FUTure PRopulsion and INTegration
towards a hybrid-electric 50-seat regional aircraft

Experimental Investigation of the Energy-Harvesting Performance of an Existing Aircraft Propeller

EASN Conference 2022

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FutPrInt50

TU Delft

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 875551

European Commission

Propellers

- Propellers have a high propulsive efficiency
- Distributed propellers allow for beneficial propulsion integration
- Use of propellers in negative thrust conditions
  - Improved control authority
  - More flexible operation (steeper descent)
  - Possible reduction of community noise
- Propellers are suitable for electrification of aviation
- Recuperation of energy during descent

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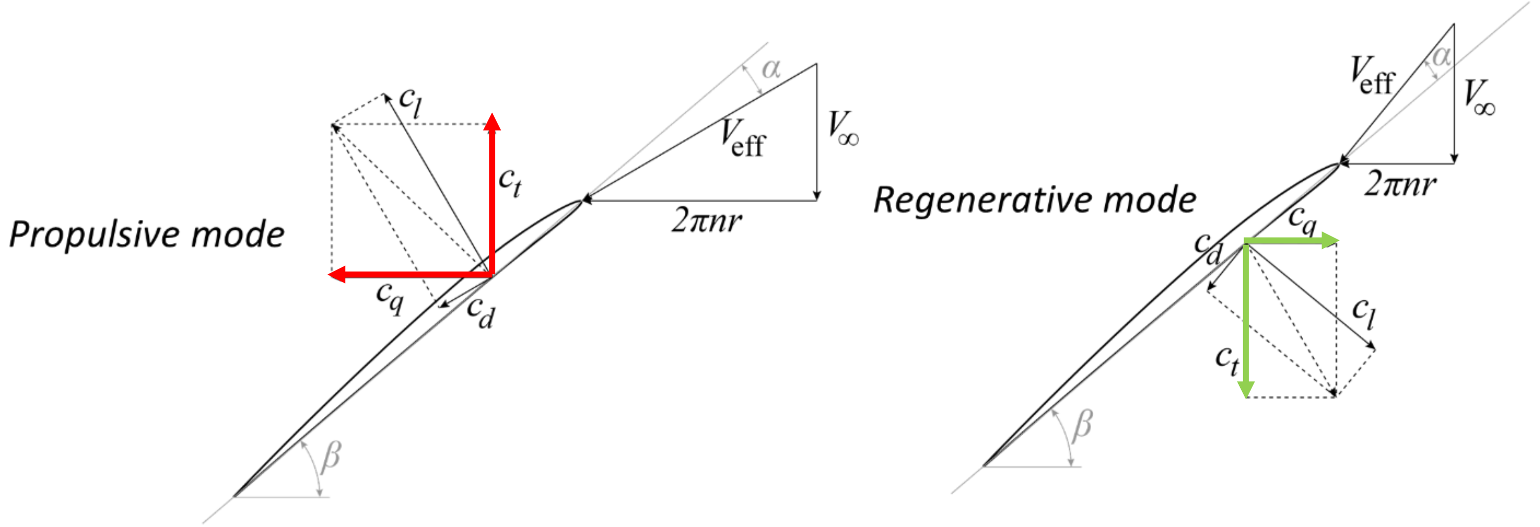
Regenerative Propellers

- Blade sections operate at negative angle of attack
- Forces are inverted compared to propulsive regime



Induced velocities ignored in sketches

Sinnige et al., AIAA 2019-3033

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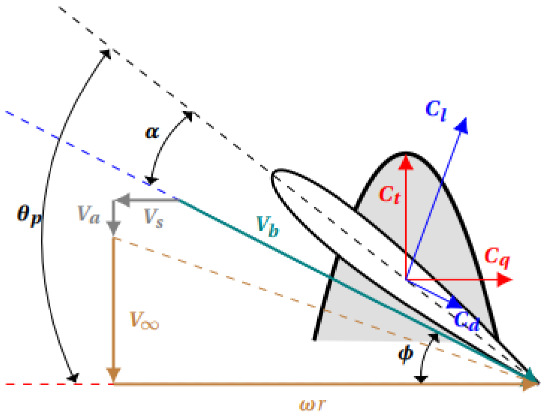
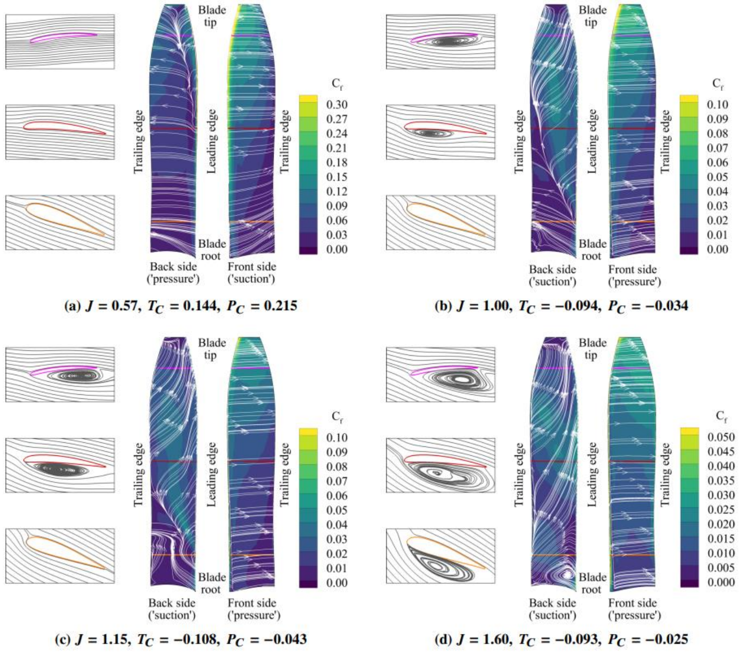
FutPrInt50 Activities

- Isolated propeller
  - Low-fidelity analysis (BEMT)
  - High-fidelity analysis (RANS + LBM)
  - Multiple experiments





Goyal et al., AIAA 2021-2187

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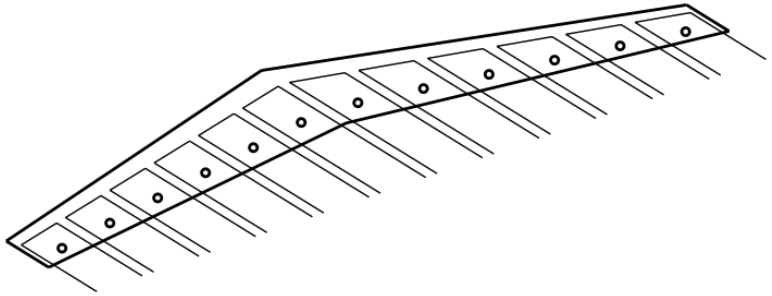
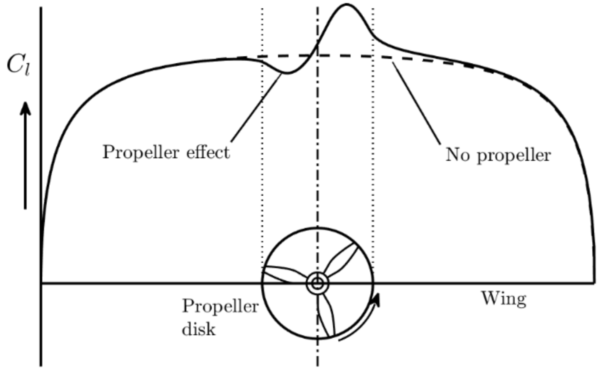
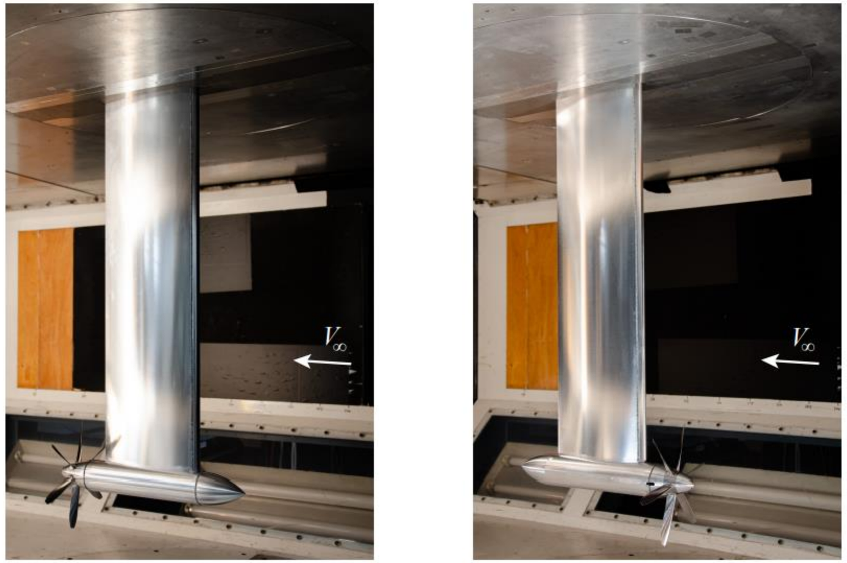
FutPrInt50 Activities

- Installed propeller-wing configuration
  - Low-fidelity analysis (VLM)
  - Installed experiment (wingtip mounted)







a) Tractor configuration b) Pusher configuration

Sinnige et al., AIAA 2021-2511

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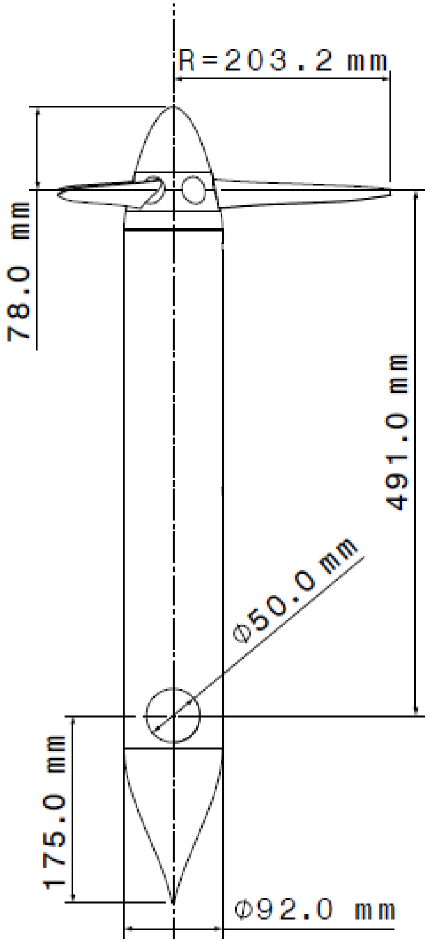
Wind Tunnel Setup

- 3-bladed XPROP propeller
- TUD LTT



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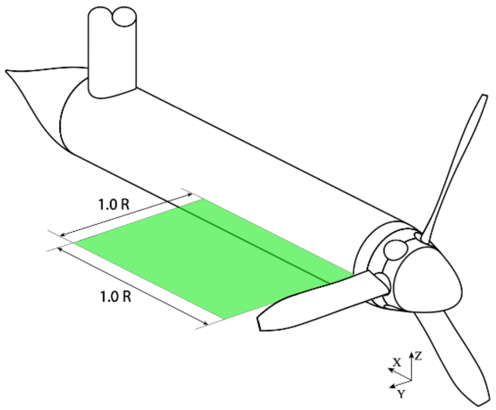
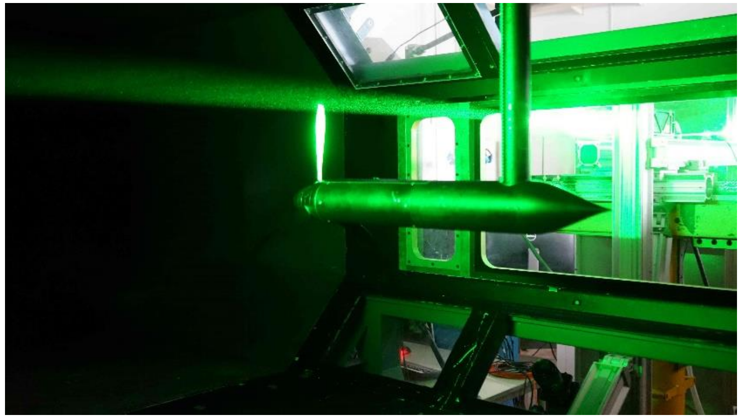
Measurement Techniques

- Propeller performance
  - 5 different pitch settings
  - External balance (system forces)
  - Stationary load cell (propeller forces)



- Flow field measurements
  - 1 specific pitch setting (15 deg blade pitch)
  - Slipstream analysis
  - Blade sectional flow



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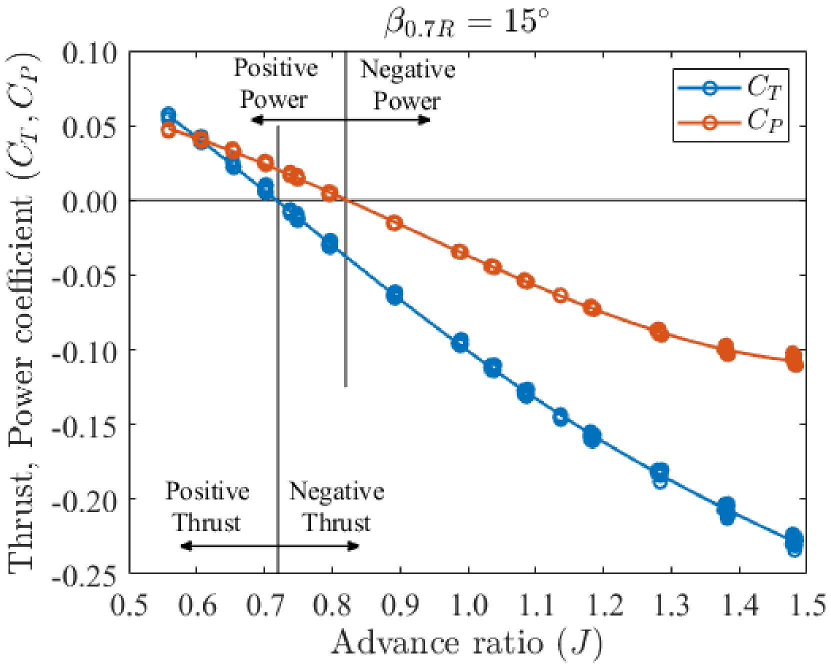
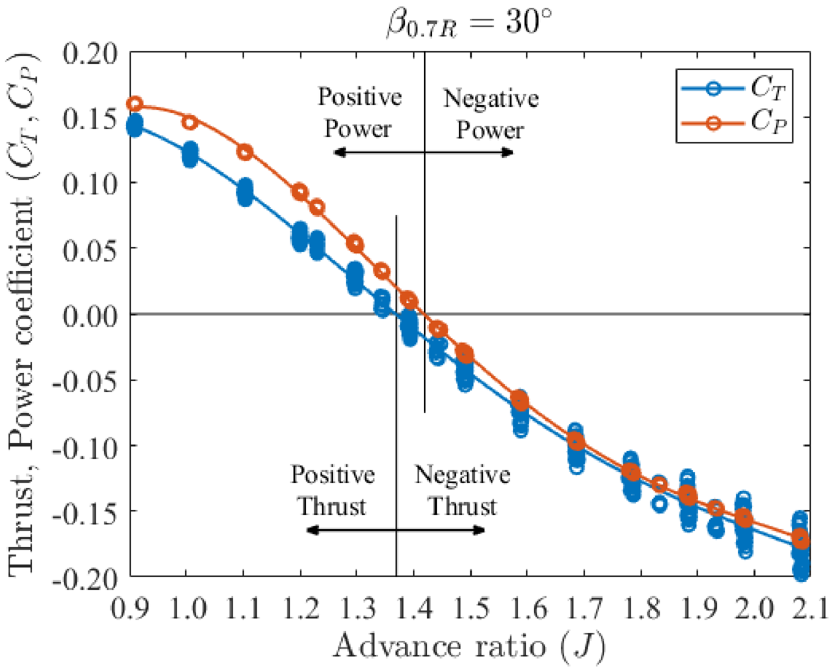
Performance in Different Regimes

- Thrust and torque in both positive and negative thrust regimes
- $C_T = \frac{T}{\rho n^2 D^4}$ $C_P = \frac{P}{\rho n^3 D^5}$





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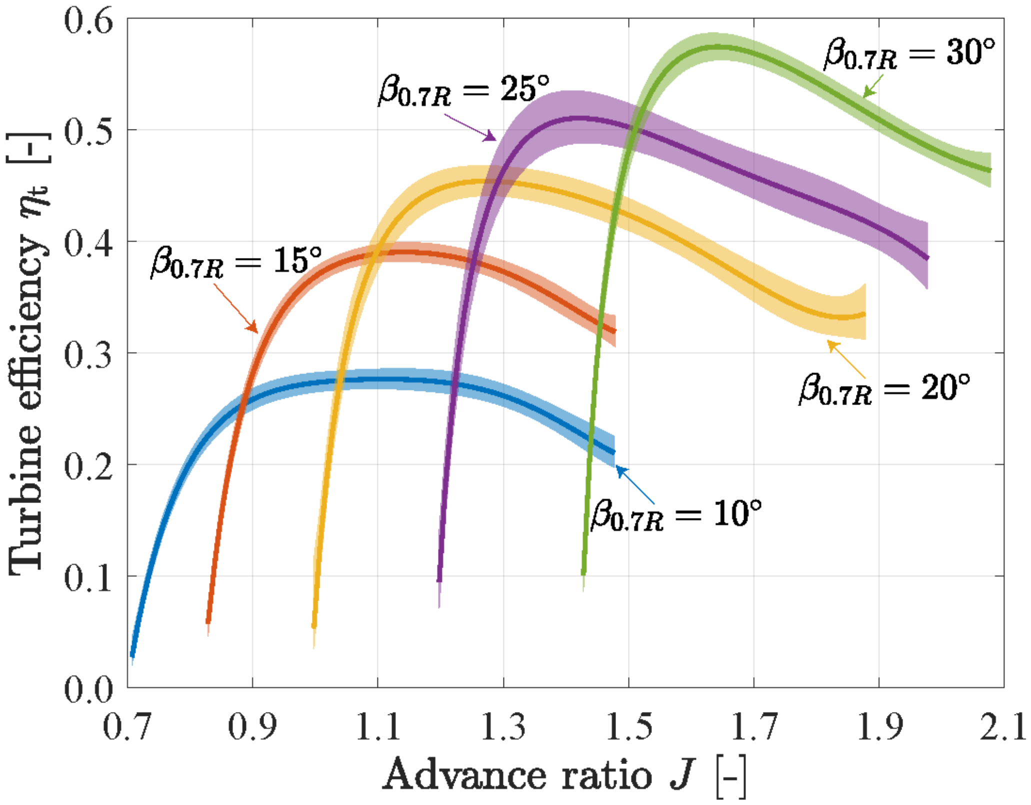
Turbine Efficiency

- Turbine efficiency is highest for large pitch angles
- $\eta_t = \frac{P}{TV_\infty} = \frac{1}{\eta_p}$



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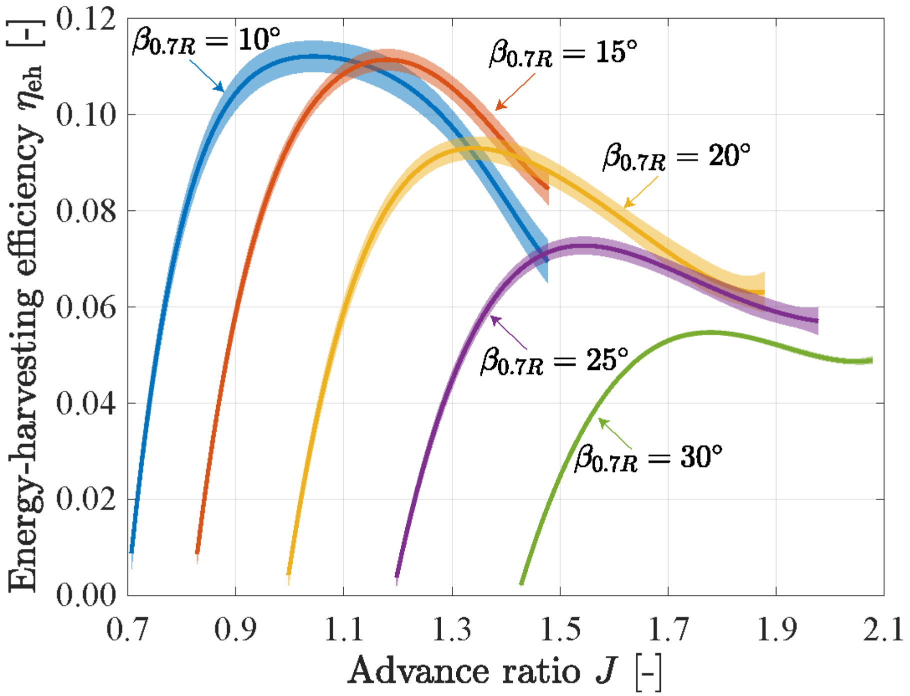
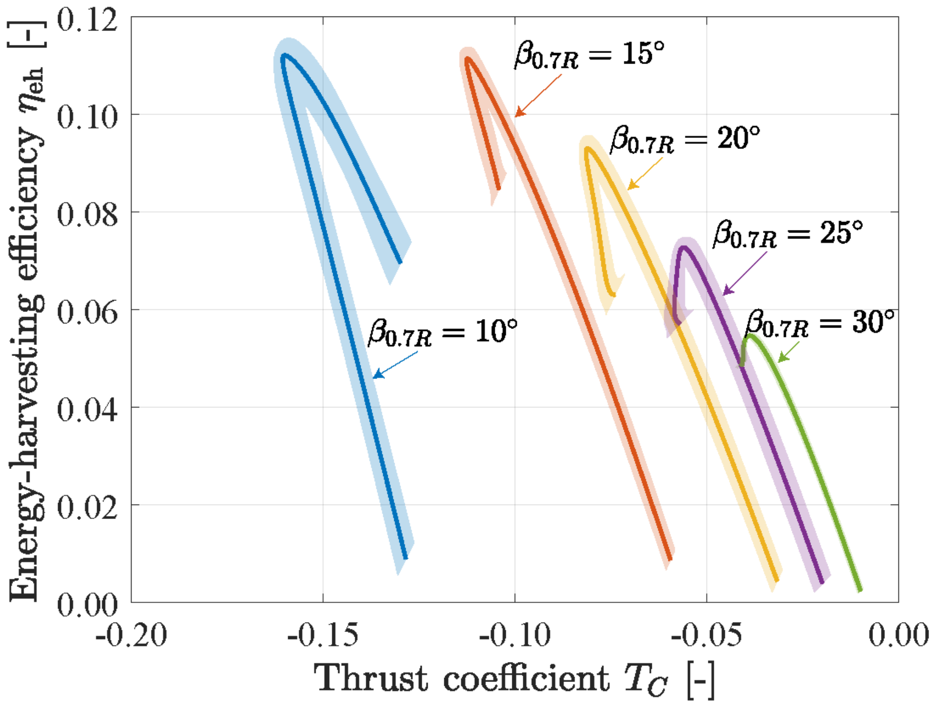
Energy-Harvesting Efficiency

- Most amount of energy-harvesting happens at small pitch angles
- $\eta_{eh} = \dfrac{P}{\frac{1}{2}\rho V_\infty^3 A}$





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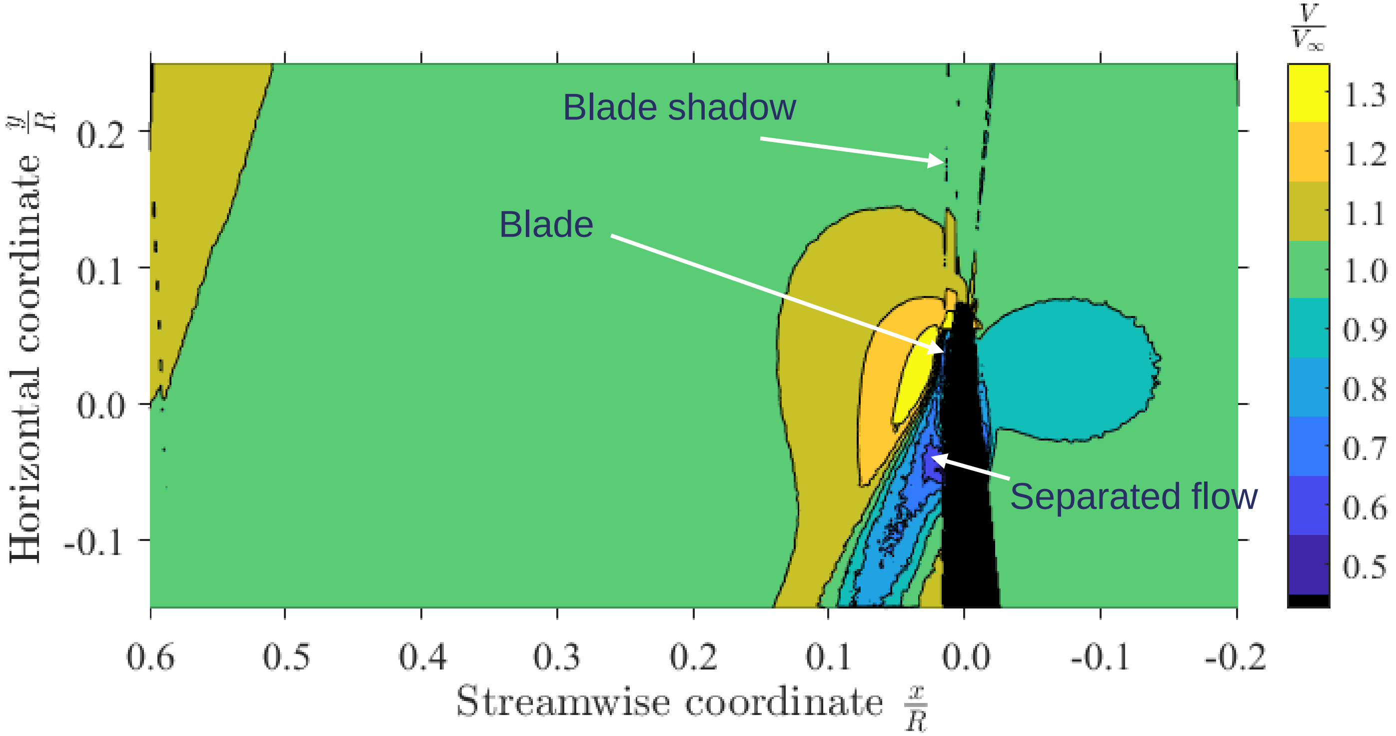
- Flow around the blade segment at the tip is separated



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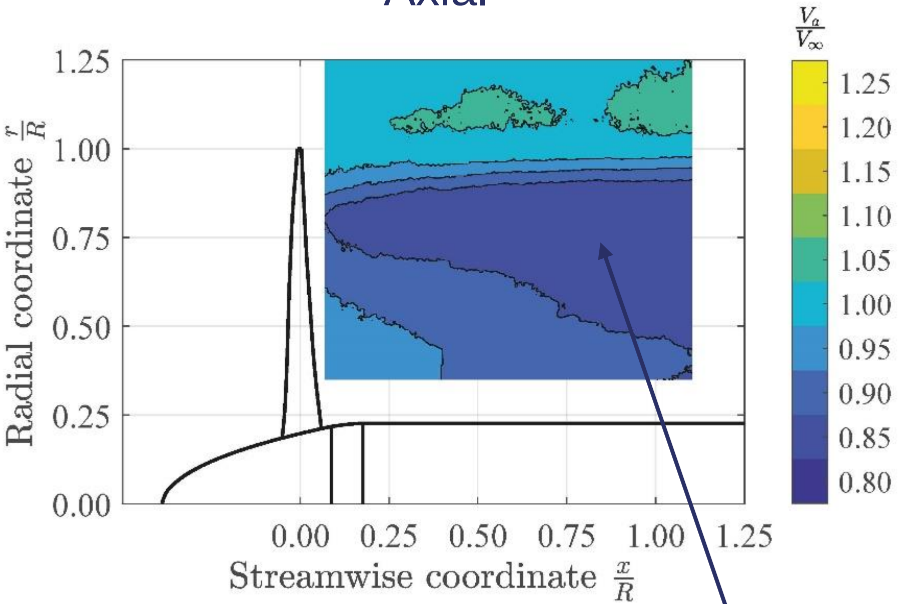
Slipstream Analysis

- Propeller induced velocities for $\beta_{0.7R} = 15°$ (J=1.10)
- Opposite to propulsive mode

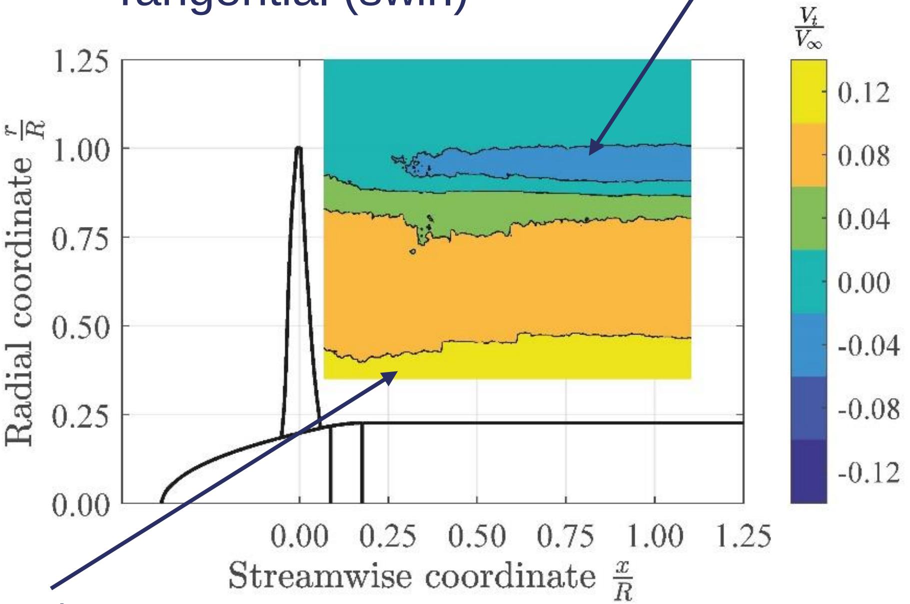
Axial



Highest deceleration

Tangential (swirl)

Positive torque
(drag due to separation)



Highest negative torque

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Conclusions

- Propellers designed for propulsive conditions have a low regenerative performance, even at low pitch settings.
- Lower pitch yields higher energy-harvesting efficiency.
- Higher pitch yields lower drag for a given energy-harvesting power.
- Energy-harvesting mode is dominated by stall on the blade segments.
- The slipstream velocities are inverted in the slipstream for the energy-harvesting mode.
- The opposite swirl direction for energy-harvesting propellers could have detrimental consequences for the propeller-wing interaction, especially for tip-mounted propellers.

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THANK YOU!

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