Multi body simulations at ECN wind
Coupling of ECN software

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Outline

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  - validation
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• Control Design Tool
• Application
  - SIMPACK model
  - research results
    - structural blade modelling
    - drive train analysis
    - pitch actuator
• Conclusions

Source: Fotovlucht Soesterberg, Eric Vorstenbosch
Introduction (ECN)

Energy research Centre of the Netherlands (ECN) [http://www.ecn.nl/]

- Strategic position between fundamental research at universities and appliance of knowledge and technologies in practice
- Departments: Solar Energy (90), Wind Energy (40), Biomass, Coal & Environmental Research (80), Energy in the Built, Environment, Intelligent Grids, Energy Efficiency in Industry, Hydrogen & Clean Fossil Fuels (65), Policy Studies (75)

Unit Wind

- Main activities (in close cooperation with industry and university):
  - Research in wind turbine technology
  - Development of wind turbine related software
  - Consultant for wind energy related problems
  - Certified measurements on prototypes (power performance, noise, loads)
- Facilities:
  - Wind turbine test site Wieringermeer (EWTW)
  - Static and fatigue testing of components for commercial wind turbines (WMC)
Introduction (MBS)

why multi body simulation of wind turbines?
• improved structural modelling
• speed vs accuracy

multi body system:
• rigid bodies connected by joints
• forces and constraints on bodies

used to model the dynamic behavior of systems that undergo large displacements
Aero-Module (overview)

Structural solver (MBS, FEM)
or
ECNAero.exe (standalone execution)

Local blade positions and velocities

Local blade forces and moments

ECNAero.DLL

BEM
Prandtl, TWS, Dynamic inflow, Year model, Adaptation

AWSM

Environment
Wind Tower Etc.

Airfoil data
Polars(C1,C2,C3) Dynamic Staff 3D corrections

Support structure + more!
Aero-Module (BEM)

PHATAS formulation as starting point
• Element or annulus approach
• Convergence using annulus averaged axial induction
• ECN Dynamic Inflow model (ECN-C-94-107)
• ECN Yaw/Tilt model (ECN-CX-98-070) – adaptation?
• Wilson TWS model ($a_T$ as user variable)
• Prandtl root/tip correction (F using root/tip induction)
• AOA evaluation at C14 or C34
Aero-Module (AWSM)

- Based on non-linear lifting line vortex wake theory
- Input of aerodynamic coefficients still necessary
- Enhanced modeling of
  - Tip effect
  - Dynamic inflow effects (e.g. pitch step)
  - Yawed flow
  - Radial dependence included
Aero-Module (Airfoil data)

- Interpolation of sectional characteristics using thickness and Reynolds nr
- Dynamic stall models (adaptation?):
  - Snel 1st order
  - Snel 2nd order
  - Beddoes-Leishmann
  - Onera
- Snel 3D correction
- Flow curvature
Aero-Module (Environment)

- Tower modelling
  - 3D-dipole
  - Tower induced velocity dependence on rotor induction
  - Extensions?

- Wind options
  - SWIFT full 3D wind field
    Stochastic (turbulence, hor and ver shear)
  - Simple wind field
    Specification of time dependent hub height wind (u,v,w). Shear optional

Source: Gomez et al., Wind Engineering Vol. 33 no. 6
Aero-Module (Validation)

- Comparison to PHATAS
Aero-Module (Validation)

Comparison to experiments MEXICO (Axial flow, Pitch = -2.3deg, U=10,15,24 m/s)
Aero-Module (Validation)

Comparison to experiments MEXICO (Yaw=45deg, Pitch =-2.3deg, U=15 m/s)
Aero-Module (Validation)

Comparison to experiments MEXICO (Yaw=30deg, Pitch =-2.3deg, U=24 m/s)
Aero-Module (Usage)

- **Coupling**
  - Initialise subroutine: initialisation, called only once
  - Finalise subroutine: finalisation, called only once
Aero-Module (Usage)

- Keyword text input

```
AEROMODEL
AEROMODEL
ATRDENSITY 1.325
AERODYN
1.510-5
EQUIL 340.3
NROBLES 3
BLADEROOT 1.2
BLADELENGTH 38.2
TOBERAREADIUS 2.1
TOBERAPRADIUS 1.3
WINDTYP 11: SIMPLE 2; SWIFT
WINDFILENAME wind.dat
ORDER
0
Y2
NROBLES
23
NROBLES
23
COERFILNAME aerofoil.dat
COERFINT 2
COERFINT 2
DYNSTATTY 0
DYNSTATTY 0
FLOWOPX 1
FLOWOPX 1
INCLUDE somefile.dat
LOGFILENAM testfile.dat
DEBFILE 1
DEBFILE 1
MARCH 80.0
MARCH 80.0
TILPEND 0
TILPEND 0
YAWANGL 0
YAWANGL 0
PITCHANGL 0
PITCHANGL 0
XHUB 15.4
XHUB 4.0
YHUB 1.99
YHUB 1.99
ZHUB 0
ZHUB 0
TEND 3
TEND 3
TENSTEP 0.01
TENSTEP 0.01
```
Control Design Tool (CDT)

Industrial control algorithm development for wind turbines
Control Design Tool (features)

CDT features:

• Feedback algorithms for pitch and generator control (PRVS mMW wind turbines)
• For certification and industrial implementation
• Knowledge transfer (control course)
• Open source license: Matlab / Simulink (cross-platform)
• Modular design structure
• 3-stage design: 1 synthesis 2 analysis 3 evaluation
Control Design Tool (design - basics)

Control is a trade-off between:
• performance (speed & accuracy)
• stability (gain & phase margin, robustness)
CDT (design - control objective)

1) part load: optimal power
(torque controlled variable speed, constant pitch)

2) full load: rated power
(pitch controlled constant speed, constant power)
CDT (design - control objective)

1) part load: optimal power
   (torque controlled variable speed, constant pitch)

2) full load: rated power
   (pitch controlled constant speed, constant power)
CDT (design - controller structure)

add-ons:
- dynamic inflow compensation
- estimated wind speed feed forward
- drive train damping
- tower resonance bridging
- pitch actuator limitation
- commissioning
**Control Design Tool (use)**

- **input specs**
- **synthesis**
- **analysis**
- **evaluation**
- **load calculation**
- **PLC implementation**
- **wind turbine**

- e.g.: ECN’s PHATAS
- e.g.: Bachmann’s M-Target for SL
- e.g.: GH Bladed

- automatic code generation (RTW)
- design iteration
CDT (use - 1 synthesis)

controller synthesis
• input specification
  (turbine model and controller)
• parameterization

gain scheduling to deal with the nonlinear aerodynamics
CDT (use - 2 analysis)

frequency domain analysis
• performance
• stability

estimated wind speed feed forward
• improves the phase margin
• reduces control delay
• increases robustness
CDT (use - 3 evaluation)

Time domain simulation
(MatLAB Simulink)
CDT (linking to aeroelastic tool)

(in this case SIMPACK + Aero-Module)

CDT interface to wind turbine
input                 output
- blade pitch angles  - generator torque setpoint
- rotational speed    - blade pitch speed setpoint
- generator torque

compiled DLL (MatLAB Real Time Workshop)
Application

SIMPACK model
- generic wind turbine model (topology)
- linking Aero-Module and CDT
- verification & validation of integral model research results
  - blade modelling
  - pitch actuator dynamics (PROTEST)
  - drive train modelling (PROTEST)
Application (SIMPACK - generic model)

- parametric wind turbine model

- model properties
  - flexible tower and blades
  - pitch actuator
  - drive train torsion
  - gearbox transmission ratio
  - gearbox support
  - foundation stiffness
  - external aerodynamics (Aero-Module) and control (CDT)
Application (SIMPACK - model topology)
Application (SIMPACK - linking code)

linking CDT through FORTRAN user routines:
1) user force performs measurements, calls controller and applies generator torque
2) user joint applies pitch angle

issues:
- variable/discrete time step
- initialization with previous runs
- generator & pitch actuator model
Application (SIMPACK - linking code)

interface:
Application (SIMPACK - baseline comparison)

- `--b` multibody model
- `--r` PHATAS
Application (results - blade modelling)

blade models compared:

- Rotor Blade Generator blade model (linearized beam, modal reduced)
- multi body blade model (nonlinear lumped mass, discrete 5DOF spring-damper elements)
- PHATAS blade model (nonlinear deflection model)
Application (results - blade modelling)

static load tip deflection:
- undeformed
- base loading (g)
- 4xbase loading

–b linearized flexible blade (RBG)
-.g nonlinear multibody model
Application (results - blade modelling)

dynamic case definition:
– wind speed step 10->14m/s
– rigid tower, no tilt & yaw
– constant rotor speed and pitch angle
– no Prandtl corr.
– no gravity

wind turbine operation ->
Application (results - blade modelling)

comparing structural blade models

- b SPCK RBG (advanced)
- r PHATAS
- g SPCK nonlinear multibody
Application (results - pitch actuator dynamics)

multi body model can be used for:
• friction analysis
• pitch drive train & motor loading
• pitch actuator dynamics (control)
Application (results - pitch actuator dynamics)
Application (results - drive train modelling)

multibody drive train model can be used for:
• global motion and loading of components
• internal gearbox dynamics
• interaction with the electrical system
Application (results - drive train modelling)

- BASE: rigid drive train
- MOD1: flexible support
- MOD2: flexible main shaft
Conclusions

• SIMPACK can be used for integral wind turbine simulation (using aerodynamics and control from external modules)
• flexible, modular setup; dedicated models for specific design load cases
• component level detail:
  - contact (drive train gearbox, pitch gear etc.)
  - (reduced) FE models can be analyzed, but not created
• subsystem modelling: integral vs isolated approach?

NB improved structural modeling needs:
  - design data & measurements
  - expertise (at component level)
CDT (part load pitch controller structure)
CDT (full load pitch controller structure)
Application (SIMPACK - features)

- multi body approach
- linear and nonlinear analysis (different solvers available)
- rigid and flexible bodies
- user routines for linking external code (aerodynamics, control)
- contact analysis
- substitution variables & parameter variation
- interfaces to MatLAB and FEM tools, code export
- GUI (pre and postprocessor)
Application (results - blade modelling)

dynamic case definition:
– wind speed step 10->14m/s
– rigid tower, no tilt & yaw
– constant rotor speed and pitch angle
– no dynamic inflow & Prantl corr.
– no gravity

wind turbine operation ->

-- b AeroDyn
-- r Aero-Module
Application (results - blade modelling)

angle of attack evaluation at $\frac{3}{4}$ chord

--b AeroDyn
--r Aero-Module
Application (results - blade modelling)

angle of attack
evaluation at ¼ chord

--b AeroDyn
--r Aero-Module
Application (results - blade modelling)

comparing structural blade models

- SPCK advanced RGB
- PHATAS
- SPCK adv (100Hz)