Determination of the Yaw Moment of a Downwind-coned Rotor under Yawed Conditions:

Limitations of a Blade Element Momentum Theory Method

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Motivation

Performance of a passively yawing FOWT dependent on

- Wave loads
- Current loads
- Aerodynamic loads on tower
- **Rotor yaw moment**

} **State-of-the art simulation methods** (Wave loads, Current loads, Aerodynamic loads on tower)

Self-aligner Cruse Offshore

Leading question:

Can we use a state-of-the art Blade Element Momentum Theory method to predict the yaw moment?

This work‘s approach:

Simulating the aerodynamic loads on TUHH model wind turbine presented @ DEEPWIND 2019 using AeroDyn

OVERVIEW: DETERMINING THE YAW MOMENT OF A DOWNWIND-CONED ROTOR

Determining the Yaw Moment of a Downwind-coned Rotor

Introduction: Passively Yawing FOWTs

Characteristics

- Numerous designs
- Mostly semisubmersible platforms
- Single-Point-Mooring
- **No yaw bearing** (except SATH)

➡ Unconventional tower constructions become feasible

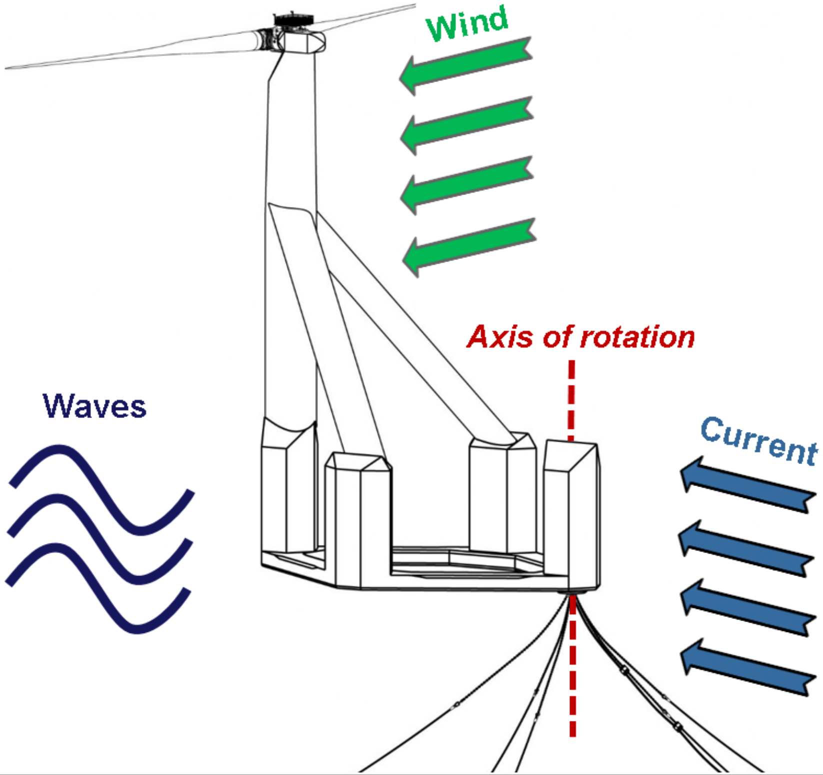
➡ Cost reduction due to reduced weight and structural loads possible

➡ Multi-rotor designs become feasible

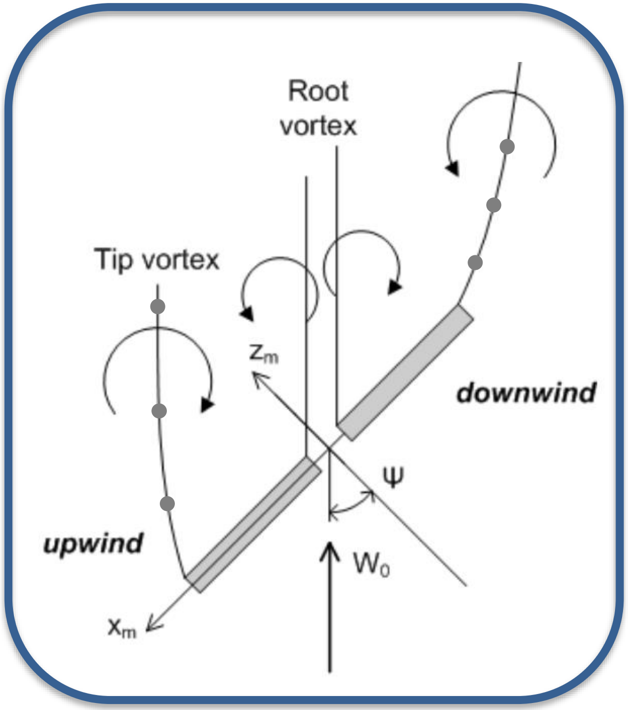
INTRODUCTION : PASSIVE YAW MECHANISM

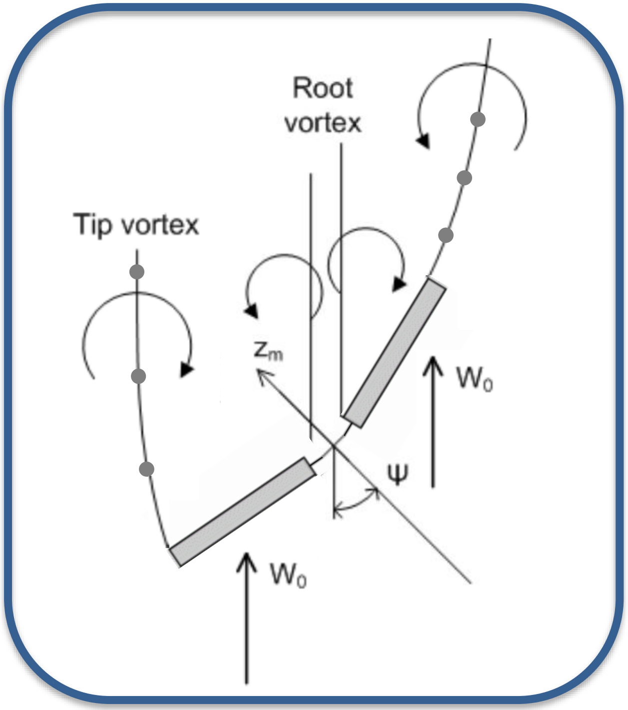
Major influence factors for passive yaw motions

- Hydrodynamic loads
  - Wave loads
  - Current drag forces
- Aerodynamic loads
  - Tower lift and drag forces
  - **Rotor yaw moment**
  - *Rotor thrust negligible*
- Loads affected by environmental conditions
  - Wind speed
  - Current speed, wave parameters
  - Wind-current misalignment



BACKGROUND: ORIGIN OF THE ROTOR YAW MOMENT





1. Lower induction at the upwind side **2. Higher inflow angle on the upwind side**

[W. HAANS, WIND TURBINE AERODYNAMICS IN YAW – UNRAVELLING THE MEASURED ROTOR WAKE (SLIGHTLY MODIFIED)]

Overview: Determining the Yaw Moment of a Downwind-coned Rotor

Determining the Yaw Moment of a Downwind-coned Rotor

TUHH Model Wind Turbine

TUHH Experimental Wind Turbine	
Rated power	130 W
Rotor diameter	**0.925 m**
Number of blades	2
Downwind cone angle	**5°**
Rated wind speed	9.3 m/s
Rated rotational speed	**1200 RPM**
Wind tunnel size	2 x 3 m
Blockage ratio	**11.2 %**
Sensor	6C - balance

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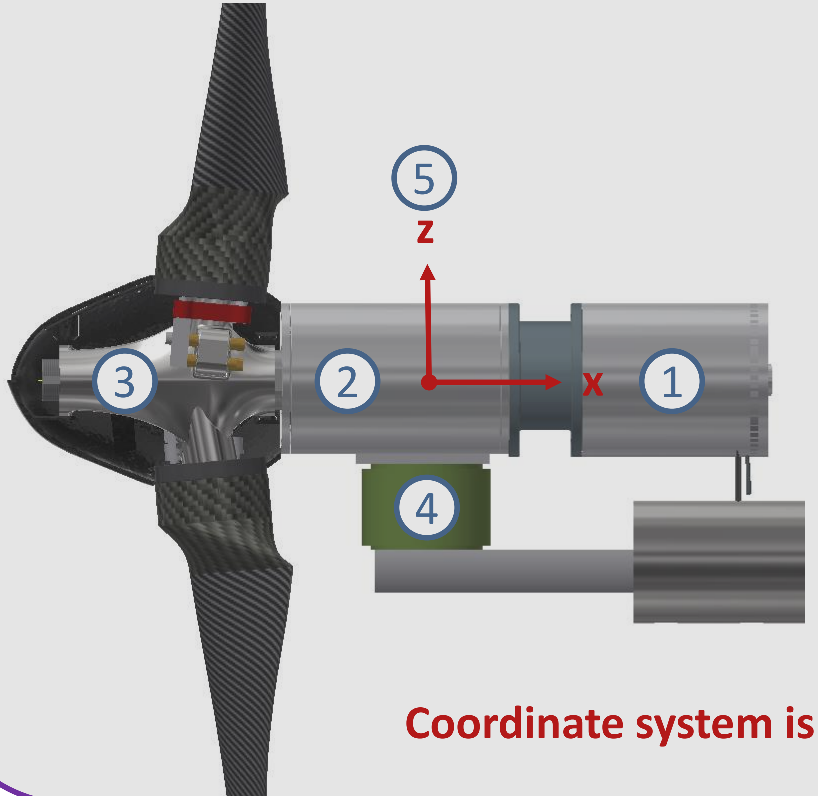
TUHH Model Wind Turbine: Nacelle, Sensor and Coordinate System



Components and sensor

1. Generator
2. Slip ring and main bearings
3. Hub
4. 6 component force/moment sensor
   - **Uncertainty below 2% in torque and 1% in thrust at rated conditions**
   - **Repeatability error of measurements: 0.5% in thrust, 1% in torque**
5. Coordinate system for measurements

Coordinate system is applied to simulations

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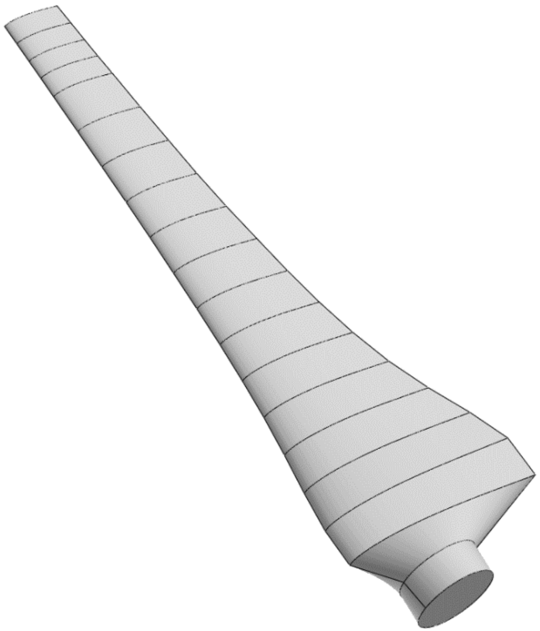
Overview: Determining the Yaw Moment of a Downwind-coned Rotor

Determining the Yaw Moment of a Downwind-coned Rotor

Background: Simulation Method

AeroDyn simulation

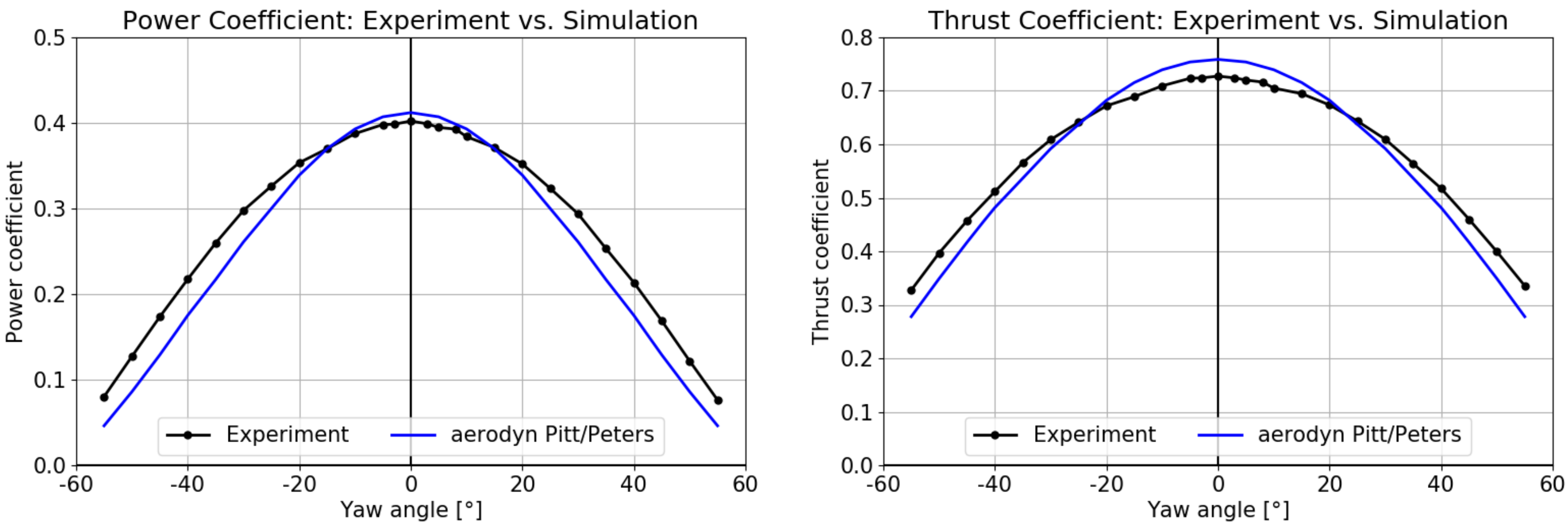
- Blade Element Momentum Theory method
  - Prantl tip and hub loss model
  - Beddoes-Leishman unsteady airfoil aerodynamics model
    - Minemma/Pierce variant
  - Pitt/Peters wake skew model
- Discretization
  - 19 blade sections
  - 3.6° per time step
- Polars
  - Calculated by Xfoil for Re 150k
    - ☑ good agreement with experimental Data
  - Nearly constant Reynolds number over blade span



Overview: Determining the Yaw Moment of a Downwind-coned Rotor

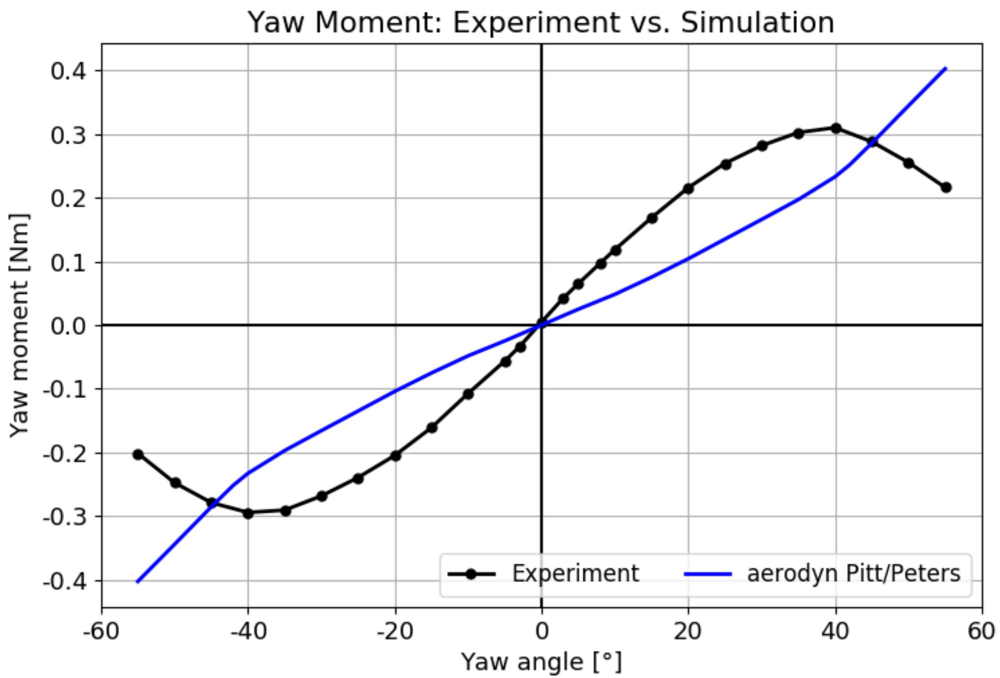
Determining the Yaw Moment of a Downwind-coned Rotor

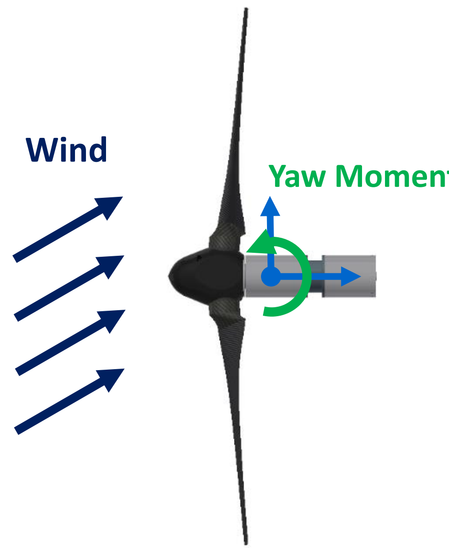
Results: Power and Thrust



- **Deviations at zero yaw angle: Power 3%, Thrust 5%**
- **Decrease of power and thrust to strong at higher yaw angles**
- **Small deviations at lower yaw angles**

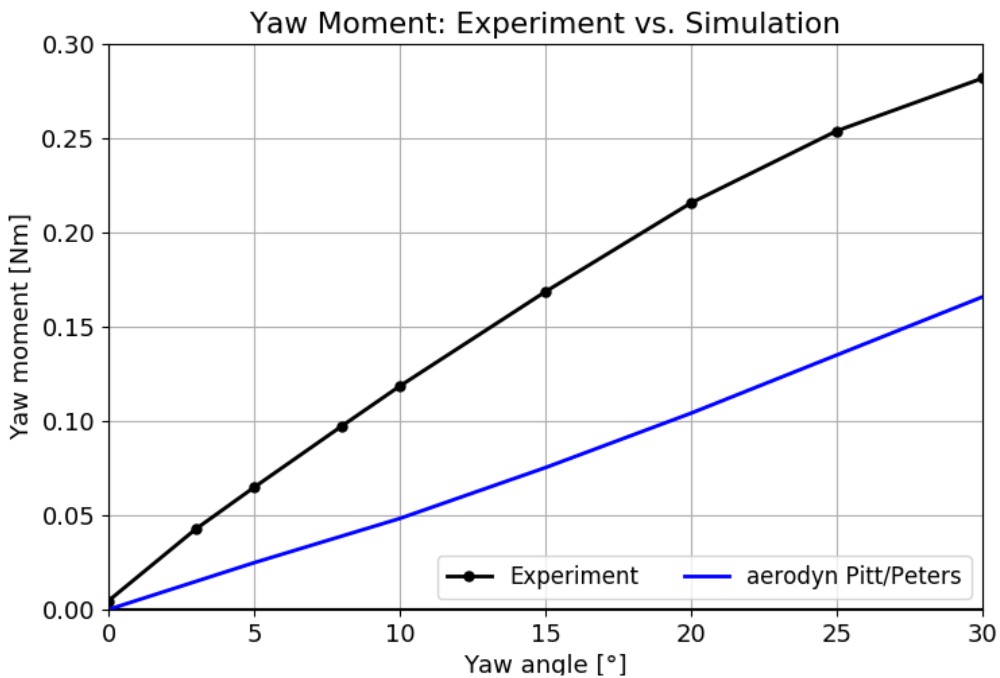
Results: Yaw Moment

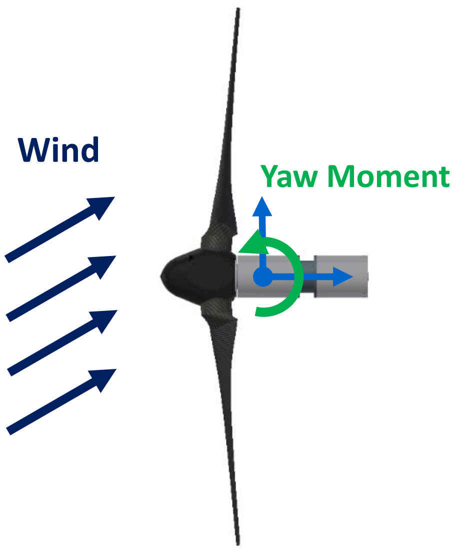




- **Different principal behavior**
- **Considerable deviations in the yaw angle range 0° to 30°**

RESULTS: YAW MOMENT AT RELEVANT ANGLES FOR PASSIVELY YAWING FOWT



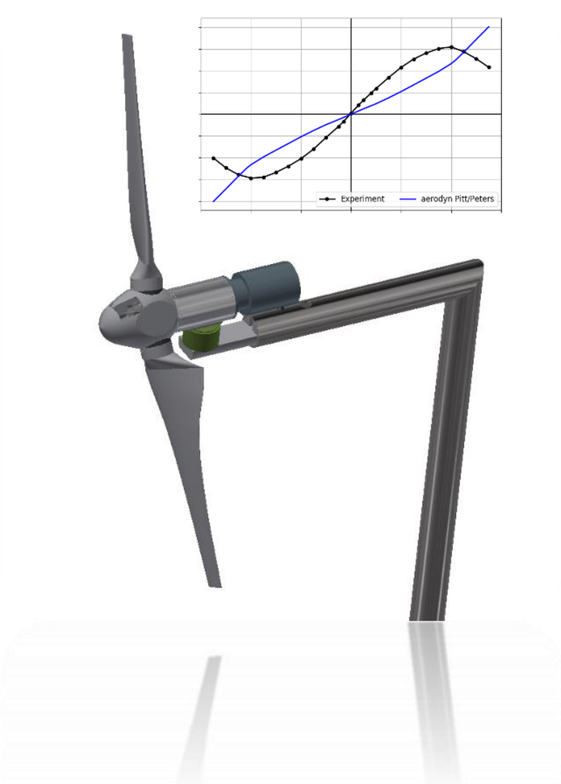


- **Slope at lower yaw angles underestimated by more then 50%**
- **Consequence: Overestimation of yaw misalignment** (of a passively yawing FOWT)

Overview: Determining the Yaw Moment of a Downwind-coned Rotor

Determining the Yaw Moment of a Downwind-coned Rotor

CONCLUSION



Conclusion

- BEM simulations of TUHH Model Wind Turbine under yawed conditions performed
- Reasonable agreement in power and thrust at intermediate yaw angles
- **Strong deviations in principal shape and slope of yaw moment**
  - **Validity of aerodynamic loads calculated with Pitt/Peters model very limited in this case**
  - Passively yawing FOWT designers should validate their model or use higher fidelity methods
  - Other wake skew models should be tested in the future

Acknowledgement

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Thank You for your Attention

Preview on experimental campaign

Christian W. Schulz