Stratified scavenging in two-stroke engines using OpenFOAM

Acknowledgements

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- Mikael Bergman at Husqvarna AB.

Outline

- Aim and purpose.
- Approach.
- The two-stroke engine and the stratified charged two-stroke engine.
- CFD.
- Mesh operations.
- Boundary conditions.
- Results.
- Future work.

Aim and purpose

- Evaluate the scavenging performance of the Husqvarna H576X engine.
- Evaluate the use of OpenFOAM for two-stroke engine simulations.

Approach

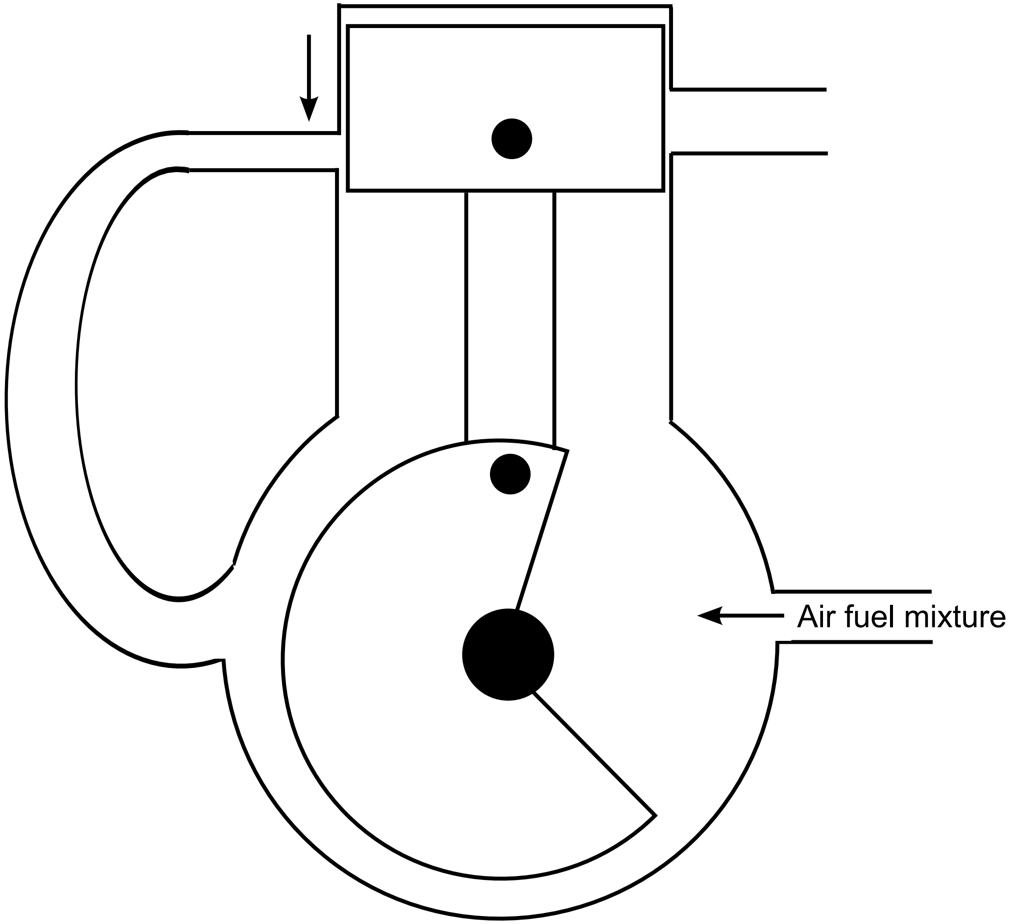
- Determine interesting information.
- Limit the problem.
- Method to find the information.
- Possibilities in OpenFOAM.
- Set up the case.
- Extract the results.
- Validation.

The two-stroke engine

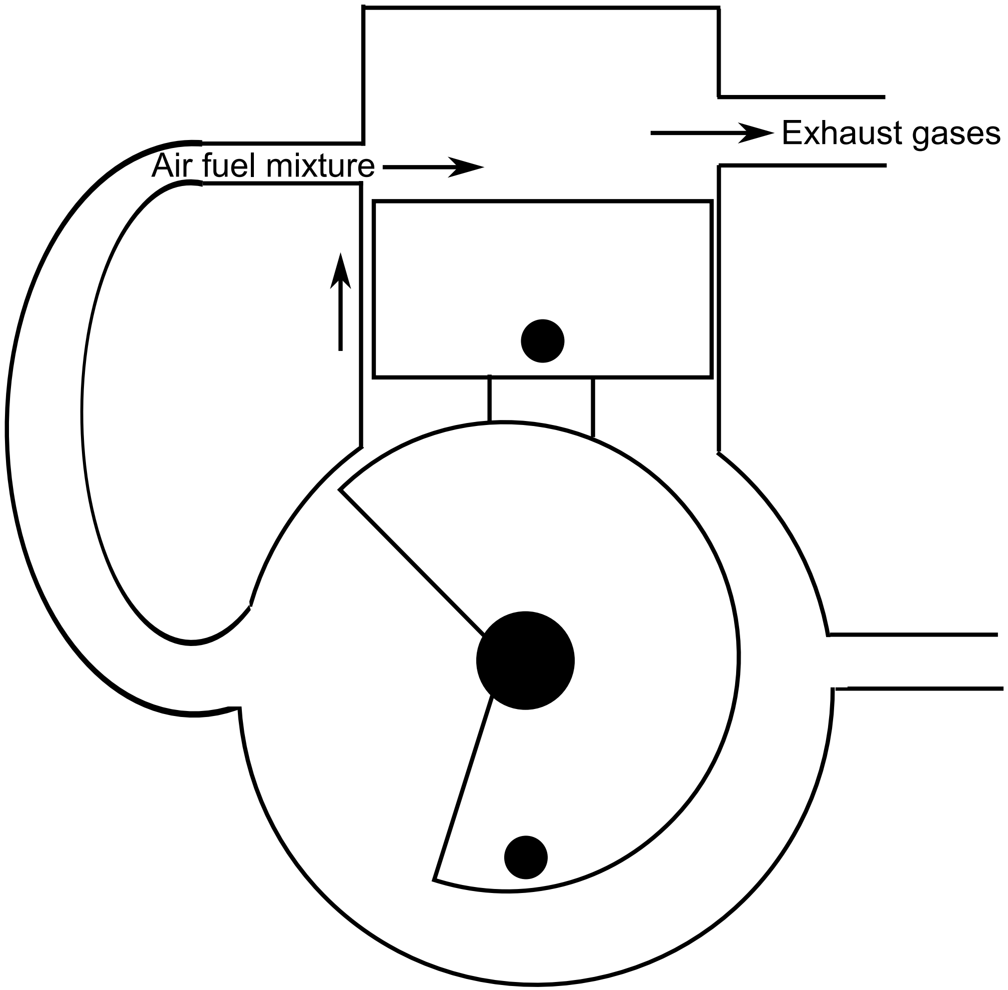
- The conventional two-stroke engine.
- The cycle of operation.
- Advantages and disadvantages.
- Trapping efficiency.

$$\eta_{tr} = \frac{\text{Mass of delivered air fuel mixture retained}}{\text{Mass of delivered air fuel mixture}}$$

Expansion stroke



Compression stroke

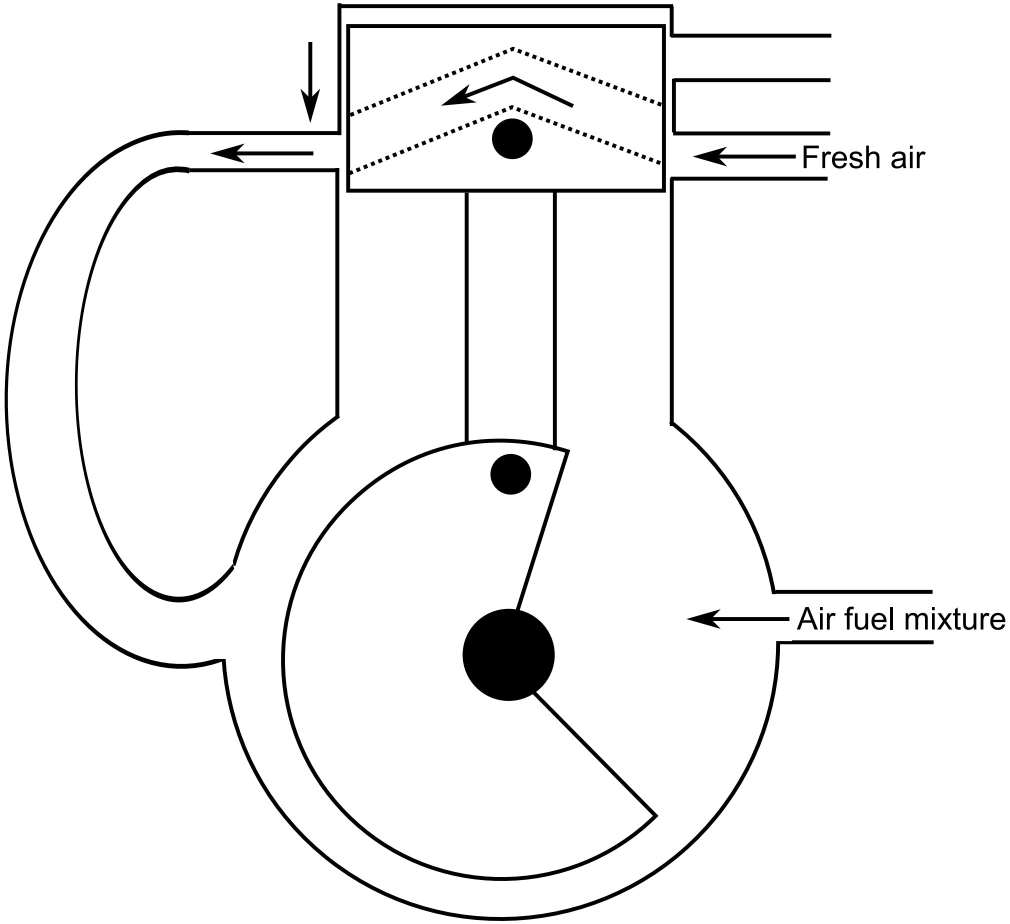


The stratified charged two-stroke engine

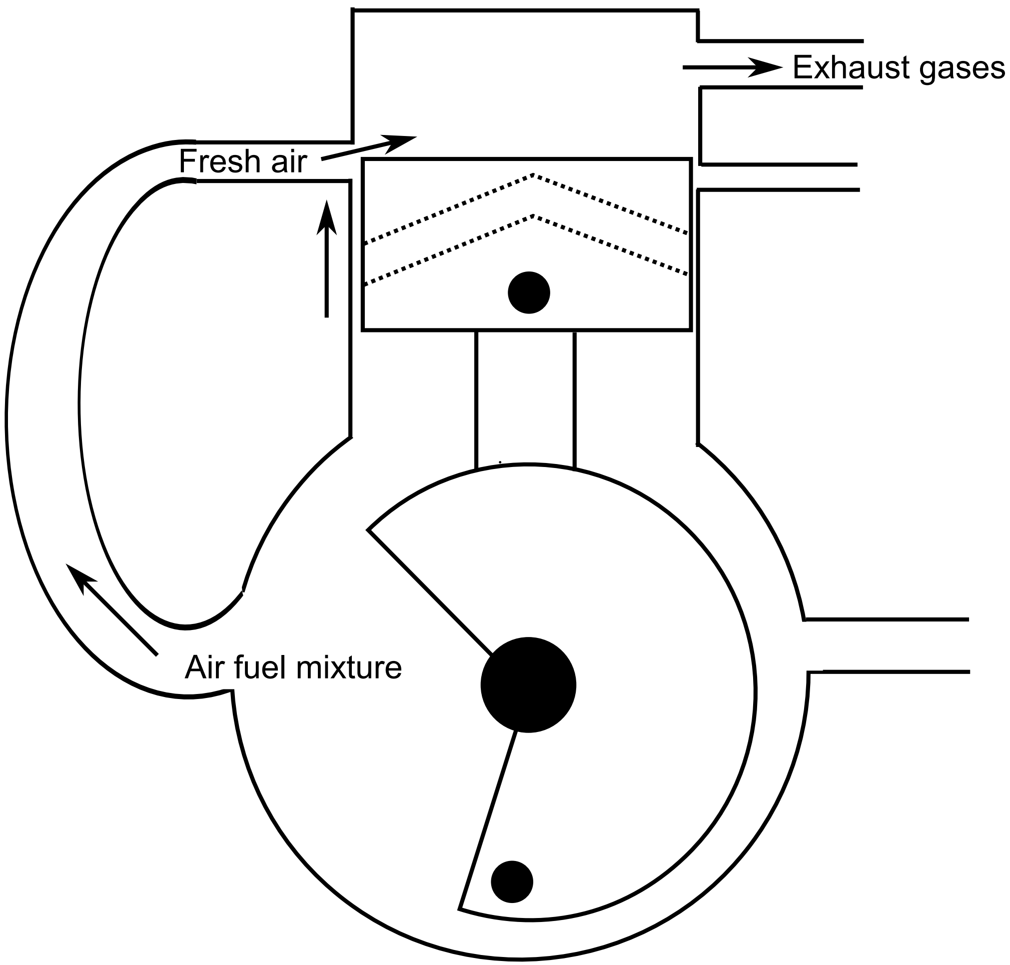
- Reduction of emissions and a lowered fuel consumption.
- The cycle of operation.
- Trapping efficiency.

$$\eta_{tr,fuel} = \frac{\text{Mass of delivered fuel retained}}{\text{Mass of delivered fuel}}$$

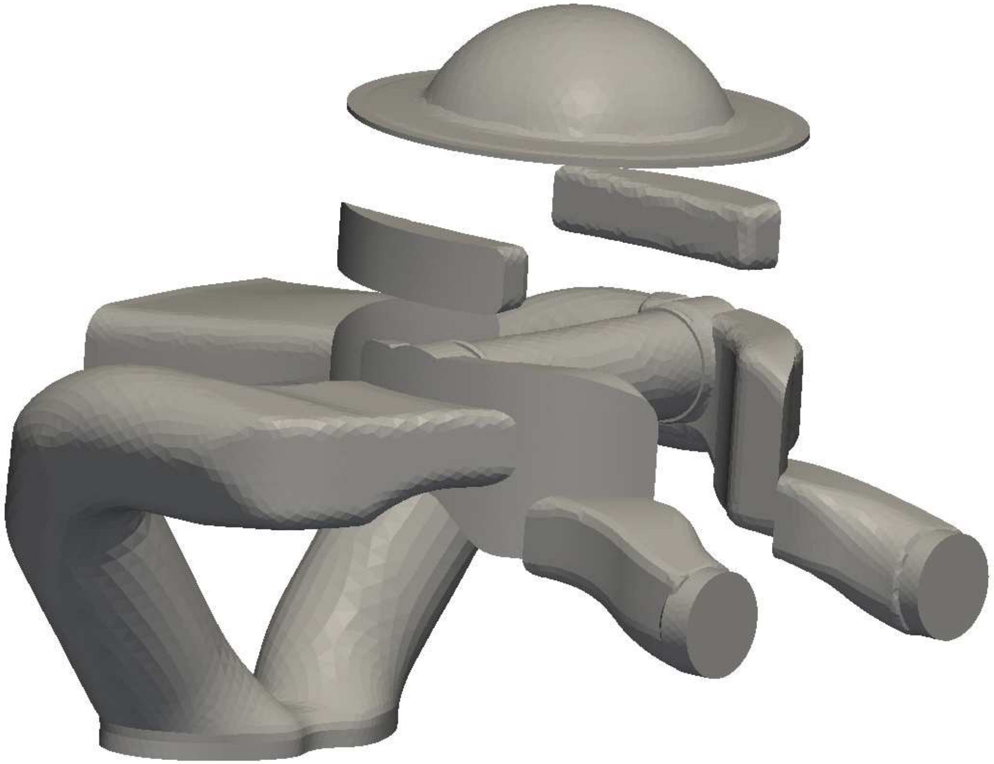
Expansion stroke



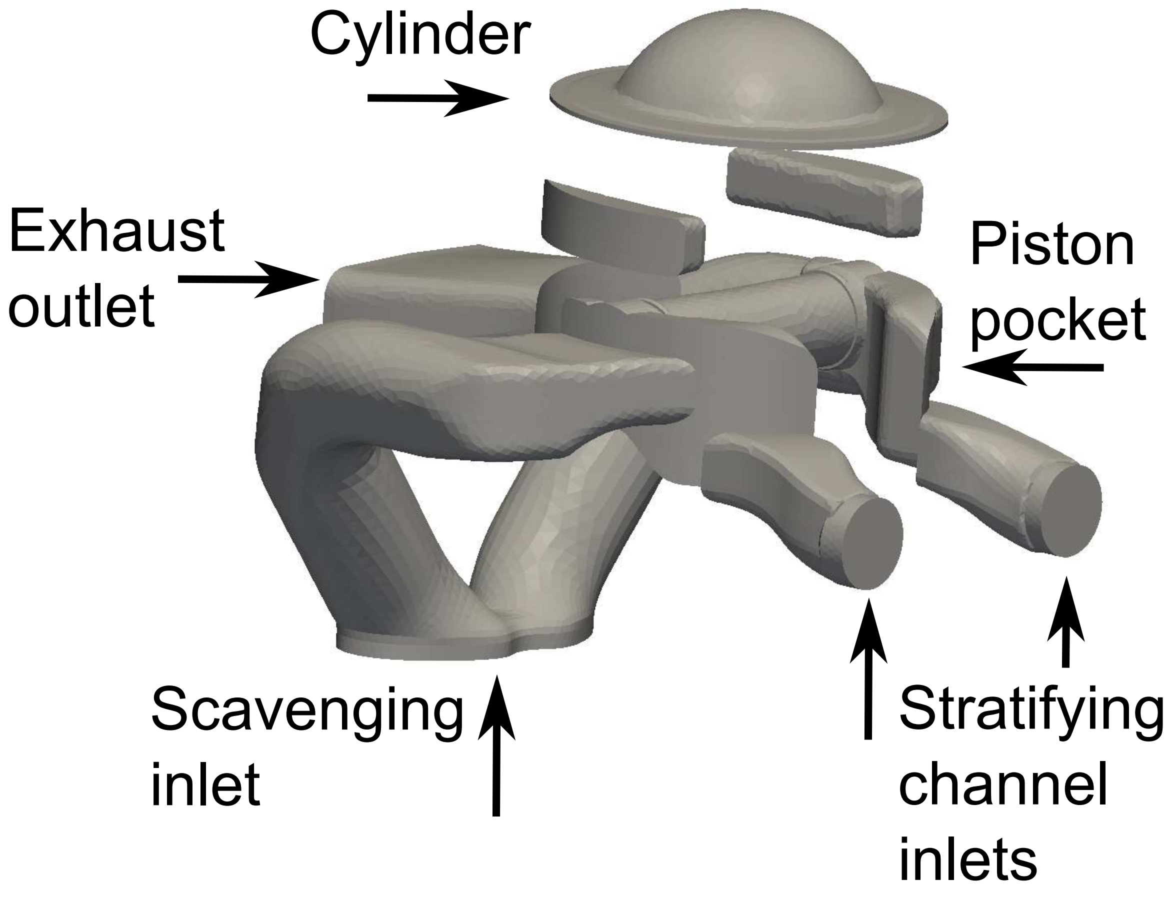
Compression stroke



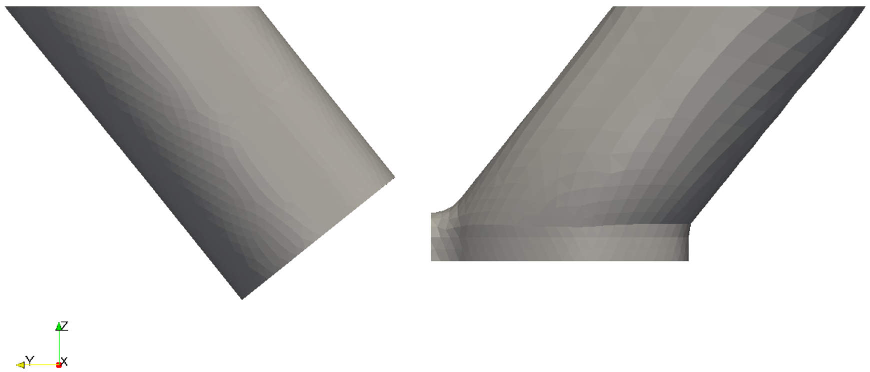
The H576X geometry

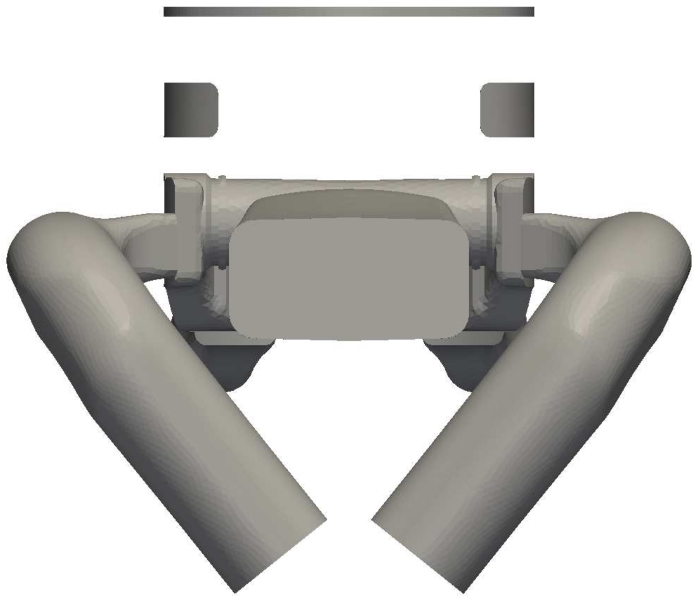


The H576X geometry description



Geometry modifications





CFD and the Finite Volume Method

- The Reynolds-Averaged Navier-Stokes equations.
- Turbulence modelling using the standard $k - \varepsilon$ turbulence model.
- Wall functions.

Fluids

- Approximation with air as the only fluid.
- No combustion, the combustion is modelled.
- Air fuel mixture for trapping efficiency
- Passive scalar transport

The passive scalar

- Adding a passive scalar, ϕ to represent the air fuel mixture.
- Convection dominated flow.
- The governing equations independent of the passive scalar.
- Volume concentration of ϕ in the cell.

The passive scalar, continued

- The passive scalar transport equation.

$$\frac{\partial(\rho\phi)}{\partial t} + \mathrm{div}(\rho\mathbf{U}\phi) = 0$$

- The cell volume passive scalar concentration.

$$0 \leq \phi \leq 1$$

- A compressible flow requires the mass to be calculated

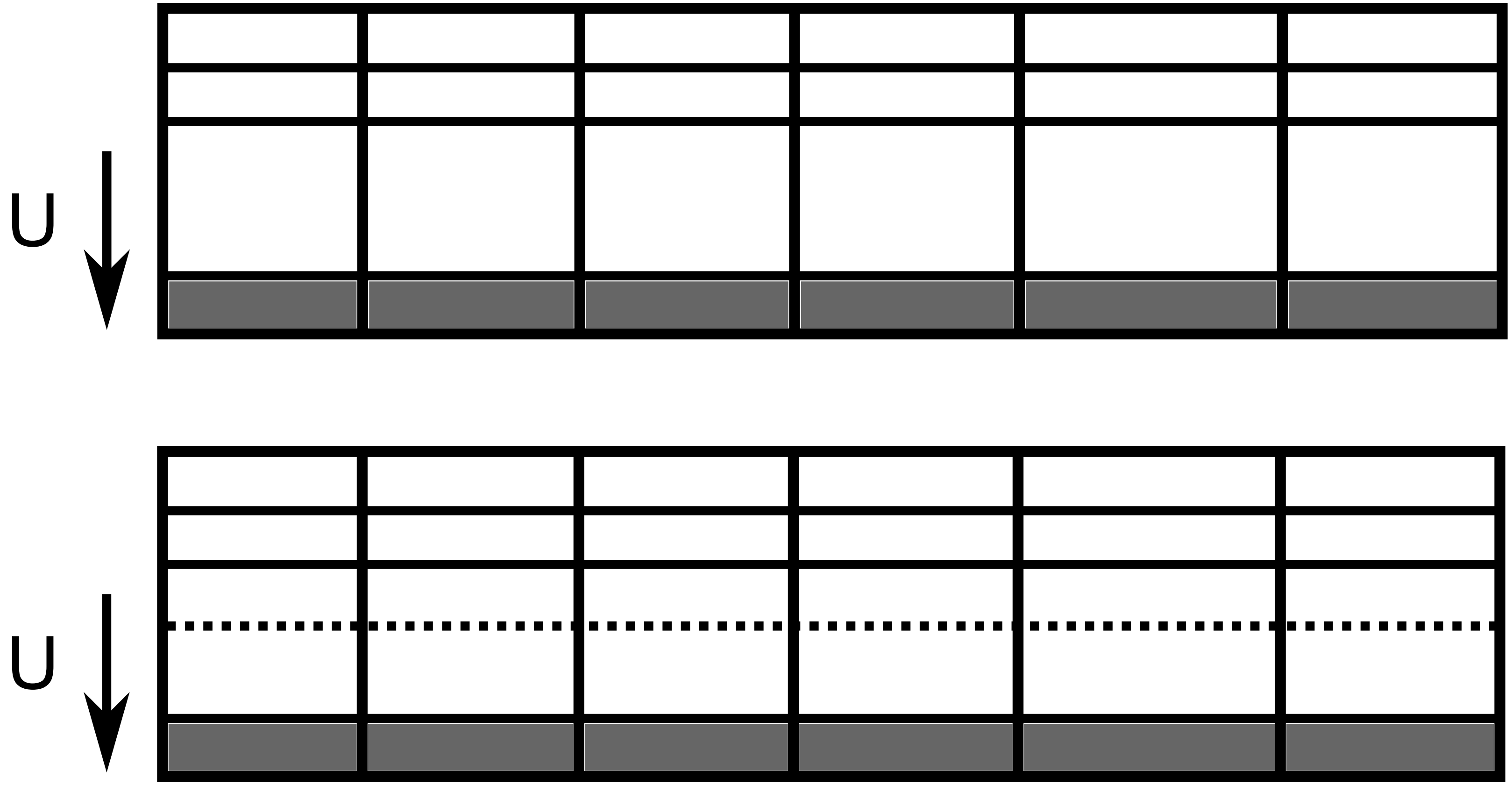
$$m_{fuel} = \rho * \phi * V_{cell}$$

Mesh operations

- The solver must manage some mesh operations.
- The cylinder volume is being compressed and expanded, `layerAdditionRemoval`.
- The cylinder and the ports must interact, `slidingInterface`.
- The `twoStrokeEngine`-library handle these features.

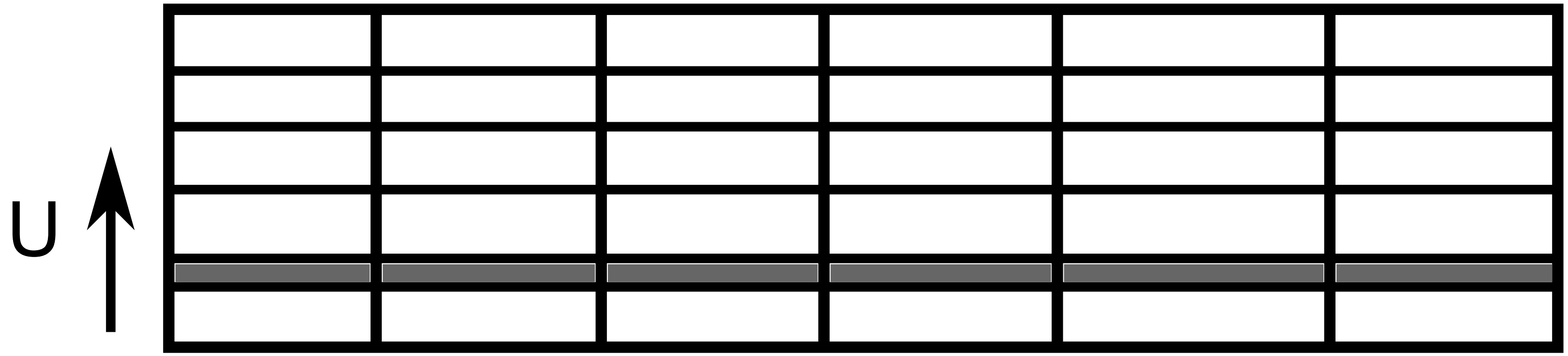
Layer addition

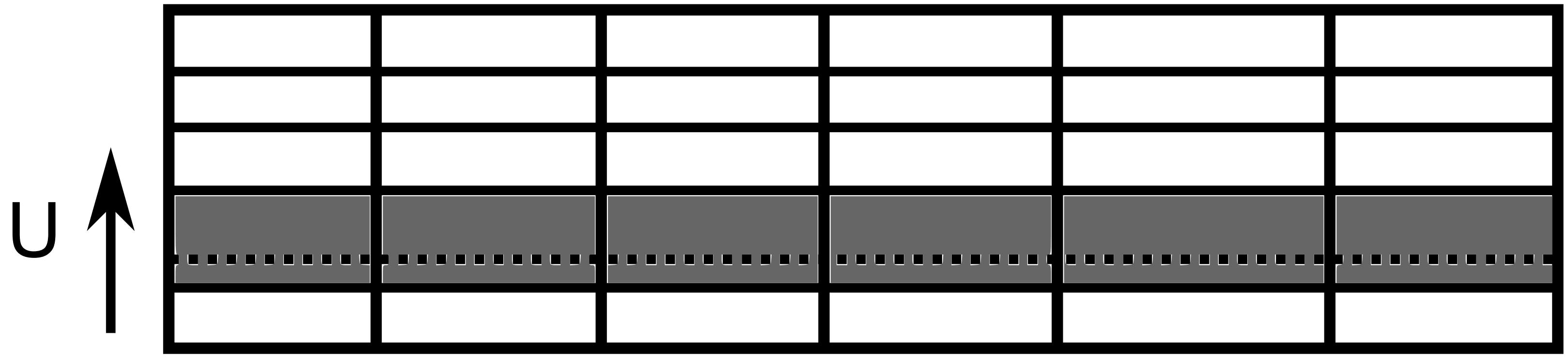
- Morphing to a certain limit.
- Layer addition.



Layer removal

- Compression to a certain limit.
- Layer removal.

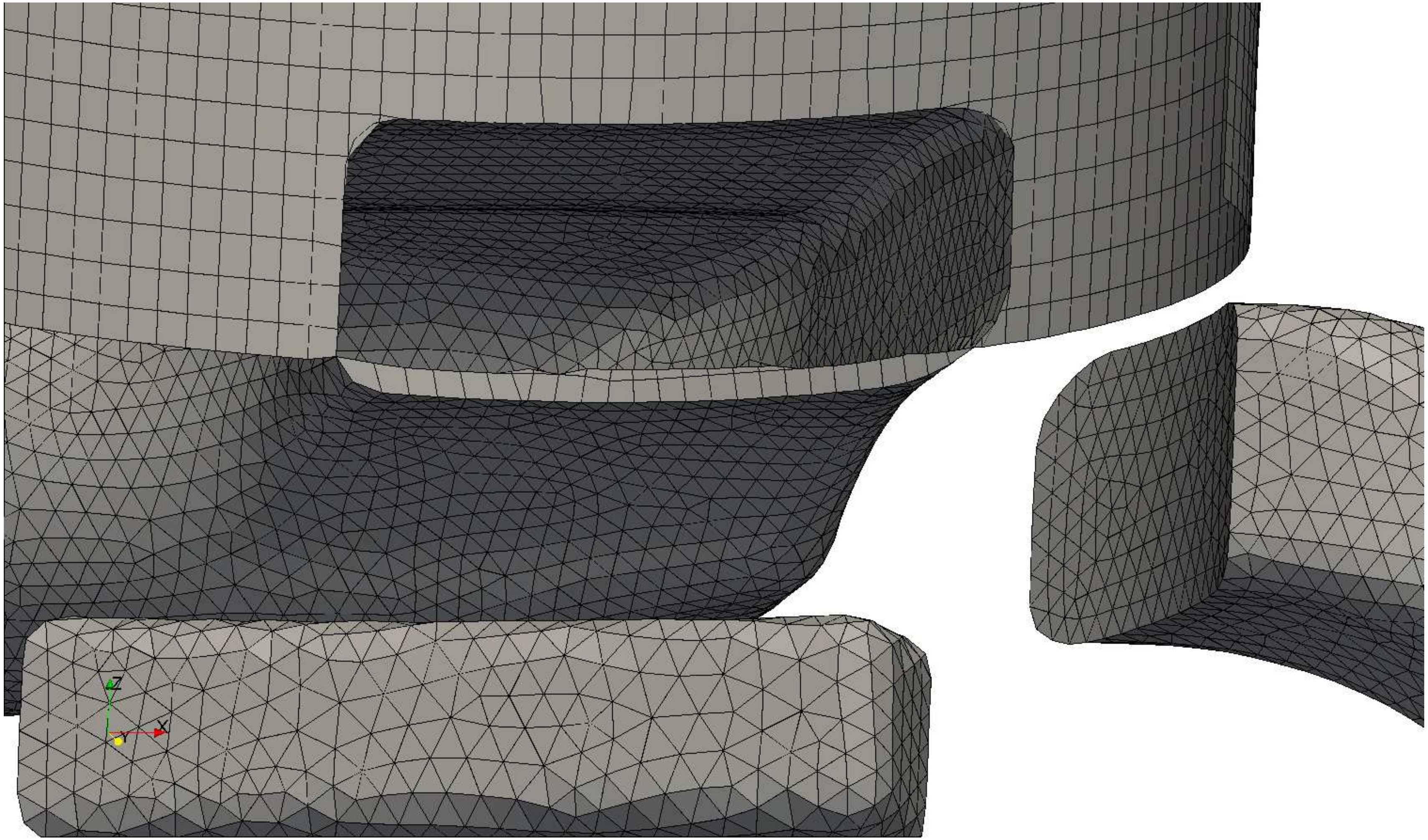




Sliding interface

- Sliding interfaces.
- Ports, cylinder and piston pockets.

Sliding interface, continued



Boundary conditions, inlets and outlets

- Scavenging channel inlets.
- Exhaust outlet.
- Stratifying channel inlets.
- Flow both into and out of the domain.
- Adaptive B.C. for temperature, T, velocity ,U, turbulent kinetic energy, k, dissipation of turbulent kinetic energy, ε, and the passive scalar, ϕ.
- Flow into the domain, Dirichlet B.C.
- Flow out of the domain, homogenous Neumann B.C.

$$\frac{\partial \phi}{\partial x_n} = 0$$

Boundary conditions, inlets and outlets, continued

- Temperature set according to results from 1-d simulations.
- Pressure set according to results from 1-d simulations.
- Turbulent properties, k and ε are set to small values.
- The passive scalar is set to a 100% concentration in the scavenging channel inlet.

Boundary conditions, inlets and outlets, continued

- Isolated walls. Homogenous Neumann for temperature and pressure and the passive scalar
- No slip for velocity
- Wall functions used for k and ε

Combustion modelling

- No actual combustion. Modelled combustion.
- Cylinder pressure and temperature set before exhaust port opens.
- Pressure from 1-d simulations.
- Temperature from 1-d simulations exhaust channel.

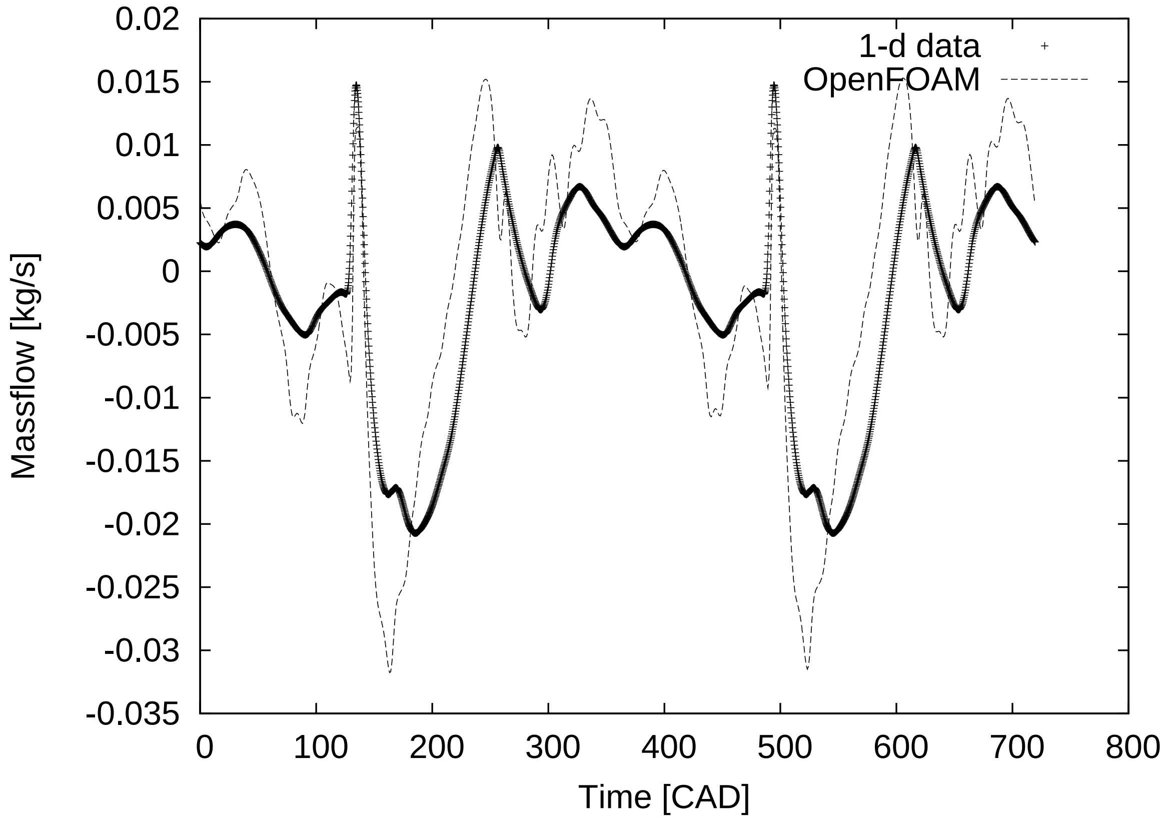
Results, scavenging

- Trapping efficiency about 93%.
- Solution is periodic within four revolutions.
- Trapping efficiency from experiments 92%.

360 CAD	720 CAD	1080 CAD	1440 CAD
99.34 %	93.14 %	93.61 %	93.77 %

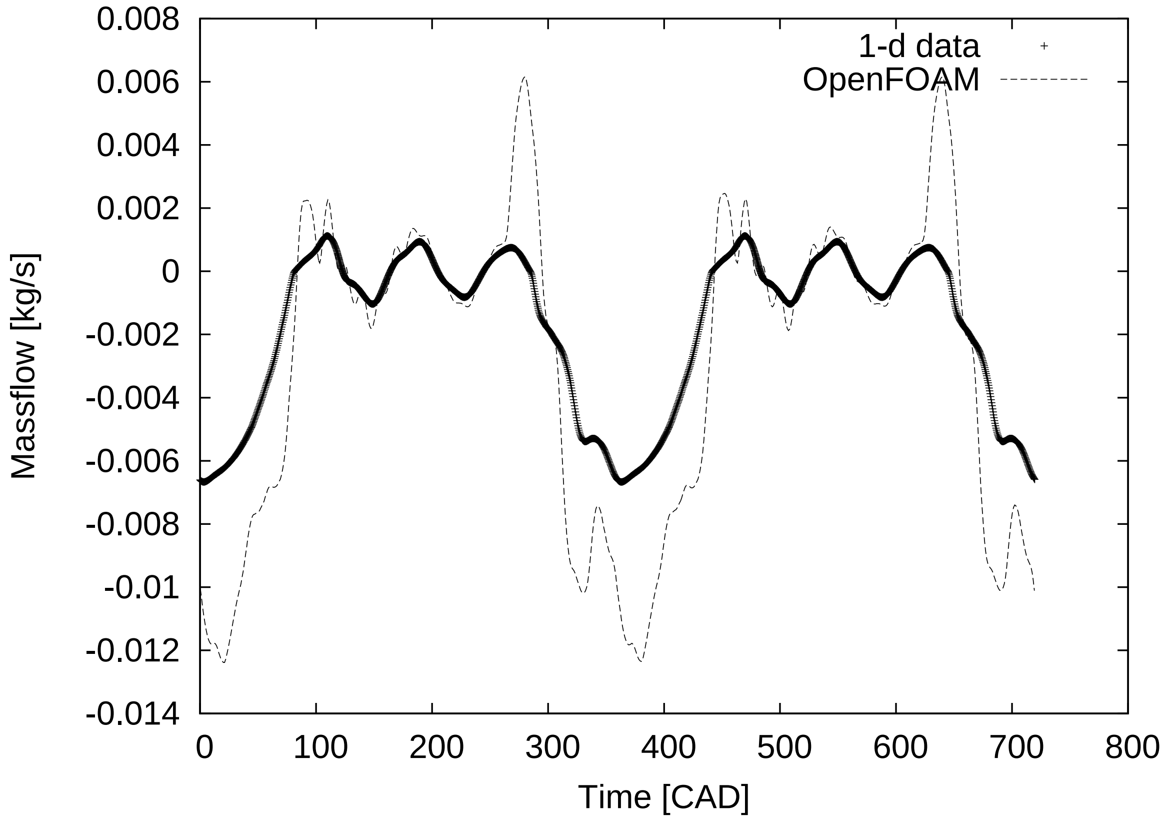
Results, validation

- Comparison in massflow over scavenging channel inlet with 1-d simulations.



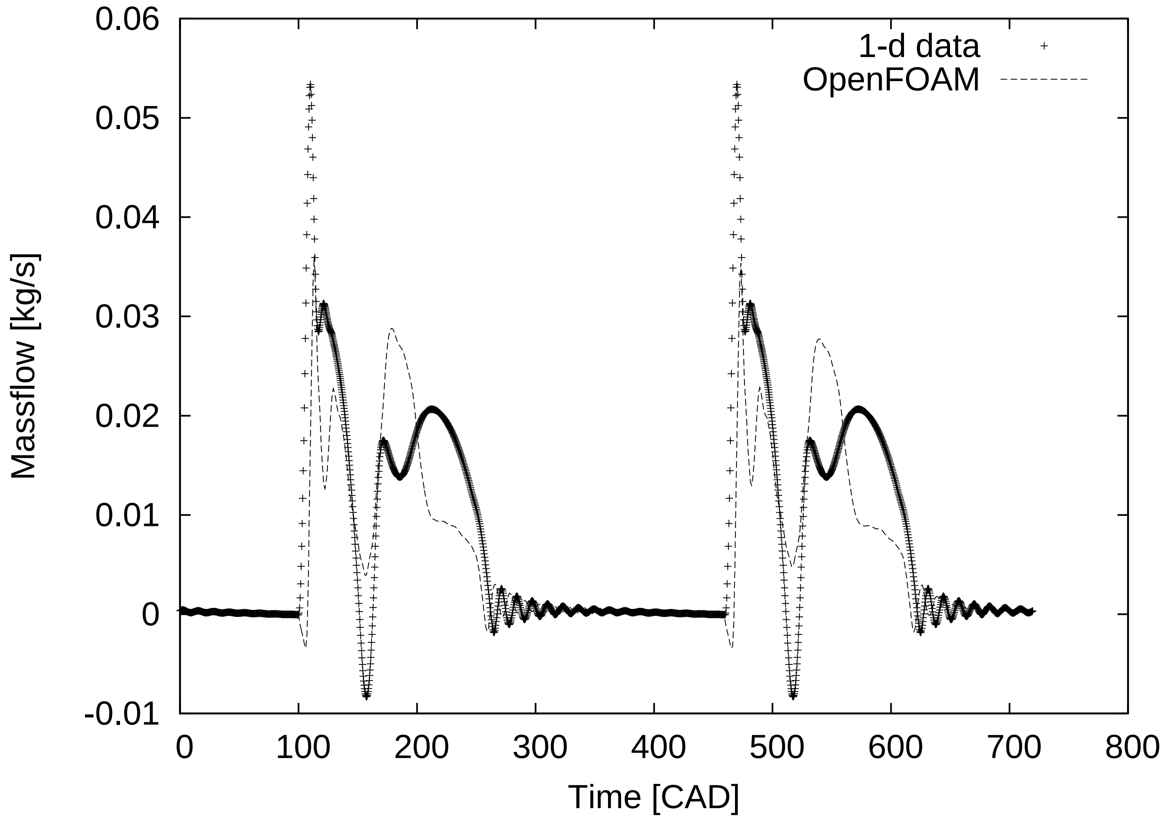
Results, validation, continued

- Comparison in massflow over stratifying channel inlet with 1-d simulations.



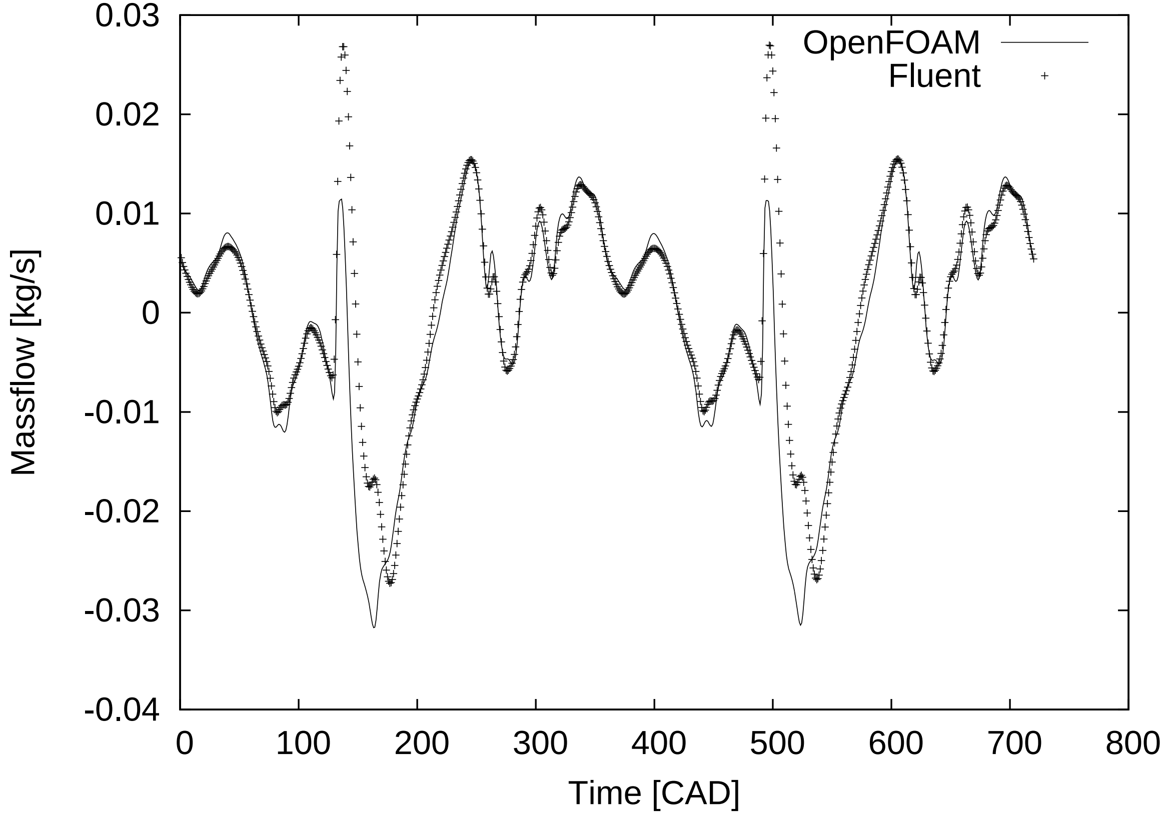
Results, validation, continued

- Comparison in massflow over exhaust outlet with 1-d simulations.



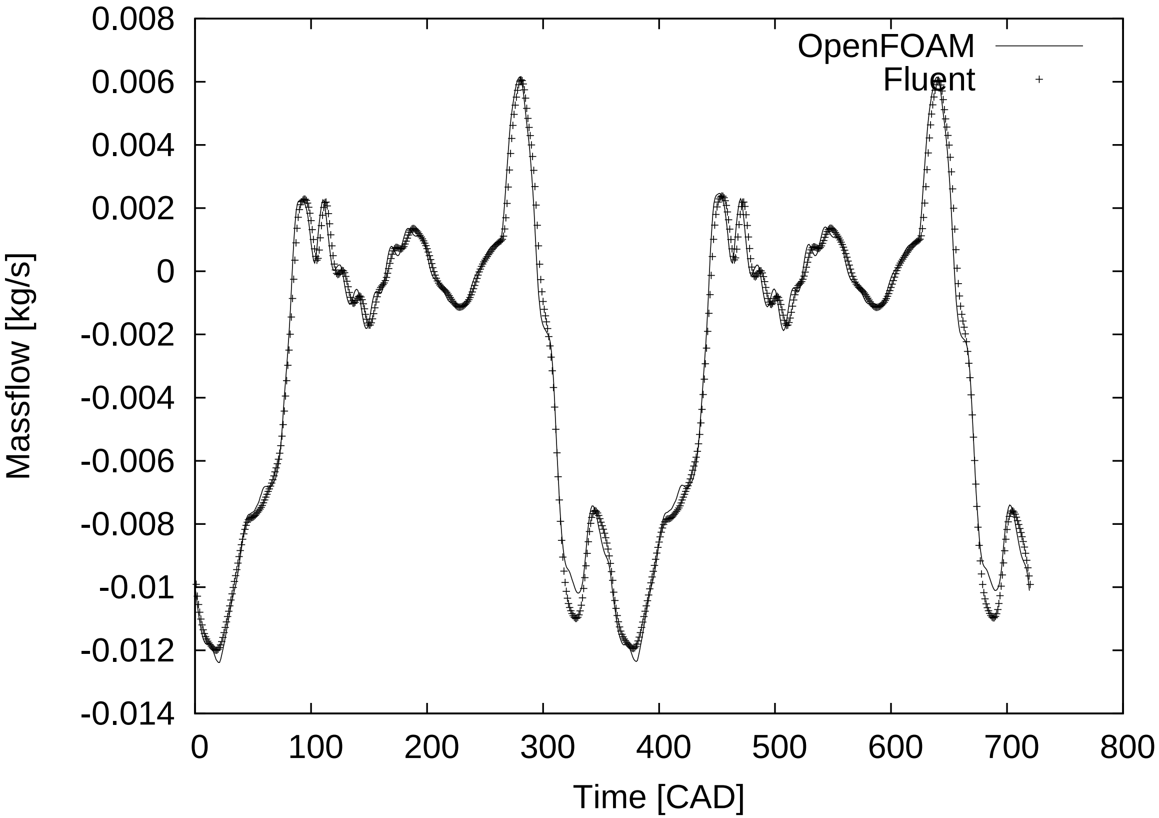
Results, validation, continued

- Comparison in massflow over scavenging channel inlet with Fluent simulations.



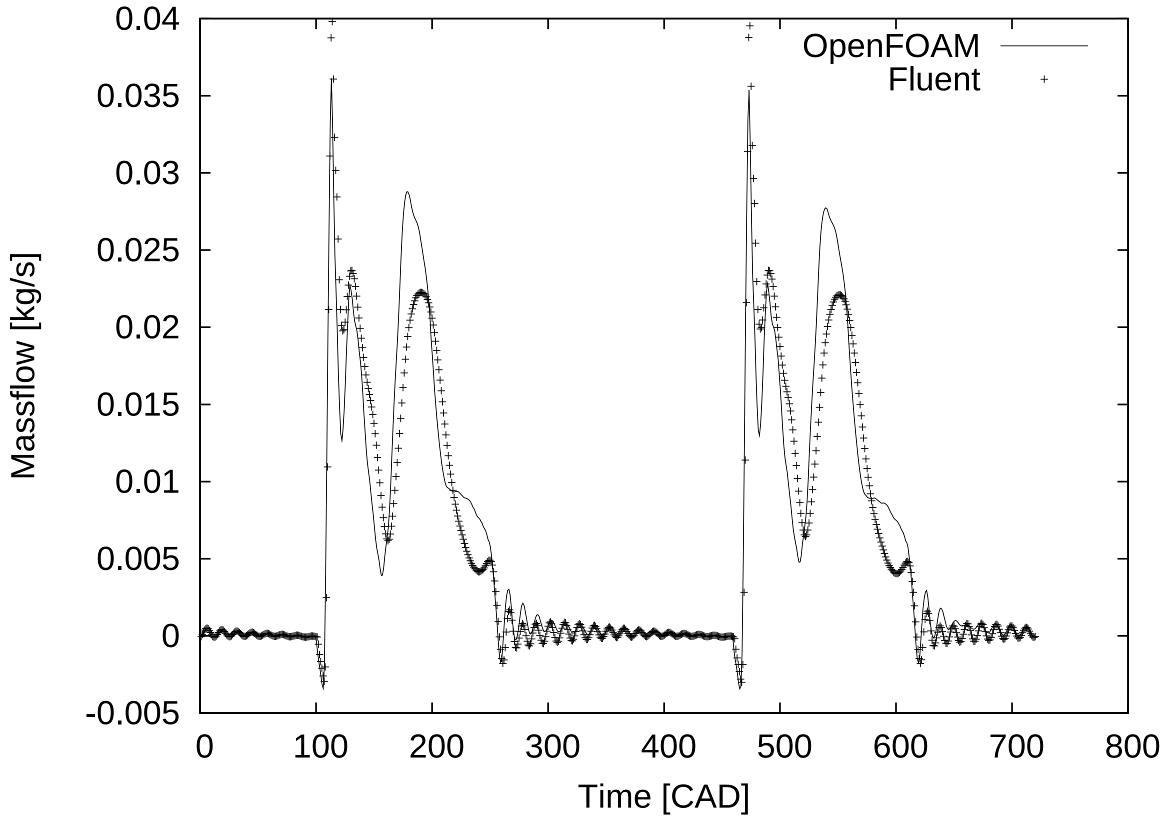
Results, validation, continued

- Comparison in massflow over stratifying inlet with Fluent simulations.



Results, validation, continued

- Comparison in massflow over exhaust outlet with Fluent simulations.



Conclusions, OpenFOAM

- Useful for two-stroke engine simulations.
- Approximately 24h per revolution with `checkMesh` on 3 CPU:s. Periodic behavior within four revolutions.
- Results in correlation with commercial CFD-code and 1-d simulations.

Future work

- Non-modified geometry.
- Expand the geometry.
- The mesh impact on the solution.
- Add more species and combustion.
- Heat transfer with walls.