Towards an Integrated Framework For Optimization of Wind Turbines Using OpenMDAO

DTU Wind Energy Python Course

Frederik Zahle

Wind Energy Department · DTU

Airfoil and Wind Turbine Optimization in AED

- AirfoilOpt and HawtOpt were developed around 10-15 years ago and has since been used successfully for the design of Risø-A, P, B, and C airfoil series, some of which are in active use in industry, as well as a number of wind turbine blades also used in industry.
- Written i C and forms a fairly ”closed” eco-system, mostly focused on optimization.
- Steady state BEM code written specifically for this application.
- HAWC2 was interfaced to HawtOpt via a Matlab interface, exchange of data started becoming quite complex.

Light Rotor Project

Aim of the Project

- The Light Rotor project aims at creating the design basis for next-generation wind turbines of 10+ MW.
- Collaboration with Vestas Wind Systems
- The project seeks to create an integrated design process composed of:
  - Advanced airfoil design taking into account both aerodynamic and structural objectives/constraints,
  - Aero-servo-elastic blade optimization,
  - High fidelity 3D simulation tools such as CFD and FEM, Structural topology optimization.

Participating Codes

- EllipSys2D/3D for airfoil/rotor shape optimization,
- HAWC2, HAWCStab2 for aero-servo elastic optimization of rotors,
- CSProps and BECAS for structural optimization of blades.

New Framework for Optimization

Requirements

- We want our framework to be able to easily adapt to updates to the participating (often external) codes,
- We want to create simple interfaces to potentially very complex codes,
- Need to handle complex workflows with many participating codes,
- *Changing* workflows: We want to be able to change around how codes are wired together, and change the optimization strategies.
- Reuseability: We don't want to code the essentially same thing over and over again to accomodate different workflows.

F Zahle
Wind Energy Department · DTU

New Framework for Optimization

Choices

- An interpreted (scripted) programming language seemed better suited than a compiled language.
- Python was the choice, I don't need to lecture you about why!
- To systematically handle the workflow and dataflow of the potentially very complex problem formulations, OpenMDAO seemed very well suited.
- OpenMDAO also gives access to a large catalogue of optimizers, optimization architectures, design space exploration etc.

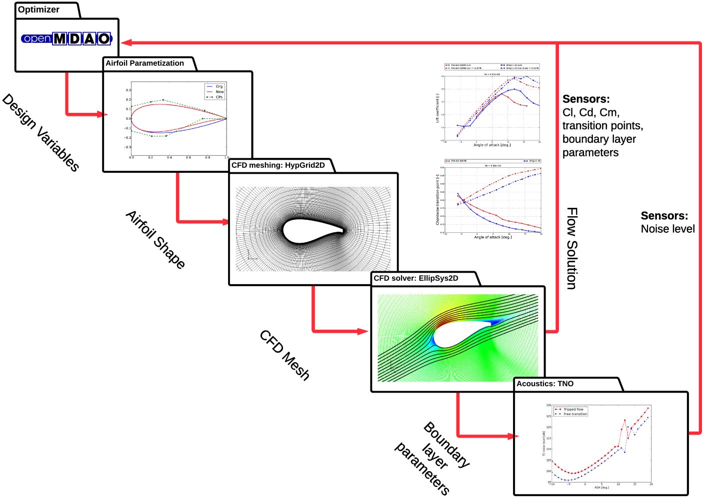
F Zahle
Wind Energy Department · DTU

Current Activities - Airfoil Optimization

Aero-acoustic optimization

- In the Light Rotor project, the aim has been to explore the potential gains of using Computational Fluid Dynamics (CFD) for airfoil optimization rather than XFOIL.
- CFD potentially offers higher accuracy, particularly for thick airfoils.
- For thinner airfoils noise is an important design constraint, which has also been a goal to incorporate in the design tool.
- HypGrid (mesh generation), EllipSys2D (CFD solver), XFOIL (panel code), and the TNO noise model have all been interfaced to OpenMDAO.
- The first two using OpenMDAO's ExternalCode class, and the latter two using p2py.

Current Activities - Airfoil Optimization



F Zahle
Wind Energy Department · DTU

Current Activities - Airfoil Optimization

Optimization of the LRP Airfoil Series using 2D CFD

- The new optimization interface to EllipSys2D was used to design two airfoils, the LRP2-30 and the LRP2-36.
- The airfoils are right now being tested in collaboration with Vestas in the Stuttgart Laminar Wind Tunnel.

F Zahle
Wind Energy Department · DTU

Current Activities - Aero-servo-elastic Optimization of Wind Turbines

Wind Turbine Optimization

- Move beyond a manual process involving: steady state BEM based optimization followed by an aero-elastic analysis, structural design and controller tuning.
- Enable concurrent integrated optimization involving planform optimization, structural optimization and controller tuning with constraints on important structural eigen frequencies.
- HAWCStab2 used to compute steady state aero loads, deflections, and frequencies; tune controller.
- HAWC2 used to evaluate the design for selected load cases.
- BECAS / CSProps used to predict the structural properties of the turbine structure.

F Zahle
Wind Energy Department · DTU

Current Activities - Aero-servo-elastic Optimization of Wind Turbines

HAWC2 / HAWCStab2 Wrapper

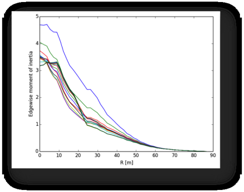
- The OpenMDAO interface to HAWC(Stab)2 allows for control of all input parameters in HAWC2:
  - Wind and operational parameters: wind speed, shear etc
  - All bodies with c2_def definition, beam structure inputs, orientations, constraints
  - Airfoil data, blade planform,
  - Standardized interface to DLLs, with specific interface to the Risoe Controller.
  - http://vind-redmine.win.dtu.dk/projects/hawc2_wrapper

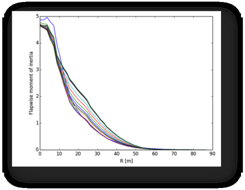
F Zahle
Wind Energy Department · DTU

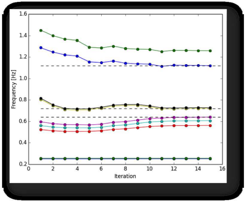
Current Activities - Aero-servo-elastic Optimization of Wind Turbines

Structural frequency placement Using HAWCStab2 (Carlo Tibaldi)

- Moments of inertia changed in both flapwise and edgewise direction
- The cost function is the square of the relative error of the placed frequencies with the desired value
- Example (Just a demonstration of the method)
- Objective:
  - Collective flap at 4P
  - Sym. edge at 4.5 P
  - 2nd yaw flap at 7P







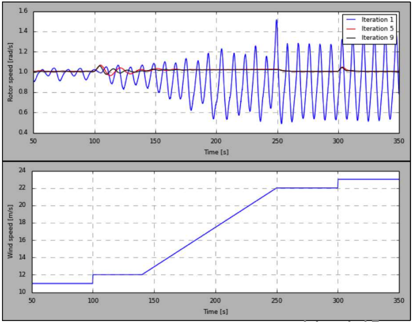
F Zahle
Wind Energy Department · DTU

Introduction

Current Activities - Aero-servo-elastic Optimization of Wind Turbines

Controller Tuning (Carlo Tibaldi)

- Tuning of the controller in the full load region and selection of the rotor speed filter frequency
- Optimization variables are:
  - Regulator mode frequency and damping
  - Rotor speed filter frequency

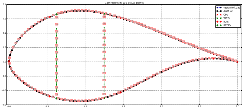


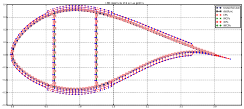
F Zahle
Wind Energy Department · DTU

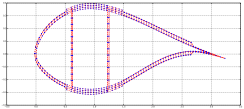
Current Activities - Structural Blade Optimization

OpenMDAO Interface to BECAS (David Verelst)

- Interface to Matlab based BECAS using Oct2Py
- Oct2Py interface wrapped in a Component





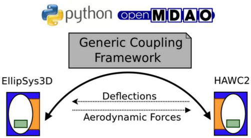


F Zahle
Wind Energy Department · DTU

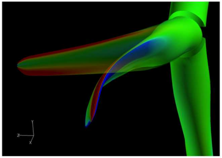
Current Activities - Fluid Structure Interaction

EllipSys3D coupled to HAWC2 (Joachim Heinz)

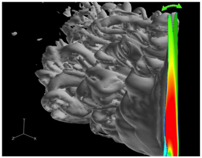
- The CFD solver EllipSys3D has been coupled to the structural model of the aero-elastic solver HAWC2 using the OpenMDAO framework.
- This coupling constitutes a new generation of aero-elastic computations where the rotor aerodynamics can be represented in greatest detail and accuracy.

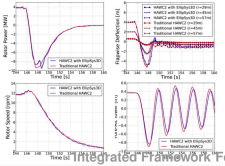


Emergency Shutdown (NREL-5MW-RWT)



Standstill Vibrations (DTU-10MW-RWT)





Conclusions

- OpenMDAO is the backbone of a number of tools aimed for optimization of wind turbines that are under development in DTU Wind Energy.
- The result is a dynamic and adaptable set of tools that can be used in a number of different contexts.
- OpenMDAO provides a common interface to all these tools making adaptation for new users more easy.

F Zahle
Wind Energy Department · DTU