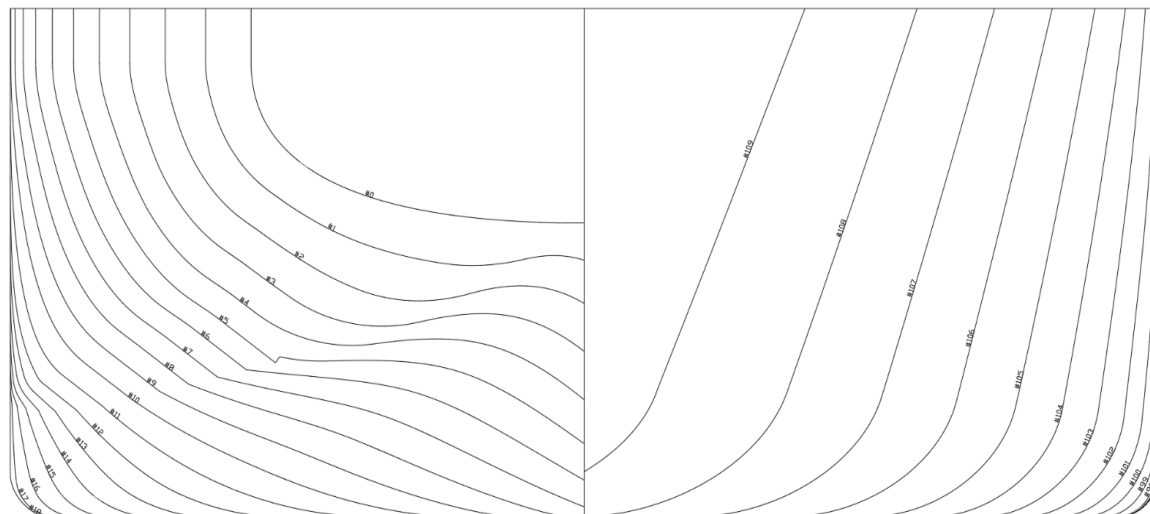




Hydrodynamic performance of a newly designed Rhine vessel integrated with various propulsion improvement devices for shallow water operations

7th MASHCON: Clean Power in Shallow Water 2025

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Motivation

IWT and climate change

Inland waterway transport (IWT)

- safer and more sustainable alternative to rail and road transportation.
- demands of energy to carry a unit cargo weight [J/t-km],
 - 17% that of road transportation
 - 50% that of rail transport



Rhine River

- runs through Switzerland, Liechtenstein, Austria, Germany, France and the Netherlands
- fleet of close to 7000 ships, around 300 million tons of goods are transported on the Rhine every year (Woehrling, 2013)



2018 dry period

- IWT is worse affected by climate volatility in turn.
- severe drought in 2018 caused the river discharge volumes to plummet drastically, and consequently hindered a considerable portion of inland transportation
- general frequency of critical dry periods is 17.6 years, but is projected to be uncertain and range between 6.5 – 22.6 years in the future (Brenk, 2021)



Small-scale ownership

- Many inland vessels are owned by families or small companies
- Limited financial capacity for costly retrofits

Retrofit = High investment

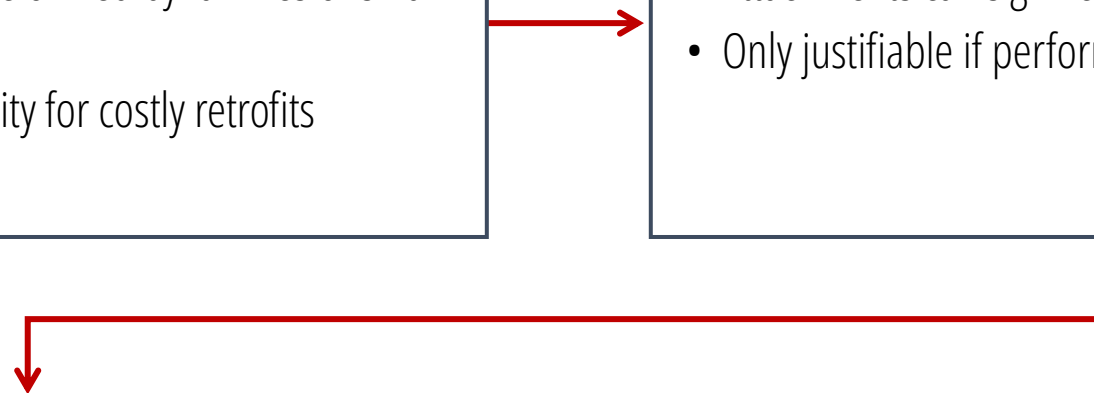
- Attachments can significantly increase ship costs
- Only justifiable if performance gain is proven

Need for evidence-based design

- Parametric tests evaluate necessity of design changes
- Model testing helps reduce investment risks

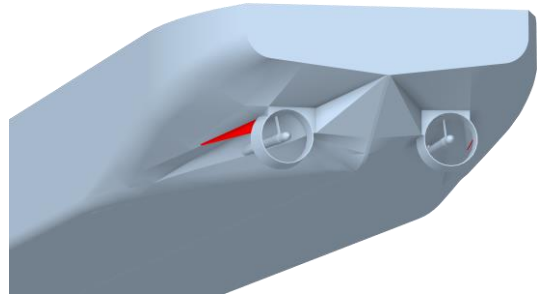
Responsibility of research

- Practical, affordable solutions for companies without R&D departments
- Enable efficient newbuilds without excessive attachments



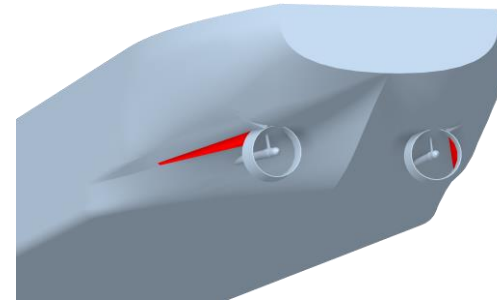
Hull design process

Iterative optimization – L x B x T – 110m x 11.45m x 2.8m



- closely resembled a typical GMS class vessel
- flow was found to be struggling to follow along the bulky stern portion
- this led to additional resistance on the hull

○ HV1

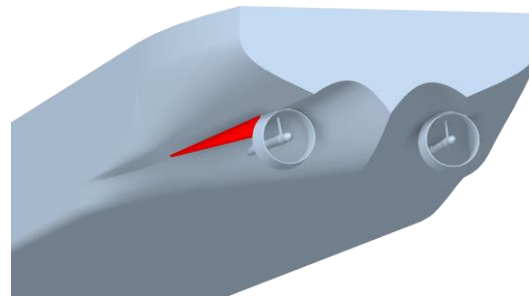


- a transom with a raised lowest edge was introduced
- this led to reduced transom wetting and ultimately decreased resistance

○ HV3

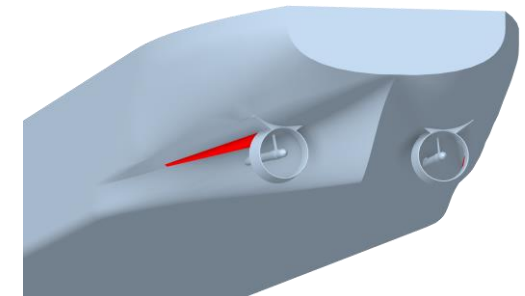
○ HV2

- stern was refined with reduced volume and smoothly transitioning contour lines Friedhoff et al. (2018)
- propeller tunnel was extended behind the propeller
- aft ship lines were smoothed out



○ HV4

- the point where the bottom-most (base) hull edges converge together was moved forward
- drag reduction of 12.7% and a power requirement reduction of about 21.5% compared to HV1

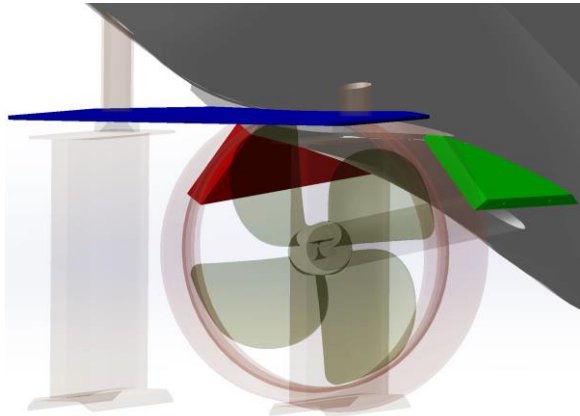


All four hulls are shown with the outer tunnel in red.

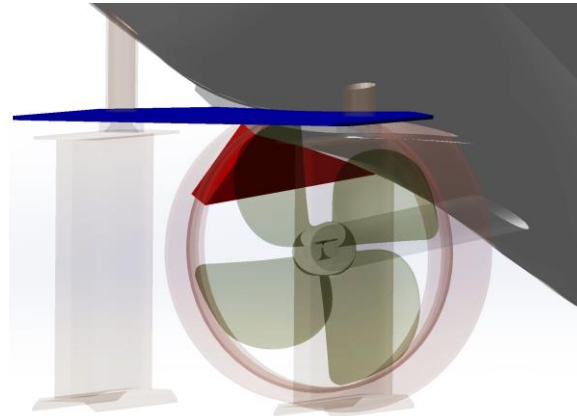
Model tests

Appendage configurations and test specifications

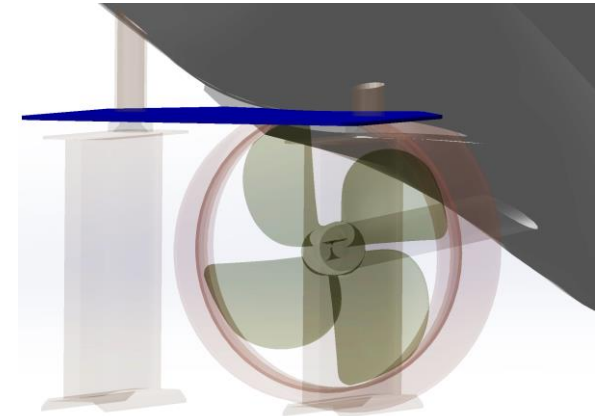
- The self-propulsion model tests with a 1:10 scale ratio
- Propeller: a scale factor $\lambda = 10$, a pitch-to-diameter ratio $P/D = 0.955$, an expanded area ratio $A_E/A_0 = 0.800$, a diameter $D = 0.110$ m



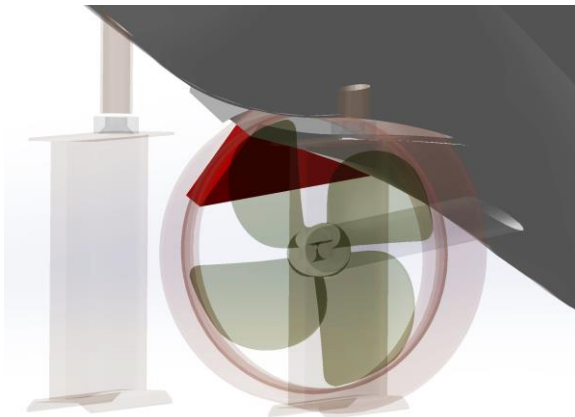
K1 - HV4 base hull appended with all three devices: flow-separation plate, outer tunnel, and inner tunnel



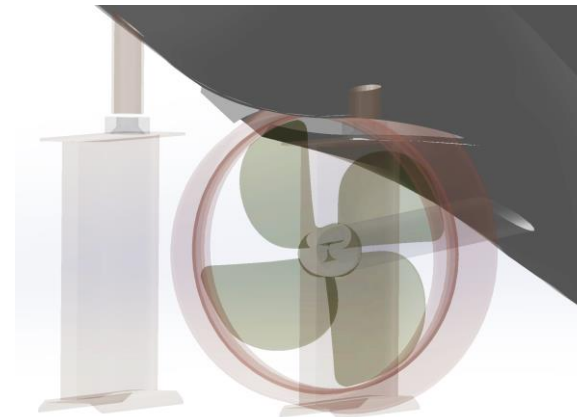
K2 - HV4 base hull appended with flow-separation plate and outer tunnel



K3 - HV4 base hull appended with flow-separation plate



K4 - HV4 base hull appended with outer tunnel

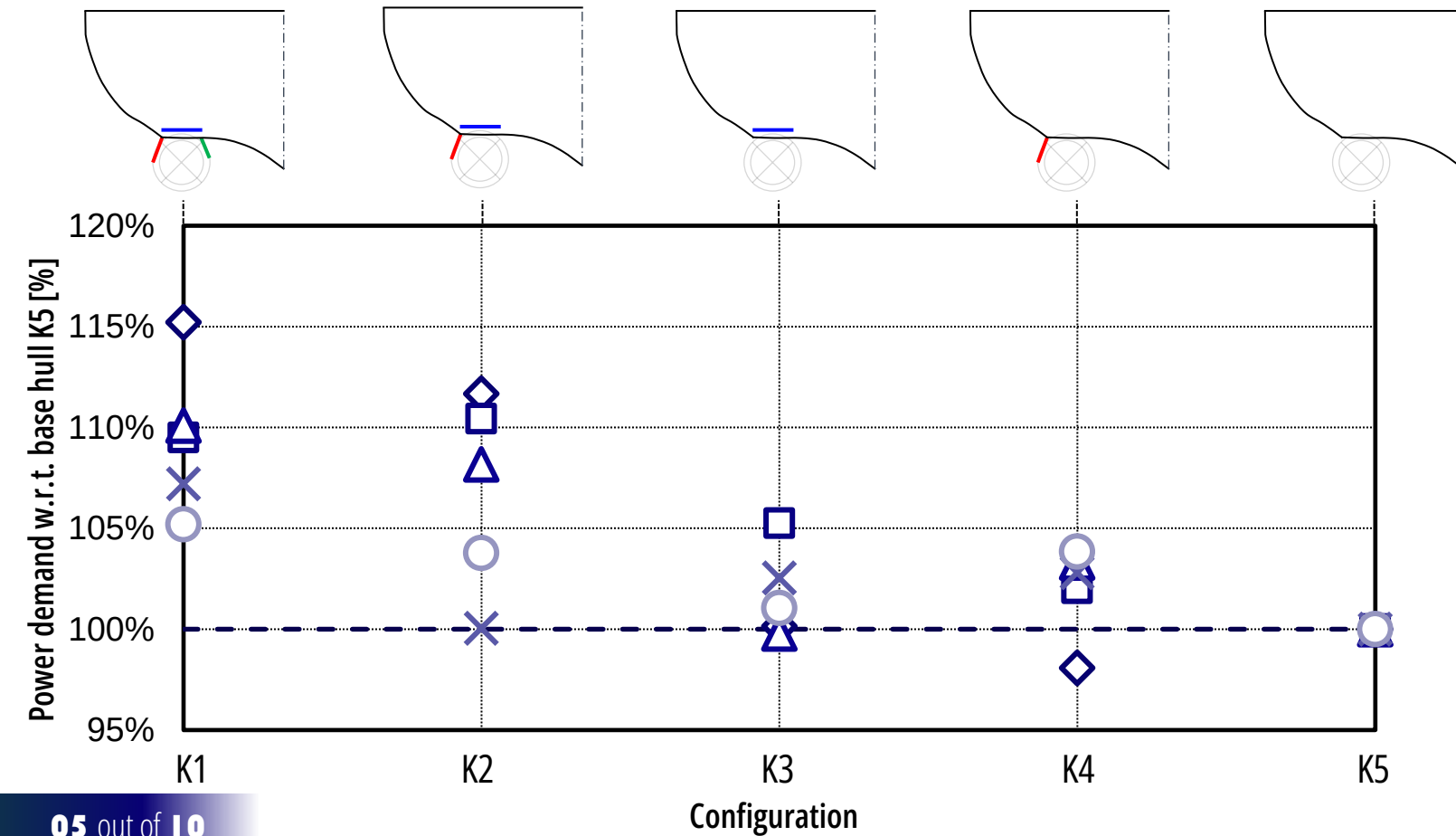


K5 - HV4 base hull without any devices

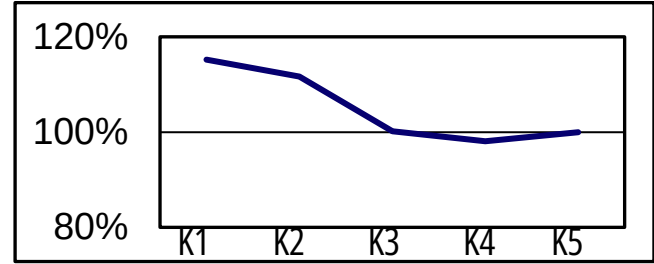
Model test results

$h = 5\text{ m}$ & $T = 2.8\text{ m}$

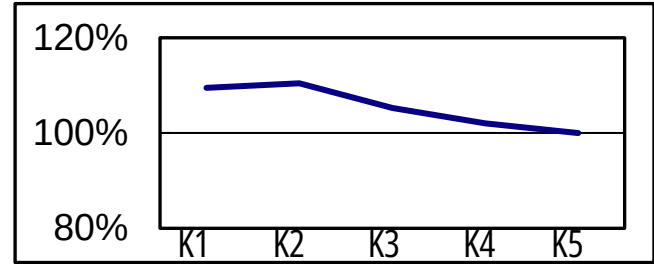
- consistent reduction in power demand as these attachments are removed



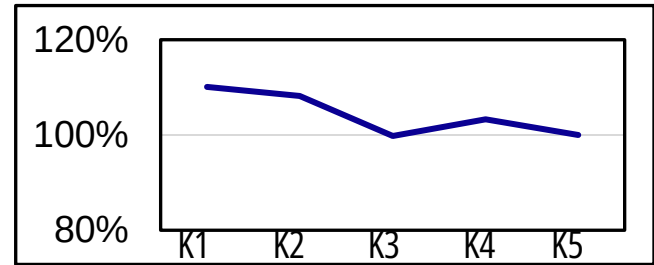
$V_s = 9\text{ km/h}$



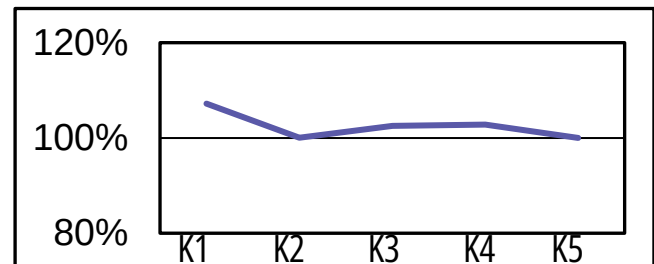
$V_s = 11.6\text{ km/h}$



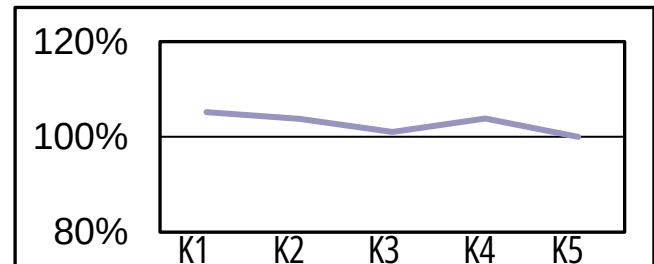
$V_s = 14.1\text{ km/h}$



$V_s = 15.1\text{ km/h}$



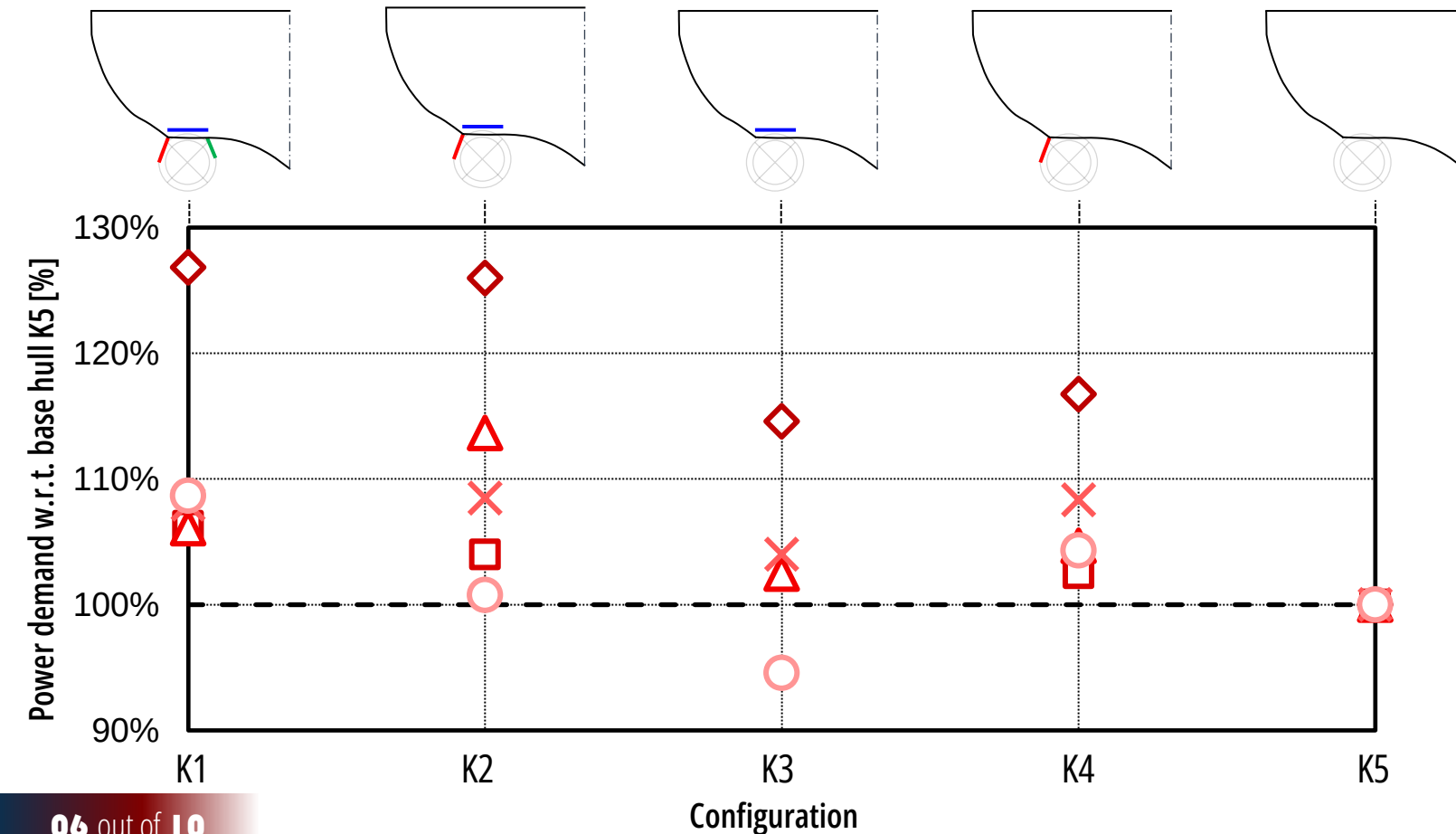
$V_s = 16.1\text{ km/h}$



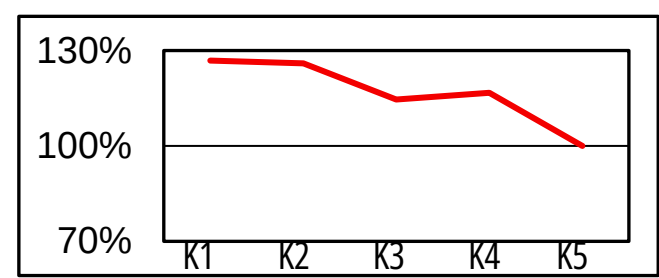
Model test results

$h = 3.5 \text{ m}$ & $T = 2.8 \text{ m}$

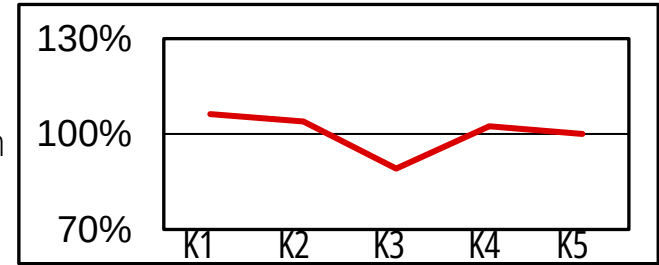
- the propulsion power demand is higher at the same speeds
- the presence of the inner tunnel significantly increases the power demand
- flow-separation plate, its impact remains inconclusive



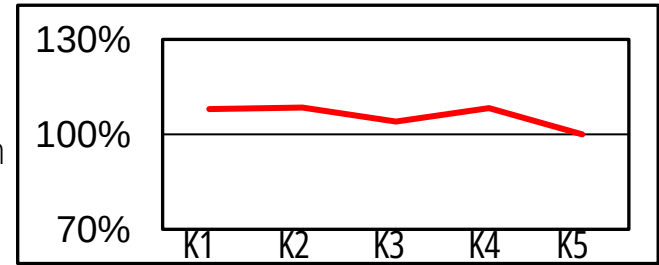
$V_s = 8.07 \text{ km/h}$



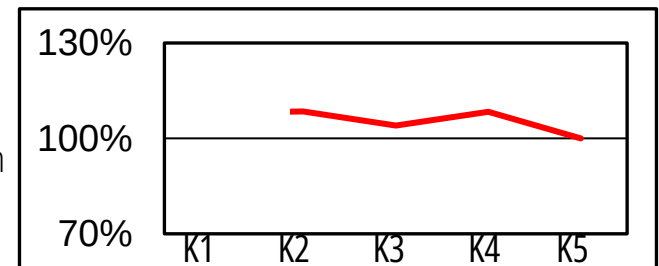
$V_s = 10.07 \text{ km/h}$



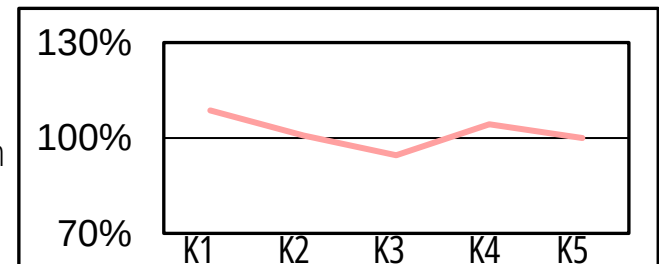
$V_s = 11.10 \text{ km/h}$



$V_s = 11.60 \text{ km/h}$



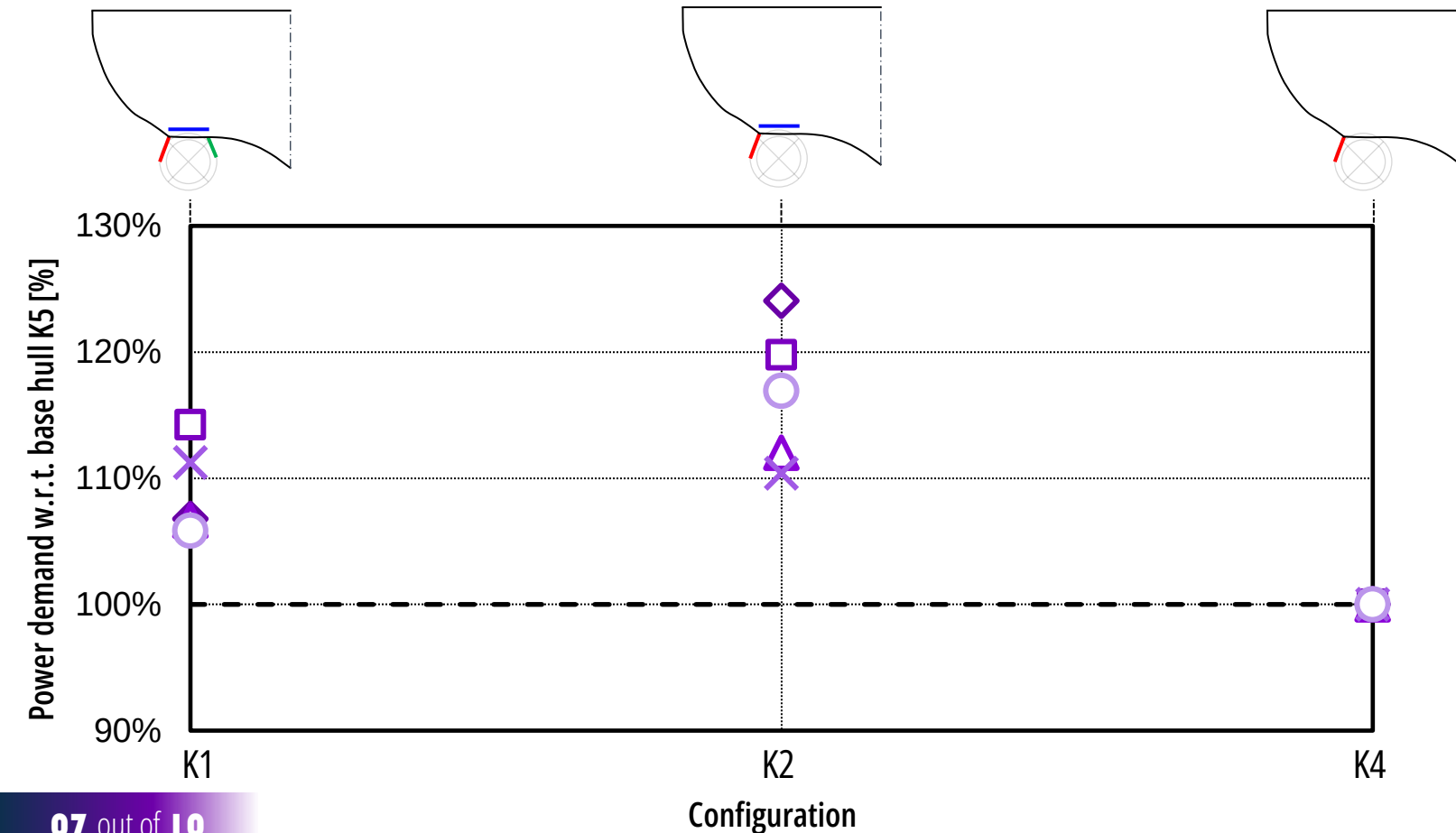
$V_s = 12.11 \text{ km/h}$



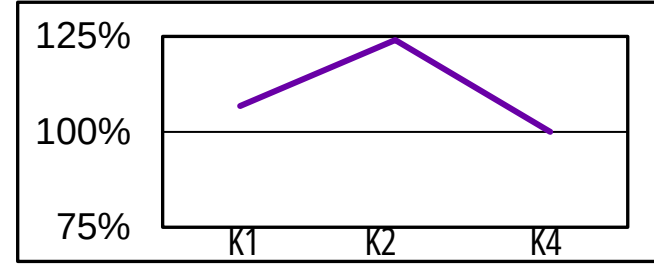
Model test results

$h = 1.6 \text{ m}$ & $T = 1.1 \text{ m}$

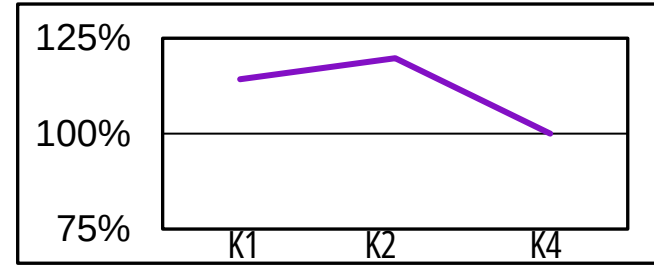
- the maximum achievable speed was limited to 8.6 km/h
- the reference configuration is changed to K4
- propeller is approximately 30% emerged from the water



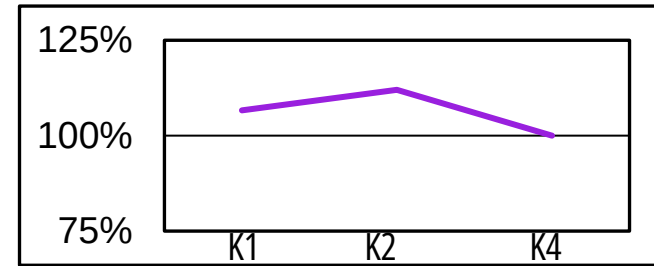
$V_s = 5.1 \text{ km/h}$



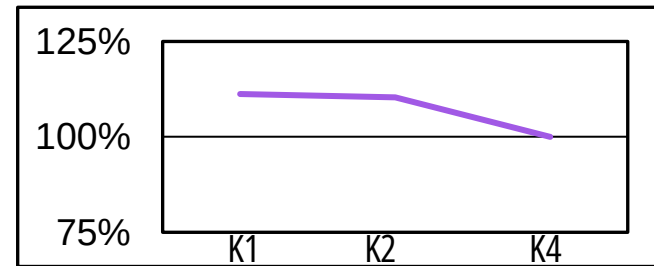
$V_s = 6.1 \text{ km/h}$



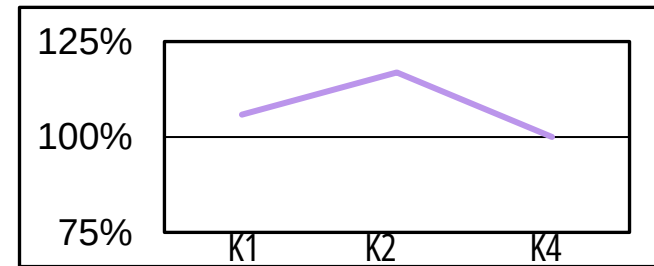
$V_s = 7.1 \text{ km/h}$



$V_s = 8.1 \text{ km/h}$



$V_s = 8.6 \text{ km/h}$

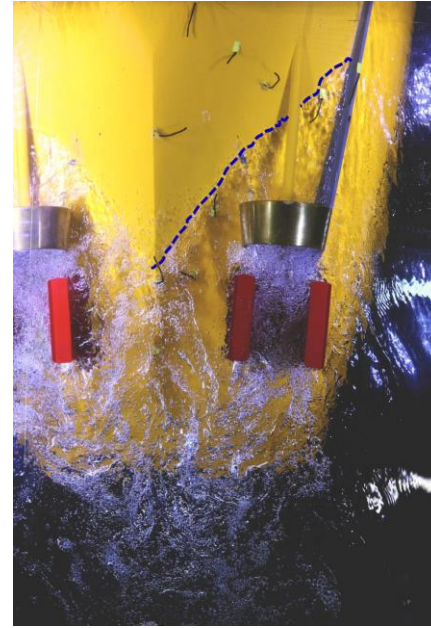


Minimum draft operation

Minimum requirement for shallow water operation

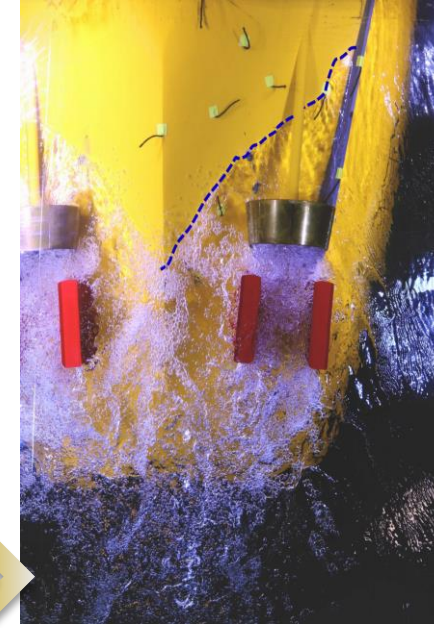
$$T_{min} = 1.1 \text{ m}$$

- speed $U_{min} = 8.6 \text{ km/h}$ to avoid bottom collision
- the propeller is 30% emerged and heavily ventilated
- without an outer tunnel, ship could not propel forward



K4

Outer tunnel is necessary to prevent ventilation



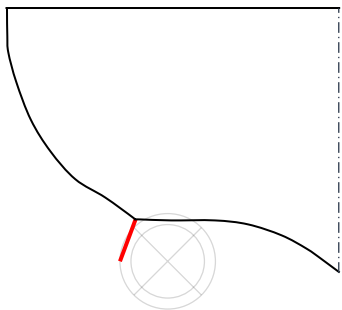
K2

Adding flow separation plate does not assist the ventilation prevention

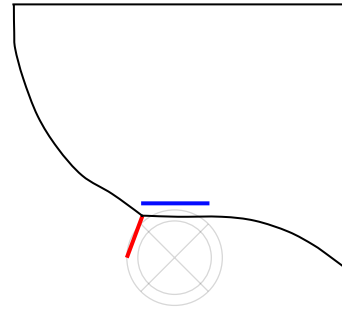


K1

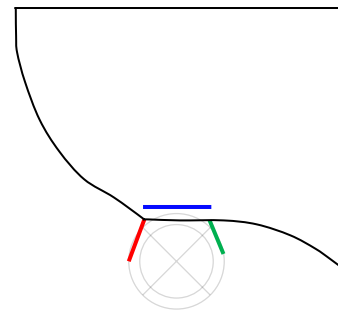
Having the inner tunnel combined with the outer tunnel prevents the ventilation better



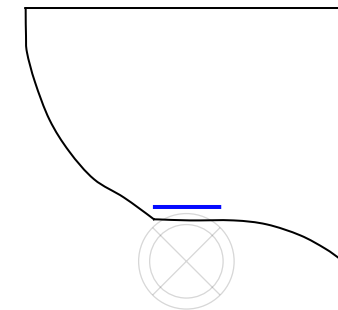
✓ **K4**



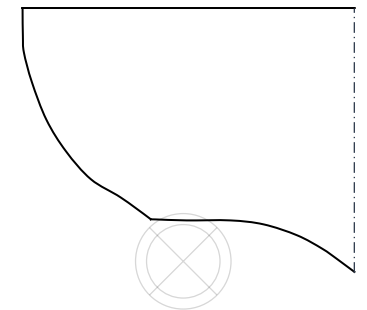
✓ **K2**



✓ **K1**



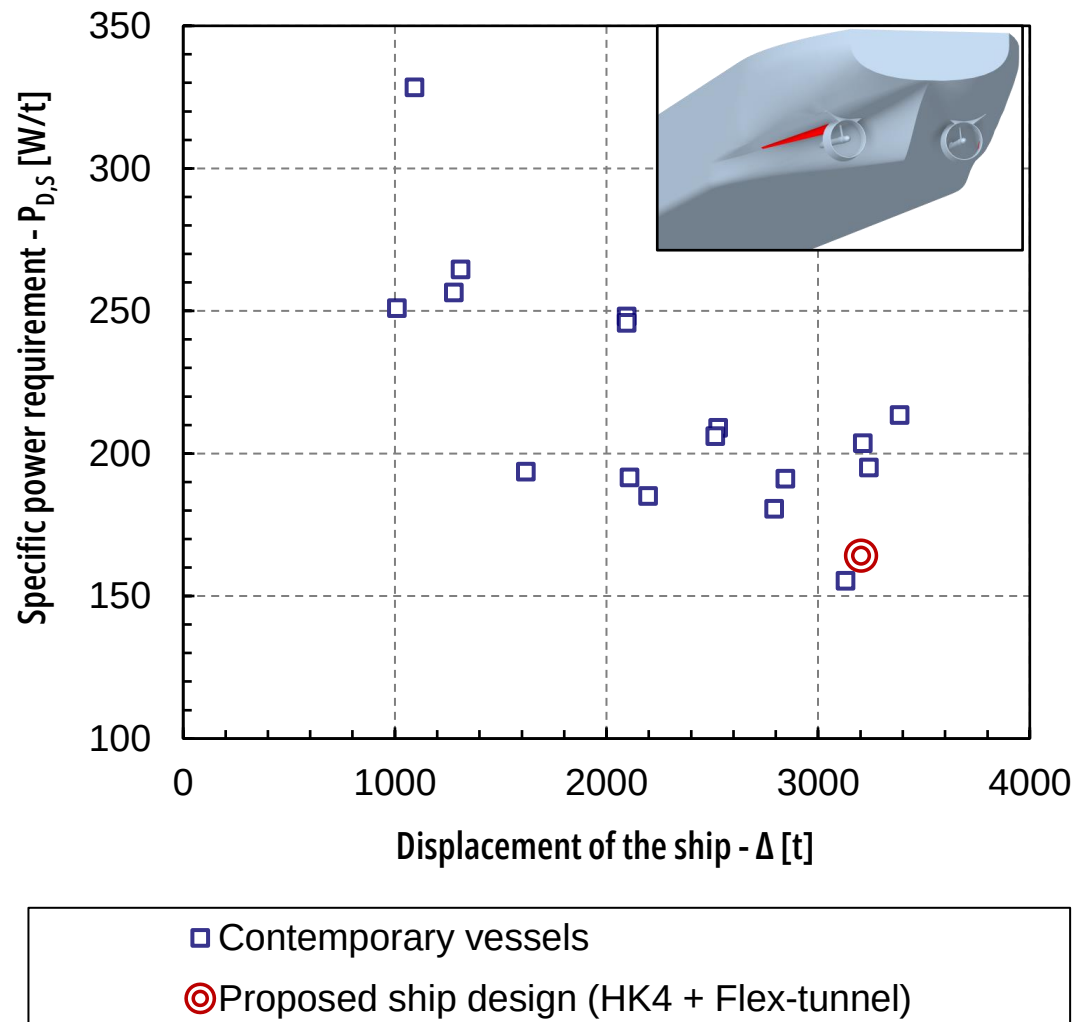
✗ **K3**



✗ **K5**

Performance evaluation

Performance of the proposed hull and appendages



Appendage Effects on Ship Performance

- No ventilation observed at deepest water depth and design draft.
- All three appendages added drag and reduced performance.

Outer Tunnel

- Essential at minimum draft for propulsion.
- Flex Tunnel reduces power demand by 4–7% at design draft.

Inner Tunnel

- Reduced ventilation, but increased resistance $\rightarrow$ net negative effect.

Flow Separation Plate

- Increased power demand at both design and minimum draft.
- Blocks part of propeller outlet at minimum draft.

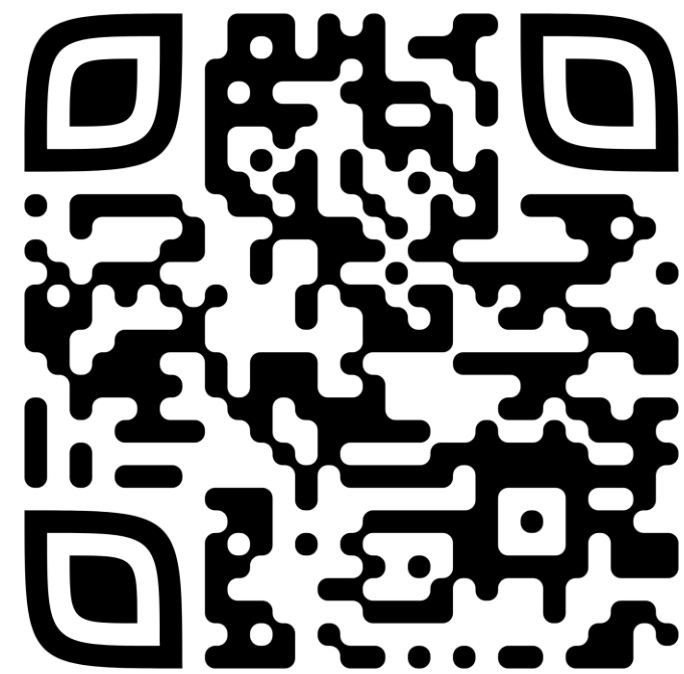
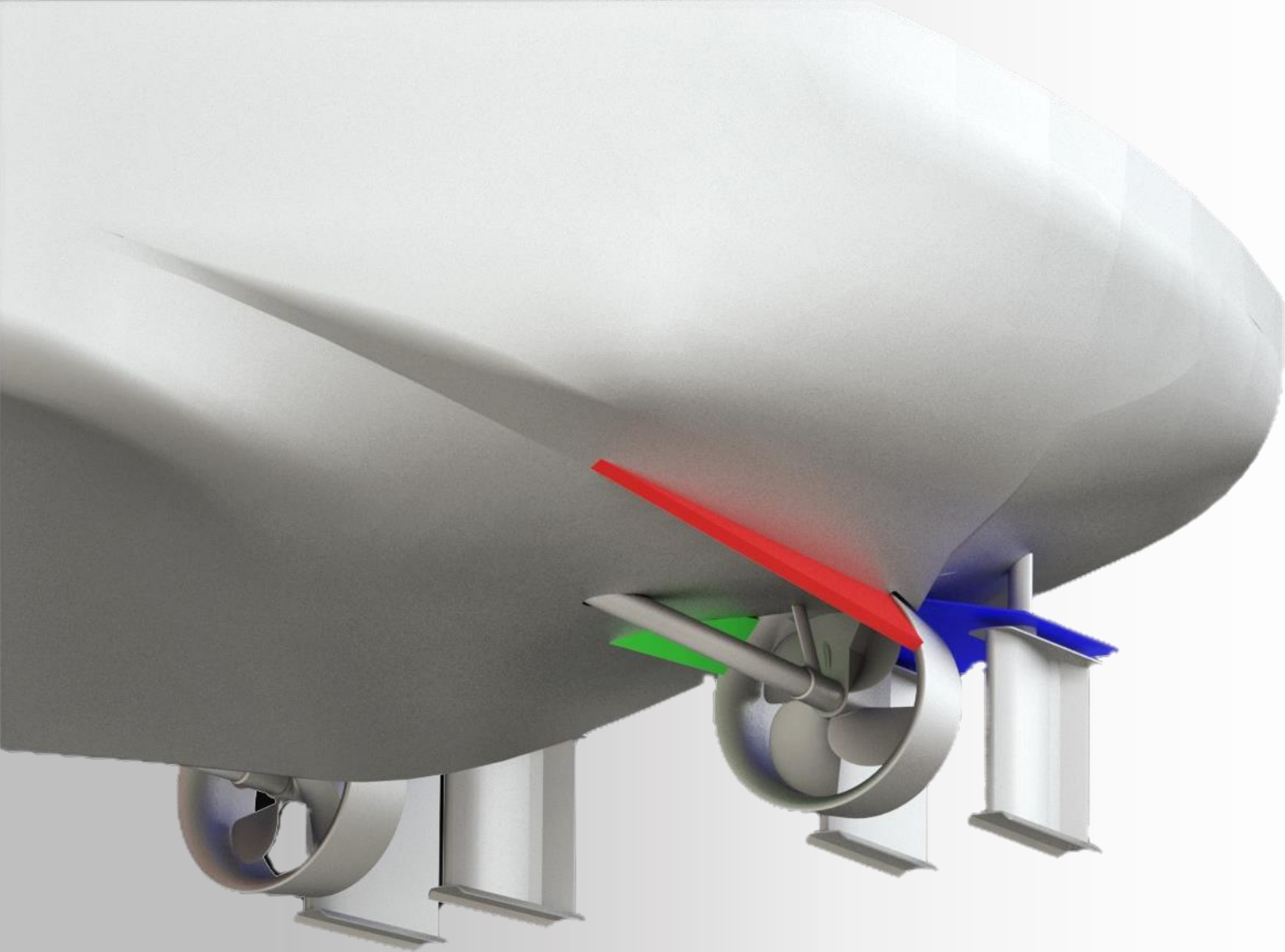
These devices may be useful as retrofits for existing, non-optimized hulls, but are not needed for the optimized design.

Future outlook

Shallow-water capability & future Outlook

- Low minimum draft enables operation in extremely shallow water.
- During the 2018 drought, could have added 80 extra operational days vs. GMS-class vessel. This represents nearly a 10% increase in total cargo volume.
- With the outer tunnel, the design offers a robust, future-proof solution for Rhine IWT under declining water levels.

Water depth	Draft	Load carrying capacity at draft	Annual days operable	Tonnage for 60 journeys per year	
[m]	[m]	[t]	[-]	[t]	
> 3.1	2.8	2543.9	140 (38.4%)	58544.5	Safe operation
3	2.7	2424.0	16 (4.4%)	6375.5	
2.9	2.6	2304.2	14 (3.8%)	5302.8	
⋮			⋮	⋮	Load carrying capacities for each draft were extracted from the hydrostatic table.
1.8	1.5	1010.4	9 (2.5%)	1494.8	
1.7	1.4	894.8	21 (5.8%)	3088.9	
1.6	1.3	780.5	28 (7.7%)	3592.4	Total possible cargo for an existing GMS ship= 94891.2 t
1.5	1.2	670.7	33 (9%)	3638.3	
1.4	1.1	558.0	19 (5.2%)	1742.8	
1.3	1	–	–	–	Additional cargo gained by the proposed ship optimized for low draft and shallow water= 8973.6 t
					Inoperable water depth
		Σ 365	Σ 97.3%	Σ 103,864	



Thank you!