

# CFD Simulations of Wind Turbines

Krzysztof Tesch

Gdansk University of Technology

# Introduction

**Introduction**

Classification

Coefficients

HAWT

VAWT

Unconventional

- Horizontal Axis Wind Turbines (HAWT)
  - ◆ One-, two-, three-bladed
  - ◆ Multi-bladed
  - ◆ Archimedes
- Vertical Axis Wind Turbines (VAWT)
  - ◆ Savonius
  - ◆ Darrieus
  - ◆ Combined
  - ◆ Banki–Michell
  - ◆ Piskorz
- Unconventional

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**Classification**

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- Torque coefficient

$$C_T = \frac{T}{\frac{1}{4}\rho U^2 DA}$$

- Power coefficient

$$C_P = \frac{\omega T}{\frac{1}{2}\rho U^3 A}$$

- Tip speed ratio

$$\lambda = \frac{\omega R}{U} = \frac{\omega D}{2U} = \frac{C_P}{C_T}$$

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# Averaged coefficients

- Torque coefficient

$$\bar{C}_T = \frac{\bar{T}}{\frac{1}{4}\rho U^2 DA}$$

- Power coefficient

$$\bar{C}_P = \frac{\omega \bar{T}}{\frac{1}{2}\rho U^3 A}$$

where  $\tau = n \Delta t$  (e.g. one revolution,  $\Delta t = \text{const}$ )

$$\bar{T} = \frac{1}{\tau} \int_t^{t+\tau} T(t) dt \approx \frac{1}{\tau} \sum_{i=1}^n T_i \Delta t = \frac{1}{n} \sum_{i=1}^n T_i$$

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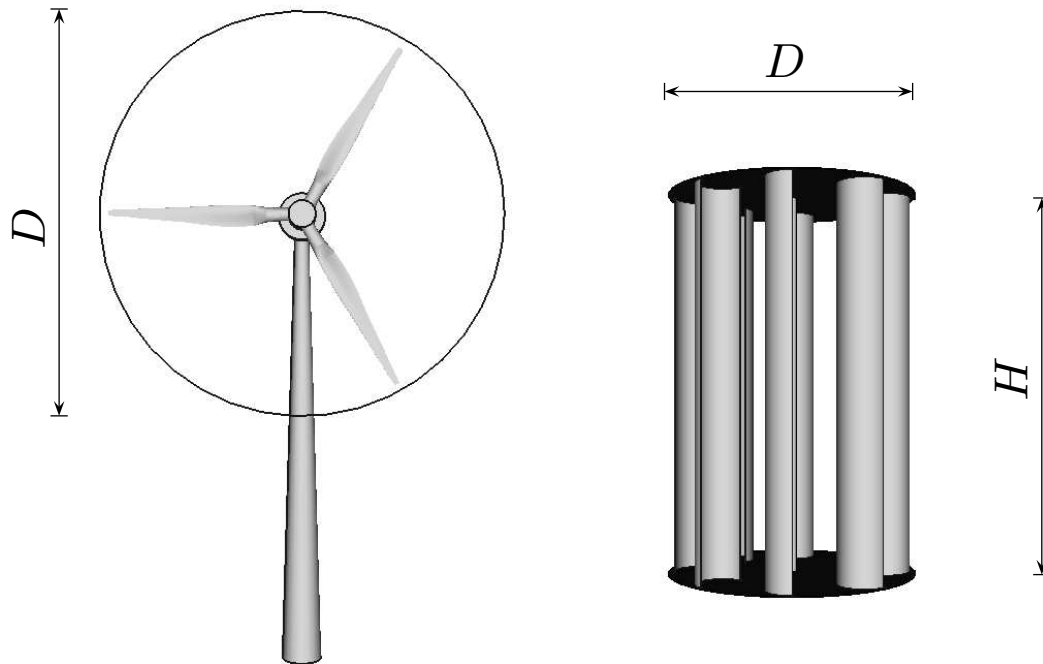
[HAWT](#)

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# Active area

$$A = \begin{cases} \frac{1}{4}\pi D^2, & \text{HAWT,} \\ DH, & \text{VAWT} \end{cases}$$



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# HAWT

Introduction

**HAWT**

Three-bladed

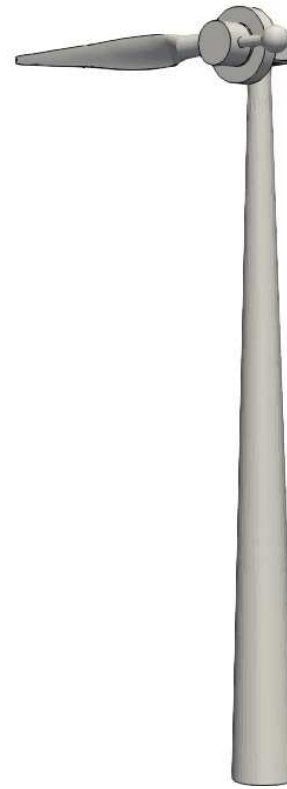
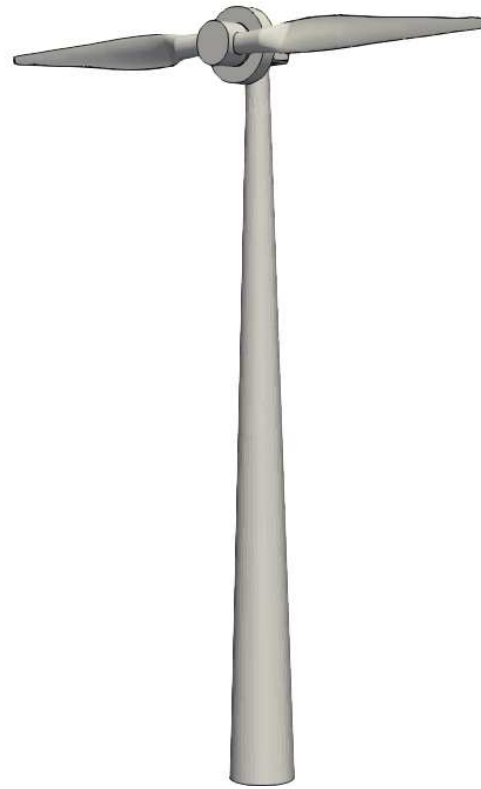
Multi-bladed

Archimedes

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# One-, two-, three-bladed



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Three-bladed

Multi-bladed

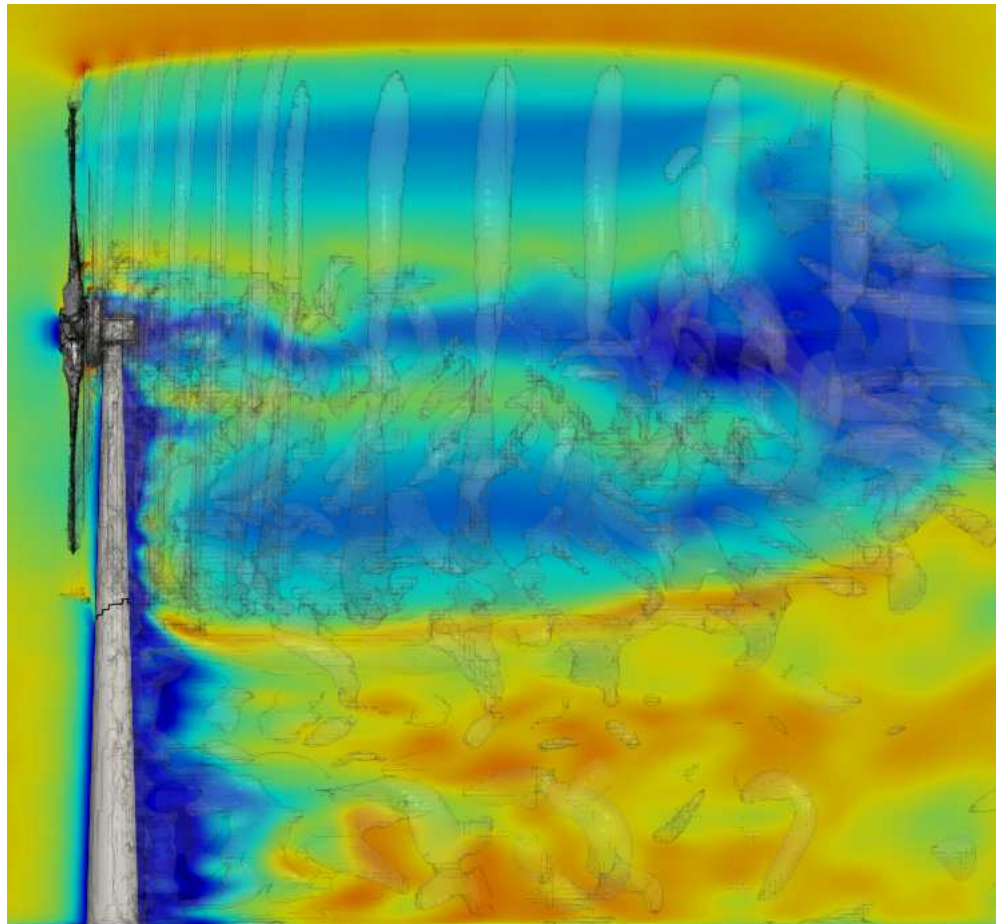
Archimedes

VAWT

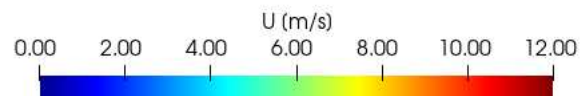
Unconventional



# Three-bladed HAWT



$t = 60.00$  s  
 $U = 8$  m/s  
 $n = 10$  rpm



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**Three-bladed**

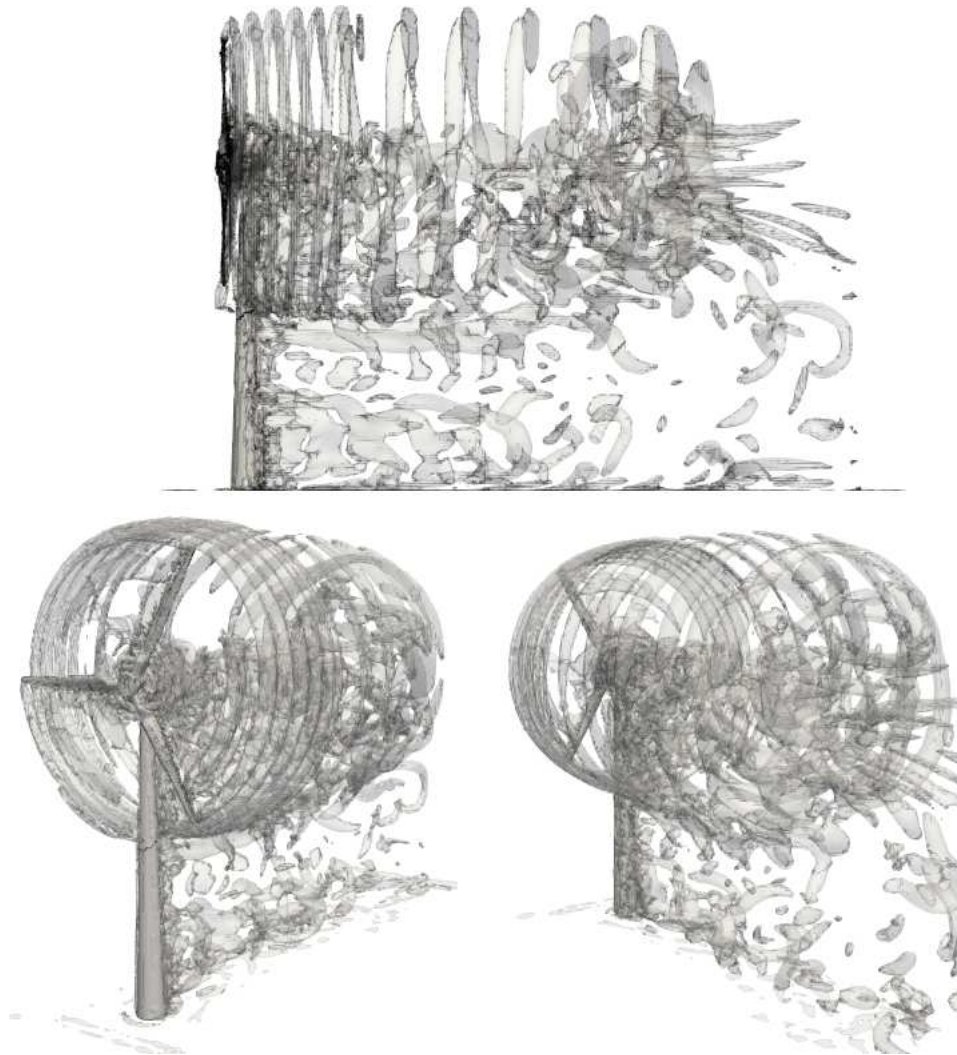
Multi-bladed

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# Three-bladed HAWT



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**Three-bladed**

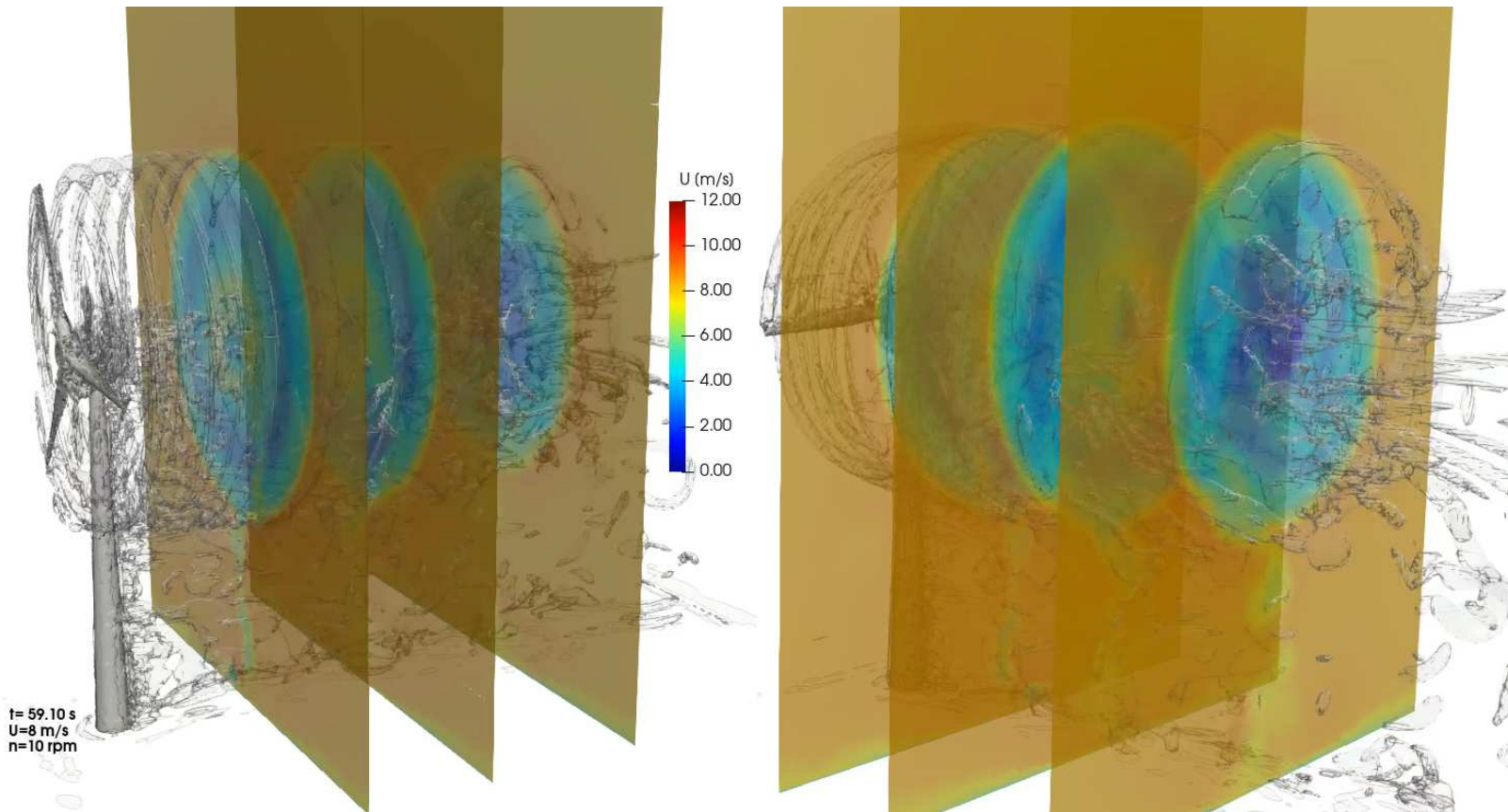
Multi-bladed

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# Three-bladed HAWT



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**Three-bladed**

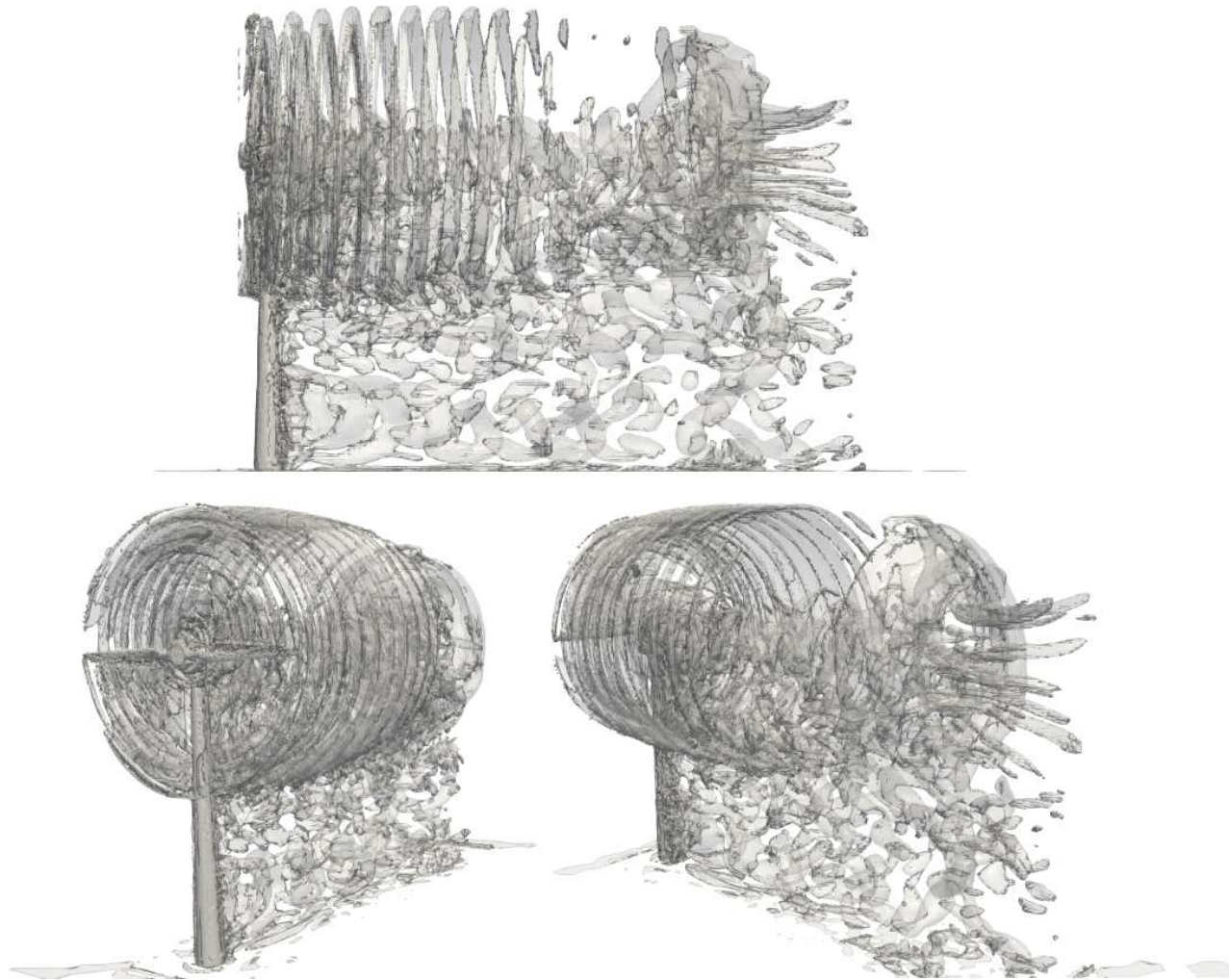
Multi-bladed

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# Two-bladed HAWT



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**Three-bladed**

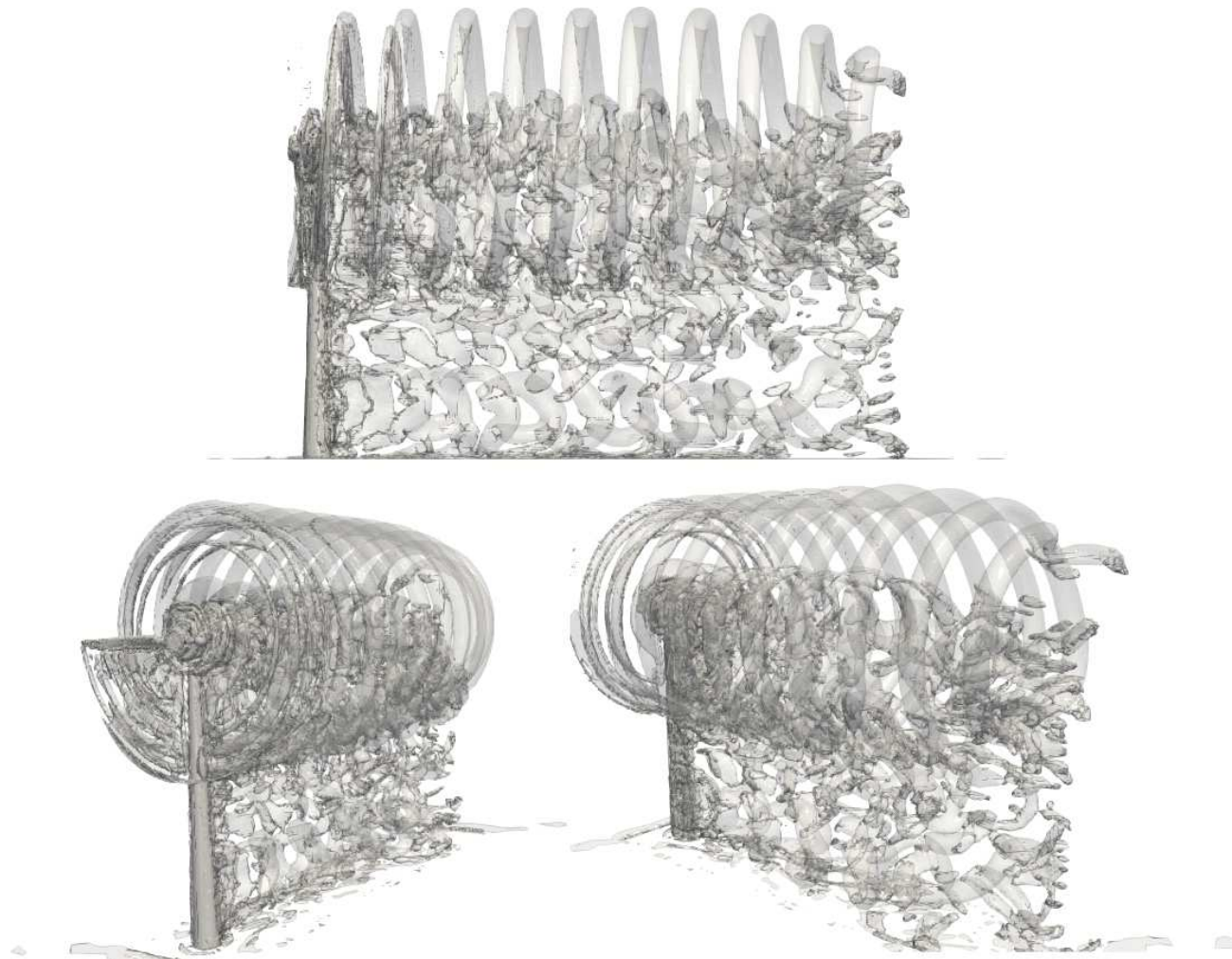
Multi-bladed

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# One-bladed HAWT



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# One-, two-, three-bladed



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**Three-bladed**

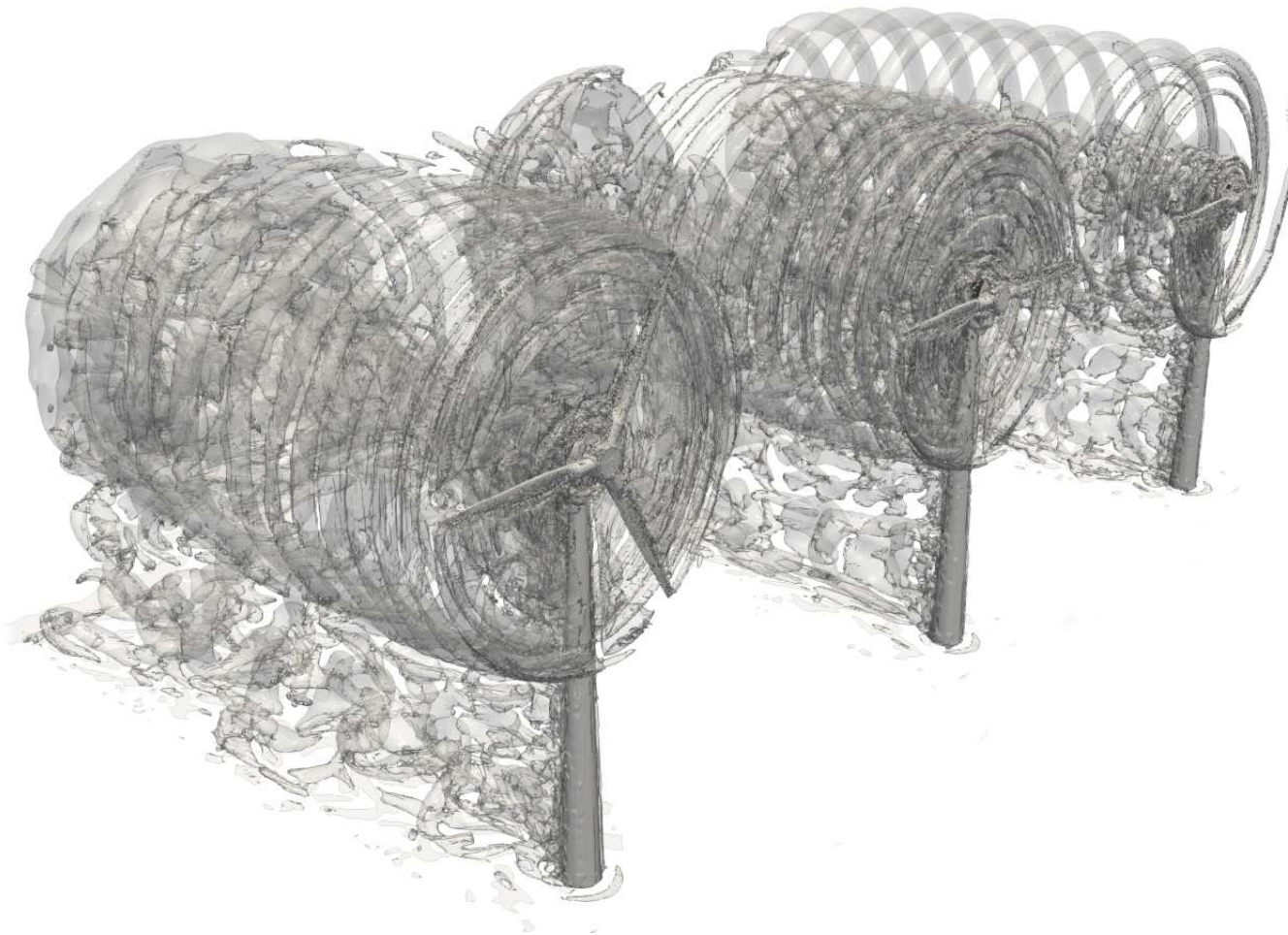
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# One-, two-, three-bladed



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# Multi-bladed

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**Multi-bladed**

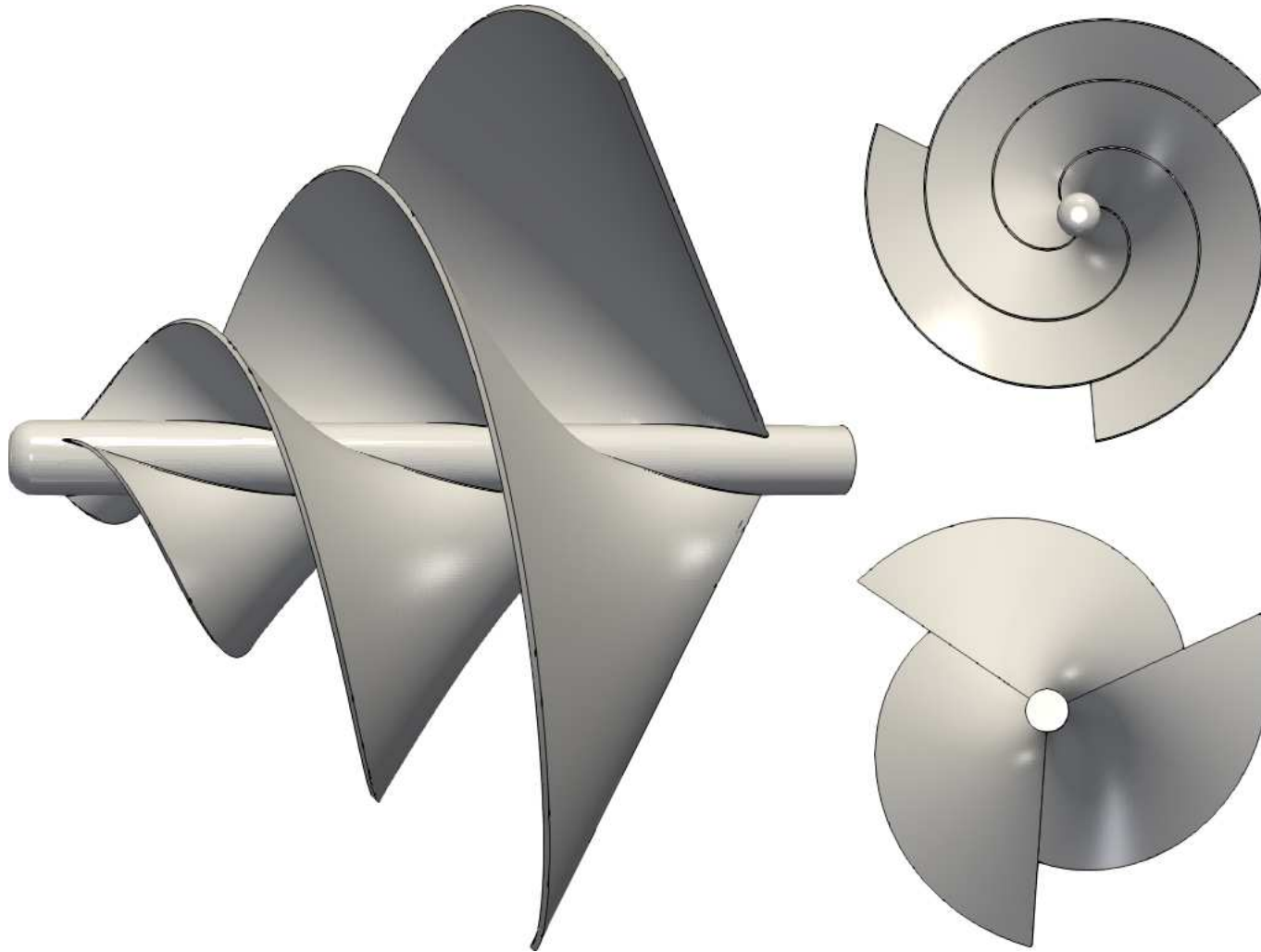
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# Archimedes



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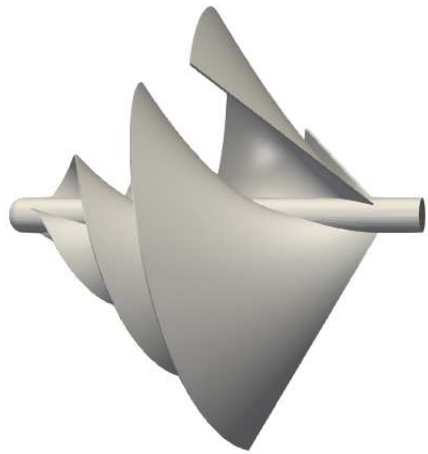
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Multi-bladed

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Time: 5.00 s

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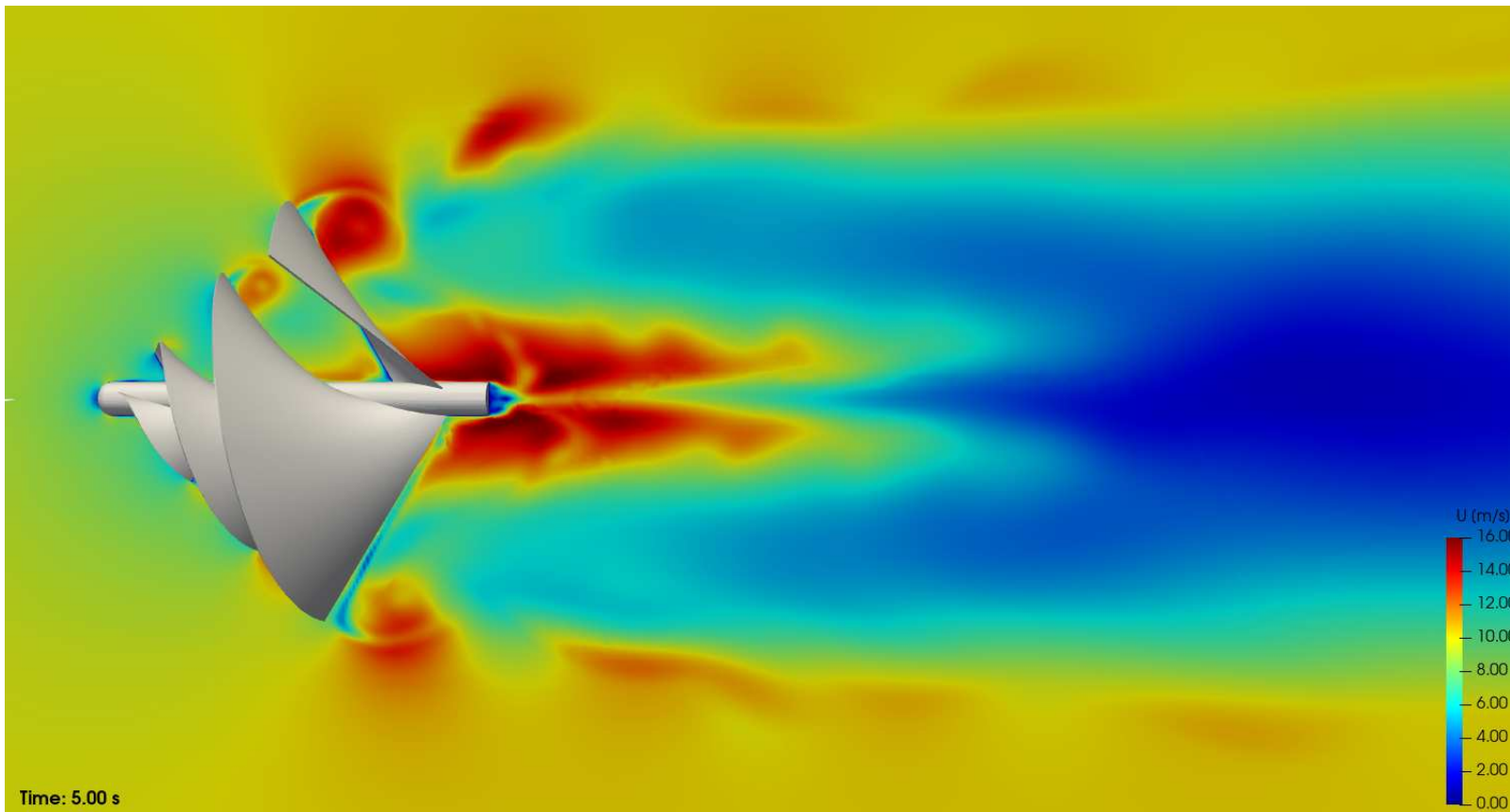
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# Archimedes



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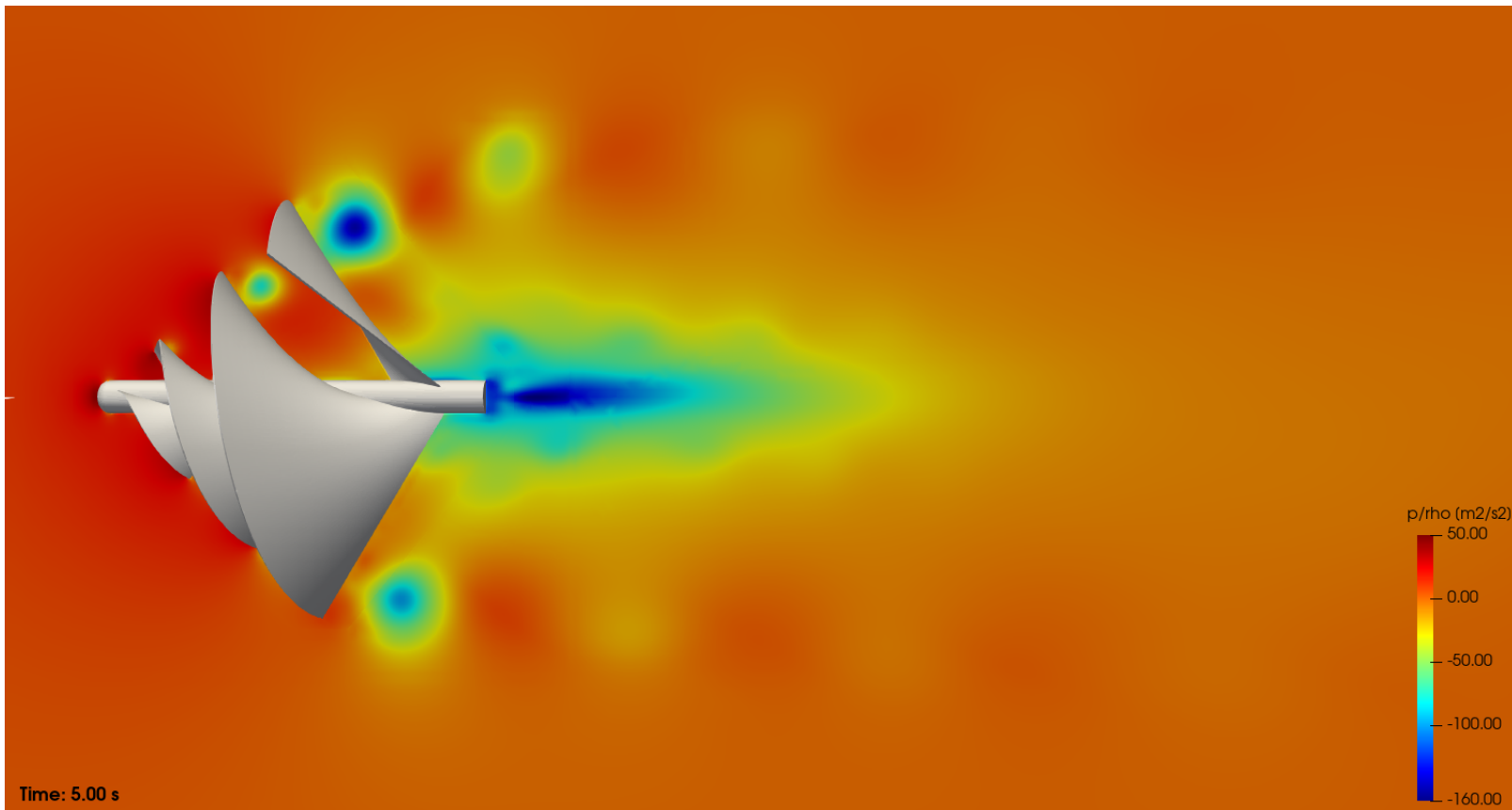
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# Archimedes



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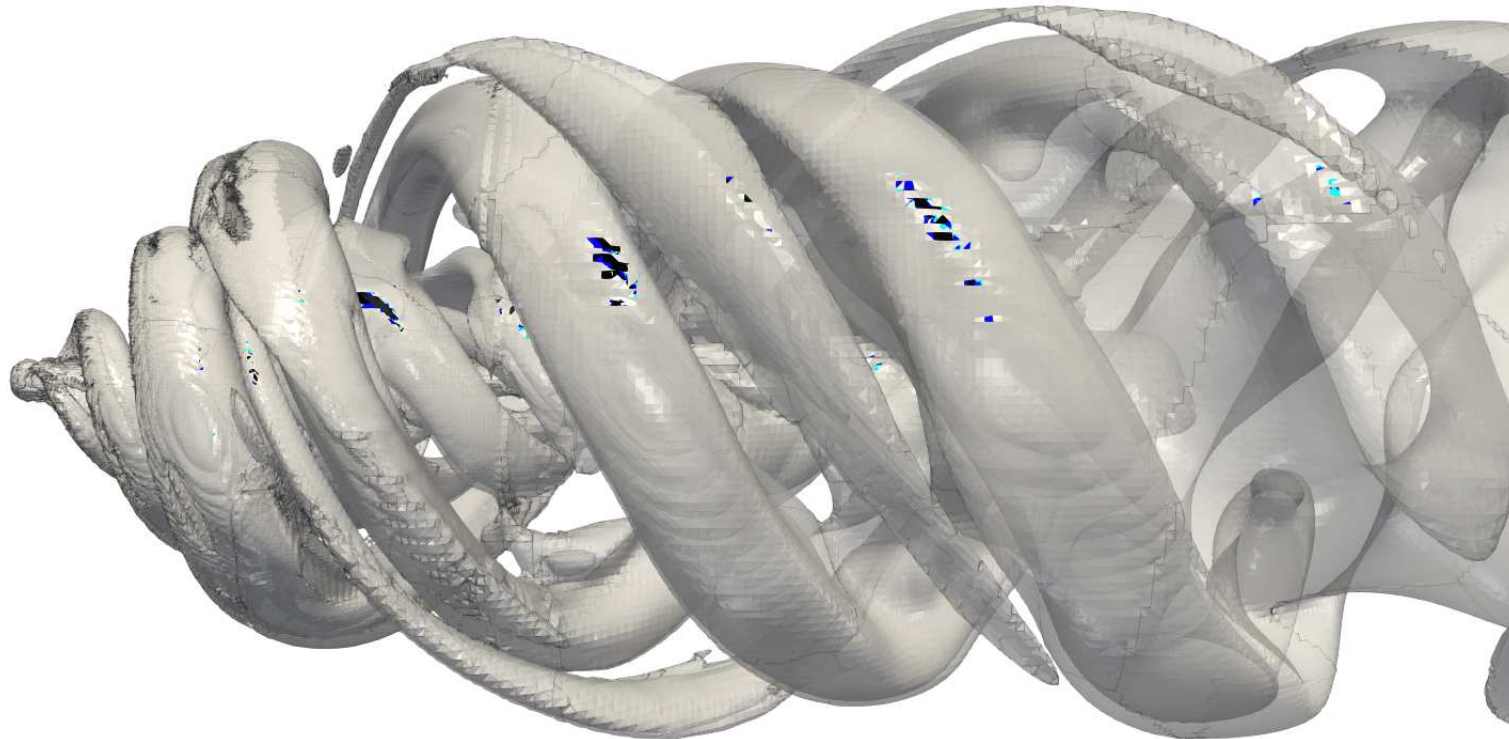
Multi-bladed

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# Archimedes



Time: 5.00 s

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# VAWT

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Savonius

Darrieus

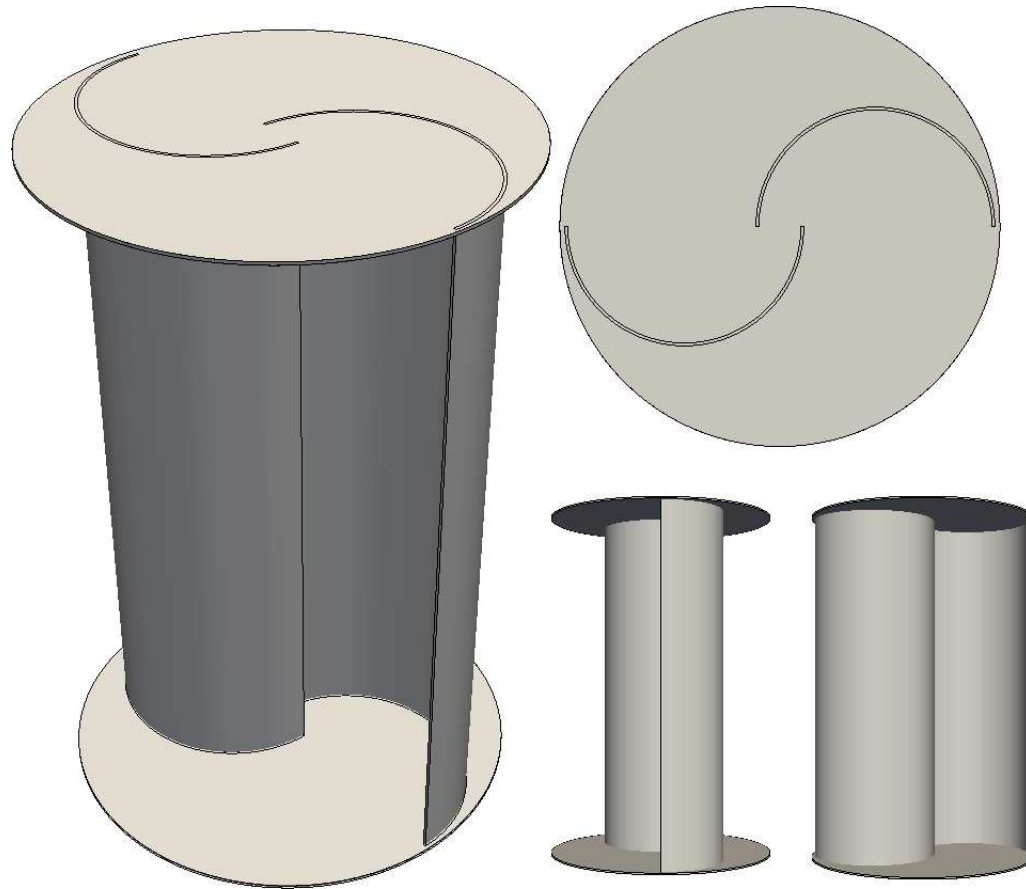
Combined

Banki–Michell

Piskorz

Unconventional

# Savonius



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Piskorz

Unconventional

- Invented by the Finnish engineer S.J. Savonius in 1922
- Already known in XVII century book *Machinae novae*
- One of the simplest (cheapest) turbines
- Low noise
- Low efficiency
- No pointing mechanism required
- Self-starting
- High torque and low rpm
- Helical blades generate smooth torque

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**Savonius**

Darrieus

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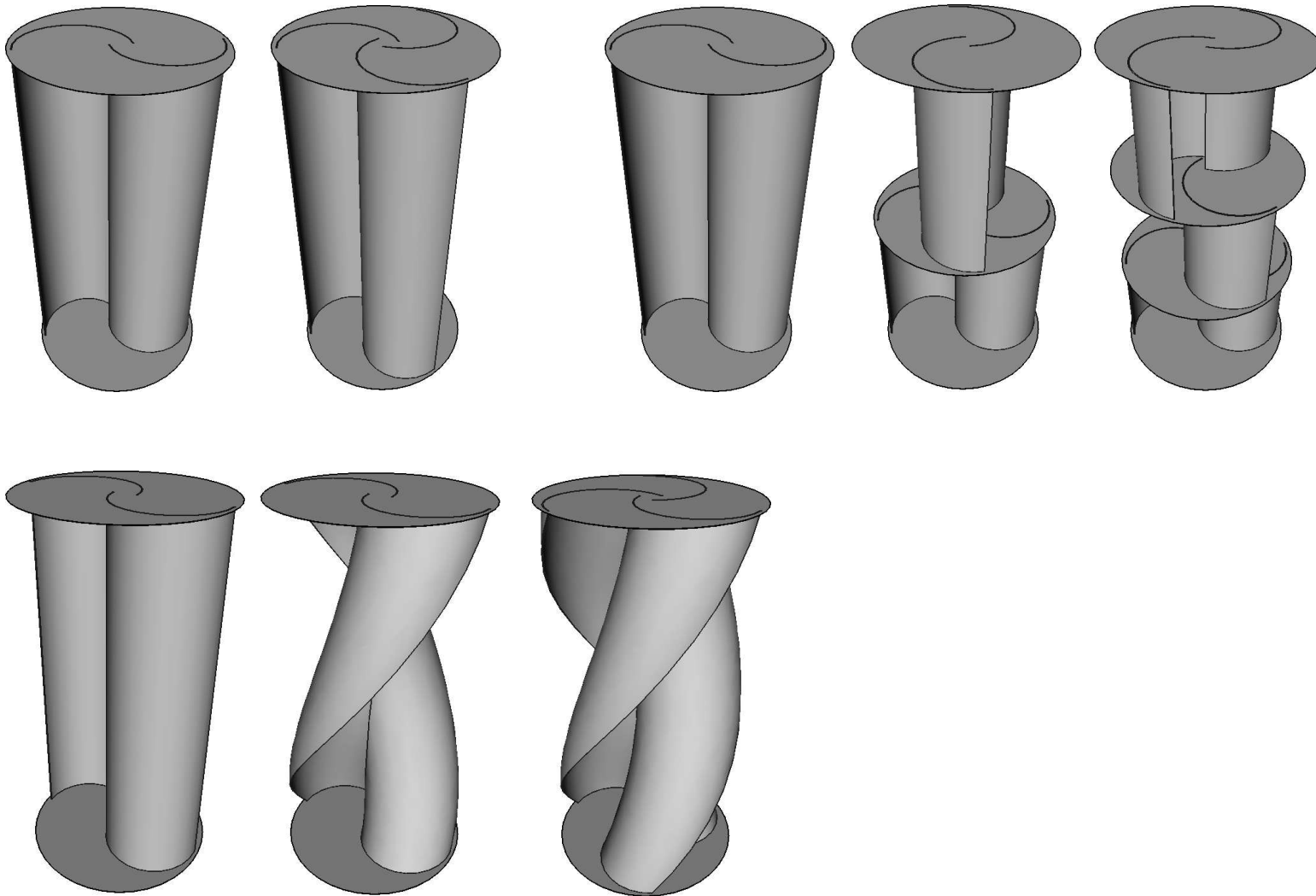
Banki–Michell

Piskorz

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# Savonius



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# Savonius

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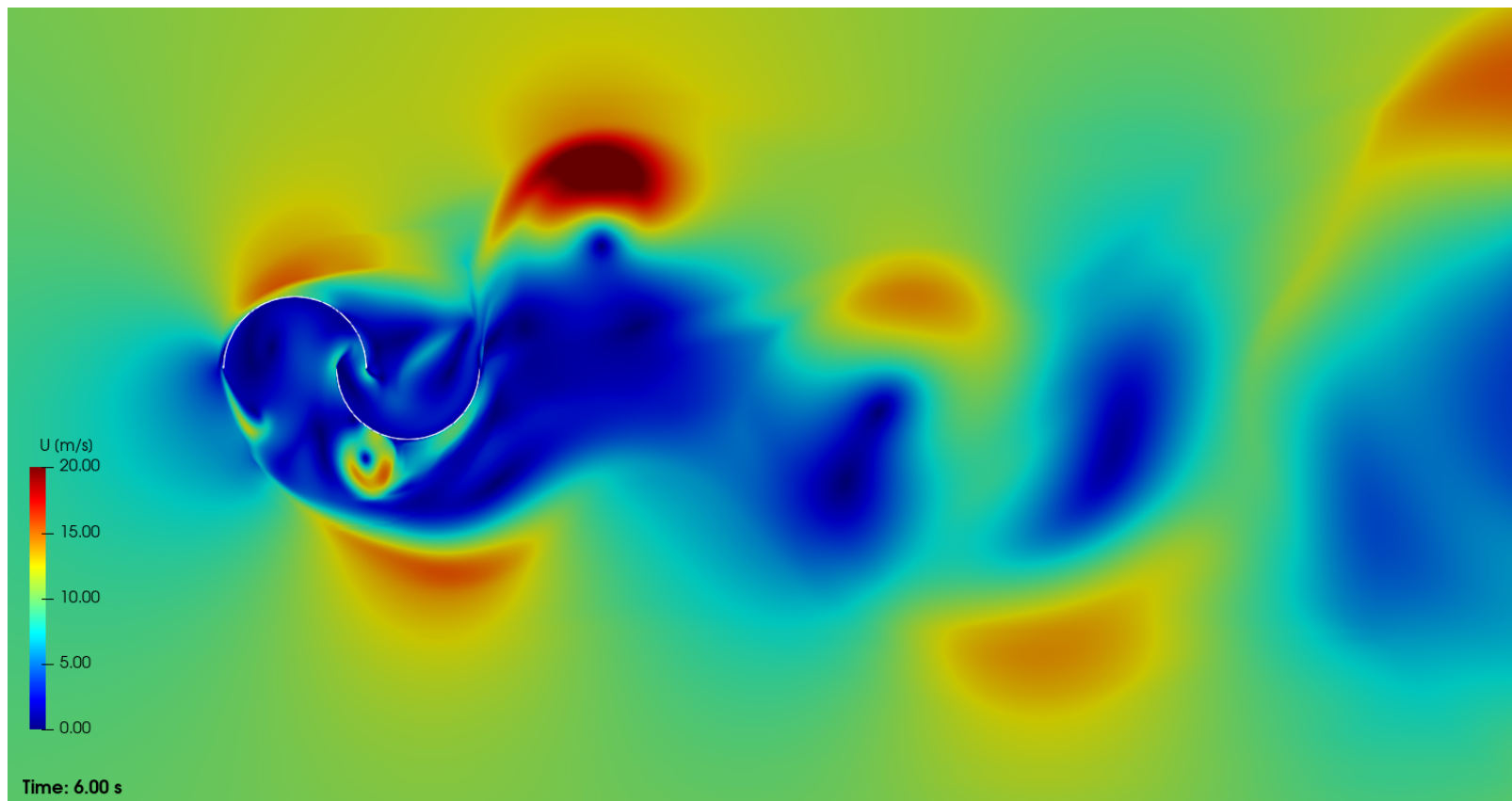
Darrieus

Combined

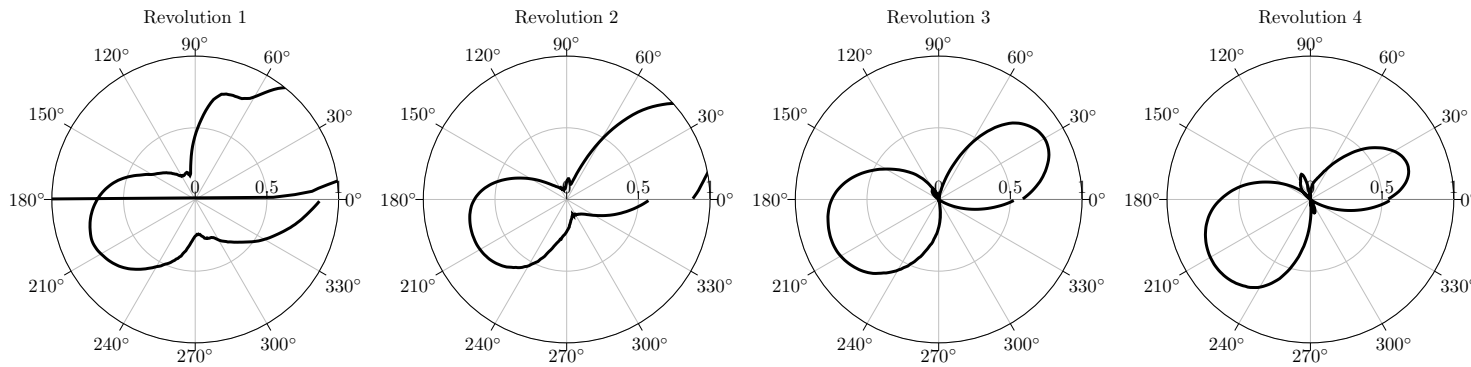
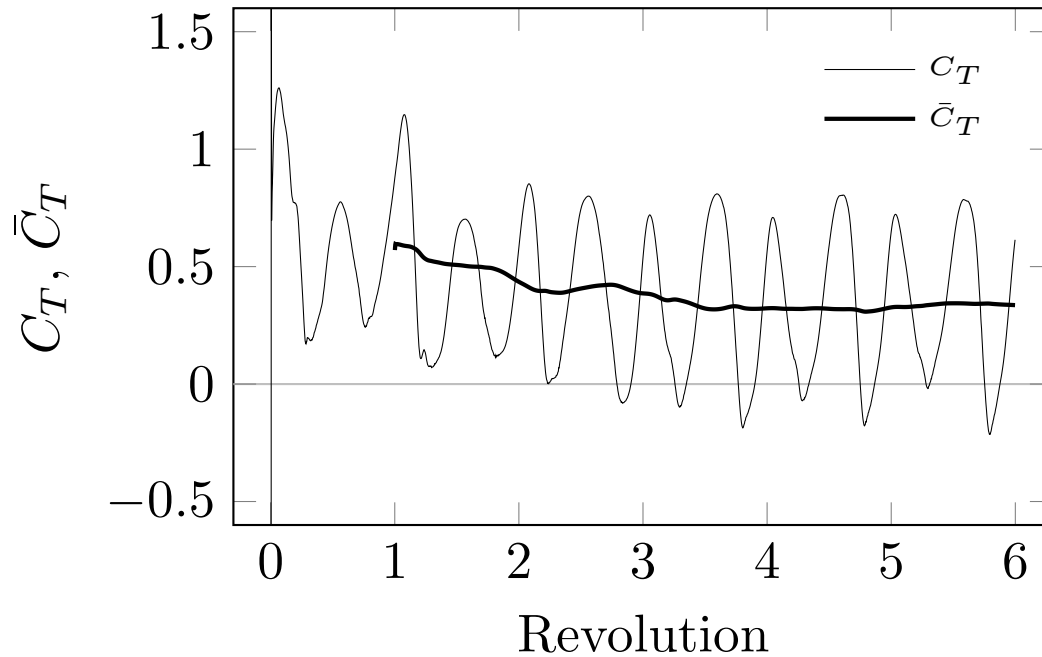
Banki–Michell

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# 2D Savonius



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Darrieus

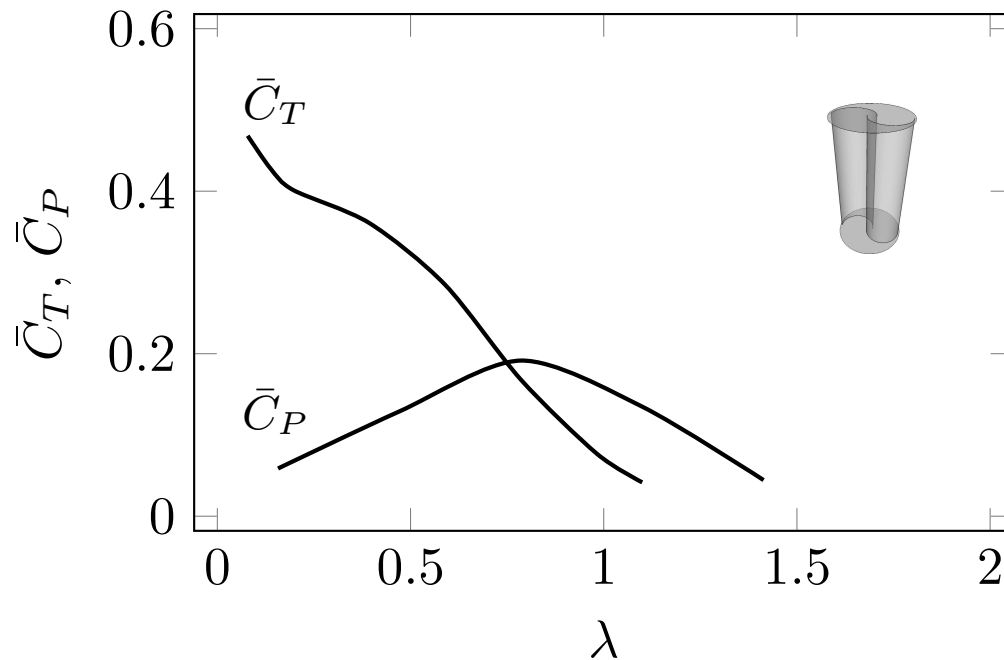
Combined

Banki–Michell

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# 2D Savonius



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Darrieus

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- Classic Darrieus
- H Darrieus
- Helical Darrieus

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**Darrieus**

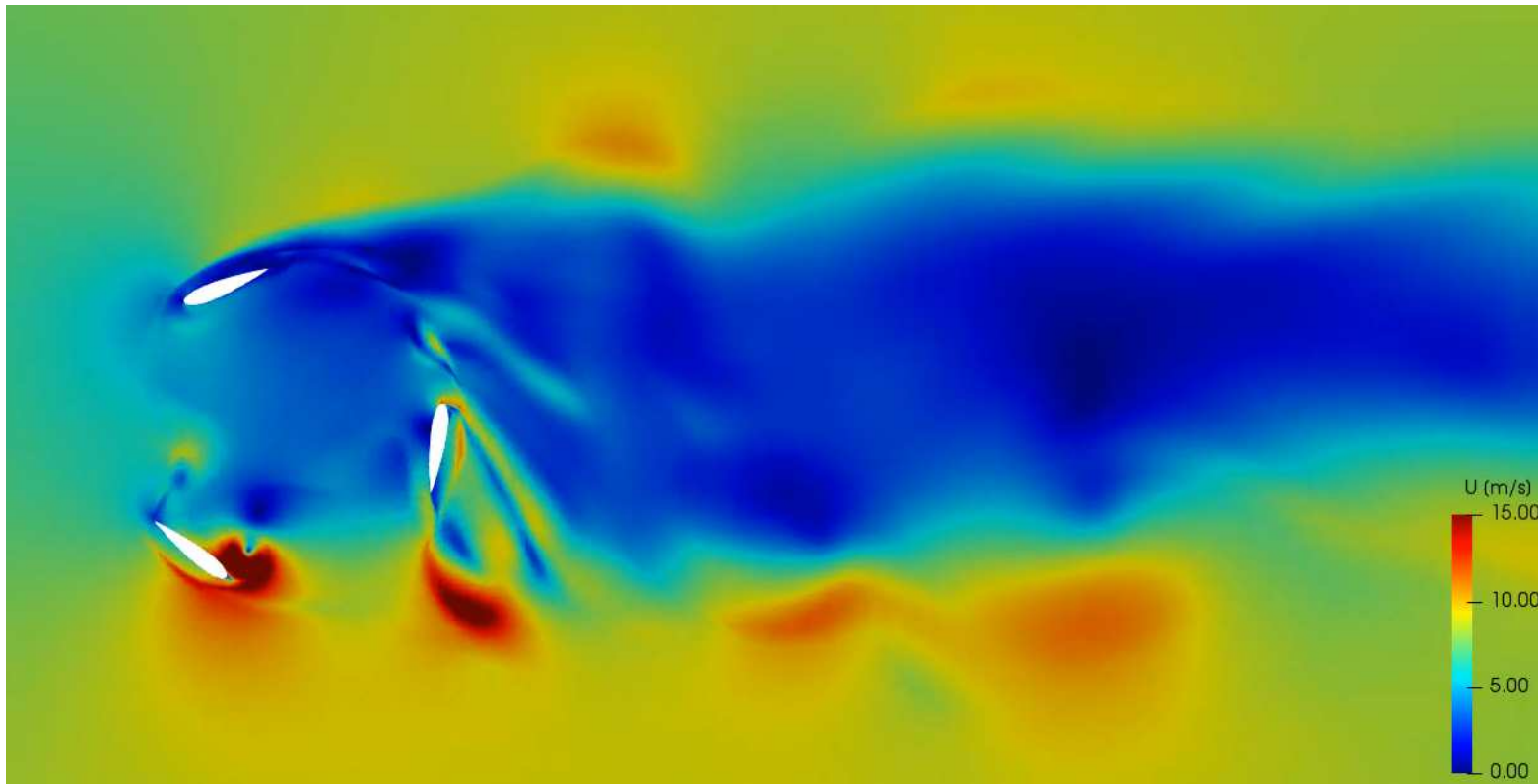
Combined

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# Darrieus



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# Combined Savonius–Darrieus

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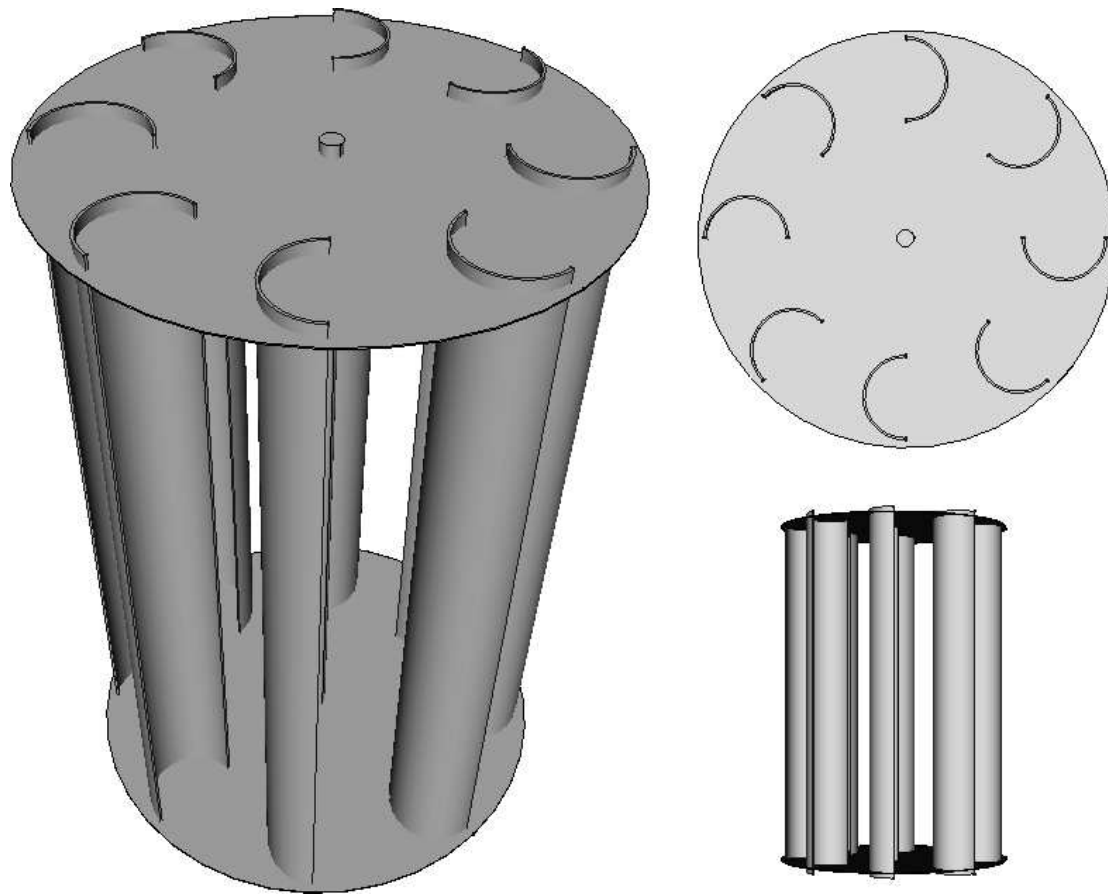
**Combined**

Banki–Michell

Piskorz

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# Banki–Michell



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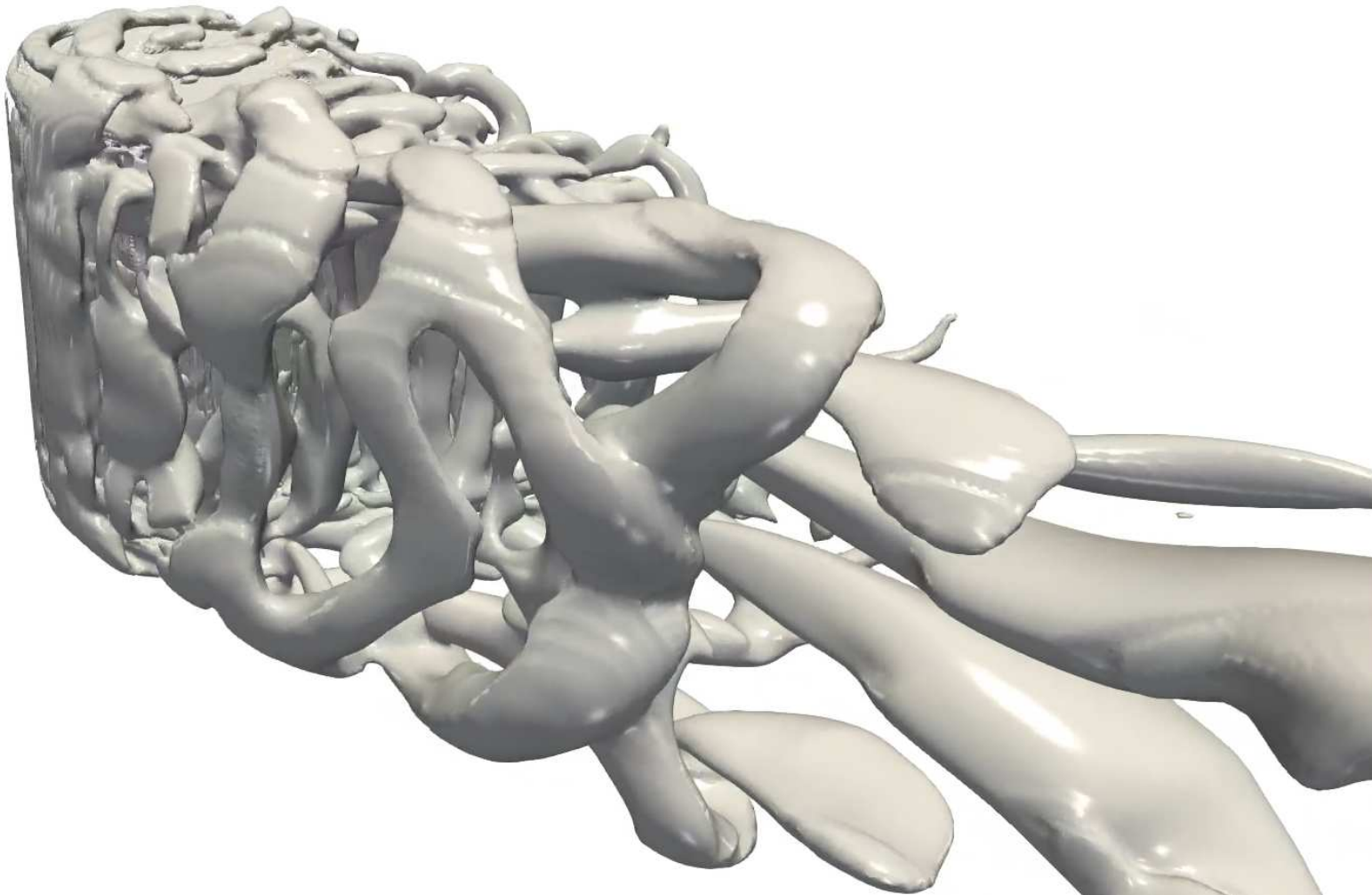
**Banki–Michell**

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# Banki–Michell



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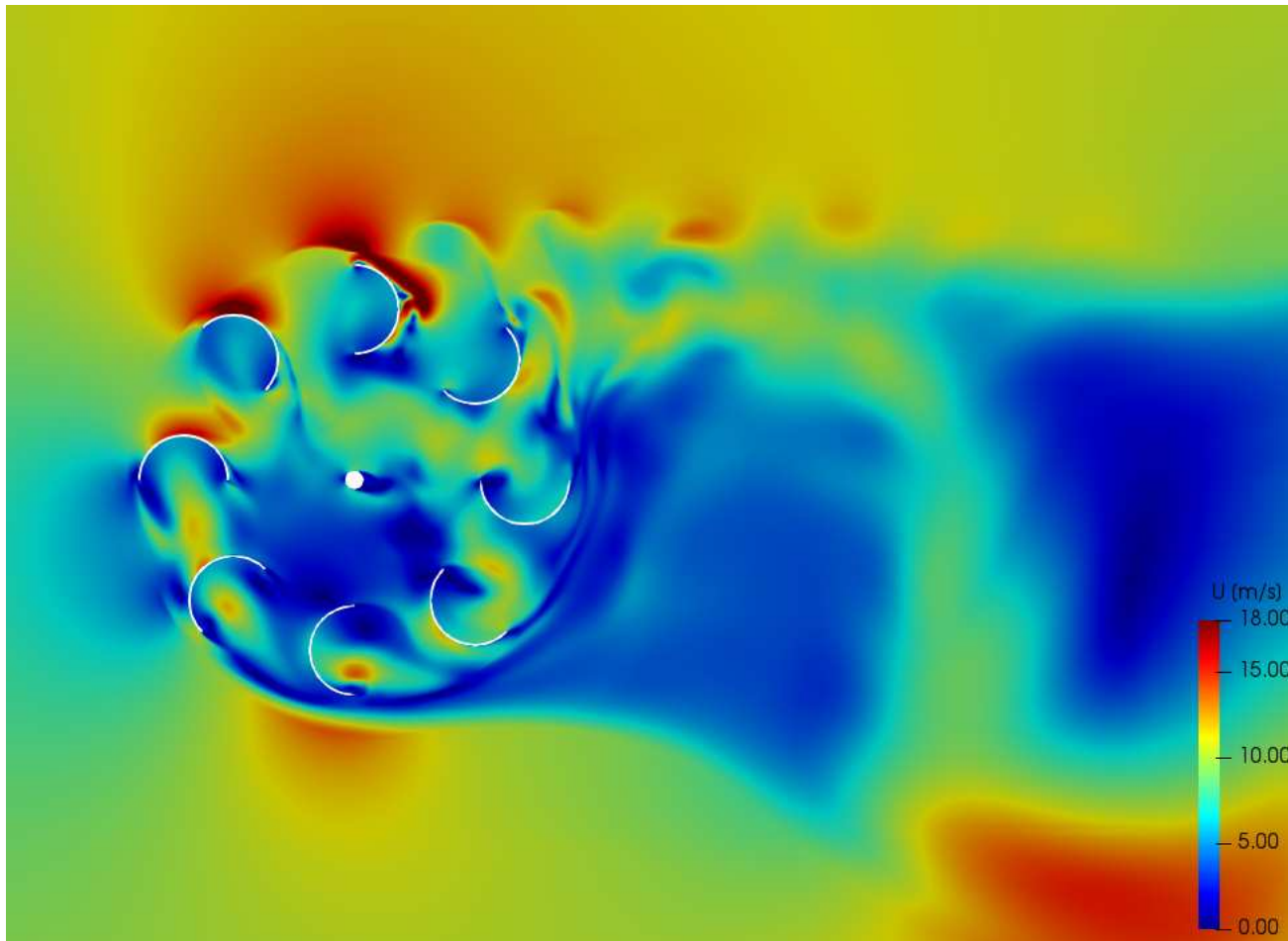
Combined

**Banki–Michell**

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# Banki–Michell



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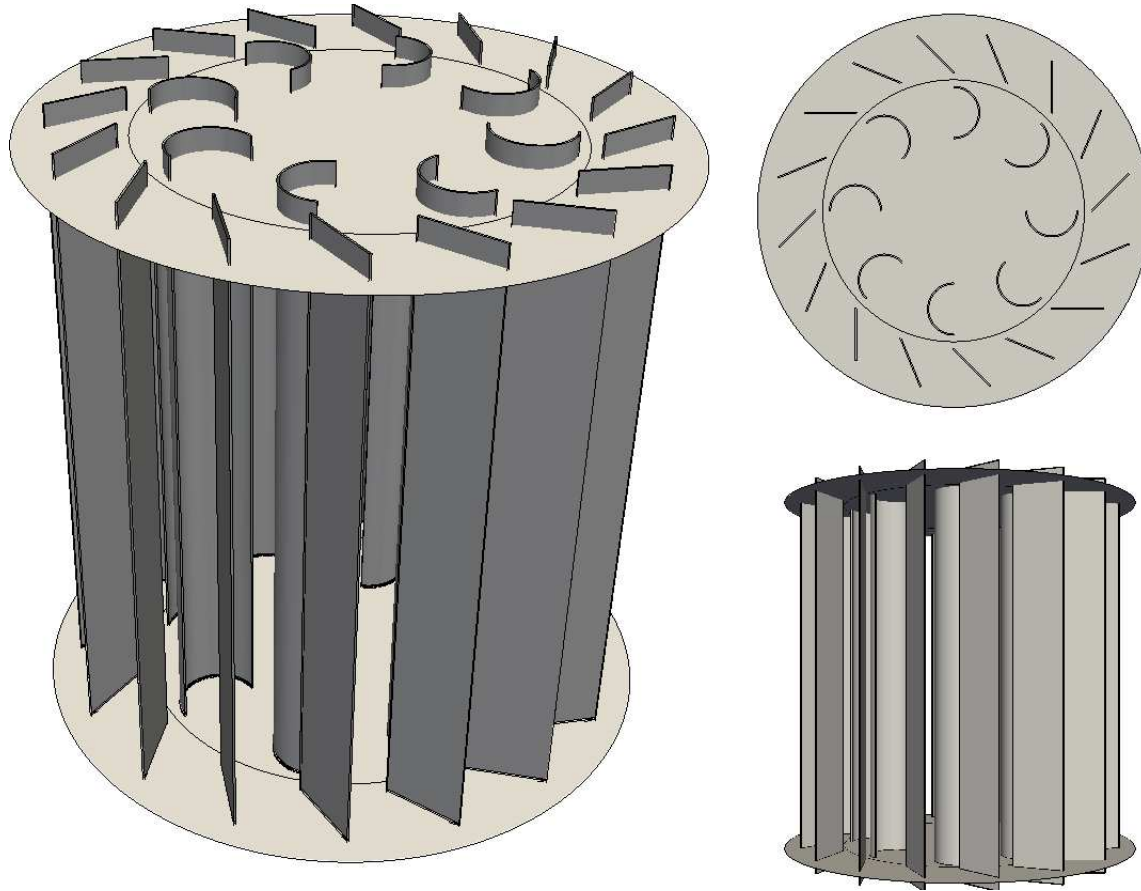
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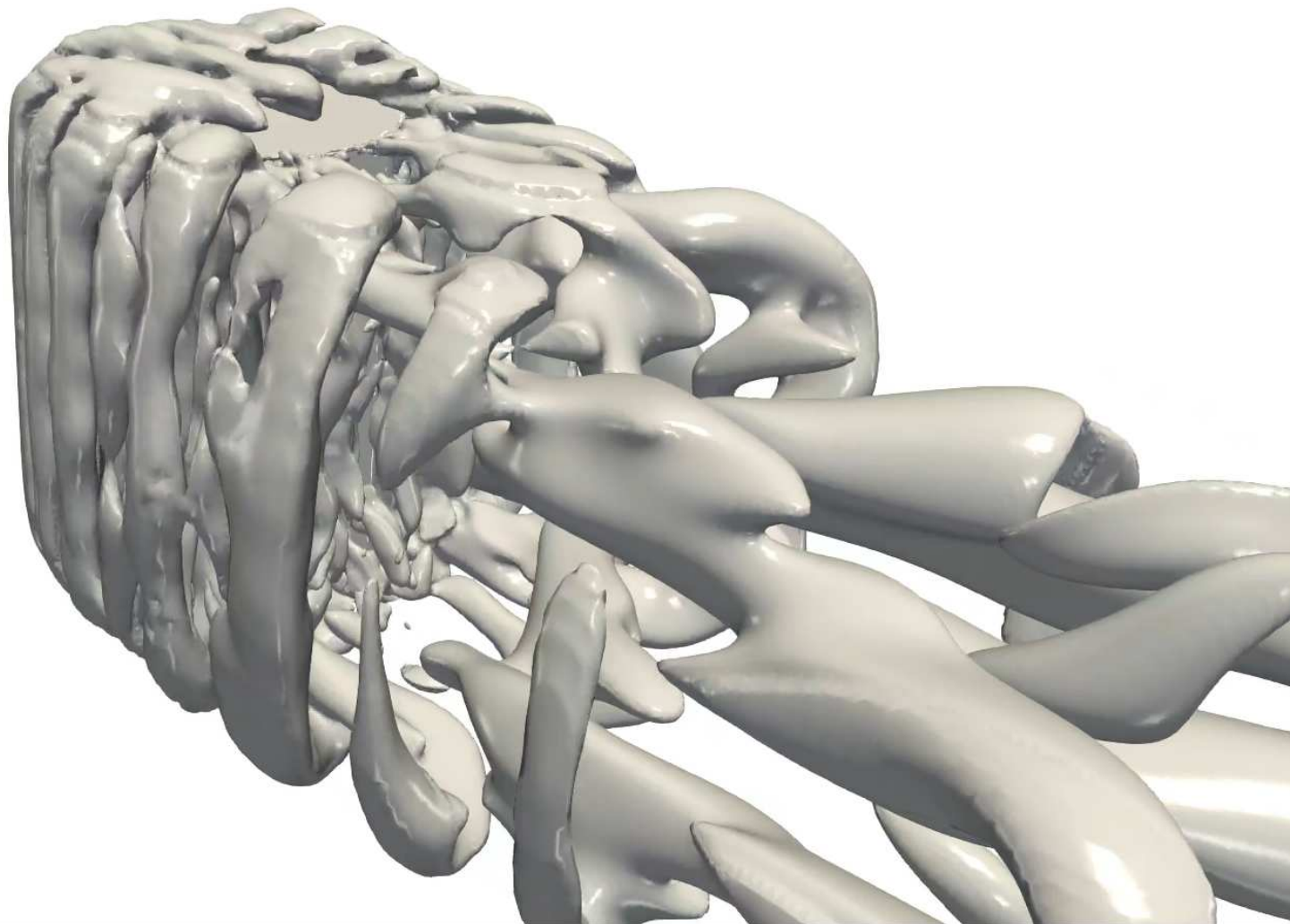
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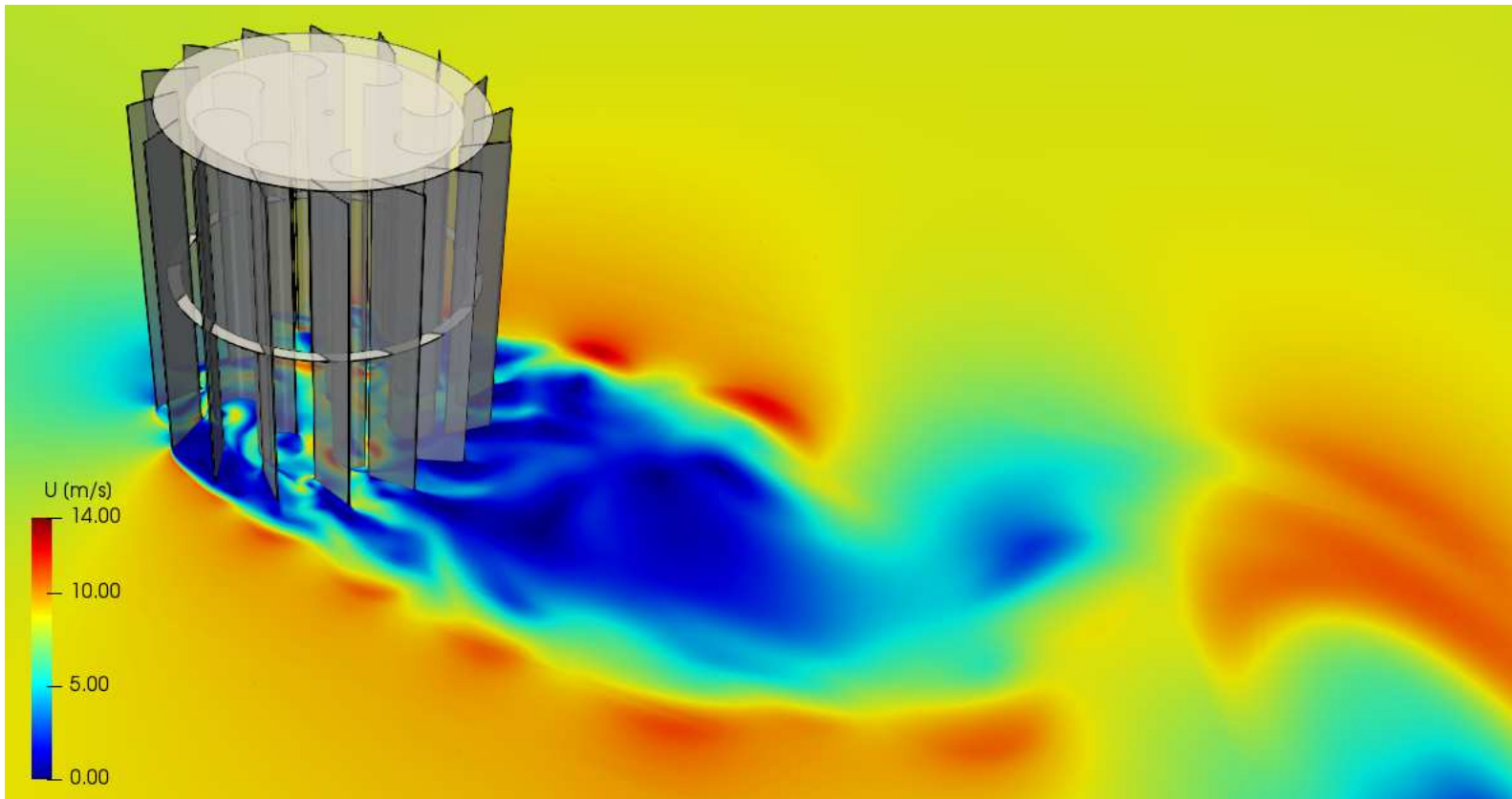
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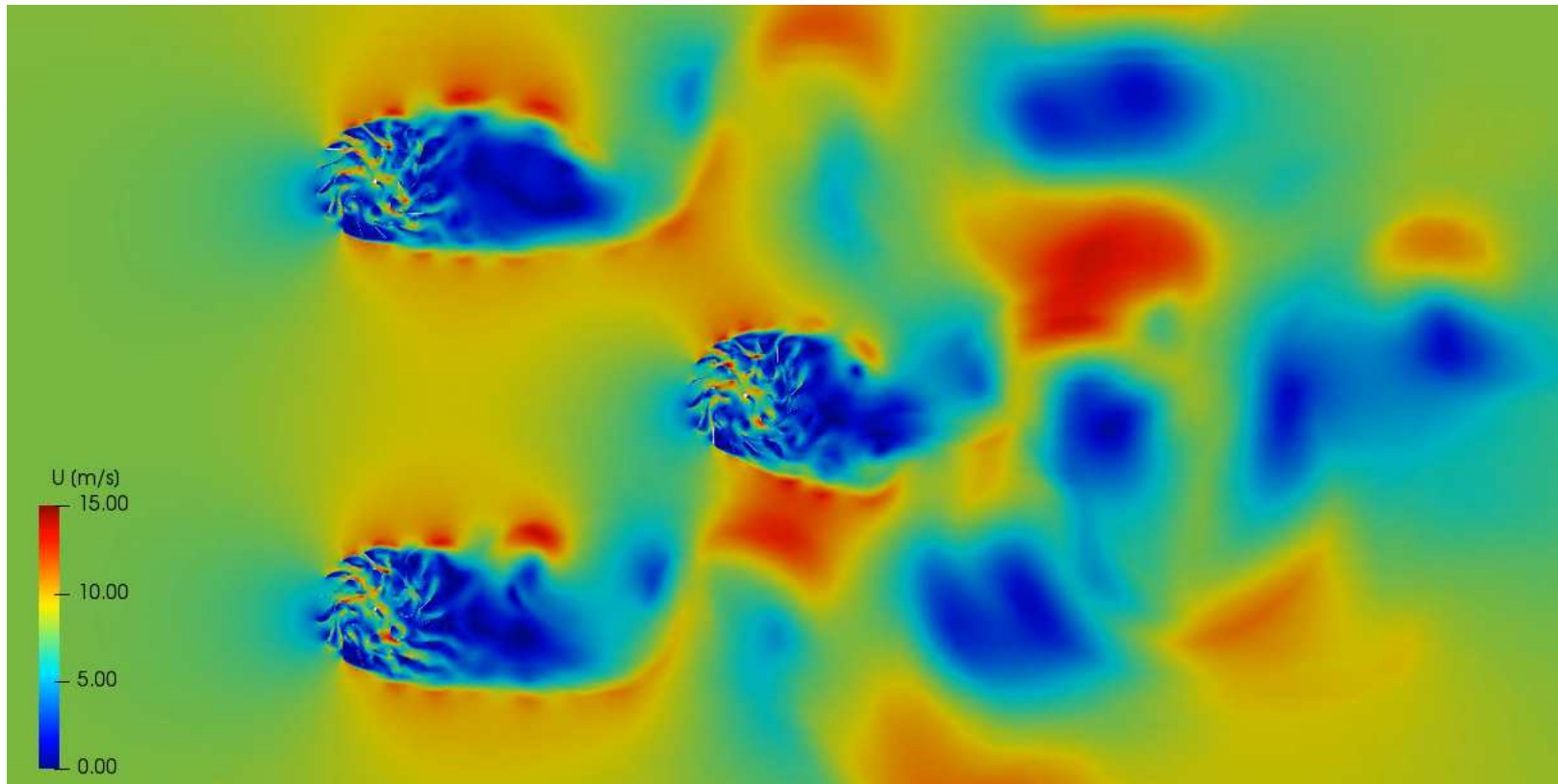
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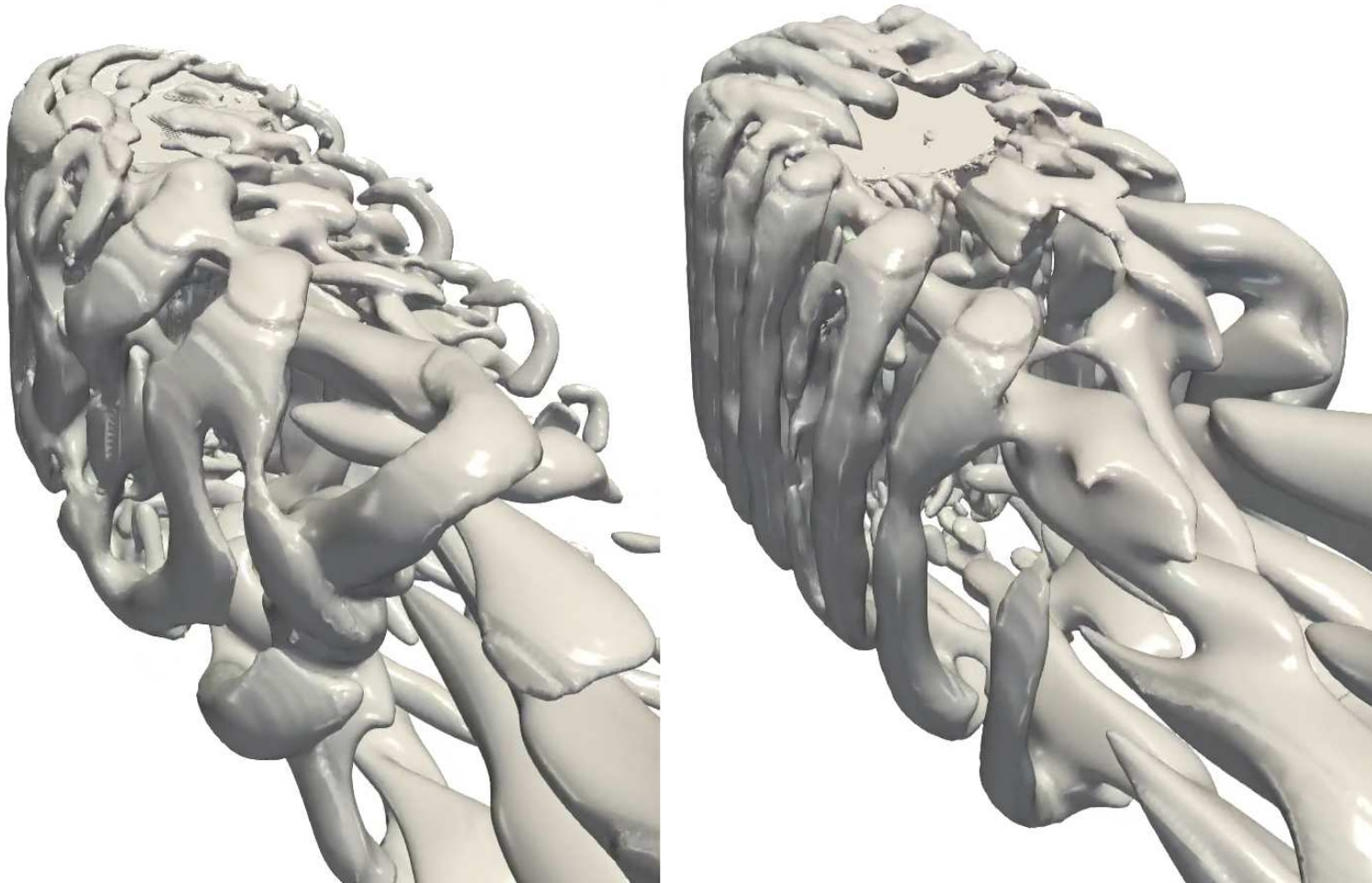
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# Piskorz vs Banki–Michell



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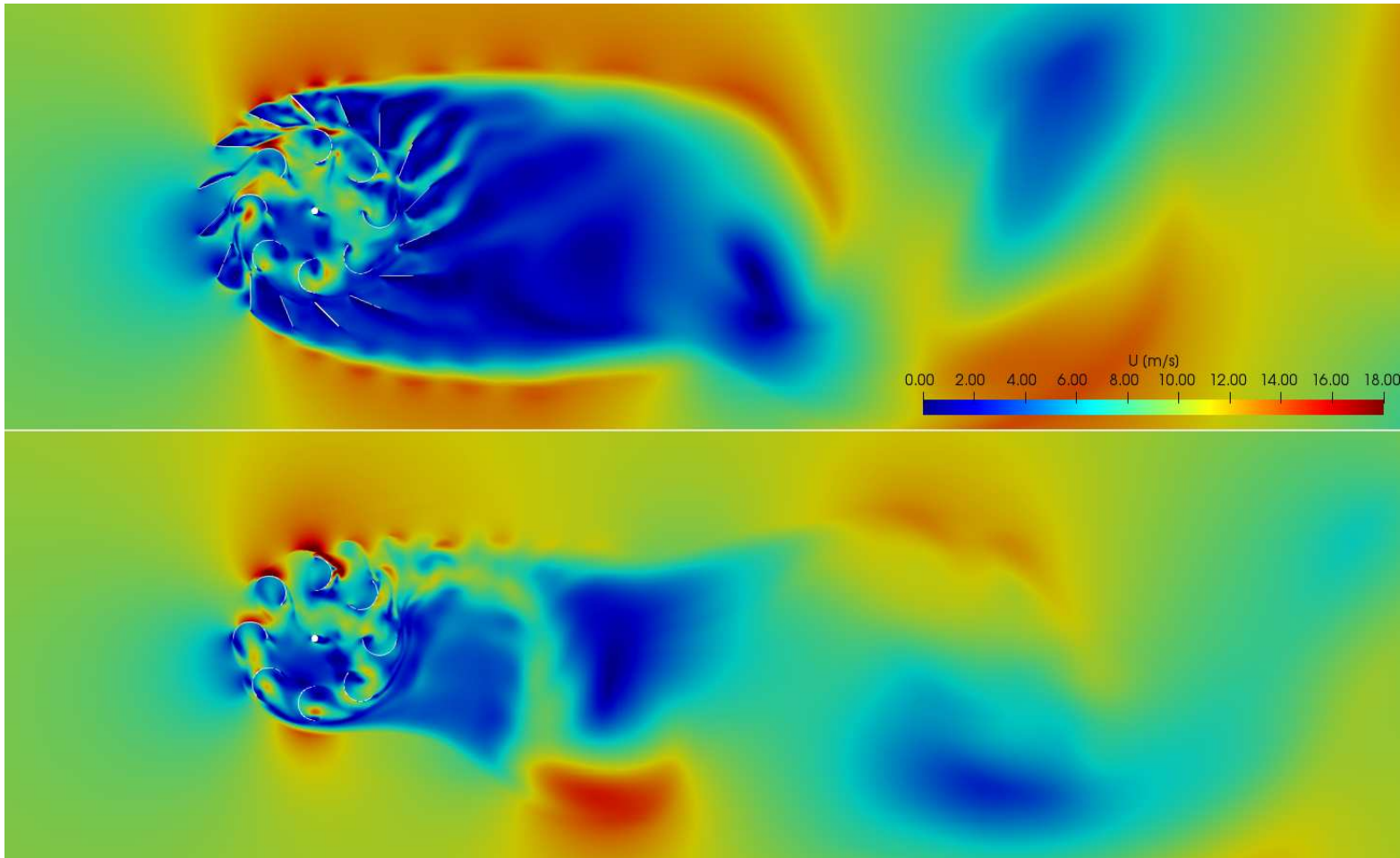
Combined

Banki–Michell

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# Piskorz vs Banki–Michell



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# Unconventional

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**Unconventional**

Counter HAWT

Counter Darrieus

Diffuser

Magnus

# Unconventional wind turbines

- Counter rotating HAWT
- Counter rotating Darrieus
- HAWT with a diffuser
- Wind turbines which utilise the Magnus effect

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Counter HAWT  
Counter Darrieus  
Diffuser  
Magnus

# Counter rotating HAWT



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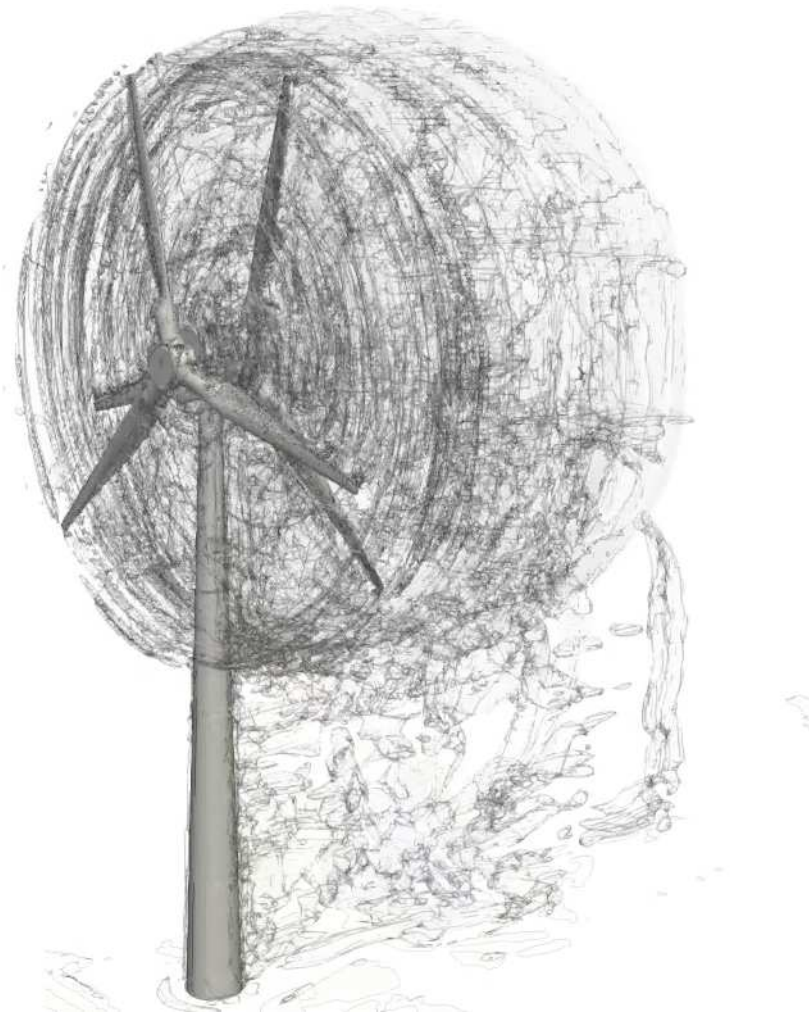
**Counter HAWT**

Counter Darrieus

Diffuser

Magnus

# Counter rotating HAWT



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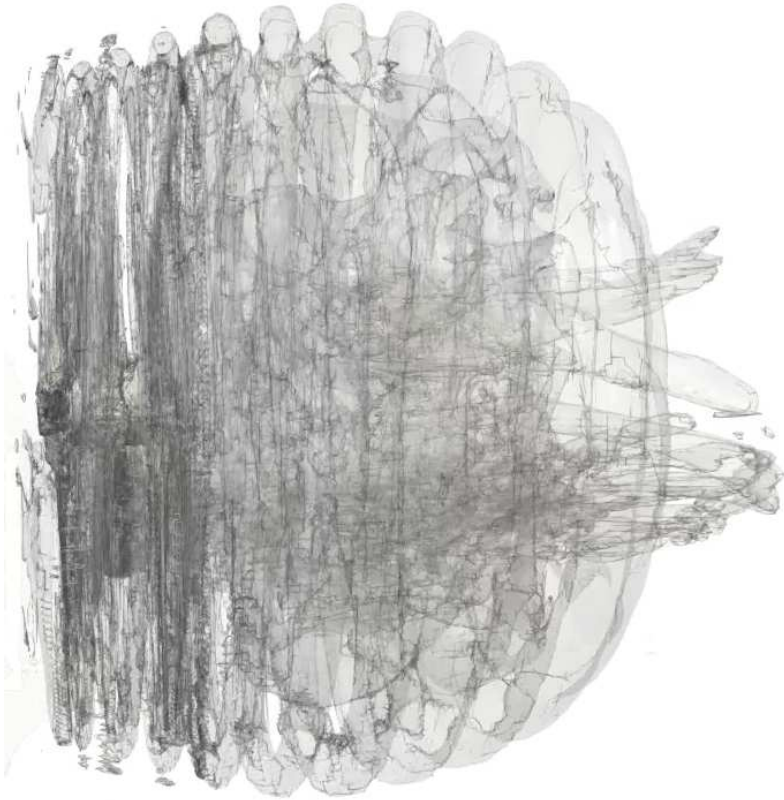
**Counter HAWT**

Counter Darrieus

Diffuser

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# Counter rotating HAWT



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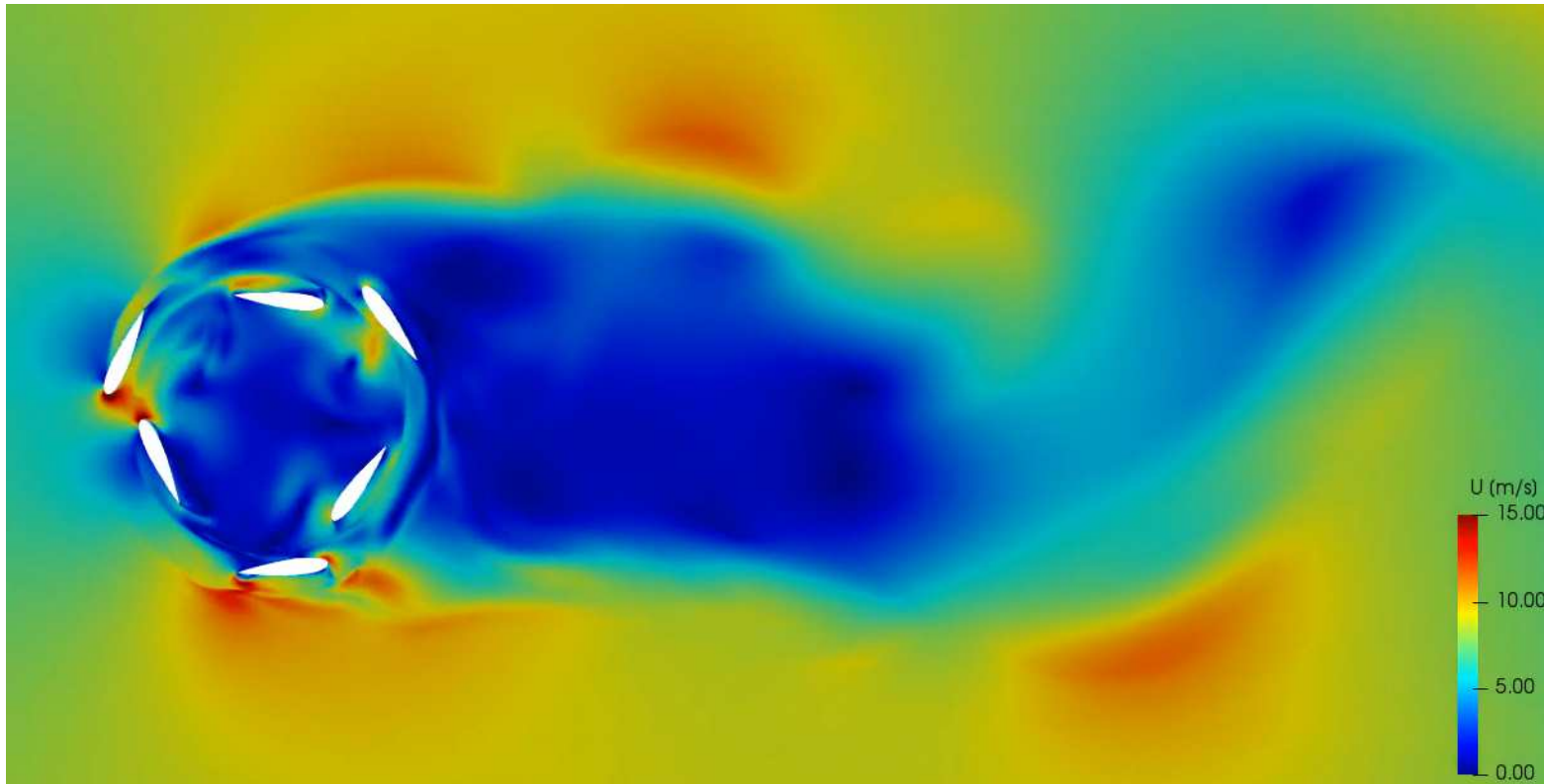
**Counter HAWT**

Counter Darrieus

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# Counter rotating Darrieus



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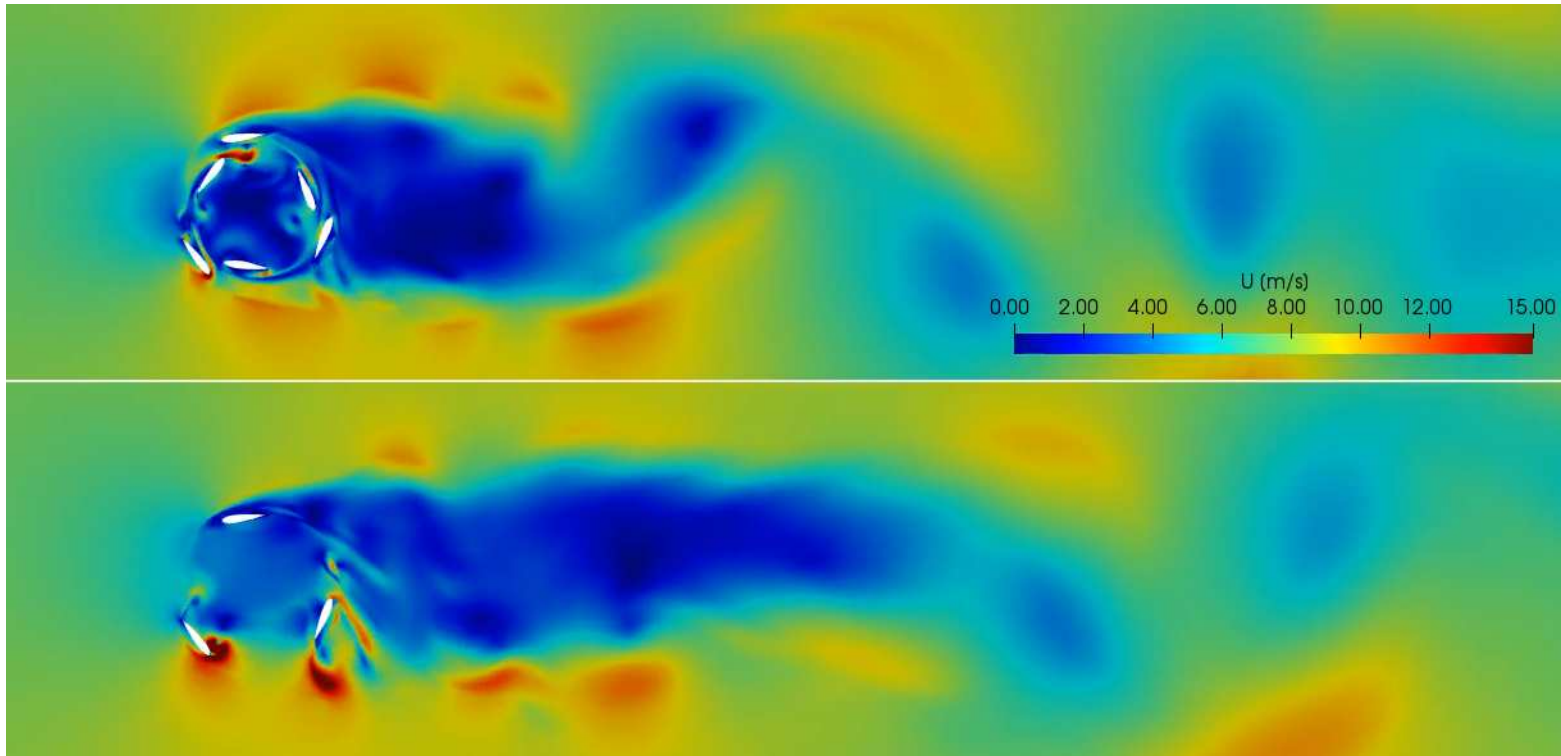
Counter HAWT

**Counter Darrieus**

Diffuser

Magnus

# Counter rotating Darrieus vs Darrieus



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**Counter Darrieus**

Diffuser

Magnus

# HAWT with a diffuser

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Counter Darrieus

**Diffuser**

Magnus



# Wind turbines – Magnus effect

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Counter Darrieus

Diffuser

**Magnus**