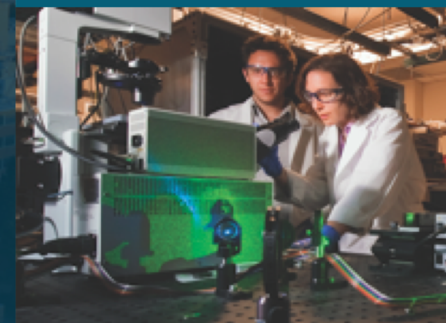
Sandia National Laboratories

Guest Lecture Stanford ME469: Nalu Overview



PRESENTED BY

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Computational Thermal and Fluid Mechanics

Sandia National Laboratories SAND2018-4619 PE

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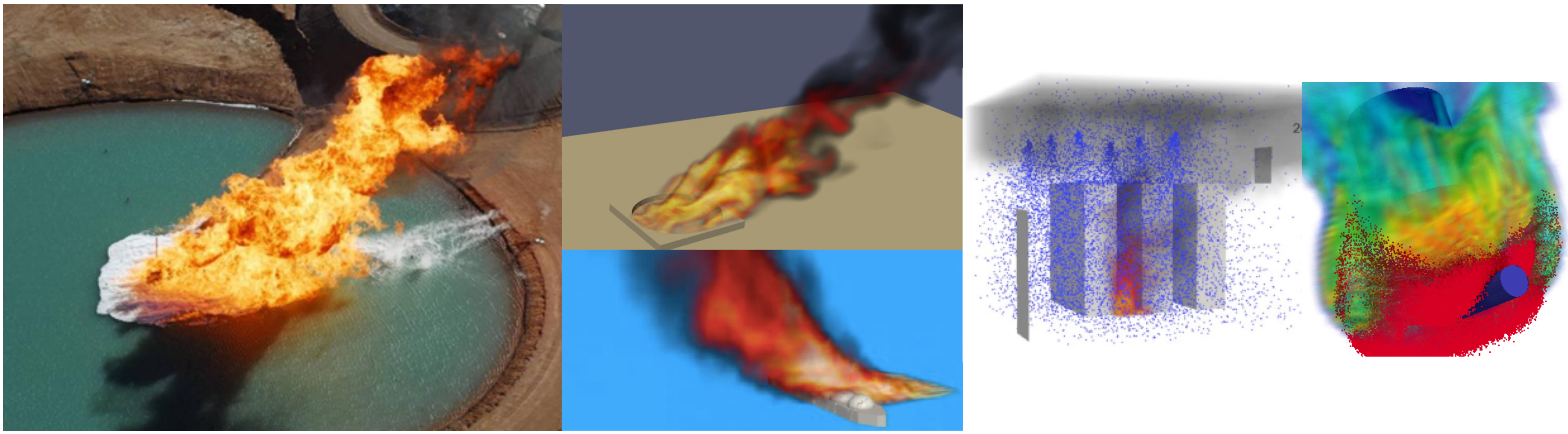
Nalu Overview: Outline

- Nalu Technology Origination: ASC
- Beyond the 32-bit Limit
- Supported Physics
- Supported Numerics
- Low- and High-order
- Moving Mesh (Sliding and Overset)
- Multiphysics:
  - Fluid Structure Interaction
  - Conjugate Heat Transfer (CHT)
  - Participating Media Radiation
- Conclusion

Core Technology Provided to Nalu Origination: Advanced Simulation and Computing Sierra/Fuego

- Use-case characterized by a highly sooting, turbulent, reacting flow with Participating Media Radiation (PMR), Conjugate Heat Transfer (CHT), and propellant mutiphysics coupling

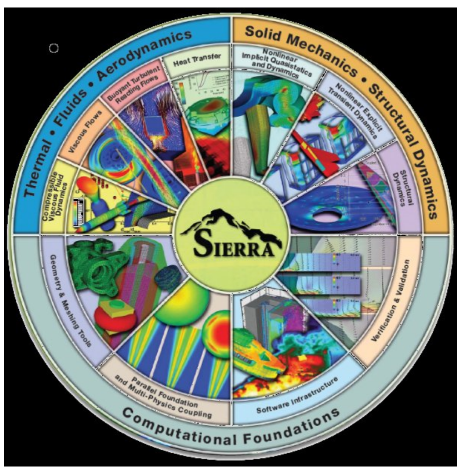


- Complex geometry has driven a generalized, hybrid unstructured discretization approach supporting Hex8, Tet4, Wedge6, and Pyramid5 elements in addition to arbitrary promotion of Hex8 to Hex27, Hex64, etc.

Goal: Beyond 32-bit Computing

- Circa 2013, many scientific production codes were limited to 32-bit
- Therefore, maximum simulation size for entities, e.g., node, edge, face, element, etc., was ~2.2 billion
- Next Generation Platforms were advocated to overcome poor MPI scaling and power needs to support Exascale computing (10^{18} floating point operations/second)
  - Platform architectures are not yet known

+ ASC IC Investments

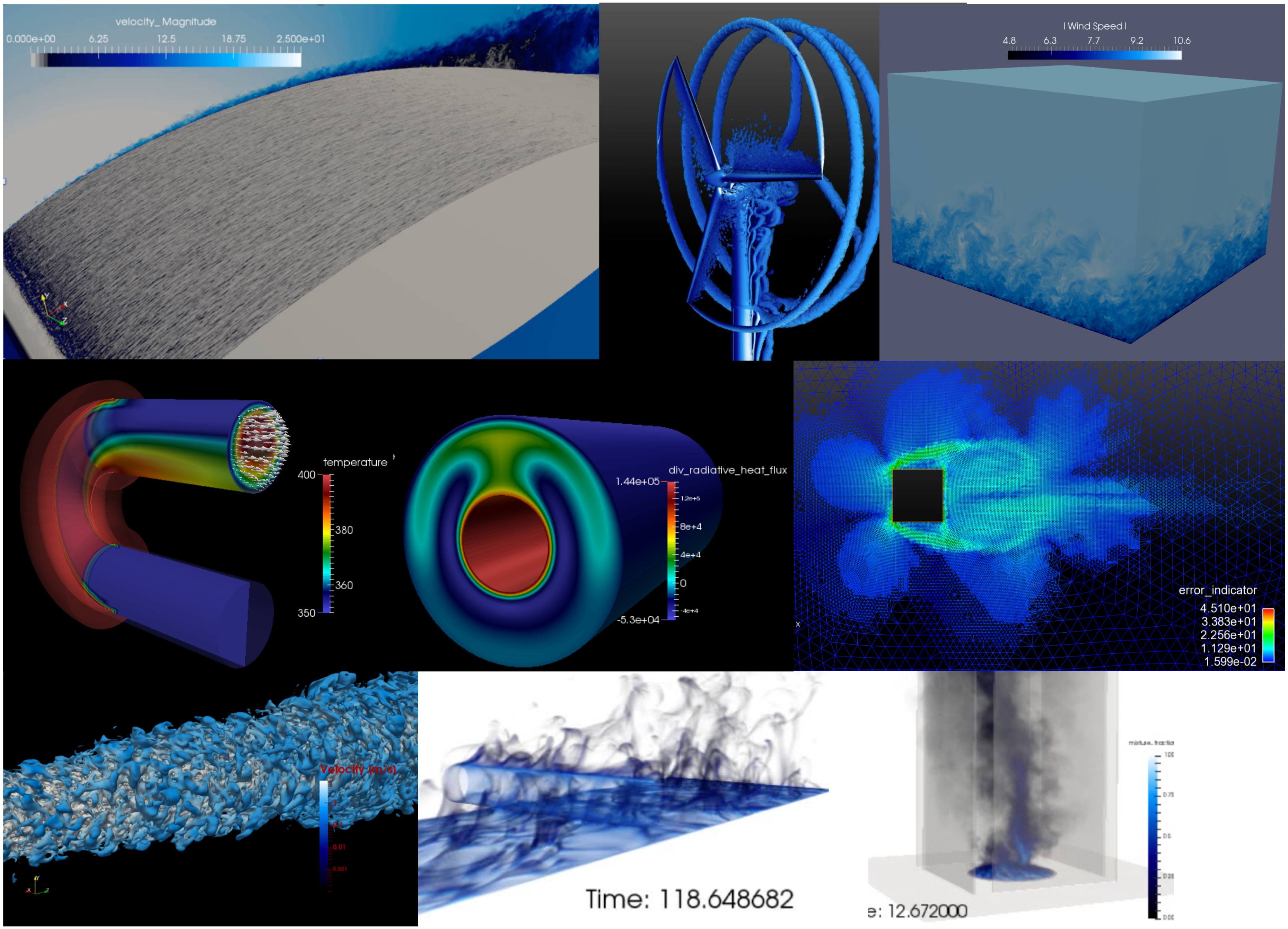


Sierra Toolkit/Trilinos (open-source)

MPI+X parallelism

Support for new architectures

Supported Physics



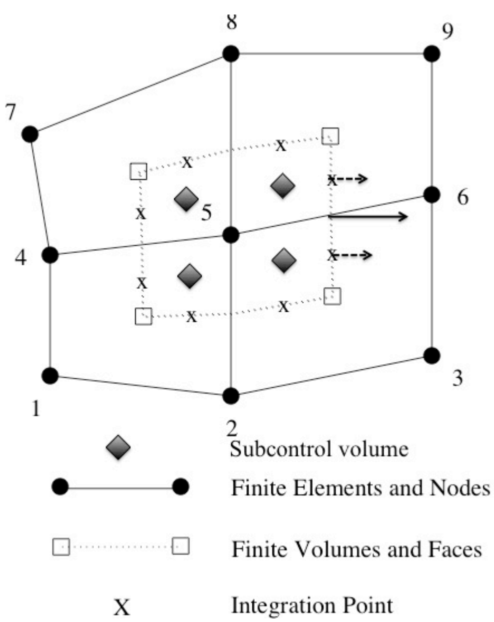
Supported Discretizations: CVFEM/FEM/EBVC

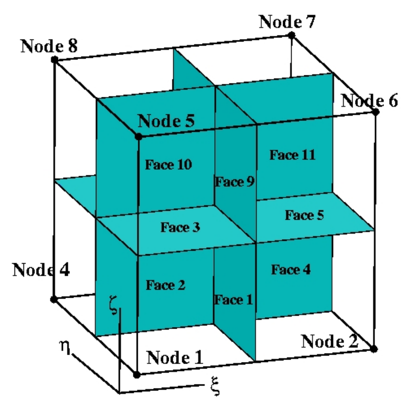
- The core discretization used in the low Mach code base has been the Control Volume Finite Element Method, CVFEM
- Finite Element Method and Edge-based Vertext Centered, EBVC, are also supported

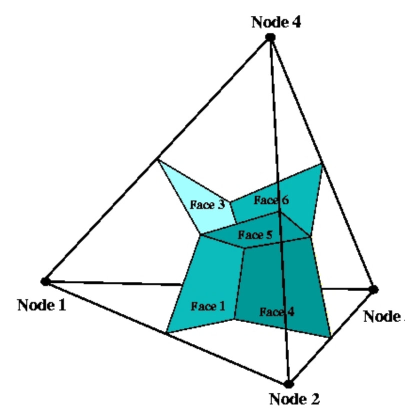
$$\int w \frac{\partial \bar{\rho}\tilde{u}_j\tilde{\phi}}{\partial x_j} d\Omega = -\int \bar{\rho}\tilde{u}_j\tilde{\phi}\frac{\partial w}{\partial x_j} d\Omega + \int w\bar{\rho}\tilde{u}_j\phi n_j \, d\Gamma$$

$$w = w_I ; \frac{\partial w_I}{\partial x_j} = -\delta(x - x_{scs})$$

$$\int w \frac{\partial \bar{\rho}\tilde{u}_j\tilde{\phi}}{\partial x_j} d\Omega = \sum_{ip} \left(\bar{\rho}\tilde{u}_j\right)_{ip} \tilde{\phi}_{ip} n_j dS = \sum_{ip} \dot{m}_{ip}\tilde{\phi}_{ip}$$

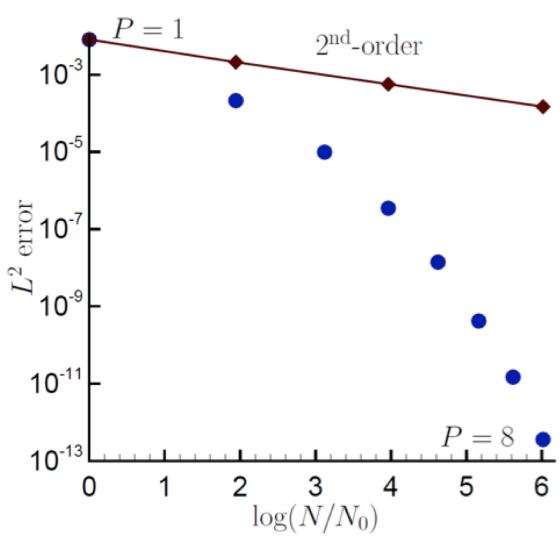




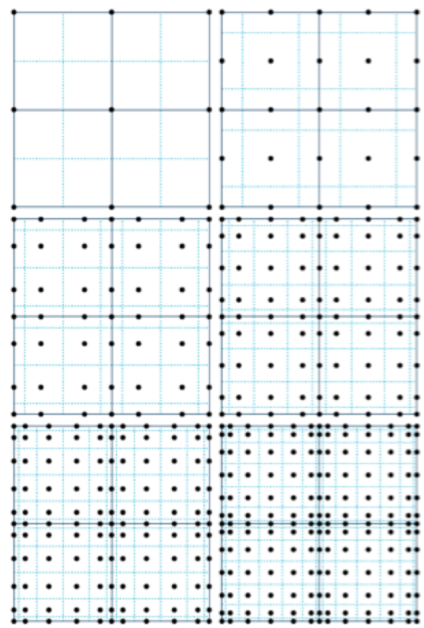


Scientific Research Platform to Evaluate Higher-Order Methods on Next Generation Platforms

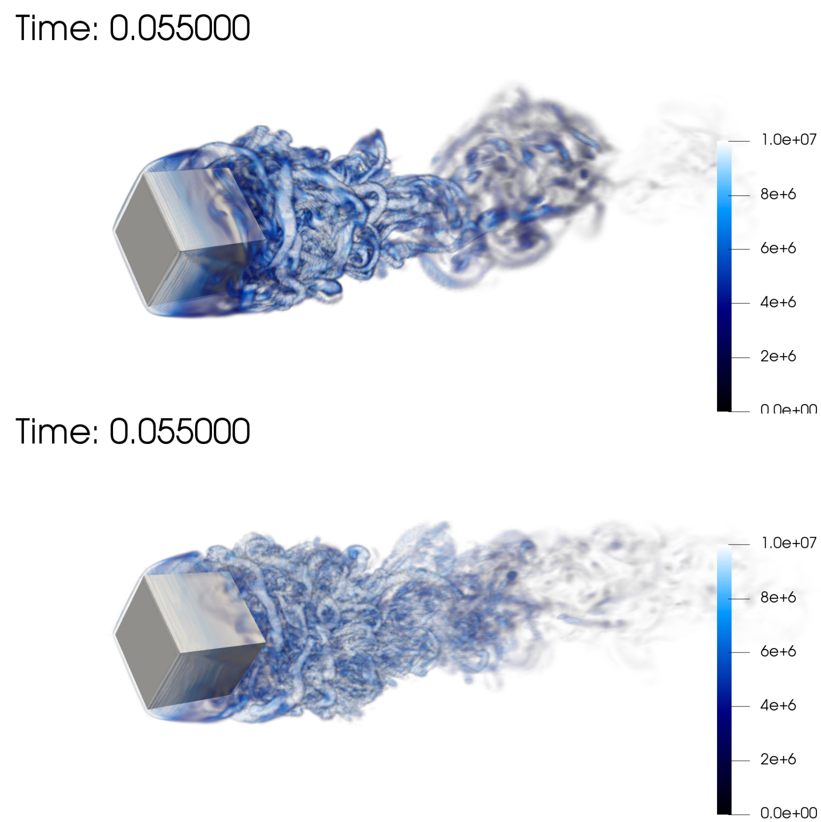
- As the cost of parallel assembly increases, should we strive to perform more local work? Higher-order achieves this design-point (at the cost of a larger memory footprint)



Spectral convergence

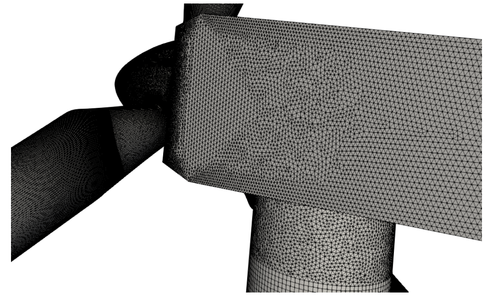


Dual-volume for promoted quad4



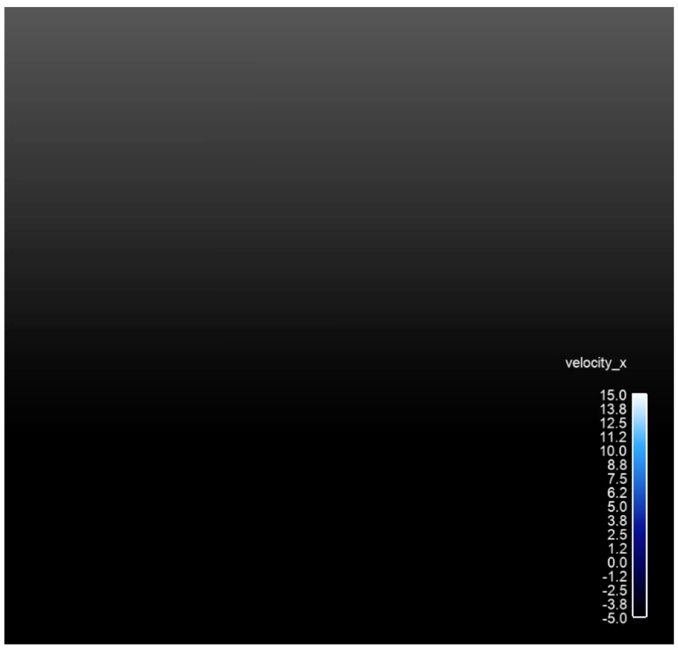
Flow-past rotating cube
Re~4000, RPM~3200
Same node count,
P=1 (top) P=2 (bot)

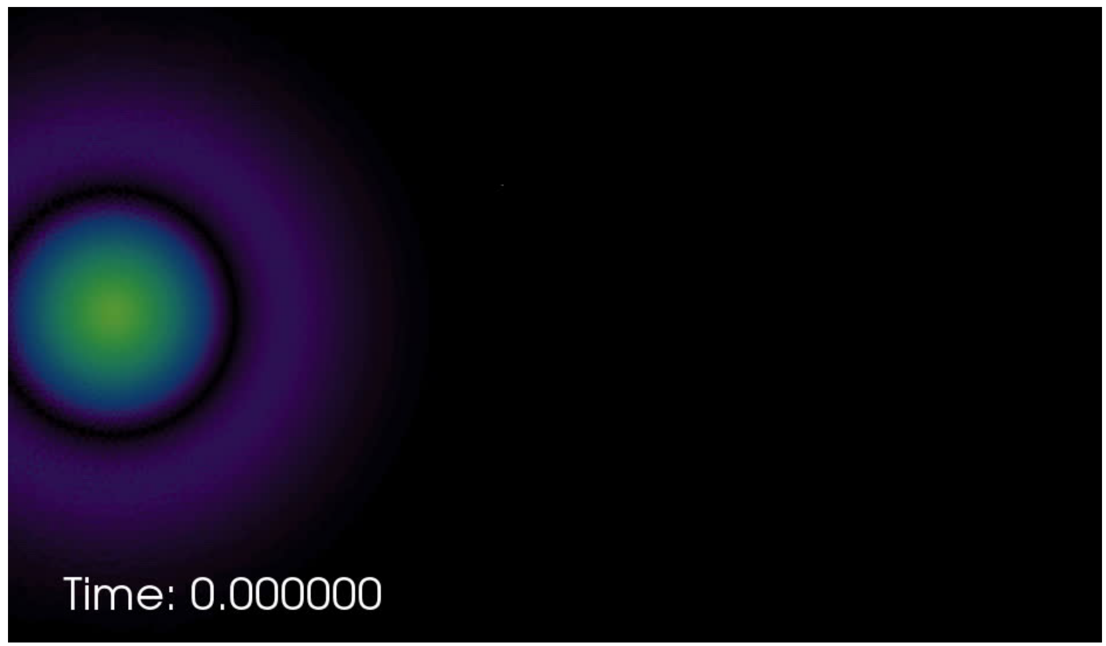
Unique Wind Energy Needs



- Low-dissipation methods with suitable nonlinear stabilization operators to perform blade-resolved physics
- Complex rotating blades, pitching blades, with possible yaw
- Transition from low-order (near the blade) to higher-order (in the wake)

Generalized, unstructured, hybrid low-order simulations shown



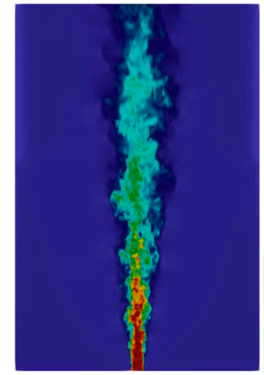


Horizontal Axis Wind Turbine (HAWT)

Vertical Axis Wind Turbine (VAWT)

Developed Open-Source BSD-clause 3 Distribution Policy

- Philosophy: Open-source collaborations



https://github.com/NaluCFD

Nalu Overview: Conclusion

- Nalu's technology has its roots in the ASC Sierra/Fuego effort
- Multi-physics capabilities are in development
- Research platform for high-order low-Mach methods
- Open-source collaboration model
- Funded through ASC, ECP, A2e, ASCR, and LDRD