Towards modeling of dual-fuel injection in OpenFOAM®

Local mesh refinement with a moving mesh.

Andreas Nygren & Anders Karlsson

Chalmers University of Technology
Division of Combustion

Two Day Meeting on Internal Combustion Engine Simulations Using OpenFOAM® Technology
25th of November

Outline

Fuel-Flexible Engine Platform

Project Goal

Project Goal

- Develop new technology for a heavy duty dual-fuel engine
- Improve fuel-efficiency for important alternative fuels.
- Comply with future emission legislation.

Combustion Modeling Subproject

- Develop a CFD model for liquid dual fuel combustion
- Combustion model that covers both diffusion and pre-mixed combustion
- Model implementation in OpenFOAM® (latest version)

Motivation for Research

- Reduce Green House Gases
- Emission Legislation
- More Fuel Efficient Engines Needed
- Collaboration Between Chalmers, Volvo Trucks and LOGE.
- Funded by the Swedish Energy Agency and Volvo Trucks

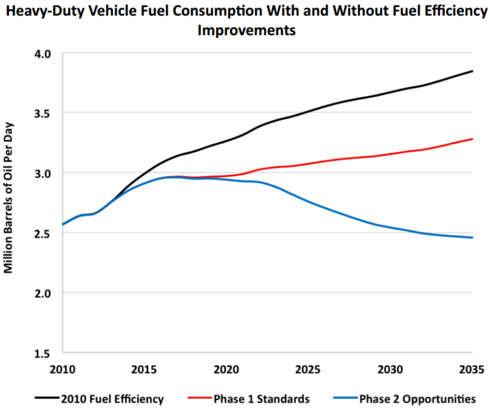


Figure: Fuel consumption for different improvement phases. Source: ACEEE

Research Gap

Current Dual Fuel Concepts

- Port injection of high octane fuel and direct injection of high cetane fuel

Our Focus

- Direct injection of both high octane and high cetane fuel.
  - Requires a combustion model that simultaneously accounts for diffusion controlled combustion and flame-propagation under stratified conditions.
- Focus on full cylinder closed cycle simulations.
- Blended-fuels/multicomponent-fuels simulation in OpenFOAM

Colliding Sprays

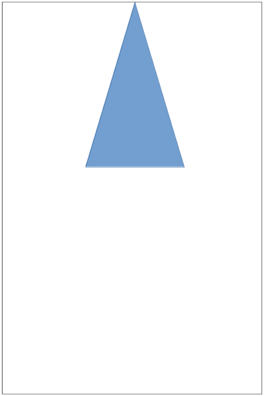


Figure: Single Injection

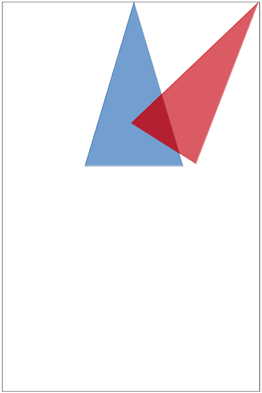


Figure: Dual Injection

Issues with Dual Injectors

Problems

- Two injectors - Arbitrary direction of Spray axis.
- The axis of the sprays will cross each other.
- How should the mesh be aligned?
- Extremely Fine Mesh is computationally expensive.

Possible Solution?

- Can we solve this by using an unstructured mesh?
- Can we resolve the spray well enough by using local arbitrary mesh refinement?

Single Injection

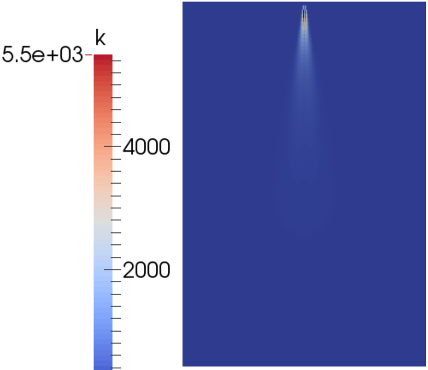
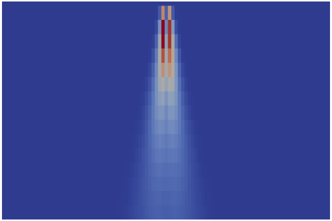


Figure: Sandia Spray-H Turbulent Kinetic Energy



- Spray axis is aligned with Mesh
- Minimizes Numerical Diffusion
- Easy to position Injector as One Cell

Non-Aligned Mesh

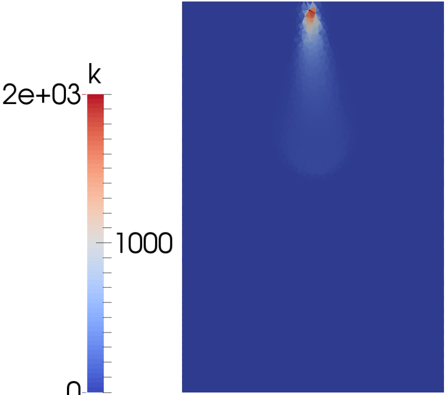


Figure: Sandia Spray-H Turbulent Kinetic Energy

- The spray axis does not line up with the mesh
- Significant Numerical Diffusion

dynamicTopoFvMesh[1]

Features

- Run-Time mesh generation and refinement.
- Tetrahedral mesh.
- Mesh refinement can be adapted to any field and gradient of a field.
- No Check-pointing

Minor Issues

- Mass Conservation
- Dynamic Load Balancing

[1] Stapf, K., Menon, S., Schmidt, D., Rieß, M. et al., "Charge Motion and Mixture formation Analysis of a DISI Engine Based on an Adaptive Parallel Mesh Approach" SAE Technical Paper 2014-01-1136, 2014.

Conservation of Mass

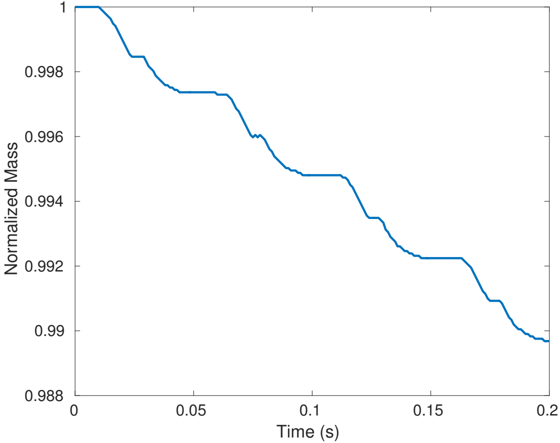


Figure: Normalized Total Mass in Cylinder

What We are currently Working on

Adaptive Mesh Refinement in OpenFOAM

- Hexahedral Mesh
  - will be based on the existing dynamicRefineFvMesh
- Tetrahedral Mesh
  - will be based on dynamicTopoFvMesh
- Mesh adaptation will be based on estimation of the subgrid field.
- Compare Hexahedral and Tetrahedral meshes

Adaptive Grid Embedding [2]

Subgrid Field

$$f' = f - \overline{f} \tag{1}$$

Estimation of Subgrid Field

$$f' = -\alpha_k \frac{\partial^2 \overline{f}}{\partial x_k \partial x_k} \tag{2}$$

In the same style as Converge CFD by Convergent Science

[2] P.K. Senecal, K.J. Richards, E. Pomraning, T. Yang, and M.Z. Dai, "A New Parallel Cut-Cell Cartesian CFD Code for Rapid Grid Generation Applied to In-Cylinder Diesel Engine Simulation" SAE Technical Paper 2007-01-0159, 2007.

Concluding Remarks

In Conclusion

- Dual Fuel Combustion is an interesting/challenging technique for the future.
- Multiple Injectors causes problems with arbitrary overlapping of spray axis.

What we propose

- Implement local mesh refinement together with mesh motion in OpenFOAM.
- Base the refinement criteria on an estimation of the sub-grid field[3].
  - Temperature
  - Velocity

[c]Best Practice according to P.K Senecal et.al

Further Implementatons in OpenFOAM

New Implementations

- Dual-Fuel Injector Model
  - Capable of Handle Two-Fuels
- Multi-Component Spray Model
  - VSB2
- Dual Fuel Combustion Model
  - Capable of Handling both diffusion and premixed combustion
  - Starting with well stirred reactor.
  - Move on to Transported PDF (Lagrangian).
- Chemistry Modeling
  - Improved chemistry mechanism with up to five components
  - Improved chemistry solver (LOGE)

Thank You For Listening!

Questions?