



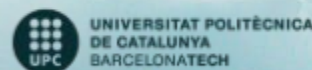
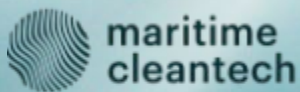
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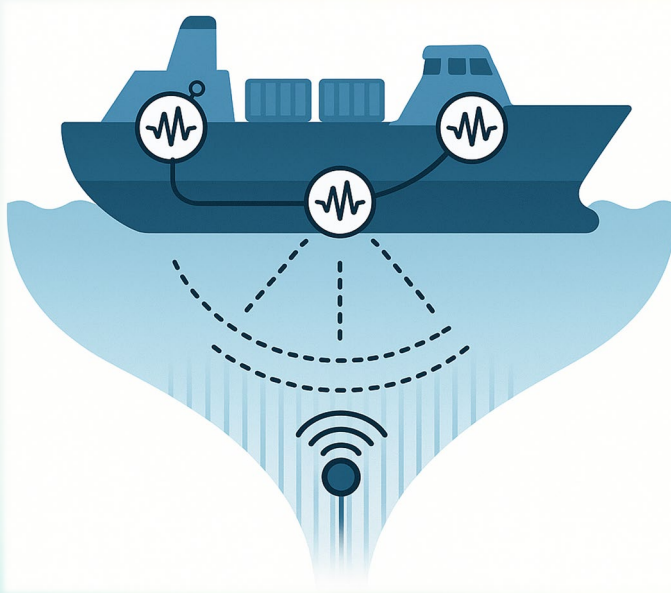
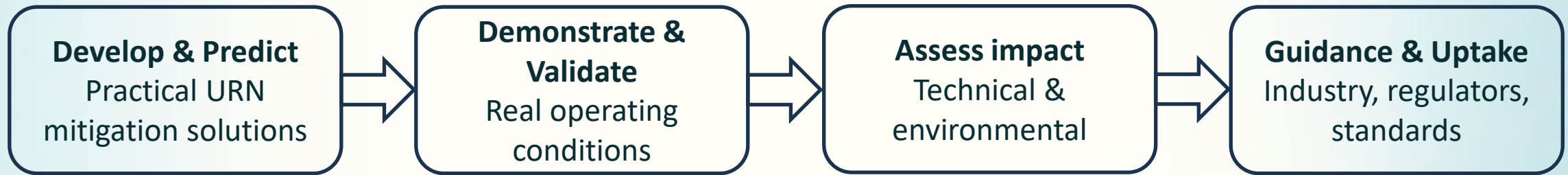
LOWNOISER

WEBINAR

Analytical modelling approaches
for Underwater Noise Reduction
in shipping

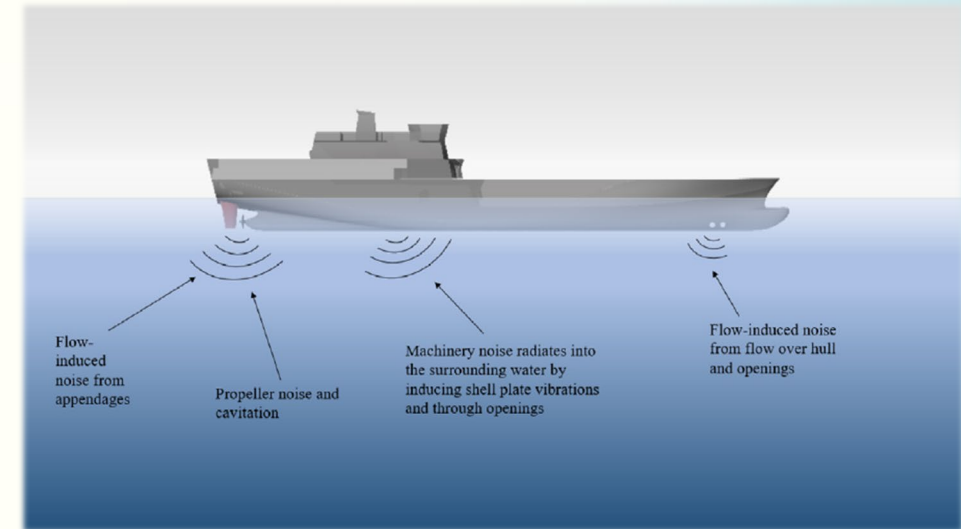
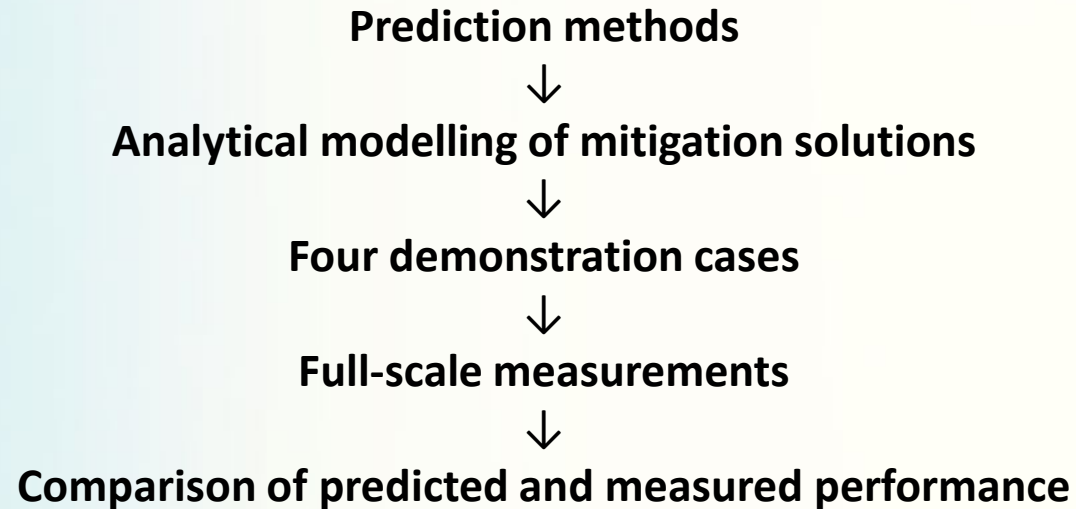


LOWNOISER – From prediction to implementation



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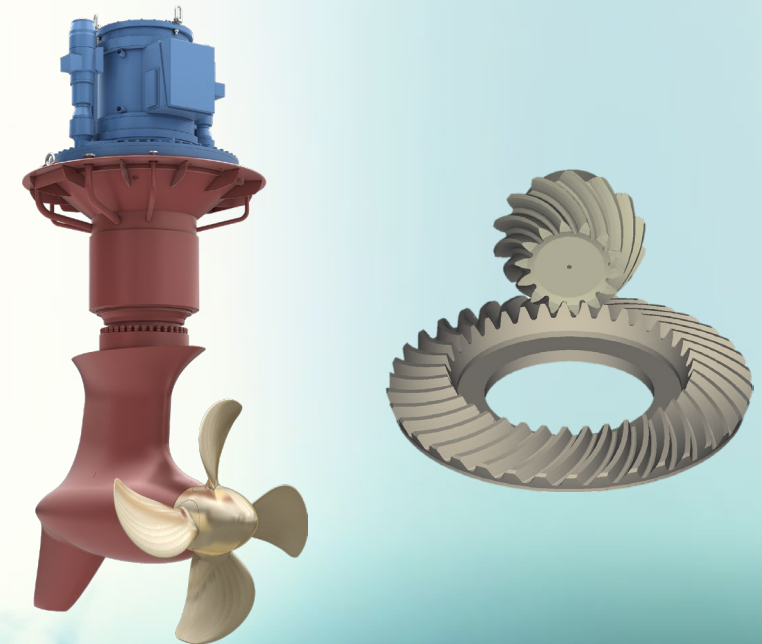
LOWNOISER – From prediction to full-scale validation



Role of analytical modelling: estimate expected URN reduction and provide a quantitative reference for full-scale validation

Case 1 – Havila Capella – Optimised bevel gear

- Full-scale demonstration on Havila Capella operating along the Norwegian coast
- Source reduction through optimised bevel gear microgeometry to reduce tonal gear-noise emissions

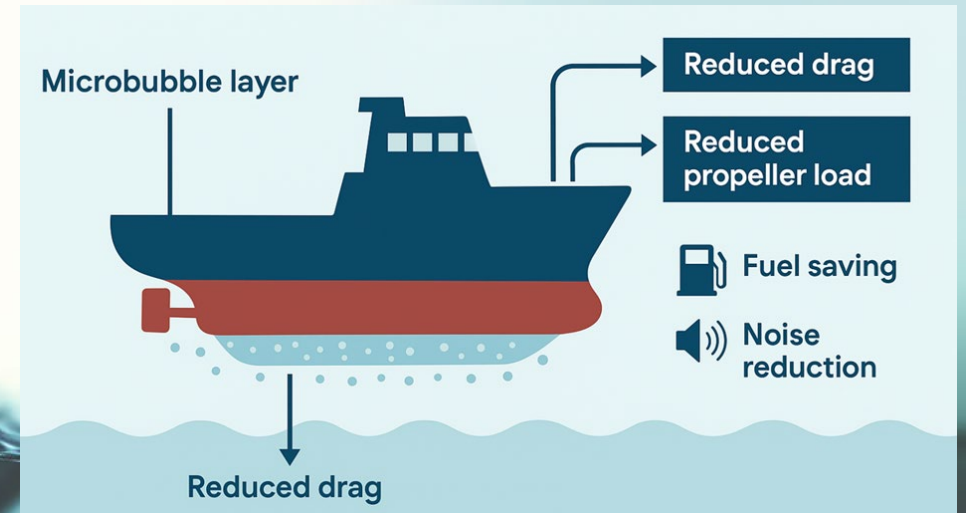


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 **LOWNOISER**

Case 2 – Vertom Joy - Air Lubrication System

- Full-scale assessment of the Air Lubrication System (ALS) on *Vertom Joy*
- Potential URN reduction through lower propulsion demand and acoustic damping
- Propulsion / hydrodynamic mitigation



Case 3 -Ibaizabal tanker – Operational noise mitigation

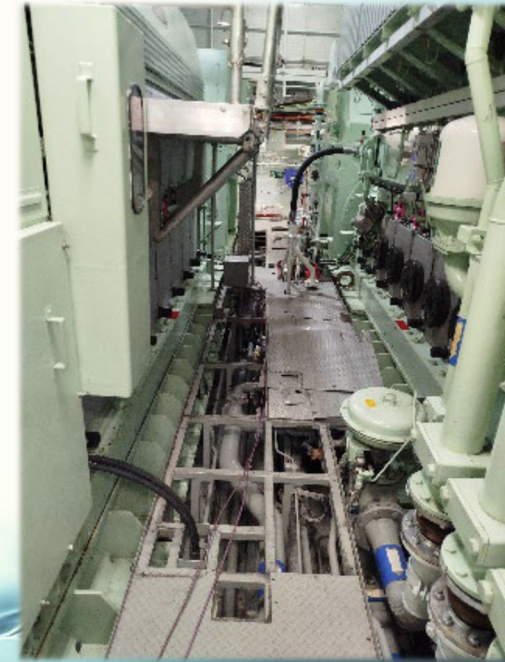
- Operational measures to reduce underwater noise
- Predict how vessel speed and operating conditions affect URN
- Combine analytical modelling with onboard monitoring and full-scale validation



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Case 4 – MS Fridtjof Nansen – Upgraded resilient engine mounts

- Upgraded resilient engine mounts to reduce machinery-related URN
- Analytical prediction of vibration isolation and transmission-path reduction
- Onboard monitoring and full-scale measurements for subsequent validation



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4 demonstrators overview

**Reducing noise at
the source**



**Energy saving
technology**



Vessel operation



Machinery vibration



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 **LOWNOISER**

First thing first!

GOAL

Reduce ship URN

TWO MAIN STRATEGIES

Intrinsic noise reduction

Component-level reduction

Extrinsic noise reduction

Improved energy efficiency



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Analytical models

NICE

RAPID EARLY INSIGHT

Fast answers from limited inputs make analytical models valuable in early-stage design.

BUT

CASE-SPECIFIC ADAPTATION

A model may not fully represent the case at hand, so extensions or modifications may be needed.

BUT

EXPERT JUDGMENT

Results must be interpreted carefully, with the model's assumptions and limitations in mind.



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Analytical models in LowNoiser



DEMONSTRATE SOLUTIONS (EU REQUEST) Show with large scale demonstrators that ship-noise abatement can be achieved alongside lower GHG emissions.



ASSESS EFFECTIVENESS AT DESIGN STAGE Use analytical models to evaluate proposed solutions and guide their design.



A REALISTIC APPLICATION OF ANALYTICAL MODELS Apply the models in a realistic design loop as they are used by engineers.



EXTEND EXISTING MODELS Improve or expand the available models wherever the project requires it.



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Modelling challenges

01 BUILD ON EXISTING TOOLS LowNoiser is a demonstration-focused project; therefore, it needs to build on existing tools.

02 USE PIANO AS THE BASELINE For overall ship noise, the most advanced available tool is PIANO—a physics-based, semi-empirical source-level model for fleet-scale ship URN prediction (MARIN + DW-ShipConsult, NAVISON, EMSA).

03 APPLY IT TO DESIGN QUESTIONS PIANO was developed to predict single-ship noise for soundscapes. Its propeller module can also estimate noise reductions from voluntary speed or power reductions.

$$L_S(f)[dB] = 10 \log_{10} \left(10^{\frac{L_{S,2S \text{ or } L_{S,4S}(f)}}{10}} + 10^{\frac{L_{S,AE}(f)}{10}} + 10^{\frac{L_{S,cav}(f)}{10}} \right)$$



Main engine Auxiliaries Propeller cavitation

Modelling challenges

HX FRIDTJOF NANSEN

IMPROVE ENGINE MODULE

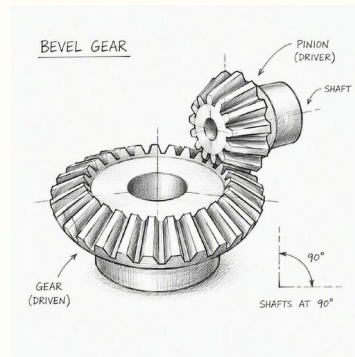
Too simplistic—especially for four-stroke engines, as acknowledged by the model authors.



HAVILA CAPELLA

INTRODUCE BEVEL GEARS NOISE

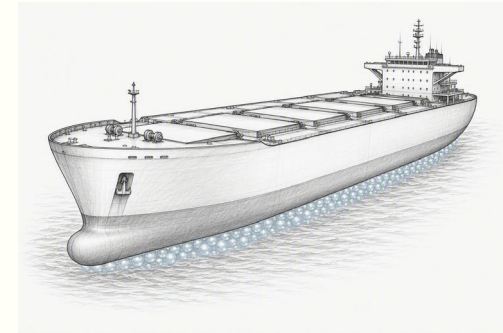
No module is available for bevel gears in marine thrusters.



VERTOM JOY

INCLUDE AIR LUBRICATION

Only partially covered: the model can address only the extrinsic component.



MONTE ESPERANZA

NO MODIFICATIONS

No particular modifications to the PIANO model were required.





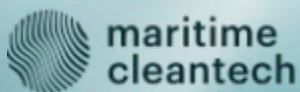
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LOWNOISER

WEBINAR

Bevel gear optimization to
reduce tonal underwater
radiated noise from
azimuthing thrusters



Havila Capella - Gear Noise Reduction

Setting the scene

Operations in Coastal Areas

Objective	Enable gear-specific URN testing and demonstrate noise mitigating actions
Partners	Havila Kystruten, Maritime Cleantech, TSI, KM
Scope	Gear replacement during the project with measurements before and after
Strategy	Layover and en route measurements

Havila Capella

Type	Coastal Cruise
Size	124 m + 640 pass.
Fuel	LNG + batteries
Thruster	2 x AZP120 L PM



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Kongsberg
Maritime



LOWNOISER

Havila Capella - Gear Noise Reduction

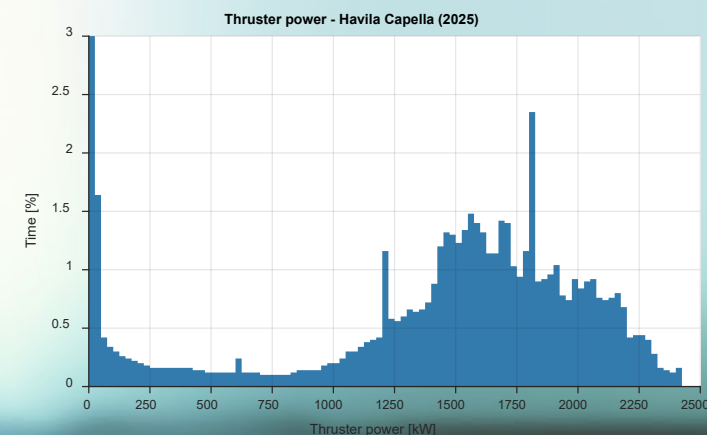
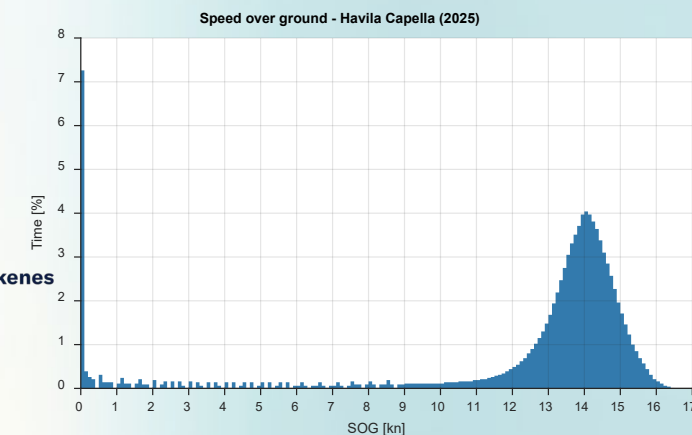
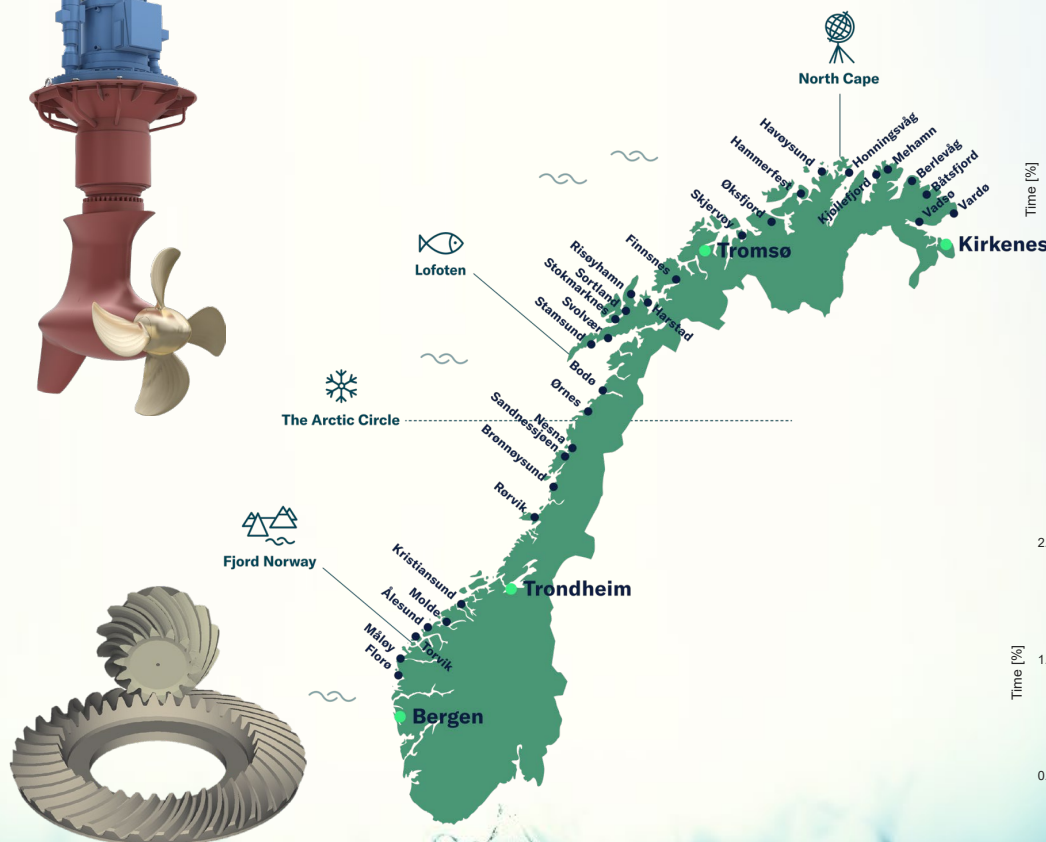
Vessel Operation

Thruster Rating

Max Power	2 x 2400 kW
Motor RPM	437 1/min
Propeller RPM	168.9 1/min
Propeller Diameter	3.3 m

Average Thruster Loading

Vessel Speed	14 kn
Thruster Power	1570 kW
Propeller RPM	143 1/min
Time Period	2025



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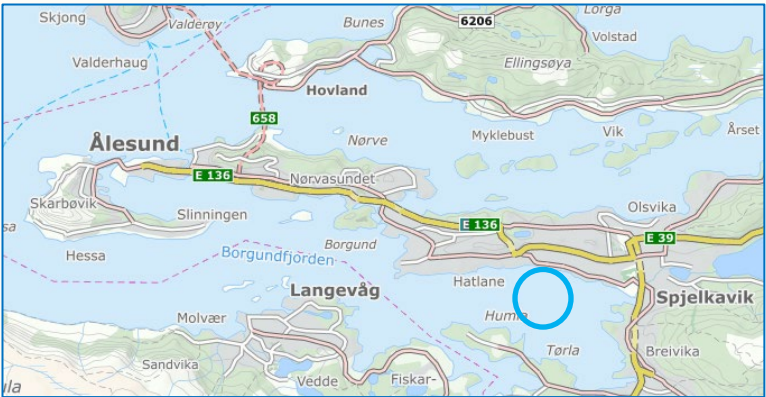
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Maritime

LOWNOISER

Havila Capella - Gear Noise Reduction

Measurement Locations and Setup

Layover - Ålesund	
Dates	March 2026 & Q1 2027
Setup	URN, load and vibration measurements
Protocol	Specific load scenarios from 8 to 14 knots



En Route - Trondheim	
Dates	Q3 2026 – Q1 2027
Setup	Battery driven, long-term URN measurements
Protocol	All Havila vessels coming in and out of Trondheim



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Havila Capella - Gear Noise Reduction

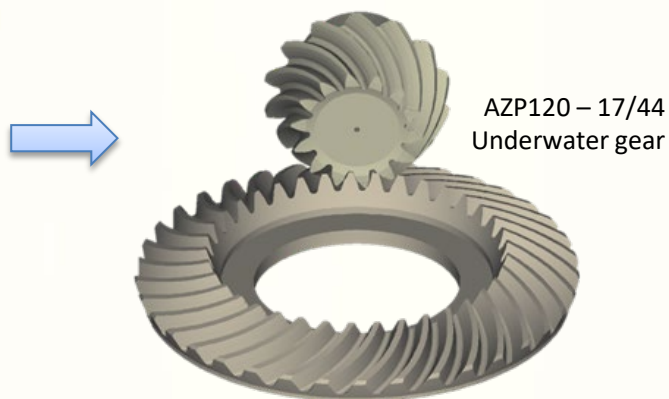
Gear Optimization

Gear Macrogeometry

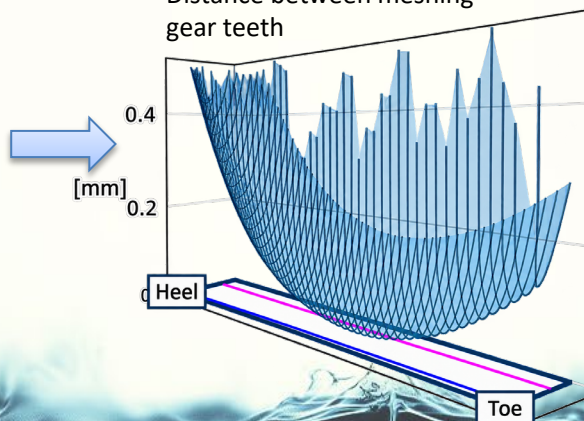
Parameters	Number of teeth, spiral angle, pressure angle ...
Effect	Overlap ratio (number of tooth pairs in contact)
BUT	Re-classification of the gears required

Gear Microgeometry

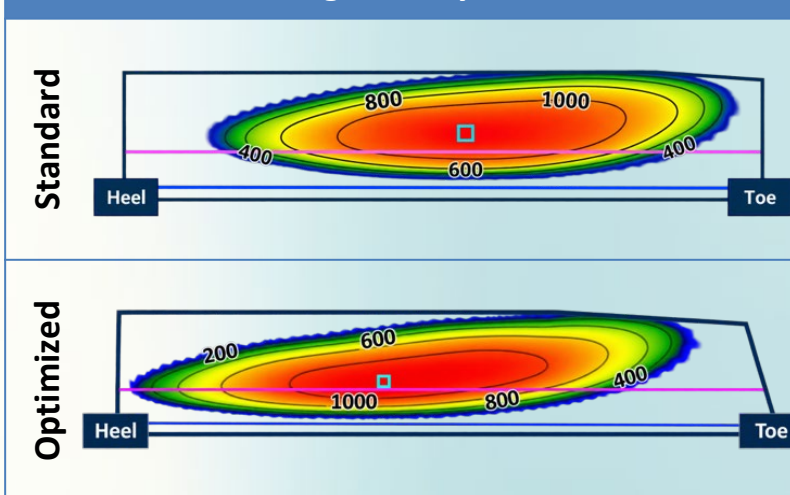
Parameters	Lengthwise and Heightwise crowning ...
Effect	Developing and movement of contact pattern
BUT	Here, limited to conventional gear machines



EaseOff: AZP120 - 17/44
Distance between meshing gear teeth



Visualization Microgeometry – Contact Pressure



Elongated and tilted contact pattern to ensure a high and constant overlap ratio



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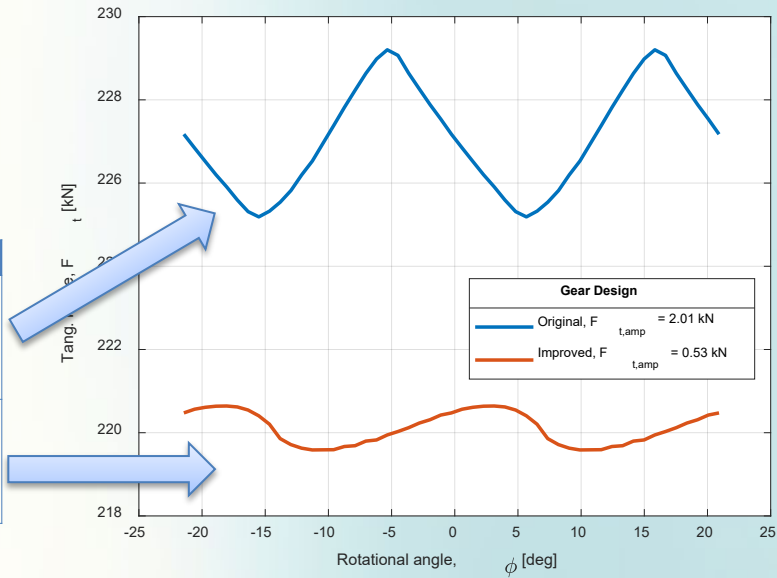
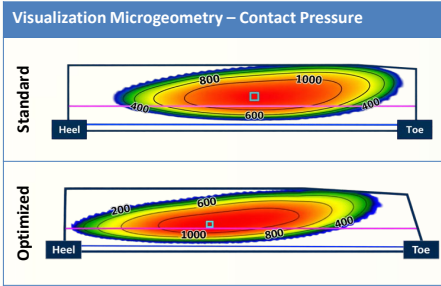


LOWNOISER

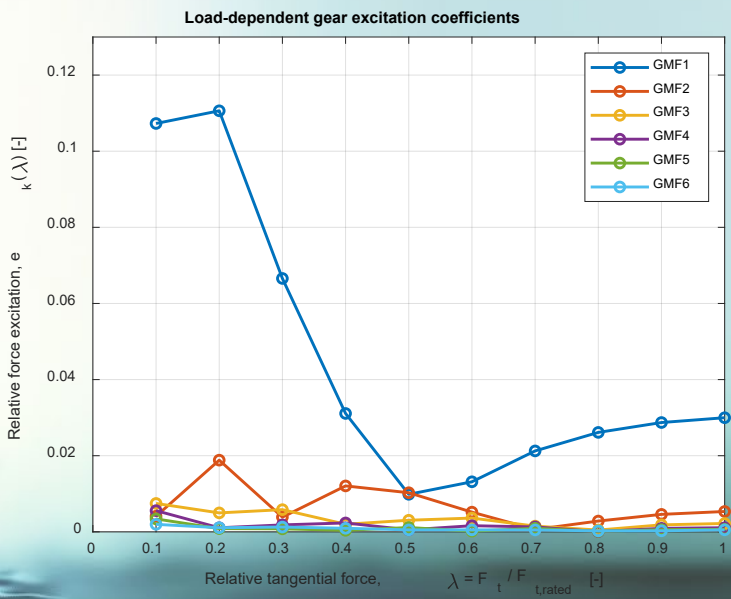
Havila Capella - Gear Noise Reduction

Gear-specific URN calculations

Optimization Approach	
Objective	Keep macrogeometry unchanged Reduce force excitation for relevant operating conditions as much as possible
Framework	From design to delivery within 1 year Production on conventional gear machines
Installation	Drydocking Havila Capella Nov 2026 Spare thruster build up October 2026
Results	Optimization for one specific operating point at approx. 50% load



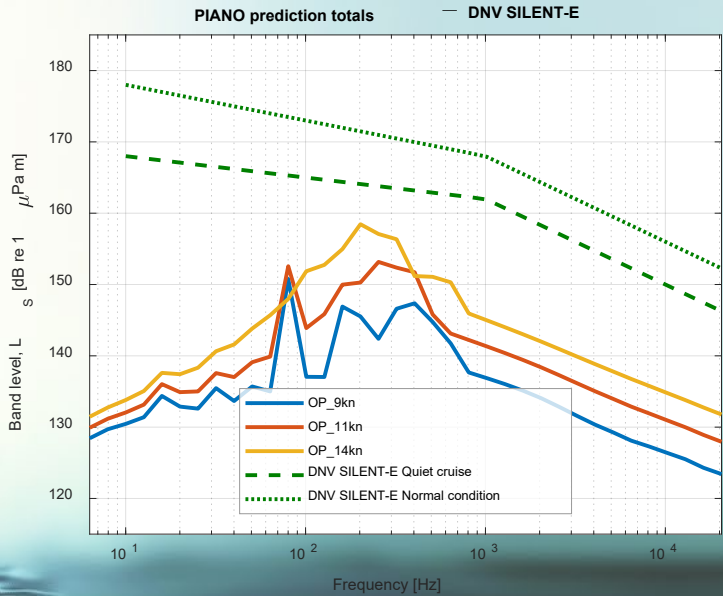
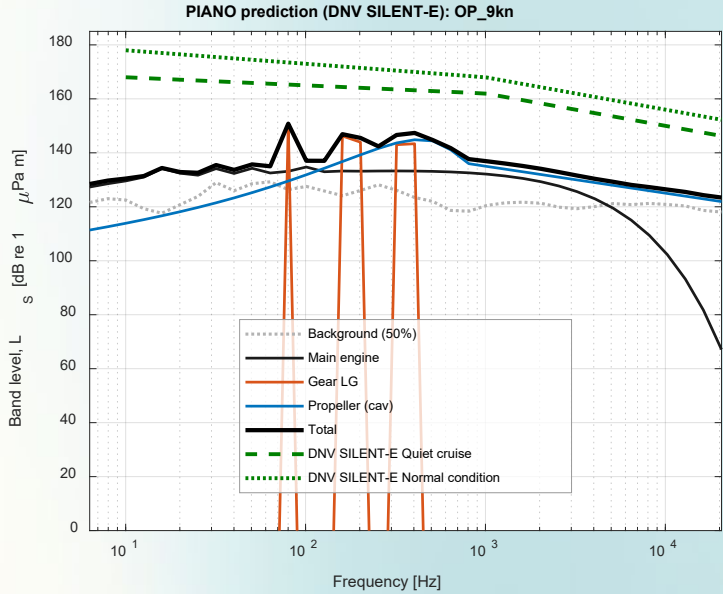
Force amplitude visualization
Quiet operation at 50 % load as per GMF1



Havila Capella - Gear Noise Reduction

Gear-specific URN calculations

PIANO Predictions	
Gear Module	Translate tonal gear excitations via a frequency-dependent transfer function to URN (calculation applies for Z- and L-drive type thrusters)
Observation	Especially at low loads / vessel speeds, machinery noise from engines and gears critical. Gear optimization needed to achieve highest Silent ratings.
Results	Load and frequency dependent response with URN reduction up to 3 dB. Some GMFs down, others up.



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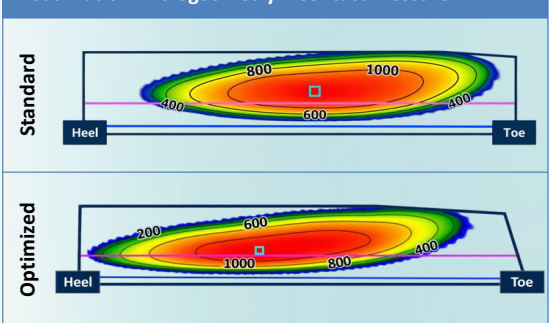
LOWNOISER

Havila Capella - Gear Noise Reduction

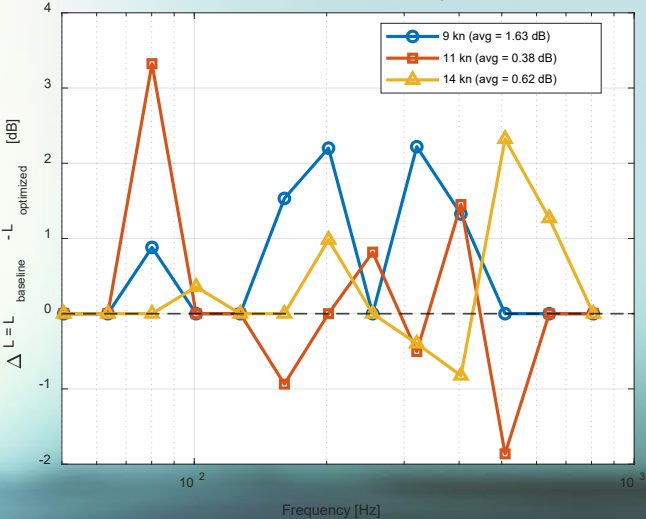
Summary

Gear Optimization – Results	
Approach	Change of the gears micro- rather than macrogeometry Gears ready to be shipped next week!
Measurements	High fidelity measurements before/after upgrade in Ålesund combined with long-term / en route measurements of all Havila Kystruten vessels outside of Trondheim
Noise optimization	Development of a force excitation function as a result of the load tooth contact analysis (BECAL) and its reduction through gear optimization
Prediction	Upgrade of PIANO framework to include tonal gear noise contribution via a frequency-dependent transfer function
Results	Frequency and operating conditions dependent results. Up to 3 dB URN reduction for GMF1 at 11 knots and average reduction 0.85 dB across GMF1-6 and all conditions.

Visualization Microgeometry – Contact Pressure



Predicted noise reduction from optimized bevel gear



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 **LOWNOISER**

AIR LUBRICATION SYSTEM

LONG HISTORY

Air lubrication has a long history of use for both noise masking and power reduction.

CIVIL APPLICATIONS

Civil applications focus on reducing drag.

MILITARY APPLICATIONS

Military applications target noise signatures, but whether the effect results from damping, masking, or both remains undisclosed.



Alfa Laval - Ocean Glide



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Air lubrication reduces noise in two distinct ways

The system acts both at the source and along the sound transmission path.

01

AT THE SOURCE

Lower shaft power

Maintain the same ship speed with less shaft power.

RESULT **Less noise and GHG generated**

02

ALONG THE PATH

Bubble-layer damping

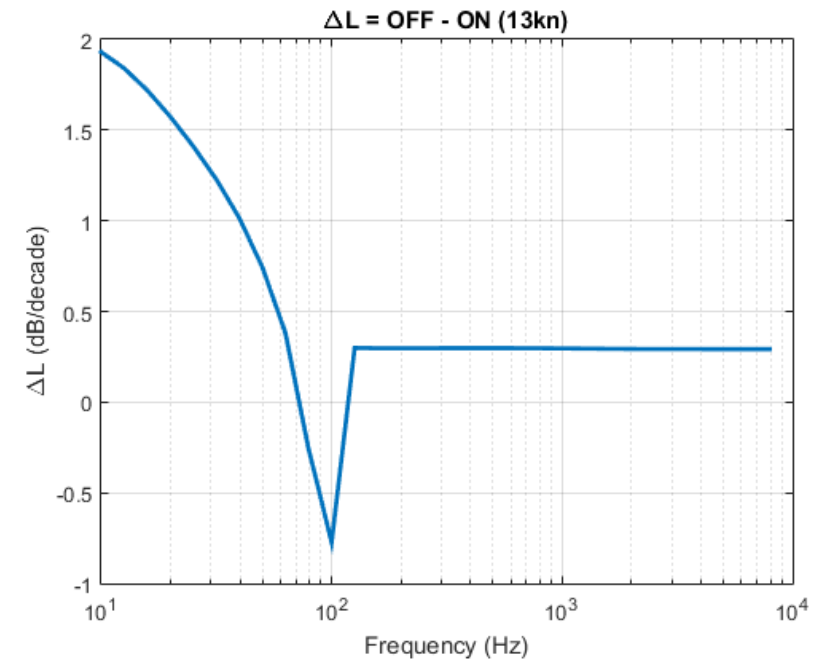
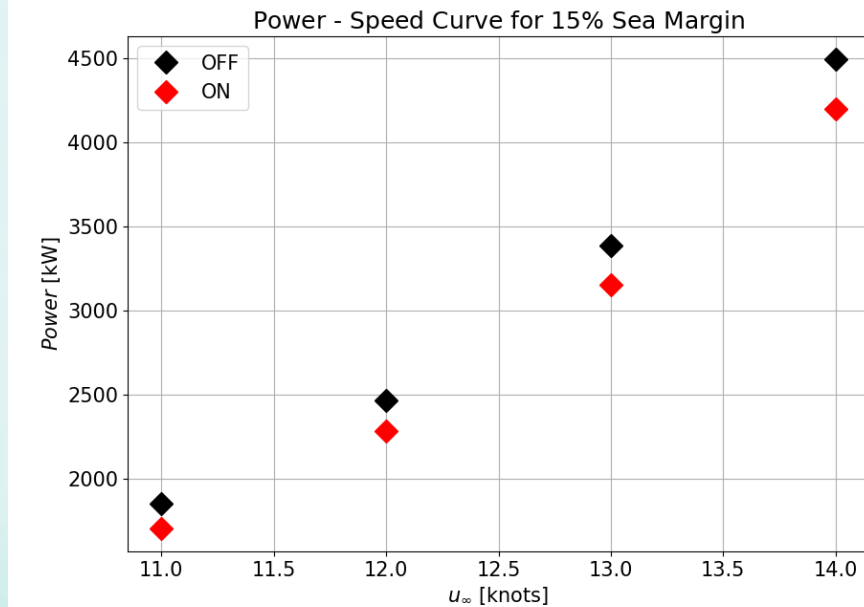
Air beneath the hull dampens the transmitted sound.

RESULT **Less noise reaches the water**

MODEL THE TRADE-OFF Also add the noise from power generation and the system's own components.

AIR LUBRICATION SYSTEM

- By reducing the power needed by the ship to keep the same speed, noise reduction can be achieved. Vertom Joy has a shaft generator, thus no extra genset needs to be running for the system to operate.
- This is a straightforward case that can be fed into PIANO



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AIR LUBRICATION SYSTEM

- **What happens to URN when ALS is turned on?**
- Many anecdotes in the industry, only a few documented cases (both in model or full scale)
- Difference between transmission losses, reflection and absorption



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Modelling assumptions

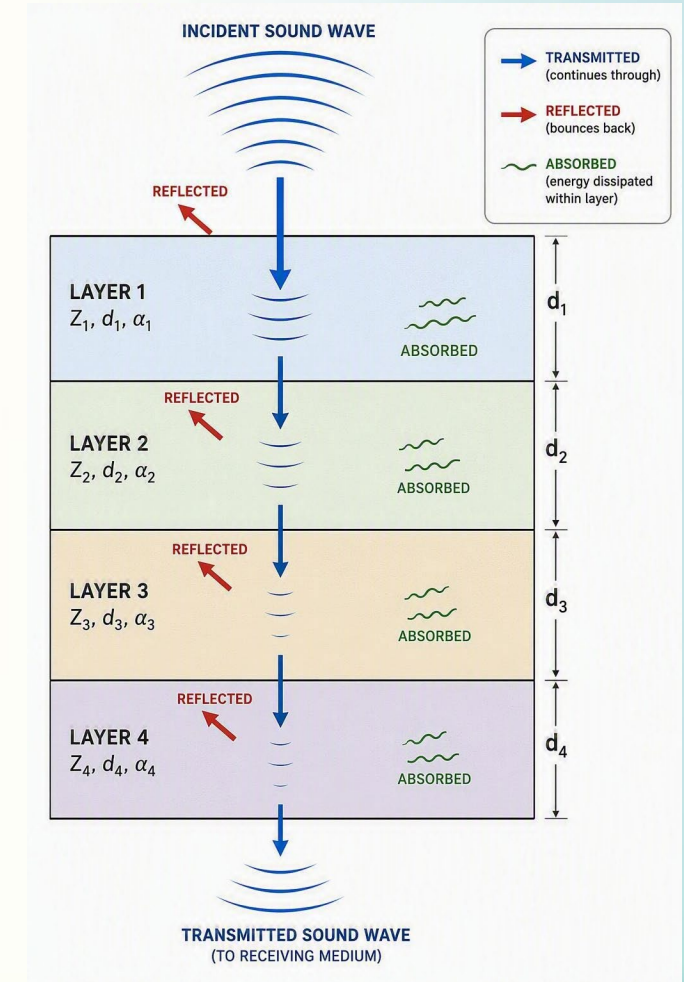
- 01 The acoustic properties of the bubble layer can be homogenized in a time averaged sense in a given location
- 02 The air layer is represented by sub-layers with uniform void fraction and bubble diameter
- 03 The acoustic effect of the bubbles can be modelled by the effective speed of sound in the medium

$$B_{eff}^{-1} = (1 - \alpha) B_L^{-1} + \alpha B_S^{-1}$$

$$B_S^{-1} = 1/B_c [1 - (\omega/\omega_0)^2 - i\omega\delta_s/\omega_0]^{-1}$$

$$\rho_{eff} = (1 - \alpha)\rho_L + \alpha\rho_c$$

$$c_{eff} = \sqrt{\frac{B_{eff}}{\rho_{eff}}}$$

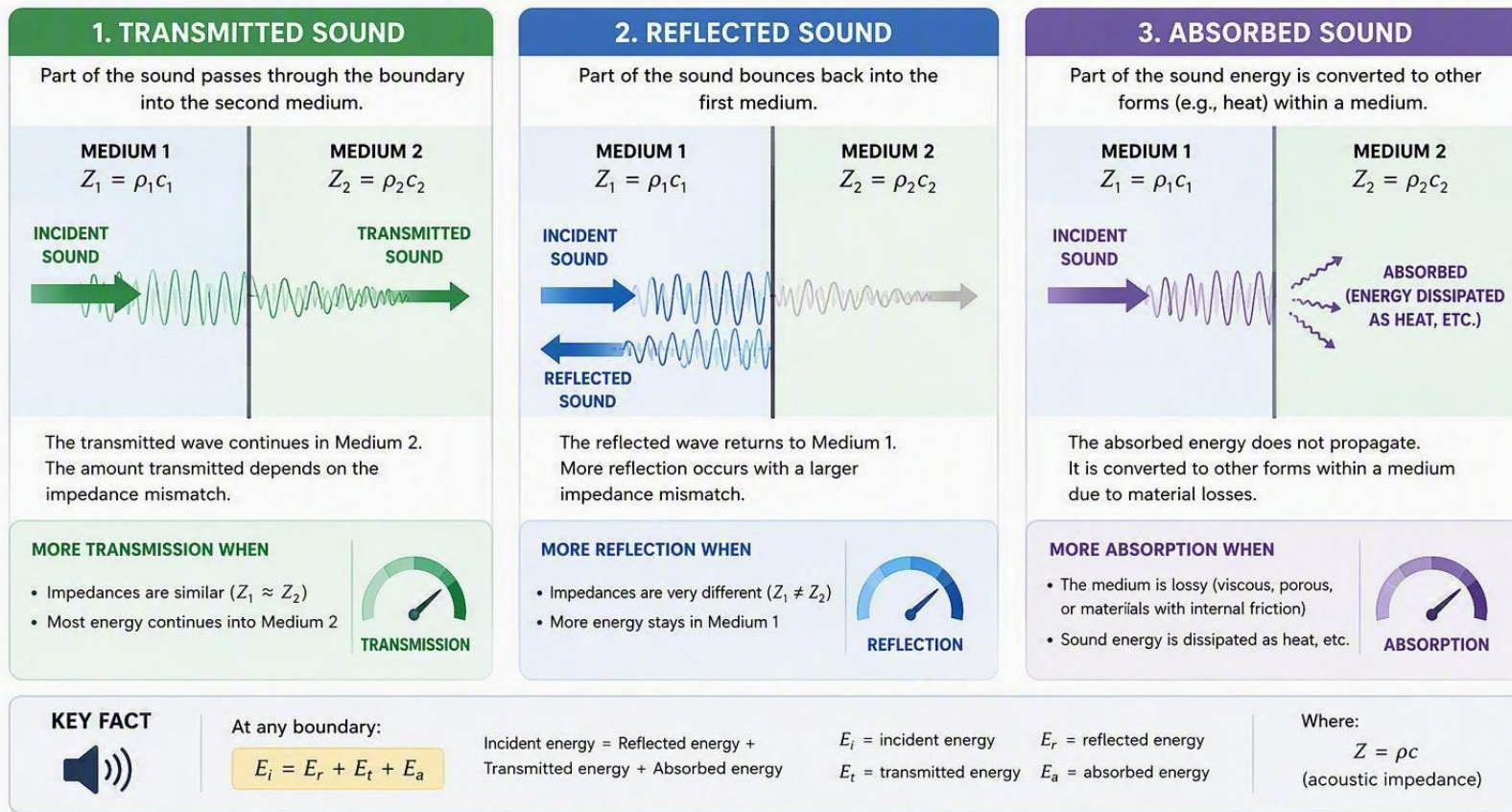


AIR LUBRICATION SYSTEM

TRANSMITTED, REFLECTED AND ABSORBED SOUND

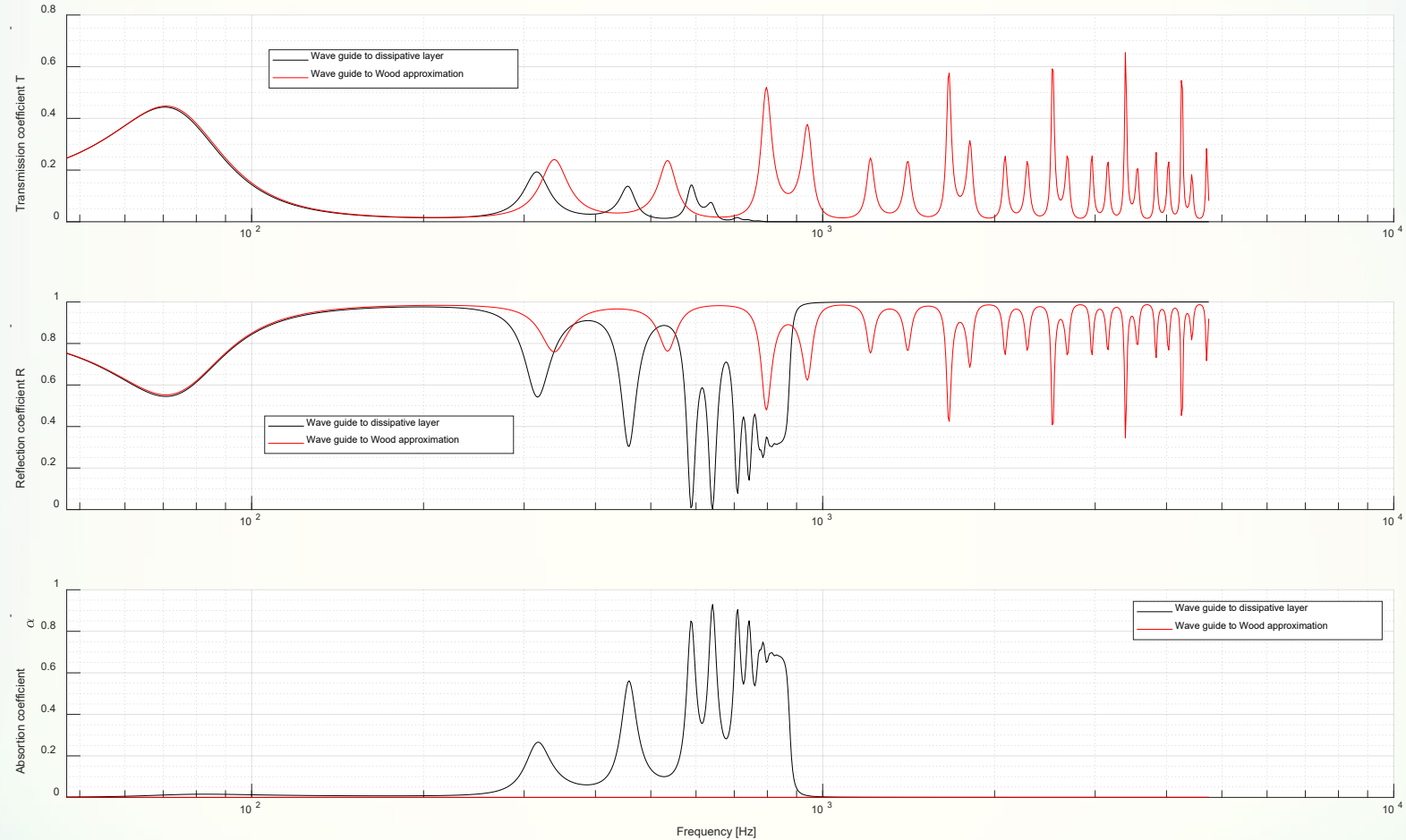
When sound reaches a boundary between two regions with different acoustic impedance, the incident sound is partially transmitted, partially reflected, and partially absorbed.

Acoustic impedance: $Z = \rho c$ (density $\rho \times$ sound speed c)



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Example



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ALS parameters

CURRENT STATUS

The Vertom Joy at the time this work was done was still in early stages.

OPERATIONAL TUNING

The amount of air that will be used in operation will be tuned during sea trials

TWO LIMITING CASES

3 mm

MINIMUM CASE • t_a

— **7 mm**

MAXIMUM CASE • t_a

Two limiting cases—a minimum ($t_a = 3$ mm) and a maximum ($t_a = 7$ mm)—were considered to assess whether the amount of air used by ALS would substantially affect noise transmission.

MODEL INPUTS

01 Void fraction distribution can be estimated by the ones observed in the experiments

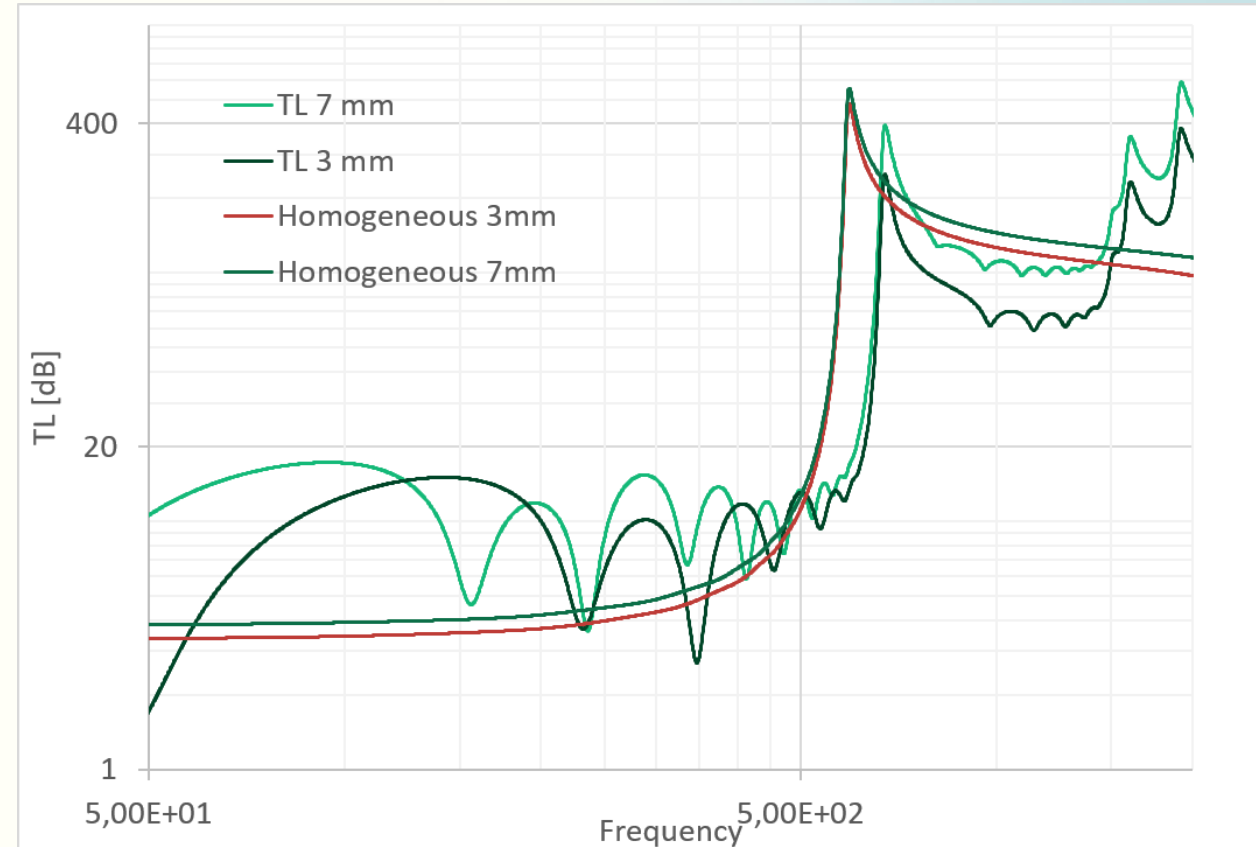
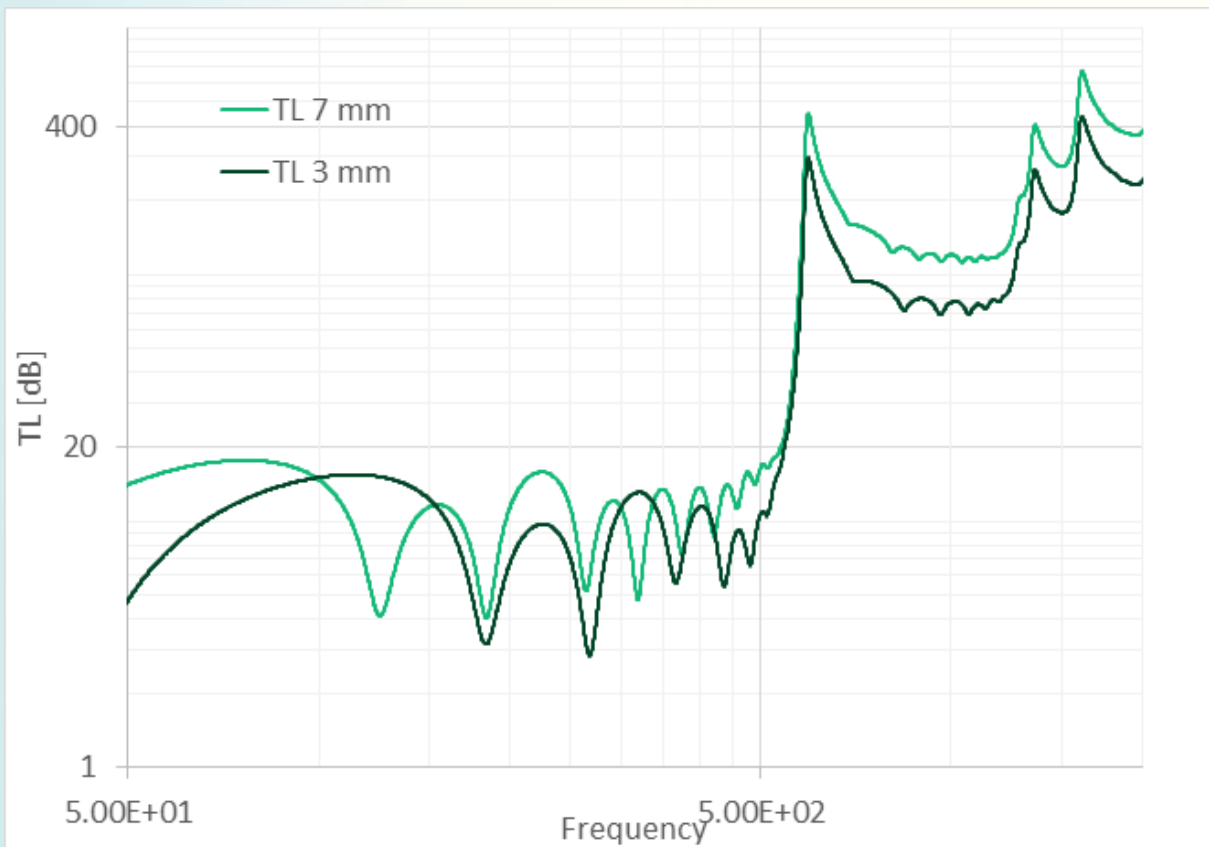
02 Bubble size by the boundary layer parameters at specific locations of the ship. (Hinze scales)



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The final result



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CONCLUSION AND FUTURE WORK FOR ALS

CONCLUSIONS

- The effect of the power reduction can be modelled directly in PIANO

- The effect of the air layer is more difficult to model; it requires knowing specifically where the noise is emitted and some information on the air layer underneath the emitter

- Some of the anecdotes have an explanation (transmission, reflection vs absorption)

FUTURE WORK

- **Two important developments:**
 - Perform a case study where a specific engine is used and the air layer added as an extra dampener

 - Model the noise of the compressors and of the air moving in the system



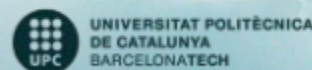
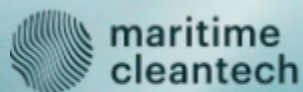
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LOWNOISER

WEBINAR

Use of onboard monitoring
systems and operational data to
support underwater noise
assessment and prediction



Introduction.- Noise mitigation by operational measures

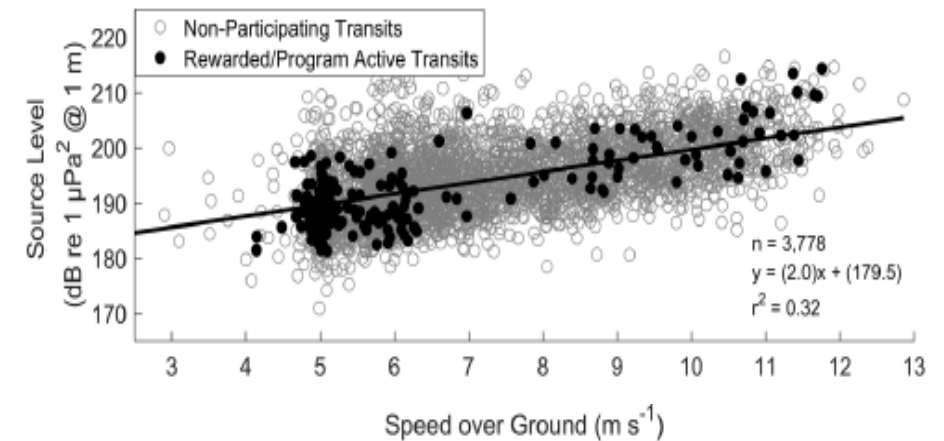
Speed reduction impact.

Research across thousands of vessel transits confirms a direct correlation between a vessel's Speed over Ground (SOG) and its Source Level (SL)

- Lower Speed = Lower Noise: A proven, immediate operational measure to mitigate underwater radiated noise (URN).
- Data-Driven Compliance: Vessel speed reduction programs demonstrate measurable acoustic relief in sensitive marine channels (*).

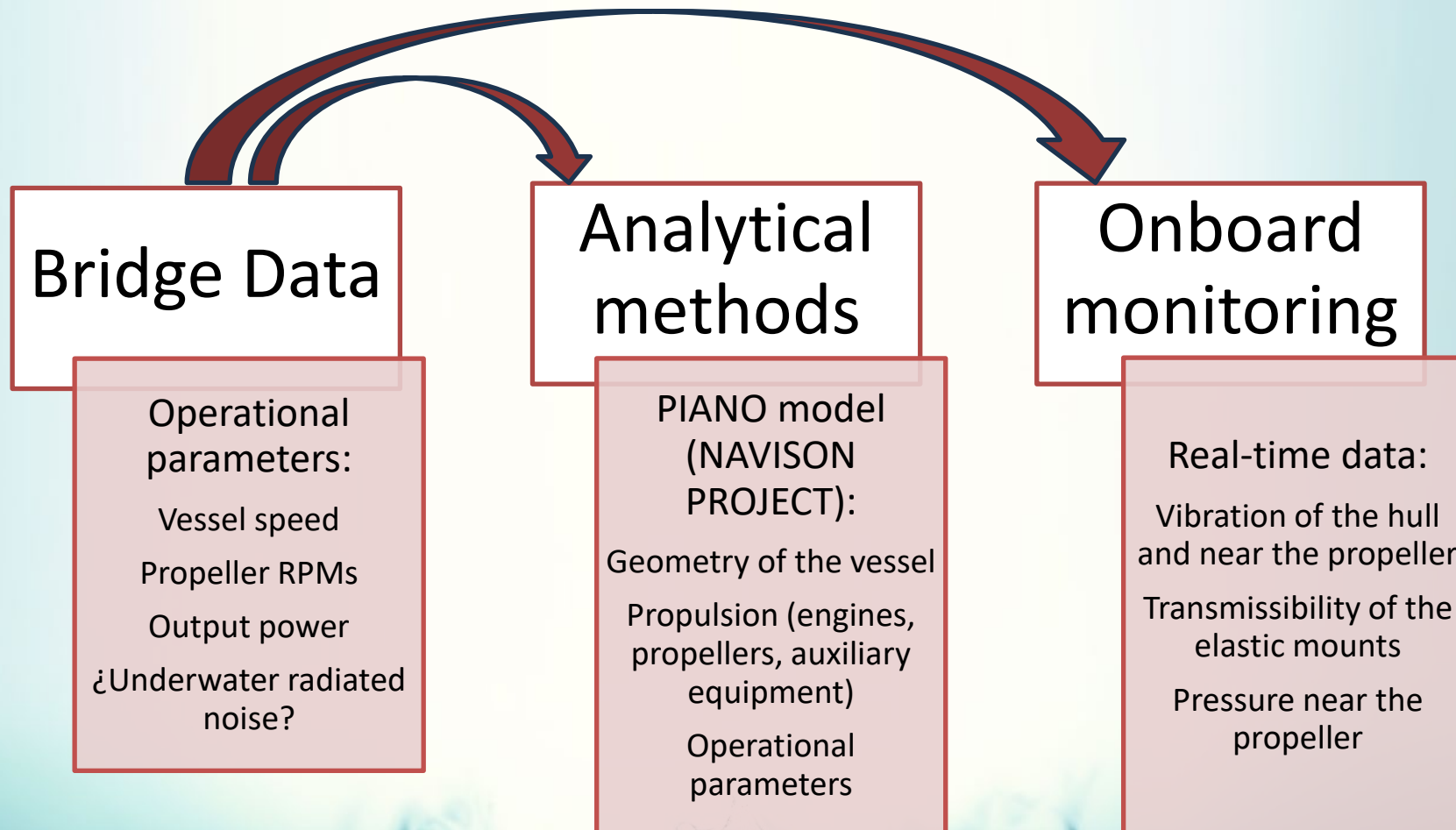


(*) Source: <https://sinay.ai/wp-content/uploads/2026/01/Design-sans-titre-5-1.jpg>



(*) Source: ZoBell, V.M., Frasier, K.E., Morten, J.A. et al. Underwater noise mitigation in the Santa Barbara Channel through incentive-based vessel speed reduction. Sci Rep 11, 18391 (2021). <https://doi.org/10.1038/s41598-021-96506-1>

Introduction.- Information Flow



Analytical methods: PIANO model

PIANO: Propulsion – Induced Acoustic Noise
in Operating condition

NAVISON PROJECT

$$L_S(f)[dB] = 10 \log_{10} \left(10^{\frac{L_{S,2S}/L_{S,4S}(f)}{10}} + 10^{\frac{L_{S,AE}(f)}{10}} + 10^{\frac{L_{S,cav}(f)}{10}} \right)$$

Main engine noise
(2/4 stroke engines)

Ship's length
Ship's breadth
Engine RPMs
Power
Elastic mounts' attenuation

Auxiliary engine noise

Ship's length
Ship's breadth
Number of aux. engines
Power
Power to weight factor
Elastic mounts' attenuation

Cavitation noise

Propeller characteristics
Propeller RPMs
Vessel speed
Power delivered by the main
engine
Semi-empirical coefficients



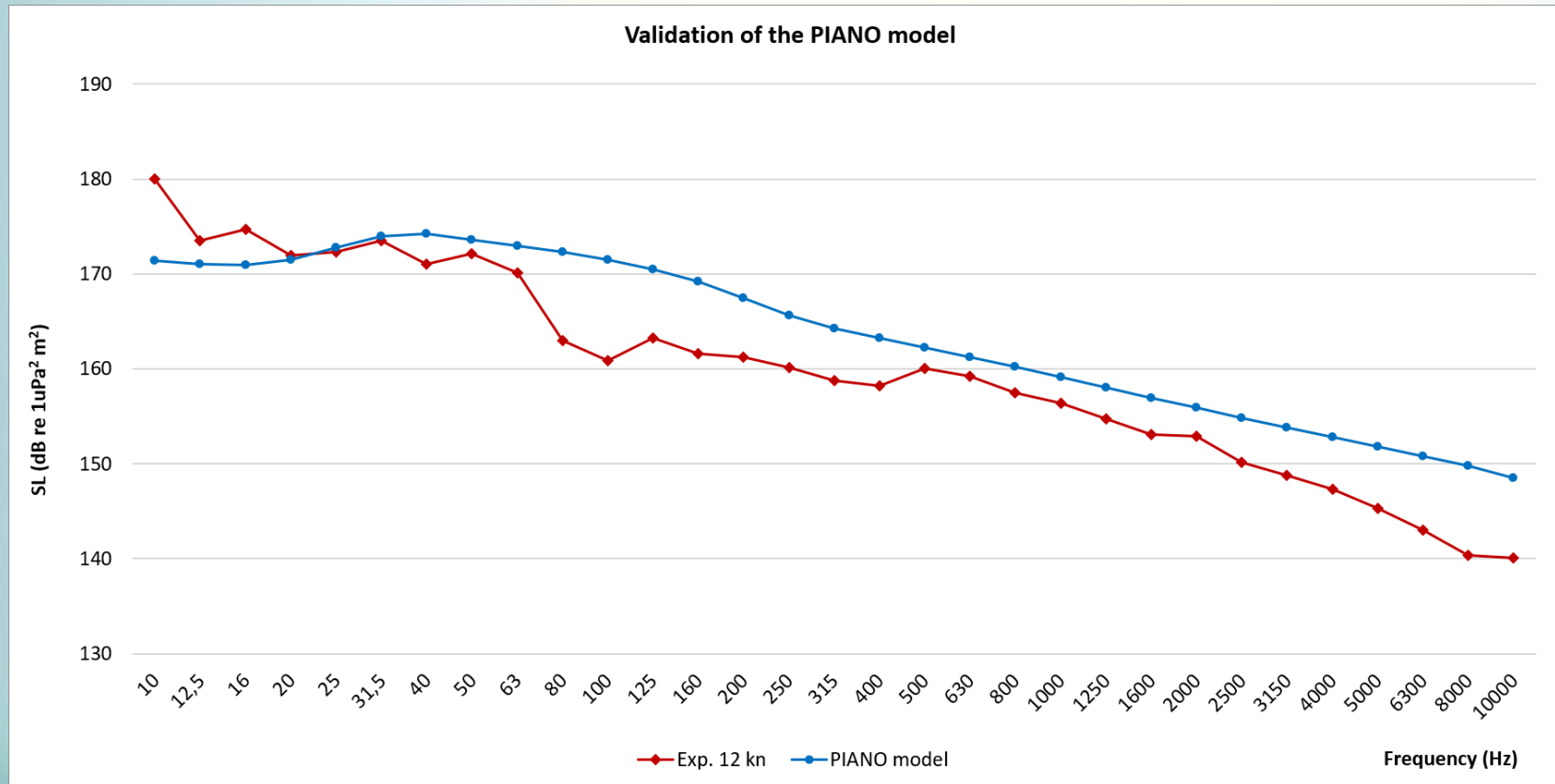
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Source: Lloyd, T., Daniel, J., Bosschers, J., & Schuster, M., "PIANO": A physics-based semi-empirical source level model for fleetscale ship URN prediction," in Proceedings of the 8th International Symposium on Marine Propulsors (SMP'24), Berlin, Germany, 17–20 Mar. 2024, pp. 65, DOI: 10.15480/882.9335



LOWNOISER

PIANO model validation: Bulk carrier



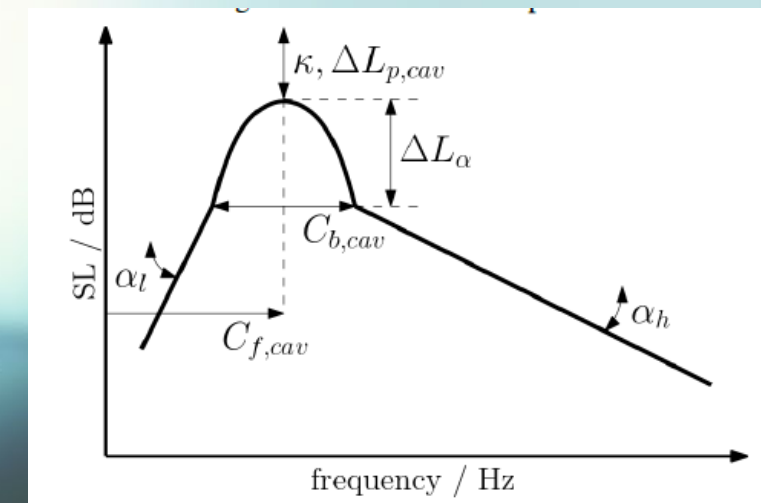
Bulk Carrier 230 m

Speed -> 12 kn

2-stroke main engine

Semi-empirical coefficients:

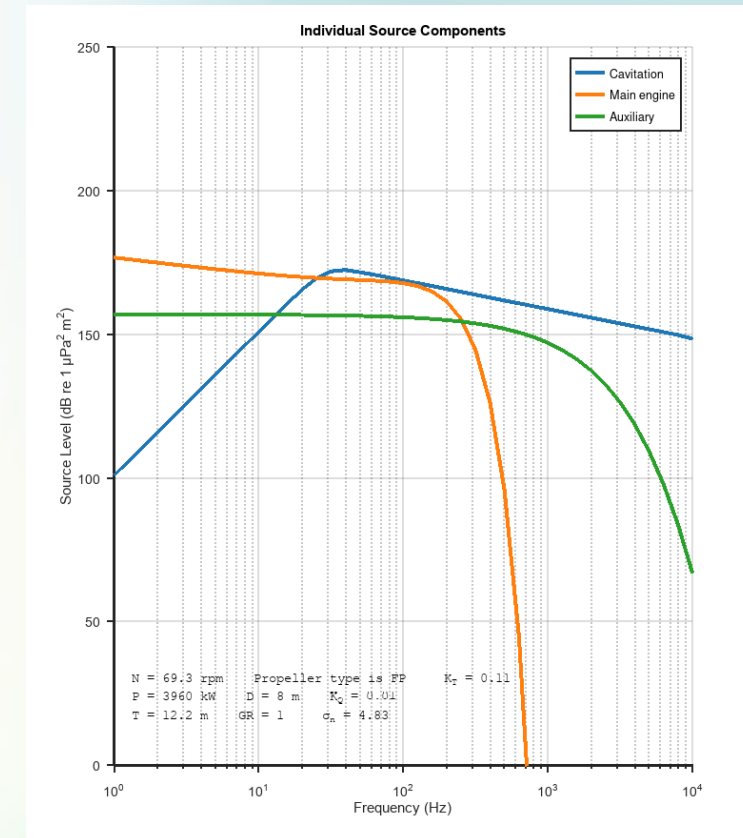
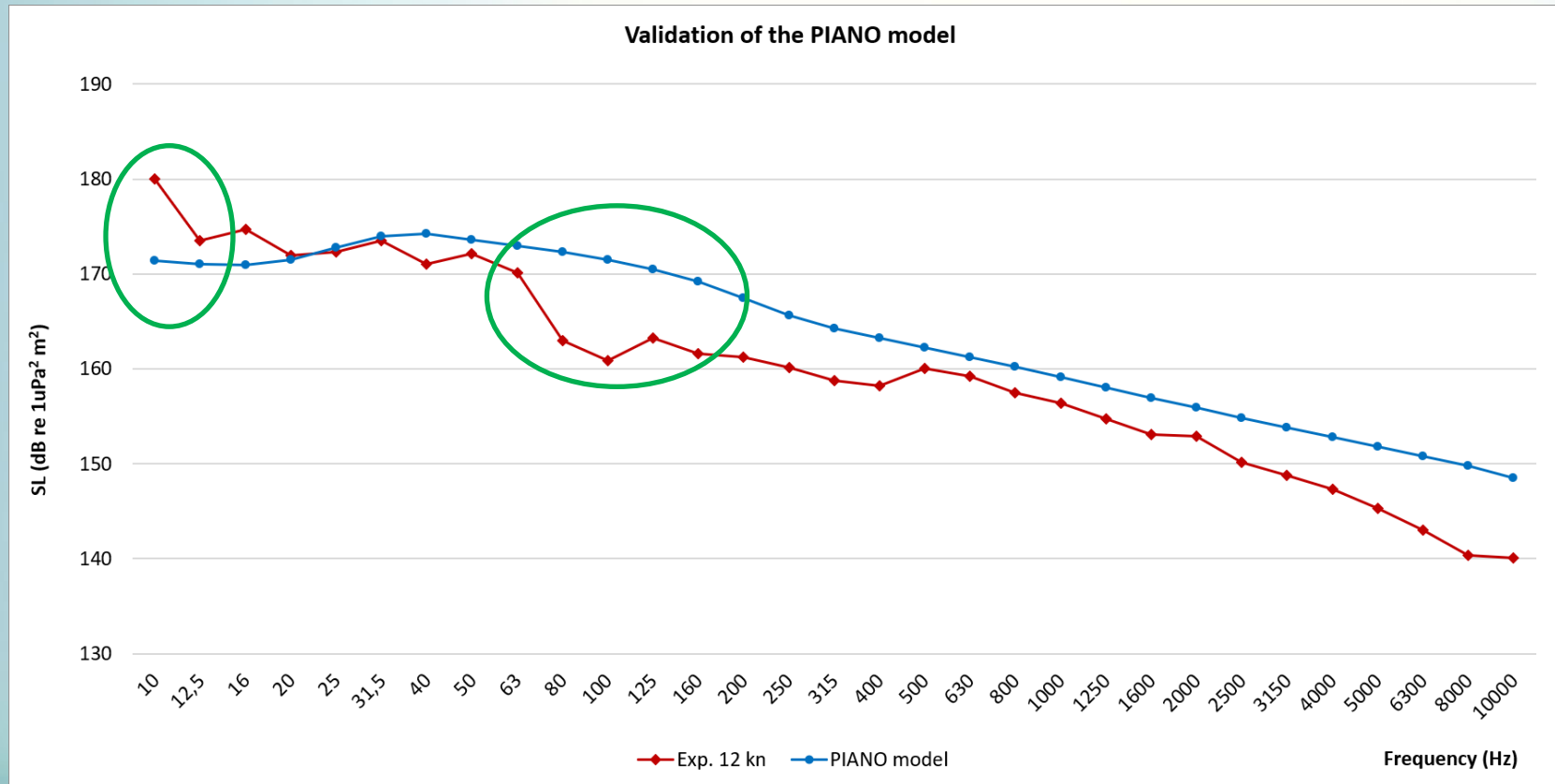
```
deltaL_cav = 18;  
Cf_cav = 0.32;  
Cb_cav = 0.7;  
deltaL_alpha = -0.45;  
kappa = 3;  
alpha_h = -2;
```



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Source: Lloyd, T., Daniel, J., Bosschers, J., & Schuster, M., "PIANO: A physics-based semi-empirical source level model for fleetscale ship URN prediction," in Proceedings of the 8th International Symposium on Marine Propulsors (SMP'24), Berlin, Germany, 17–20 Mar. 2024, pp. 65, DOI: 10.15480/882.9335

PIANO model validation: Bulk carrier

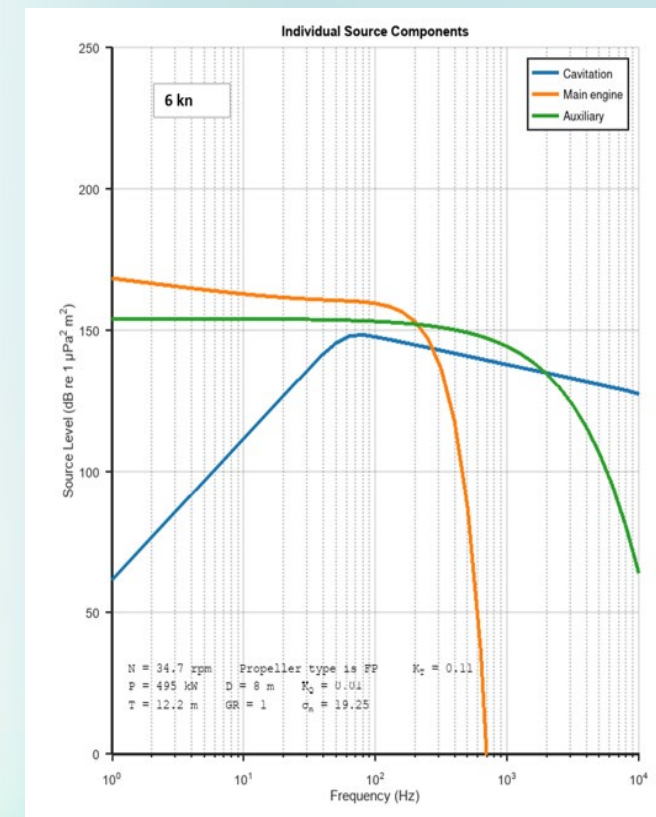
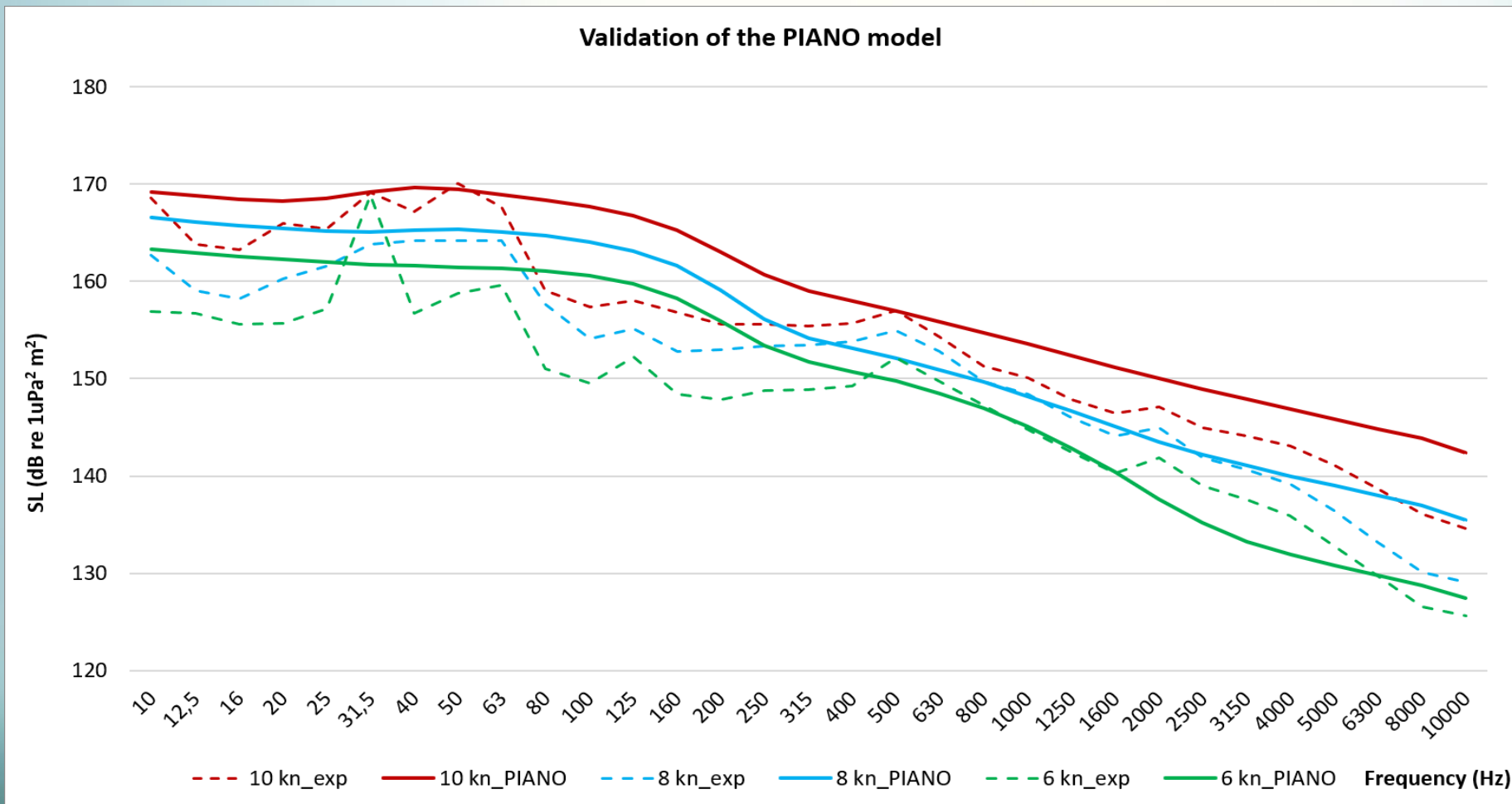


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Source: Lloyd, T., Daniel, J., Bosschers, J., & Schuster, M., "PIANO: A physics-based semi-empirical source level model for fleetscale ship URN prediction," in Proceedings of the 8th International Symposium on Marine Propulsors (SMP'24), Berlin, Germany, 17–20 Mar. 2024, pp. 65, DOI: 10.15480/882.9335



PIANO model performance: Bulk carrier



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Onboard monitoring

Machinery noise

Vibration measurements on both sides of the elastic mounts.
Efficiency of the antivibration systems.
Transfer functions between the machinery and the hull.
Vibration of the hull.

Cavitation noise

Accelerometers / pressure sensors near the propulsion system.
NI-CDS -> Cavitation detection system through TSI patented algorithm.

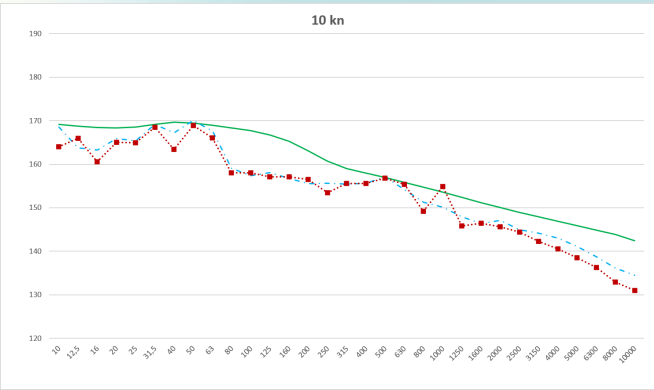
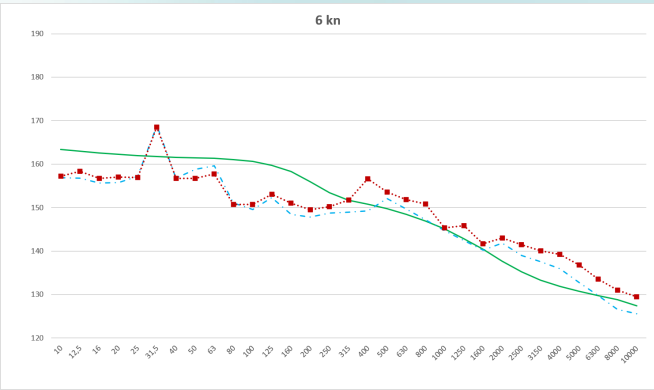
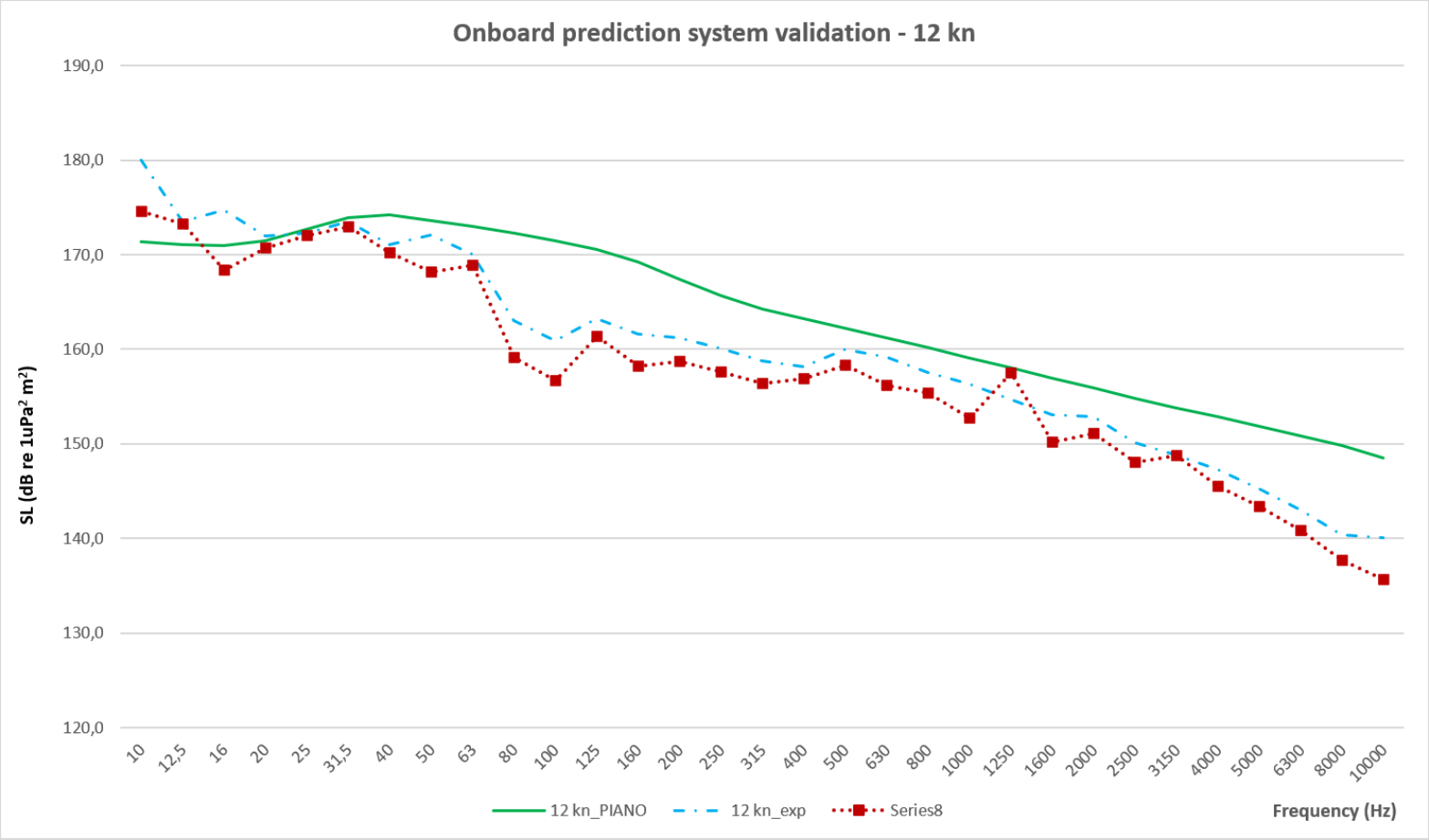
VIBROACUSTIC
TRANSFER FUNCTIONS

VIBROACUSTIC
TRANSFER FUNCTIONS

URN



PIANO model vs onboard monitoring system vs experimental data: Bulk carrier

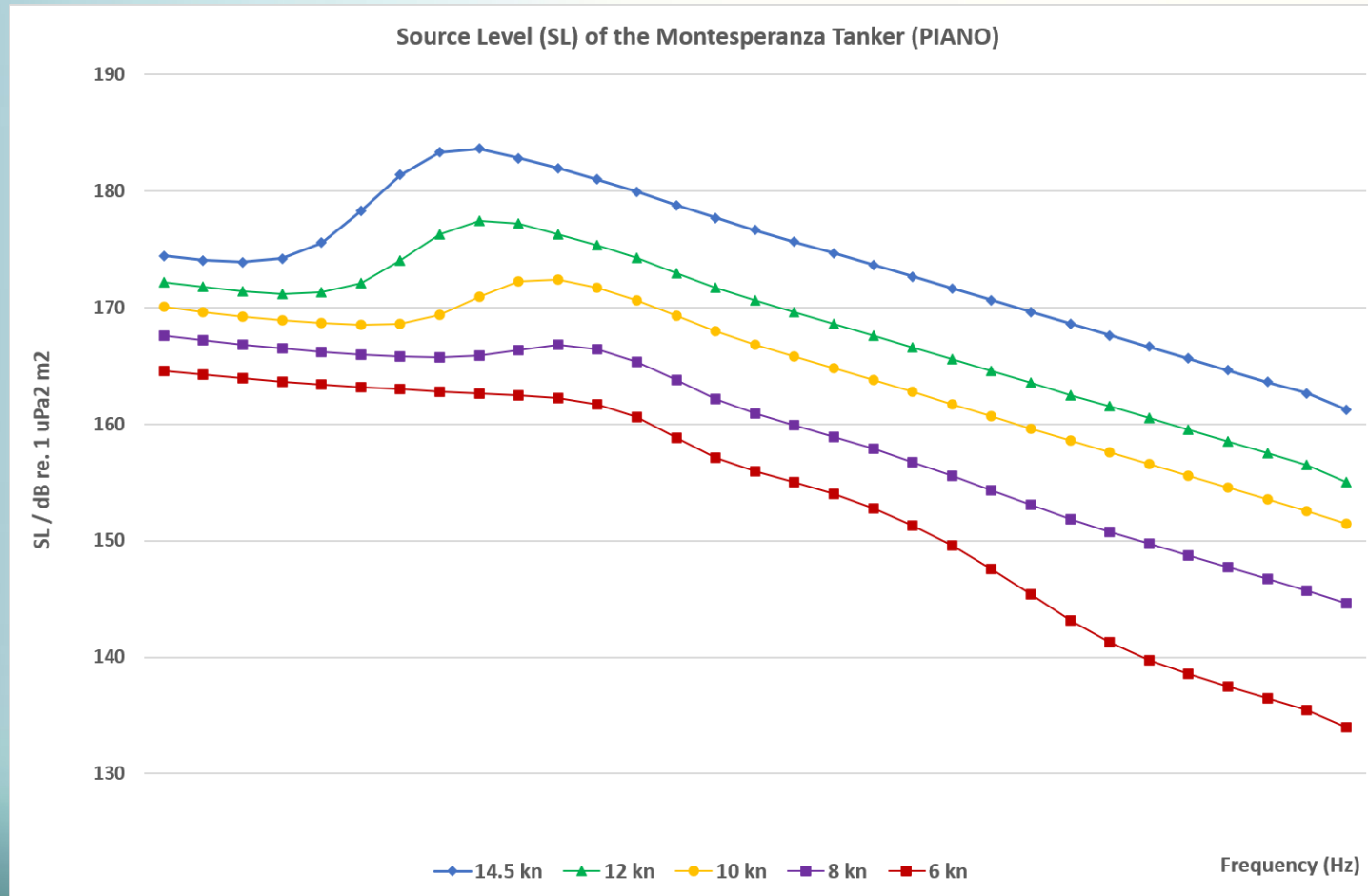


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THE CHALLENGE



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Engine mount optimisation



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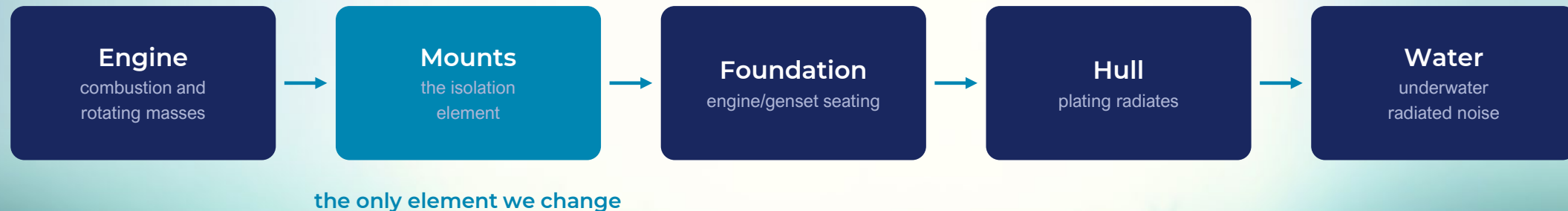
The transmission path

TAKEAWAY Slow the ship down and cavitation falls away. What is left at low frequency is machinery noise, carried into the hull through the engine mounts.

- Machinery dominates below the cavitation inception speed and whenever the propeller is lightly loaded
- Speed reduction, the standard mitigation measure, suppresses cavitation and leaves machinery as the residual source

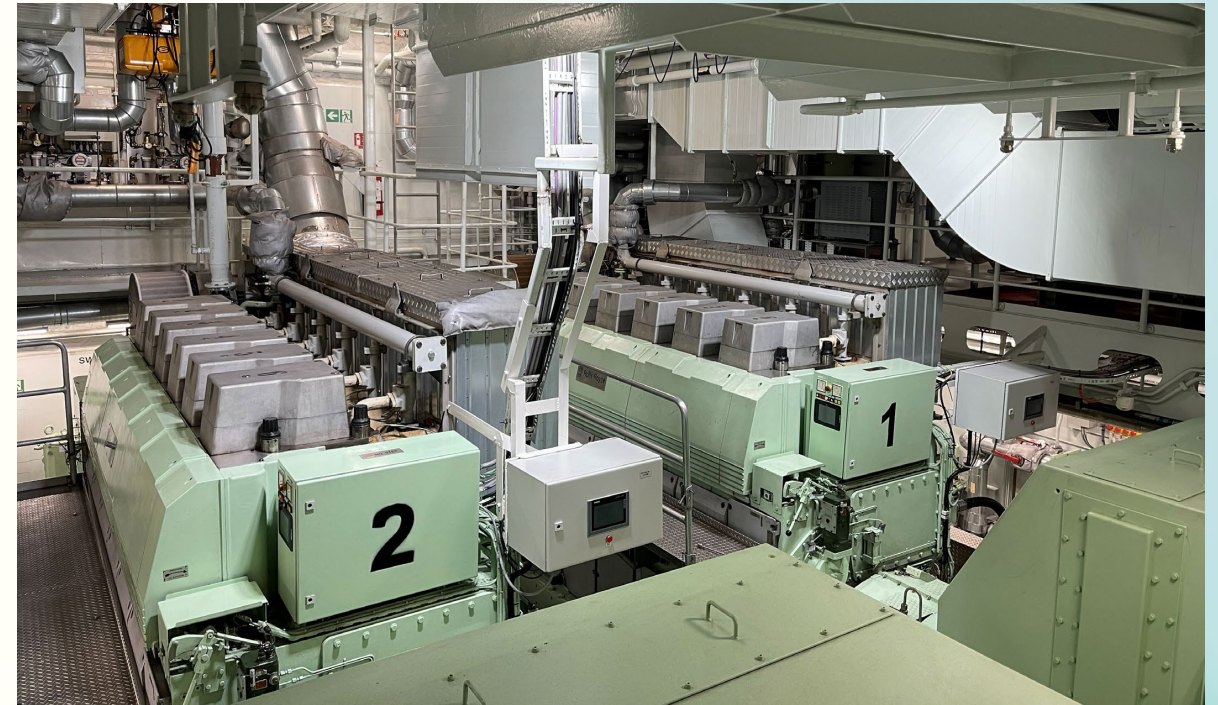
Fridtjof Nansen operates where this matters

Coastal and polar routes through noise-sensitive areas, at low speed and under manoeuvring, which is exactly the condition where the machinery contribution governs.



The demonstrator

Vessel	Fridtjof Nansen, HX Expeditions
Power plant	Hybrid diesel-electric, four gensets
Engine	Bergen B33:45L6A, in-line six-cylinder, four-stroke medium speed
Rated power	3600 kW each
Nominal speed	720 rpm
Year built	2018



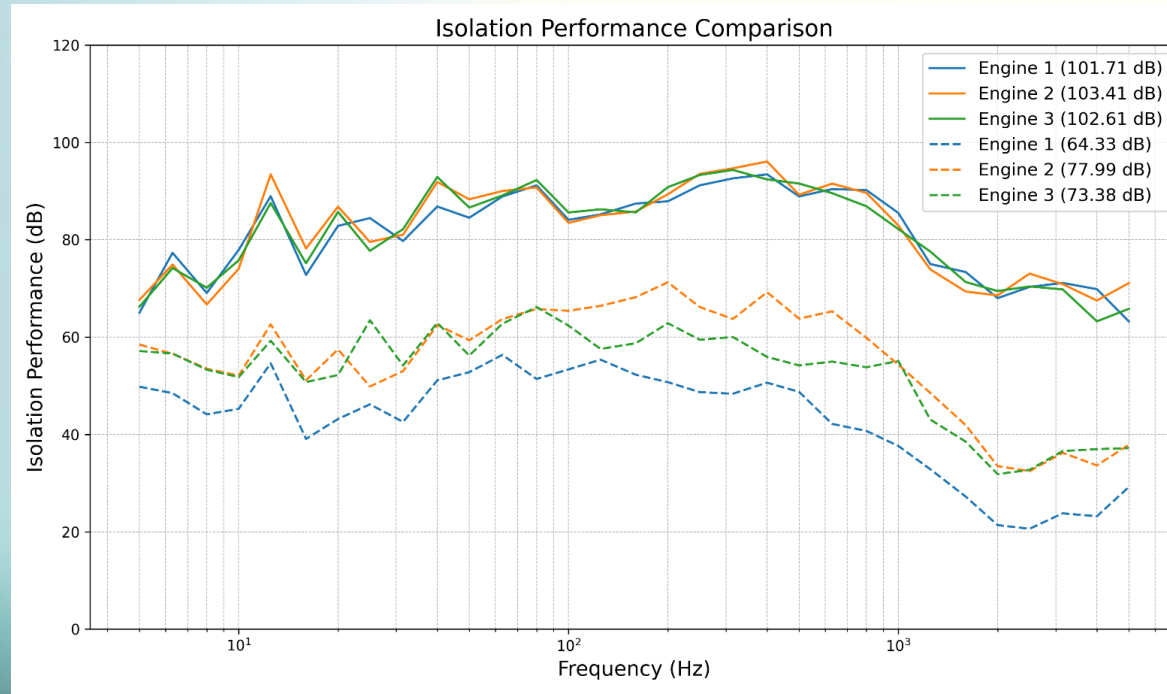
Two of the four generating sets, Fridtjof Nansen (D3.1 Figure 14)

720 rpm sets everything that follows

Rotational frequency 12 Hz. Firing frequency $(6 / 2) \times 12 = 36$ Hz, the third engine order.

Where the existing model runs out

TAKEAWAY PIANO applies one fixed mounting reduction to every vessel built after 2010. Measurements on one engine type show a 12 dB spread between mountings.



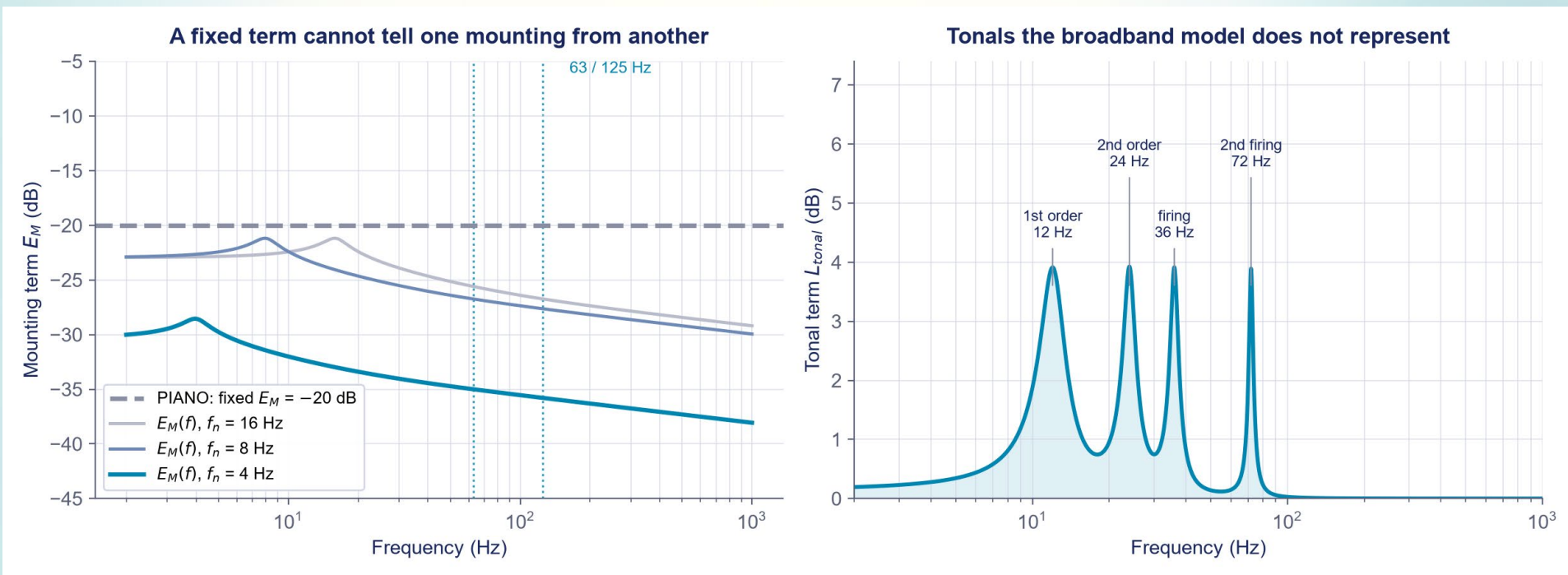
- PIANO predicts four-stroke machinery noise from installed and operating power, engine count and hull dimensions, all obtainable at fleet scale
- The mounting enters as a single term, fixed at 20 dB, independent of frequency, load and mounting design
- The engine tonals are absent: machinery is treated as broadband

The consequence

A mounting retrofit is invisible to the model. D2.4 puts the underestimation of abatement potential at 5 to 10 dB in the 63 and 125 Hz bands.

Same engine type, three mounting systems. Solid: above the mounts. Dashed: below. (D2.4 Figure 7)

What D2.4 changed



Frequency-dependent mounting term

Single degree of freedom force transmissibility. No isolation below the mount natural frequency, amplification near it, roll-off above 1.41 times it.

Additive tonal term

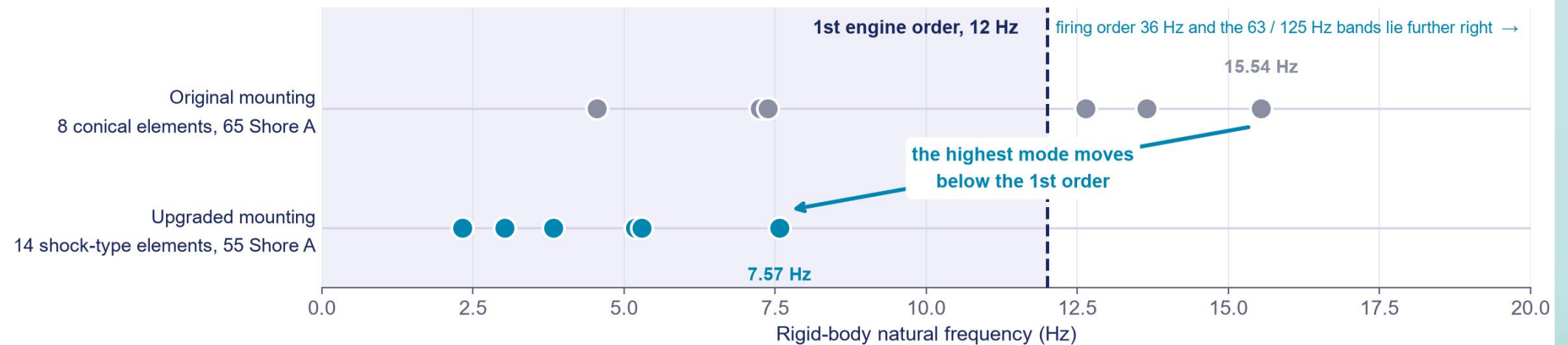
Narrow peaks at the first and second rotational orders and the first and second firing orders, width scaled to the rotational frequency.

Inputs stay obtainable

Mount natural frequency and damping ratio from the resilient mounting calculation class already requires. Speed and cylinder count from the nameplate.

The mounting upgrade

TAKEAWAY Softer elements with more rubber volume lower every rigid-body natural frequency. The highest mode drops from 15.54 Hz to 7.57 Hz.



What changed

Eight conical elements at 65 Shore A become fourteen shock-type elements at 55 Shore A: more rubber volume, more deflection, lower stiffness.

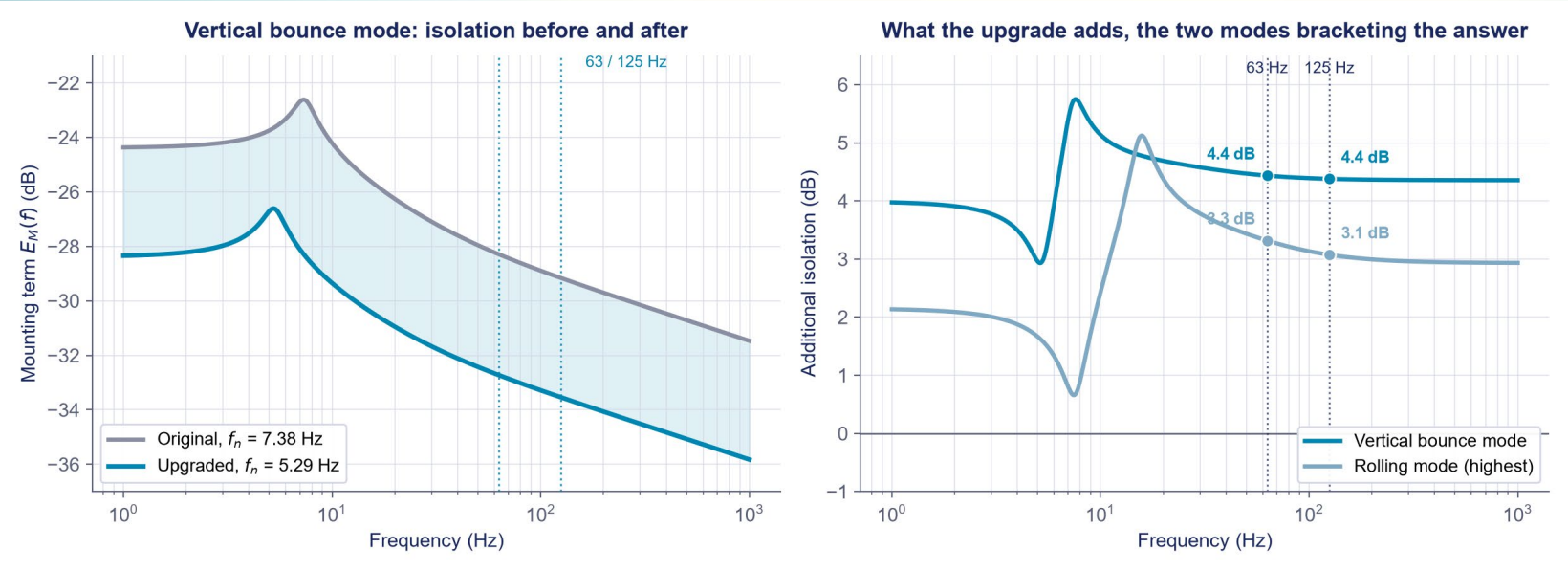
How the frequencies were found

Six degree of freedom rigid-body analysis of the generating set on its mounts, run for both configurations.

Why it matters

Every mode now sits below the 1st order, and 36, 63 and 125 Hz sit well above 1.41×7.57 Hz, firmly in the isolation region.

Predicted abatement



Additional isolation (dB)

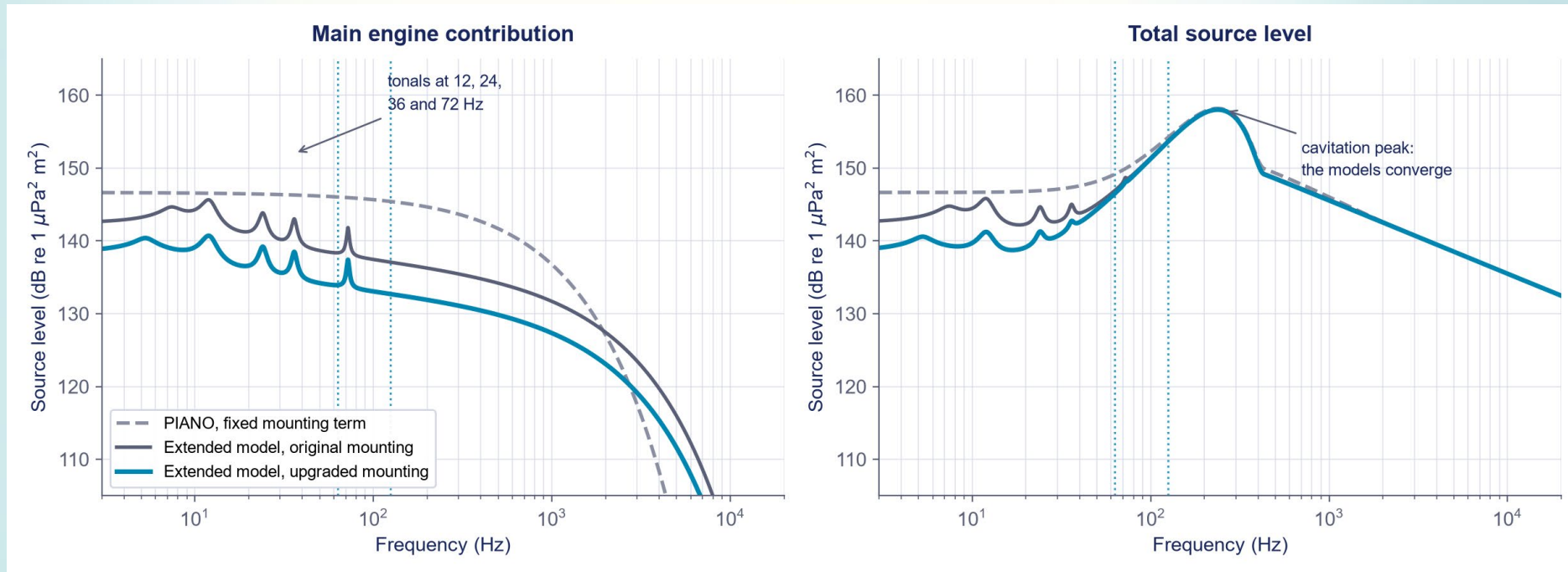
Band	Bounce	Rolling
16 Hz	4.8	5.1
31.5 Hz	4.6	3.7
36 Hz	4.5	3.6
63 Hz	4.4	3.3
125 Hz	4.4	3.1
250 Hz	4.4	3.0

Damping ratio assumed at 0.10. Only the mounting term differs between the two cases.

Roughly 3 to 4.5 dB across the regulatory bands, the two modes bracketing the answer

Below the upgraded resonances the mount cannot isolate and a small adverse effect is predicted. It sits below 8 Hz, outside the range that governs underwater radiated noise.

Effect on the total source level



Machinery contribution

Tonals appear at 12, 24, 36 and 72 Hz, and the roll-off falls away differently at high frequency than the fixed-term model.

In the total, be precise

At this operating point cavitation governs from roughly 80 Hz upward, so the 4.4 dB machinery gain shows in the total mainly at the 36 Hz firing order, around 2 dB.

Where it converts

At low speed and manoeuvring, with weak cavitation, the machinery contribution and the mounting benefit extend across a wider part of the spectrum.

How the prediction gets tested

TAKEAWAY The measurement chain is installed and running. The prediction is the left-hand end of it; the before-and-after result is what the project will report.



– The gensets already show low vibration levels and the existing mounts already isolate effectively, which sets the expectation for the upgrade

Still open
Not yet validated against full-scale URN. Damping ratio assumed rather than measured. Element count provisional. Tonal amplitudes to be calibrated from these measurements.



Three things to take away

1

A fixed mounting term hides the upgrade

Making it frequency-dependent, from inputs the classification calculation already provides, turns the mounting system into something you can evaluate before you buy it.

2

On this demonstrator, 3 to 4.5 dB

The upgrade moves every rigid-body mode below the first engine order and predicts 3 to 4.5 dB of additional isolation in the 63 and 125 Hz bands.

3

It is a prediction, not a result

The measurement chain to test it is installed and running. The before-and-after comparison is what the project will report.



Conclusions for analytical models

- **Analytical models** were applied to the four LowNoiser demonstrators that are suitable for them
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- **In most cases** models had to be developed or improved. The demonstrators were also at very different stages of maturity. In engineering practice this is very common to face limitations of the models and that the same models need to be applied at different stages of the project.
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- **The PIANO model** worked very well both as starting point but also for integrating the results from the improved/new models
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- **The technologies studied** can be applied to a range of vessel types, not just the vessels that will host the demonstrators, offering potential benefits across the world fleet.





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