Preliminary results with ECFM–3Z LES

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1° step: multi-cycle analysis of a “test” engine cylinder with LES

Aims:
- Potentials of LES
- Combustion: “qualitative” comparison with literature

Operating conditions:
- 10,000 rpm
- Spark Time = 675°
- Phi = 1
- Premixed Fuel
In some problems the upstream turbulent kinetic energy transport is negligible considering the one generated from local sources (such as flows with detachments, abrupt changes in flow section, direction, etc.) The use of a mean profile of the inflow variable can be justified.
Boundary/Mesh Generation:
Mesh Generation:

The usual trim tutorial procedure is used to create the mesh template.

The template is then modified in order to meet the following targets:

1) Homogeneous mesh.
2) 0.5 mm in-cylinder cell size.
3) 1.0 mm cell size in the exhaust and intake ports.
Resulting Mesh
7.8 e+06 cells

In-cylinder section at BDC
Mesh results 7.8 millions cells:

Filter Length Average during combustion

No Events

Filter length [mm]
**Setup:**

- LES initial conditions: derived from one RANS cycle
- Premixed fuel C8H18
- Turbulence model: LES/Smagorinsky
- Intake/exhaust time-varying mean pressure options:
  - pressure option STATIC
  - Environmental ON
  - Mean ON
- Solution Algorithm PISO
- Under relaxation for pressure correction 0.3
- MARS (blending factors) = 0.5
- Residual tolerance for species and enthalpy = $1 \times 10^{-12}$
- Multi-components limiter ON for all species and enthalpy
- Switch 26 on (flow remedial)
- Time step size during combustion = 0.009 CA° ($1.3 \times 10^{-07}$ s)
Results: Average Pressure LES & RANS

![Graph showing pressure over CA with different lines representing Average_P_RANS, Average_P_LES_1, Average_P_LES_2, Average_P_LES_3, Average_P_LES_4, and Average_P_LES_5.](image-url)
c*(1-c) : normalized distance to front ends

LES front flame thickness
1° cycle
1° cycle Vs 2° cycle LES: normalized distance to front ends

Kernel flame convected away from spark center

LES – 1° cycle  LES – 2° cycle
Fresh fuel pockets break the flame front and complete their reactions in the burnt zone.
Results: Average Pressure

LES Pressure traces

- Average_P_LES_1
- Average_P_LES_2
- Average_P_LES_3
- Average_P_LES_4
- Average_P_LES_5

bar

CA

660 680 700 720 740 760 780 800
Results: Trapped Fuel Mass

LES C8H18 mass
Results: Global & Local variables

LES Pressure traces

1° LES cycle

2° LES cycle
Results: Global & Local variables

Spark time 675 CA - T

Spark time 675 CA - VMAG

Spark time 675 CA - SGS-TE

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Results: Global & Local variables

LES Pressure traces

4th cycle
Results: Burnt Fuel % & HRR

Green line – 4th cycle
LES cycles comparison: Flame front
LES cycles comparison: Flame front
LES cycles comparison: Flame front
LES cycles comparison: Flame front
Computational details:

Domain: 7.8 million cells

Cluster performance:

- 6 nodes dedicated to this test
- 12 cores per node
- 48 Gb RAM per node
- Scientific Linux
- Intel 5065 processor
- Parallel disks PANASAS

Using `michele.sh.set`

10 Days per cycle
Internship at CD-adapco + Post Graduate

2° step: multi-cycle analysis of a “real” engine cylinder with LES

Aims:
- Cycle-to-cycle dispersion
- Application of LES to industrial R&D process
- Combustion: “quantitative” comparison with data

Operating conditions:
- 7,000 rpm
- GDI
- Actual Fuel
Template
2D
“coarse”
Mesh results:

Filter Length
F154AM coarse

Filter length [mm]
Experimental data:

- Average Pressure In-cylinder cycle-to-cycle dispersion at 7,000 rpm:
RANS cycle as initial field for LES
Equivalence Ratio distribution:
Ignition Hitches

- Eulerian AKTIM with default constants generates a weak kernel that did not reach $c=1$ in reasonable time.
  (“Towards the understanding of cyclic variability in a spark ignited engine using multi-cycle LES” by Vermorel et al.)

- Lagrangian AKTIM (RANS–model like) $c = 1$ never reached.

- **Possible cause:**
  - Mesh cell size too coarse (0.45 mm) close to the spark plug.
Ignition Hitches

- Customized Eulerian AKTIM Ignition model needed.

- Flame Kernel Radius set to $c=1$.

- Need more time to validate this new procedure.
Flame Front Thickness:

~2mm
LES Results, Average Pressure:

Pressure

![Graph showing pressure over CA (Cam Angle)]
HRR LES (spikes smoothed): \( ts \sim 1 \times 10^{-6} \) s during combustion
Near-term developments:

1) Validate the new ignition model just defined.
2) Comparison with a finer mesh, test-case like. Already generated, it is about 5.5 million cells the whole model at the BDC. Investigation of main differences and limitations.
3) Find out differences between using time varying boundary obtained by means experimental data, coupled simulations or adding an intake plenum to the computational domain.
Next Targets:

- Investigations of low rpm where the cycle-to-cycle dispersion is higher than high rpm.
- Analysis of Knock/pollution connected with it.
- Other than cycle-by-cycle, LES can face also cylinder-to-cylinder dispersion.
Main References:

- Towards the understanding of cyclic variability in a spark ignited engine using multi-cycle LES. (O. Vermorel, S. Richard, O. Colin, C. Angelberger, A. Benkenida and D. Veynante)
- Internal Combustion Engine Fundamentals. (John B. Heywood)
Thank you all for your attention

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