



Uncertainty aware Prediction of Added Resistance using an Adapted Semi empirical Formula

Mittendorf, Malte; Nielsen, Ulrik D.; Bingham, Harry B.; Liu, Shukai

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Malte Mittendorf, Ulrik D. Nielsen, Harry B. Bingham & Shukui Liu (NTU)

Uncertainty-aware Prediction of Added Resistance using an Adapted Semi-empirical Formula

Nordic Maritime Universities Workshop 2022, Horten

Prediction of Added Resistance

➤ Second order force resulting from exposure to waves

- **Radiation**
- **Diffraction**
- Their interaction

➤ **Quadratic** transfer function $C_{AW} = \frac{R_{AW} L_{pp}}{\rho g \zeta_a^2 B^2}$

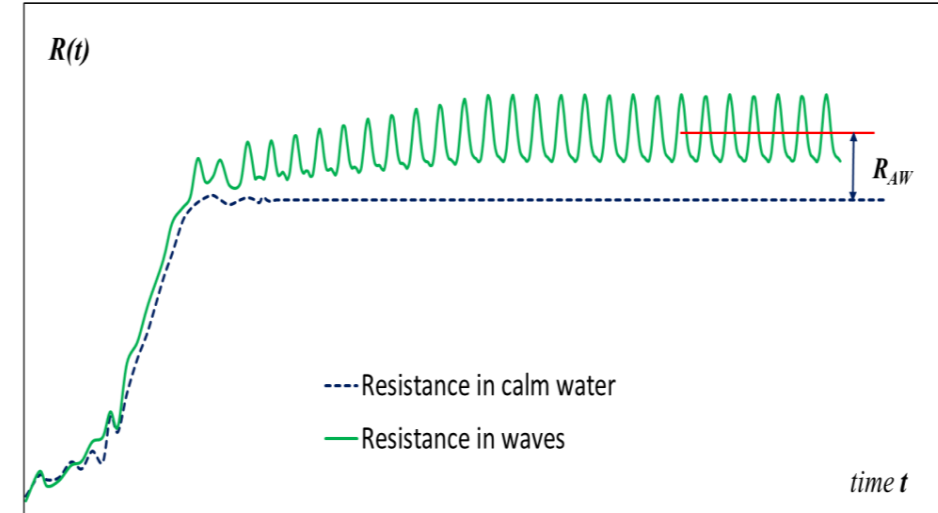
➤ Prediction by **SNNM formula**

- Proposed by Liu and Papanikolaou (2020)
- Recommended by ITTC SOS committee

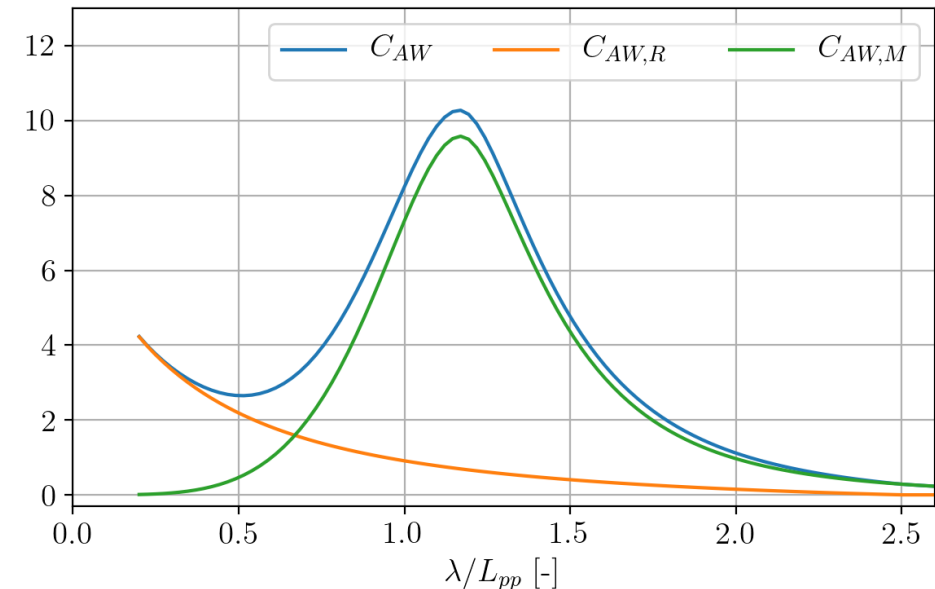
➤ Decomposition into **base** and **residual** term

$$C_{AW} = C_{AW,M} + C_{AW,R}$$

- Empirical Jinkine and Ferdinande formula
- Faltinsen's asymptotic formula



Papanikolaou and Liu (2021)



Motivation

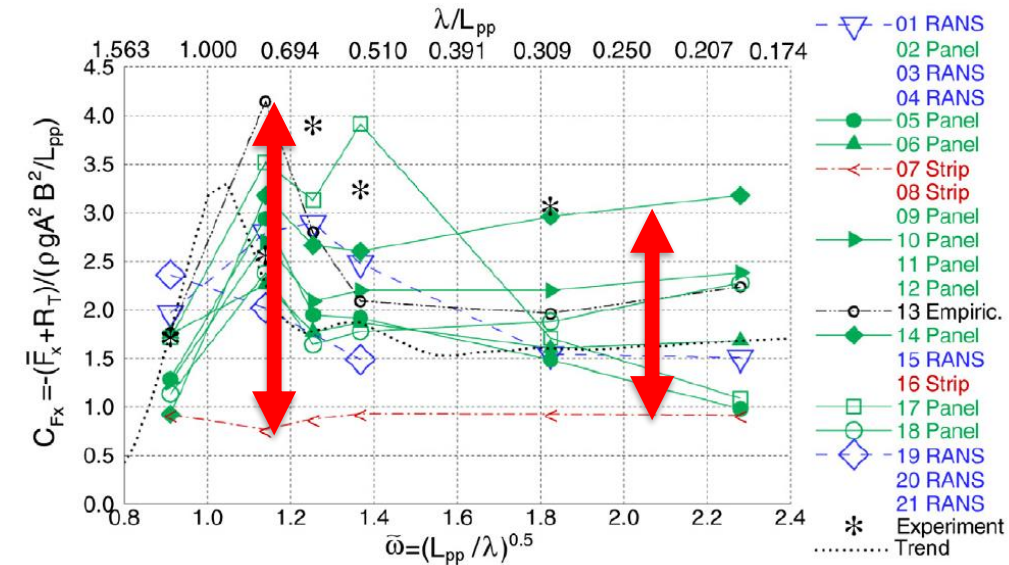
- Practical **application** cases:
 - Minimum propulsion power assessment for, e.g. EEDI (IMO 2013)
 - In-service ship performance analysis (ISO 19030)
 - Sea trial corrections (ISO 15016)

- **SHOPERA** benchmark study: Uncertainty in numerical and experimental data

- Large **uncertainty** around resonance and in short waves

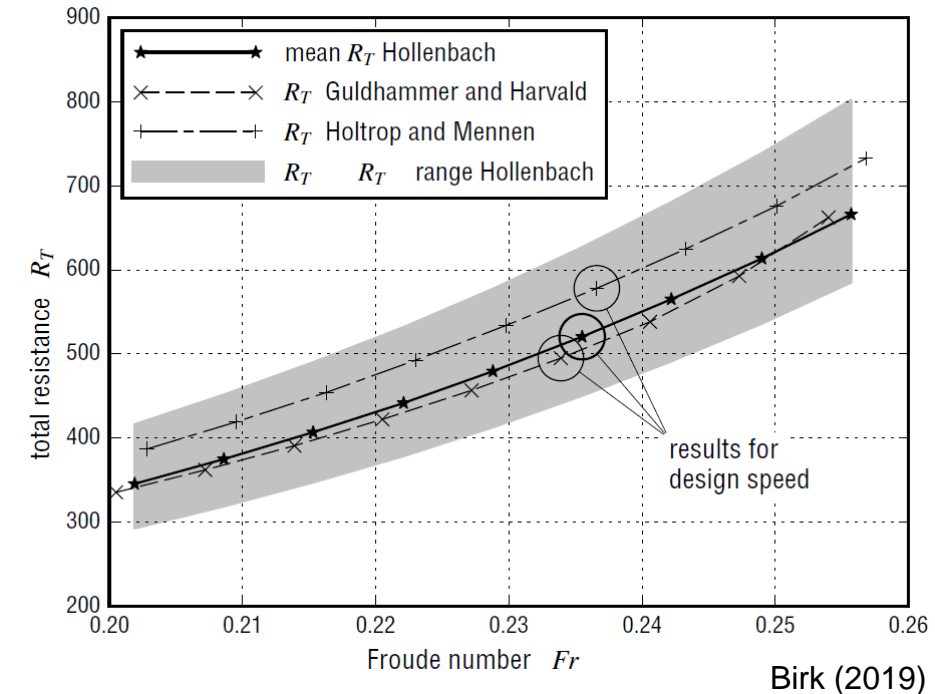
- Inspiration from Hollenbach's method for calm water resistance

- **Deterministic** approach for uncertainty quantification



KVLCC2 (6 knots in head waves)

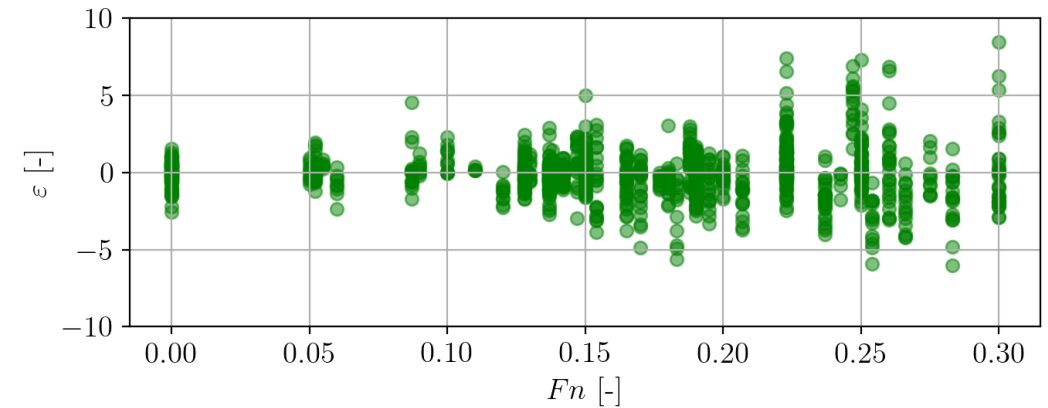
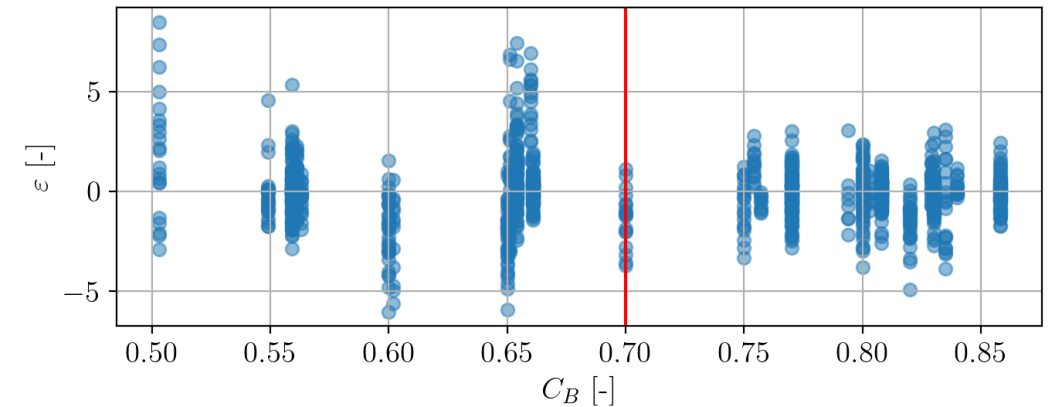
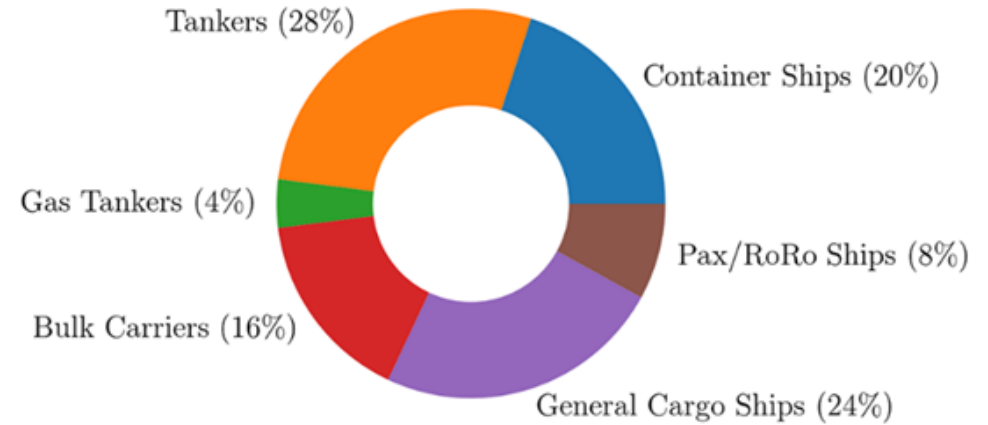
Shigunov et al. (2018)



Birk (2019)

Residual Analysis

- Publicly available **experimental** data
- Database of 25 ships including ca. **1100 samples**
- **Residual analysis** of original SNNM formula
- **Splitting** for slender and blunt-type ships
- **Variance increase** with advance speed (F_n)



Uncertainty Categories

➤ Epistemic uncertainty

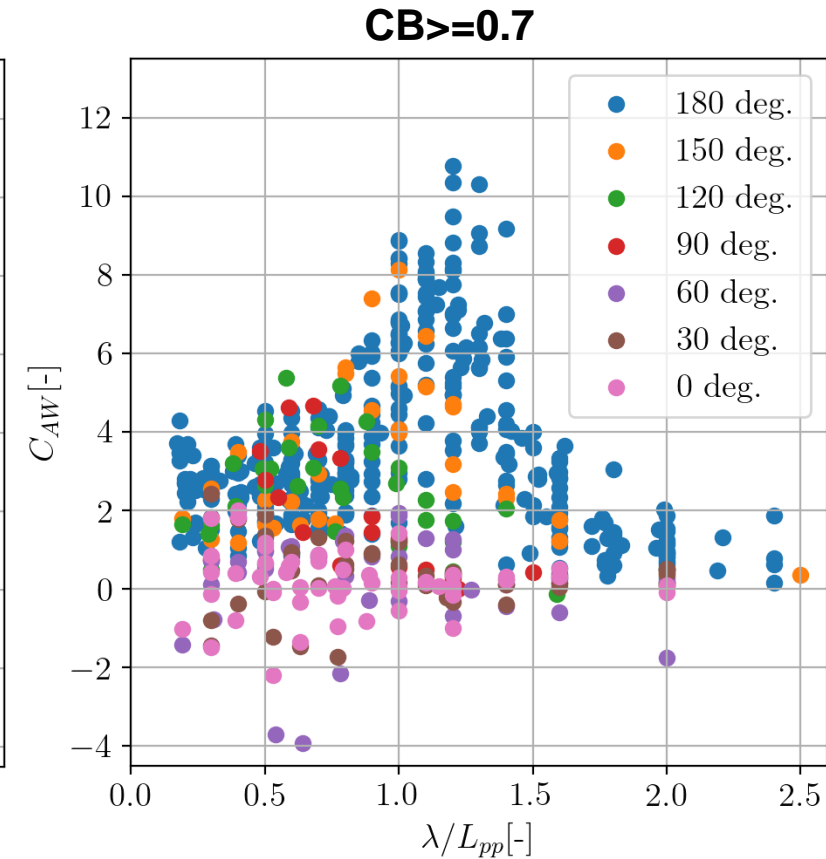
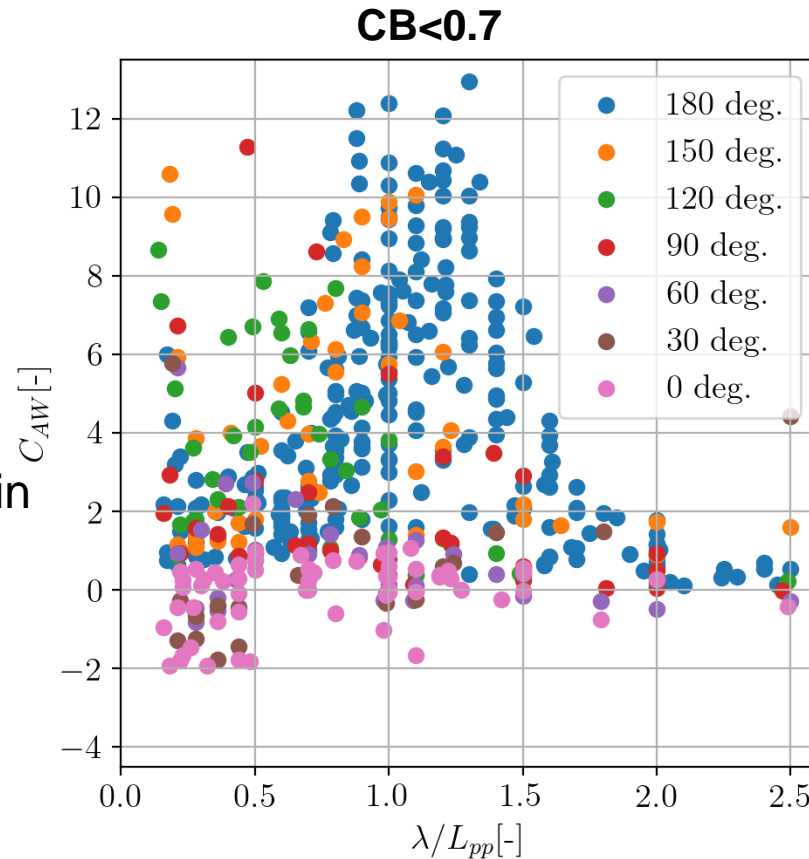
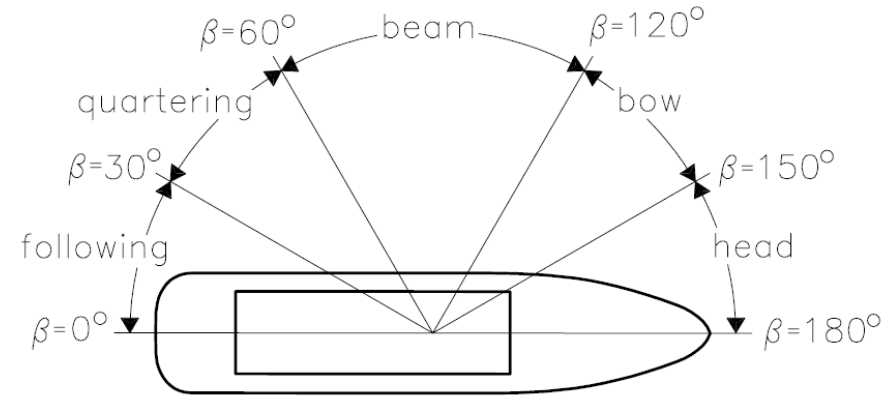
- Unbalanced data (short & oblique waves)
- No information about wave **amplitude & steepness**

➤ Aleatoric uncertainty

- Variance due to experimental noise and data aggregation

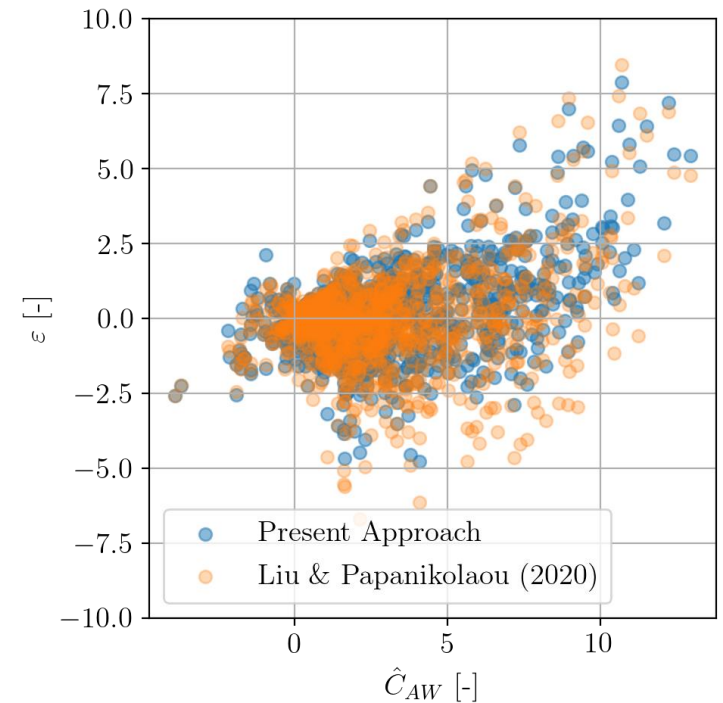
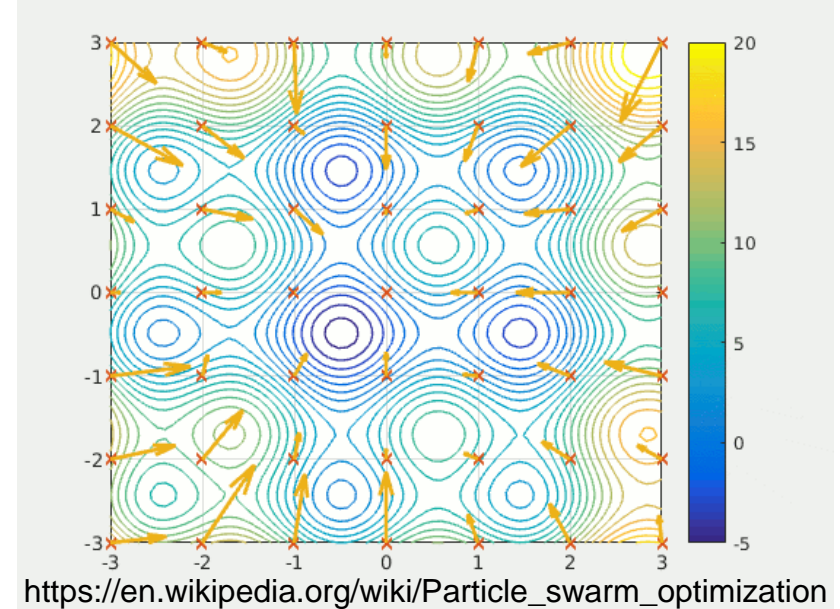
➤ Pronounced **non-linear** behaviour in case of slender ships

- Large flare angles
- Wave breaking



Calibration using Particle Swarm Optimization

- **Metaheuristic** PSO optimization algorithm
 - PSO mimics the behavior of **fish swarms**
 - Randomized and **population-based** (gradient-free)
- **Minimization** of epistemic uncertainty using squared loss
- Derivation of two **separate**, updated parameter vectors
- 30 parameters, i.e. **high-dimensional** search space
- Increase in accuracy of $\sim 8\%$ according to R^2
- **Bias correction** for higher added resistance values

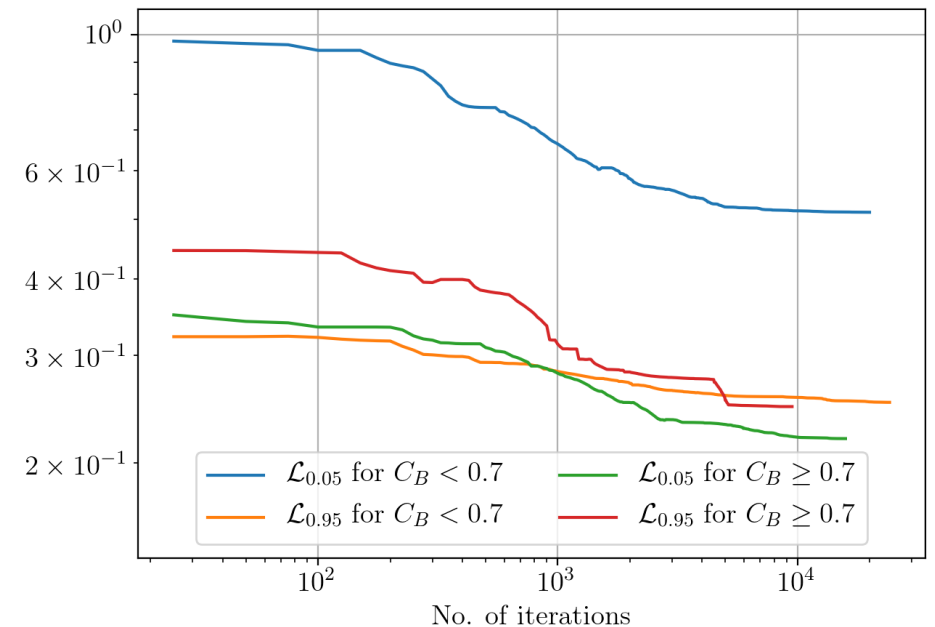
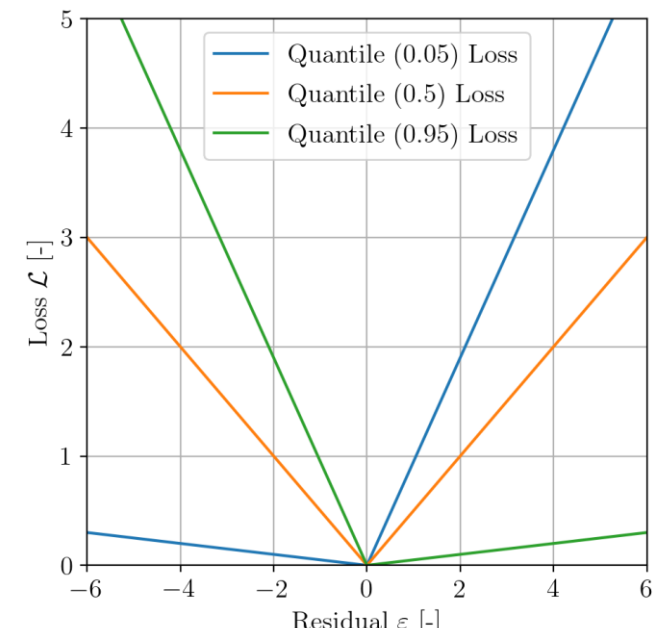


Quantile Regression

- Quantile regression is an **extension** of linear regression

$$\mathcal{L}_\gamma(y, \hat{y}) = \begin{cases} (\gamma - 1)(y_i - \hat{y}_i) & \text{for } y_i < \hat{y}_i \\ \gamma(y_i - \hat{y}_i) & \text{otherwise} \end{cases} \quad \text{where the quantile is } \gamma \in [0, 1]$$

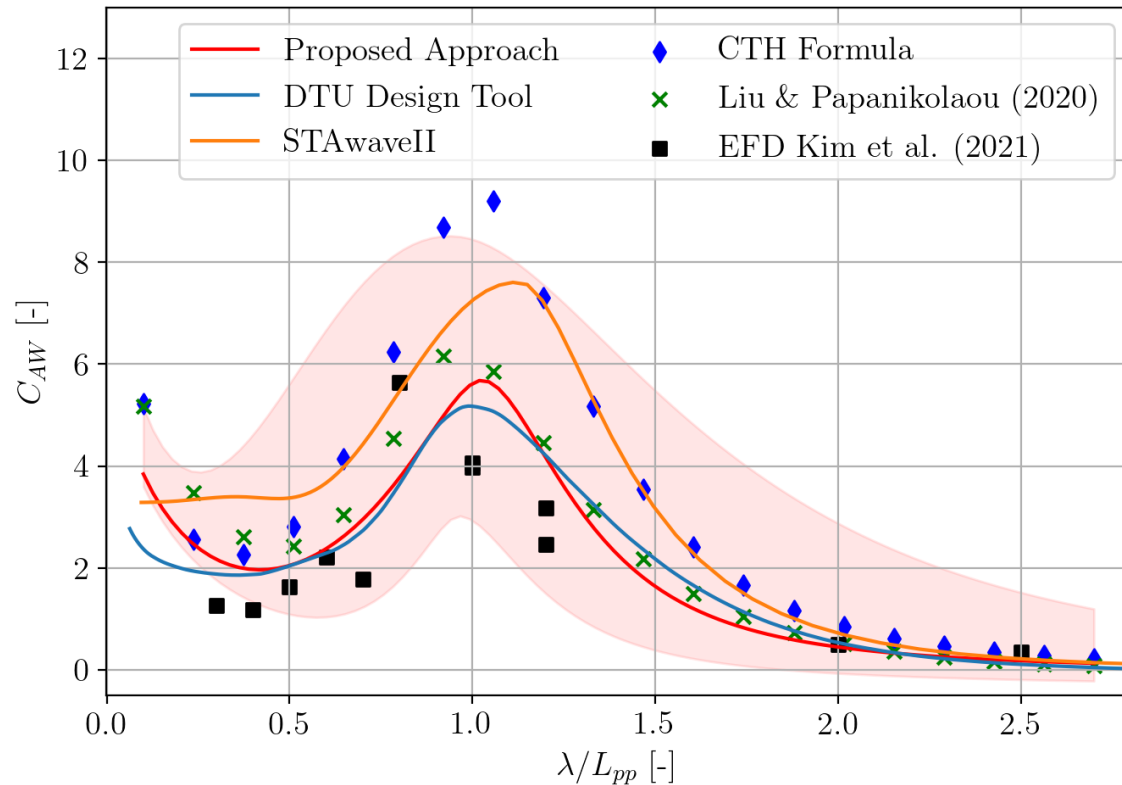
- Determination of **conditional quantiles** of dependent variable
- Visualizing **aleatoric** uncertainty by 90% **prediction interval**
- Derivation of four **additional** parameter vectors
- **Parameter constraints** vital for sufficient results
- Different error magnitudes and **convergence behaviors**



Validation

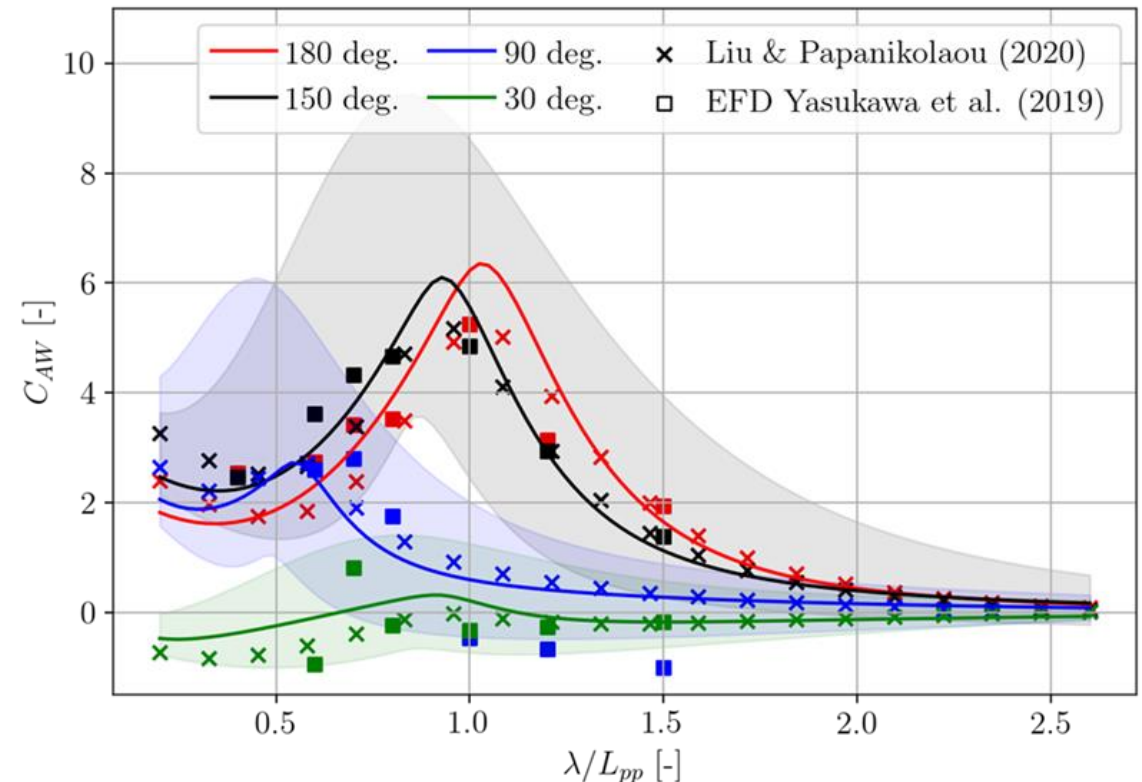
➤ LNG carrier (CB = 0.79)

- $Fn = 0.19$
- $\beta = 150\text{deg.}$



➤ Bulk carrier (CB = 0.84)

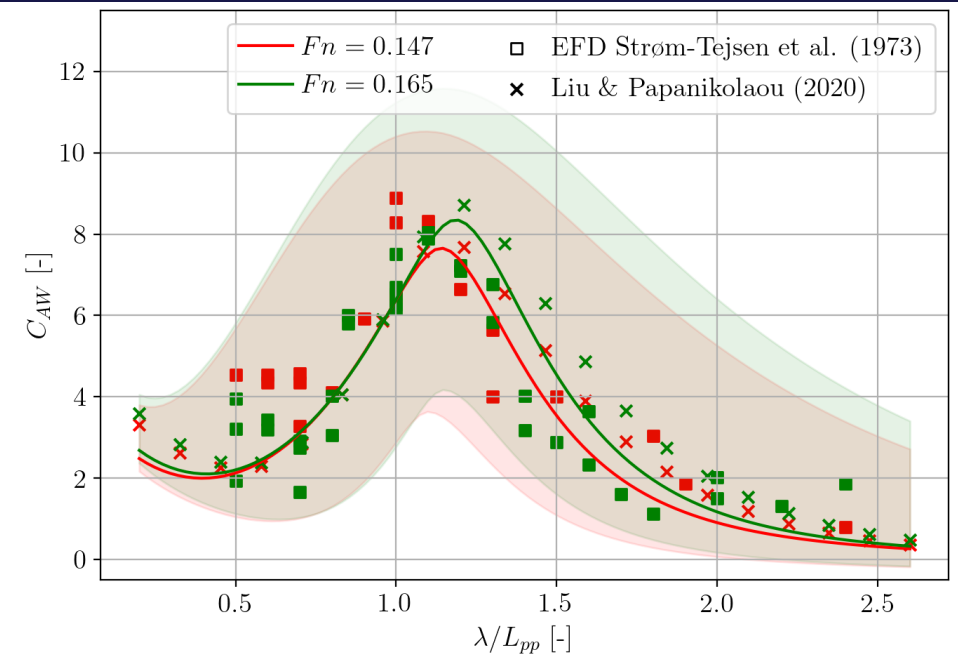
- $Fn = 0.1$
- Out-of-sample data



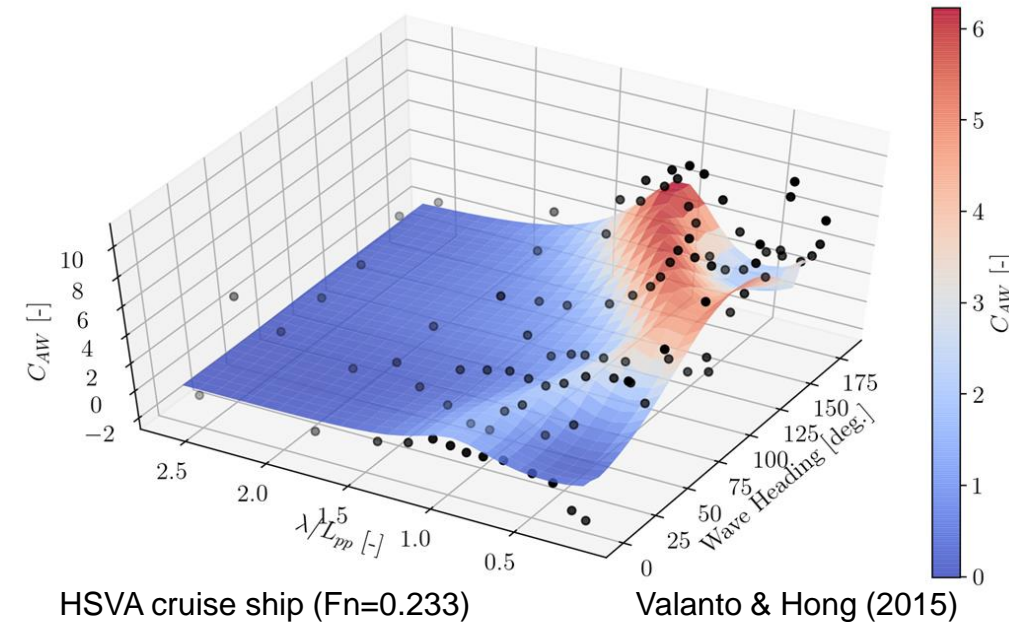
Summary and Future Work

- Significant increase in accuracy and **transparency**
- Visualization of aleatoric uncertainty by **prediction intervals**
- Good **agreement** with model test data

- Further development, e.g. wave **steepness** correction
- Application to irregular and **short-crested waves**
- **"Method-agnostic"** methodology



Series 60 (CB=0.8) in head waves from Ström-Tejsen et al. (1973)



Many Thanks for your Attention!

DTU



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