



# Next Generation Generalized Unstructured low Mach Algorithms

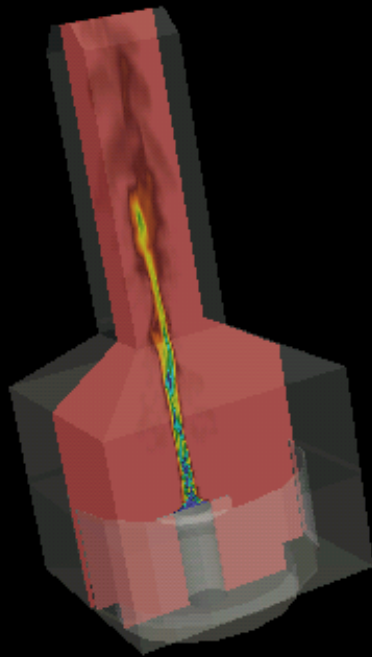
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Computational Thermal and Fluids Mechanics  
Sandia National Laboratories, NM  
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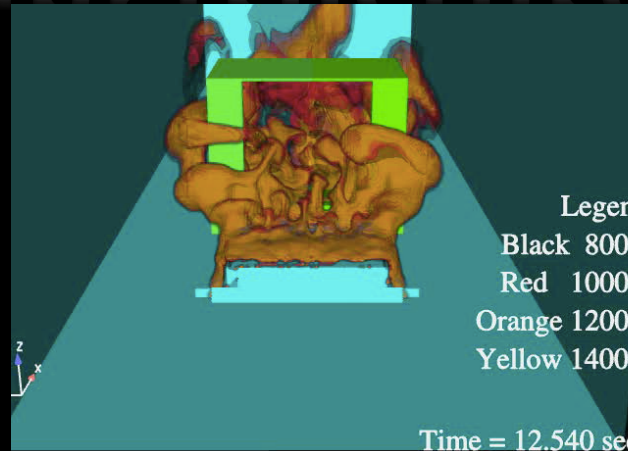


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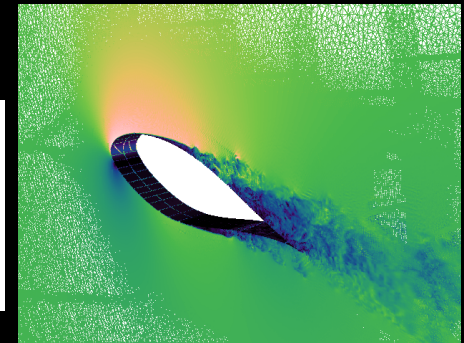
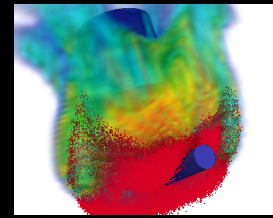
# Low Dissipation; generalized (low order) Unstructured LES



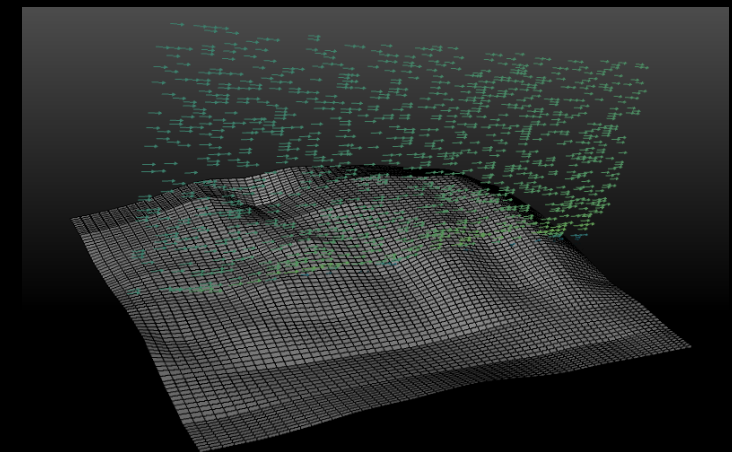
FLAME Facility



TTC

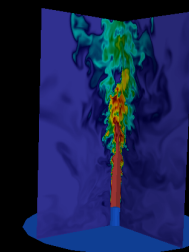
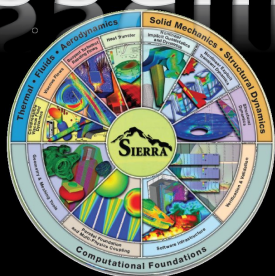


Downward prop burn; VAWT wing



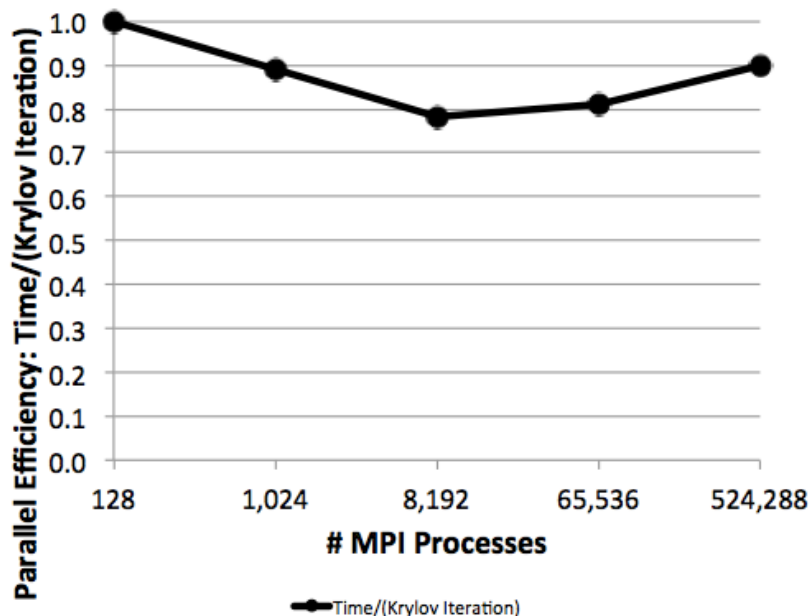
1.6 km section of Angel Fire, NM

# Current Algorithmic State: Near Ideal Implicit Solve/ Assembly Weak Scaling



Abdel et al

Nalu Momentum Weak Scaling (17000 Elem/  
core) BGQ: Solve Parallel Efficiency (Time/Iter)



UVW coupled fully implicit solve  
(GMRES/SGS)

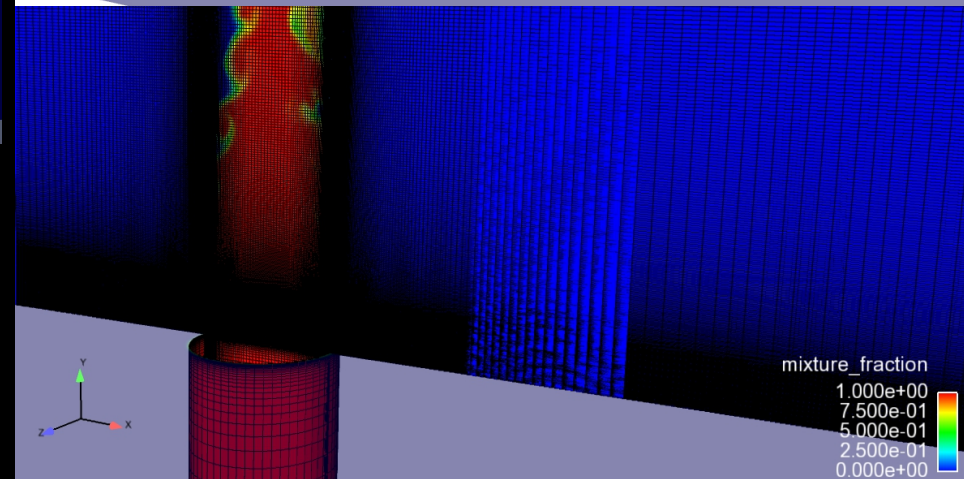
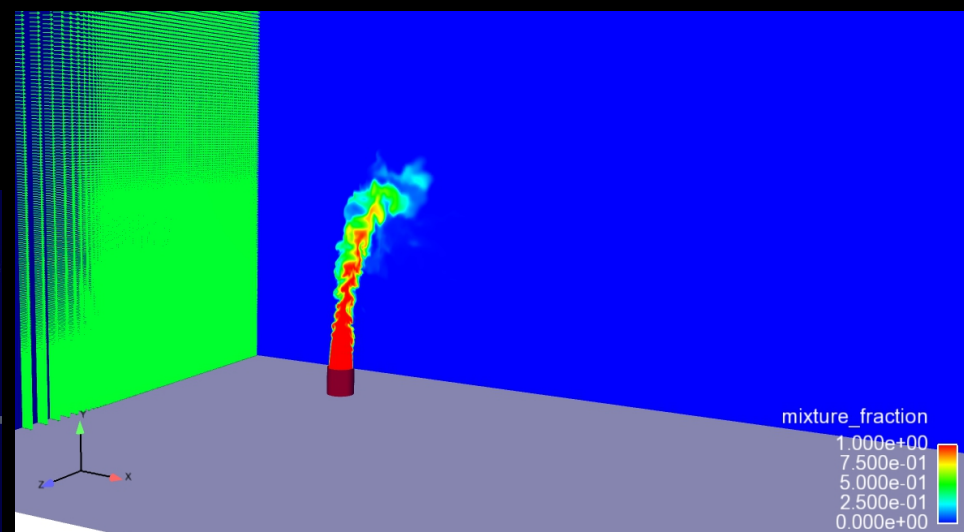
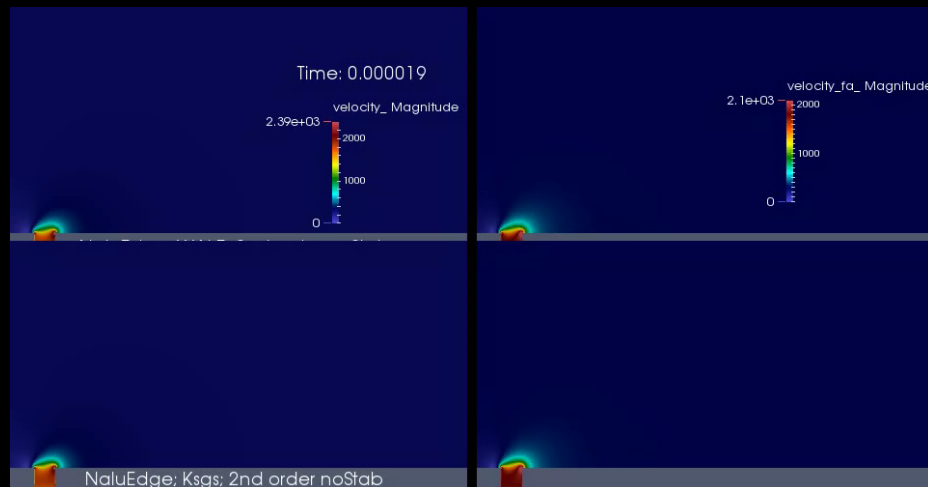
Core Algorithm:  
generalized unstructured  
approximate projection method

~20million:10 billion  
unstructured hex mesh

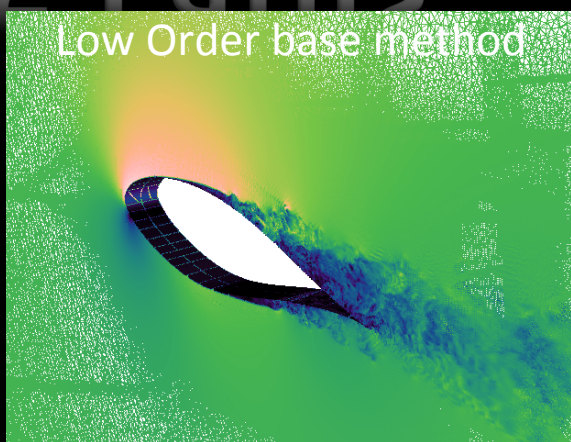
# User Constraint: where to place the mesh resolution?



Jet in Xflow (Su and Mungal);  $Re \sim 5000$



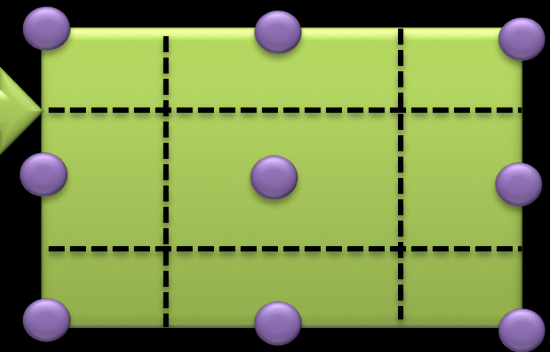
# Possible Paths



Refine! →

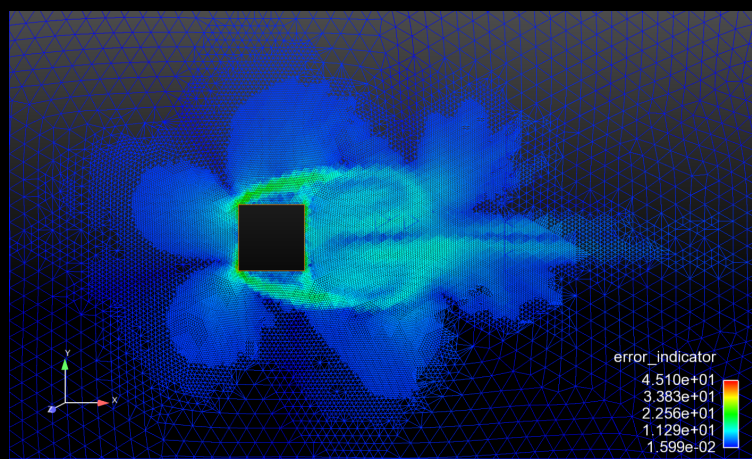
Trillion element low order simulations

Higher order →



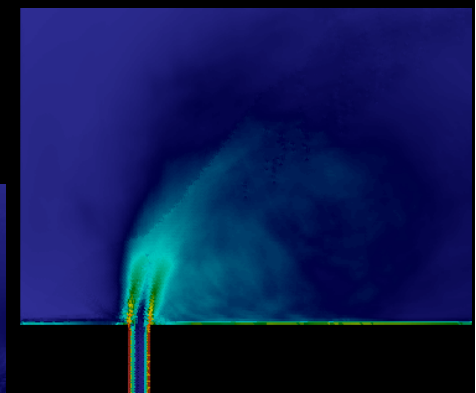
$P = 2, 3, \dots$

H-adapt ←

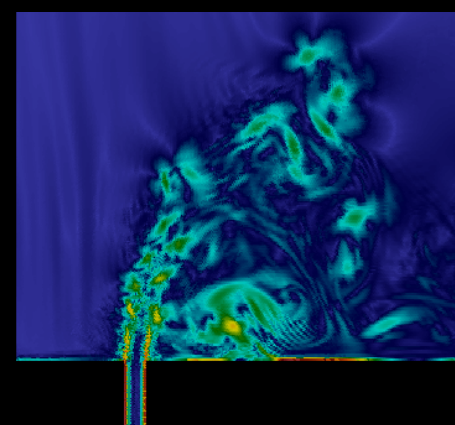


p-adapt ↙

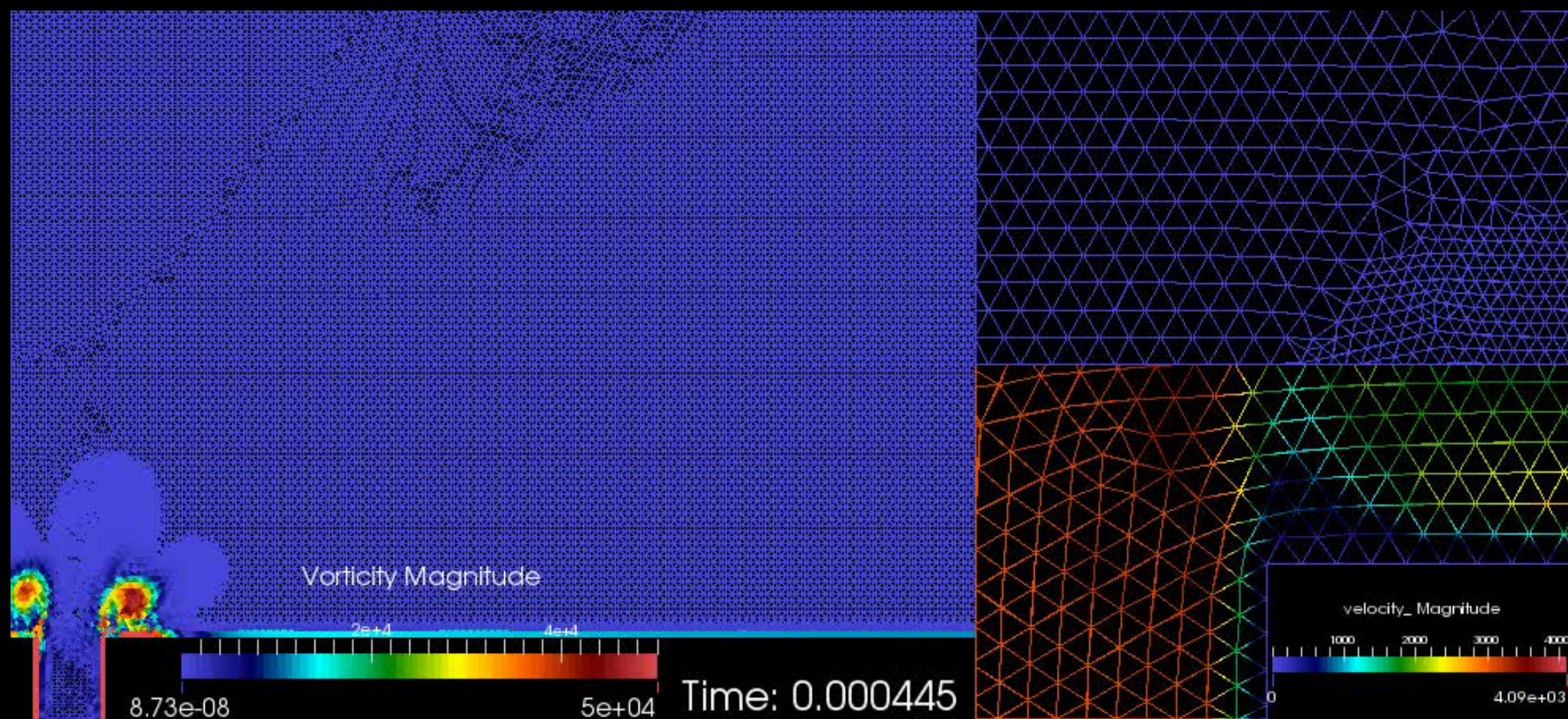
mean EI →



instantaneous EI →



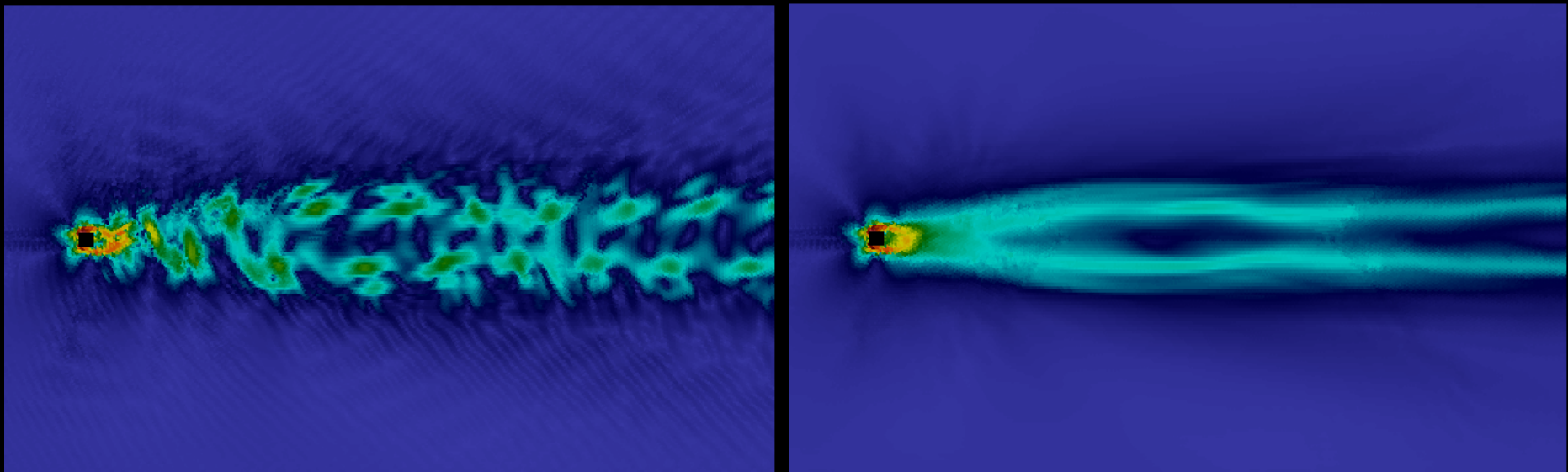
# Su and Mungal (with h-adapt)



Re 5,000 variable density jet-in-Xflow

# Is the cost affordable?

Matrix/pre-conditioner re-initialization, marking, refining, hanging node elimination, error indicator (physics-based, numerical-based, adjoint, error transport)



Re 500 flow past square cylinder (left: instantaneous EI; right Reynolds averaged)

# Research Plan

## Towards Adaptivity:

- Explore new error indicator approaches, e.g., error transport, for low Mach flows
- Evaluate costs associated with tracking structure vs time mean approaches

## Towards Higher Order:

- Implement higher order CVFEM ( $p=1,2,\dots,?$ )

Metric: time to a given error for translating vortex