



BETTER SHIPS, BLUE OCEANS

Shallow water speed/power trials with cruise liner for benchmarking

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- Introduction, joint research projects
- Objective
- Approach
- Results
 - Corrected
 - Shallow water effect
 - Uncertainty
- Summary & conclusions

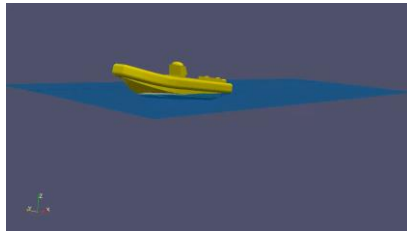
Concept



Design

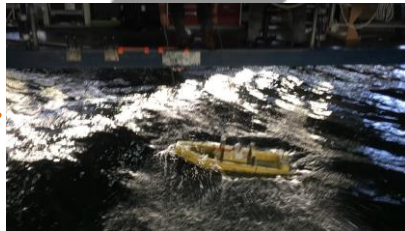


Operation



Simulations

Desk / Computer



Model tests

Prototype



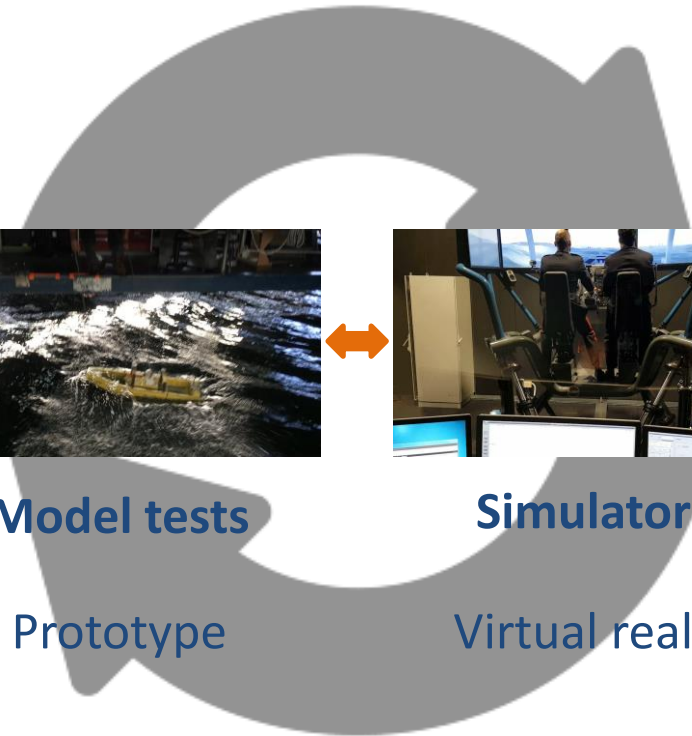
Simulators

Virtual reality



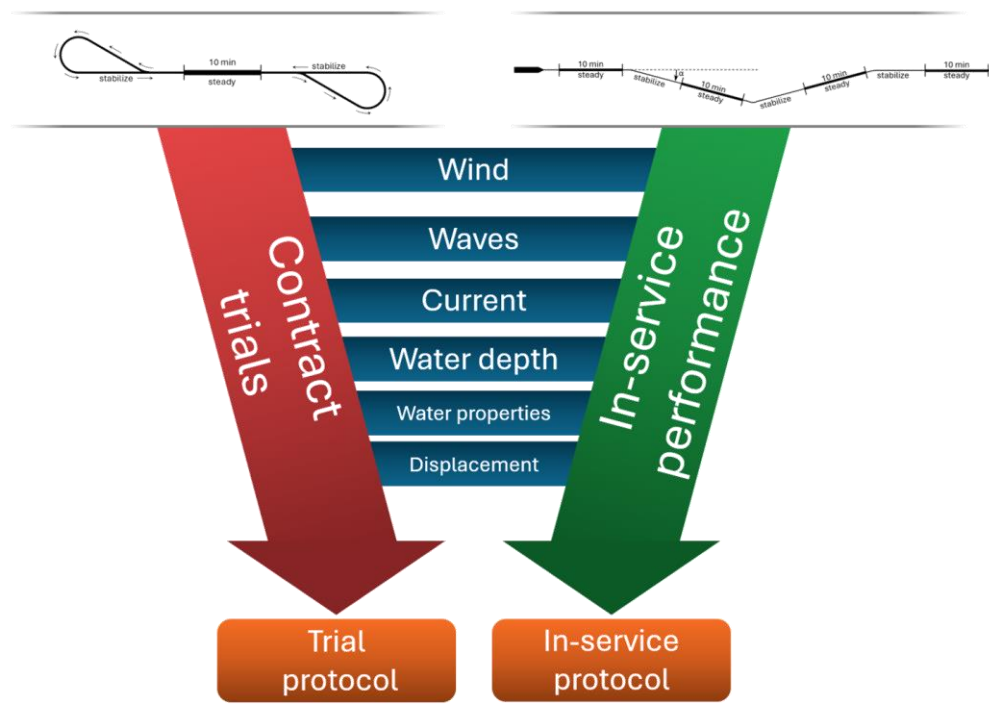
Monitoring

Reality



Objective:

more accurate and reliable determination of the actual, full-scale speed/power performance of ships, both from speed trials and in-service measurements



- JoRes project set out to develop full-scale benchmark data for CFD validation
- Within the project, 5 ships were tested with at least speed/power trials
 - Some also dedicated model tests at trial conditions
 - CFD workshops within the project
- All data and reports publicly accessible at <https://jores.net/>



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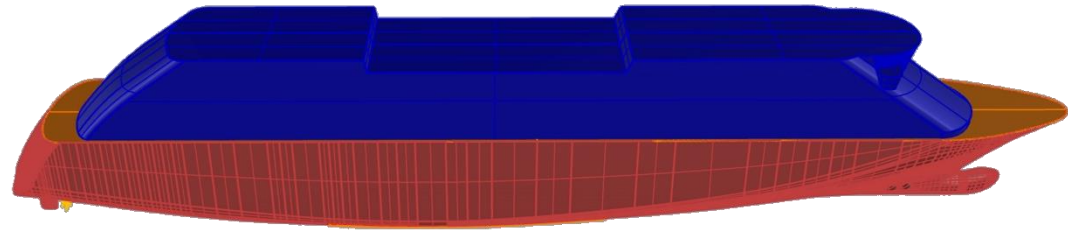
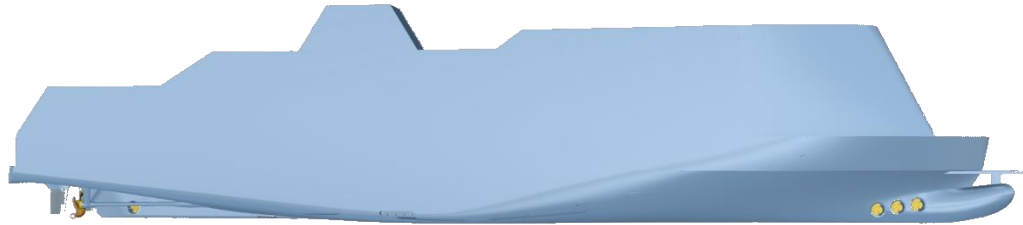
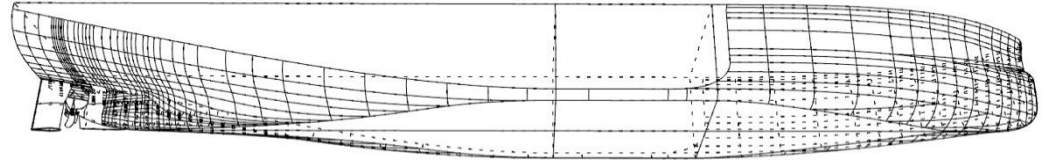
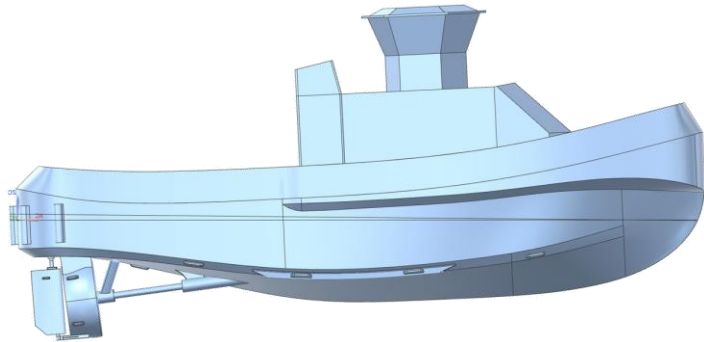
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JOINT RESEARCH PROJECT

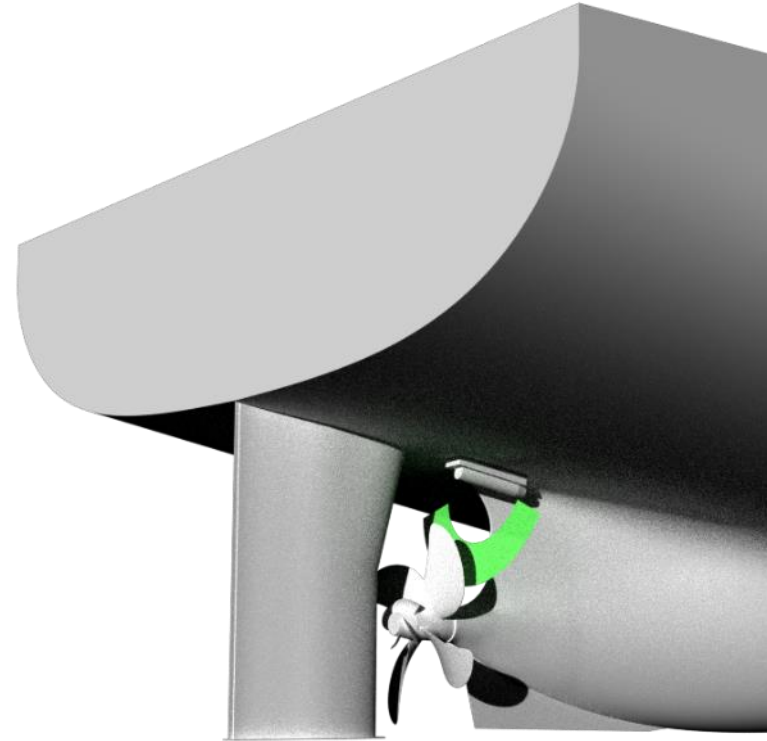
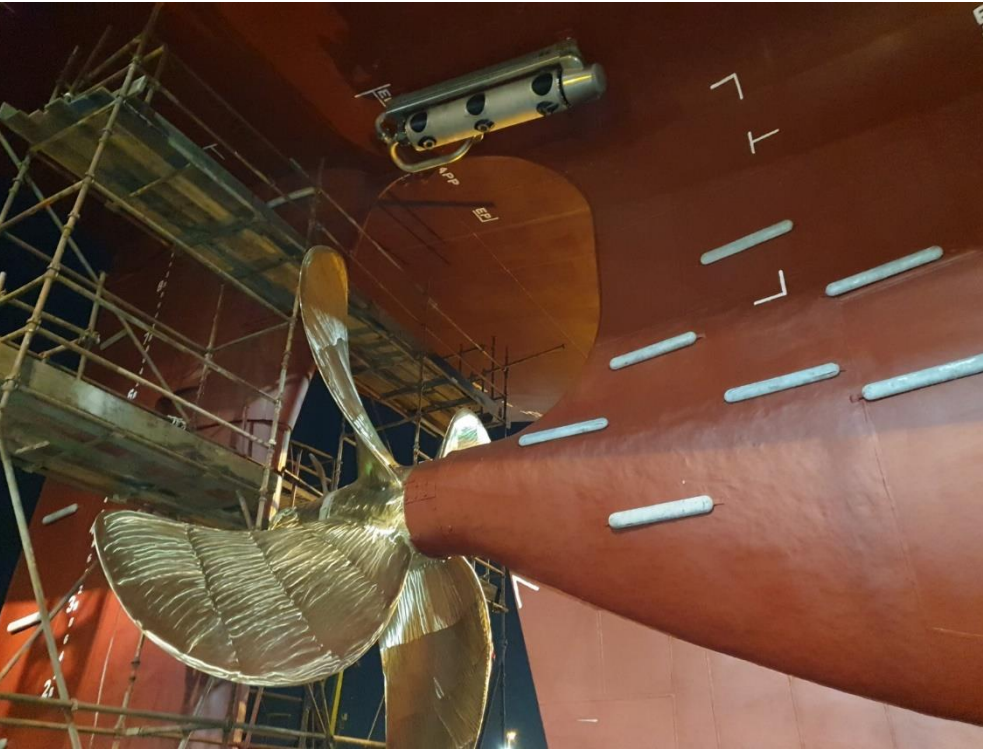
Development of an industry recognised benchmark for Ship Energy Efficiency Solutions

The project was completed in 2023, and all the results are now publicly available! Register below for full

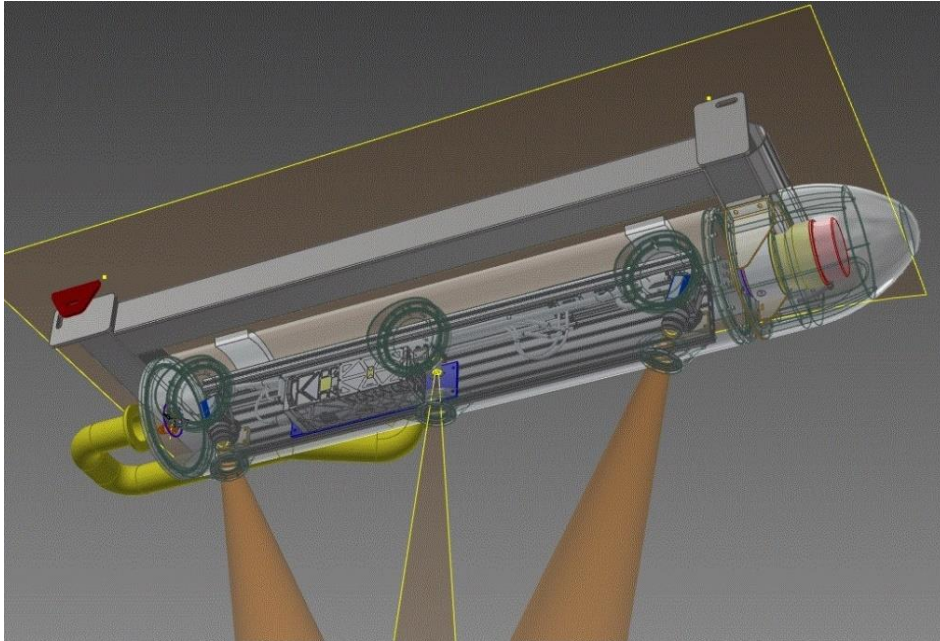
- Regal/Tailwind
- JoRes1 Tanker
- JoRes2 RoRo Ferry
- JoRes3 Cruise Liner
- JoRes4 Denis Tug

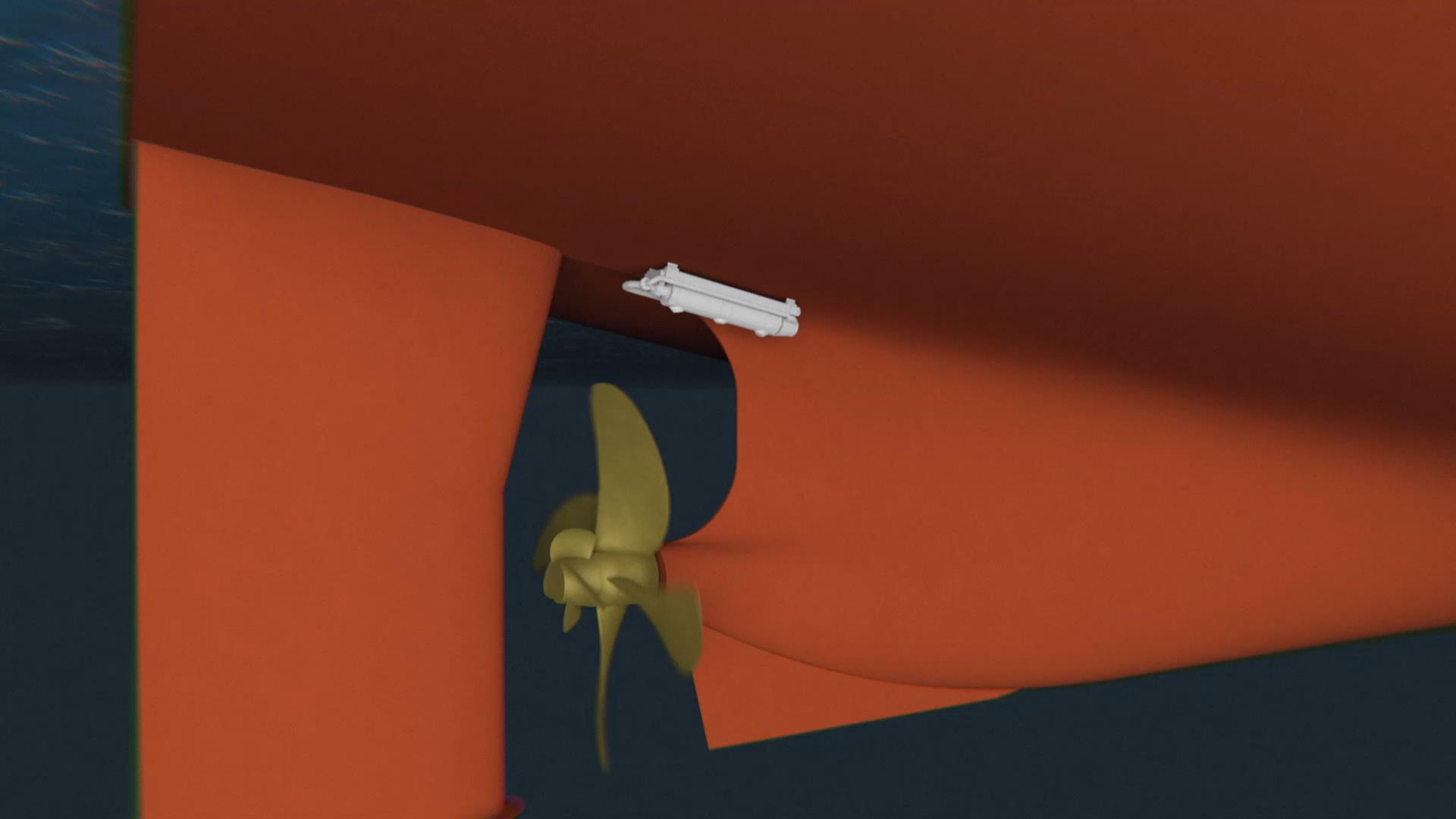


- For JoRes1 Tanker, a unique full-scale PIV wake field measurement was conducted



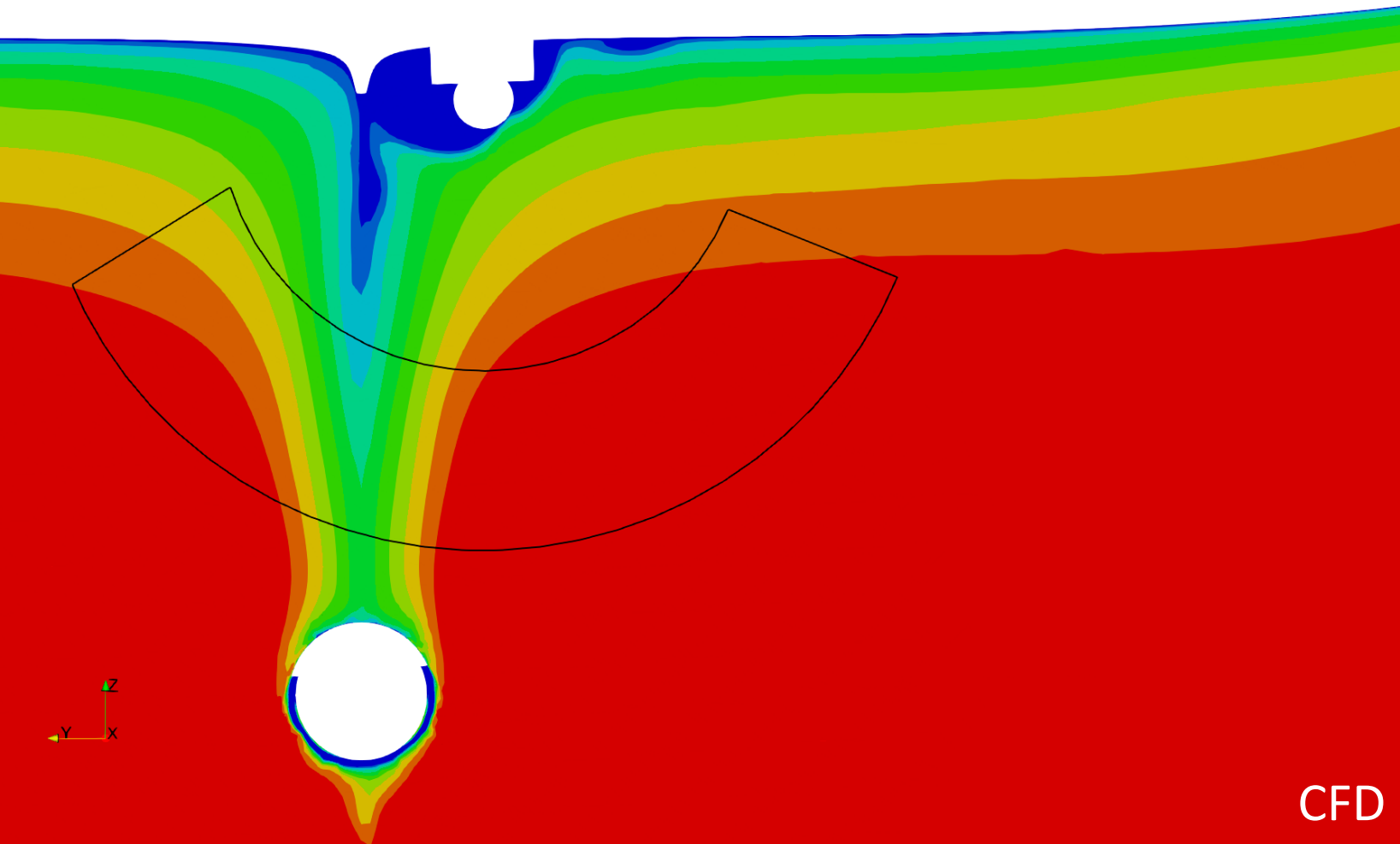
- FlowPike was developed as large-scale submersible PIV setup





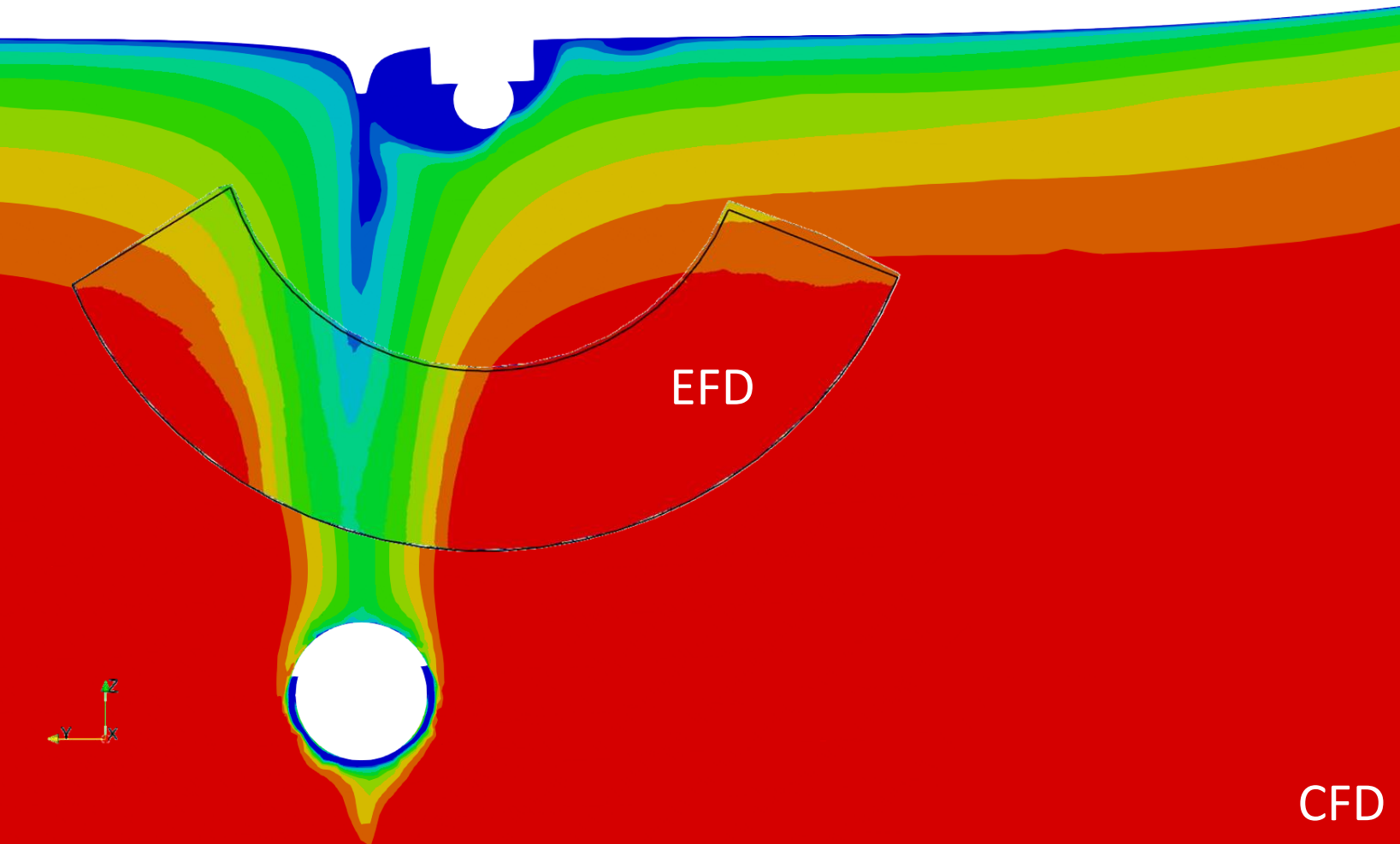
$V_{\text{norm}}/V_{\text{ref}}$

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$V_{\text{norm}}/V_{\text{ref}}$

MARIN



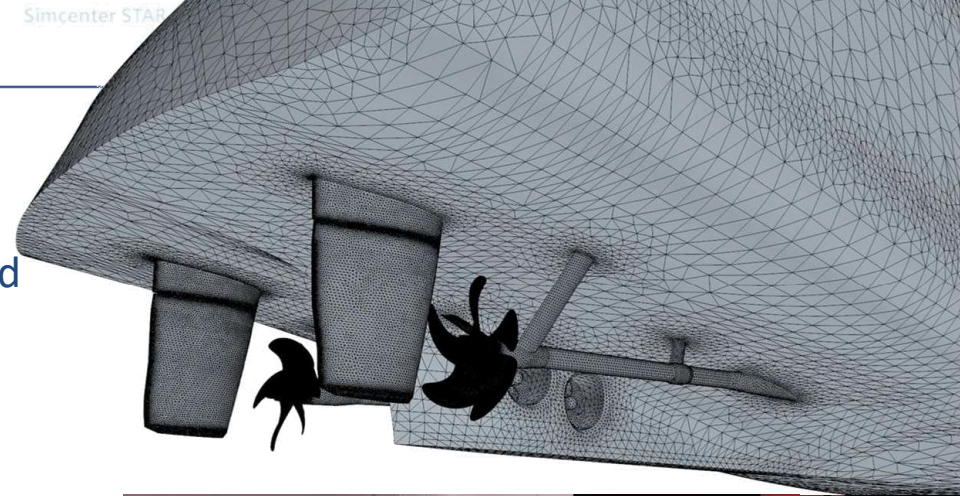
Objective

- Deliver full-scale validation data on the effects of shallow water on speed/power performance

JoRes3 Cruise Liner

Geometry and ship condition

- Complete 3D hull and propellers files were constructed by CETENA from available 3D and 2D drawings
 - Hull, bare hull
 - Propeller
 - Rudder
 - Thruster propeller
 - Thruster tunnel
 - Thruster tunnel blend
 - Shaft
 - Brackets
 - Bilge keel
- Hull and propeller roughness were measured



Geometry and ship condition

- Slightly different loading shallow and deep water tests
 - (displ. vol. +4.4% for deep water)

Description	Abbreviation	Unit	Shallow water trial	Deep water trial
Length between perpendiculars	LPP	[m]	225.840	225.840
Length on waterline	LWL	[m]	238.051	236.677
Length over all submerged	LOS	[m]	238.974	217.091
Breadth max. moulded on waterline	BWL	[m]	32.200	32.200
Draught moulded fore perpendicular	TF	[m]	6.608	6.953
Draught moulded amidship	TM	[m]	6.722	6.964
Draught moulded aft perpendicular	TA	[m]	6.835	6.974
Trim		[m]	-0.227	-0.021
Displacement volume moulded	DISV	[m³]	32792	34227
Water density (trial site)	ρ	[t/m³]	1.023	1.025
Displacement mass	DISM	[t]	33546	35082
Wetted surface area	S	[m²]	8639	8807
Max. frame area	AFR	[m²]	214.5	221.6
Frame area at frame 10	AFR10	[m²]	210.8	218.6
Waterplane area	AWL	[m²]	6184	6245
Position of centre of buoyancy aft of FP	FB	[m]	123	122
Longitudinal centre of flotation aft of FP	LCF	[m]	125	125
Block coefficient	CB	[-]	0.671	0.676
Midship section coefficient for frame 10	CM10	[-]	0.974	0.975
Prismatic coefficient for frame 10	CP10	[-]	0.689	0.693
Midship section coefficient for frame with AFR	CMMAX	[-]	0.991	0.988
Prismatic coefficient for frame with AFR	CPMAX	[-]	0.677	0.684
Waterplane coefficient CWP = AWL / (LWL x BWL)	CWP	[-]	0.807	0.819

- Perform speed/power runs in deep and shallow water
- Zig-zag runs also performed in deep and shallow water

Limitations

- The Cruise Liner was in operation on the North Sea with guests on board
- "We'll weather the weather, whatever the weather"
- Ultimately up to operators (captain, watchkeepers) to deem what is a safe depth to perform speed runs in



Test programme

- Two double runs at same propeller RPM
- (one double run for 10/10 zigzag tests)
- (one double run for 20/20 zigzag tests)
- Normally into and following dominant wave direction, for shallow water runs along constant depth contour

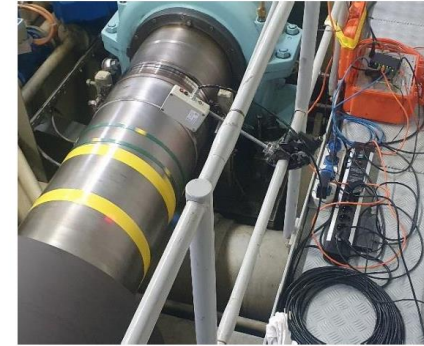
Instrumentation

- Twin DGPS: position, SOG, COG, HDG



Instrumentation

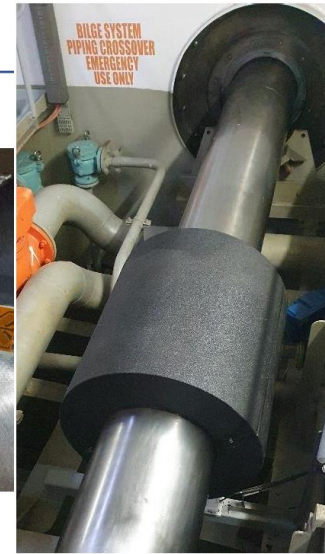
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- Power Measurement System (strain gauge): Shaft RPM, torque, power



Approach

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- VAF TT-Sense: Shaft thrust



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- MRU: Ship motions
- Wave buoy & wave radar: sea state
- Ship's depth sounder: UKC
- Ship's anemometer: apparent wind speed + direction
- Manual: water temp + density, air temp + pressure, draughts



Performed runs

	Run no.	Run set	propulsion setting	Run start time (LT)	Run dir.	Heading	SOG (made good)	Water depth (h)	h/T_M
	[-]	[-]	[rpm]	[HH:MM]	[F/R]	[deg]	[kn]	[m]	[-]
Shallow	1	1	79	11:09	F	274.0	10.97	23.9	3.6
	2	1	79	11:49	R	84.9	13.52	24.2	3.6
	3	1	79	12:21	F	272.4	10.97	24.4	3.6
	4	1	79	13:04	R	81.5	13.36	24.2	3.6
				(+2 days)					
Deep	11	2	79	14:20	F	7.9	13.50	80.1	11.5
	12	2	79	15:19	R	182.5	12.44	80.2	11.5
	13	2	79	16:10	F	7.2	13.51	80.4	11.6
	14	2	79	16:54	R	182.0	12.43	79.9	11.5

Environmental conditions

- Shallow water runs: poor conditions
 - true wind speed of 21 knots from the NW
 - significant wave height of 2.7 m at a peak period of 8.5 s
 - (Wave buoy deployed)

Environmental conditions

- Shallow water runs: poor conditions
 - true wind speed of 21 knots from the NW
 - significant wave height of 2.7 m at a peak period of 8.5 s
 - (Wave buoy deployed)
- Deep water runs: more benign
 - true wind speed of 13 knots from the SE
 - significant wave height of 1.2 m at a peak period of 8.3 s
 - (Wave radar used)



**Conditions during
shallow water runs**

Environmental conditions

- Shallow water runs:
 - Wave incidence angle 60 - 100 deg → SPAWAVE used for wave correction

Corrections to 'ideal conditions'

- Wind correction: C_x used from generic cruise liner
- Wave correction: SPAWAVE used (suitable for all wave directions) instead of STAWAVE-1 or STAWAVE-2 (bow quartering only)
- Current correction: mean of means method using the double double runs

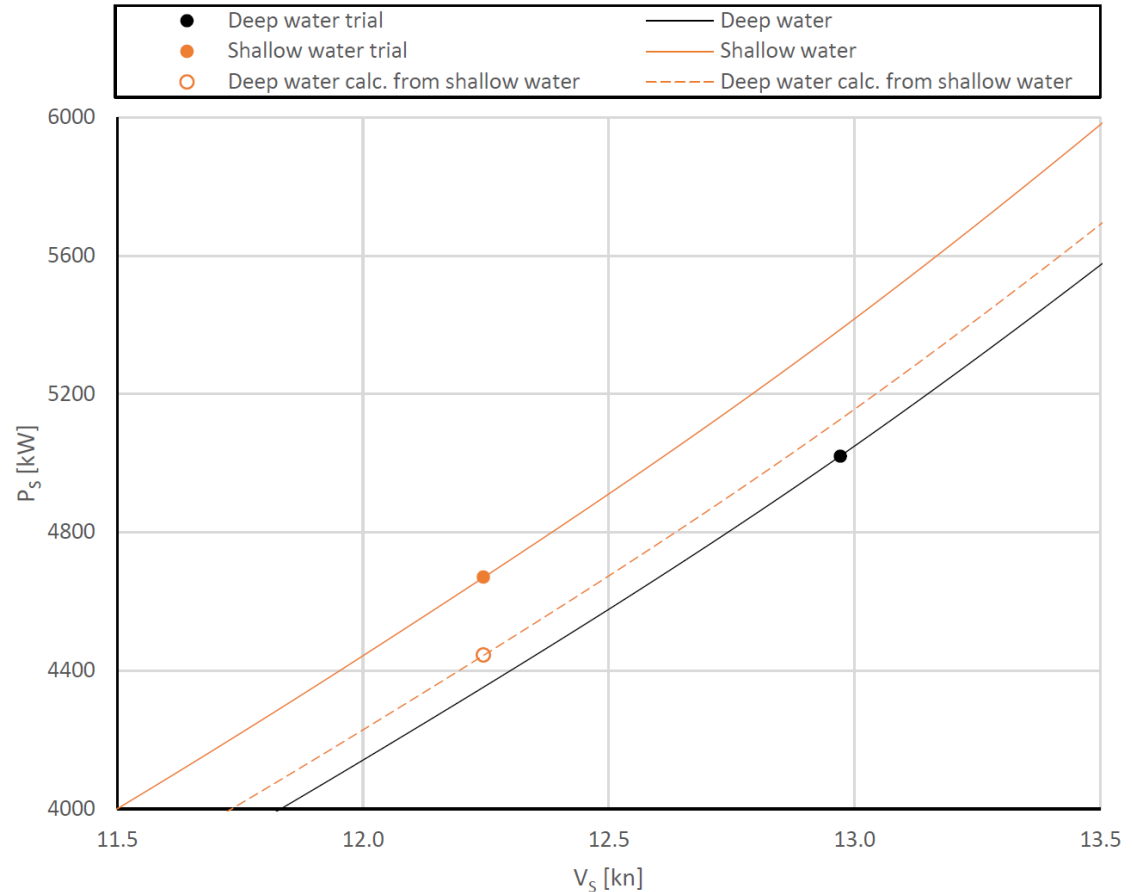
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- Wave correction: SPAWAVE used (suitable for all wave directions) instead of STAWAVE-1 or STAWAVE-2 (bow quartering only)
- Current correction: mean of means method using the double double runs
- → this corrected data is delivered to compare CFD at these depths and draughts in ideal conditions.

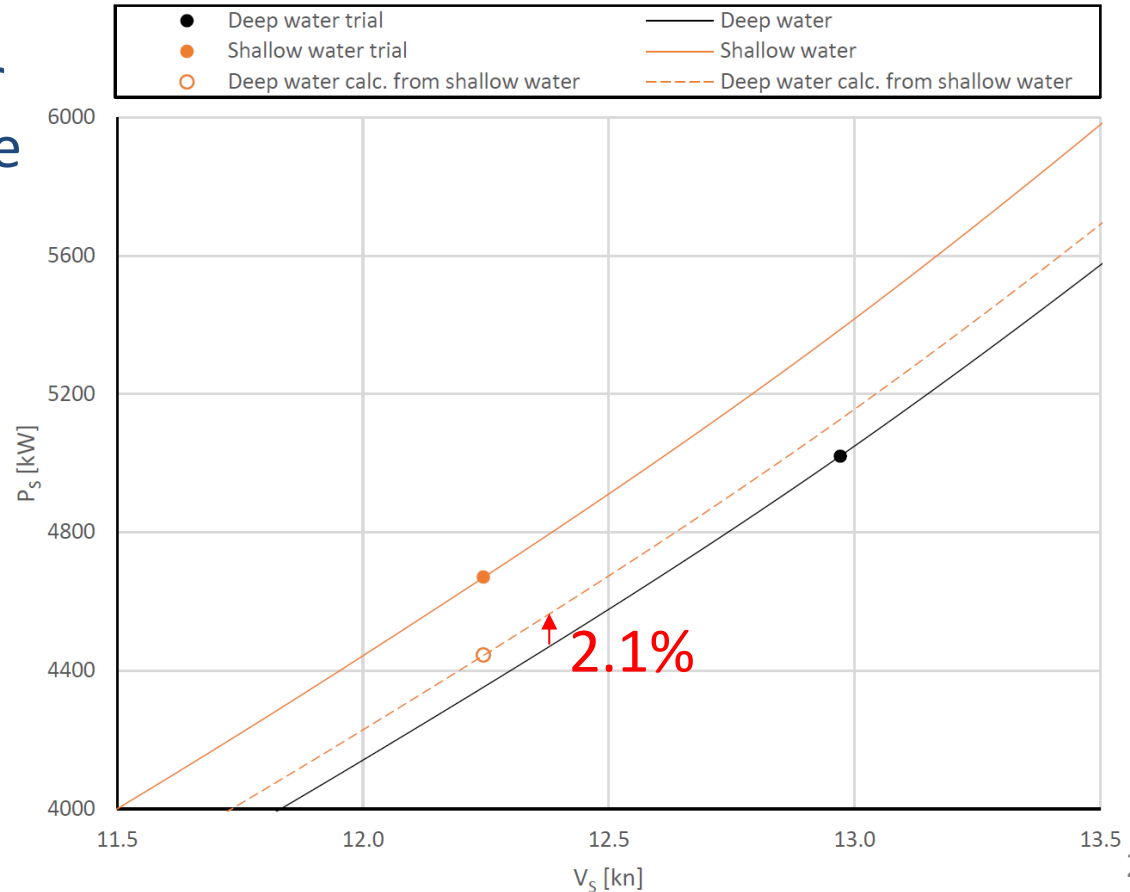
	T _F m	T _A m	Disp. Vol. m ³	V _{sc} [kn]	N _{avg} [1/min]	Q _{sc} [kNm]	P _{sc} [kW]	T _{sc} [kN]
Shallow	6.608	6.835	32792	12.24	77.6	575.0	4671	471.8
Deep	6.953	6.974	34227	12.97	77.9	633.5	5166	527.1

- If then also corrected for displacement difference, we can investigate shallow water effect and compare to predictions from Raven's method.

- If then also corrected for displacement difference, we can investigate shallow water effect and compare to predictions from Raven's method.
- Curve fitting to compare at equal speed



- Raven's method predicts a deep water power 2.1% above the deep water trial results
- A fair result, considering all uncertainties and differing conditions between the two trials.



Uncertainty on measurements

- Speed

	Shallow	Deep	
GNSS	0.1%	0.1%	
STW (current correction)	3.7%	1.4%	
Total propagated to speed	3.7%	1.4%	[%V_{sc}]

- Power measurement

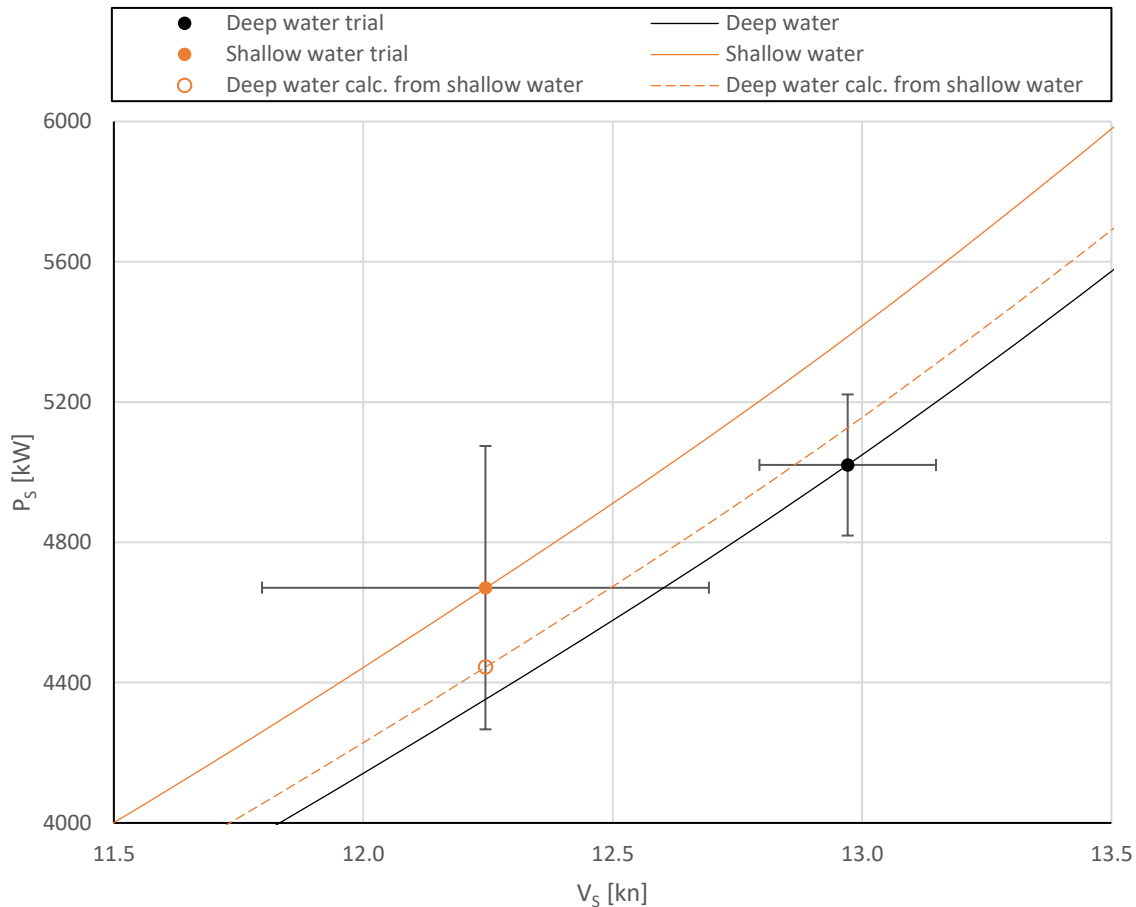
Component	U	Propagation to Q_{ms}	Propagated
Sensor: strain gauge	1.0%	Linear	1.0%
Installation error	1.0%	Linear	1.0%
Zero calibration	0.3%	Linear	0.3%
Shaft diameter	0.1%	Via polar section modulus: $Z_P = \frac{\pi}{16} D^3 \sim D^3$	0.2%
G-Modulus	2.5%	Linear	2.5%
Total			2.9%

Uncertainty on corrections

	Shallow	Deep	
GNSS	0.1%	0.1%	
STW (current correction)	3.7%	1.4%	
Total propagated to speed	3.7%	1.4%	[%V_{sc}]
Shaft power measurement	2.9%	2.9%	
Displacement	0.5%	0.4%	
Wind correction	1.8%	1.6%	
Wave correction	5.5%	1.2%	
Total propagated to power	6.4%	3.5%	[%P_{SM}]
	8.6%	3.9%	[%P_{sc}]

Uncertainty results

	Shallow	Deep	
GNSS	0.1%	0.1%	
STW (current correction)	3.7%	1.4%	
Total propagated to speed	3.7%	1.4%	[%V_{Sc}]
Shaft power measurement	2.9%	2.9%	
Displacement	0.5%	0.4%	
Wind correction	1.8%	1.6%	
Wave correction	5.5%	1.2%	
Total propagated to power	6.4%	3.5%	[%P_{SM}]
	8.6%	3.9%	[%P_{Sc}]



- The trials were conducted on the North Sea with the ship in operation at $h/T = 3.6$ and $h/T = 11.5$.
- The environmental conditions were poor for the shallow water runs, moderate for the deep water runs
- The speed/power data is analysed following ISO15016:2015, using STAIMO software. Corrections were made for the effects of wind, waves and current.

- Sensor uncertainties are low for shaft power and speed over ground
 - Dominant factors in the total propagated uncertainties for this case:
 - corrections for wind and waves,
 - shaft G-modulus
 - current corrections
 - Evaluated at same displacement, the Raven shallow water correction method predicts a deep water power 2.1% above the deep water trial results
- A fair result, considering all uncertainties and differing conditions between the two trials.

- Data is available in digital format upon simple request to info@shallowwater.be
- Full time traces available in both CSV and HDF-5 file formats
 - GPS (lat, lon, heading, SOG, COG)
 - Motions (roll/pitch/yaw angles and rates)
 - Shaft (RPM, torque, power)
 - UKC
 - STW
 - T_F/T_A
 - Wind (AWS, AWA, TWS, TWA)

```
import pandas as pd

runs = range(1, 4)

for i in runs:
    filename = "dfrun_" + str(i)
    df = pd.read_hdf('hdf5/' + filename + '.h5')
    df.to_csv('csv/' + filename + '.csv')
```

Our gratitude goes out to

- The ship owner
- Ghent University - Ships and Marine Technology

Questions?

Gijs Struijk, MSc.

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