BETTER SHIPS, BLUE OCEANS

Towards high Reynolds performance models

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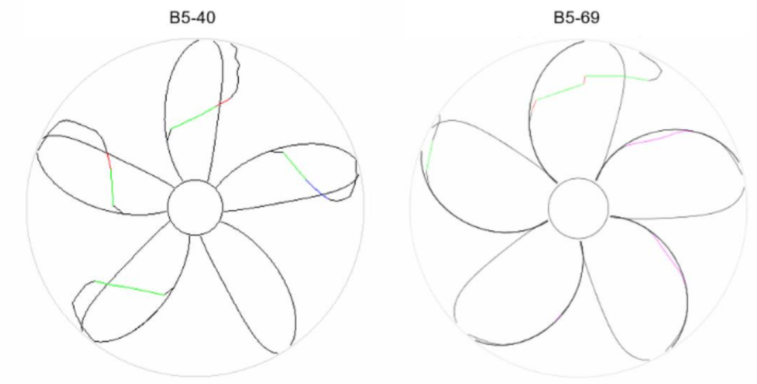
BACKGROUND

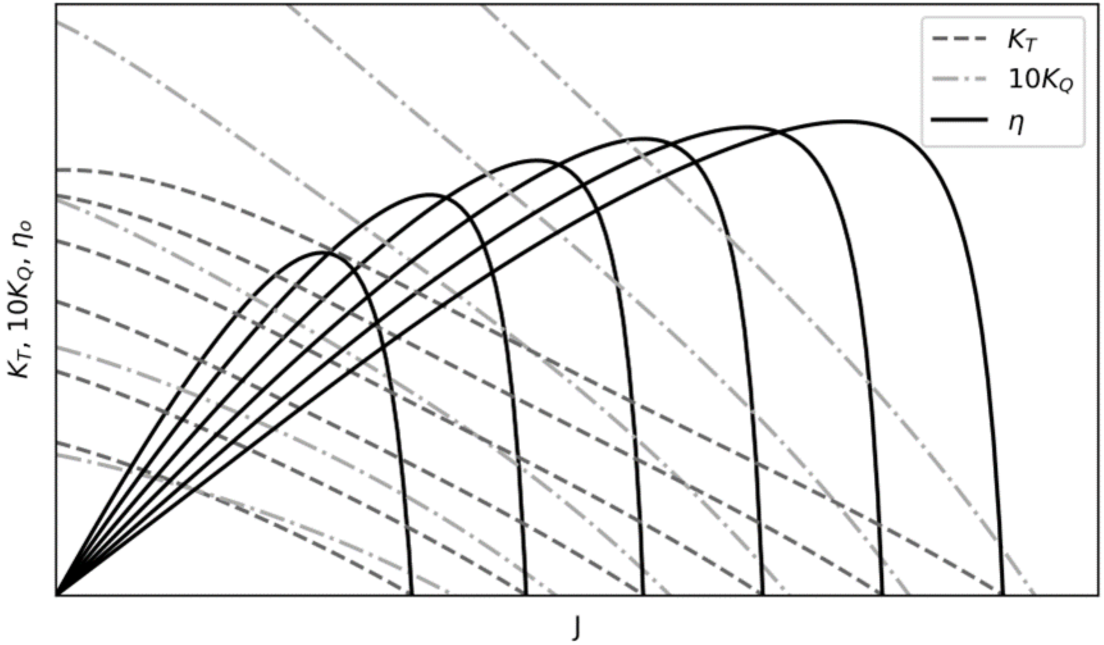
- Propeller series
  - K_T, K_Q, η_O as a function of Z, PD, BAR, J
  - Select propeller in preliminary design
    - Optimal rotation rate for given diameter
    - Optimal diameter for given rotation rate
  - BAR and Z usually pre-selected



K_T	Thrust coefficient
K_Q	Torque coefficient
η_O	Open water efficiency

Z	Number of blades
PD	Pitch ratio
BAR	Blade area ratio
J	Advance ratio

BACKGROUND



$$K_T = \frac{T}{\rho n^2 D^4}$$

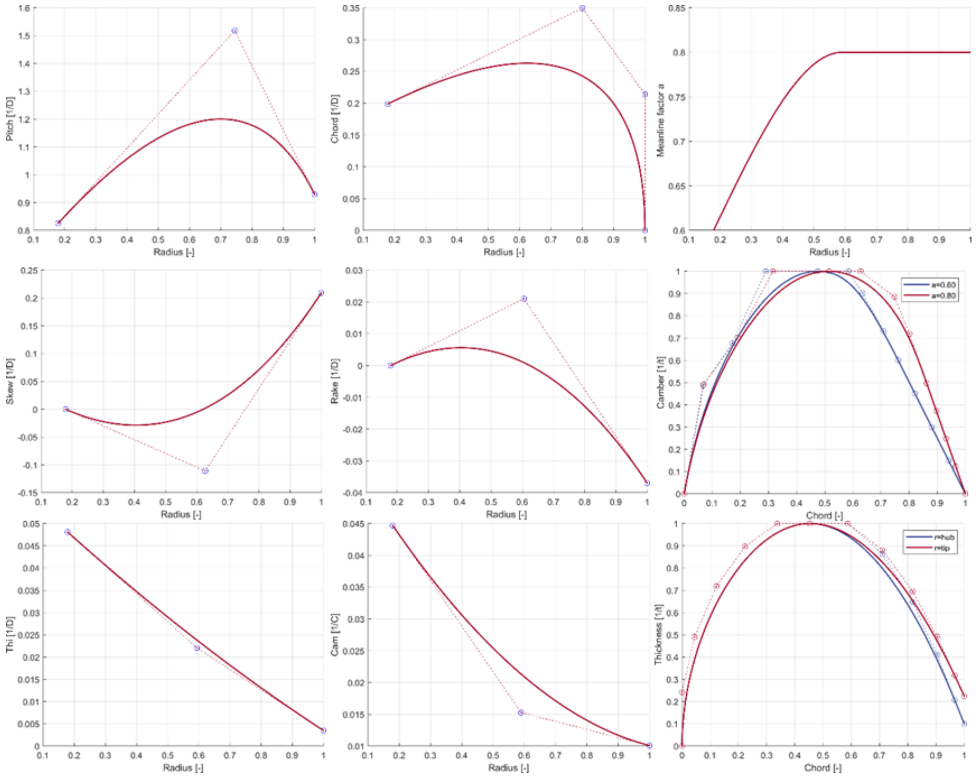
$$K_Q = \frac{Q}{\rho n^2 D^5}$$

$$\eta_o = \frac{J}{2\pi} \frac{K_T}{K_Q}$$

$$J = \frac{V}{nD}$$

*Propeller series, performance as f(Z, BAR, **PD**, **J**)*

BACKGROUND



Propeller series, geometry as f(Z, BAR, PD)

BACKGROUND

- Summary propeller series MARIN:
  - 1937-1969: B-Series
    - Fixed pitch, non-ducted
    - Tested at various Re, faired and corrected for Re
  - 2018: C-series
    - Controllable pitch series
    - First CFD studies on transition modelling
  - 2023: F/Fc-series
    - Modern alternative to B-series
    - CFD analysis
    - Improved paint tests
  - **2024: Tripping JIP**
    - Boundary layer tripping
    - Experiments + CFD at different Reynolds numbers

BACKGROUND

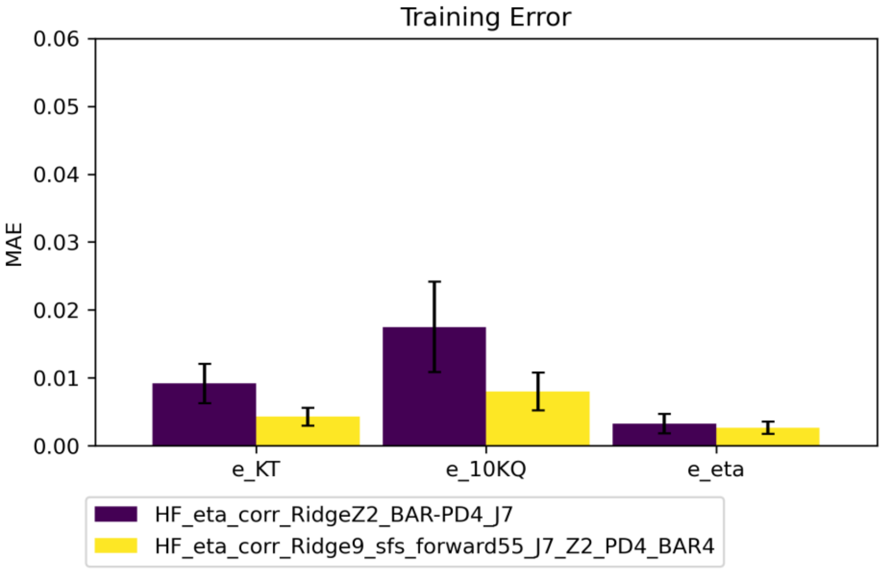
- F-series (150 propellers):
  - Standard series of fixed pitch propellers
  - Optimised for seven selected ship types
  - Tested in open water using QSO

- Fc-series (24 propellers):
  - Different blade design
  - Focus on higher demand for comfort levels, e.g. cruise vessels and yachts
  - Subset of F-series for Z, PD, BAR

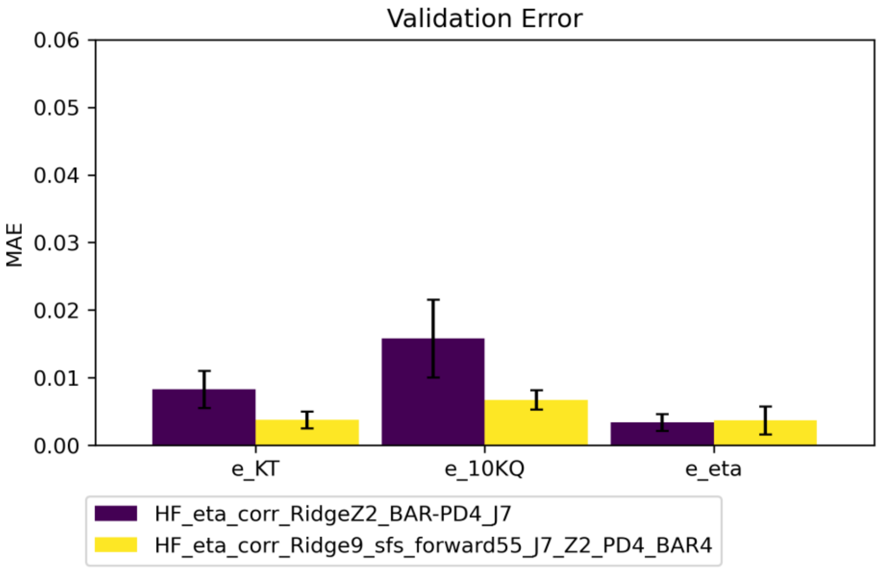
	F	Fc
Z	5 (3,4,5,6,7)	3 (4,5,6)
PD	6 (0.6-1.6)	5 (0.8-1.6)
BAR	25 (5 per Z)	9 (3 per Z)
J	~2000 per prop	~2000 per prop

- Summary Fc-series fit
  - Limited number of data points
  - Evaluation by cross-validation approach
    - Comparison different (polynomial) models
    - Model selection

FC-SERIES FIT



Fc-series fit



Fc-series fit

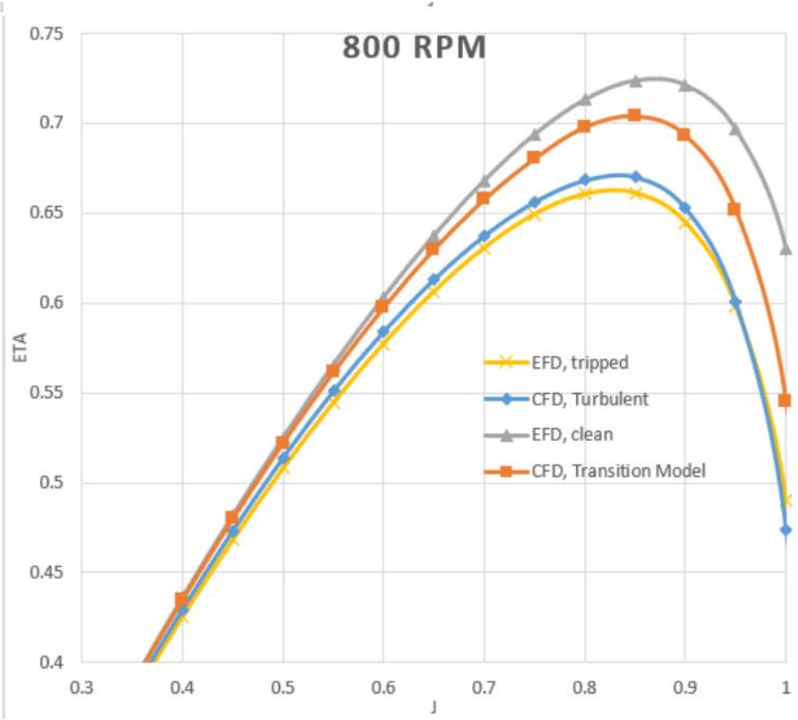
MARIN

- Main ideas:
  - Experiments with boundary layer tripping (turbulators)
  - CFD with turbulence models (without transition models)
    - More similar Reynolds number regimes
    - More consistent propulsion coefficients
  - CFD at full scale for scale and roughness effect corrections
  - Exploration of best modelling approach
  - Individual propeller fits

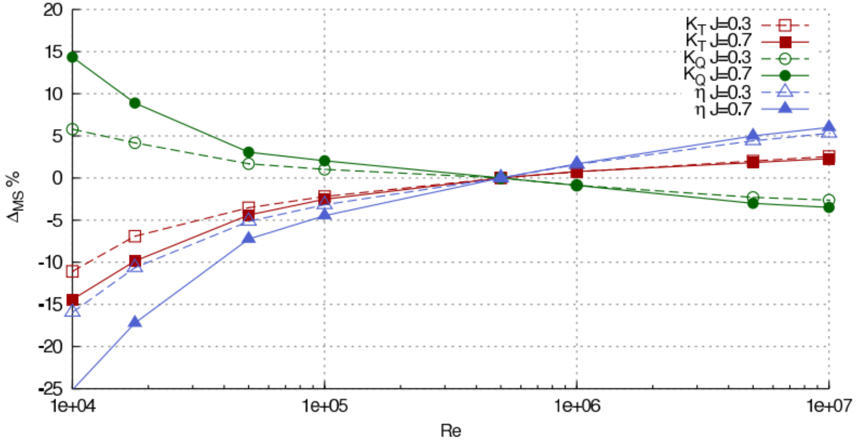
    -> Propeller series fits

      -> Generic correction fits for concept design

TRIPPING JIP



Efficiency at different Reynolds number regimes



CFD propeller performance at different Re

- Experiments
  - Multiple model-scale Re
    - In-behind (η_r)
    - Open water efficiency (η_o)
  - Hydrodynamically smooth
- CFD simulations
  - Model-scale and full-scale Re
  - Hydrodynamically smooth and rough
    - Equivalent sand roughness (k_s) at full scale Re

TRIPPING JIP

- Propeller series
  - KT, KQ = f(J, Z, BAR, PD)
  - Model-scale evaluations
    - Experiments
    - No boundary layer tripping

- Tripping JIP
  - **Δ**KT, **Δ**KQ = f(J, Z, BAR, PD, **Re, $\mathbf{k_s}$**)
  - Model-scale evaluations
    - Experiments and CFD
    - With boundary layer tripping
  - Full scale evaluations
    - CFD

- Fitting use cases:
  1. Model tests at different (model-scale) Reynolds numbers
     - Relative rotative efficiency (in-behind Re)
     - Open water efficiency (highest Re)

- Fitting use cases:
  1. Model tests at different (model-scale) Reynolds numbers
  2. Correlation between experiments and CFD
     - Experiments and simulations at same Re

- Fitting use cases:
  1. Model tests at different (model-scale) Reynolds numbers
  2. Correlation between experiments and CFD
  3. Scale effects
     - CFD simulation at different Re

- Fitting use cases:
  1. Model tests at different (model-scale) Reynolds numbers
  2. Correlation between experiments and CFD
  3. Scale effects
  4. Roughness effects
     - Full scale CFD with different k_s

- Fitting use cases:
  1. Model tests at different (model-scale) Reynolds numbers
  2. Correlation between experiments and CFD
  3. Scale effects
  4. Roughness effects
  5. Full-scale polynomials
     - Including Re and k_s effects

- Open questions:
  - How to construct full scale propeller performance models?
  - How to go from individual propeller fits to generic corrections?
  - Which models and fitting approaches to use?
  - How to evaluate models (validation)?
- Collaborative research MARIN and JIP partners
  - Share knowledge
  - Open discussion on results
  - Incorporate feedback

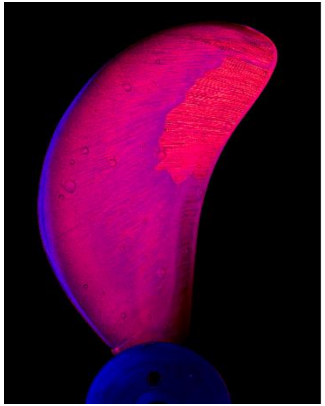
TRIPPING JIP

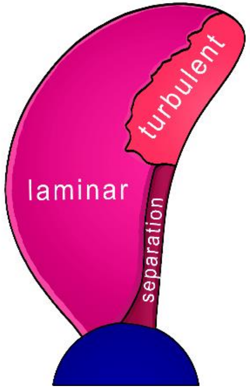
MARIN

Problem

Boundary layer flow transition and flow separation occurs at model scale conditions

This complicates the extrapolation process to full-scale propeller performance prediction



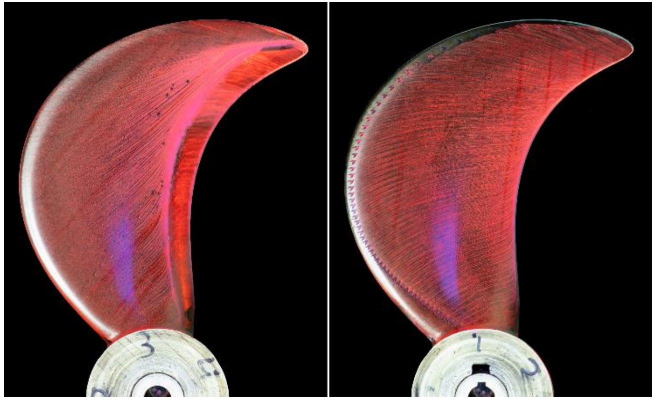


Solution

Boundary layer control

Towards flow similarity, i.e. a turbulent boundary layer at model scale

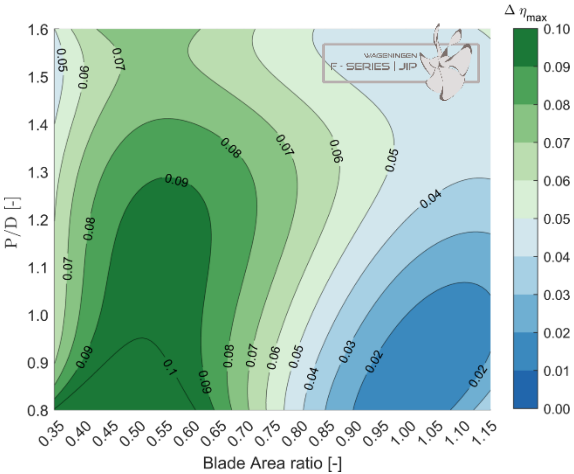
Applying turbulators to efficiently trip the laminar boundary to a turbulent one



Impact

Effect on performance without boundary layer control is highly dependent on propeller design and operation condition

Computational Fluid Dynamics (CFD) should assist towards improved extrapolation procedures



Improve propeller performance prediction

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Schuiling, Kerkvliet & Rijpkema, *An Experimental Study on Flow Visualisation and Passive Control of Model Propeller Boundary Layers*, SMP‘24, Berlin, Germany, 2024

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Wageningen F-Series Propellers
MARIN DEEPWATERBASIN