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National Laboratory of the Rockies

BERKELEY LAB

KYNEMA (EXAWIND) SOLVER SUITE

DOE IESO Open Source Summit

Presented by Lawrence Cheung

Sandia National Laboratories, Livermore CA

Albuquerque, NM

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SAND2026-24686C

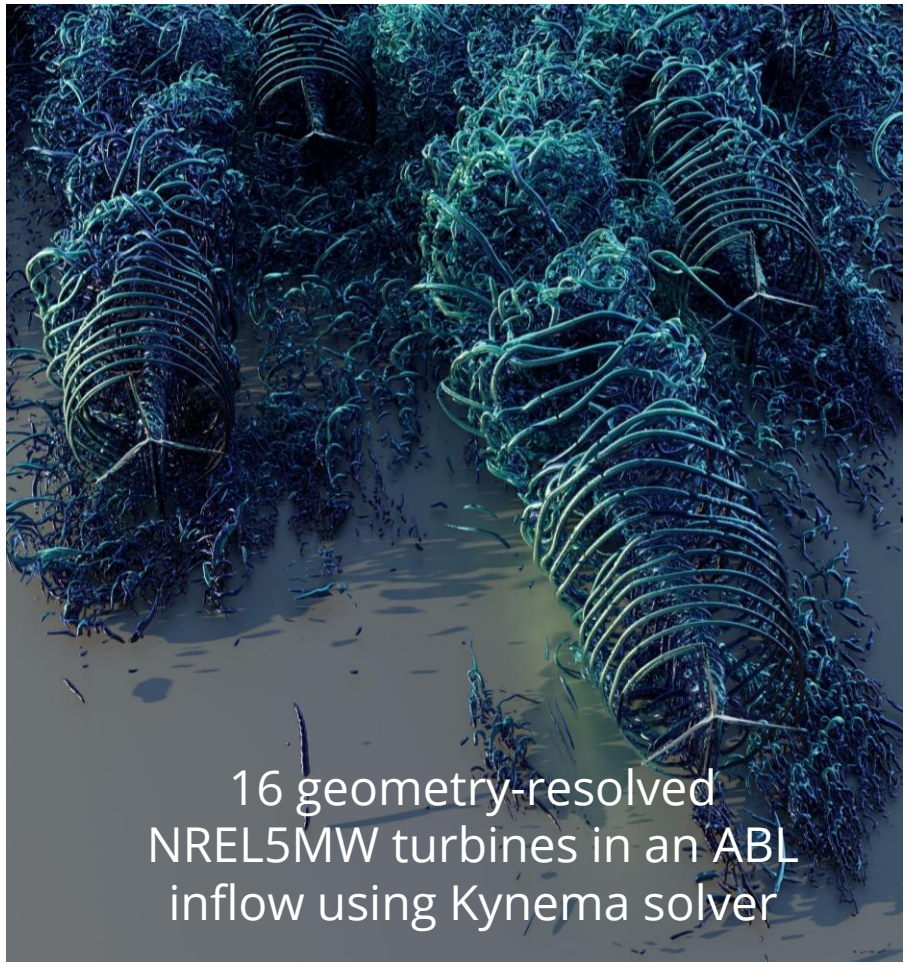
BACKGROUND

Current high-fidelity wind energy simulation codes are very complex

- Span large of scales
  - Airfoil boundary layers (several mm)
  - Large scale atmospheric structures (many km's)
- Cover many different physics
  - Atmospheric boundary layers
  - Airfoil aerodynamics
  - Turbine fluid/structure interactions
  - Offshore waves/two-phase flows

Kynema (formerly ExaWind) solver

- High performance, scalable open-source computational fluid dynamics and structural dynamics codes for energy applications
- Jointly developed by NLR, Sandia, LBNL
- https://github.com/kynema



16 geometry-resolved NREL5MW turbines in an ABL inflow using Kynema solver

OVERVIEW OF KYNEMA SOLVER STACK

Solver components

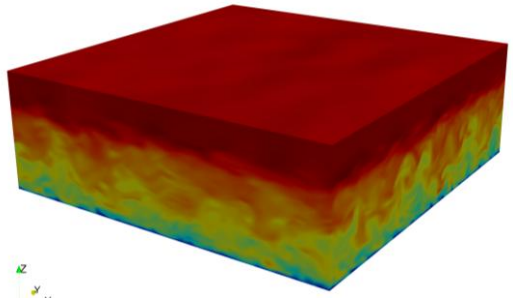
Kynema-UGF[1] (Nalu-Wind) Solver:
LES flow solver
- Unstructured, node-centered finite-volume solver
- Implicit BDF2 time-stepping algorithm
- Uses Sierra Toolkit libraries (STK) for unstructured mesh data structure

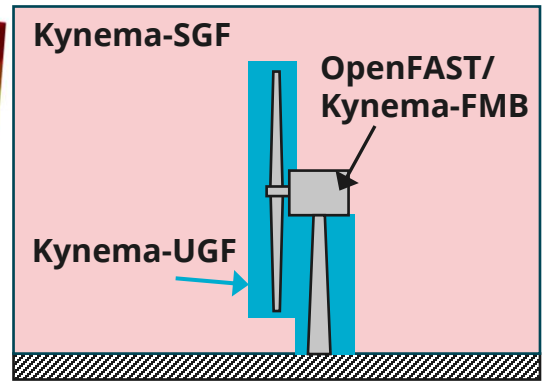
Kynema-SGF[2] (AMR-Wind) Solver
LES code focused on scalable on next-generation exascale supercomputers with GPU acceleration
- Structured grid finite-volume background solver with **adaptive mesh refinement (AMR)**
- Built on AMReX libraries
- Multi-level geometric multigrid linear-system solvers

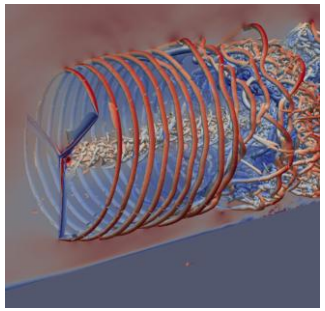
OpenFAST[3] turbine simulator:
Model turbine behavior
- Aero-elastic structural response
- Turbine controller behavior
- BEM aerodynamics
- Floating turbine and mooring line dynamics

Additional option: **Kynema-FMB[4]**
- Flexible multi-body dynamics solver

ExaWind hybrid simulations combines AMR-Wind and Nalu-Wind with overset approach


Kynema-SGF ABL mesh



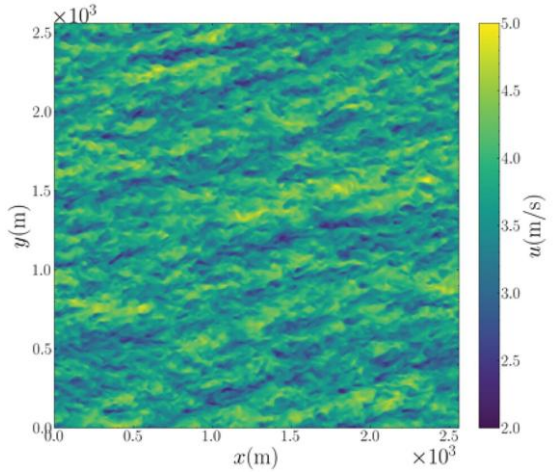

Kynema-UGF
blade-resolved mesh

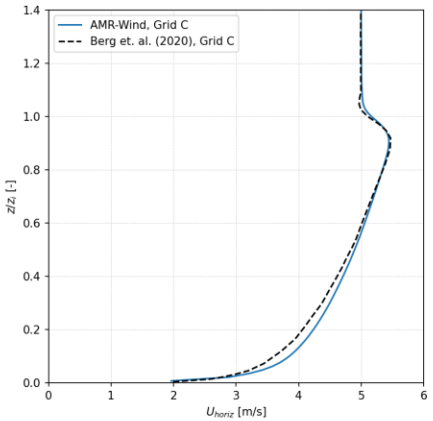
[1] https://github.com/kynema/kynema-ugf
[2] https://github.com/kynema/kynema-sgf
[3] https://github.com/OpenFAST/openfast
[4] https://github.com/kynema/kynema-fmb

KYNEMA COMPONENT SIMULATIONS

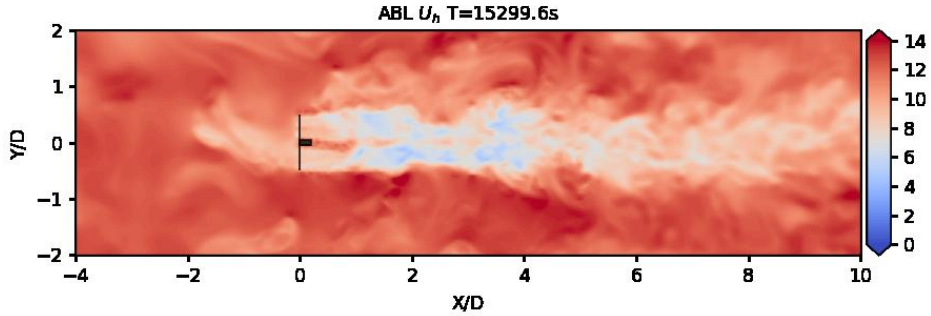
Kynema-SGF solver cases

Atmospheric boundary layers; turbines using actuator line method





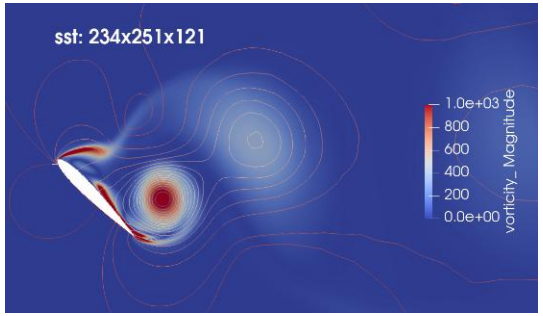
Neutral ABL



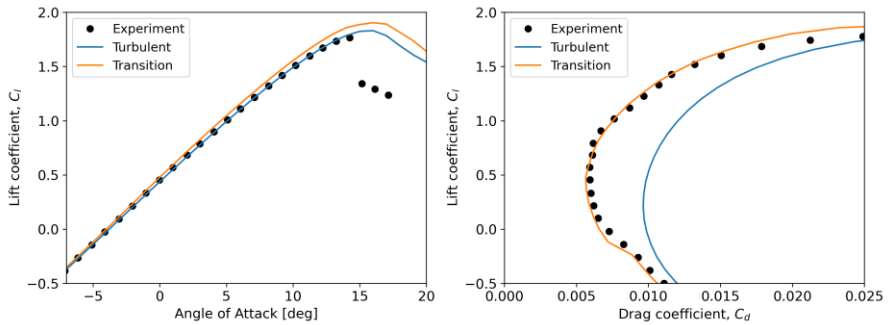
NREL5MW Turbine in ABL using ALM
(with and without FSI)

Kynema-UGF solver cases

Geometry resolved turbine components: blades and airfoil sections



Deep stall in NACA 0012 airfoil

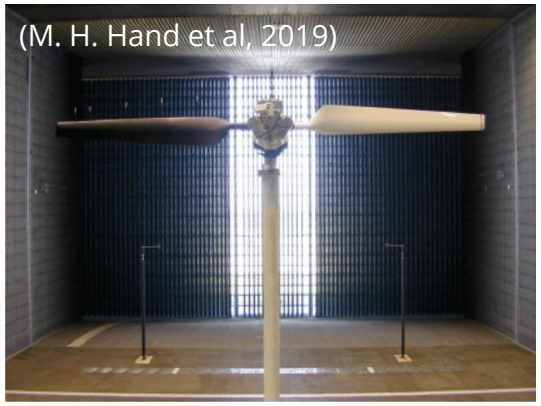


NLF(1)-0416 and DU00-W-212 airfoil

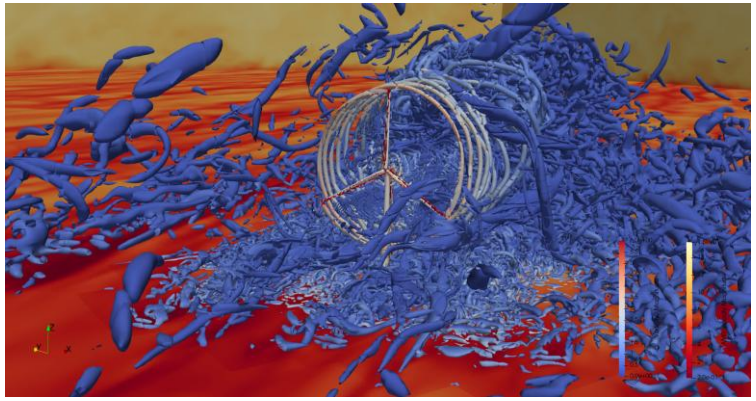
KYNEMA COMPONENT SIMULATIONS

Hybrid solver cases

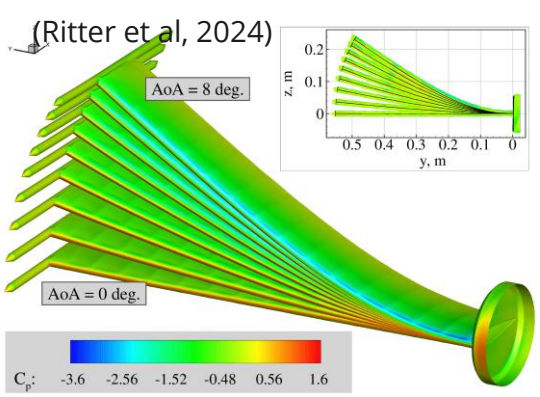
Cases with both AMR-Wind and Nalu-Wind run simultaneously



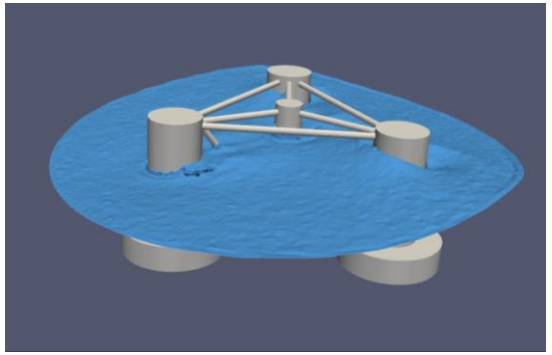
NREL Phase VI Rotor



NREL 5MW turbine in ABL (with and without FSI)



Pazy wing FSI case



OC6 platform in ocean waves

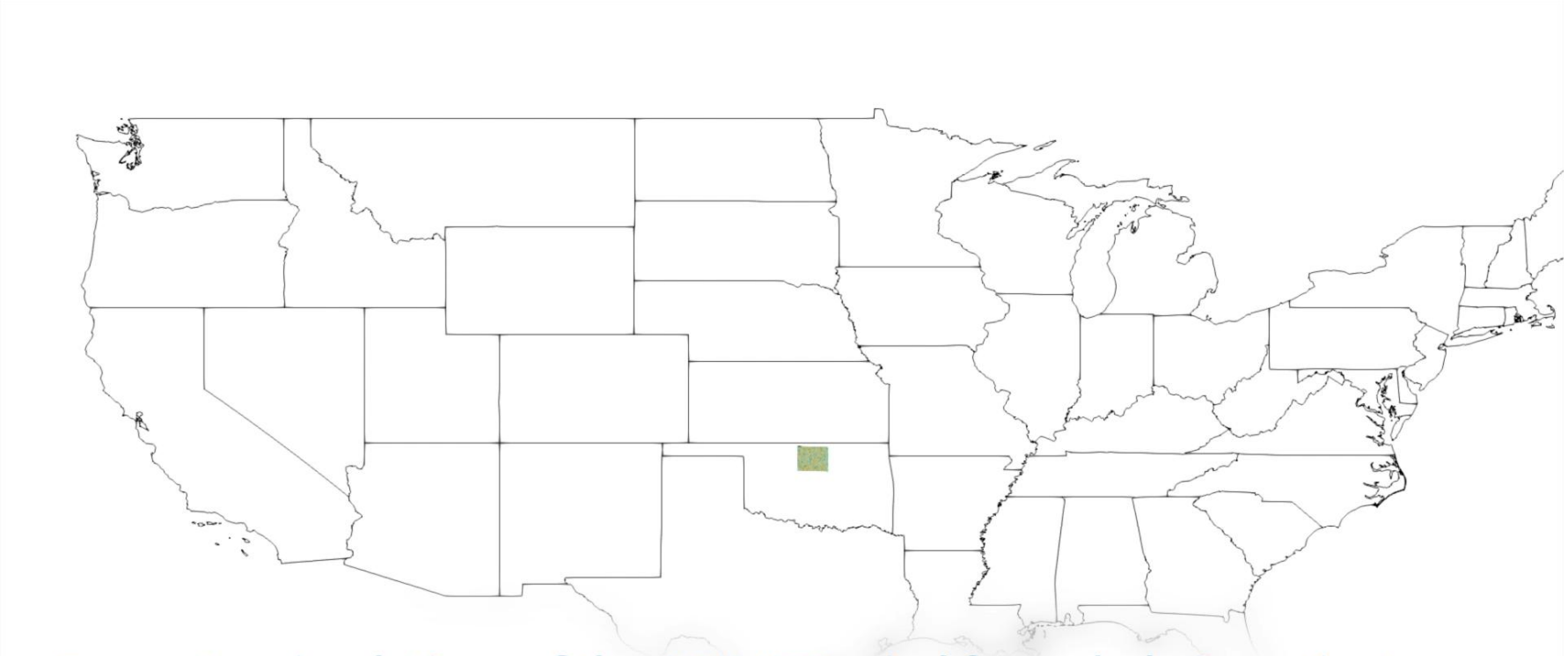
Additional cases also added to benchmark repository in near future

GEOMETRY RESOLVED WIND FARM SIMULATION

- 16 geometry-resolved NREL5MW turbines in a convective ABL inflow
- Domain size: 5km x 5km
- Mesh size: 1.7B total
  1.5M for Kynema-SGF
  256M for Kynema-SGF
- Run on OLCF Frontier cluster with 384 Nodes (3072 GPU/21,504 CPU)
- Total simulation time: 129 sec

SIMULATION VISUALIZATION: LARGE AMR-WIND RUN

- Large scale simulation of AWAKEN wind farm in 100km x 100km domain with over 500 ALM turbines in Kynema-SGF
- Run with 20B mesh on OLCF Summit



Computer simulations of the AWAKEN wind farms help investigators determine instrumentation placement and understand the physical interactions in the wind farms.

ONGOING AND FUTURE APPLICATIONS FOR KYNEMA

Benchmarking and validation of Kynema

- https://kynema.github.io/kynema-benchmarks/
- Publicly accessible repository for benchmark problems related to high-fidelity wind energy simulations
- Documentation of simulation inputs, meshes, and expected results
- Comparison with established results and experimental measurements

Expanding application of Kynema outside of wind energy

- Drones
- Water power: tidal turbines in estuary flow
- Other applications with fluid/structure interactions

Acknowledgements

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