A Framework for Energy Saving Device (ESD) Decision Making

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Presented by

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2. Propulsion improvement
3. Practical application of ESDs
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Background

- Fuel cost likely to increase further
- Emission regulations (EEDI) underway
- Operators challenged to improve ship propulsion
- Increasing concern also on underwater noise on marine life (!)

MARIN

Background

- *Structural failure*.
  [improved FEM]
- *Lack of accuracy in full-scale measuring capability*.
  [full scale monitoring]
- *Lack of transparency of the savings in actual operational conditions*.
  [new op’s profile based approach]
- *Limited insight into the detailed working principles of the devices* and therefore a lack of ship-specific design capability.
  [CFD]
- *Lack of ownership accountability.*
  [EEDI]

Approach

Below a typical approach is suggested for the selection and verification of ESD options:

- Select retrofit using data indicated by the owner/supplier;
- Optimize by ap
- Model test to v
- Trial to confirm

the type and details of the hull form

the variations in draft/trim

the ship speed(s),

the relevant operational circumstances

Approach

- Optimize by applying CFD & check viability;
- Model test to validate;
- Trial to confirm.

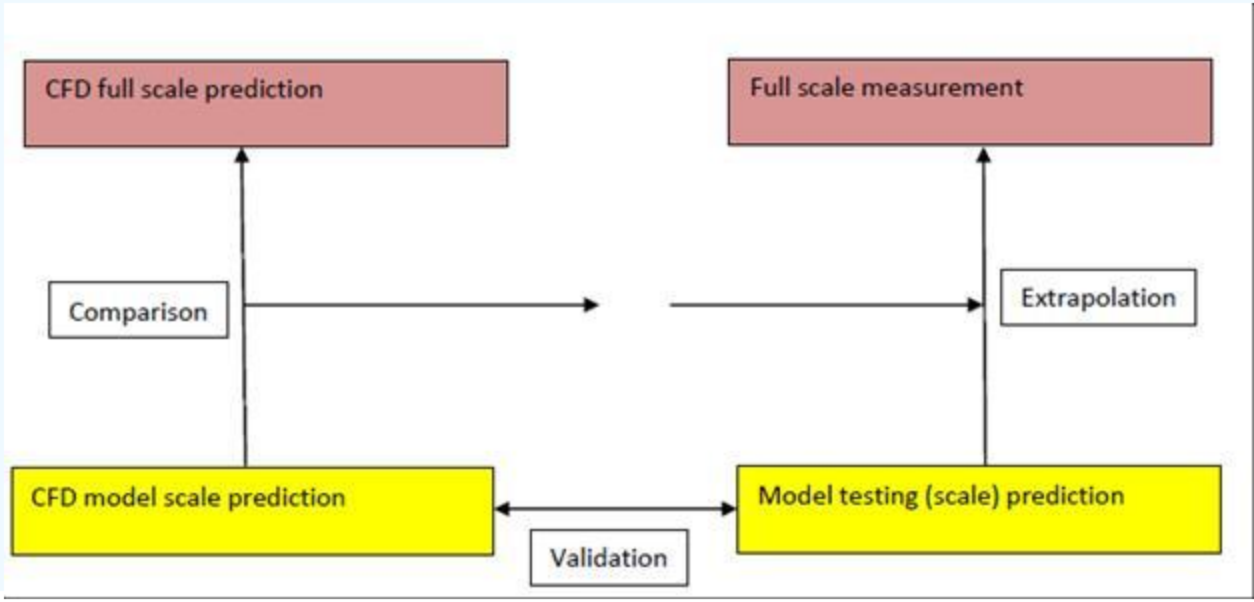
Getting confidence in the proposed ESD as a real energy saver.

Tuning the design of the ESD for the particular ship and its operation

Preparing for the interpretation of the efficiency gain predictions derived from model tests

Approach

- Select retrofit using data indicated by the owner/supplier;
- Optimize by applying CFD & check viability;
- Model test to validate (incl. CFD);
- Trial to confirm.



Approach

- Select retrofit using data indicated by the owner/supplier;
- Optimize by applying CFD & check viability;
- Model test to validate (incl. CFD);
- Trial to confirm.

MARIN has energy saving high on its agenda and currently runs a Joint Industry Projects (20 partners) called Refit2Save investigating:

- Meewis duct
- Rudder mounted post –swirl stator
- Ducted propeller
- Hull vane

- Majority of the ESDs improve the flow in front or behind the propulsor
- Energy saving and flow improvement (cavitation noise)
- Look at the overall efficiency

$$\frac{P_E}{P_D} = \eta_D = \frac{J}{2\pi}\frac{K_{To}}{K_{Qo}} \; \frac{K_{Qo}}{K_Q}\frac{K_T}{K_{To}} \; \frac{1-t}{1-w}$$

$$(\eta_{Po}) \qquad (\eta_R) \qquad (\eta_H)$$

(Hull resistance)

Propulsor-hull interaction

- Majority of the ESD's improve the flow in front of behind the propulsor
- Energy saving vs. flow improvement (cavitation, noise)
- Look at the overall efficiency

$$\frac{P_E}{P_D} = \eta_D = \underbrace{\frac{J\ K_{To}}{2\pi K_{Qo}}}_{(\eta_{Po})} \ \underbrace{\frac{K_{Qo}\ K_T}{K_Q\ K_{To}}}_{(\eta_R)} \ \underbrace{\frac{1-t}{1-w}}_{(\eta_H)}$$

(η_{Po}): Axial losses, Rotation losses, Viscous losses (friction), Non-uniformity (blades etc)

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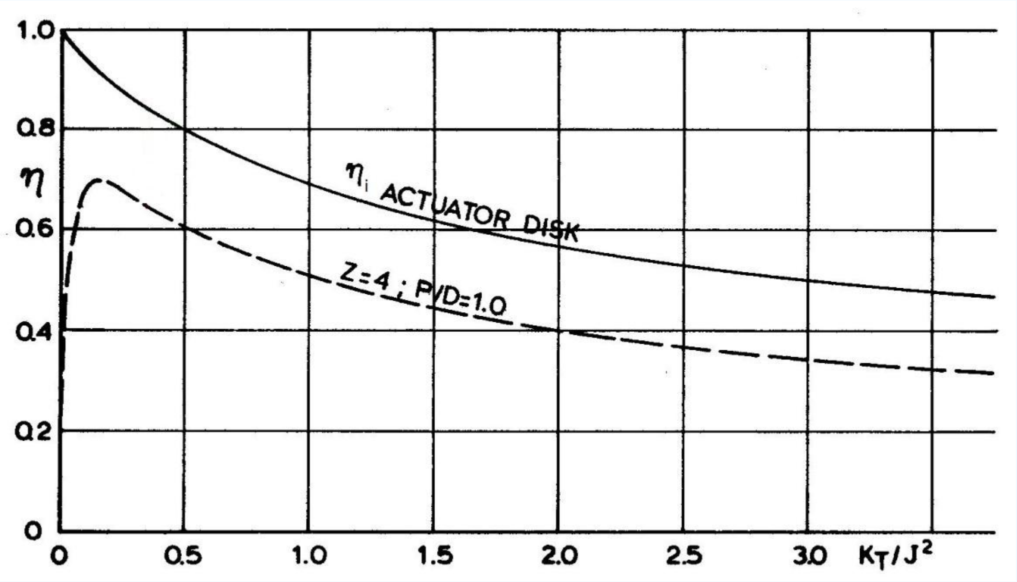
Wake adaptation

Hub shape

- Objective of ESD is to improve:
  - Propulsor efficiency or
  - Propulsor – hull interaction or
  - both

Propulsor efficiency

- From basic axial actuator disc theory follows an ‘ideal’ propulsor efficiency.
- Good propulsor designs are within a range of that ideal efficiency.
- Difference accounts various energy losses.
- Highest efficiency found for low thrust loading (CT = KT/J2)

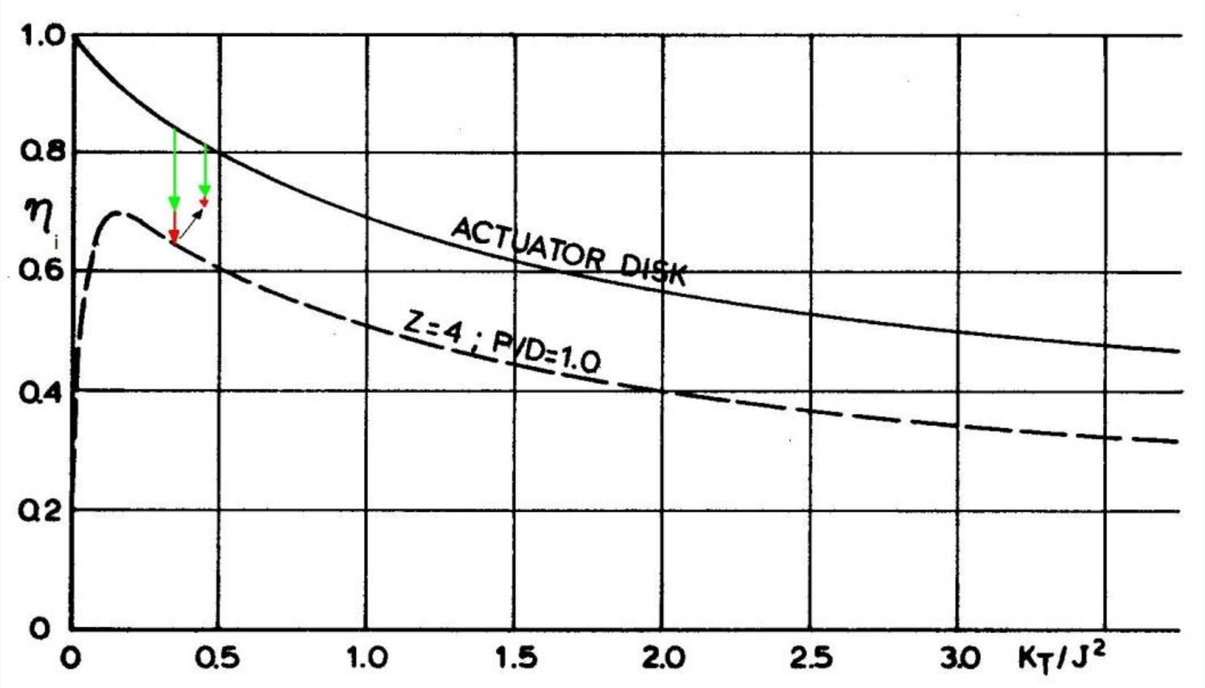


Propulsor efficiency

- Swirl generating devices
  - Recover rotational energy losses by producing swirl velocity in opposite direction.
  - Design result should be minimisation of rotational energy losses aft of the system.
  - Rotational energy can be ‘locked-up’ in the propulsion system.

- Focus can be shifted in optimisation to minimisation of frictional energy losses.
- Optimum diameter decreases

Propulsor efficiency



Rotational and viscous losses respectivey indicated by red and green arrows

ESD examples

- Swirl generating devices
  - Contra-rotating propeller
  - Pre-swirl stators
  - Post-swirl stators
  - Grim’s vane wheel
- Propeller hub devices
  - Rudder bulbs
  - Propeller boss cap fin (PBCF)
- Nozzles
  - Propeller nozzles
  - Pre-nozzles (WEDs)

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DSME Pre-swirl stator

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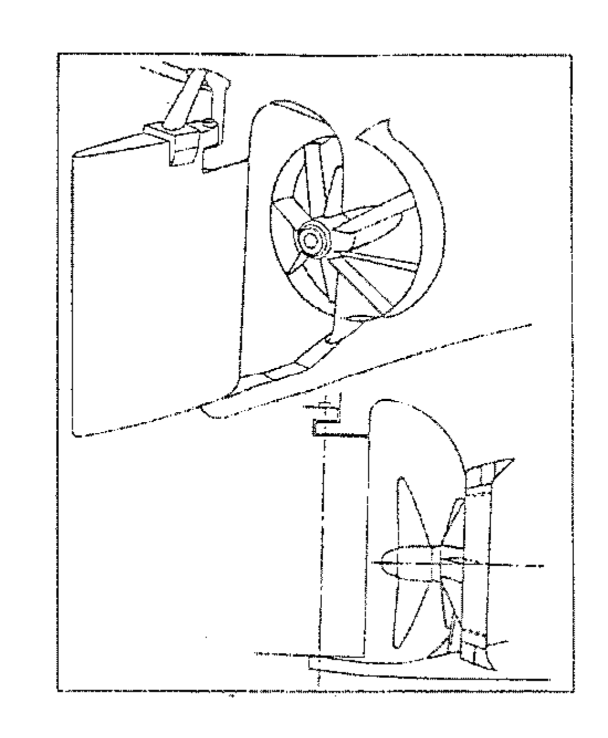

Mitsubishi HI

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Nautican nozzle

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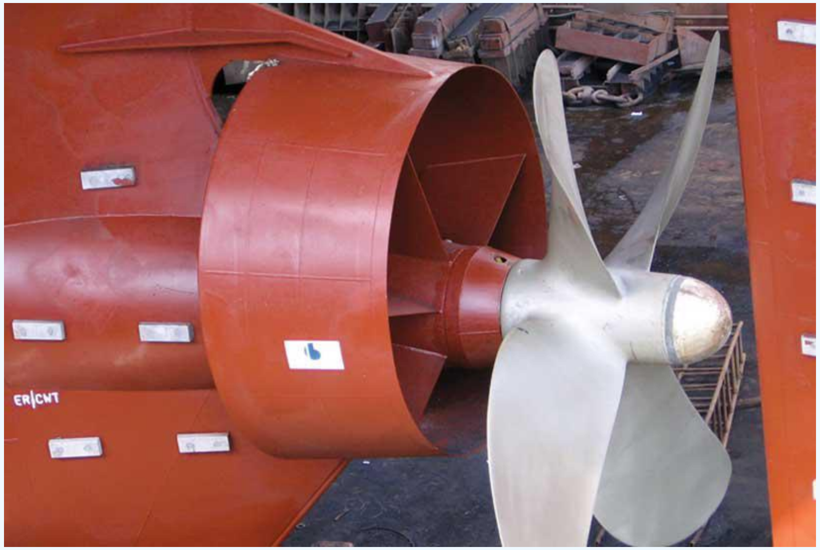
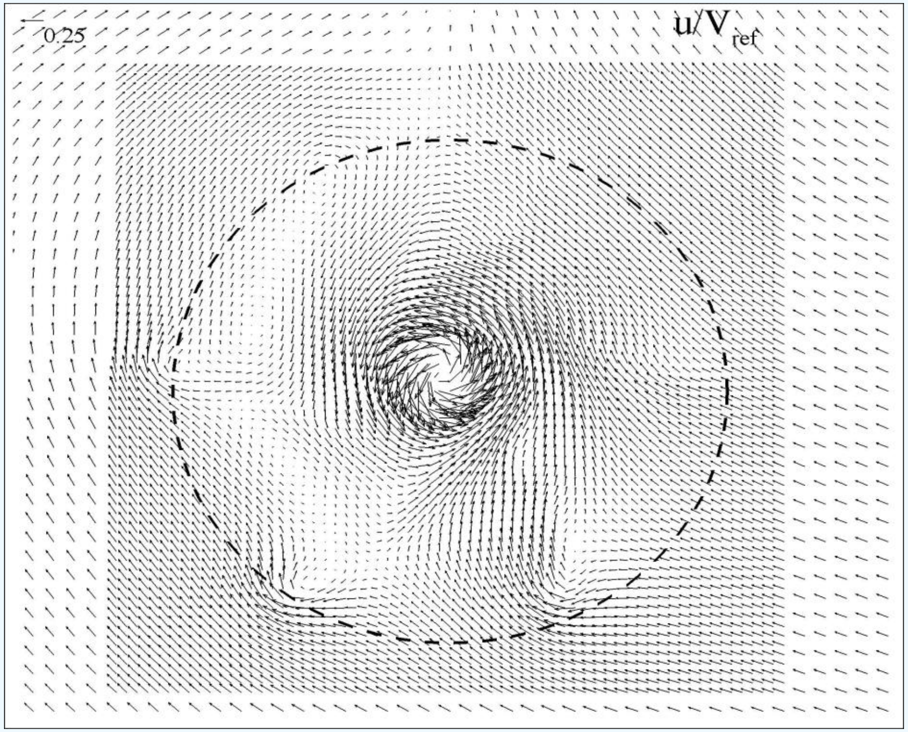


Mewis Duct

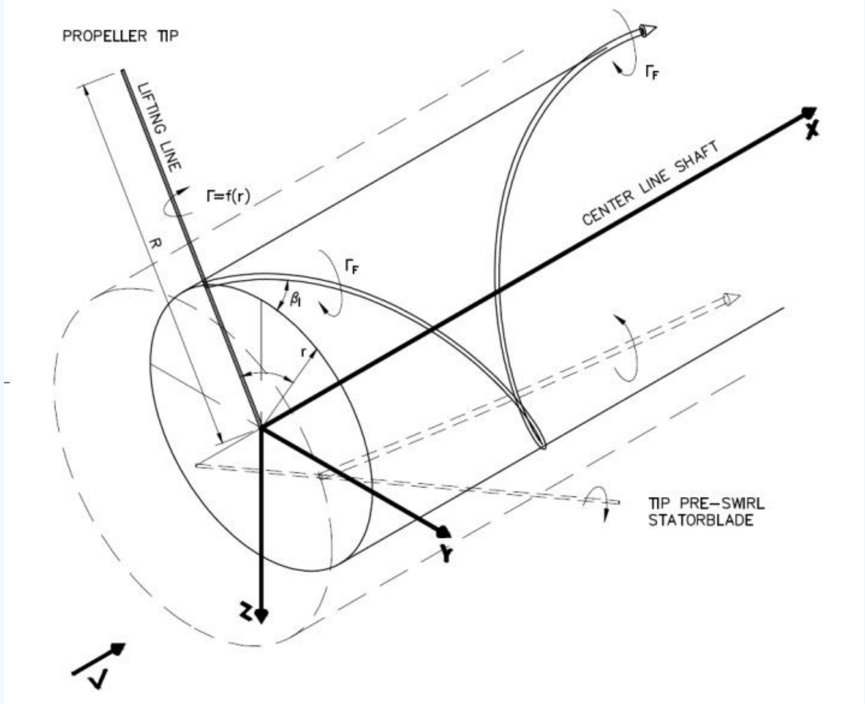
Pre-swirl

- Stator blades induce swirl velocity in front of propeller
- Pre-swirl flow is neutralized by the propeller
- ⇨ Less kinetic energy remaining in rotating flow behind propeller
- Gains not only from recovery of rotation energy but also from reduced friction drag (smaller optimum propeller diameter)
- Gains reduced by reduced post-swirl stator effect of the rudder



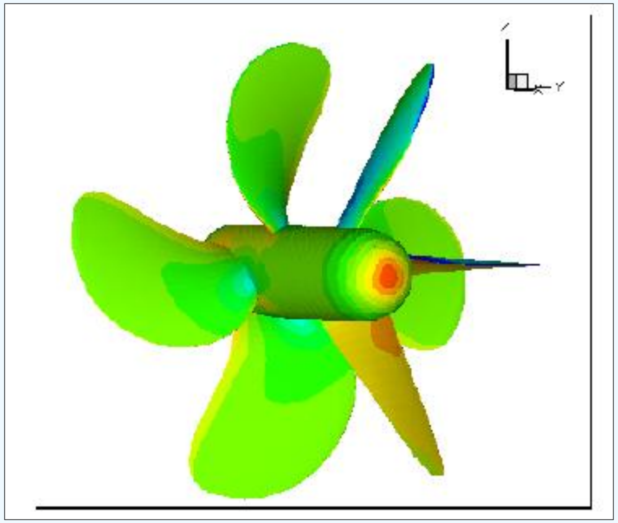
Design procedure

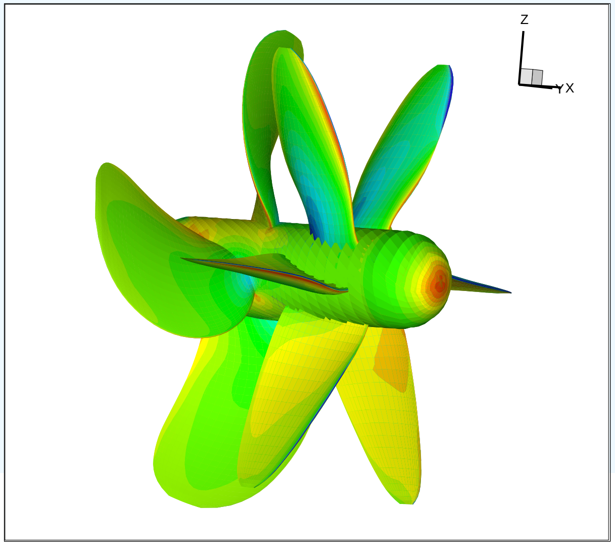
- Step #1 : Preliminary design using lifting-line model
  - Influence of many parameters to be explored
  - Computationally inexpensive
- Step #2 : Analysis and systematic variation using unsteady BEM
- Step #3 : Verification with viscous flow solver



Design procedure

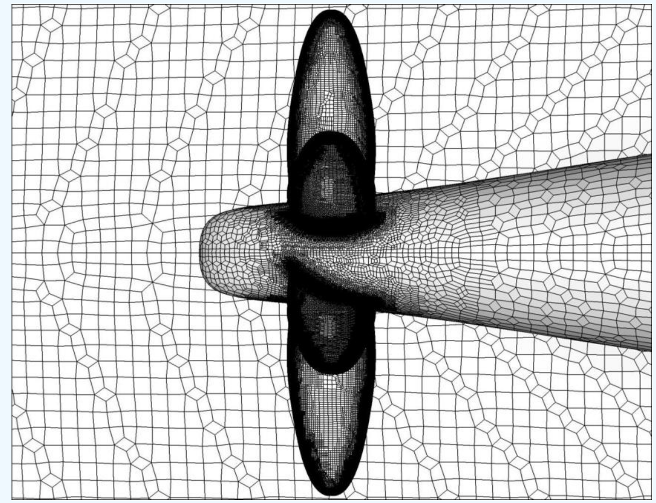
- Step #1 : Preliminary design using lifting-line model
- Step #2 : Analysis and systematic variation using unsteady BEM
  - Propeller cavitation analysis
  - Selection of final design variant
- Step #3 : Verification with viscous flow solver

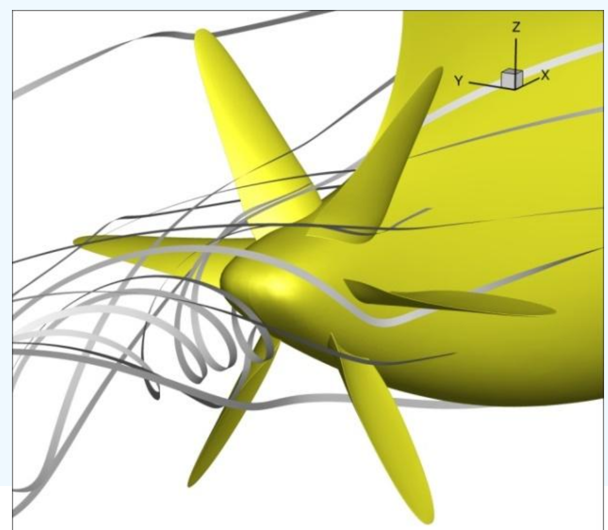




Design procedure

- Step #1 : Preliminary design using lifting-line model
- Step #2 : Analysis and systematic variation using unsteady BEM
- Step #3 : Verification with viscous flow solver
  - Identification of flow problems
  - Identification of scale effects in model experiments





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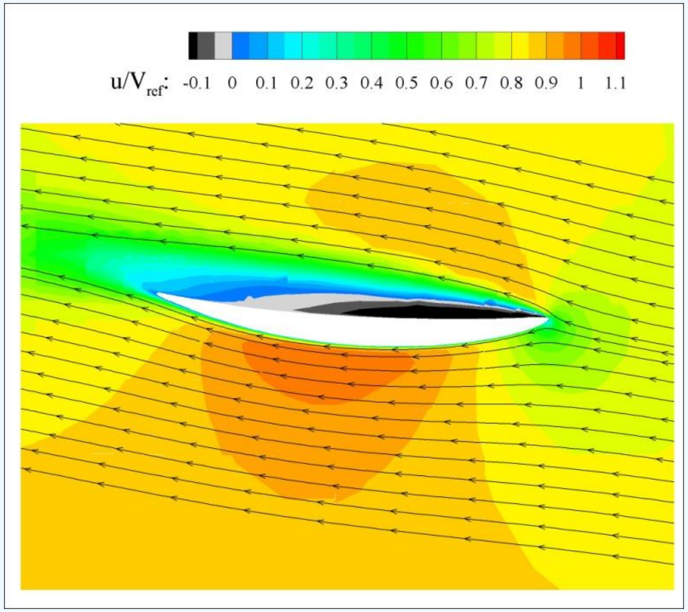

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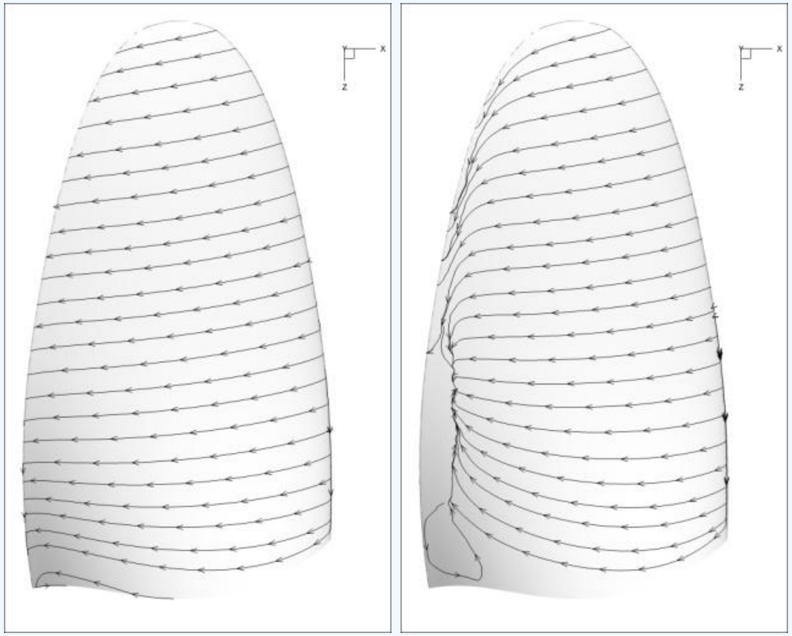
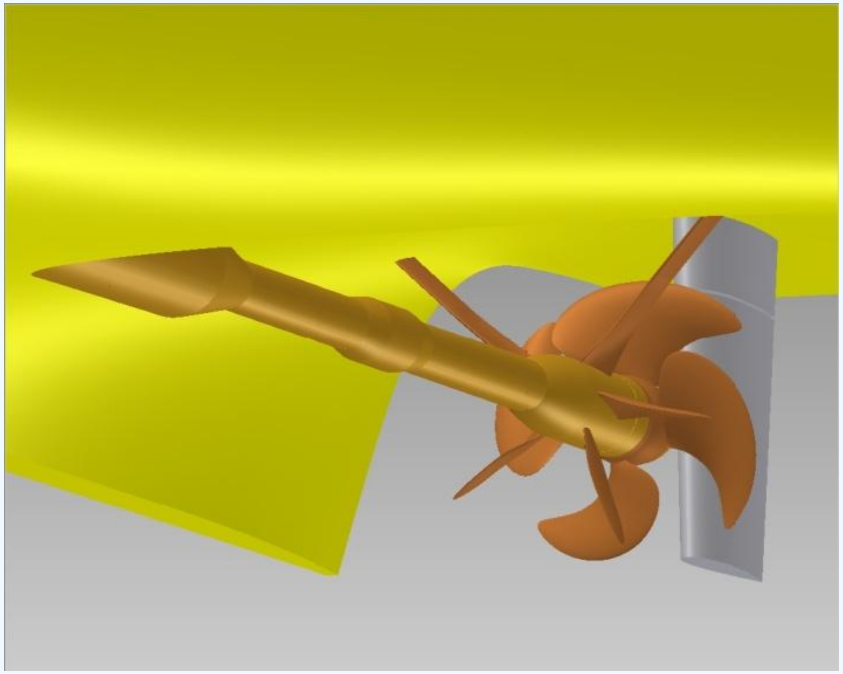


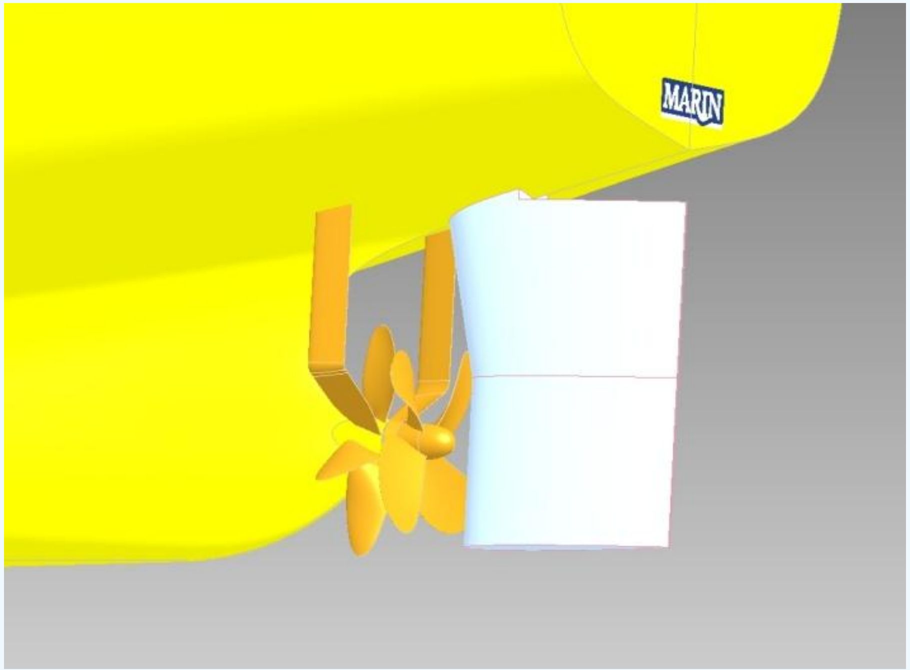
Model tests

- Verification of design calculations
  - Model propulsion tests on vessel fitted with designed pre-swirl stator and 6 and 4 blade stock propeller
  - 2.5 % power reduction gained for 6-blade propeller (100.2 to 96 RPM)
  - 5% power reduction for 4-blade propeller
  - Efficiency gains and RPM drops indicate that design method is promising

Some examples of stator integration



twin screw vessel with pre-swirl stator



Bulk carrier with a L-J Van Lammeren duct and pre-swirl stator

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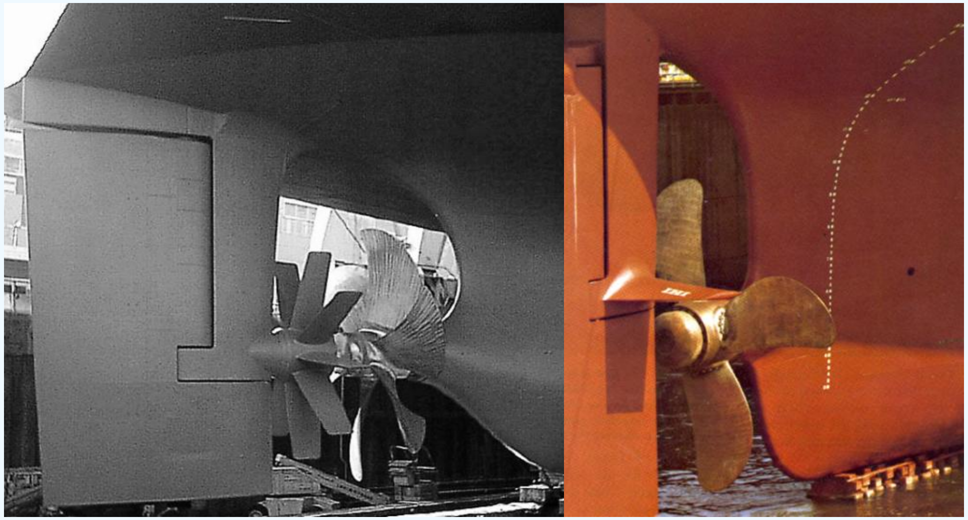

Rudder stators & fins

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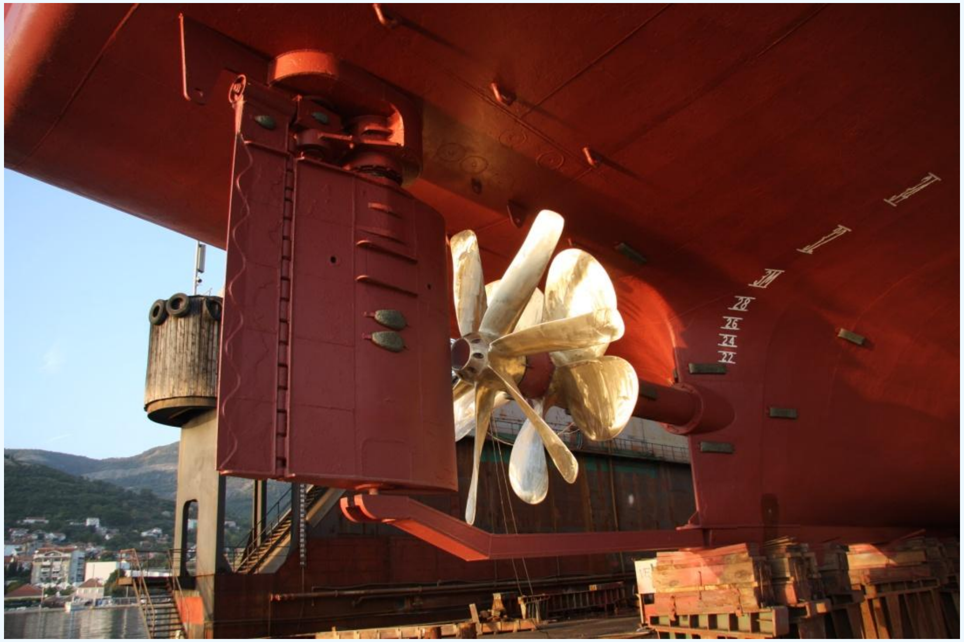

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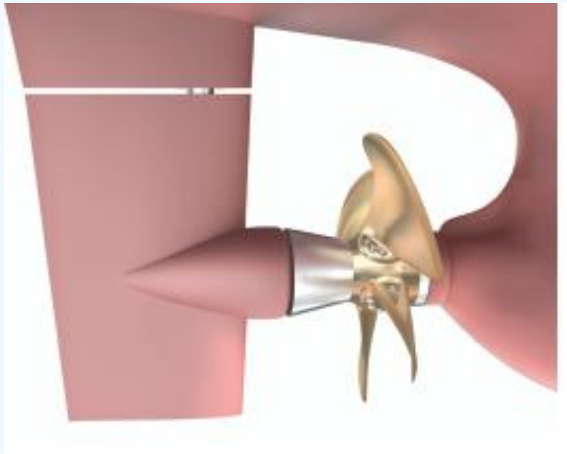

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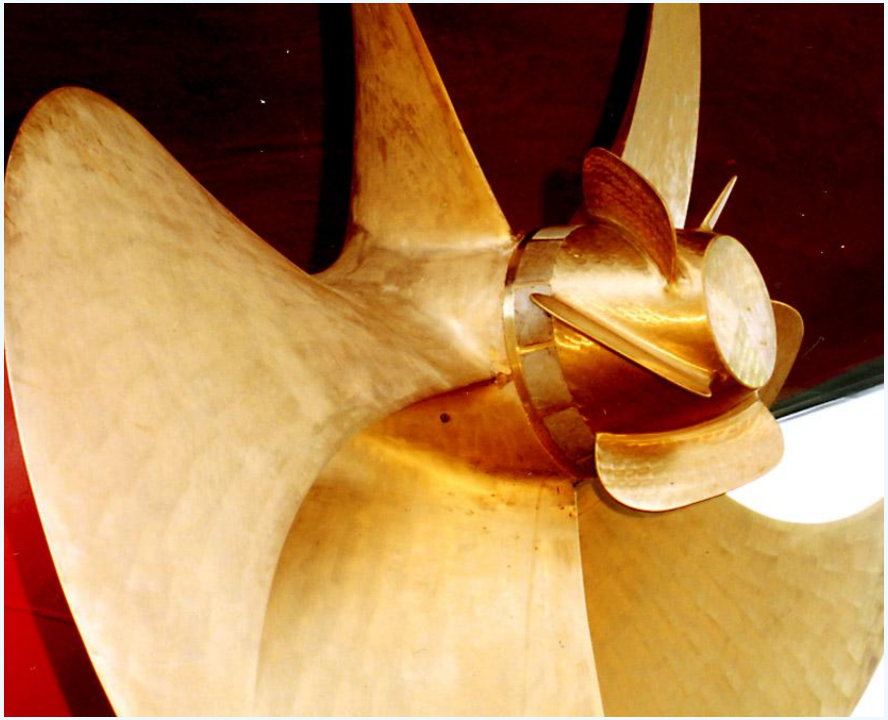
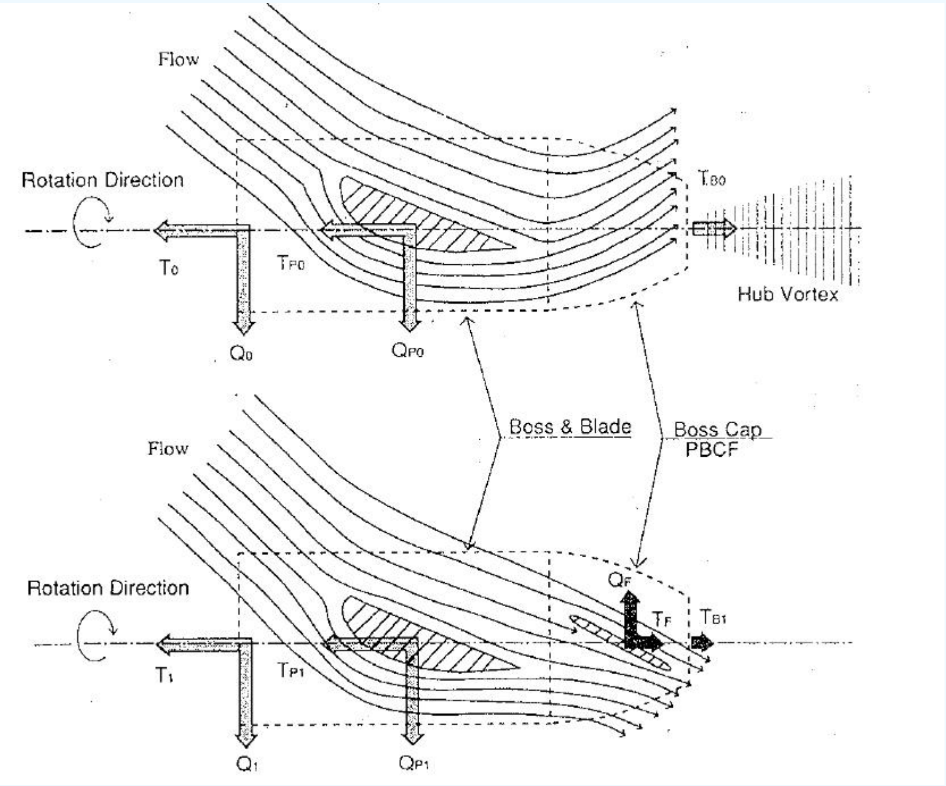


Working mechanisms

- Propulsion:
  - Torque reduction (Qf)
  - Some thrust penalty (Tf)
  - Reduction rotational loss (hub vortex)
- Resistance:
  - Perhaps some reduced pressure drag of propeller hub due to removed hub vortex



Source:K. Ouchi et al. (Japan Society of Naval Architects and Ocean Engineers, 1992)

- PBCF seems cost effective and without risks.
- For the hydrodynamic mechanism to work:
  - Rotation losses of single propeller should be significant enough.
  - Thus, the higher the loading at the inner radial profile sections the better.
    - (not common feature for properly designed propellers)
    - (maybe PBCF works best for dedicated propeller designs)
    - Make the right comparisons!
  - Large propeller hub diameter
  - Notice that rudder is also recovering propeller rotational losses

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Nozzle on hopper dredger by IHC

Propeller-nozzle combinations

- Well-known “Kort” nozzle developed as early as the 1930’s by Stipa and Kort.
- Nozzles begin generating sufficient amounts of thrust when the propeller suction is high enough.
- Can outperform open propellers when roughly the thrust loading CT > 1.5 - 2.5.
- However:
  - For structural reasons not accepted for large diameters.
  - Nozzle supports can bring significant additional resistance.
  - Key factor is proper integration of nozzle and ship hull ! (e.g. tunnels)

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Mewis duct

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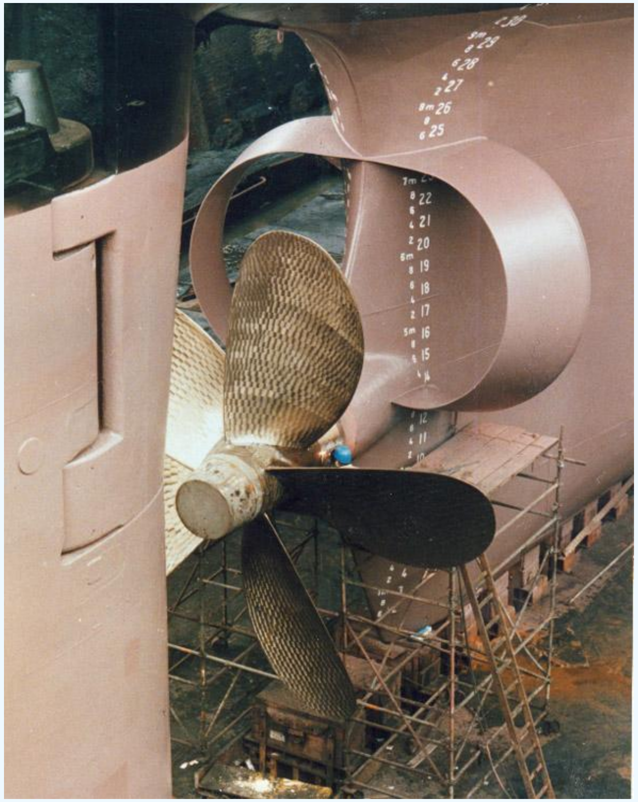

Schneekluth duct

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Combined with fins

Working mechanisms

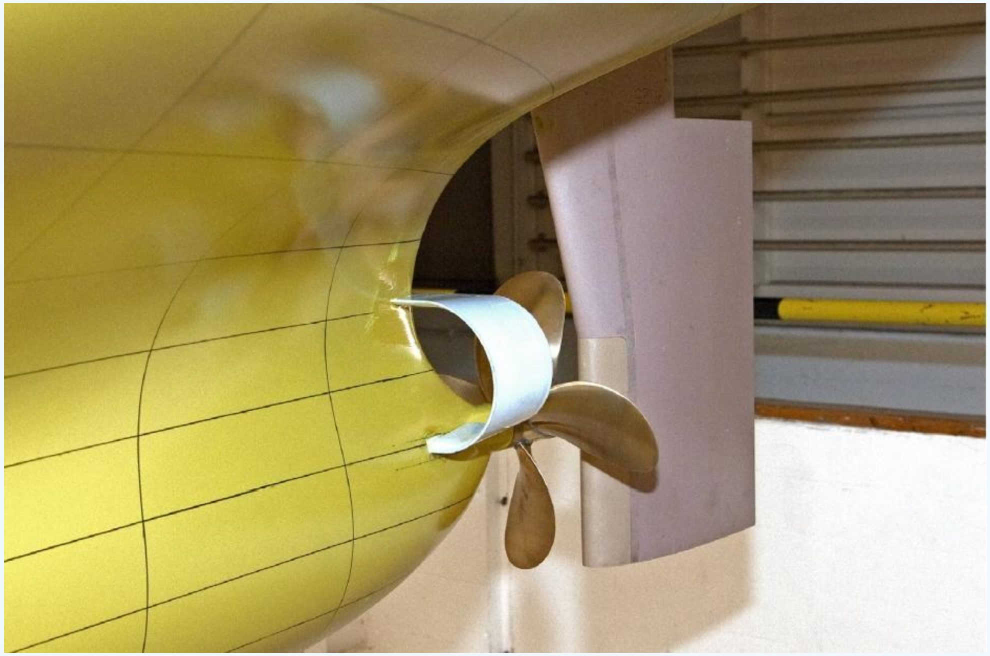
- Many possible working mechanisms:

- Propulsion:
  - Wake concentrator: $$\eta_D = \frac{J\ K_{To}}{2\ \pi K_{Qo}} \frac{K_{Qo}\ K_T}{K_Q\ K_{To}} \frac{1-t}{1-w}$$
  - Additional nozzle thrust due to foil lift.
  - Possible contribution of pre-swirl in propeller plane

- Hull resistance:
  - Flow alignment in axial direction (viscous and wave resistance)
  - Possible prevention of flow separation (scale effects!)

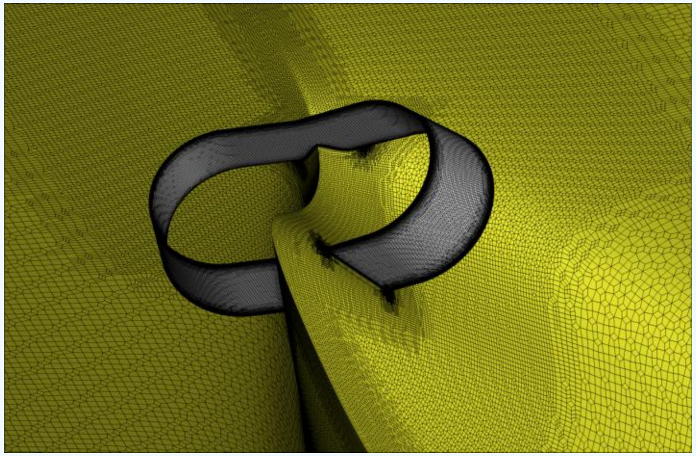
Model tests

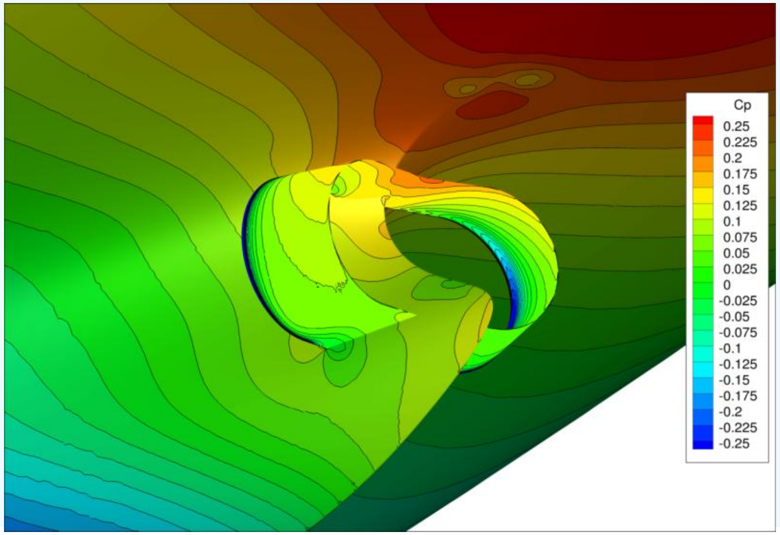
- Show distinct positive effect in order of 5% reduction of resistance (wake fraction).
- Influence on propeller performance.
- Scale effects are bound to exist.



Numerical simulations

- Given the many potential mechanism accurate simulation by CFD is demanding
- Nice pictures still requires verification and validation!
- Requirements:
  - Capturing of all relevant phenomena (vortices, separation, waves, flow interactions)
  - Difficult due to unsteady parts





Conclusions & future developments

- Complexity of ESD design is shown.
- Numerical flow simulation brings a lot of new insight in flow mechanisms but capturing all relevant details is extremely challenging.
- Design & analysis procedures are being developed including quality standards in CFD.
- Fuel saving and reduction of underwater noise can go hand in hand using ESDs