Technical Committee on Energy Saving Methods

2017-2021

Chairman : Inwon Lee
Members : James Gose, Andrea Coraddu, Jianting Chen, Munehiko Hinatsu, Ramon Quereda, Tie Li

1. Introduction

- **Membership and Meetings**

✓ Members

- Professor Inwon Lee, Pusan National University, Korea (Chairperson)
- Dr. James Gose, University of Michigan, USA (Secretary)
- Dr. Andrea Coraddu, University of Strathclyde, UK
- Professor Jianting Chen, Shanghai Ship and Shipping Research Institute, China
- Professor Munehiko Hinatsu, Osaka University, Japan
- Dr. Ramon Quereda, CEHIPAR, Spain
- Professor Tie Li, Shanghai Jiao Tong University, China

✓ Meetings

- Pusan National University, Korea, 15-16 March 2018
- CEHIPAR, Spain, 5-6 November 2018
- University of Michigan, USA, 17-18 June 2019
- University of Strathclyde, UK, 6-7 February, 2020

1. Introduction

- **Terms of Reference of the 28th ITTC**

1. Continue a systematic survey of energy saving methods (excluding machinery), devices, applications and possible savings, including the influence on the EEDI formula.
2. Continue identifying and update the physical mechanisms for the newly introduced energy saving methods.
3. Update a survey on frictional drag reduction methods, including air lubrication and surface treatment.
4. Update a survey on energy savings based on the use of wind energy.
5. Develop guidelines for: CFD methods, model tests, scaling, for energy saving devices, taking into account Tokyo 2015 CFD workshop results investigating the influence of ESD. Continue to identify the needs for new model test procedures (resistance and propulsion, extrapolation methods) to investigate the effect of energy saving methods.
6. Collect and discuss the full scale data obtained through relevant benchmark tests on the effect of energy saving methods.
7. Identify and recommend the tasks related to energy saving methods and devices that should be undertaken during the 30th ITTC by general committees.

2. Survey of Energy Saving Methods

- **Category of ESMs (Energy Saving Methods)**
  - ✓ **Modifications from 28th Conference**
    - No major modifications
    - Minor modification: “Gate Rudder” is newly added in “inflow management”
    - Minor modification: "Ducted Contra-Rotating Propeller (DCRP)" is newly added in “Inflow Management” and “Reduce rotational energy in the propeller wake”.

Principle	Mechanism	Technique	Methodology
Direct drag reduction	frictional resistance	less wetted sueface area less sheer force	air lubrication
			low friction paint
	viscous pressure resistance	boundary layer control	generate local vortex by fins
			hull form optimisation
	wave-making resistance	bow shaping	bulbous bow
			hull form optimisation
	wind drag reduction	shaping of upper structures	corner rounding
			downsizing of upper structure
	added wave resistance	incident wave reflection	bow shaping
		ship motion	hull shape
Reducing Propulsive losses	relative rotative efficiency	bilge vortex energy recovery	pre swirl stators
			vortex generators
	hull efficiency	hull-propeller interaction	vortex generators
			hull-propeller optimisation
	rotational efficiency	reduce rotational energy in the propeller wake	pre swirl stators
			contra-rotating propeller
			reaction rudder
			rudder fin
			hub fins
			overlapping propeller
	axial efficiency	hub vortex recovering	hub fins
			rudder bulb
		reduce tip vortex	tip-fin propeller
			tip-rake propeller
			CLT propeller
		inflow management	ducts
			overlapping propeller
	frictional efficiency	coatings	low friction paint
		injection	
	propeller design	blade design	area, thickness, section, tip loaded propeller
		CFD, optimization	

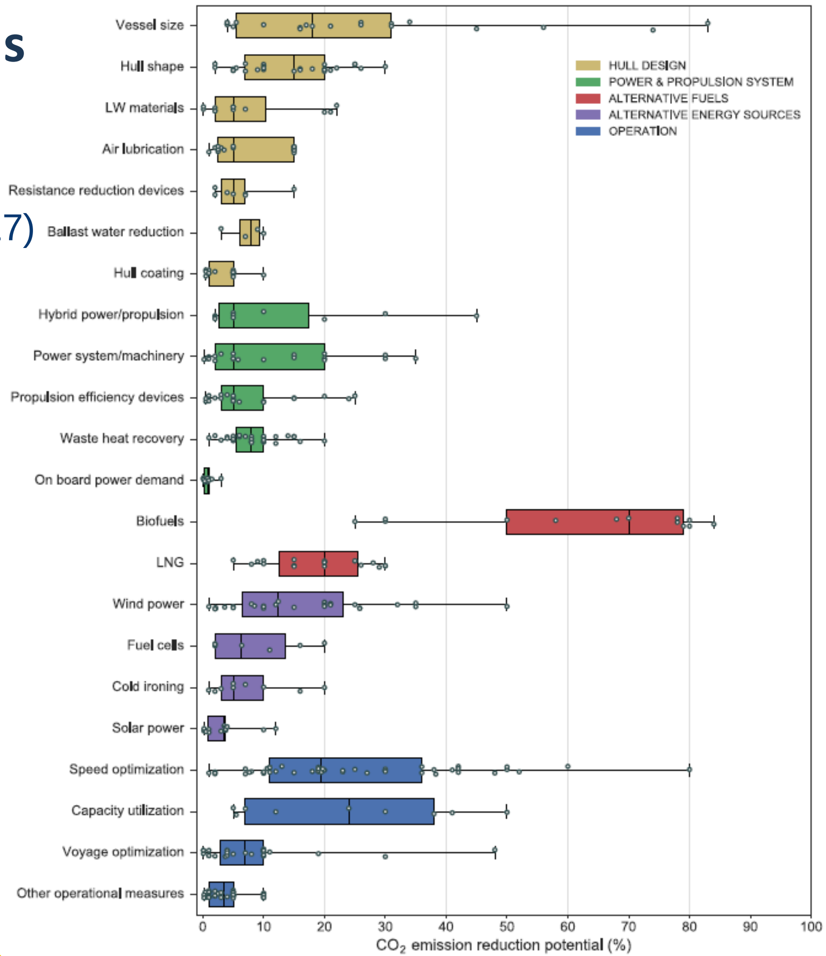
2. Survey of Energy Saving Methods

- Category of ESMs (Energy Saving Methods): cont'd
  - ✓ Modifications from 28th Conference
    - No major modifications
    - Minor modification: "Gate Rudder" is newly added in "inflow management"
    - Minor modification: "Ducted Contra-Rotating Propeller (DCRP)" is newly added in "Inflow Management" and "Reduce rotational energy in the propeller wake".

Principle	Mechanism	Technique	Methodology
Use of renewable energy	wave	wing theory in waves	forebody fin
	wind energy	thrusut by wing lift	sail
			kite
			flettner rotor
	solar energy	energy change	photovoltaic panels
Operation	optimisation in operation	ICT	weather routing
			slow steaming
	aging	maintenance	docking
			roughness treatment

2. Survey of Energy Saving Methods

- **State-of-the-art of ESMs**
  - ✓ **CO$_2$ emission reduction potential**: Bouman et al. (2017) investigated current nominal ESMs performance by surveying papers issued from 2009 to 2016.



2. Survey of Energy Saving Methods

Review of recent research on ESM: literature survey

✓ Journals: published 2017 – 2021

- Applied Ocean Research (AOR)
- China Ocean Engineering (COE)
- International Shipbuilding Progress (ISP)
- International Journal of Naval Architecture and Ocean Engineering (IJNAOE)
- Journal of Hydrodynamics (JHD)
- Journal of Marine Science and Technology (JMST)
- Journal of Ship Research (JSR)
- Ocean Engineering (OE)

✓ Conference Proceedings

- Advanced Model Measurement Technology for the Marine Industry (AMT): 2017, 2019
- Computer and IT Application in the Marine Industries (COMPIT): 2017, 2018, 2019, 2020
- Symposium on High-Performance Marine Vehicle (HIPER): 2016, 2017,
- Hull Performance & Insight Conference (HullPIC): 2017, 2018, 2019, 2020
- International Naval Architecture and Maritime Symposium (INT NAM): 2018
- International Ocean and Polar Engineering Conference (ISOPE): 2017, 2018, 2019, 2020

2. Survey of Energy Saving Methods

- **Review of recent research on ESM: literature survey**
  - **Conference Proceedings**
    - International Conference on Computational Methods in Marine Engineering (MARINE): 2017, 2019
    - Technology and Science for the Ships of the Future, 19th International Conference on Ship & Maritime Research: 2018
    - Numerical Towing Tank (NuTTS): 2017, 2018, 2019
    - International Conference on Ocean, Offshore and Arctic Engineering (OMAE): 2017, 2018, 2019
    - International Symposium on Practical Design of Ships and Other Floating Structures (PRADS): 2019
    - International Symposium on Marine Propulsors (SMP): 2017, 2019
    - Symposium on Naval Hydrodynamics (SNH): 2018, 2020

2. Survey of Energy Saving Methods

Direct Drag Reduction: Frictional Resistance

Air lubrication method

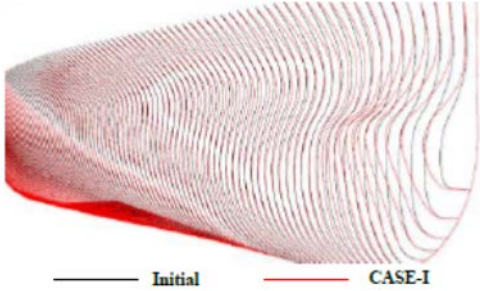
- Rotte et al. (2018): Numerical simulation of flat bottom boundary layer with air cavity.
- Arakawa et al. (2018): CFD of ship flow in air lubrication with/without pre-swirl duct.
- Wang et al. (2017): Experiment using 5-m long flat bottom shallow ship, obtained 15.5% drag reduction.
- Kawakita (2018): Widely reviewed air lubrication method from the view point of actual ship design.
- Bondarenko & Fukuda (2018): Analysed the main engine plant system under scavenging bypass condition to inject air beneath the ship bottom.

Effect of hull coating, Low friction paint

- Goler & Bozkurt (2017): fuel consumption for alternative hull coating using 8 sister high speed Ro-Ro vessels. >> Full scale
- Demirel (2018) : Review and investigation of marine coating to prevent biofouling on ship.
- Delfos et al. (2017), Greidanus et al. (2017): Compliant coating.
- Schrader et al. (2019): about 3% drag reduction using bionic hull coating along the hull model of small boat.
- Lee & Park (2017, 2018): about 10% frictional drag reduction using self-polishing co-polymer (FDR-SPC), applied on 176k bulk carrier.

2. Survey of Energy Saving Methods

- **Direct Drag Reduction: Viscous Pressure Resistance**
  - ✓ **Hull form optimization**
    - With increase of performance of computers, researches of hull form optimization using CFD are increasing in number.
    - Relevant keywords: **Multi-fidelity meta-modelling; surrogate based global optimization; multi-objective optimization**
- **Direct Drag Reduction: Wavemaking Resistance**
  - ✓ **Hull form optimization**
    - Huang et al. (2017): a new vortex search algorithm, aiming at avoiding trap in the local optimum solution
    - Liu et al. (2017): optimization using variance-based sensitivity analysis, Sobol and kriging model-based tensor-product basis function methods.
    - Goren & Calisal (2017): a mathematical programming procedure based on Wolfe's algorithm
    - Yu et al. (2017): bow hull form optimization at calm and irregular head waves to achieve 13.2% reduction in the wave-making resistance and 9.5% reduction in the mean added resistance at sea state 5.
    - Ouyang et al. (2020): invisible bow → 18% decrease of the residual resistance, 2.9% decrease of the total resistance.



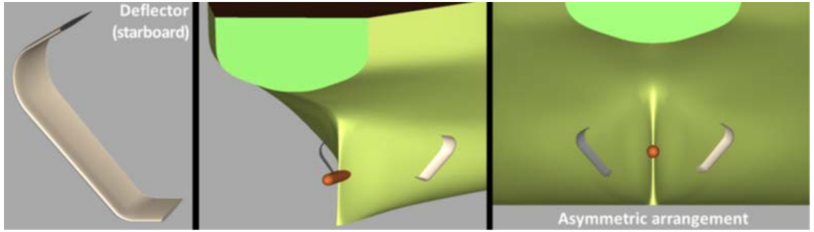
Invisible bow by Ouyang et al. (2020)

2. Survey of Energy Saving Methods

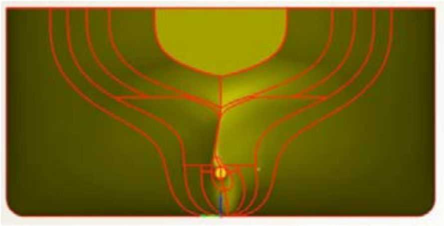
Reducing Propulsive Losses: Relative Rotative Efficiency

✓ Appendages & vortex generators

- Schrader & Marzi (2017): special appendages aimed to deflect the outer flow field towards the hull surface
- Suryateja et al. (2019): asymmetric stern form for KVLCC2 full scale ship to improve the propulsive efficiency



Schrader et al. (2017)


Suryateja et al. (2019)

Reducing Propulsive Losses: Rotational Efficiency

✓ Pre-swirl stator/duct, rudder bulb, rudder fin, PBCF, CRP

- Quite a lot of researches categorized here have been carried out.
- EU's GRIP (Green Retrofitting through Improved Propulsion) Project Results: reported in International Shipbuilding Progress Vol.63, No.3-4, 2016/2017
- Researches in Scale effect for ESD using CFD can be found. Flow analyses using PIV are increasing in number.

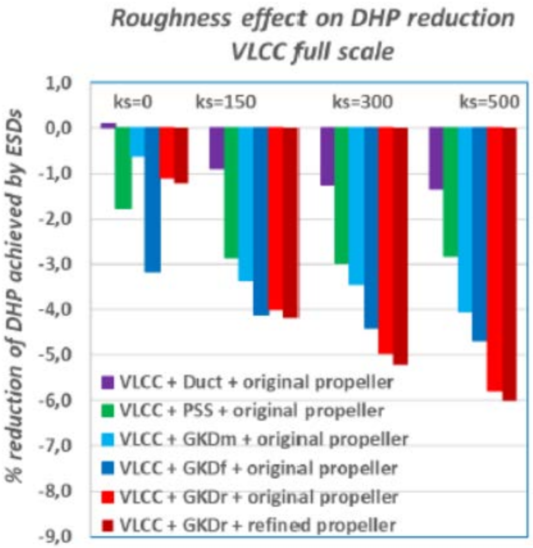
2. Survey of Energy Saving Methods

Reducing Propulsive Losses: Rotational Efficiency

✓ Pre-swirl duct

- Many works have been done at many organizations and many types of pre-swirl ducts.
- Tacar & Korkut (2017): study the performance of 9 different ducts for 7k DWT tanker.
- Furcas et al. (2019): Wake Equalizing Duct (WED)
- Katayama et al. (2017), Kobayashi et al. (2017): Neighbor Duct with 4.4% energy saving predicted in full scale ship

- Kim et al. (2020): ESD performance at full scale ship decreases from that at model scale. However, if we consider the effect of roughness at full scale, ESD performance increases. This means that the effect of the roughness is very important to estimate the ESD performance at full scale ship.



Kim et al. (2020)

Reducing Propulsive Losses: Rotational Efficiency

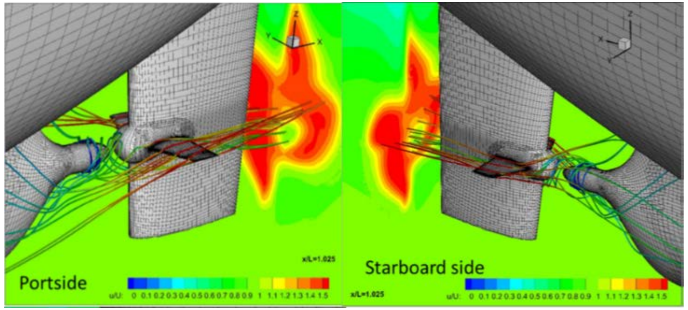
✓ Pre-swirl stator

- Many works have been done at many organizations.
- Kim et al. (2017): propose an extrapolation method for analysis of a self-propulsion test with a pre-swirl device.
- Voermans (2017): CFD analysis for pre-swirl stator
- Krasilnikov et al. (2019): Full-scale CFD simulation for three different types pre-swirl stators and considered the mechanism of the performance difference.
- Nielsen & Wei (2019): Full scale optimization of Controllable Pre-Swirl Fins (CPSF) by CFD

Voermans (2017)

✓ Rudder bulb fin

- Truong et al. (2017): PIV & CFD flow investigation around stern flow for KVLCC2 with rudder-bulb fin → optimization of angles of attack & chord lengths of port/starboard fin separately

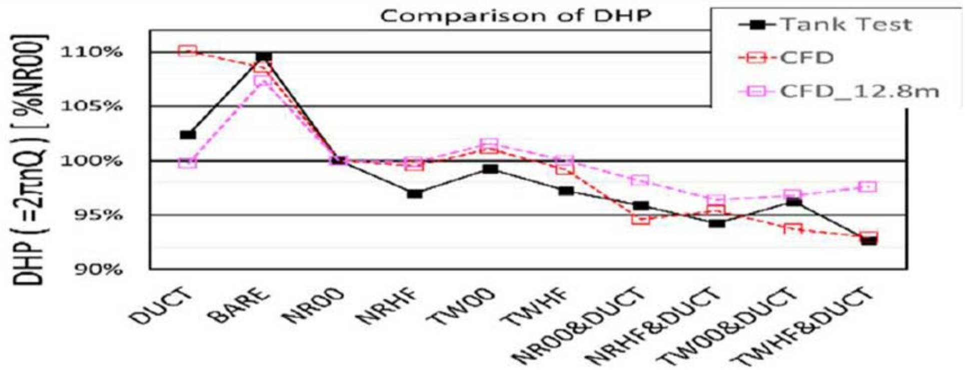


Truong et al. (2017)

2. Survey of Energy Saving Methods

- **Reducing Propulsive Losses: Rotational Efficiency**
  - ✓ **Combined ESDs**
    - Lee et al. (2017): Combination of pre-swirl stator, tip rake propeller and wavy twisted rudder → 5.47% combined energy saving effect, but being less than sum of energy saving effects of respective devices
    - Hori et al. (2017): Combination of rudder bulb, duct, rudder fin and twisted rudder and search optimized combination

Lee et al. (2017)



Hori et al. (2017)

3. Use of Wind Energy

Background

✓ Types of wind energy harvesting system

- Parker (2013): Flettner rotors, kites or spinnakers, soft sails, wing sails and wind turbines
- Smith et al. (2016): wind propulsion is most effective at slower speeds (e.g. less than 16 knots), and on smaller ships (3,000 - 10,000 tonnes), which account for one-fifth of global cargo ships.

✓ Energy savings from wind energy

- Traut et al. (2014): 2-24% for a single Flettner rotor, 1-32% for a towing kite
- eConowind sails (which pack into a single container): up to 25% estimated by Traut et al. (2014) and 10 to 60% at slow speeds by Smith et al. (2016)

✓ Barriers to wide adoption of wind energy solutions

- Rehmatulla et al. (2017): unfamiliarity with technology, safety and reliability concerns, and lack of demonstration
- No data on capital costs were found for the installation of wind assistance systems as they are at an early stage of development.

3. Use of Wind Energy

- **Various Types**
  - **Wing sail**
    - Viola et al. (2015): showed the possibility to reduce the propeller thrust of a KVLCC2 by up to 10% in cross winds.
  - **Towing kite**
    - Leloup et al. (2016): With a 320m^2 kite on a 50k DWT tanker, the fuel savings predicted were about 10% for a Beaufort 5 sea state, and could reach values of 50% for wind velocities corresponding to a Beaufort 7 sea state.
  - **Flettner rotor**
    - The most frequent research topic
    - Pearson (2014), Craft et al. (2014), Lu & Ringsberg (2020): fuel savings ranging between 5.6% and 8.9% were achievable

Viola et al. (2015)

Enercon's E-Ship 1 shown in Craft et al. (2014)

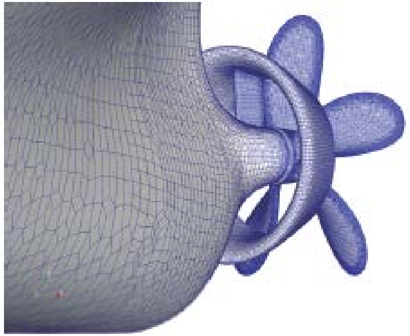
CFD Methods for Energy Saving Device (ESD)

✓ Tokyo 2015 CFD workshop

- Purpose: to assess state-of-the arts of the contemporary CFD codes for ship hydrodynamics
- Analysis cases: three ship hulls / 17 test cases specified by the organizers
- 30 groups submitted their computed results for one or more cases.

✓ Implication of Tokyo 2015 CFD workshop pertaining to ESM

- Japan bulk carrier (JBC) was associated with ESD, with resistance and self-propulsion performance being carried out either with ESD and without ESD.
- Review topic #1: Numerical errors between the case with ESD and without ESD would imply how adequately the state of the art CFD simulation deal with the propulsive performance of ESD.
- Review topic #2: statistics of CFD parameters, which can give an idea on the best practice of CFD.



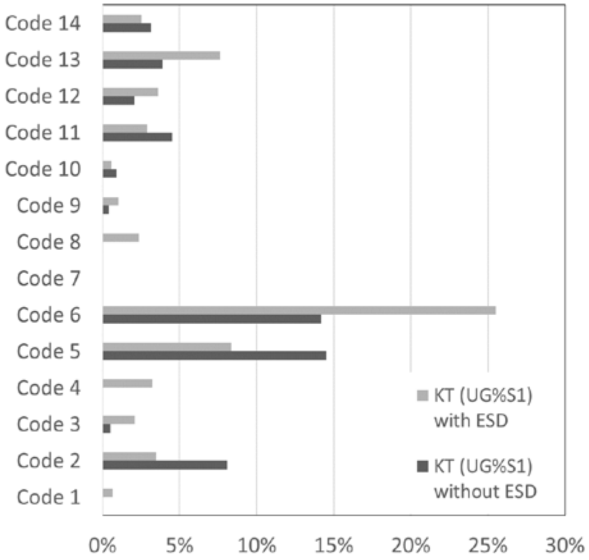
Surface mesh of the ESD considered for JBC

4. CFD, EFD & Scaling Methods

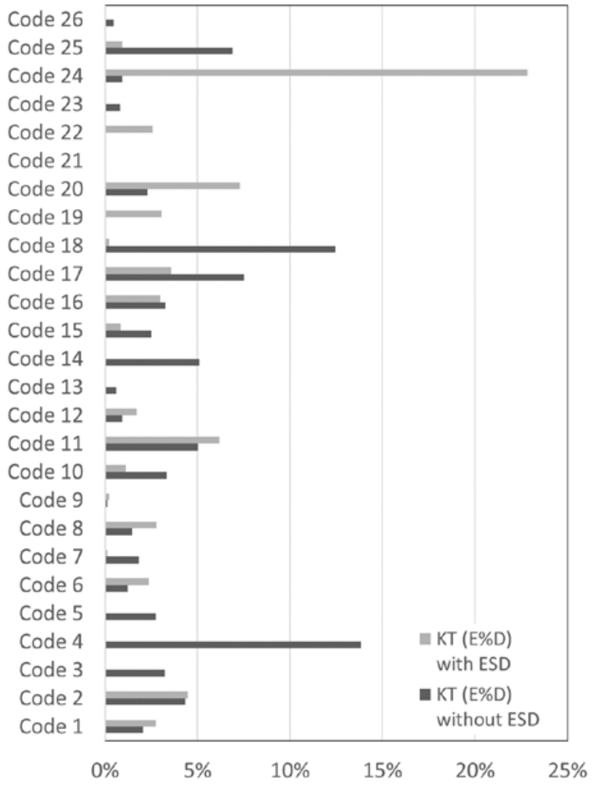
CFD Methods for ESD

✓ Review topic #1:

- Question: The errors in ESD cases are systematically larger than those in no-ESD cases ?
- <u>The answer is NO</u>.
- There is no evidence to support the inadequacy of current CFD technique in dealing with ESD.
- The needs for a particular, dedicated CFD procedure for ESD is not identified.



Comparison of the grid uncertainty associated with thrust coefficient K_T

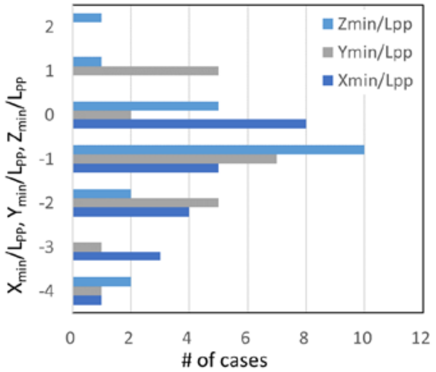


Comparison of % error in thrust coefficient K_T

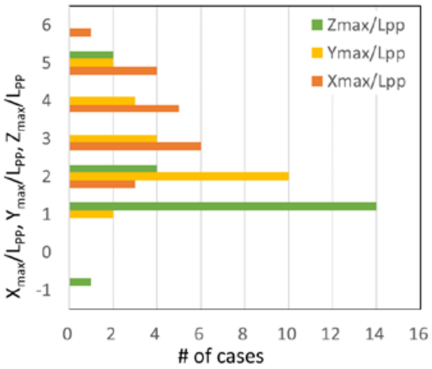
CFD Methods for ESD

✓ Review topic #2:

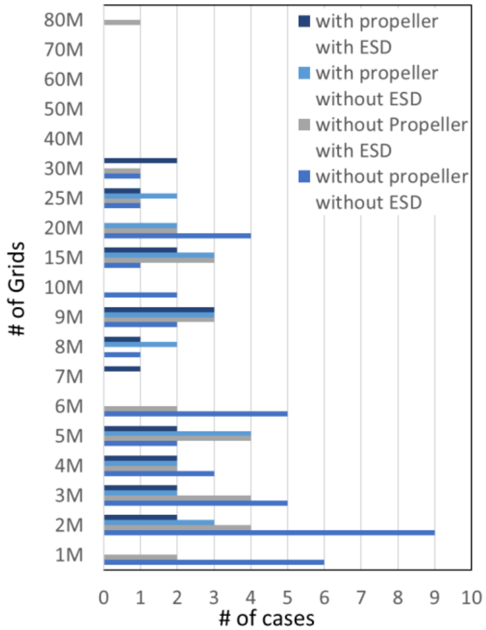
- Statistics of CFD parameters: # of grids, wall function y^+, the size of computational domain
- Wide variation in the parameters is noted.



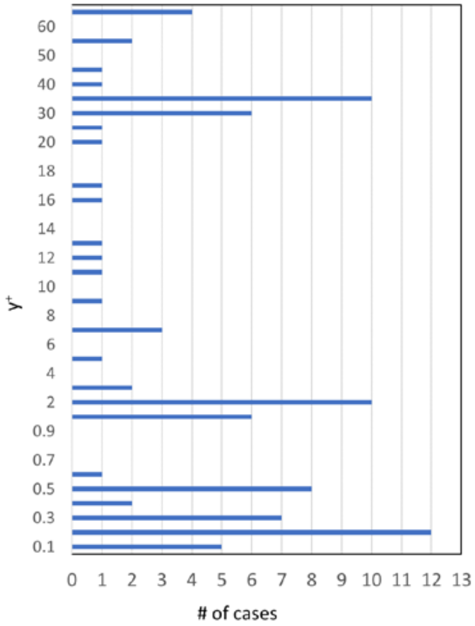
Minimum values of computational domain



Maximum values of computational domain



Distribution of # of grids



Distribution of value of y^+

4. CFD, EFD & Scaling Methods

➢ Review of the proposed CFD guideline from PRADS 2016

✓ Hino et al. (2016)

- presented a benchmark data for the validation of CFD simulation results for a Japan bulk carrier (JBC) equipped with an energy saving circular duct ⇔ JBC case with ESD in Tokyo 2015 Workshop on CFD

✓ Comparison between the existing ITTC guidelines related to CFD

- ITTC (2014a) 7.5-03-02-03 Practical Guidelines for Ship CFD Applications.
- ITTC (2014b) 7.5-03-02-04 Practical Guidelines for Ship Resistance CFD.
- ITTC (2014c) 7.5-03-03-01 Practical Guidelines for Ship Self-propulsion CFD.

✓ Experts' opinion & Conclusion

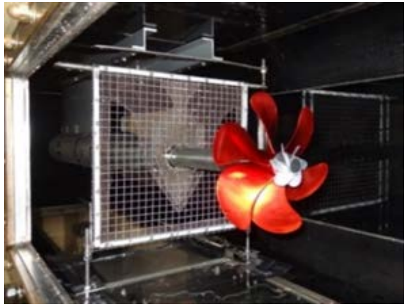
- Some of the statements in the proposed guideline are not included in the existing guidelines.
- On the other hand, those suggestions are largely well-known in the CFD community.
- It is hard to ascertain that the guideline took into considerations for the relevant aspects of diverse types of ESDs, because only the circular duct was dealt with.
- **Conclusion**: It is premature to setup a CFD guideline dedicated to ESD in the absence of reliable database of CFD as well as EFD results for various kinds of ESD.

4. CFD, EFD & Scaling Methods

Experimental methods for ESM

✓ PBCF & Rudder bulbous fin

- Kimura et al. (2019): evaluated the full scale energy saving effect of PBCF by reversed POT with wire-mesh screen to simulate the ship wake.
- Müller et al. (2017): wide use of 3D printing technology in the manufacture of model ESD
- Truong et al. (2017): studied the rudder bulbous fin system with EFD and CFD methods.

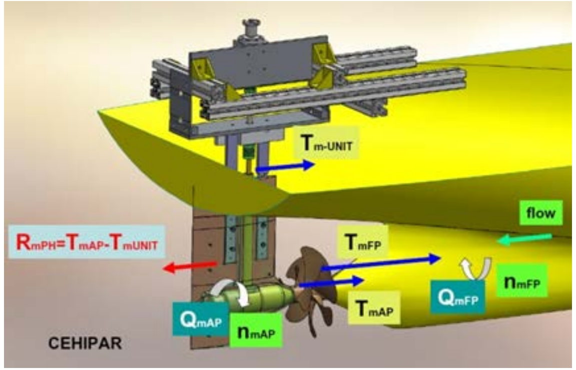


Arrangement of Wire mesh screen (Kimura et al., 2019)

Various hub caps with fins (Müller et al., 2017)

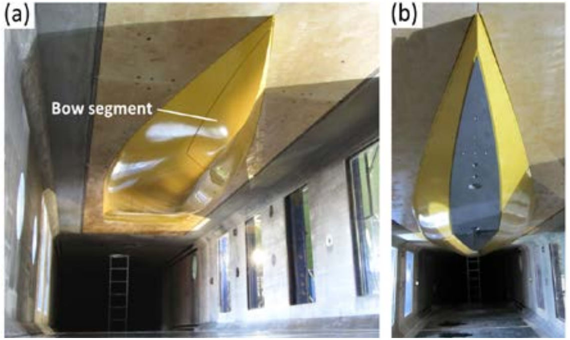
Rudder bulbous fin system (Truong et al., 2017)

- **Experimental methods for ESM**
  - ✓ **CRP-POD propulsion system**
    - Quereda et al.(2017): employed a CRP-POD propulsion system configuration including two different propellers arranged in the same geometrical shaft with a short distance in between them and rotating in opposite sense but with a specific driven system.



Arrangement of self propulsion test (Quereda et al., 2017)

  - ✓ **Bionic technology**
    - Schrader (2018): conducted the coating tests in the Hydrodynamics and Cavitation Tunnel. The compliant coating similar to dolphin was made from polymeric materials.



Schrader (2018)

4. CFD, EFD & Scaling Methods

➢ Experimental methods for ESM

✓ Energy saving in waves

- Chiu et al. (2018): installed the pitch collapsing bow fin energy-saving device on a container ship model, and verified the energy-saving effect of about 4.29% by model test in waves
- Yasukawa & Ishikawa (2017): studied a Catamaran in Waves by a biologically inspired hydrofoil plate. The spring was put inside the foil model to produce a restoring force for roughly keeping the initial angle of attack of the wing. The tests were carried out in calm water and regular head wave conditions and the maximum EHP reduction ratio by the hydrofoil was about 10-15%.

Ship model with active pitch oscillating bow fin
(Chiu et al., 2018)

Models (left: catamaran, right: hydrofoil) by
Yasukawa & Ishikawa (2017)

Experimental methods for ESM

✓ Survey on the best practice of model tests for air-layer injection

- 7.5-02-02-03: a guideline to extrapolate model test results to a full-scale prediction adopted by the 28th ITTC
- The model test procedure for air lubrication, however, has not been standardized yet.
- 11 organizations replied to a 12-item questionnaire
- **Question #4 (Ship types considered)** Mark all relevant ship types which have been involved with air lubrication mode tests. (multiple answers allowed)

Choice	Type	# of choices (%)
1	Oil/Chemical Tanker	4 (19.0)
2	Bulk/Cargo Carrier	6 (28.6)
3	Containership	3 (14.3)
4	LNG/LPG carrier	2 (9.5)
5	Passenger/RORO/Cruise	2 (9.5)
6	Other types	3 (14.3)
7	No idea	1 (4.8)

- **Question #5 (Scale factor)** Mark all relevant ranges of scale factor λ which your past model tests fall into. (multiple answers allowed)

Choice	Type	# of choices (%)
1	$\lambda = 1.0$ (Full scale)	1 (6.3)
2	$1.0 < \lambda \leq 10.0$	3 (18.8)
3	$10.0 < \lambda \leq 50.0$	4 (50.0)
4	$50.0 < \lambda \leq 100.0$	1 (6.3)
5	$\lambda > 100.0$	1 (6.3)
6	No idea / None	2 (12.5)

Experimental methods for ESM

✓ Survey on the best practice of model tests for air-layer injection: cont'd

- **Question #7 (Injection pressure)** How high was the air pressure set just before the injection hole(s) in the model test? (pressure in the settling chamber/regulator before injection hole(s); multiple answers allowed)

Choice	Type	# of choices (%)
1	Atmospheric pressure	1 (8.3)
2	Full scale (hydrostatic pressure in full scale)	0 (0.0)
3	Model scale (hydrostatic pressure in model scale)	6 (50.0)
4	Polytropic expansion $pv^n = C$	0 (0.0)
5	Arbitrary pressure	2 (16.7)
6	None of the above	0 (0.0)
7	No idea	3 (25.0)

- **Question #8 (Injection flow rate)** How large was the air flow rate set in the model test? (multiple answers allowed)

Choice	Type	# of choices (%)
1	Full scale (same as full scale flow rate)	1 (7.1)
2	Same as the critical value of film thickness $t_f = Q_a/B \cdot U$ in full scale	8 (57.1)
3	Geometric scale of the critical value of film thickness $t_{f.model} = t_{f.full\ scale}/\lambda$	1 (7.1)
4	Arbitrary flow rate	2 (14.3)
5	None of the above $t_a = Q_a/B_a \cdot U$ or $t_b = Q_a/B_i \cdot U$ (B_a = breadth of air covered area, B_i = air injector breadth)	1 (7.1)
6	No idea	1 (7.1)

Experimental methods for ESM

Survey on the best practice of model tests for air-layer injection: cont'd

- **Question #9 (Extrapolation method)** What kind of extrapolation method was used for extrapolation to full scale?

Choice	Type	# of choices (%)
1	Never (only model scale performance was measured)	3 (27.3)
2	ITTC recommended guideline 7.5-02-02-03	0 (0.0)
3	ITTC 1978 7.5-02-03-01.4 Performance Prediction Method	4 (36.4)
4	Own guideline	3 (27.3)
5	No idea	1 (9.1)

- **Question #10 (R_{TM} reduction)** How large was the reduction ratio of total resistance of model $r_M = 1 - R_{TM,air\ injection}/R_{TM,baseline}$ upon air lubrication? (multiple answers allowed)

Choice	Type	# of choices (%)
1	$0\% < r_M \leq 5\%$	5 (26.3)
2	$5\% < r_M \leq 10\%$	2 (10.5)
3	$10\% < r_M \leq 15\%$	1 (5.3)
4	$15\% < r_M \leq 20\%$	5 (26.3)
5	$r_M > 20\%$	5 (26.3)
6	No idea	1 (5.3)

5. Recommended Guideline

- **ITTC 2021: New Guideline to be Adopted at the 29th ITTC**
  - ✓ **Scaling Method for ship wake fraction with pre-swirl devices**
    - Purpose: to complement the ITTC 1978 procedure for the prediction of the delivered power and rate of revolutions for single and twin screw ships with either **Pre-Swirl Stator (PSS)** or **Pre-Swirl Duct (PSD)** being installed.
  - ✓ **Limitation of ITTC 1978**
    - Pre-swirl device makes not only a counter swirl but also axial flow retardation.
    - Figure 30 (b): pre-swirl device causes the relative velocity as U_R' with increased angle of attack $\alpha + \Delta\alpha$, thereby increasing thrust
    - Figure 30 (c): overestimation of axial induced velocity u_x' by ITTC 1978

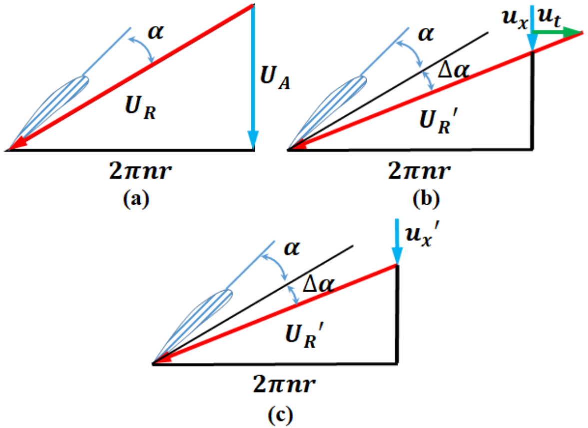


Figure 30: Change of inflow angle at the propeller blade section due to the induced velocity of the ESD

5. Recommended Guideline

ITTC 2021: New Guideline to be Adopted at the 29th ITTC

✓ ITTC 1978

- Wake scaling: $w_S = (t + 0.04) + (w_M - t_M - 0.04) \times \frac{C_{FS}+C_A}{C_{FM}}$

✓ ITTC 1999: SC on Unconventional Propulsors, 22nd ITTC

- Basically same as ITTC 1978 except full-scale wake prediction
- A method: propeller together with the stator is considered as a propulsion system

- **<u>B method (ITTC1999): The stator is considered as the part of hull</u>**
- Wake scaling: $w_S = (t_{MO} + 0.04) + (w_{MO} - t_{MO} - 0.04) \times \frac{C_{FS}+C_A}{C_{FM}} + (w_{MS} - w_{MO})$
- w_S: wake fraction of a full-scale ship
- w_{MO}: wake fraction of a model-ship w/o stator
- t_{MO}: thrust deduction of a model-ship w/o stator
- w_{MS}: wake fraction of a model-ship w/ stator
- **Limitation: tangential counter swirl (potential) & axial retardation (viscous) actions are dealt with as if both were tangential action**

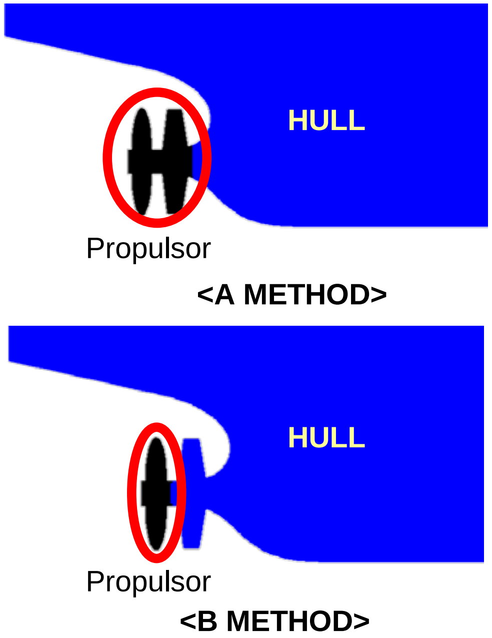


Figure 31: ITTC 1999 method

5. Recommended Guideline

ITTC 2021: New Guideline to be Adopted at the 29th ITTC

✓ ITTC 2021 wake scaling

- Background: axial and tangential wake should be treated separately according to ship & device types (PSS/PSD)
- Kim et al. (2017): The portion of the increase of angle of attack by axial and tangential flow is different for PSS/PSD.

- $w_S = (t_{MS} + 0.04) + \left(w_{MS\_Axial} - t_{MS} - 0.04\right)\frac{C_{FS}+C_A}{C_{FM}} + w_{MS\_Tangential}$
- $w_{MS\_Axial} = w_{MO} + (w_{MS} - w_{MO}) \cdot factor_{Axial}$
- $w_{MS\_Tangential} = (w_{MS} - w_{MO}) \cdot factor_{Tangential}$

- w_{MO}: wake fraction of a model-ship w/o stator
- t_{MS}: thrust deduction of a model-ship w/ stator
- w_{MS}: wake fraction of a model-ship w/ stator

ESD (ship) Type	Results	$factor_{Axial}$	$factor_{Tangential}$
Pre-Swirl Duct (KVLCC2)	CFD by Kim et al. (2017)	0.79	0.21
	ITTC 2021	**0.8**	**0.2**

ESD (ship) Type	Results	$factor_{Axial}$	$factor_{Tangential}$
Pre-Swirl Stator (KCS)	CFD by Kim et al. (2017)	0.33	0.67
	ITTC 2021	**0.3**	**0.7**

6. Full Scale Data

➢ Background

✓ Aim

- To get effect of ESM
- To get the validation data for full scale CFD

✓ Scale effects

- Increased studies in CFD between model and full scale
- Some comparisons between model tests and sea trials

✓ Very little Full scale data

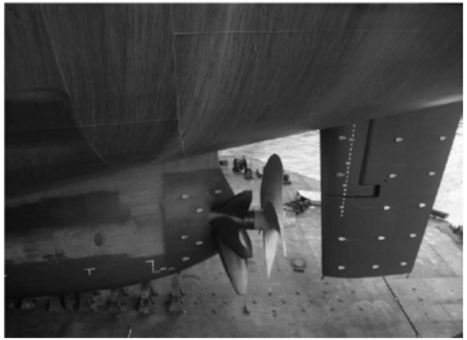
- Required special skill, equipment and cost
- Difficult to get occasion to measure

✓ IP issue

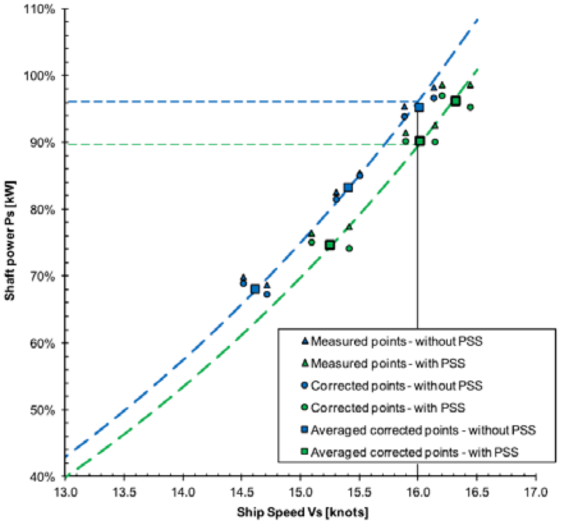
- Hull form data, ESD data

6. Full Scale Data

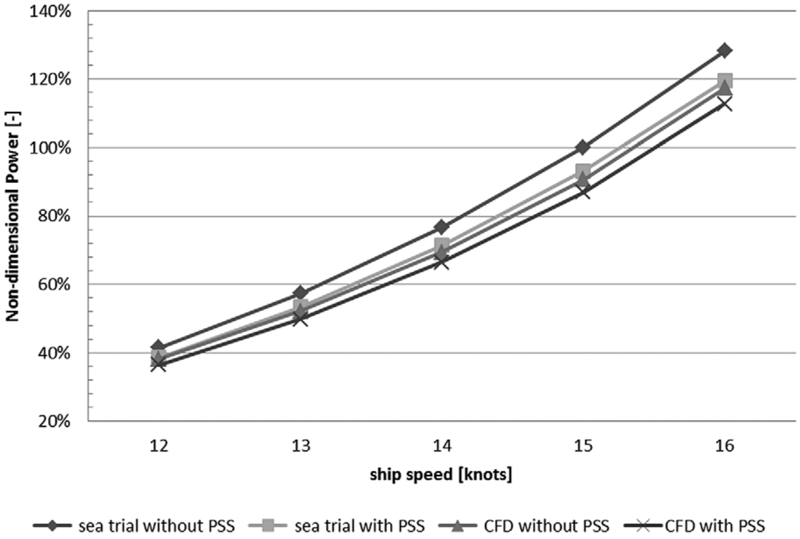
- **Survey of Literature**
  - ✓ **Energy Saving Device**
    - **EU's GRIP project** (Hasselaar & Yan, 2017): Pre-Swirl Stator (PSS) retrofitted on 52k DWT bulk carrier → 6.8% energy saving at trial condition



52k DWT bulk carrier
"M/V Valovine"



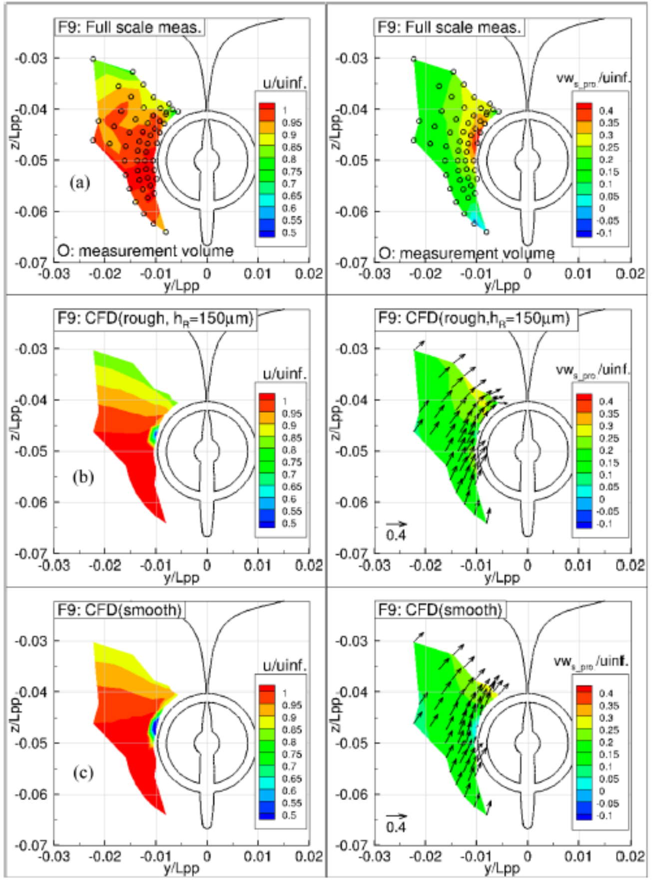
Sea Trial result with/without PSS



CFD result with/without PSS

6. Full Scale Data

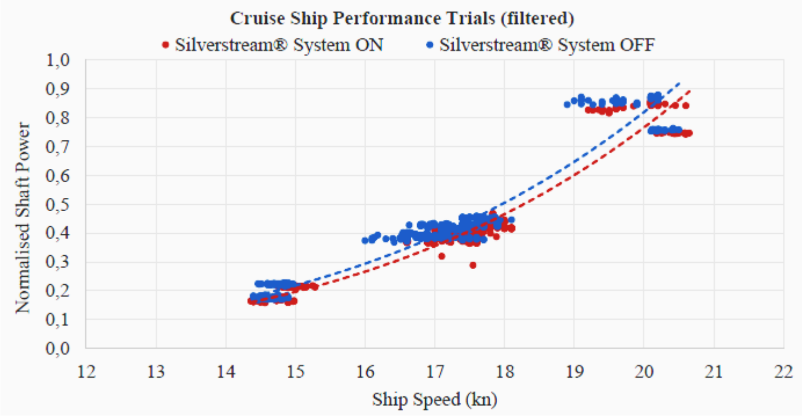
- **Survey of Literature**
  - ✓ **Energy Saving Device: cont'd**
    - Wienke (2017): showed 4 examples (3 PBCF & 1 duct), model test sometimes overestimates power saving effect for different draft
    - Themelis et al. (2019): Mewis duct led to saving of fuel oil consumption by 3.5 – 5%.
    - Sakamoto et al. (2020): comparison of the full-scale wake between EFD (PIV) and CFD for 1,600TEU containership & 63k DWT bulk carrier equipped with pre-swirl duct.



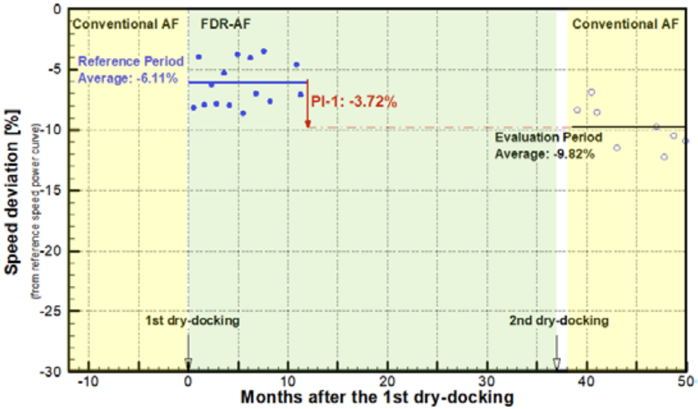
63k DWT bulk carrier wake: PIV vs. CFD (Sakamoto et al., 2020)

6. Full Scale Data

- **Survey of Literature**
  - ✓ **Air lubrication**
    - De Freitas et al. (2019): Silverstream equipped on 40k DWT chemical tanker → 4.3% energy saving at sea trial and about 5% energy saving at actual sea
  - ✓ **Frictional drag reduction, anti-fouling (FDR-AF) coating**
    - Cho et al. (2021): ISO19030 analysis for in-service performance of 176k DWT bulk carrier → speed increase by 3.72% due to coating (equivalent to 11.7% power saving)



Speed-power curves with air lubrication being ON/OFF
De Freitas et al. (2019)



Speed difference due to coating change
Cho et al. (2021)

7. Conclusions

- **Potential Tasks for the Next Committee**
  1) Continue to monitor the development of relevant techniques for ship energy saving and identify the needs to complement the present EEDI framework in response to the adoption of alternative fuels and the receptivity of innovative technologies. Consider, if necessary, a complementary metric to EEDI to represent power savings.
  2) Identify the necessity of guidelines for CFD methods, model tests and scaling for energy saving devices.
  3) Collect full scale data obtained through relevant benchmark tests on the effect of energy saving methods. Use the full scale data for validating the effect of ESM. Develop a guideline to conduct in-service performance evaluation for ESM.

- **Recommendations to the Conference**
  - ✓ The 29th ITTC Specialist Committee on Energy Saving Methods recommends adopting the new guideline on **'Scaling Method for ship wake fraction with pre-swirl devices'**.