Development of h-p Adjoint-based error estimation for LES of reactive flows

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Meeting I
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Outline:

Introduction I

- Cost of experiment vs numerical simulation
- Moore's law
- Turbulent combustion

Scope of research I

- Reducing numerical error
- High Order ... CENO
- Explicit filtering
- Adjoint based error estimation
- Using h and p adapatation

Methodology I

- Favre Averaged Governing Equations
- Large Eddy Simulation:
  - Explicit Filtering
  - Some LES errors: Aliasing, Commutation
  - Sub-filter scale (SFS) modeling
- High-order finite volume methods: CENO technique - benefits of higher accuracy on a coarse mesh
- AMR
  - Block-based AMR: speed and parallelization
  - Anisotropic vs Isotropic: how cell count (computational cost) can be reduced
  - Now the non-uniform vs the uniform block modification
  - Mesh geometry: CFFC can deal with cartesian or curvilinear coordinates - is this via using mapping functions for reference elements?

Existing framework I

- The CFFC code already includes the following required features:
- Block-Based : people, year
- AMR:
- Deconick's research on explicit filters
- High Order FVM with CENO:
- Scott's work/input: Newton iterations and gmres solver
- Lucie's non-uniform approach - improves accuracy of flux evaluations and reduces computational cost for anisotropic
- PCM-FPI combustion modelling: modeled by F. Hernandez-Perez and N. Shahbazian
- Initial adjoint analysis done by Martin for the advection equations

Overview of error I

Types of numerical error

- Truncation error
- Solution error Then explain a bit how they arise and how they can be dealt with

Adaptive mesh refinement (AMR) I

- Benefits of AMR
- How the block-based technique works
- Ghost cells for intercommunication
- Current stencils
- how the high-order will affect the current stencil

High order finite volume method and CENO I

- Lucien's work
- Ramy's work
- Marc Charest's work
- Luiz's work
- how the high-order works, and how it reduces numerical error
- separate slide of other groups researching this: Ihme and Poinssot. show some of their results

Adjoint-based error estimation I

- separate slide on gradient-based techniques
- separate slide explaining what the adjoint is.
  - who was the first to use adjoint
  - Cite initial work for this: Giles and Pierce, venditti and darmofal, fidkowski, jameson
- continuous and discrete adjoint formulations
  - continuous adjoint formulation
  - discrete adjoint formulation: methods to evaluate the discrete adjoint
    - one
    - two
    - three
- description of the adjoint methods to evaluate psi
- techniques to evaluate dR/dU
  - complex step

Adjoint-based error estimation II

- finite differencing
- automated differentiation
- approximate method

- error estimation indicators, residual weighting (flag for refinement) and a 1D cartoon example, perhaps, of restriction/prolongation
  - projecting onto fine space
  - restricting onto coarse space
  - getting the error in the residual and using this as a flag for refinement
- treatment of steady vs unsteady adjoints
- expected benefits of adjoint vs gradient based methods
- separate slide on mesh adaptation as based on the adjoint. Enough diagrams from venditti and darmofal, fidkowski

Basis of refinement: h and p I

Show or put some figures with citations. Show what other groups have done. WHO has researched or is using **adjoint with AMR**?

- Fidkowski and Darmofal [2011] - Review of Output-Based Error Estimation and Mesh Adaptation in Computational Fluid Dynamics
- Hartmann, ERROR ESTIMATION AND ADJOINT-BASED ADAPTATION IN AERODYNAMICS, [2006]
- Nemec and Aftosmis [2007] - Adjoint Error Estimation and Adaptive Refinement for Embedded-Boundary Cartesian Meshes

Basis of refinement: h and p II

- Hartmann, Held and Leicht [2010] - Adjoint-based error estimation and adaptive mesh refinement for the RANS and k- turbulence model equations
- Woopen, May and Schütz [2013] Adjoint-Based Error Estimation and Mesh Adaptation for Hybridized Discontinuous Galerkin Methods
- Li, Allaneau and Jameson [2011] - Continuous Adjoint Approach for Adaptive Mesh Refinement
- Diskin and Yamaleev [2011] Grid Adaptation Using Adjoint-Based Error Minimization

How we can use this I

- using it for mesh refinement - how some previous groups used this
- how we can link mesh adaptation AMR to the adjoint via h
- how we can use p based refinement

Progress to date I

- CFFC code familiarization : LES test case - on parallel clusters - SciNET. Job scheduling and post-processing results (tecplot)
- creating and solving linear systems in parallel implementation - trilinos and MPI
  - 2D Poisson problem
  - 3D Poisson problem
- Preliminary work with the discrete adjoint - shockcube problem
  - give the initial states, l and r
  - how the code was modified - multiblock and multiproc for uniform blocks
  - some results
  - work in progress
    - boundary conditions
    - compare with other techniques to get dR/dU

Timeline: April 2015 - January 2016 I

- Put a table of what you have done till now

Projected milestones I

- Put a table of what you will do in the next steps

Thank You For Your Attention!

Questions?

References I

[1] Driver, D., and Seegmiller, L., 1985, "Features of a Reattaching Turbulent Shear Layer in Divergent Channel Flow," American Institute of Aeronautics and Astronautics, **23**(2) pp. 163-171.

Backup Slide

- Important backup slide point.