Computation of Turbulence with Stabilized Finite Element Methods

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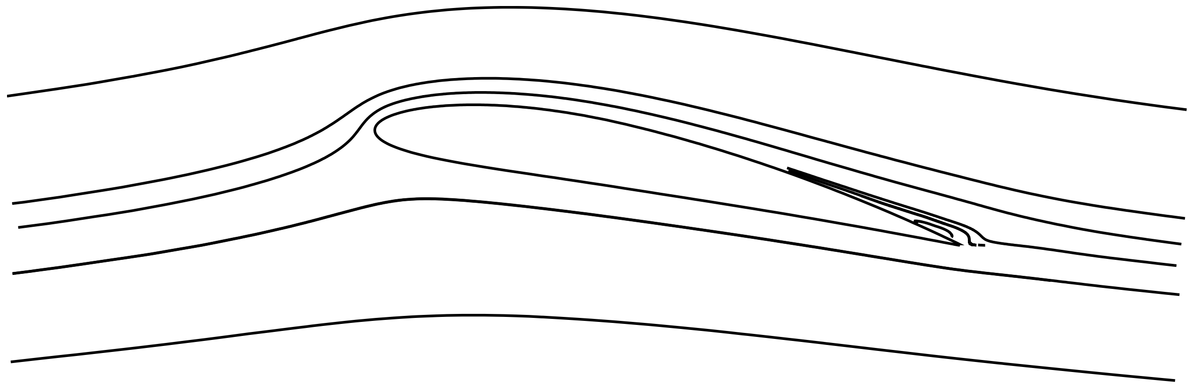
Outline

- Motivation
- Different Approaches to Computing Turbulence
- Advances in Large Eddy Simulation
- Finite Element Formulation
- Computational Results
- Conclusions

3D Section of a NACA 4412 Airfoil at Maximum Lift



Current case:

- Angle of attack = 12 degrees
- Chord Re_c = 1.64 million
- Mach number = 0.2

To validate against the experiments of:

- Coles and Wadcock (1979)
- Hastings, Moreton, and Clark (1984)
- Hastings and Williams (1987)
- Wadcock (1987)

Discretization

- Massively parallel, Galerkin/least squares finite element method
- 8.5 million tetrahedral elements
- 150,000 time steps in complete simulation
- Over 1 trillion non−linear equations solved using 512 processors on the AHPCRC CM5

Turbulent Flow over a Cavity

Current case:

- **Fully developed turbulent boundary layer**
- **Boundary layer thickness, δ, Reynolds number = 14,000**
- **Cavity height = 2 δ, length = 4 δ, width = infinite (periodic)**
- **Mach number = 0.1**

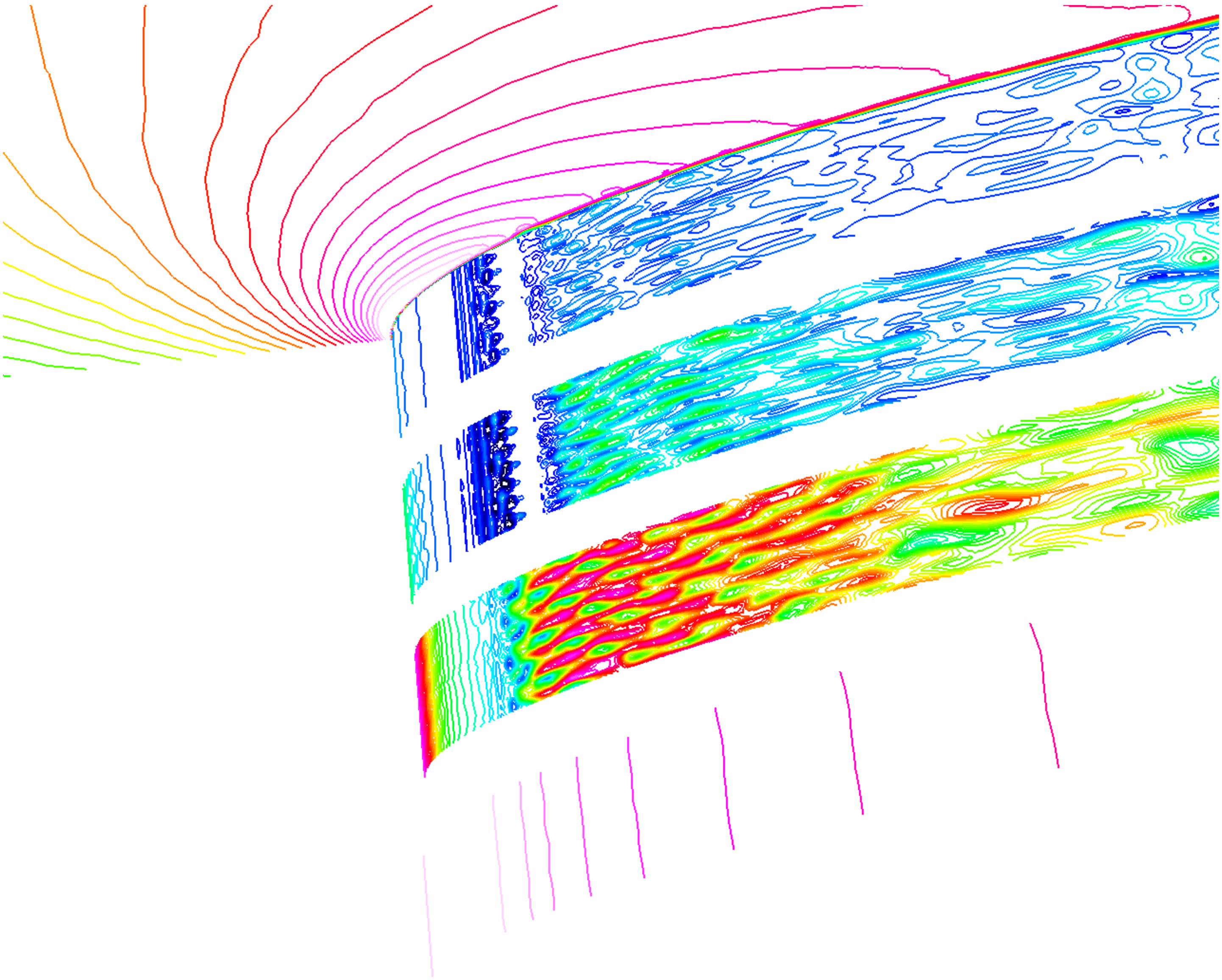
This configuration corresponds to experiment of:

- **Rockwell (in preparation)**

Discretization

- **Massively parallel Galerkin/least squares finite element method**
- **2.5 million tetrahedral elements**
- **50,000 time steps in complete simulation**
- **Over 0.1 trillion non–linear equations solved using 256 processors**

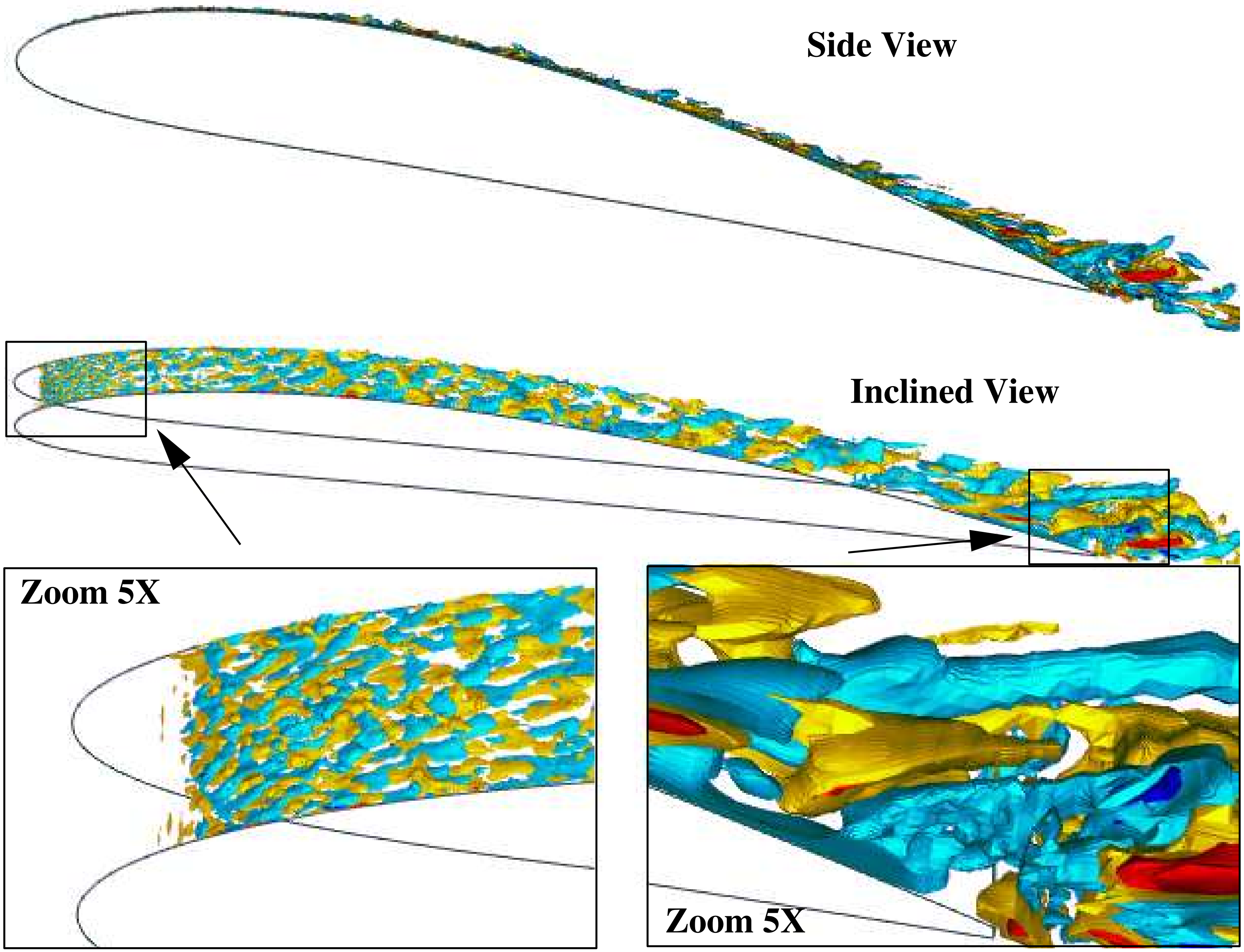
Streamwise Velocity Contours



Note:

- **Small structures near solid surface**
- **Larger structures in outer layer**
- **Spanwise uniform flow in last layer**

Isosurfaces of Spanwise Velocity



Conclusions

- **Discussed briefly methods for computing turbulence**
- **Extended dynamic model LES to unstructured grids**
- **Outlined a robust Galerkin/least−squares FEM**
- **Developed unstructured mesh generators for LES**
- **Applied Methods to:**

Problem	Non−linear equations per step (Millions)	Steps in a complete simulation (Thousands)	Equations in complete simulation (Trillions)
IC engine	1.0	20	0.02
Cavity	2.5	40	0.10
Jet	4.0	30	0.12
Airfoil	7.5	150	1.13

- **Hierarchic basis is being explored to reduce this effort**