IMPACT OF TURBULENCE ON WIND TURBINE BLADE LOADINGS

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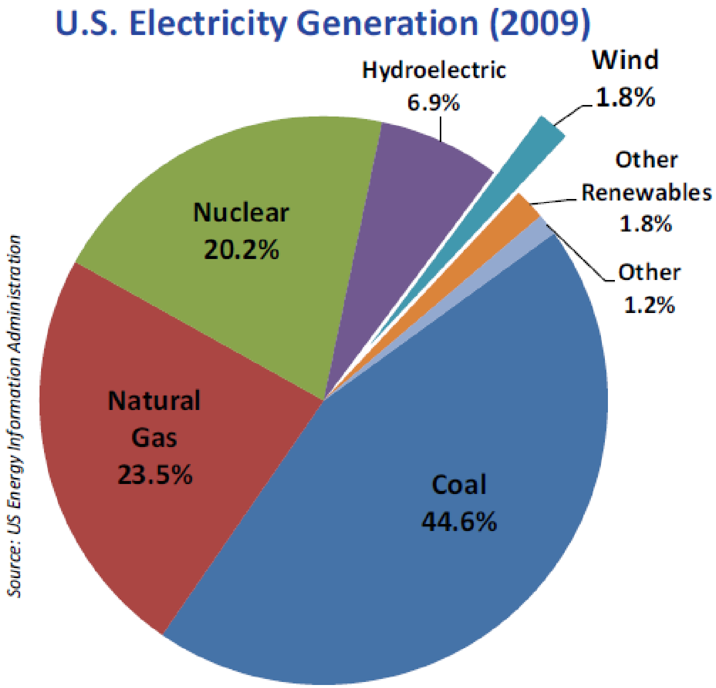
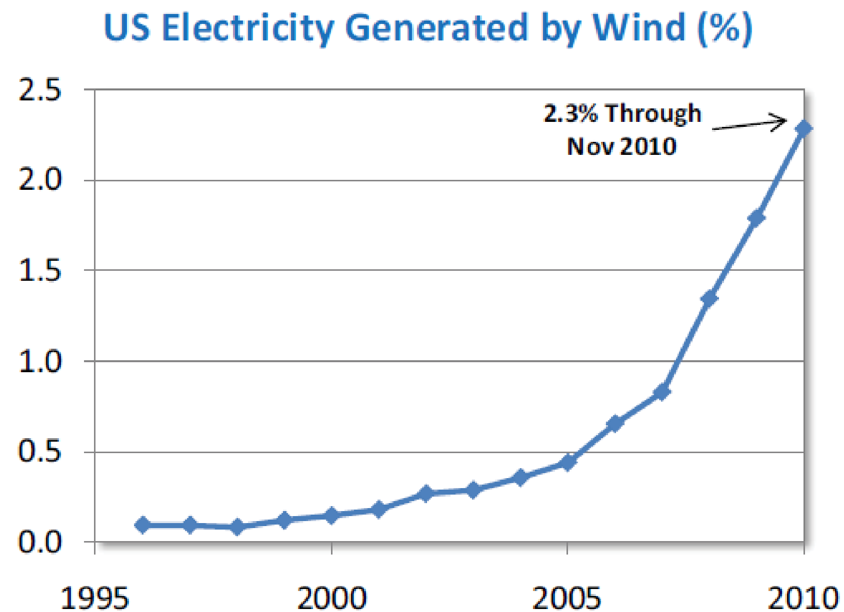
DOE's Goal is to Increase Wind Power to 20% by 2030





Top 5 wind power countries (Feb 2011)

China : 44.8GW

US: 40.1GW (2.3%)

Germany: 27.2GW (9%)

Spain: 20.7GW (16%)

India: 13.1GW

3MW wind turbine can provide electricity to 3000 homes

300 GW by 2030 (~300 million homes)

16GW per year after 2018

(5000 – 8000 turbines/yr)

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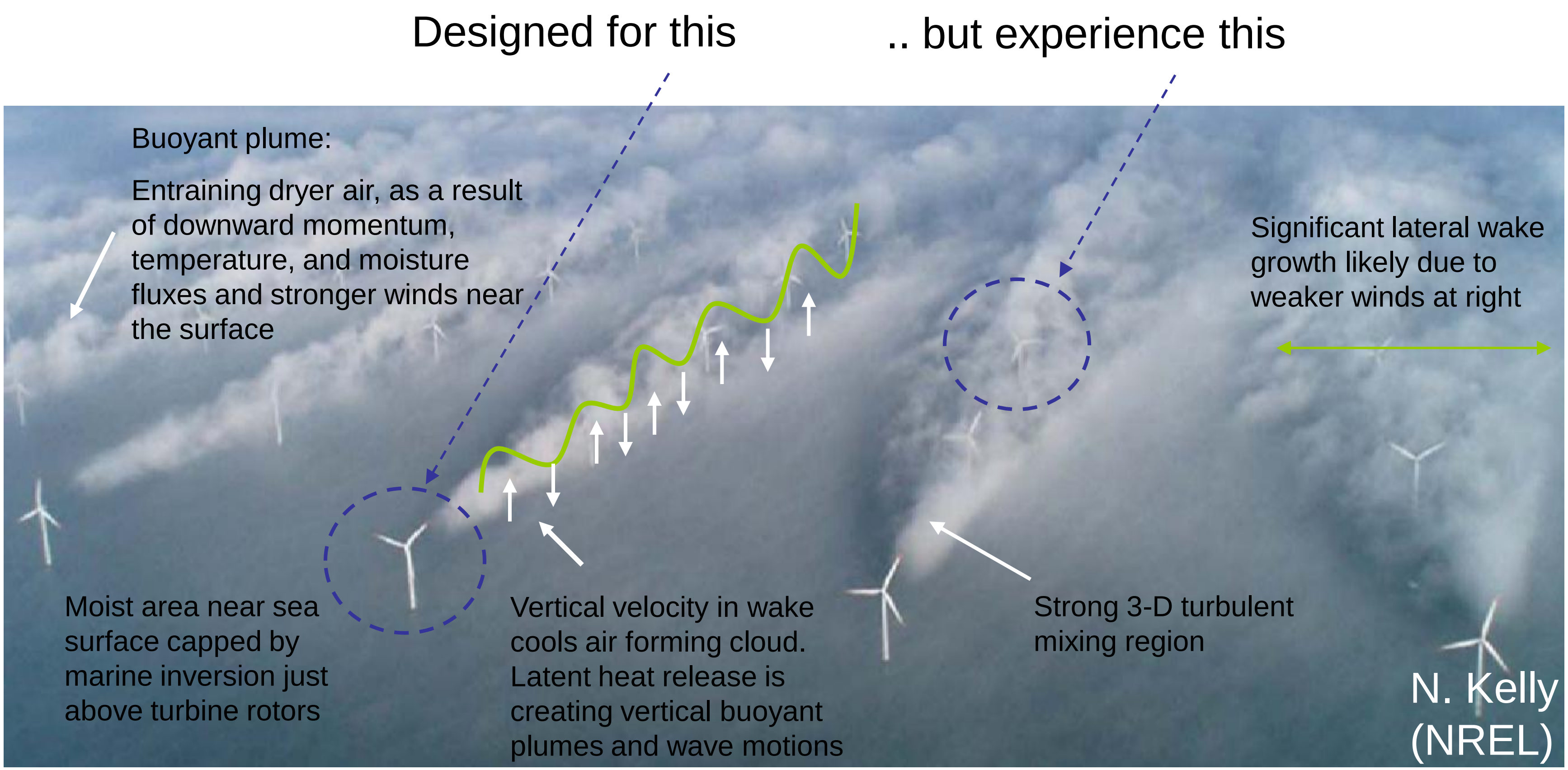
Modeling Tools for Wind Turbine design



-Offshore wind studies suggest that wake losses are greater than anticipated when there are multiple rows of turbines

-Need to better understand offshore wakes

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Previous Studies

•K. Thomsen and P. Sørensen, “*Fatigue loads for wind turbines operating in wakes*” J. Wind Engineering & Industrial Aerodynamics (1999)

-The flow field was experimentally measured to compute wind speed deficit, turbulence intensity, horizontal shear and turbulence spectrum length scale.

-The predicted turbine loads were computed using HAWC in which the fatigue loading was found to increase for wind farms compared to free flow cases

•S. Frandsen, “*Turbulence and turbulence generated structural loading in wind turbine clusters*” Risø-R-1188 (2005)

- Increased fatigue loading in the wind farm interior is due to the changes in turbulence scale and the horizontal shear flow.

- Quantified turbulence wake effects due to upstream turbines provided improved models for wind turbine design standard (IEC61400-1, 2005)

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Previous Studies

•Lavely *et al*. "*Space-Time Loadings on Wind Turbine Blades Driven by Atmospheric Boundary Layer Turbulence*" AIAA 2011-635

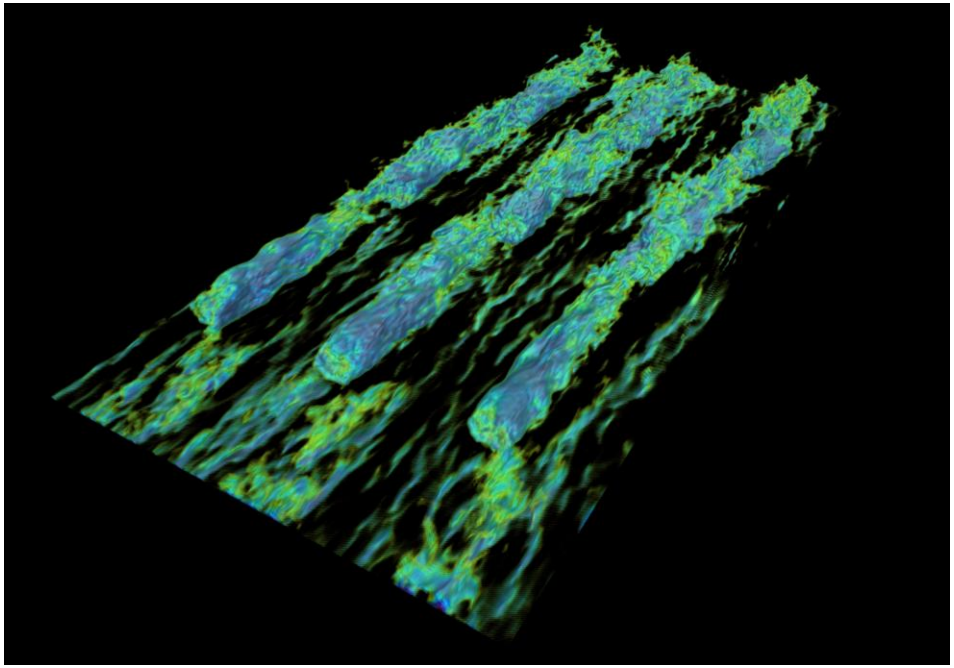
-Interaction between spatial-temporal loadings on wind turbine blade and turbulence structure was quantified using Large Eddy Simulation coupled with aero-elastic code (FAST)

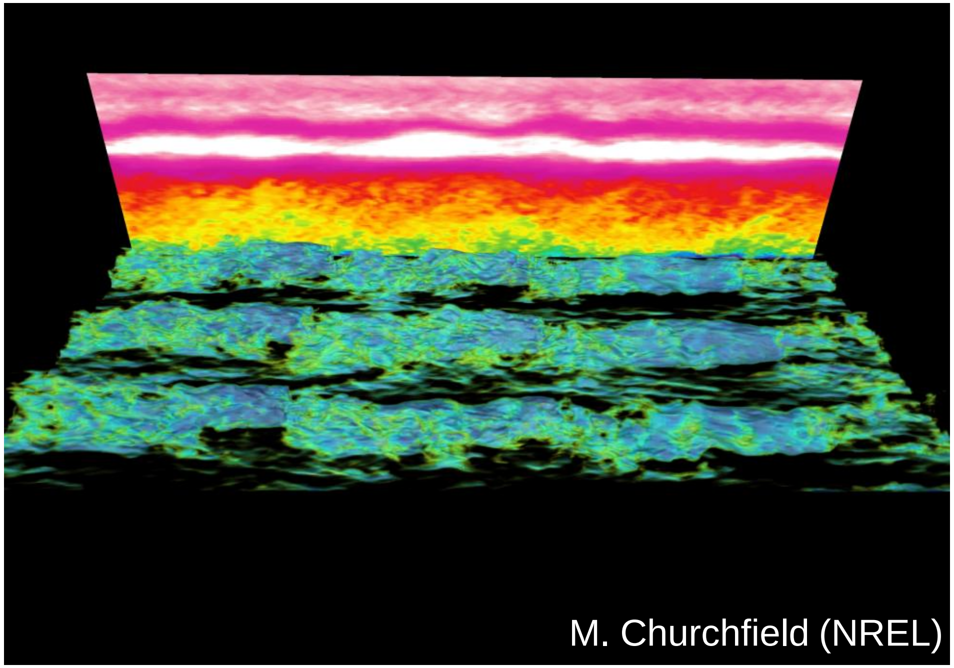
-Atmospheric turbulence is a major contributor to blade loadings and the force distribution has strong correlation with the turbulence structure which amplifies peak loadings

-Stability of the atmospheric boundary layer (ABL) plays an important roll in the structural loading

LES of 9 Turbines under Neutrally Stable Atmospheric Boundary Layer

Contours of streamwise velocity





-Power loss prediction is an essential component of wind engineering

-Turbulent wake generated by the upstream turbine has a significant impact on the fatigue loading for the downstream turbines

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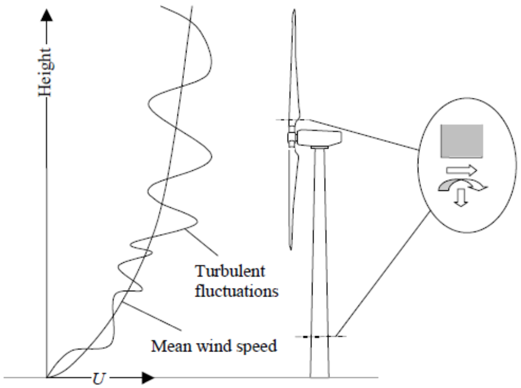
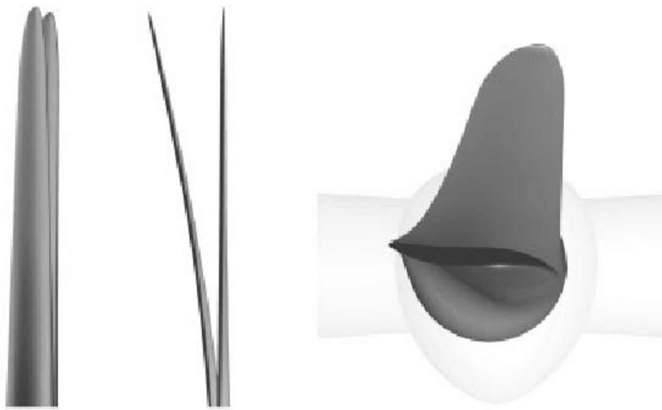
Current Efforts

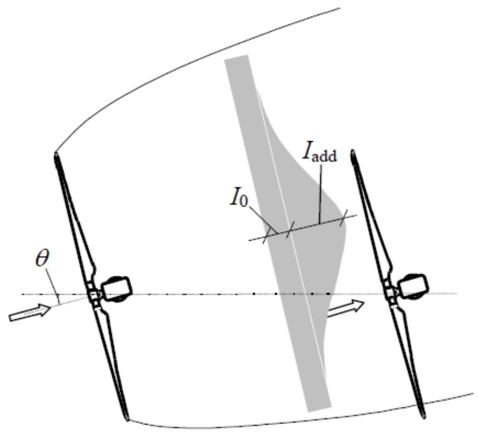
Quantify structural loading due to turbulence from incoming ABL and upstream turbine wakes and investigate the structural response to the flow (two way coupling)



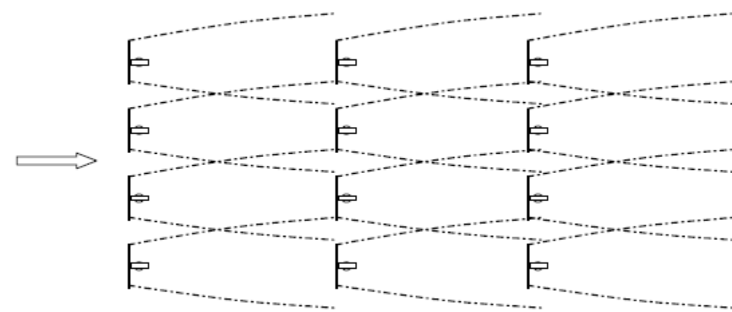
Incoming turbulent ABL



Blade deflections

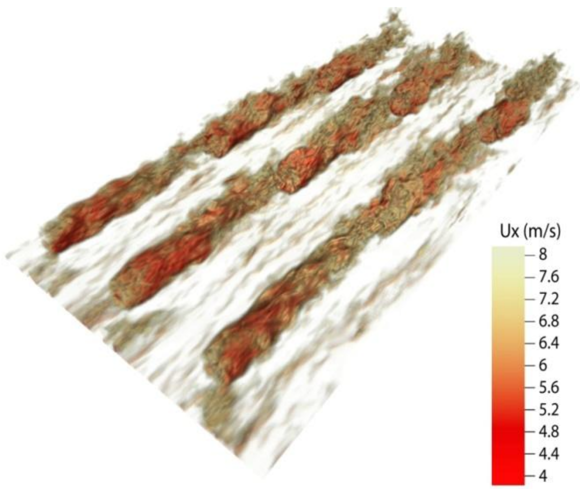


Increased turbulence



Wakes in wind farm

Strategy of Two-way Coupling



OpenFOAM

Do while (t < tmax)

call FLOW_Solver

call openFOAM2FAST

call FAST

call Fast2OpenFOAM

End do

velocity

FAST

(NREL aero-elastic code)

Compute structural response and blade rotation

aero-forces (body force) + new blade coordinates (with deflection)

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Compiling Mixed Language

- **To embed FAST into OpenFOAM (driver code), mixed language compilation issue must be resolved**
  - \- OpenFOAM written in C++ and FAST is Fortran 90

- **<u>Compiling mixed language example</u>**
- consider a Fortran function:

- integer function fortranfuntion(a, b)
- double precision a, b...
- end

- It must be called from C++ as:
- extern "C" { int fortranfuntion_(double&, double&); }
- ...

- int main() {
- double a, b;
- ...
- int i = fortranfunction_(a, b);
- ...
- }

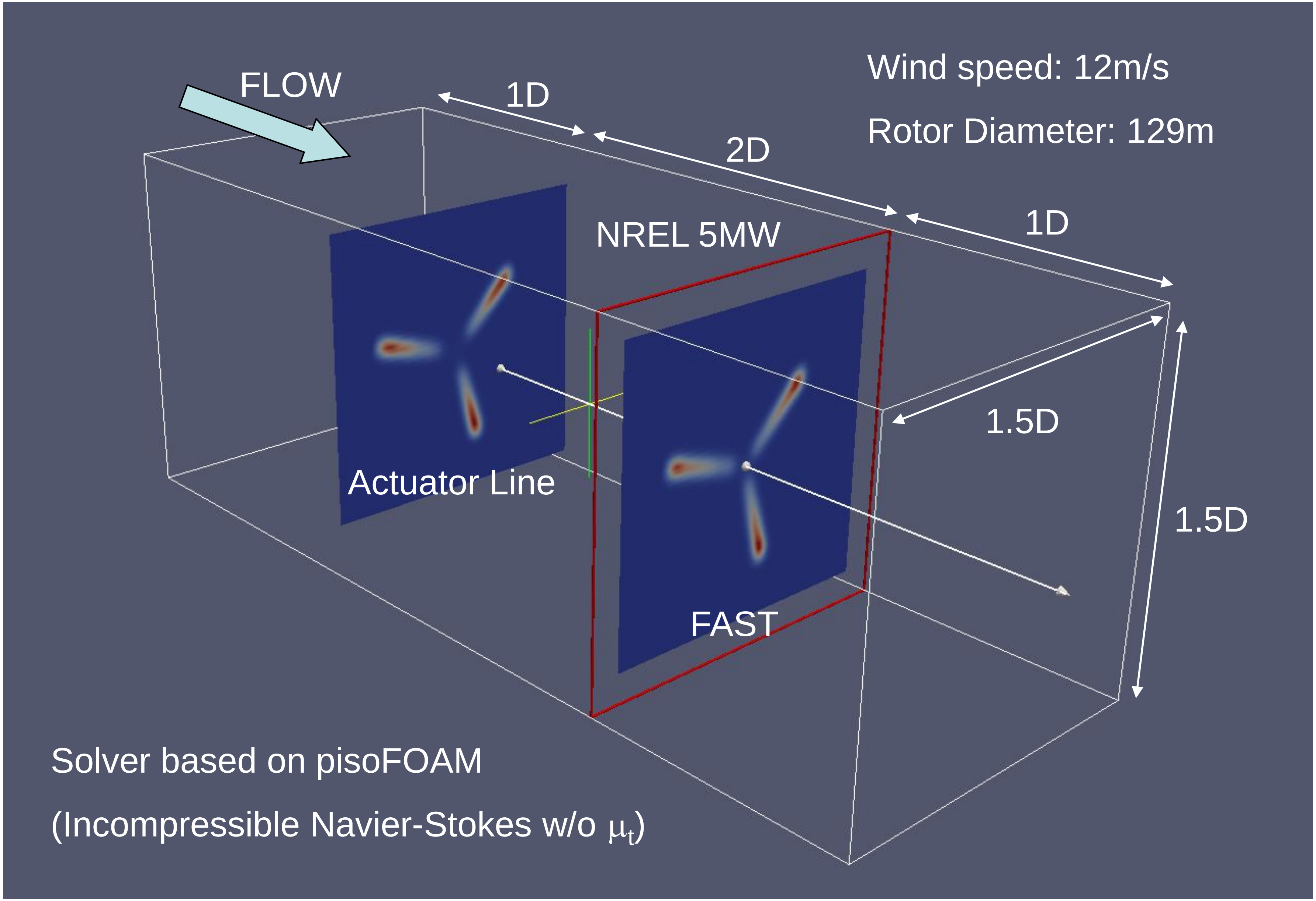
Compiling Mixed Language

• Successfully made calls to the individual FAST subroutines (pre-compiled in gfortran) to a test C++ program with a linker option ‘lgfortran’

•   > g++ c_objectfiles –o executableName –lgfortran fortran_objectfiles

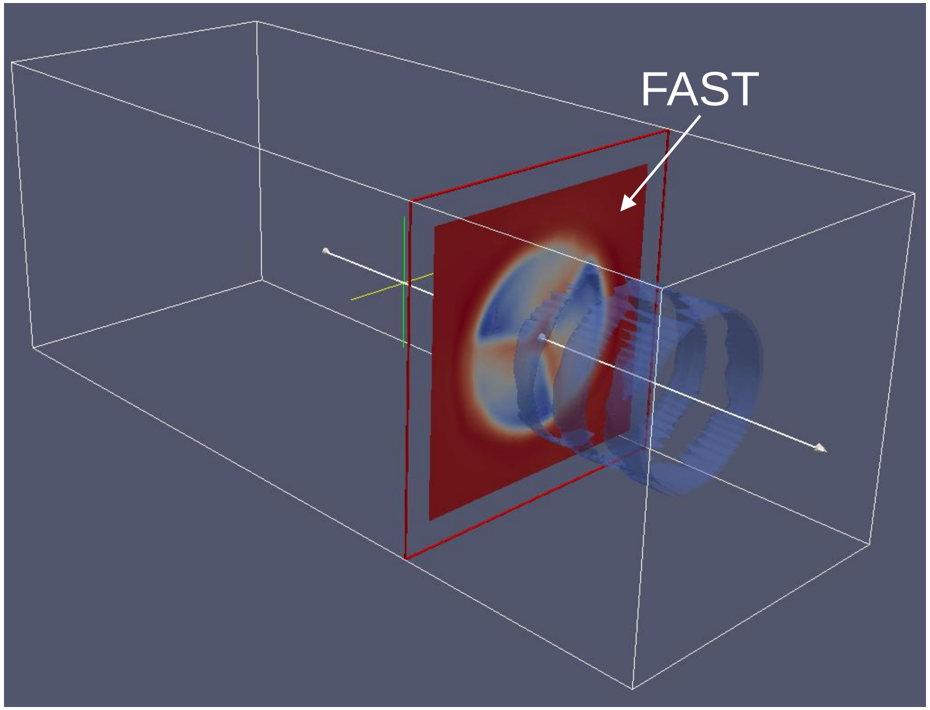
•Mixed language compile works with gcc-4.3.4 or above

Computational Domain

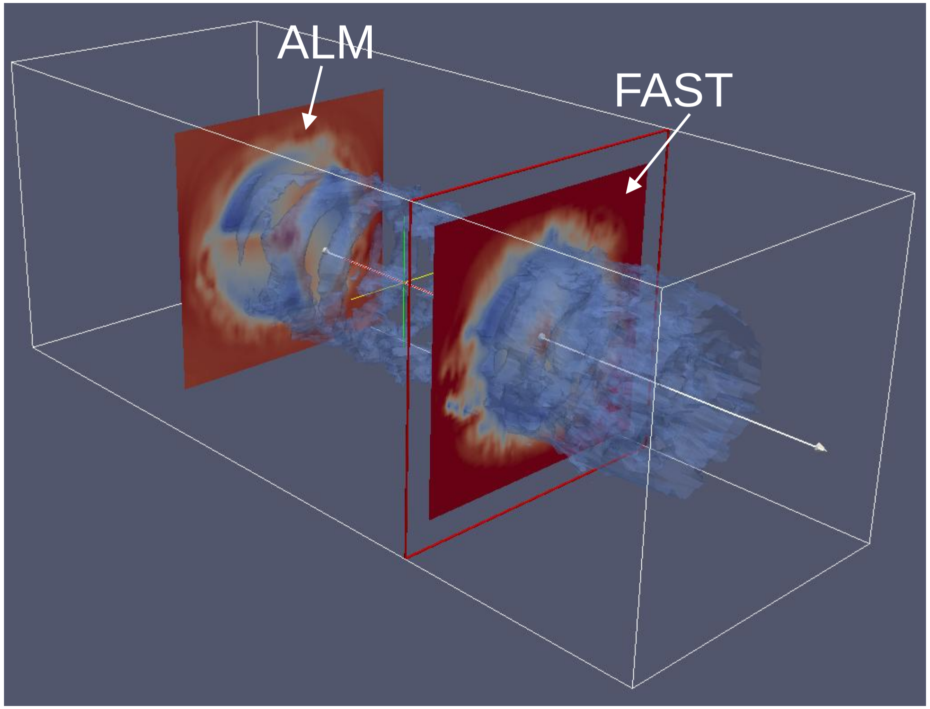


Streamwise Velocity Contours

Blade loadings are computed using FAST



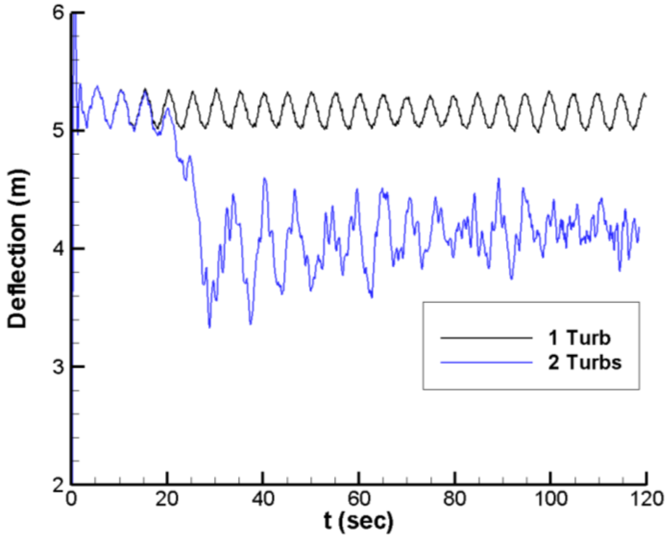
1 wind turbine



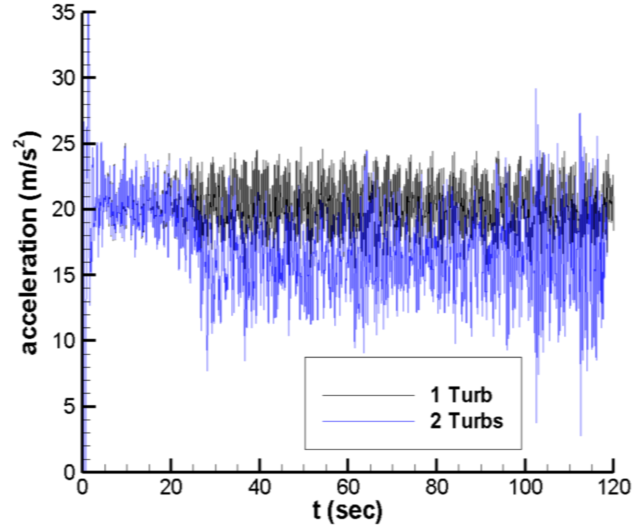
2 wind turbines

Downstream turbine is being approached with wake structures

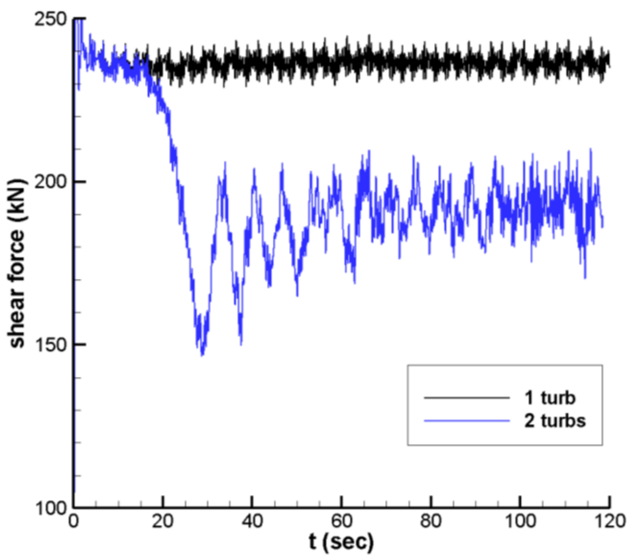
Flapwise Blade Loadings computed with FAST



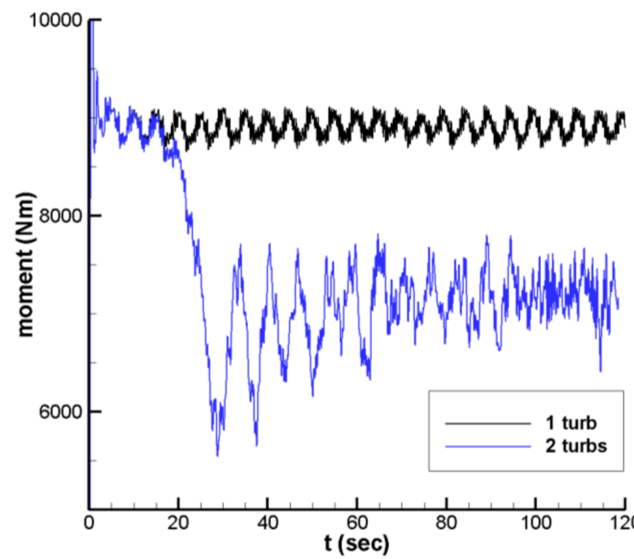
Blade-tip deflection



Blade-tip acceleration



Blade root shear force



Blade root moment

Future Work

-Further studies on upstream wake turbulence impact on blade loadings for various flow conditions and wind turbine positions (staggered arrangement, distance, etc.)

-Investigate wake turbulence interaction in a wind farm

-Modify FAST code to handle multiple turbines and couple to OpenFOAM

Questions

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