle	t	-0.00907	-0.00907	deg	$t = arctan\left(\frac{T_{FP} - T_{AP}}{L_{PP}}\right)$
Displaced volume	∇	35820.3	35847.5	m^3	
Wetted surface area	A	7335.45	7360.93	m^2	
Longitudinal centre of buoyancy	x_{CB}	97.11	97.07	m	
Transversal centre of buoyancy	y_{CB}	0.00	0.00	m	
Vertical centre of buoyancy	z_{CB}	4.005	4.005	m	
Longitudinal centre of gravity	xCG	97.0643	97.062	m	Based on actual draughts
Transversal centre of gravity	yCG	0.00	0.00	m	
Vertical centre of gravity	zCG	7.705	7.705	m	Assumed to be T_M
Radius of gyration	k_{xx}	11.291	11.291	m	$0.35 \cdot B$
Radius of gyration	k_{yy}	45.5	45.5	m	$0.25 \cdot L_{PP}$
Radius of gyration	k_{zz}	45.5	45.5	m	$0.25 \cdot L_{PP}$

Table V: Suggested main particulars of the propeller

Characteristic		Value	Units	Notes
Propeller Diameter	D_P	5.8	m	
Pitch Ratio	$\frac{P}{D_P}$	0.723	-	
Area Ratio	$\frac{A_E}{A_0}$	0.631	-	
Hub diameter Ratio	$\frac{D_H}{D_P}$	0.15776	-	
No. of blades	Z	4	-	
Propeller Position	$Pos_{Prop}(x, y, z)$	3730.0, 0, 3210.0	mm	ship coordinate system

The total resistance is then calculated from

$$R_T = \frac{1}{2}\rho C_T S V^2$$

If we exclude the corrections for roughness, the total resistance R_T can be simply written as

$$R_T = R_{CFD} + R_{Air} + R_{BK}$$

R_{Air} is the air resistance, R_{BK} the resistance of the bilge keels. Table VI summarises the added air and bilge keels' resistance for each speed.

Table VI: Summary of added air and bilge keels resistance

Ship Speed	Air Resistance	Bilge Keels Resistance	Total Added Resistance
13.65 kn	18.23 kN	10.27 kN	28.04 kN
15.25 kn	22.75 kN	12.82 kN	35.57 kN
16.02 kn	25.11 kN	14.15 kN	39.25 kN
16.32 kn	26.06 kN	14.68 kN	40.74 kN

Comparing the submitted result for the difference between total resistance and propeller thrust shows that some of the calculations used different values for added resistance from the suggested values in the table.

For the CFD simulations, participants were free to use their preferred meshing methods, but the domain size was suggested to follow these values:

Minimum extent of domain = (-3.0, -2.0, -1.5) $\cdot L_{PP}$
Maximum extent of domain = (3.0, 2.0, 0.5) $\cdot L_{PP}$

The fluid properties, according to sea trial weather conditions, are defined as no wind, no waves, deep water, water temperature of 15 °C, water density of 1025 kg/m^3, and air density of 1.225 kg/m^3. The calculated kinematic viscosity of water from the temperature and salinity is $1.188 \cdot 10^{-6}$ m^2/s and for air is $1.457 \cdot 10^{-5}$ m^2/s.

Participants chose an adequate method for simulating the propeller thrust in the self-propulsion case. This can be fully resolved by the propeller or coupled RANS-BEM approaches. Simulations were performed at a given constant ship speed, while propeller RPM was adjusted to find the self-propulsion point. The submitted results presented in this paper are for the hull free to sink and trim, taking into account air resistance and bilge keels.

As for the surface roughness, the following values are used in the computations (the values are the same as for the JoRes1 tanker):

- the hull equivalent sand grain roughness k_s=53 µm (this corresponds to the measured Average Hull Roughness of 218 µm)
- the rudder equivalent sand grain roughness k_s=63 µm (this corresponds to the measured Average Rudder Roughness of 243 µm)
- the propeller equivalent sand grain roughness k_s=3.79 µm
- the PSS equivalent sand grain roughness k_s=6 µm

All calculations were performed in full scale and included the free surface.

5. Result of the Workshop

Seven participants (S01–S07) contributed simulation data for full-scale hull performance under free sinkage and trim conditions. Results were compared and analysed by RISE. Participants submitted computed torque, RPM, Resistance, thrust and power values for the JoRes5 bulk carrier operating at four speeds: 13.65, 15.25, 16.02, and 16.32 kn. Each case includes simulations with and without Pre-Swirl Stators (PSS). Some participants provided partial data, with missing entries for certain speeds or PSS configurations. Four of these submissions (S01, S04, S06 and S07) included all speeds for two cases (with and without PSS). While two participants (S02 & S05) only submitted one speed of 13.65 kn, one participant (S03) submitted all speeds for the hull without PSS. All participants used the RANS solver with $k\omega - SST$ turbulence model. Table VII lists the software type and the solver model of the submitted cases.

Table VII: CFD software used in the computations

Submission	Software	Propulsion Model
S01	FreSCo+	RANS_BEM Coupling
S02	StarCCM+ v23.10	Overset mesh for vessel, sliding mesh for propeller
S03	StarCCM+ v24.10	-
S04	SstarCCM+ v14.04	RBM model for propulsion
S05	StarCCM+ v23.02	-
S06	StarCCM+ v18.06	Sliding Mesh
S07	StarCCM+ v13.04	-

The computed power values show consistent trends across participants: Power increases with speed, as expected due to higher resistance and propulsion demand. PSS generally reduces power consumption, indicating improved propulsion efficiency. Table VIII summarizes the mean computed power across all valid submissions.

Table VIII: Average values of the submitted results of CFD simulations

Speed	Mean Power w/o PSS	Mean Power with PSS	Average Reduction
13.65 kn	5.0 MW	4.8 MW	3.0%
15.25 kn	7.2 MW	7.0 MW	2.7%
16.02 kn	8.9 MW	8.7 MW	2.1%
16.32 kn	9.6 MW	9.4 MW	2.0%

The submitted results included values for trim angle, sinkage of the hull, thrust exerted, torque and RPM of the propeller and hull resistance. Fig.7 presents the submitted values for the sinkage and trim of the vessel at different speeds for the cases with and without PSS.

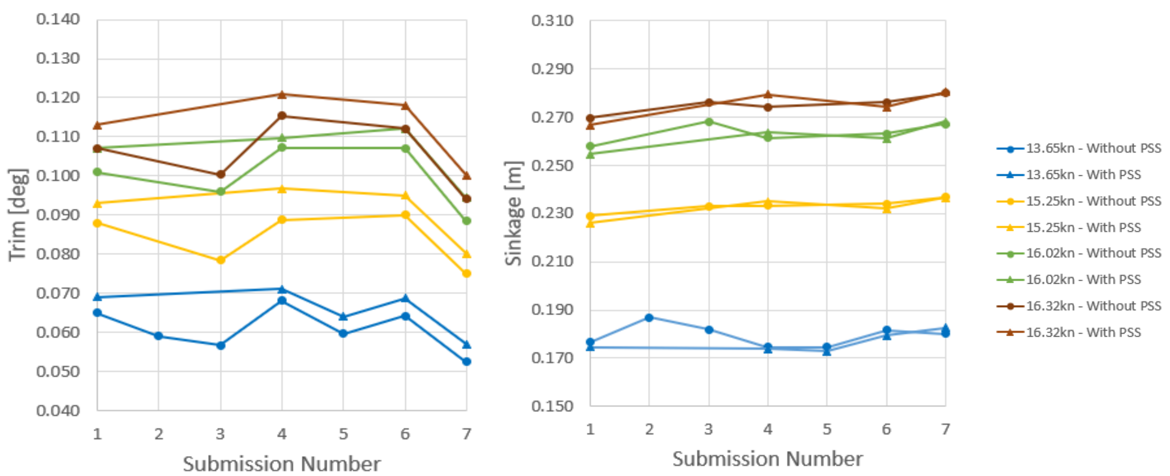

Fig.7: Computed Trim angle and Sinkage at different speeds

The power reduction due to PSS varies slightly among participants, ranging from ~1% to ~5.7%, depending on speed. Comparing the thrust and resistance forces showed that S06 did not consider the added resistance due to air and appendages, and S01 overestimated the added resistance at a lower speed of 13.65 kn.

Fig.8 presents the calculated power at different speeds for two cases. The percentages of power reduction due to PSS are also presented, and the horizontal solid line indicates the sea-trial result for the given ship speed.

Fig.9 shows the computed propeller rotational speeds, while horizontal lines represent sea trial values for the given ship speed and case. Fig.10 shows the computed thrust force at different ship speeds and cases.

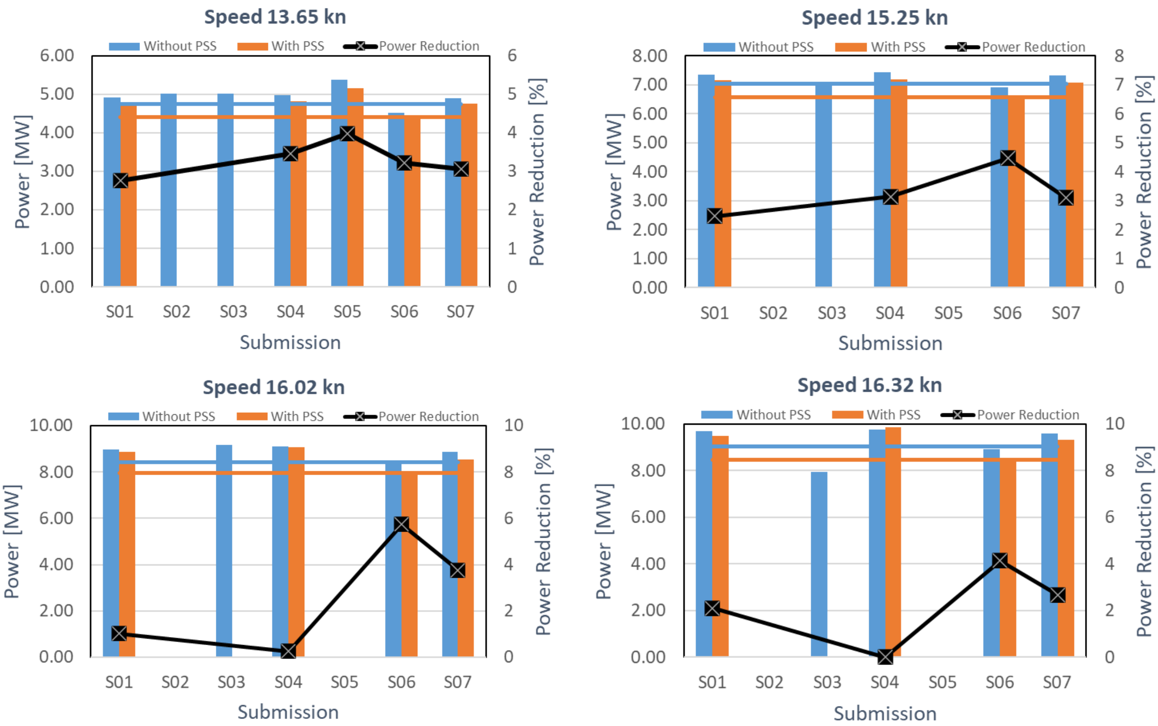

Fig.8: Power calculated at different speeds for two hulls with and without PSS. Horizontal lines represent sea trial values.

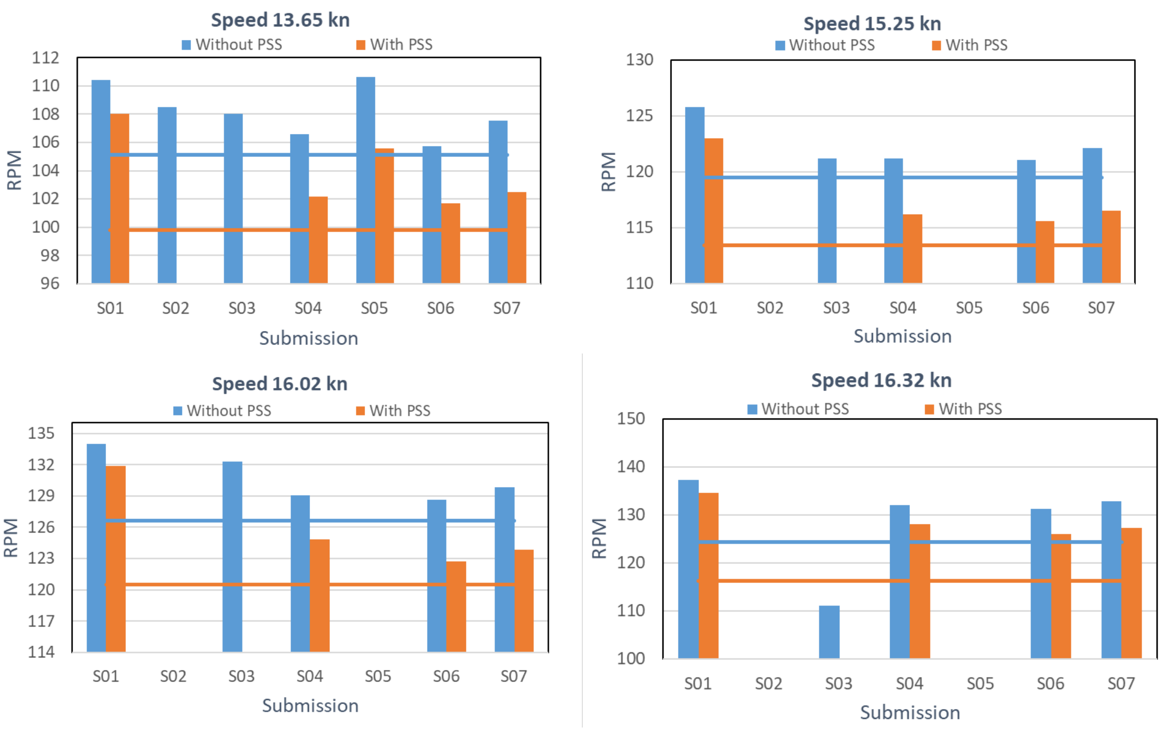

Fig.9: Computed propeller rotational speeds. Horizontal lines represent sea trial values

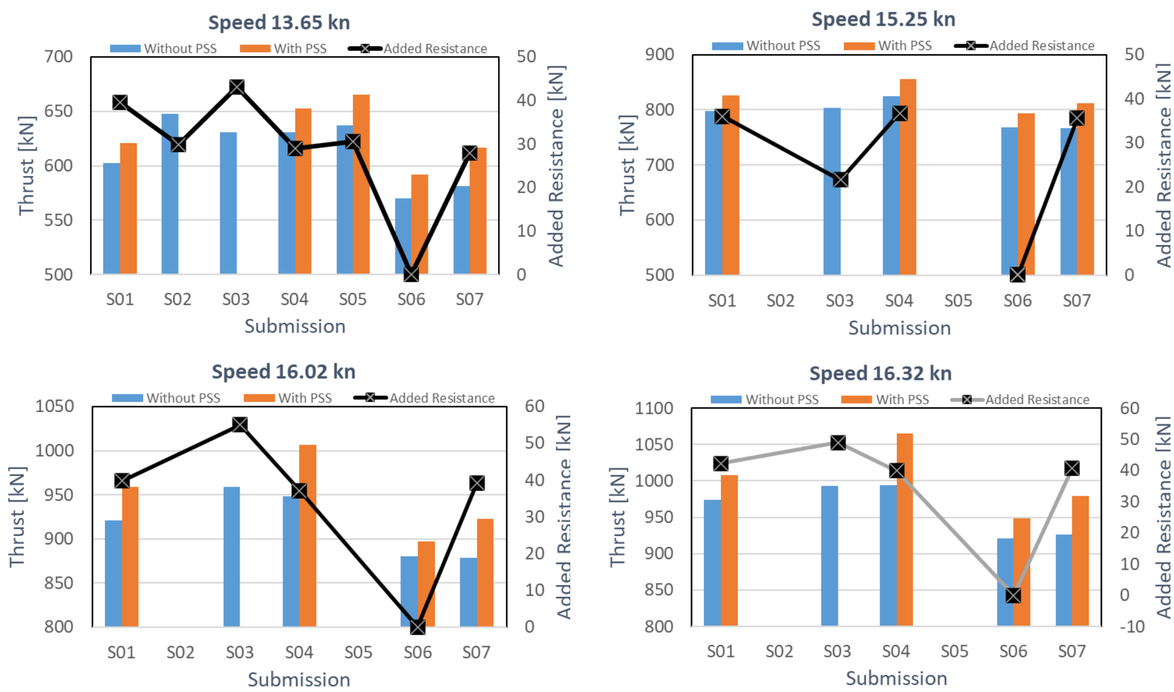

Fig.10: Computed thrust at different speeds

6. Summary and Conclusion

The average submitted data across all participants overestimated the RPM and power values according to Table IX.

Table IX: Difference between RPM and Power valued computed and sea trial

Speed	Without PSS		With PSS	
	RPM	Power	RPM	Power
13.65 kn	2.94%	4.41%	4.19%	8.15%
15.25 kn	2.32%	2.04%	3.92%	6.59%
16.02 kn	3.29%	5.56%	4.41%	8.25%
16.32 kn	-0.40%	1.74%	4.85%	9.79%

The average submitted power saving of the PSS is under-estimated by 50% according to Table X.

Table X: Power saving due to PSS

Delivered Power Reduction		
Speed	Computed	Sea Trial
13.65 kn	3.29%	7.10%
15.25 kn	3.30%	6.65%
16.02 kn	2.69%	5.79%
16.32 kn	2.00%	6.08%

Unfortunately, despite the commitment of the participants and their submissions, the results are not fully representative because two out of seven participants did not submit the complete set of results, and one participant did not take into account the added resistance due to superstructure and bilge keels. So, only 4 out of 7 sets can be compared. Moreover, S04's results do not appear very consistent; they predicted that at a speed of 16.32kn, the vessel would require more power with PSS rather than without

PSS. All other predictions do not show the exact same results, but they are, in general, consistent with the measurements. *Andersson et al. (2022)* introduced a similar concept: an energy-saving duct was built for KVLCC, and participants were asked to run the case with and without the duct. The results of that workshop were very inconsistent, and the saving prediction varies from −2.9% to ＋3.4% excluding several outliers with ±10%. Therefore, compared to that case, there is an improvement in the results consistency. As the data (geometries, sea trials results, etc.) is now fully available in the public domain at the JoRes website, it is expected that other researchers will perform further simulations, and the results dataset will become larger and more representative for comparison.

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