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SHIP DESIGN ASPECTS OF UNMANNED AND AUTONOMOUS VESSELS

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Overview

- Ship hull design
- Propeller design
- Environmental and interaction effects
- Automated system design
- Electric and hybrid technologies

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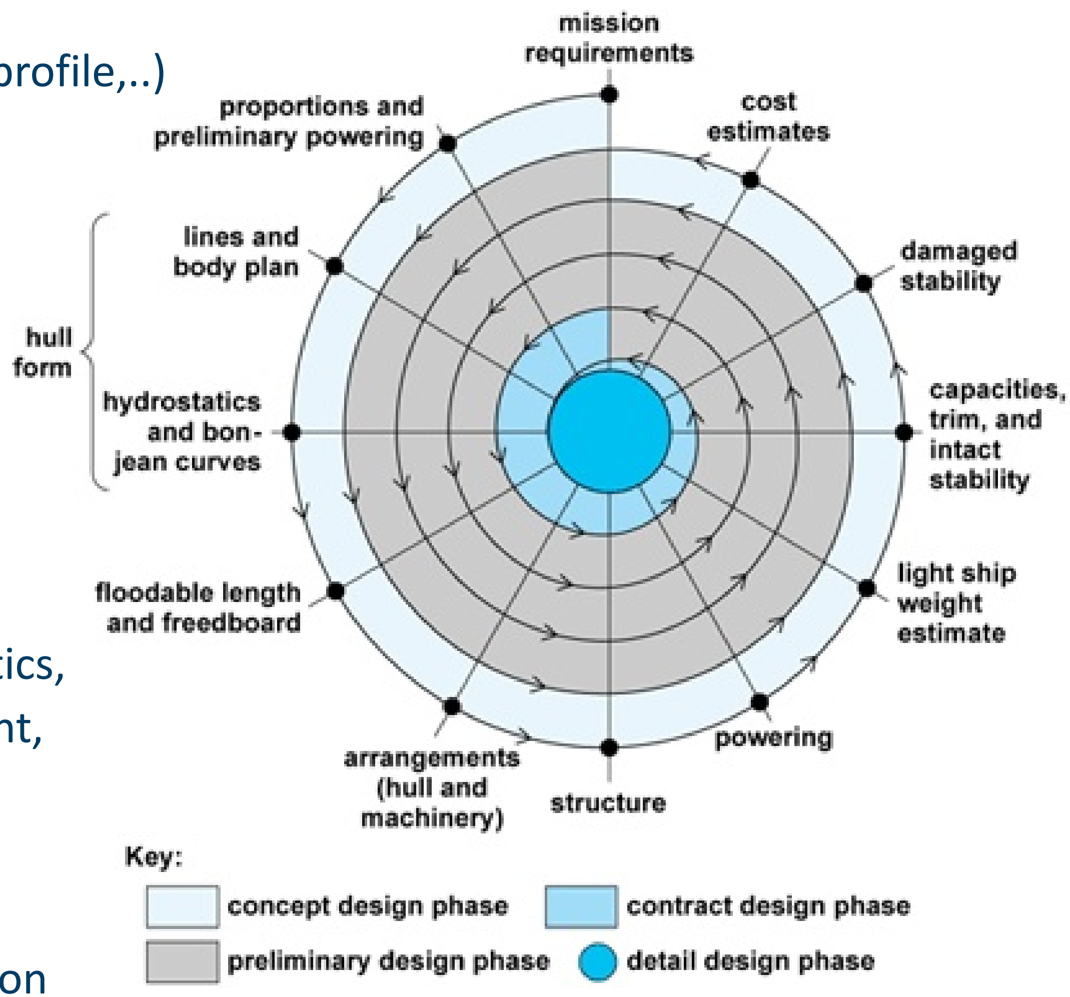
Ship hull design

- Concept design
  - Mission requirement (tasks, capacity, performance, operation profile,..)
  - Main dimensions and weight estimation
- Preliminary design
  - Improvement and elaboration of main ship characteristics influencing building cost and ship performance.
  - Fixing length, beam, deadweight and power
- Contract design
  - Hull form, powering, seakeeping and manoeuvring characteristics, structural details, weight, centre of gravity, general arrangement, overall spacing of machinery, fuel, water, cargo, living…
- Detailed design
  - Final details regarding working plan, installation and construction



What can/should be different for hull design of autonomous and unmanned vessels

- Higher level of operational safety and reliability is required.
- Better ship stability.
- Predictable performance (effects like broaching should be avoided).
- No manual voluntarily speed loss possible in unfavourable sea states. Slamming susceptibility to be avoided, for example with a different flare design.
- More structural strength in certain parts of the vessel disposed to floating wood and debris, not detected by sensors, which is usually avoided by the captain on a traditional vessel. This is valid also for tunnel thruster openings.
- Directional stability of high importance.
- Taking into account automated docking.

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What can/should be different for hull design of unmanned vessels

- For unmanned vessels, limitations related to human on board are omitted.
- Sea sickness criteria does not need to be considered.
- No accommodation and gangways required.
- More flexibility for positioning of machinery.
- More flexibility for positioning of cargo.
- Traditional bridge not present.
- No evacuation plan required.
- The vessel can be stiff in roll, allowing for different favourable design, for example, the cargo can be placed further down, resulting in better stability.

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Ship propeller design for traditional ships

- To aim the highest possible level of propeller efficiency while keeping vibration and noise and hence cavitation and pressure pulses at the lowest possible level.
- Conflicting boundary conditions: less cavitation results in a large blade ratio, whereas high propeller efficiency requires small blade ratio.
- A propeller design can only be initiated after the design criteria have been selected.
  These criteria are:
  - type of ship
  - mission profile
  - limitations regarding diameter, ship speed, cavitation, etc.

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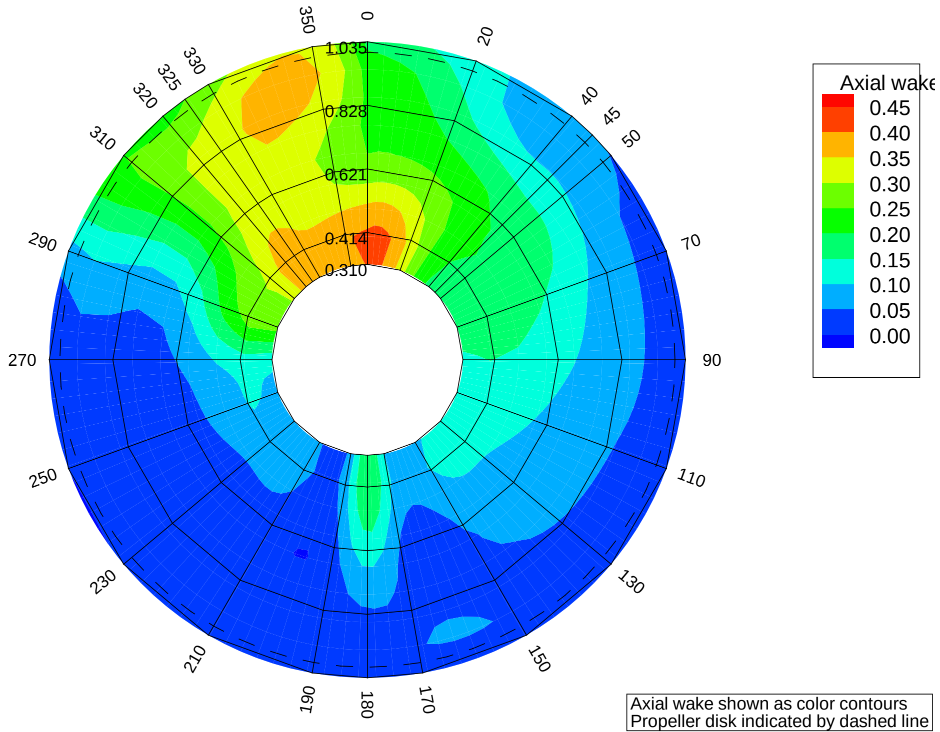
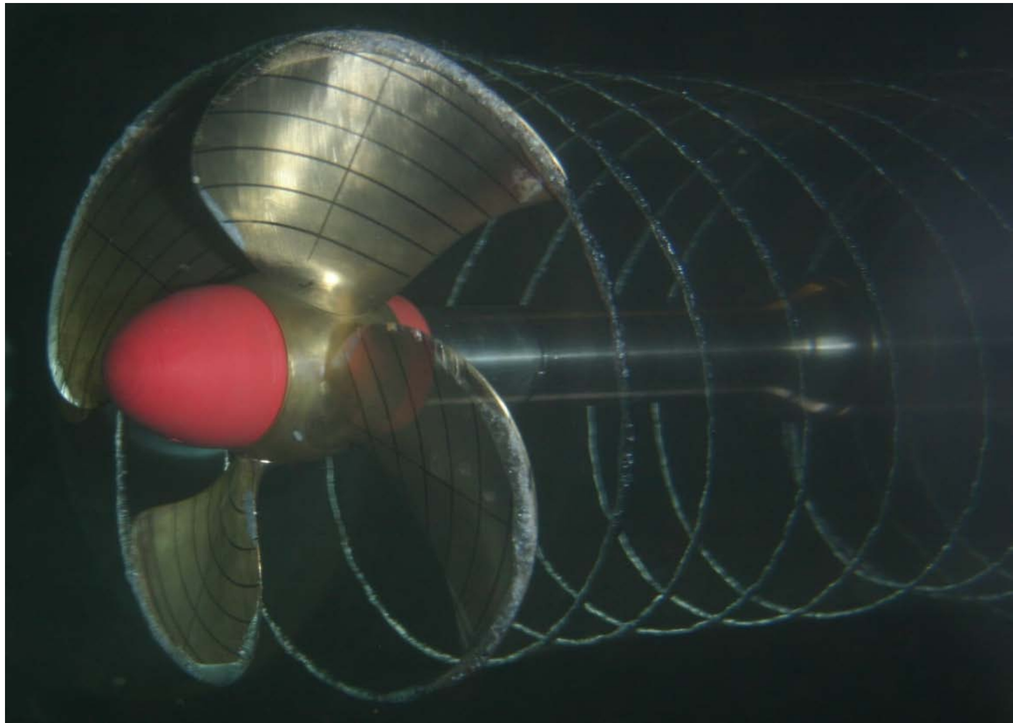
Propeller design factors for traditional vessels

- Diameter: as large as possible
- Shaft speed (rpm): as slow as possible
- Cavitation: should be avoided. Its controlling factors are among others: blade tip speed and inflow.
- The pressure pulses on the hull:
  - are inversely proportional to the tip clearance.
  - increase with increased power density (power divided by the propeller disc area).
  - increase with increased inflow disturbance from the tip. The inflow at the propeller blade tip is less than the ship speed. Angle of attack of the blade profile of the propeller varies during one revolution.



What can/should be different for propeller design of autonomous and unmanned vessels

- Higher level of operational safety and stability is required.
- Redundancy must be highly considered. Resulting in at least two separate propulsors, with their redundant power generation and transmission
- Stable performance of the propeller is very important to keep the operation safe and allow effective control algorithms.
  - Erratic and unstable cavitation must be avoided.
  - Propeller air drawing (ventilation) must be avoided.
  - Pulsating separation and vortices must be avoided.



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What can/should be different for propeller design of unmanned vessels

- If the vessel is unmanned, some what larger on-board noise and vibration levels can be tolerated.
- This results in better optimisation towards higher efficiency by allowing higher noise and pressure pulses. For example diameter can be larger or blade area ratio lower.
- But there are several limiting factors:
  - Existing classification rules
  - Erosion due to cavitation
  - Structural consideration regarding vibrations
  - Instrumentation and control considerations regarding vibrations
  - Noise pollution in ocean and its impact on ocean inhabitants

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Thorough validation and verification

- Standard validation by numerical calculations and specially model testing but more operational conditions to be covered (off-design conditions, special manoeuvres, etc)
- Thorough verification in different environmental conditions, different sea states, current, wind.
- If operating in confined waters, corresponding tests required, shallow water, channel.
- Ship-to-ship interaction to be studied, at least in simulator.
- Different fault scenarios to be investigated, for example losing one propulsor, or control device (rudder etc.), fault in control system, possible damaged compartment etc.

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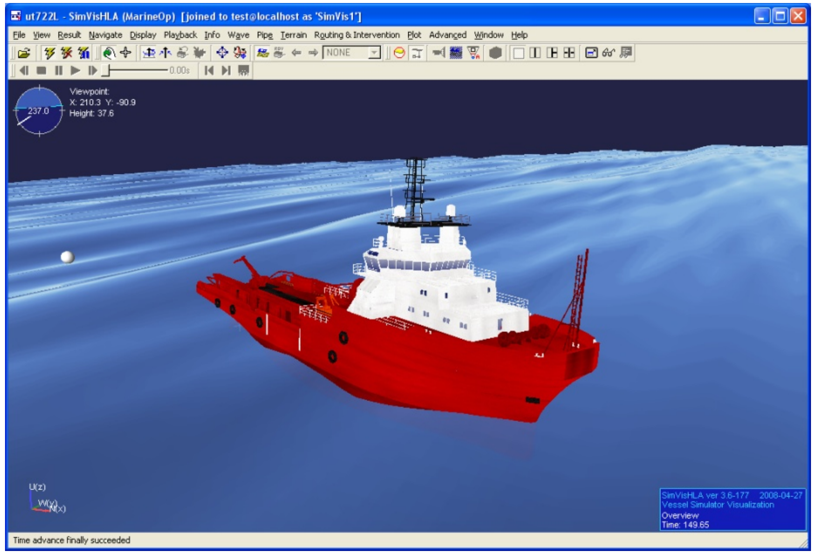
Ocean Basin Laboratory

Length: 80 m
Width: 50 m
Depth: 0-10 m
Carriage speed: 6 m/s

Accurate modules and simulators on shore

- Accurate numerical modules and digital twins are required to be able to develop and design appropriate sensors and control systems and to be able to train the crew on-board or on-shore.



- This should include hydrodynamic performance of the vessel in calm water as well as in adverse sea conditions, considering waves, wind, current and water depth.
- Accurate ship-to-ship and ship-to-shore interaction modules are required.
- These modules should include hull and propulsors but importantly also their interaction with machinery and their performance as a system.

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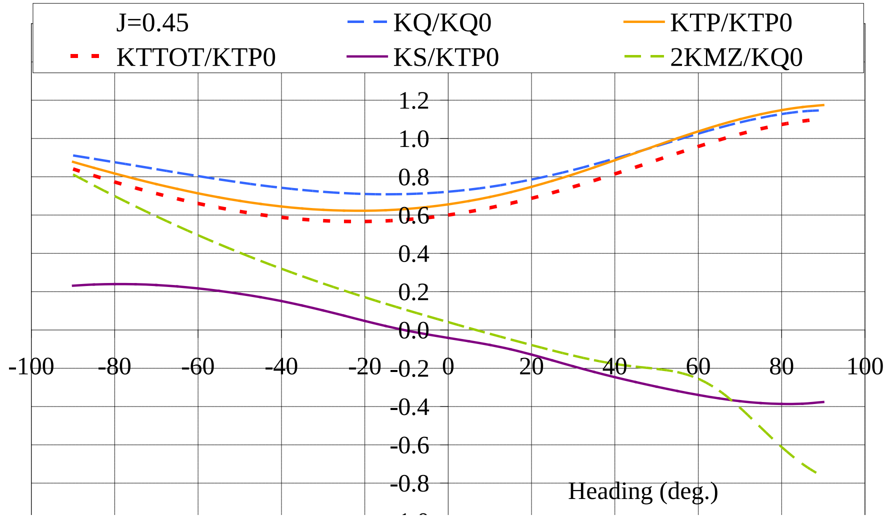
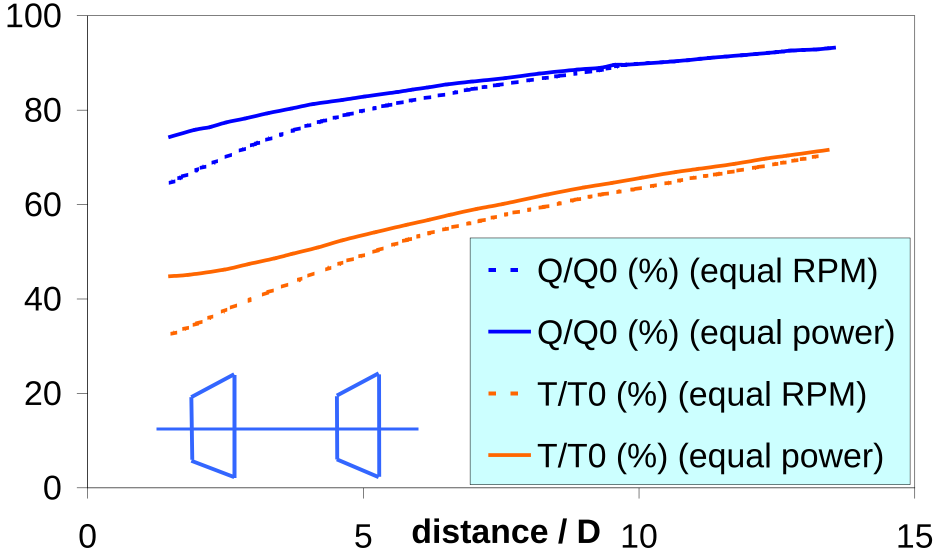
Environmental and interaction effects on propulsors

- Propulsor – propulsor interaction
- Hull – propulsor interaction
- Machinery – propulsor interaction
- Submergence
- Waves
- Current
- Water depth
- Different manoeuvres
- Propulsor motion (6 dof, except homogenous surge)





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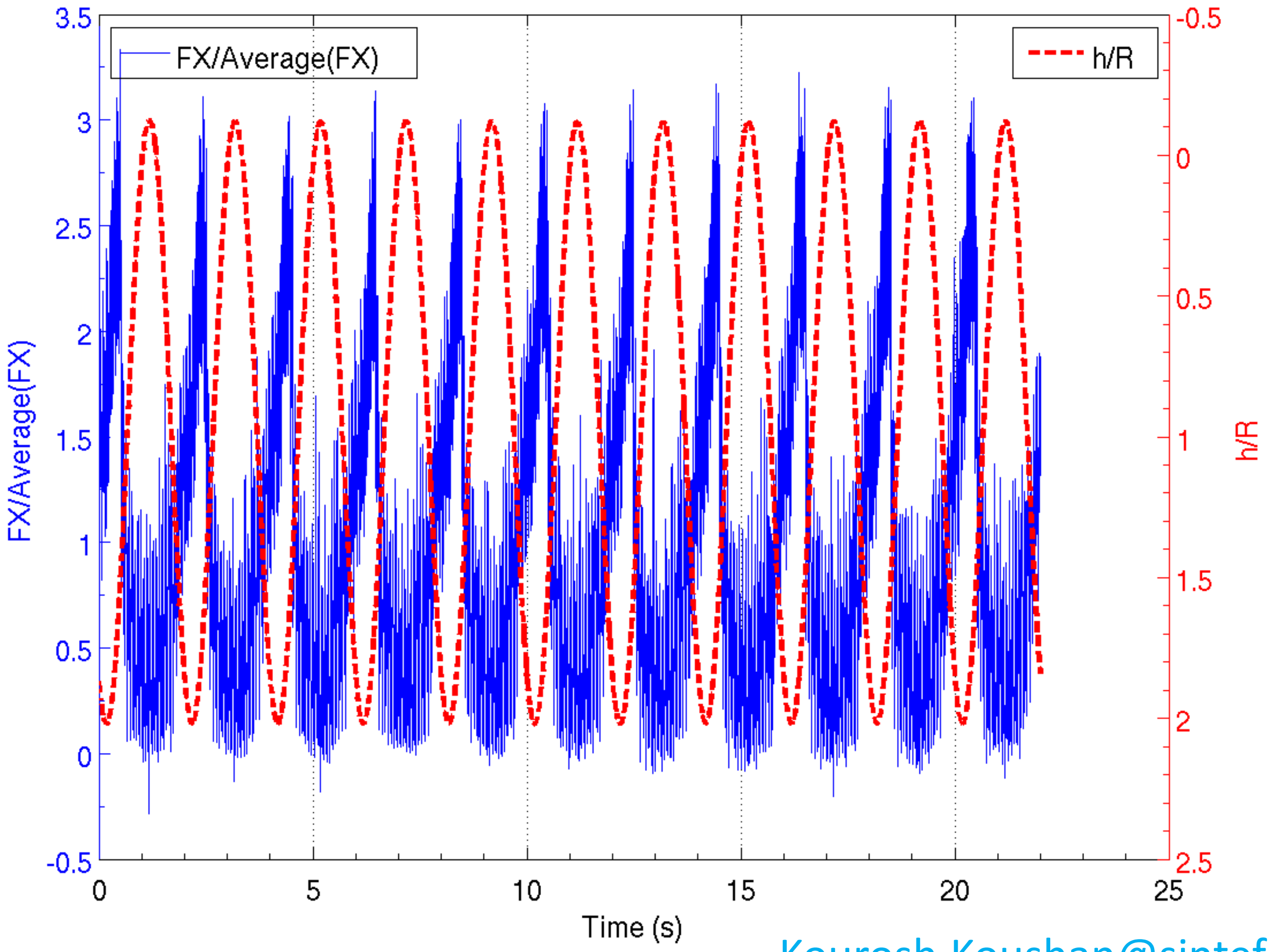
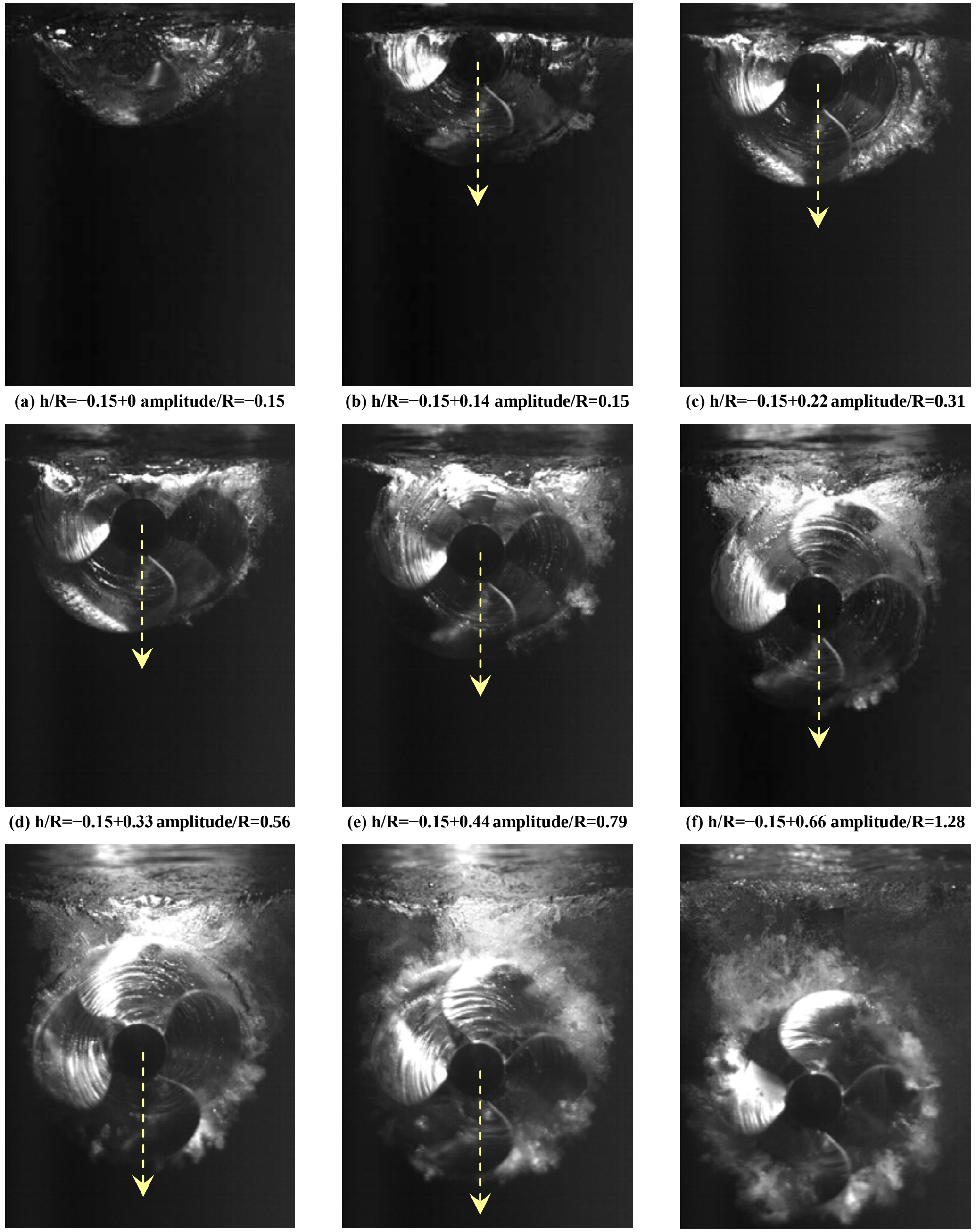
Effect of propeller ventilation on thrust





(a) h/R=−0.15+0 amplitude/R=−0.15 (b) h/R=−0.15+0.14 amplitude/R=0.15 (c) h/R=−0.15+0.22 amplitude/R=0.31

(d) h/R=−0.15+0.33 amplitude/R=0.56 (e) h/R=−0.15+0.44 amplitude/R=0.79 (f) h/R=−0.15+0.66 amplitude/R=1.28

(g) h/R=−0.15+0.76 amplitude/R=1.48 (h) h/R=−0.15+0.84 amplitude/R=1.66 (i) h/R=−0.15+1 amplitude/R=2

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Electrical and hybrid technologies

- Environmental aspects
- Control and reliability aspects
- Unmanned vessel resulting in
  - Lighter vessel, better range for same battery capacity
  - No energy consumption for the crew accommodation (sanitary, ventilation, light, cooking, entertainment, etc.)
  - More efficient hull and propeller design provides less energy consumption and better range.

Automated system design

- New possibilities and challenges of design arising from special characteristic of unmanned and autonomous vessels might result in radically different optimal ship designs.
- Traditional ship design is highly relied on designers experience, however the designer is not familiar with the new design space for autonomous and unmanned vessels.
- Therefore an automated, artificial intelligence based ship design optimization method might end up with radically new designs, which would not have been considered by a human designer.
- It is also important to do optimization of the whole system, considering hull, propeller, machinery and control systems.

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