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Towards Large-Eddy Simulation (LES) of Pulverised Coal Combustion

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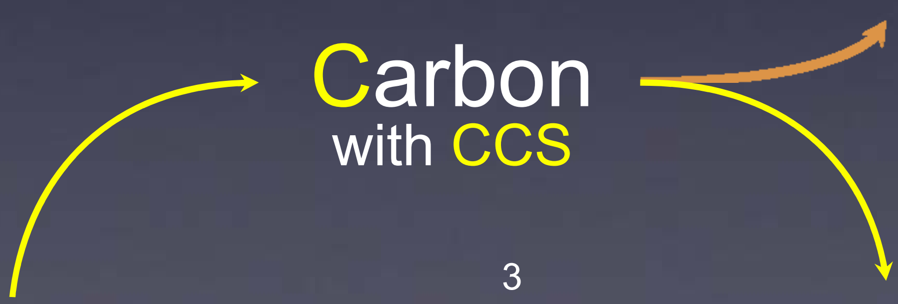
Motivation: Mitigation of Global Warming

- Regenerative Sources
- Nuclear
- Bio-mass & bio-fuels
- Carbon Capture and Storage

- Hydrogen
- Electricity
- Heat



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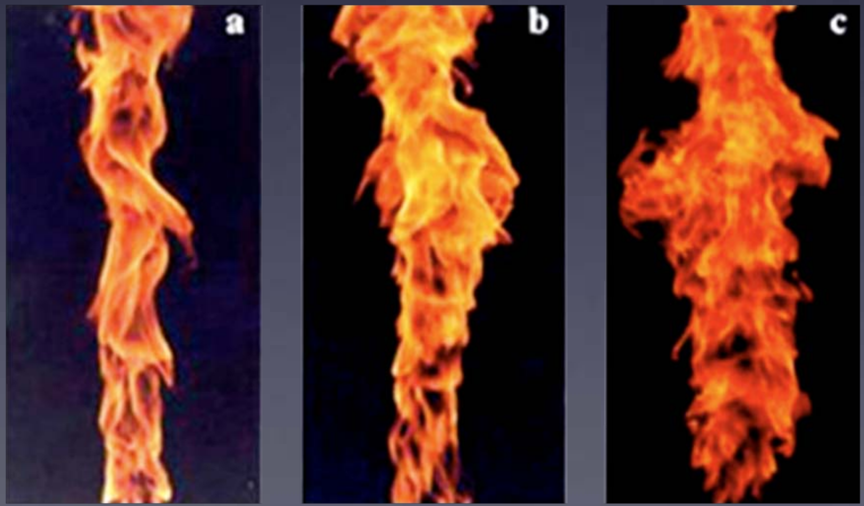
Nature of Turbulent Combustion

- Engineering flows are generally turbulent
- High power density: flame is wrinkled
- Aims: save, clean, economic
  - Better understanding and models for turbulence, combustion, and their interaction.
  - More difficult with ‘green’ fuels & CCS.

The pictures are short exposure (1/1000 s) soot emission photographs of turbulent ethylene flames at (a) Re_o = 8,200, (b) Re_o = 15,600 and (c) Re_o = 24,200. The axial view extends from 85 to 160 diameters (39 to 73 cm) from the burner exit. ▶



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Simulating Turbulent Flames

- Multi-scale problem: 10^{-5} – 10 m
- Resolve everything (DNS)
- Closure models for smallest scales only (LES)
- Closure models for everything to obtain time-averages (RANS)

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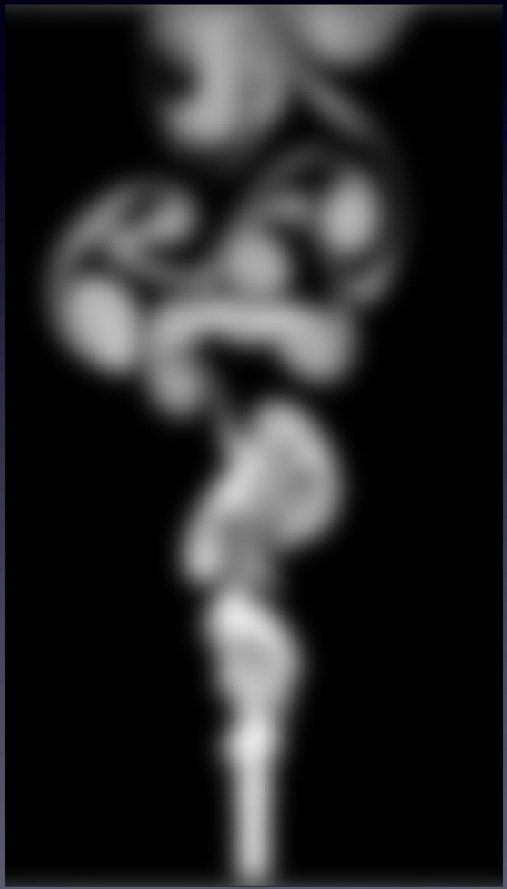
Large Eddy Simulation (LES)

- Solve equations describing large scales
- Closure models for small scales only
  - More intermediate scale features → better statistics → easier to model accurately
  - Do not remove time-dependent behaviour (like RANS)
  - Remove ‘irrelevant features’ before calculation, not after (DNS)
- In-house code for general scalars Φ, Ψ



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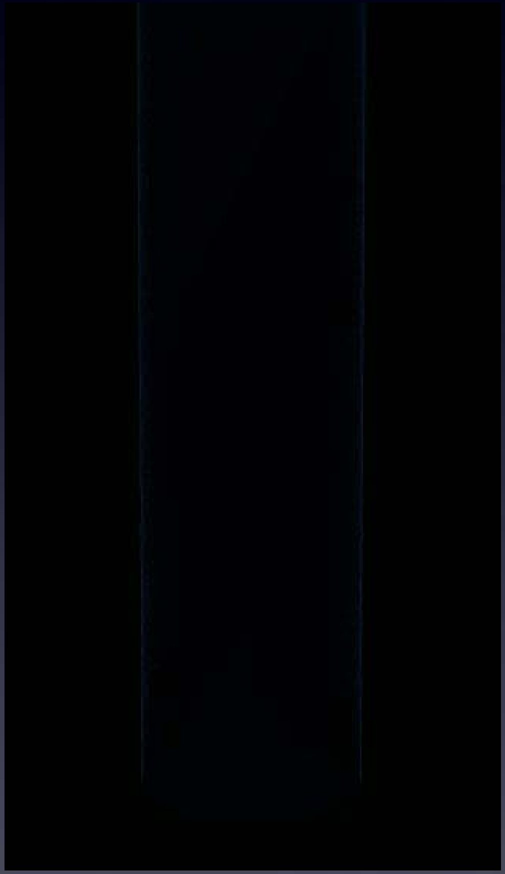
LES of Non-Premixed Gaseous Combustion

- Fuel and air are mixed in combustor
  - save, simple, stable
  - standard for aviation
  - mixing affects emissions
- Using mixture fraction approach
- Assumed subgrid distribution: (beta function / top-hat)



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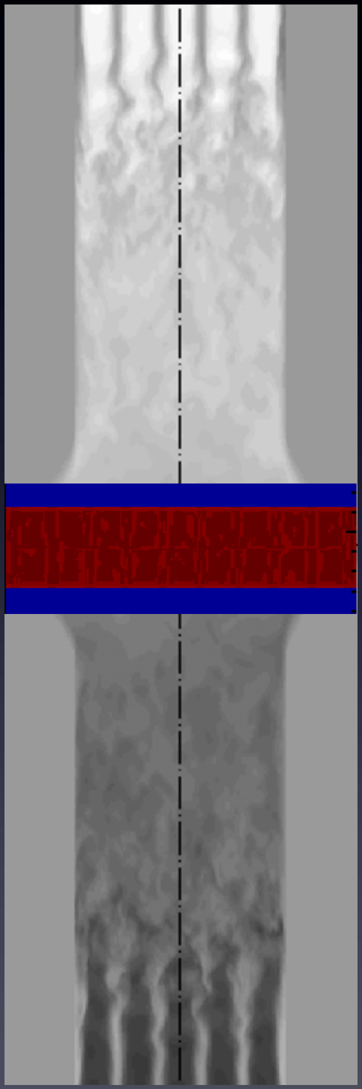
LES of Premixed Gaseous Combustion

- Fuel and oxidiser mixed upstream
  - Excellent emission control (low NO_x)
  - Less save, more complicated, less stable
  - State of the art for stationary GT,
  - but still a challenge for simulations
- Simulation using LES with
  - Flame Surface Density (FSD) Models
  - Linear Eddy Mixing (LEM) Model



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Revival of Coal Combustion

- Coal is (relatively) cheap and available
- Coal boilers are due for replacement (in UK 20+ years)
- Clean coal combustion has become possible with CCS
- Provide the tools for clean coal technology
    - Difficult experiments in coal furnaces
    - New fuels (bio-fuels)
    - New oxidisers (oxygen)

→ More detailed predictions required

BERR/DB Oxycoal II

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Current Work on Pulverised Coal Combustion I

Doosan Babcock's Multi-Fuel Burner Test Facility (MBTF)

- Thermal Input: 90 MW
- Fuel Versatility:
  - Coal
  - Heavy Fuel Oil
  - Natural Gas
  - Orimulsion
- Facility Usage:
  - New Burner Development
  - Contract Burner Testing
  - Third Party Burner Testing

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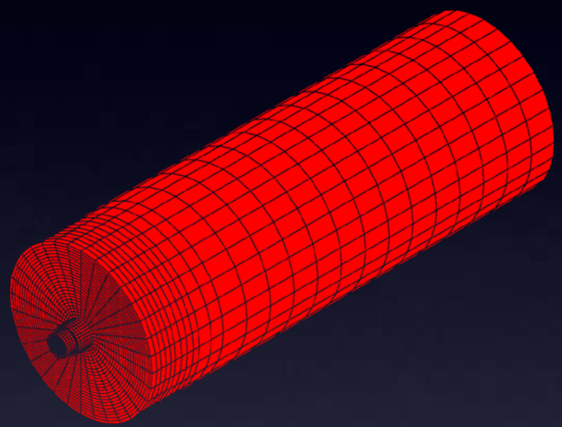
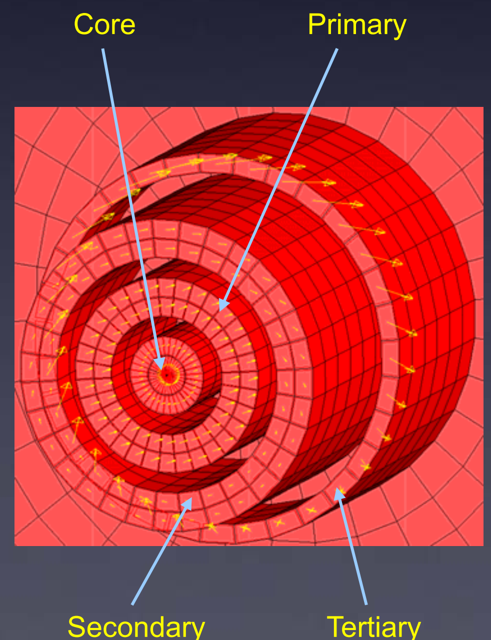
Current Work on Pulverised Coal Combustion II

RANS-CFD Modelling with StarCD, Version 4.08

- Steady state simulations
- Standard k-eps turbulence model
- Simplified geometrical representation:
  - Mesh type: Cylindrical
  - Dimensions: ø = 6.0m, L = 18m
  - 30,500 cells
  - Local refinement near the burner
  - Boundary conditions: 4 inlets, 1 outlet





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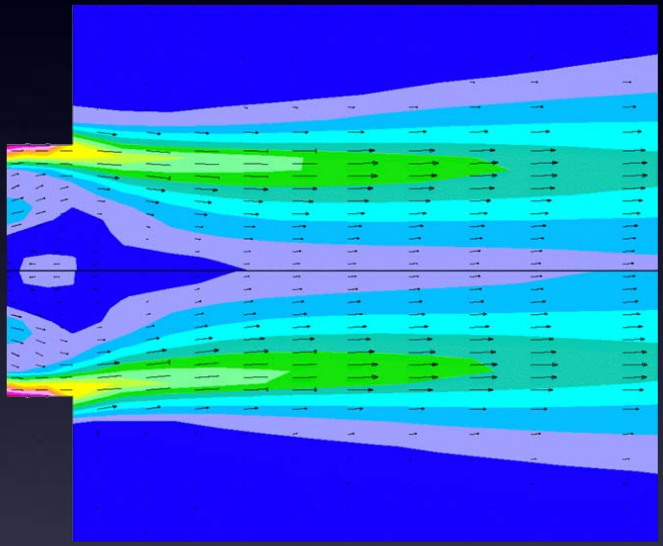
Current Work on Pulverised Coal Combustion III

3-Step RANS Modelling Approach:

- Non-reacting flow (fully converged)
- Coal combustion with simple sub models (air firing)
- Coal combustion with complex sub models (air / oxycoal firing)



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Future Work on Pulverised Coal Combustion

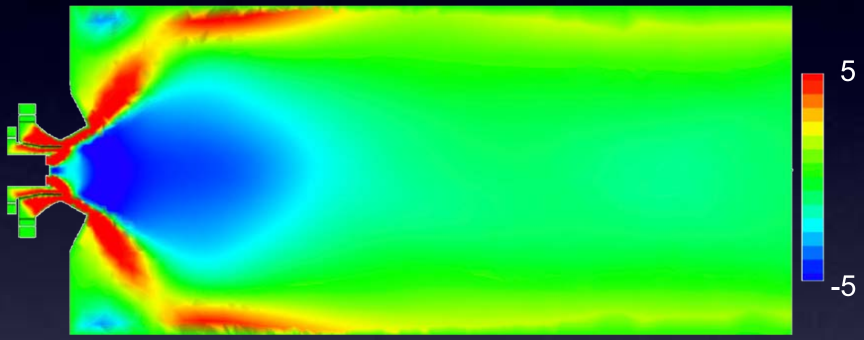
Advantages of Coal-LES:

- Improved prediction capability compared to RANS: Coal sub models rely on an accurate description of turbulent flow.
- Unsteady analysis
- Capturing of extreme events

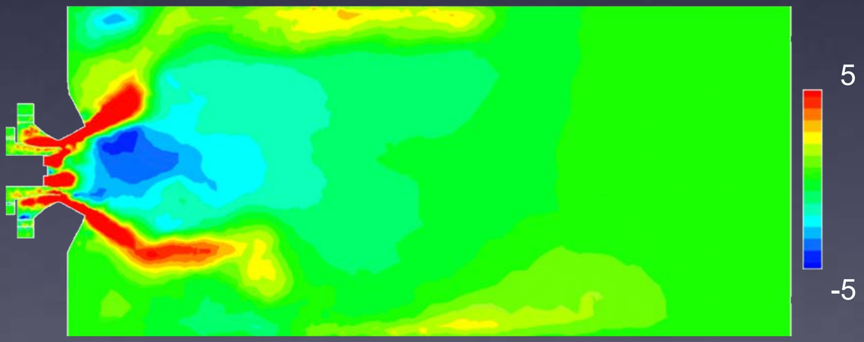
Disadvantages of Coal-LES:

- More expensive simulations
- Sensitivity to (often unknown) inflow conditions

RANS



LES



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Future Work on Pulverised Coal Combustion

Upcoming Research Projects:

- Development of a global model *for Coal-LES*
- Development of sub models *for Coal-LES*
    - Transport
    - Devolatilisation
    - Combustion of volatile content
    - Char burnout
    - Radiation
- Implementation of models
- Test, verification, validation

EPSRC EP/G06315X/1 **EPSRC** EP/G062153/1

Conclusions

- We must improve combustion to control and minimise CO_2 emissions, and hence climate change.
- The current economic climate can be an opportunity.
- This group develops tools to help improve combustion.
- Coal-LES can help to design clean coal combustion devices for CCS.

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Thank you for your attention!