# Aeroelastic blade design

## slender blades with high lift airfoils

## compared to traditional blades

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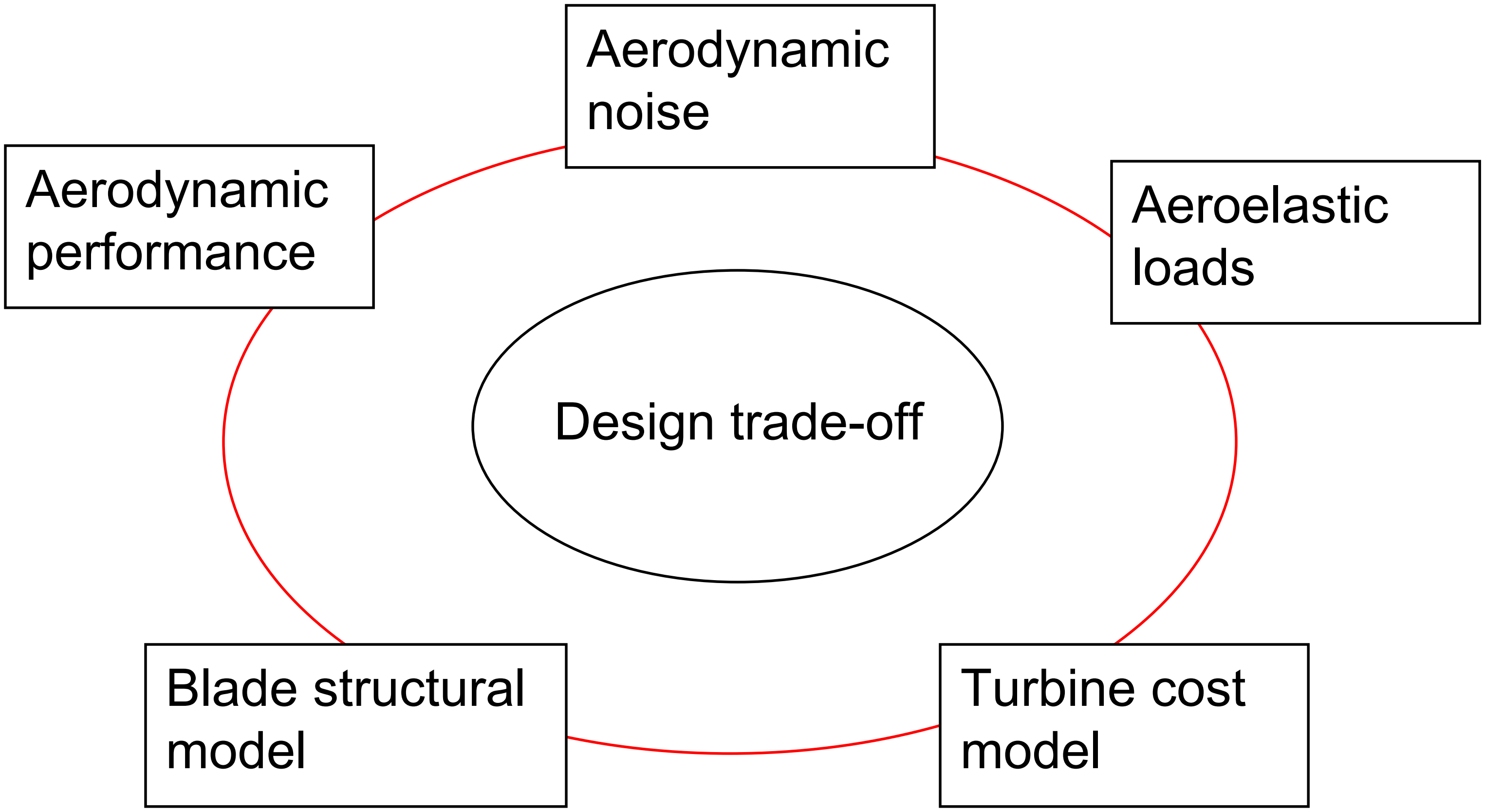
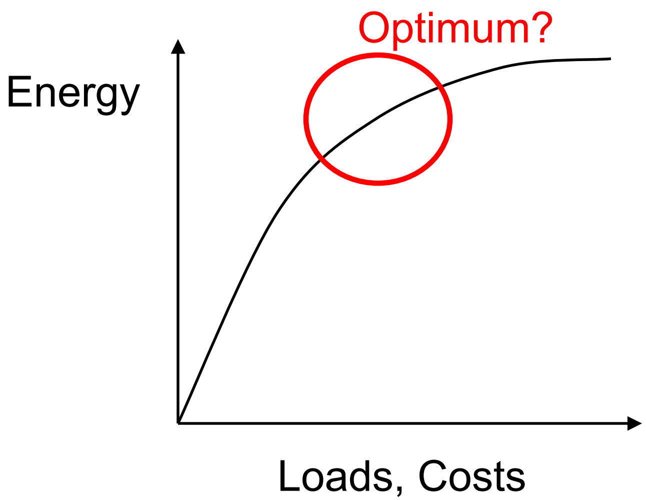
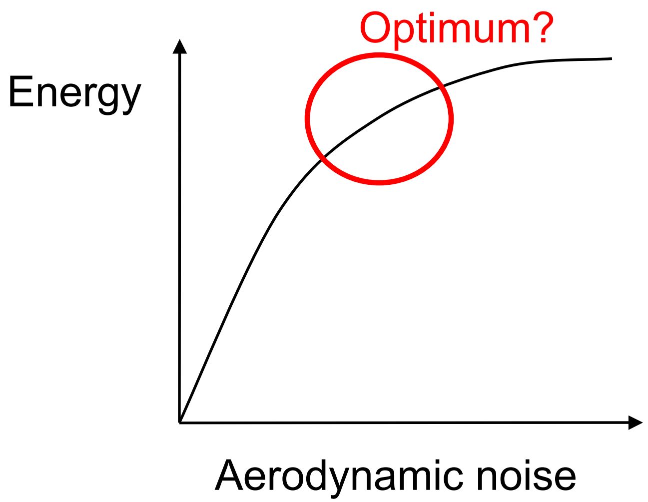
# Risø blade design philosophy



# Risø blade design philosophy

- **Trade-off examples**

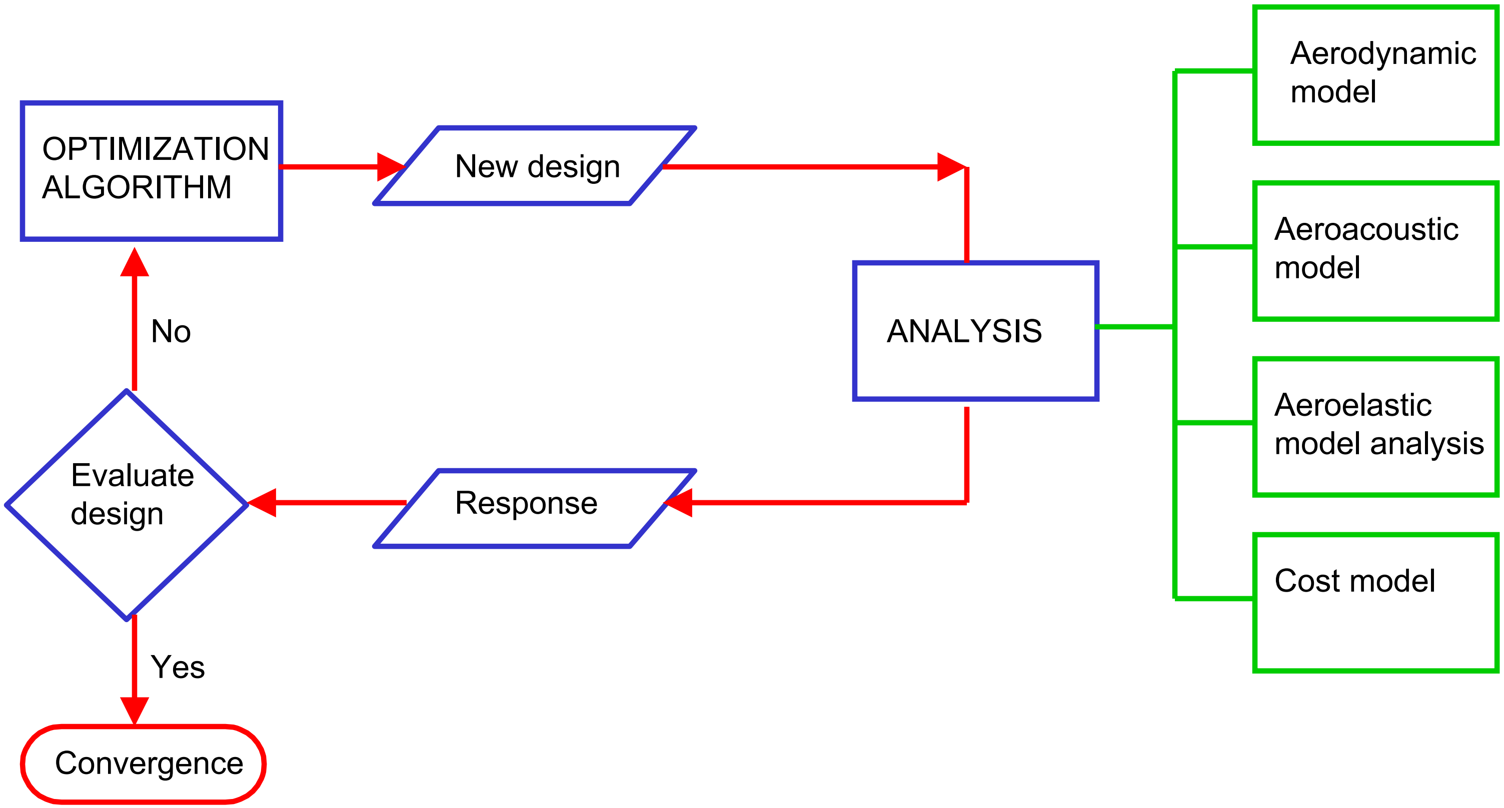



- **Required analysis:**
  - Power curve, energy yield.
  - Total sound power level.
  - Design load cases, I.e., fatigue and extreme loads.
  - Cost modelling, I.e., blade mass or cost, turbine cost.

# Risø blade design philosophy - HAWTOPT

- **Advanced turbine parametric modeling**
- **Multi-disciplinary optimization tool**



# Multi-MW turbine comparison

- **Investigation of pitch control and variable speed multi-MW turbine**
- **Direct comparison of:**
  - A slender blade with high lift airfoils
  - An ordinary blade with traditional airfoils
- **The only difference is the airfoil choice and the blade solidity.**
- **Calculations:**
  - Power curve.
  - Energy yield.
  - Aerodynamic noise.
  - Complete set of load cases.

# Why slender blades?

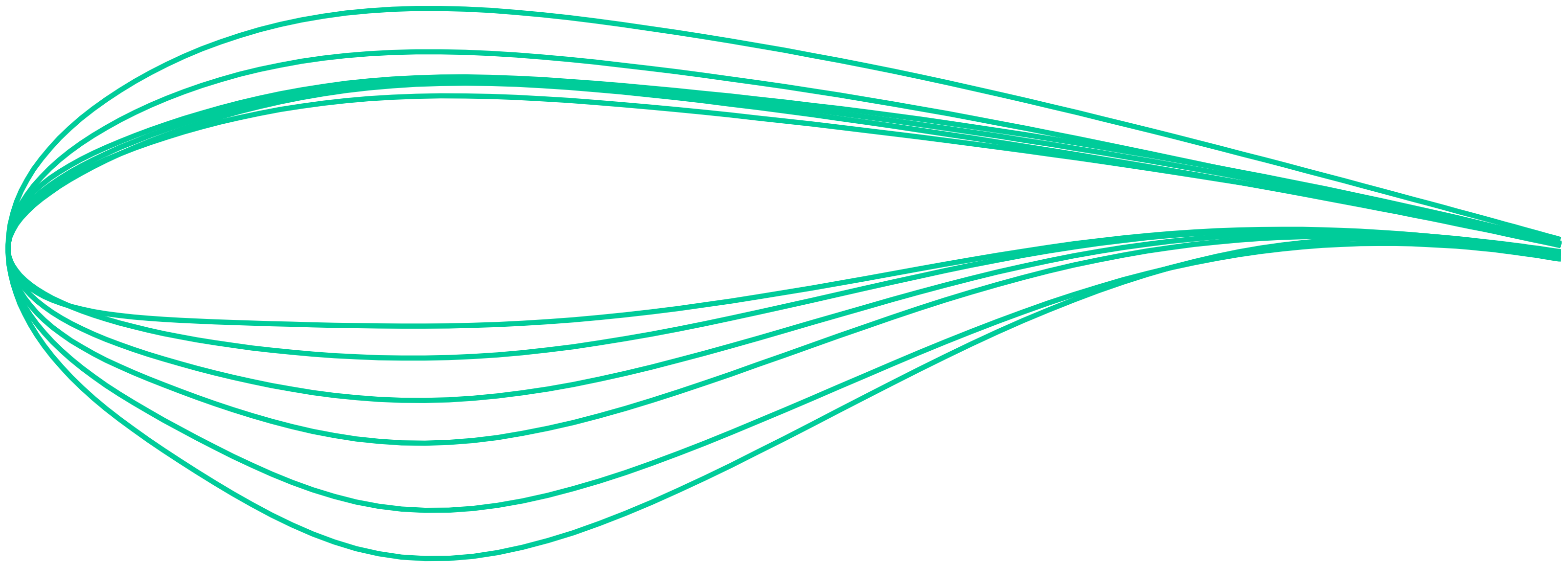
## Advantages

- Reduce turbine loads.
- Reduce turbine costs.

## Disadvantages

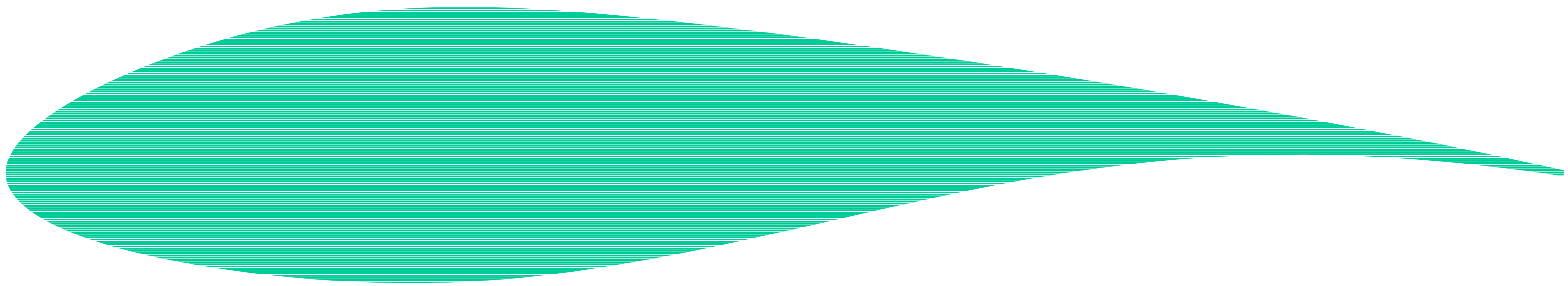
- Reduce energy yield.
- May lead to more expensive blades.
- Reduce tower clearance.
- Possibly higher total noise level.
- Poorer low noise operation.

# Risø-B1 airfoils

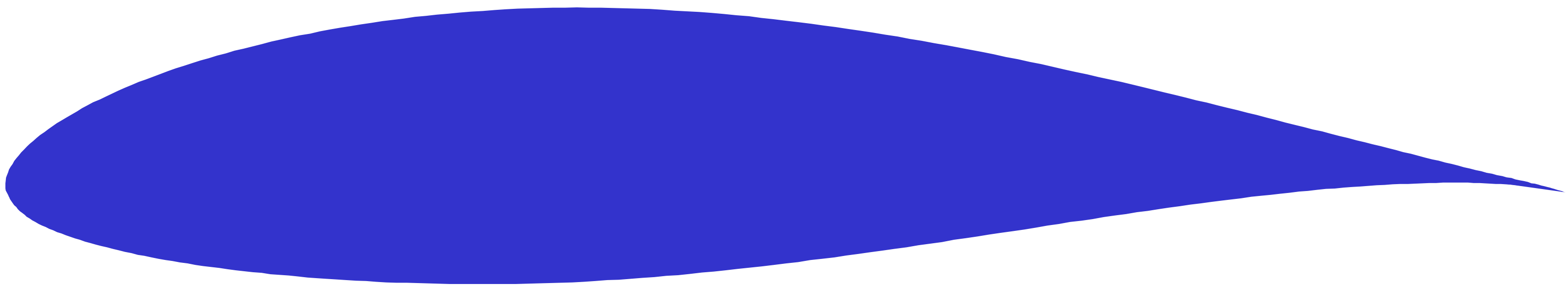


# Risø-B1-18 vs. NACA 63-418 - Contour

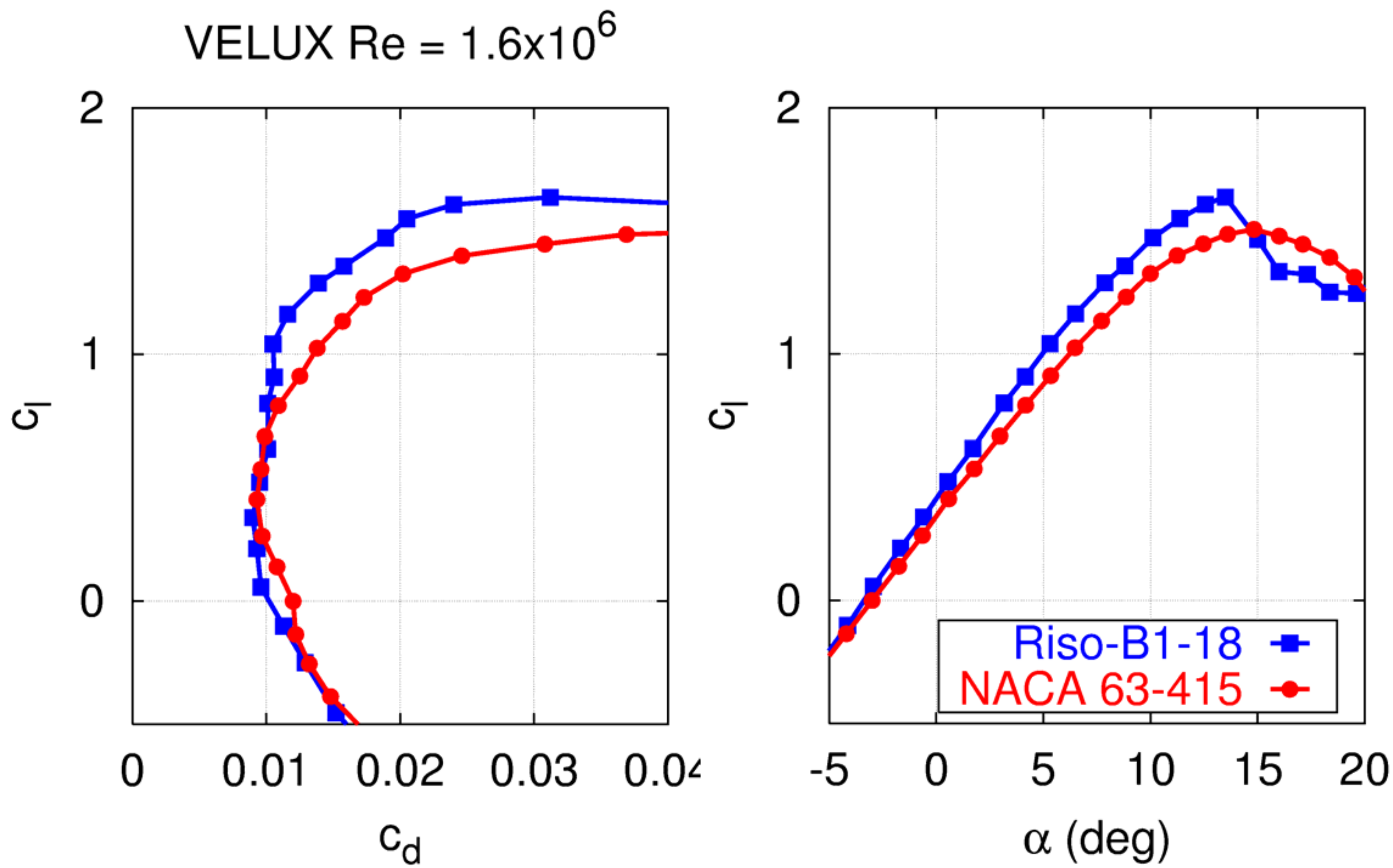
**Risø-B1-18**



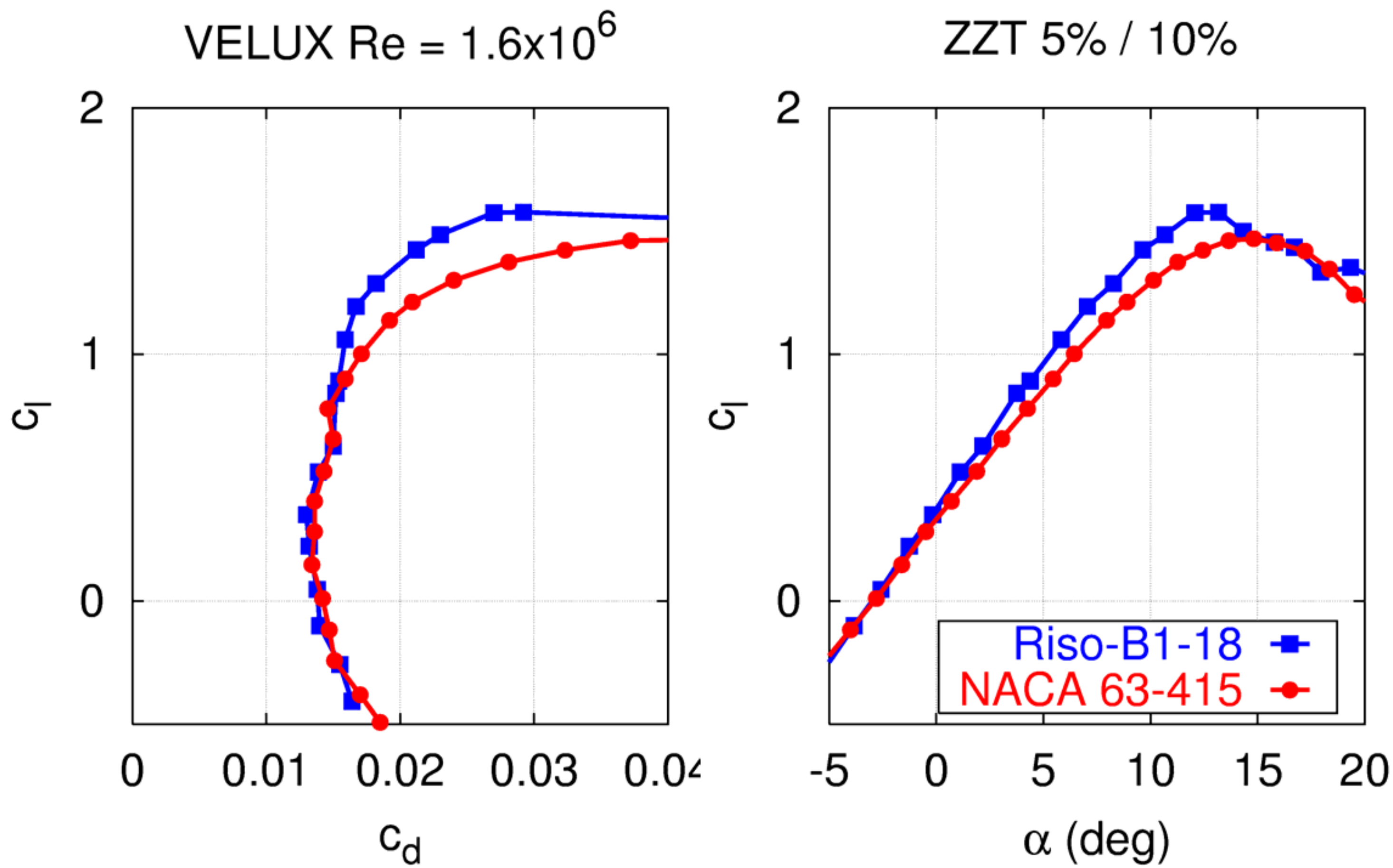
**NACA 63-418**



# Risø-B1-18 vs. NACA 63-415
# - Clean airfoil

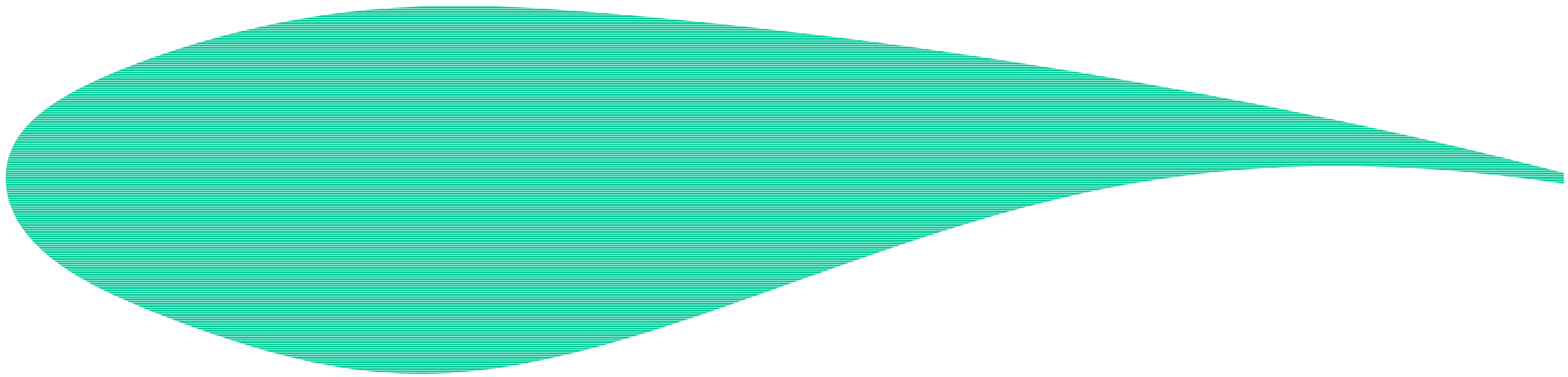


# Risø-B1-18 vs. NACA 63-415
# - Leading edge roughness

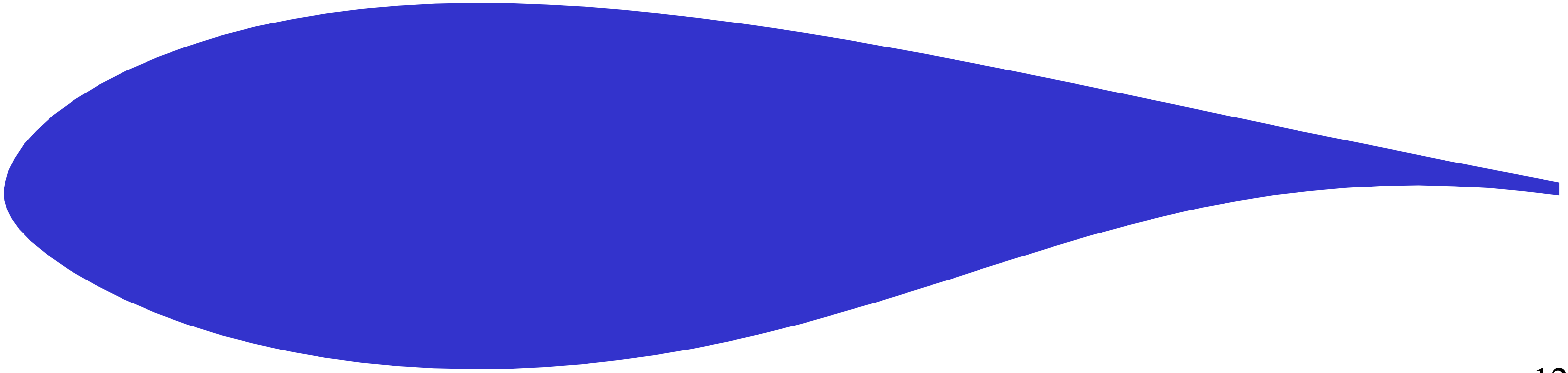


# Risø-B1-24 vs. FFA-W3-241 - Contour

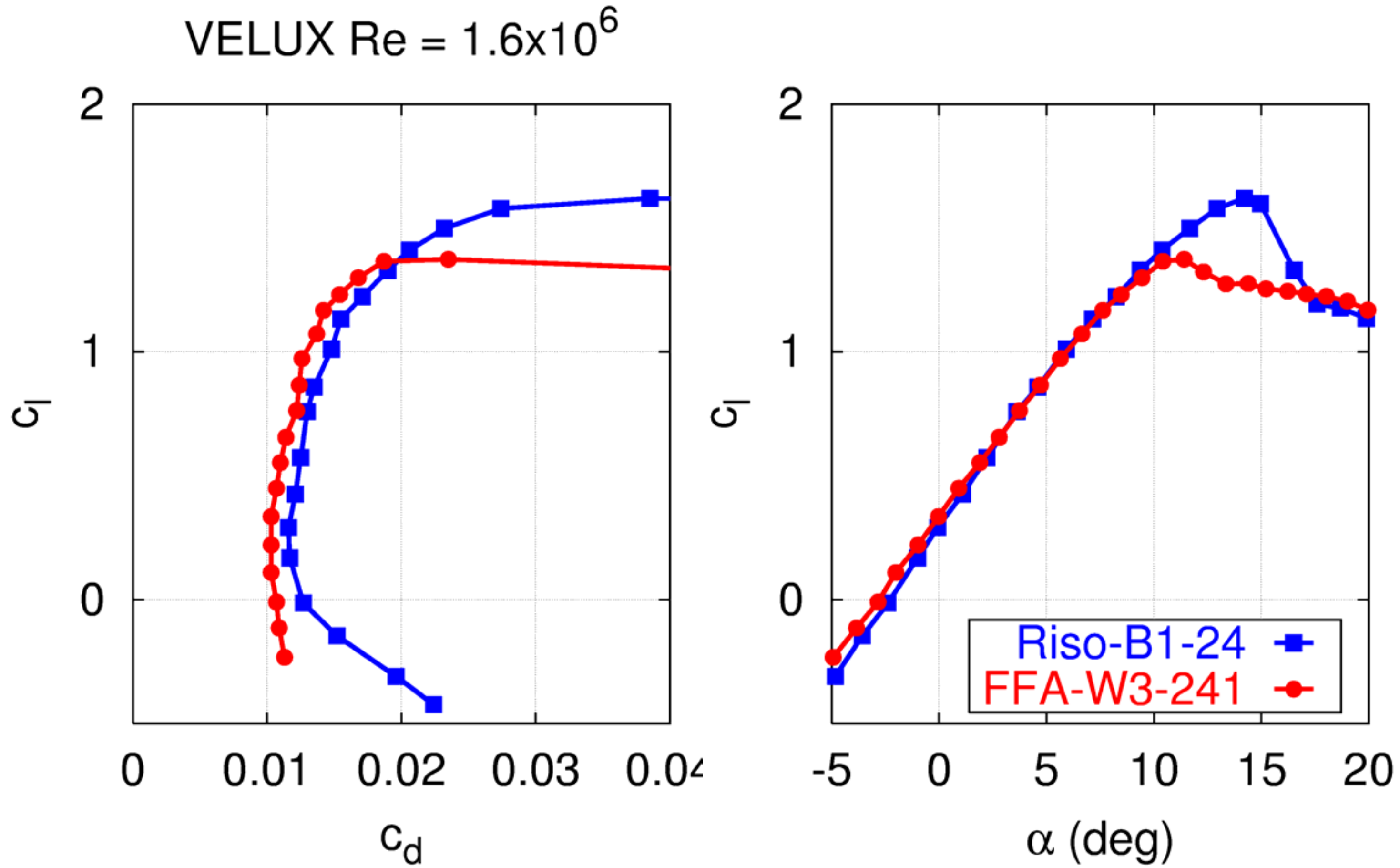
**Risø-B1-24**



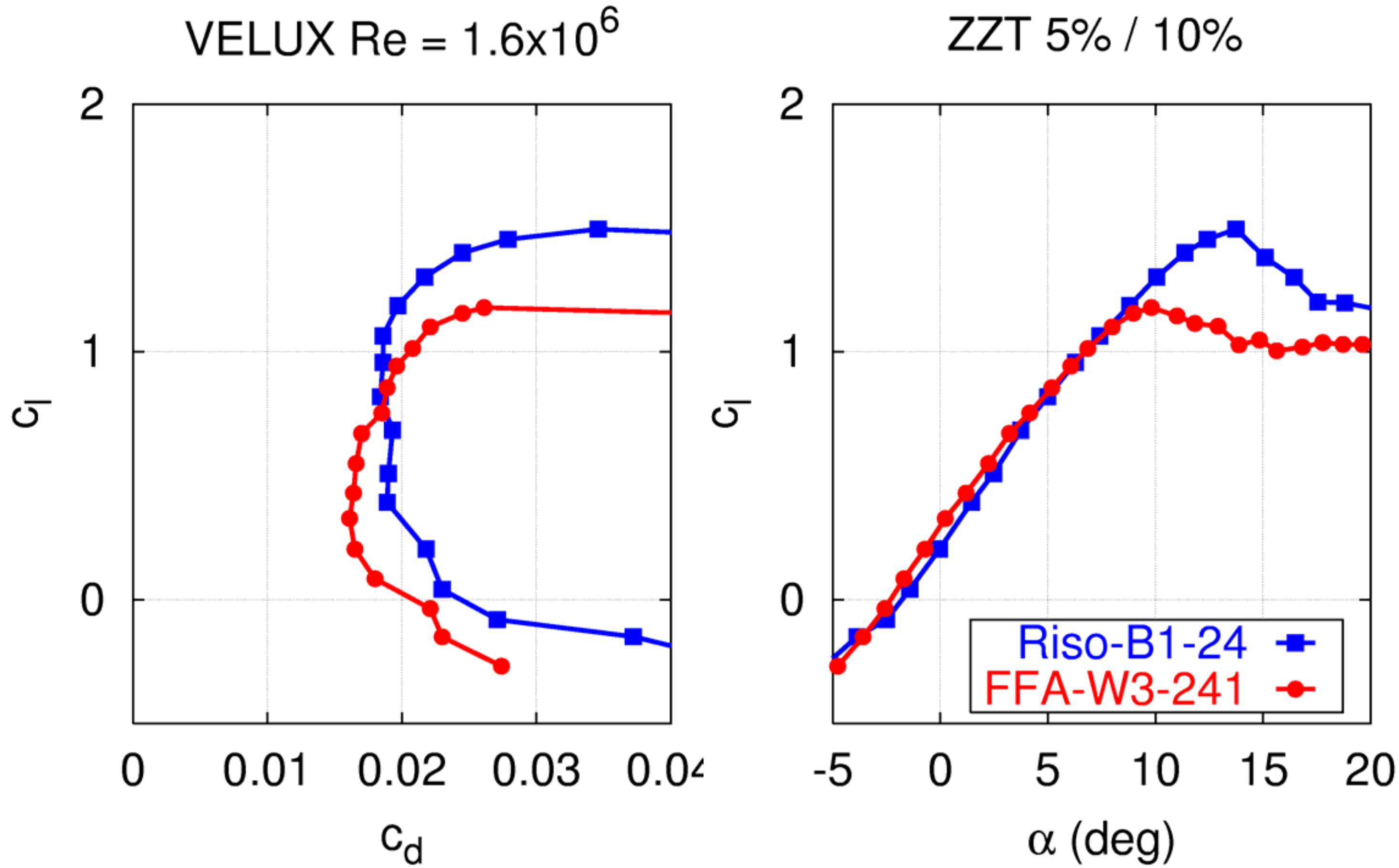
**FFA-W3-241**



# Risø-B1-24 vs. FFA-W3-241
# - Clean airfoil



# Risø-B1-24 vs. FFA-W3-241
# - Leading edge roughness



# Why Risø-B1 airfoils?

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| Advantages | Disadvantages |
| --- | --- |
| • More energy yield. | • Reduced tower clearance. |
| • Reduce aerodynamic noise at low wind speeds<br>• Limited loss in energy yield at low noise operation. | • Possibly higher total noise level. |
| • More degrees of freedom for blade thickness and width.<br>• Excellent performance with leading edge roughness.<br>• Better performance with errors from manufacture..<br>• Better geometric compatibility. | • Increased risk because of the limited verification of airfoil characteristics:<br>• Costs to licensing and validation. |

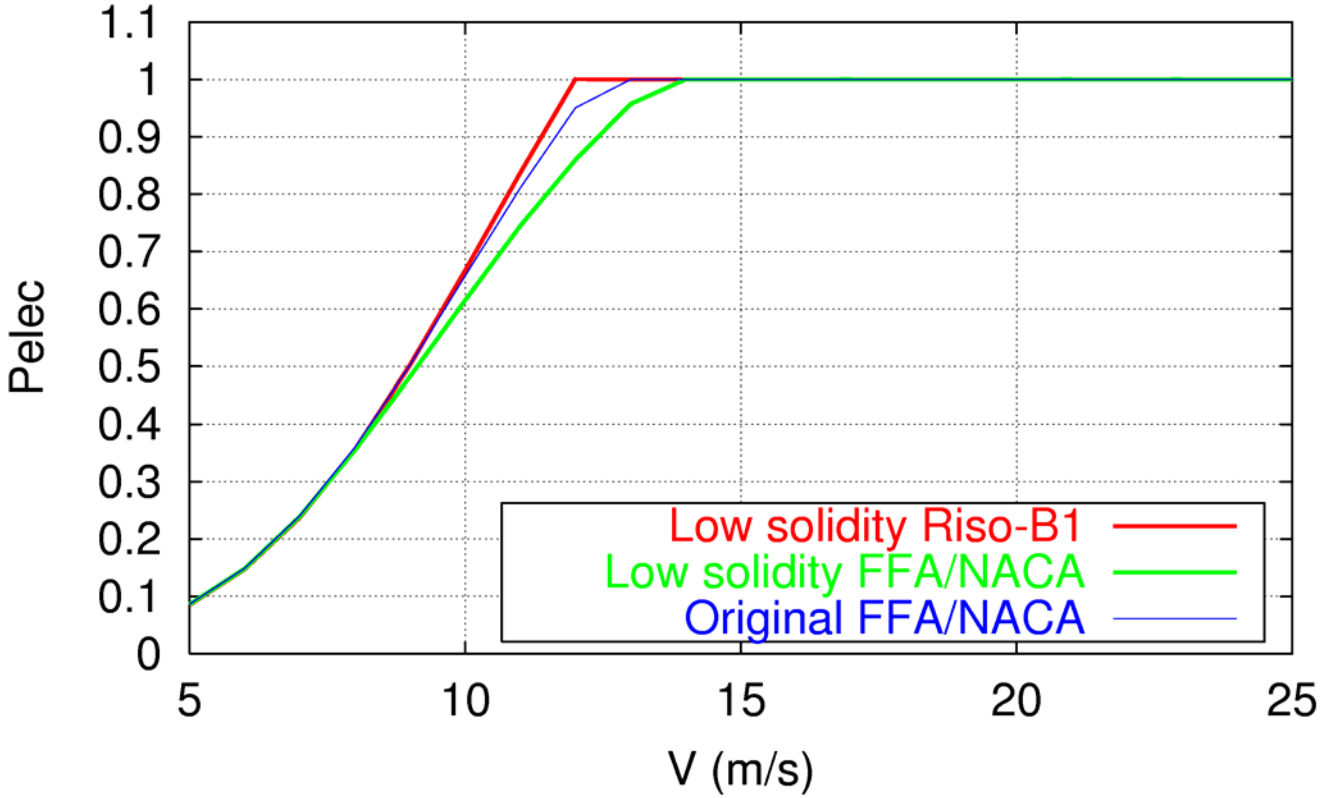
# Multi-MW turbine comparison - Scope

- **Investigation of pitch control and variable speed multi-MW turbine**
- **Direct comparison of three configurations:**
  1. Risø-B1 on a 90% solidity blade.
  2. FFA-W3 / NACA 63-6xx on a 90% solidity blade.
  3. FFA-W3 / NACA 63-6xx on a 100% solidity blade.
- **The only difference is the airfoil choice and the blade solidity.**
- **It is a limitation that the blades are not optimized to the specific airfoils!**
- **All results are normalized because of confidentiality.**

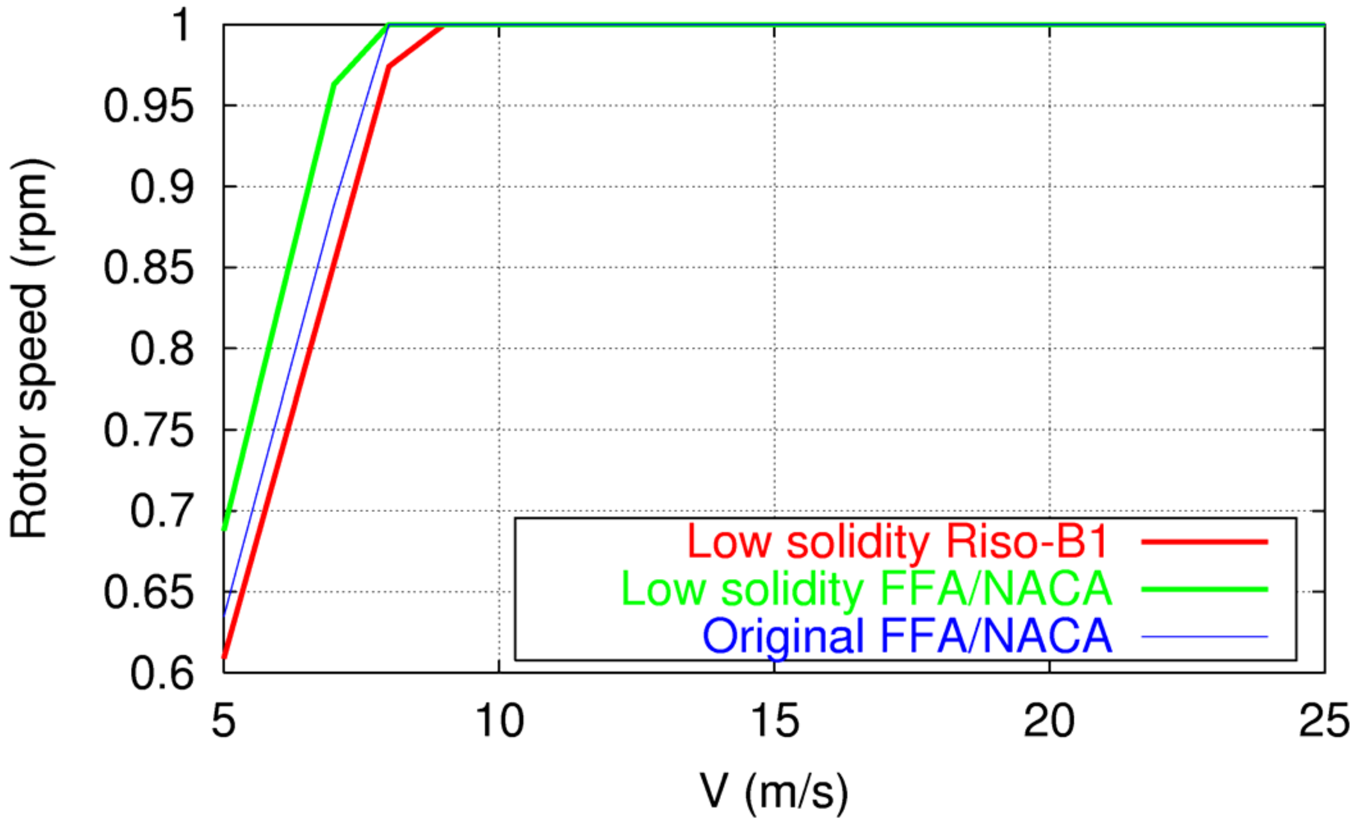
# Multi-MW turbine comparison - Assumptions

- **Identical blade thickness and blade twist.**
- **Identical blade structure.**
- **3D airfoil data for both airfoil families on the same basis.**
- **Power control:**
  - Optimized for each blade versus wind speed.
  - Controller in aeroelastic code was not tuned individually.
- **Power curves are calculated with and without turbulence.**
- **Energy yield is calculated at AMWS = 8 m/s.**
- **Aerodynamic noise is calculated with a Risø in-house noise prediction tool:**
  - Depends on local inflow.
  - Insensitive to airfoil contour.
- **Design loads are based on IEC 2A:**
  - Complete fatigue and extreme load investigation.

# Multi-MW turbine comparison
# - Power curve, I = 0.1



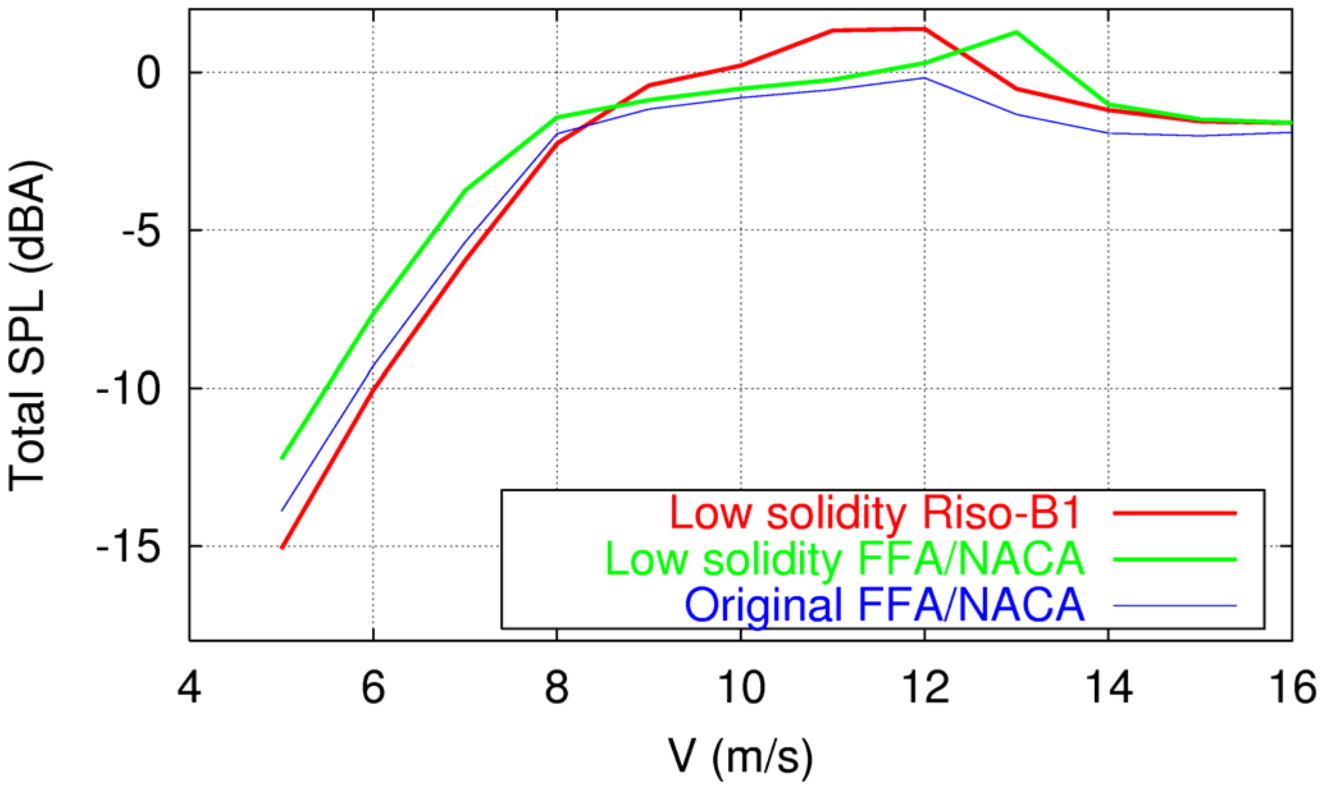
# Multi-MW turbine comparison
# - Rotor speed curve, I = 0.1



# Multi-MW turbine comparison - Energy yield

| Turbulence intencity | Energy yield: Risø-B1 low solidity blade compared to low solidity FFA-W3 / NACA 636 blade | Energy yield: Risø-B1 low solidity blade compared to ordinary FFA-W3 / NACA 636 blade |
|---|---|---|
| 0.0 | +3.8% | +1.0% |
| 0.1 | +4.5% | +1.4% |
| 0.2 | +7.0% | +3.0% |

# Multi-MW turbine comparison
# - Aerodynamic noise



# Multi-MW turbine comparison
# - Fatigue loads

| **Sensor** | **s-n eksponent** | **Fatigue for Risø-B1 low solidity blade compared to ordinary FFA-W3 / NACA 63-6 blade** |
|---|---|---|
| Blade root edgewise bending | 10 | +0.7% |
| Blade root flapwise bending | 10 | -4.3% |
| Shaft torsion | 6 | +1.4% |
| Nacelle tilt | 6 | -3.4% |
| Nacelle yaw | 6 | -2.8% |
| Tower base bending | 6 | -6.1% |

# Multi-MW turbine comparison
# - Extreme loads

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| Sensor | Extreme loads for Risø-B1 low solidity blade compared to ordinary FFA-W3 / NACA 63-6 blade |
|---|---|
| Blade root edgewise moment | -7.3%. |
| Blade root flapwise moment | -8.3% |
| Shaft torsion | -0.4% |
| Nacelle tilt | -7.7% |
| Nacelle yaw | -10% |
| Tower base bending | -13% |

# Multi-MW turbine comparison - Conclusions

- **Power curve:**
  - Turbulence has minimum influence on the power curve.
  - Rotor speed is reduced at low wind speeds.
- **Energy yield:**
  - Increased by 1.0% without turbulence.
  - Increased by 3.0% with 20% turbulence.
- **Aerodynamic noise:**
  - Maximum noise is (possibly) 1 dB higher.
  - Aerodynamic noise is reduced a low wind speeds.
  - Better low noise operation.
- **Loads:**
  - Fatigue loads were typically reduced by 5%.
  - Extreme loads were reduced by up to 13%.
  - Tower clearance can be expected to be reduced by 5% to 10%.