20/5/2021

Growing Importance of Computational Tools and Techniques in Marine Propulsors

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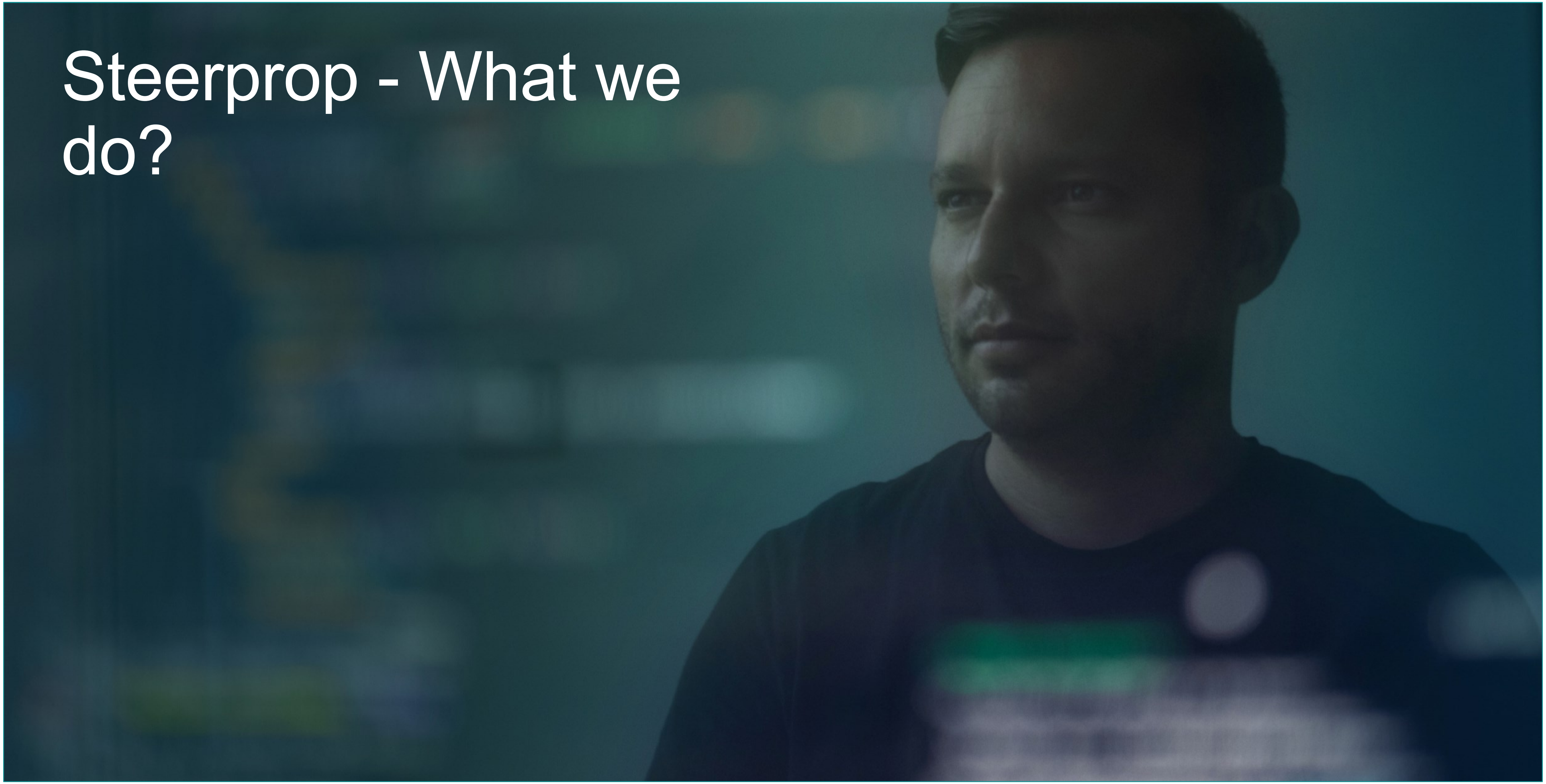
Agenda

- Steerprop: What we do?
- Introduction to Propeller Geometry
- Key Terminologies
- Design Process - Propeller
- Design Tools
- Importance of Computational Tools
- Future with Full Scale Computations

Steerprop - What we do?



Steerprop in Brief

Steerprop is the leading designer and manufacturer of azimuth propulsion solutions for the most demanding applications and toughest conditions. Since our founding in Finland in 2000, we have delivered fit-for-purpose propulsion units for vessels working in the arctic, offshore, tug, workboat and cruise industries.

Employs more than :

450

Order book :

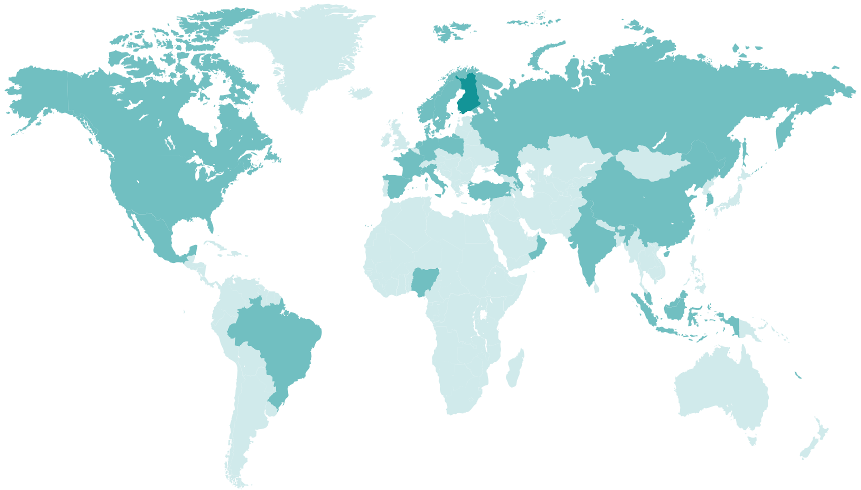
60 MEUR

Units delivered :

close to 900

Operates direct or with authorized distributors or agents in

more than 50 countries



Condition monitoring

in every delivery

Operating hours in total :

over 10 million

Steerprop propulsion units

in every third icebreaker

Steerprop Propulsors

	SP 10–80	SP 10–45 CRP	SP CRP ECO	SP CRP ECO ARC	SP PULL	SP ARC
Power range [kW]	900–7000	900–3500	5000–15 000	Up to 12 000 (depending on ice class and application requirements)		
Propellers available	Open and ducted	Contra-rotating propellers			Open pulling	Open and ducted
Configuration	Z-drive or L-drive					

All Steerprop propulsors match each application and built up to 12 MW for ice classes or 15 MW for open water.

- Pushing units
- Contra-rotating units
- Pulling units

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Selected References

BALTIKA
Oblique icebreaker

Main propulsion: 3 x SP 60 PULL
Power per unit: 2,500 kW
Build by: Arctech Helsinki Shipyard Oy

CELEBRITY FLORA
Expedition Mega Yacht

Main propulsion: 2 x SP 20 CRP
Power per unit: 1,250 kW
Owner: Celebrity Cruises
Build by: Shipyard De Hoop

ESVAGT SCHELDE
Windfarm Service Vessel

Main propulsion: SP 20 W D LM
Power per unit: 1,100 kW
Owner: Esvagt
Build by: Havyard Ship Technology AS

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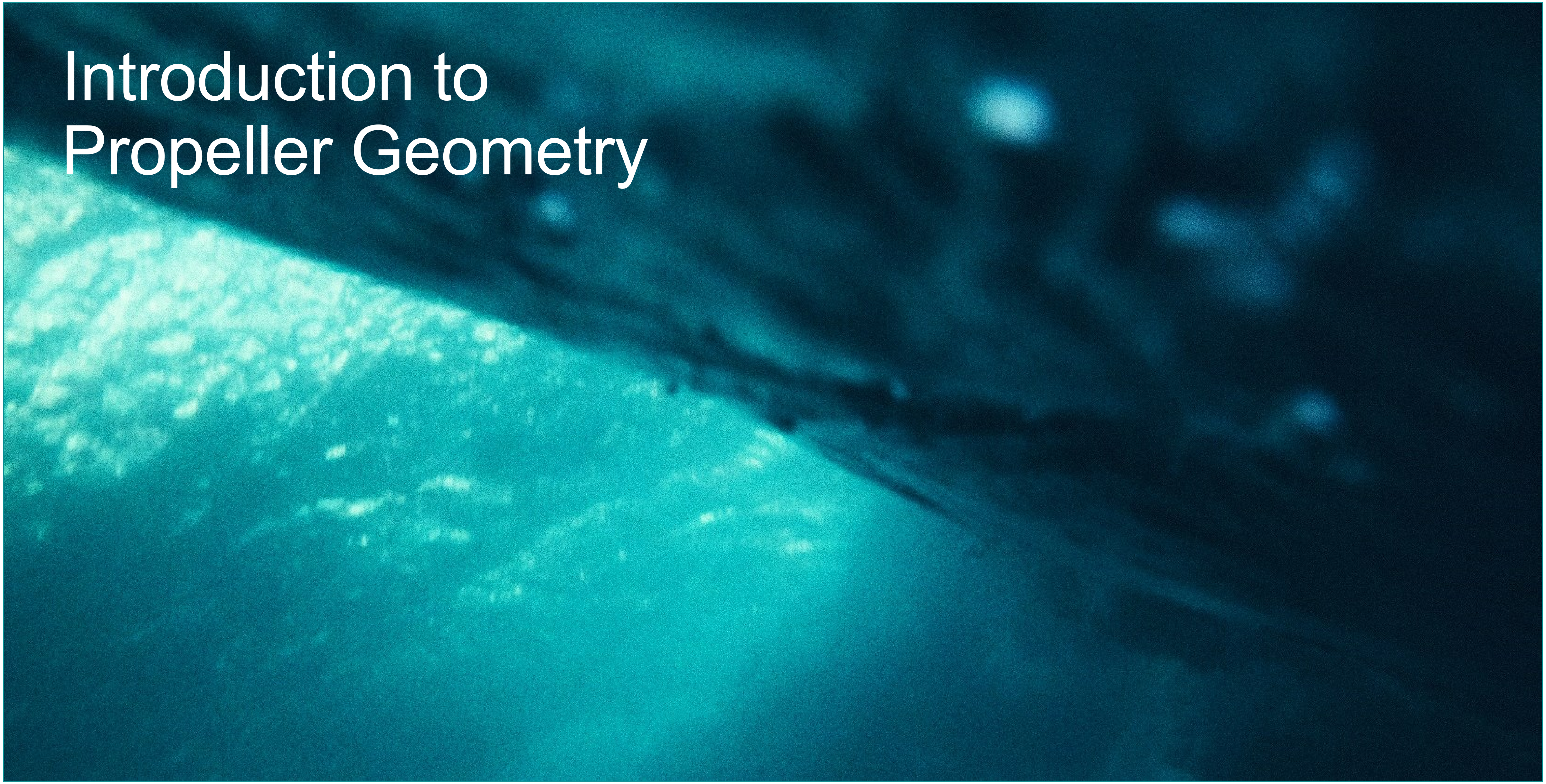
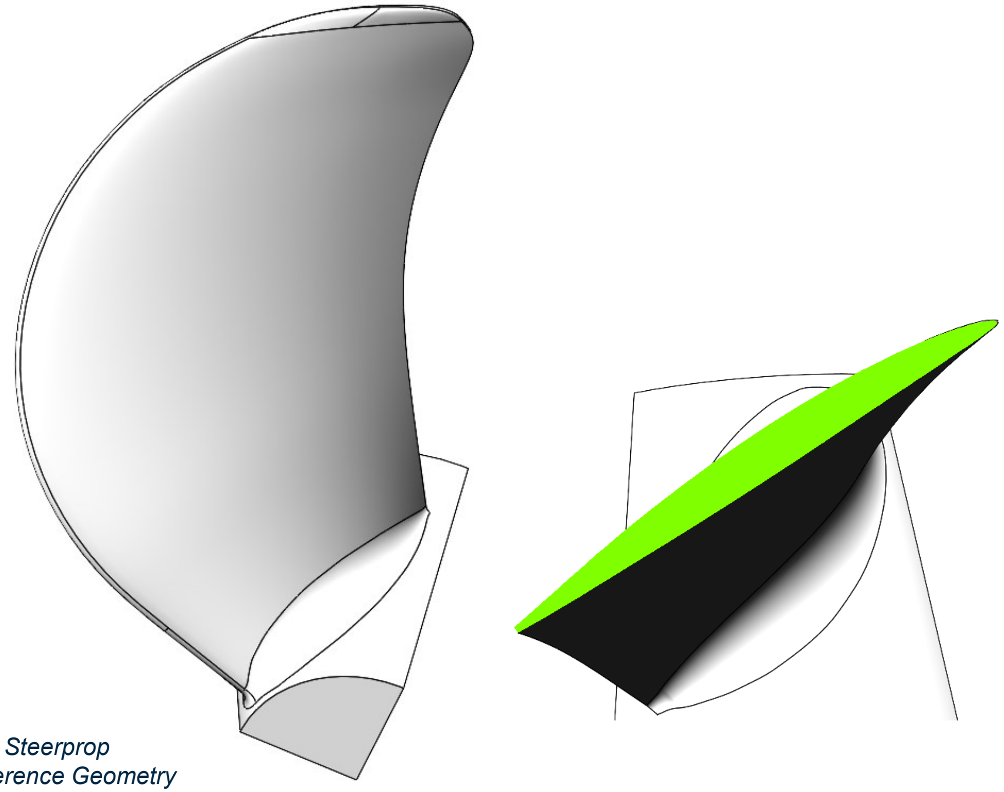
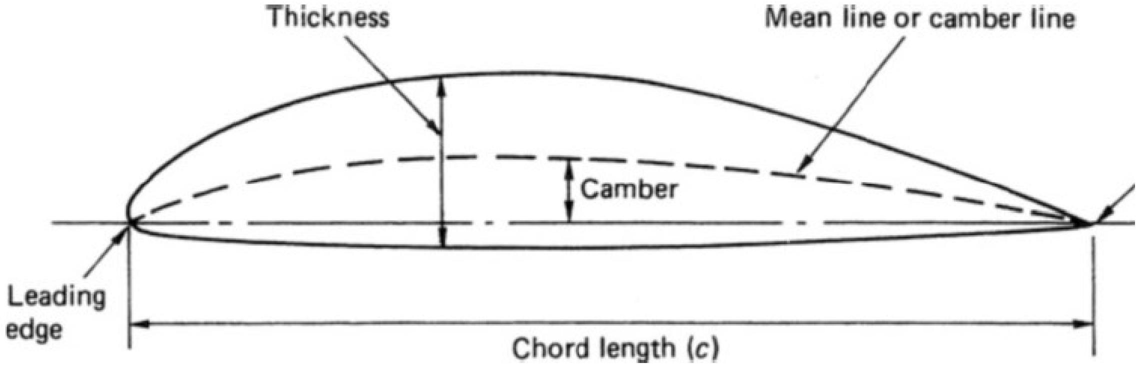
Introduction to Propeller Geometry



Foil Geometry and Definitions



Ref: Steerprop
Reference Geometry

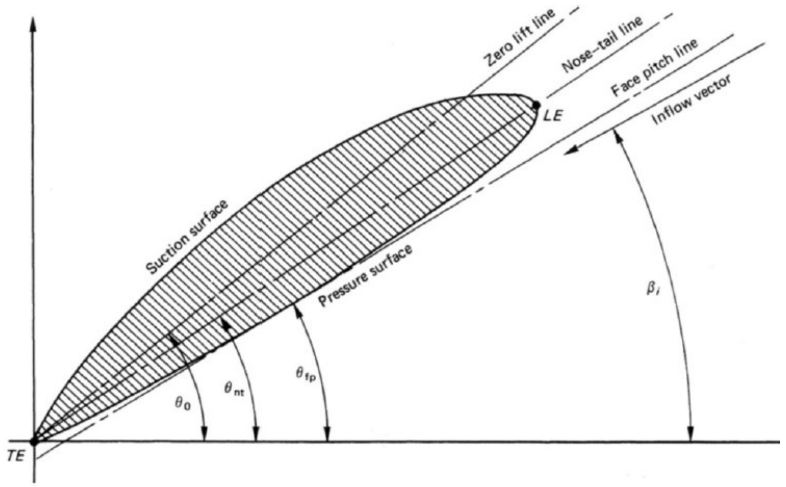


Ref: Marine Propellers and Propulsion: John Carlton

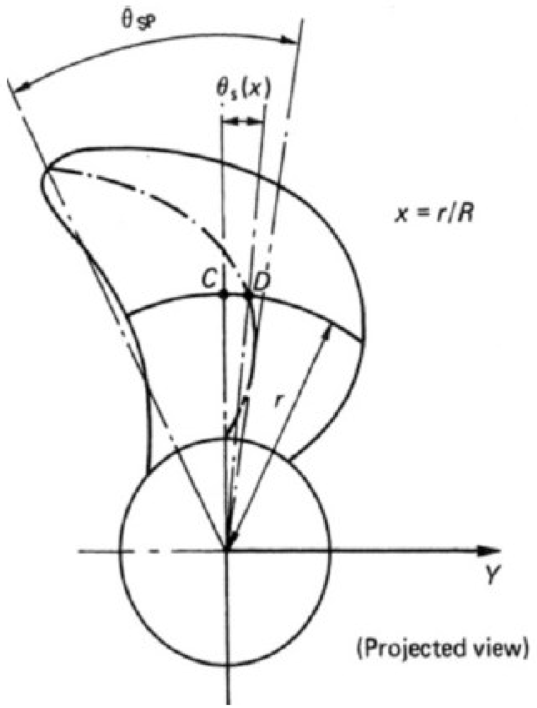
Widely used Propeller geometry NACA a=0.8 meanline with NACA 66 (mod) thickness distribution.

Foil Geometry and Definitions

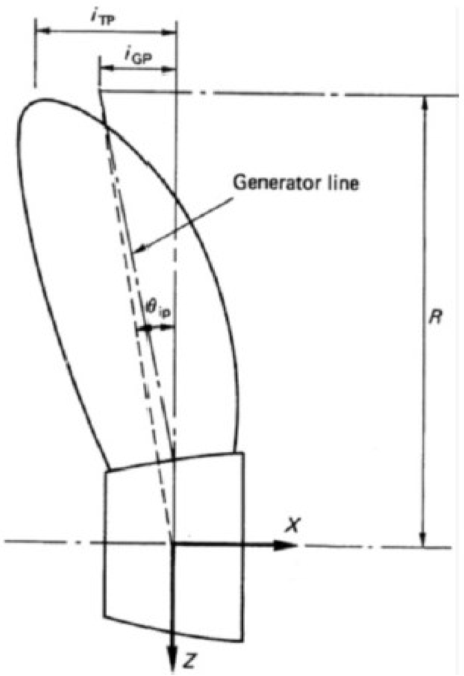
Pitch



Skew



Rake



Ref: Marine Propellers and Propulsion: John Carlton

Key Terminologies

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$$C_T = \frac{T}{\frac{1}{2}\rho {V_A}^2 (\pi R^2)}$$

$$C_Q = \frac{Q}{\frac{1}{2}\rho {V_A}^2 (\pi R^3)}$$

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

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

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

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

Non-Dimensional Performance Coefficients

- During Open Water Test, Thrust(T), Torque (Q) ,rate of revolutions(n) and speed of advance (V_A) are recorded.
- The measured values are normalised and could be applied to full scale with suitable Rn scaling.

Wake

Wake represents difference between the ship velocity and actual velocity felt at the propeller plane.

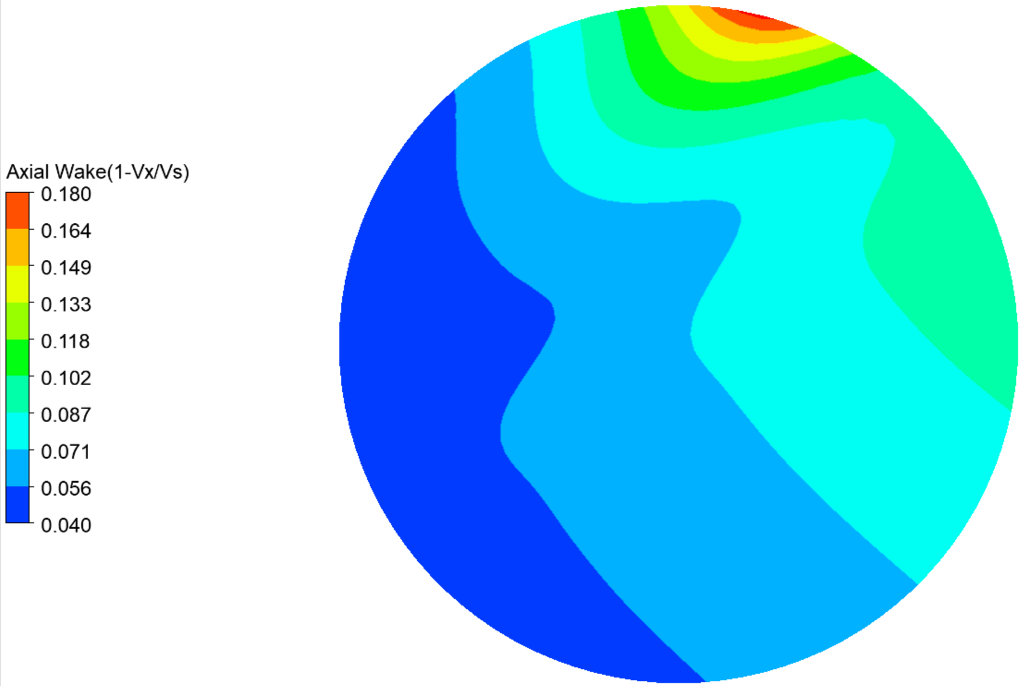
The most known aspects resulting in observed wake pattern

- Reynolds Dependent Flow Aspects
- Pressure distribution over hull
- Wave Pattern

Nominal Wake: Wake Field Measured at propeller plane without presence of propeller.

Effective Wake: Wake Field at propeller with the effect of propeller on wake considered.

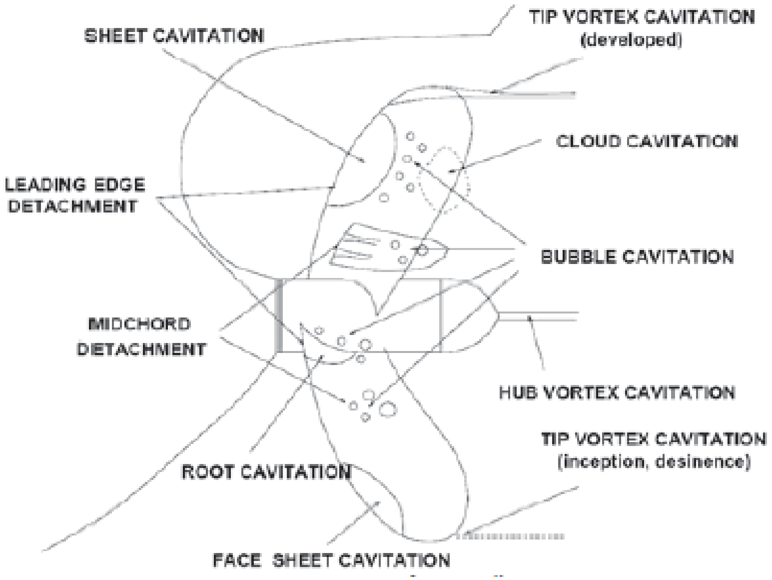
Effective Velocity= Nominal Velocity+ Propeller Interaction velocity



Nominal Wake

Ref: Steerprop Test Case

Cavitation



Implications:

- Performance of propeller : KT ,KQ
- Erosion of the blade surface

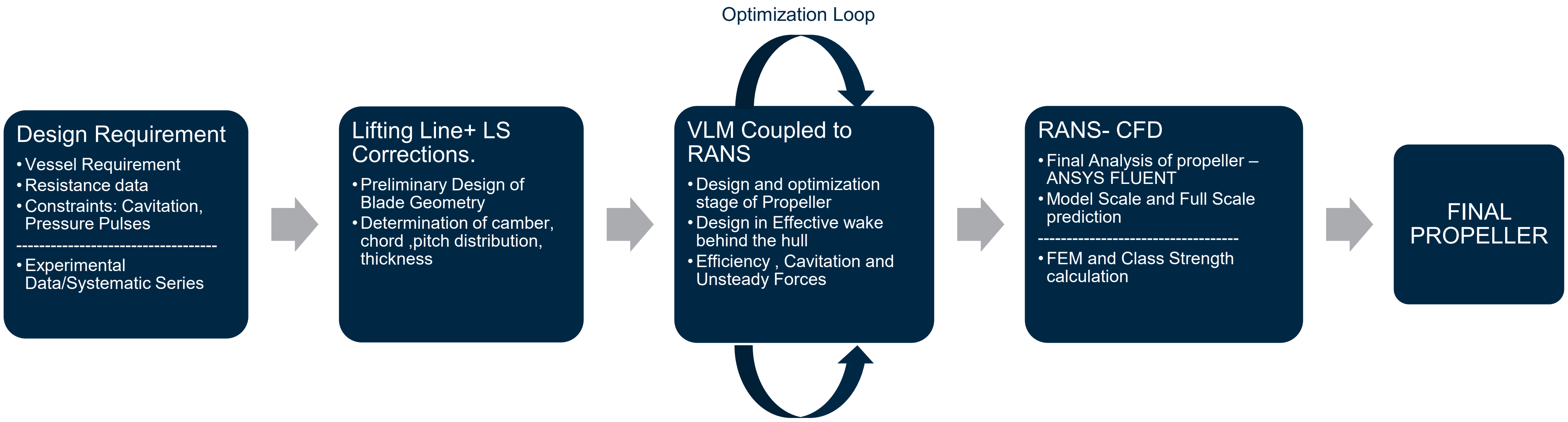
Sheet cavitation

- Can develop either on face or suction side.
- Trigger is large suction pressure at the LE and grows both radially and chordwise as the incidence angle increases.
- Thus extent depends on the loading.
- Sheet cavitation are typically stable. Unsteadiness should eb carefully watched.
- To delay sheet cavitation camber is increased to move the loading away from LE . However this increases susceptibility to bubble cavitation.

Design Process

Design Process of Marine Propeller

A state of the art design process for propellers with computational tools



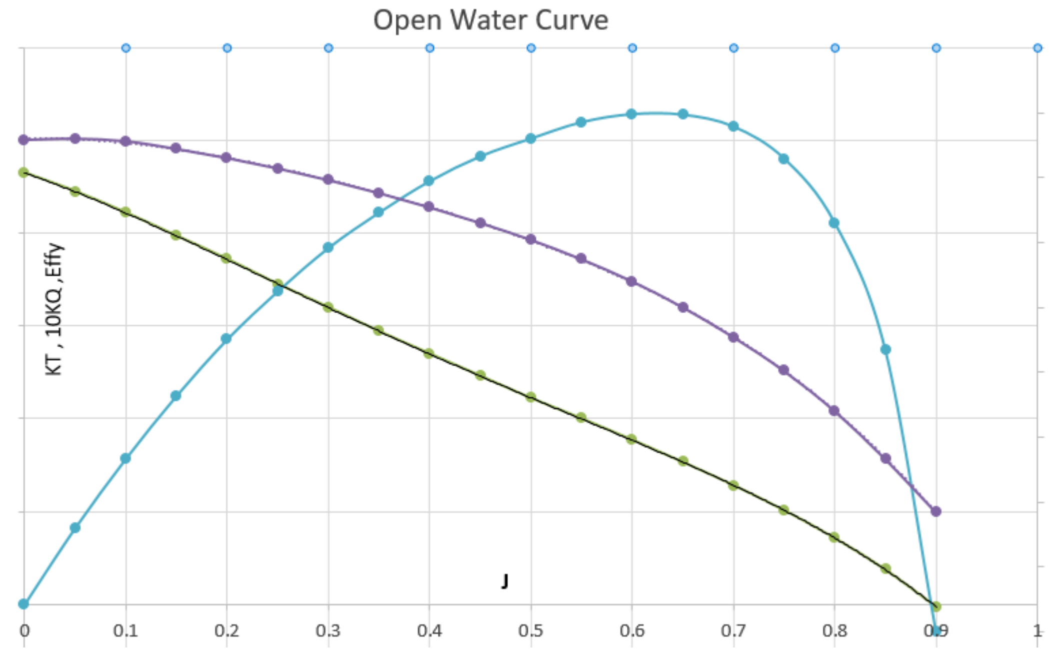
Design Tools

Experimental Data /Systematic Series

- Old Model Test data or widely used systematic series.
- Convert these large data and develop regression equations for KT, KQ as functions of J, P/D , Ae/Ao ratios and number of blades Z.
- Make use of Keller and such other criteria for cavitation - Blade Area ratio.

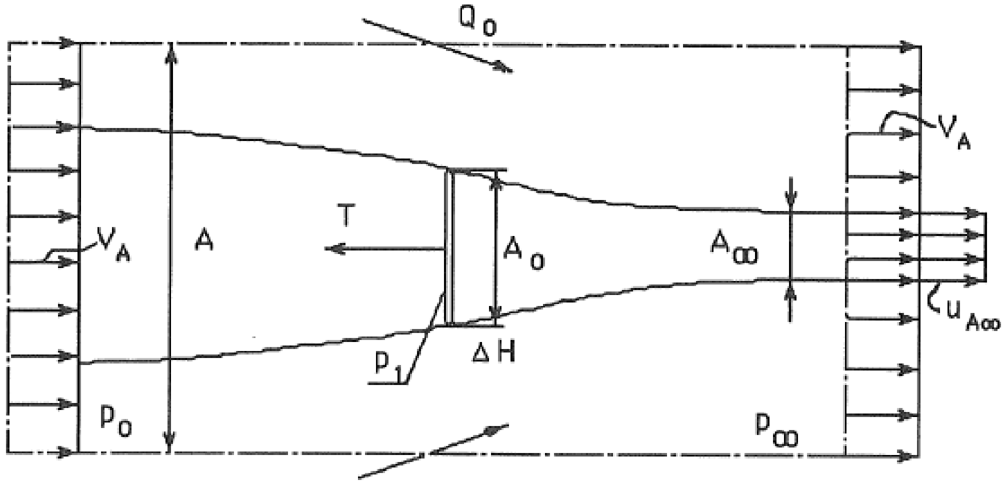
What we miss?

- Largely depends on designers experience
- No wake adapted propellers
- Optimization is rarely possible



Actuator Disk

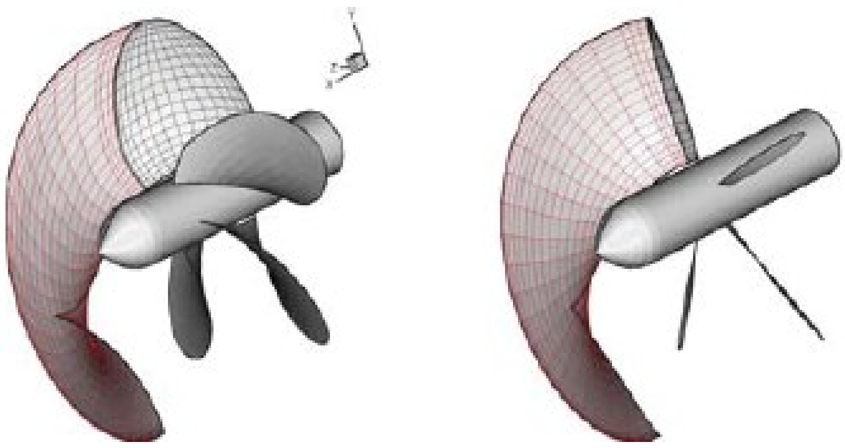
- Simplest possible idealization of a propeller.
- Propeller is represented as a disk of radius R. The disk introduced a pressure jump to the fluid passing through the disk.
- Accelerates the fluid and in return generates thrust.
- Quite handy to take into account propeller modelling in self propulsion simulations.
- It doesn't include any foil geometry and hence not suitable for propeller design.

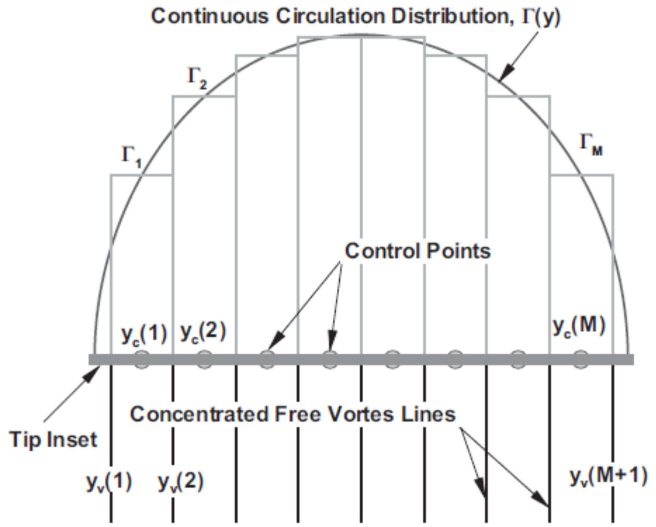


Ref: Ship Propulsion MMA155-Chalmers University

Lifting Line

- Limiting case of lifting surface with zero chord length.
- Single vortex strength Ꞁ(r) on each blade and corresponding trailing vortices γf(r).
- Low aspect ratio blades results in complex 3d flow features which limits lifting line methods
- Lifting surface corrections are introduced to include the 3D effects
- No details of geometry.
- Viscous effects are included with empirical relations.
- Quite popular as preliminary design tool.





Ref: PNA : Propulsion

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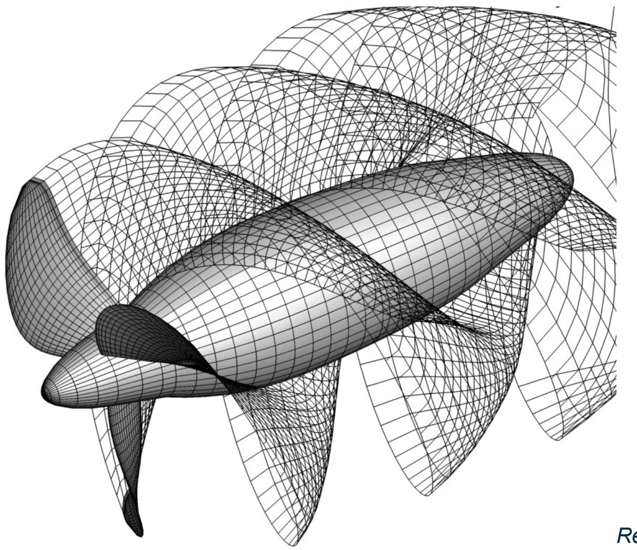
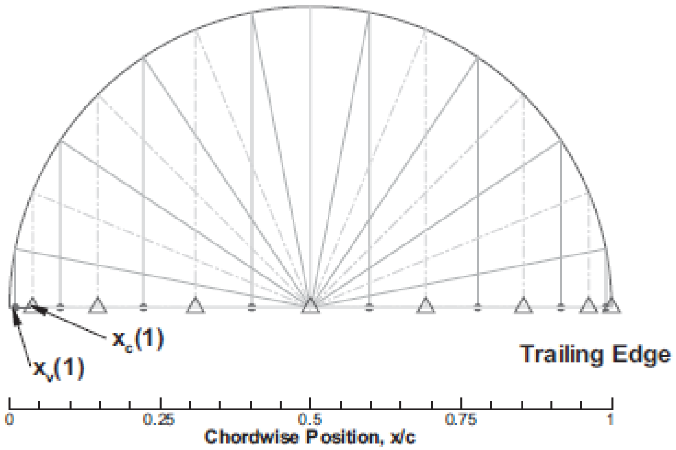


Ref: Steerprop Test Case

Vortex lattice Representation of marine Propeller



Ref: PNA : Propulsion

Lifting Surface (Vortex Lattice Method)

- Includes both span-wise and chord-wise panels.
- A foil is represented as distribution of vortex strengths along mean line.
- The thickness effects on the lift are included using the suitable numerical modelling of thickness loading coupling.
- Corrections only needed for viscous effects.
- More accurate method is the panel method blade surface is discretised to panels.

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Full Blown RANS Computations

- A very good agreement has been achieved between model scale tests and numerical results.
- Opened up a new horizon in studying detailed flow features and scaling with proper post-processing.
- RANS-CFD is used as final analysis in propeller design process.
- Computationally very expensive.

Ref: Steerprop Test Case CRP

Importance of Computational Tools

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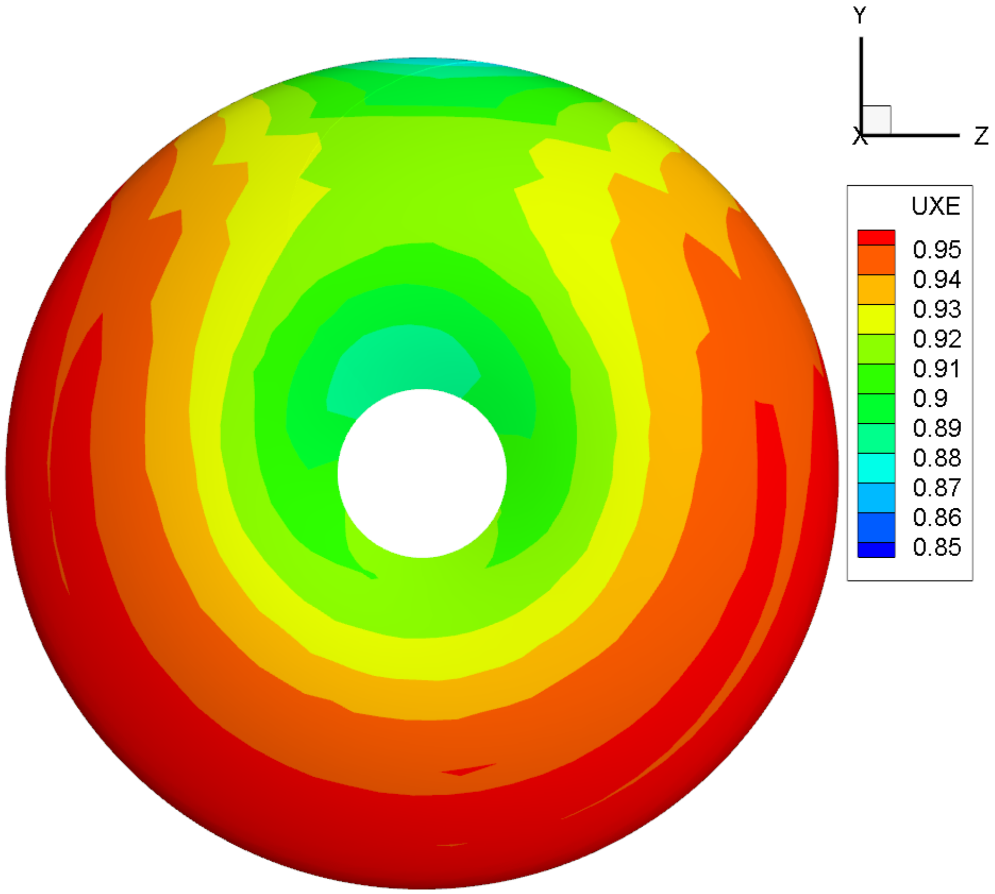
Design in Effective Wake

- The available wake data from model test is nominal wake.
- Wake is largely dominated by viscous scale effects. Different semi-empirical scaling methods are recommended by ITTC and has its own limitations.
- The presence of propeller with pod rearranges flow field. Propeller designers are more interested in effective wake and not nominal wake data.

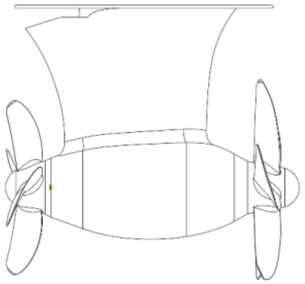
The availability of effective wake data is essential nowadays especially while optimizing the propeller for excellent performance with low to no cavitation



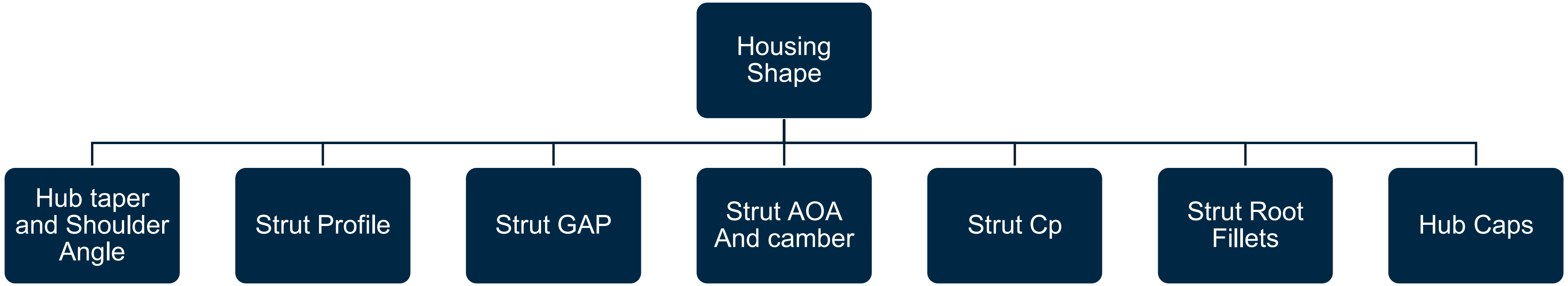
Effective Wake
(MPUF Code Coupled with FLUENT)

"Codes like Lifting Surface coupled to RANS brings in the possibility to design the propeller with effective wake"

Optimize with Parametric Study



- Each individual component of housing could be isolated and studied.
- More than 100s of cases could be evaluated.
- The interaction effects between various components like propeller and housing could be introduced as a parameter of study.
- All constraints based on both mechanical and flow related constraints could be easily included as a part of study.



“ Opens up a whole new possibility for design optimization”

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Pod-Housing Scaling

Open Water Test:

- Determine propulsion unit performance characteristics KT, KQ ,Effy at model scale
- Scaling has to be carried out to predict performance at FS
- Two separate scaling practices :
  - Propeller blades –ITTC friction scaling
  - Pod Housing Drag – Different Testing institutes has different approach which is not fully conclusive. Eg: No actual geometry, no rotational inflow
  - Form factors are suitable for streamlined bodies with no significant separations

Table3 A summary of details of existing semi-empirical correction methods for pod housing drag

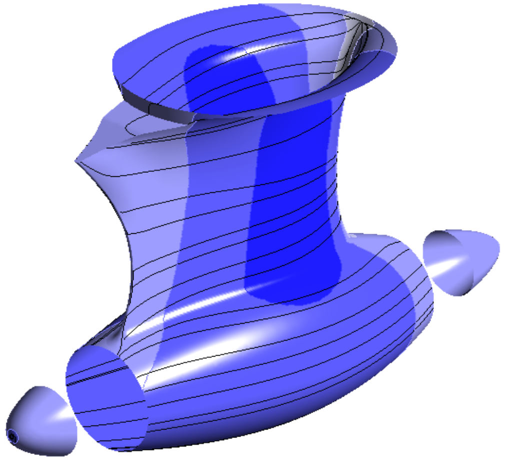
Establishment	HSVA	MARIN	SSPA	SUMITOMO
Number of calculation zones	3(4)	3	3	3
Frictional Resistance calculation method	Schoenherr	ITTC 1957	ITTC 1957	ITTC 1957
Pressure Resistance calculation	No	form factors	form factors	form factors
Strut- pod body interaction	No	No	Yes	Yes
Inflow velocity components	Axial only	Axial only	Axial only	Axial only

Ref: 25 th ITTC Recommendation

Unconventional Propulsors Push- Pull CRP s

Shorter Strut and Torpedo compared to conventional podded propulsors

- What is the implications on housing ?
  - Thicker BL in model scale .May/may not be separation observed at model scale
  - No separation at Full Scale
  - This can affect the scaling of housing drag
- What about aft propeller ?
  - Subjected to different wake at two scales
  - Will simple ITTC scaling works?

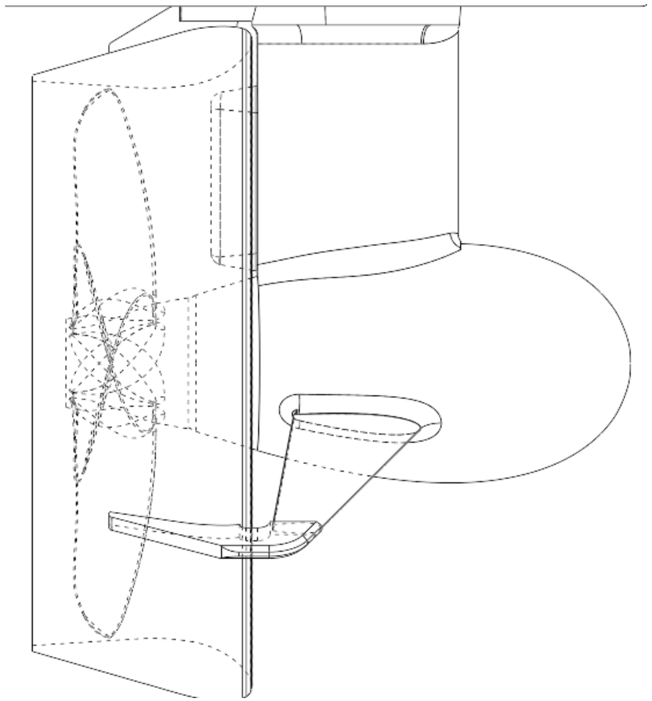


Ref: Steerprop Case Study

" RANS based scaling takes into account better physics and actual pod geometry compared to semi-empirical formulations used at testing institutions"

Scale Effects in Ducted Propellers

- Scale effects of the nozzle is very significant in ducted propellers especially at max efficiency point i.e high J.
- Scaling effects depends on duct profile.
- Duct thrust is higher at FS with increase in pressure component and lowering of viscous drag. The magnitude depends on shape of the duct.
- The efficiency difference of as good as 5-7 % are experienced due to scale effects.



“ Designing of propeller with right understanding of scaling effects is the key”

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Future With Full Scale Computations

- RANS based codes at model scale are now-a-days quite extensively validated with model scale test results.
- It provides the designer with good qualitative prediction of flow features e.g. cavitation patterns
- Lifting surface code when coupled with suitable RANS code provides the designer with excellent opportunity to avoid over designs
- Good Effective wake is the key if we are looking for optimized propulsion units achieving a balance between high efficiency and low cavitation and pressure pulses.
- These computational tools helps to perform parametric optimization. It creates a huge set of database which can be used for developing propulsion solutions for wide applications
- RANS based scaling looks like the future since it is based on better flow features and actual housing geometry than any currently based semi-empirical corrections

'Acceptability of full-scale computations are still limited by available FS data. With growing availability of onboard monitoring data , the reliability of the computational tools will extend in years to come'


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Thank You!
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