

DESIGN OF A FUEL-EFFICIENT TWO-STROKE DIESEL ENGINE FOR MEDIUM PASSENGER CARS: COMPARISON BETWEEN STANDARD AND REVERSE UNIFLOW SCAVENGING ARCHITECTURES

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1. INTRODUCTION

- CONTEXT
- OVERVIEW OF SCAVENGING ARCHITECTURES
- BENCHMARK OF SCAVENGING CONFIGURATIONS

2. SYSTEM SIMULATION ANALYSIS

- INTRODUCTION
- SIMULATION METHODOLOGY
- RESULTS
- CONCLUSIONS

3. 3D CFD ANALYSIS

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- SIMULATIONS DETAILS
- QUALITATIVE RESULTS
- QUANTITATIVE RESULTS

4. MAIN CONCLUSIONS & PERSPECTIVES

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REWARD project

- REal World Advanced Technologies foR Diesel Engine
- H2020 project funded by the European Union
- A consortium formed by European industries, R&I providers and Universities
- Improving Diesel engine efficiency
- Main targets
 - $\geq 5\%$ improved fuel economy
 - ≥ 3 dB less noise
 - $\geq 50\%$ less particles emission
 - Compliance with post Euro 6 limits under Real Driving conditions



Development a fuel efficient 2-stroke Diesel engine

- Target = Medium / class C vehicles
- Partners = Groupe Renault, CMT-Universitat Politècnica de València, Czech Technical univ., AVL, Delphi and IFP Energies Nouvelles

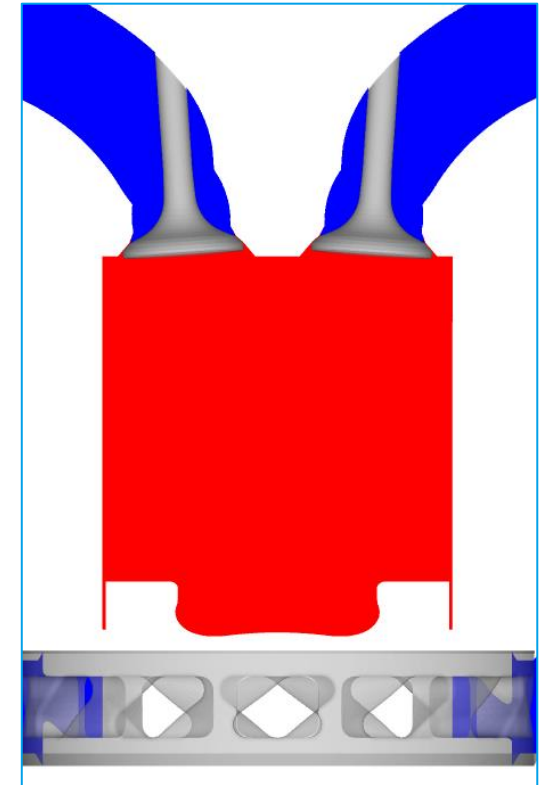
Diesel engine market for automotive applications = 4-stroke

But a renewed interest of 2-stroke Diesel engines

- Larger power density
- Reduction of the number of cylinders
 - Compactness
 - Weight reduction thus potential cost reduction
- Natural operation with IGR \Rightarrow NOx in transient (no EGR latency)

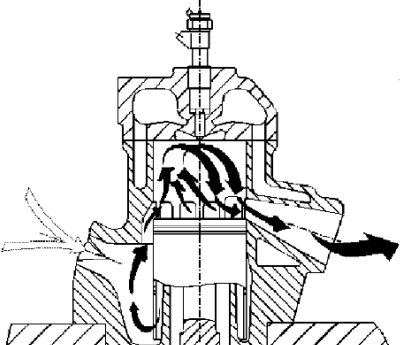
Key point is scavenging

- Combustion each revolution \Rightarrow small time devoted to gases transfers
- Scavenging = quasi overlapping of the intake & exhaust
- Targeted features
 - Trap fresh gases as much as possible
 - Short-circuiting as low as possible



INTRODUCTION

OVERVIEW OF SCAVENGING ARCHITECTURES

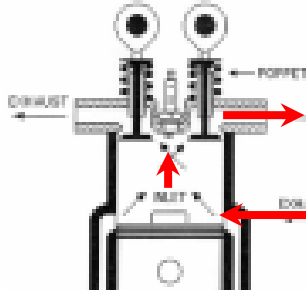
Type	Outline	Advantages	Drawbacks
Transfer ports only		<ul style="list-style-type: none">• No camshaft• Low friction• Simplicity• Large ports permeability	<ul style="list-style-type: none">• Long piston skirt / deflector• Fixed intake/ exhaust timings and diagrams• Short-circuiting

INTRODUCTION

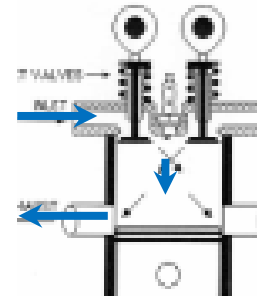
BENCHMARK OF SCAVENGING CONFIGURATIONS

First step of the project = Standard or Reverse uniflow ?

Standard uniflow
Intake by ports
Exhaust by valves

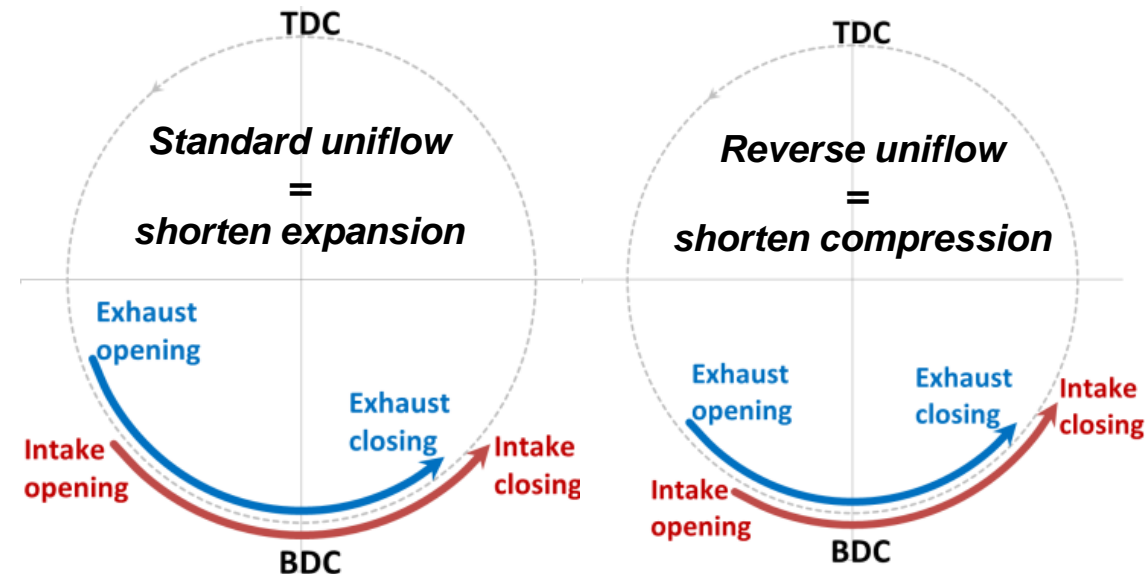


Reverse uniflow
Intake by valves
Exhaust by ports



Question 1 = Shorten expansion or shorten compression ?

- No flexibility on the ports diagram
 - No flexibility on the transfer ports diagram
 - Symmetric diagram centered around BDC
 - Exhaust occurs earlier than intake
- System code simulations
 - LMS Imagine.Lab Amesim code
 - Several intake & exhaust diagrams investigated

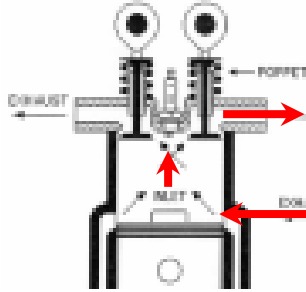


INTRODUCTION

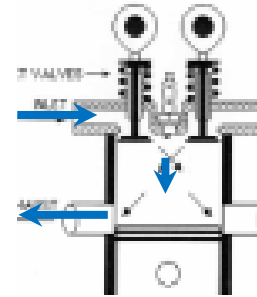
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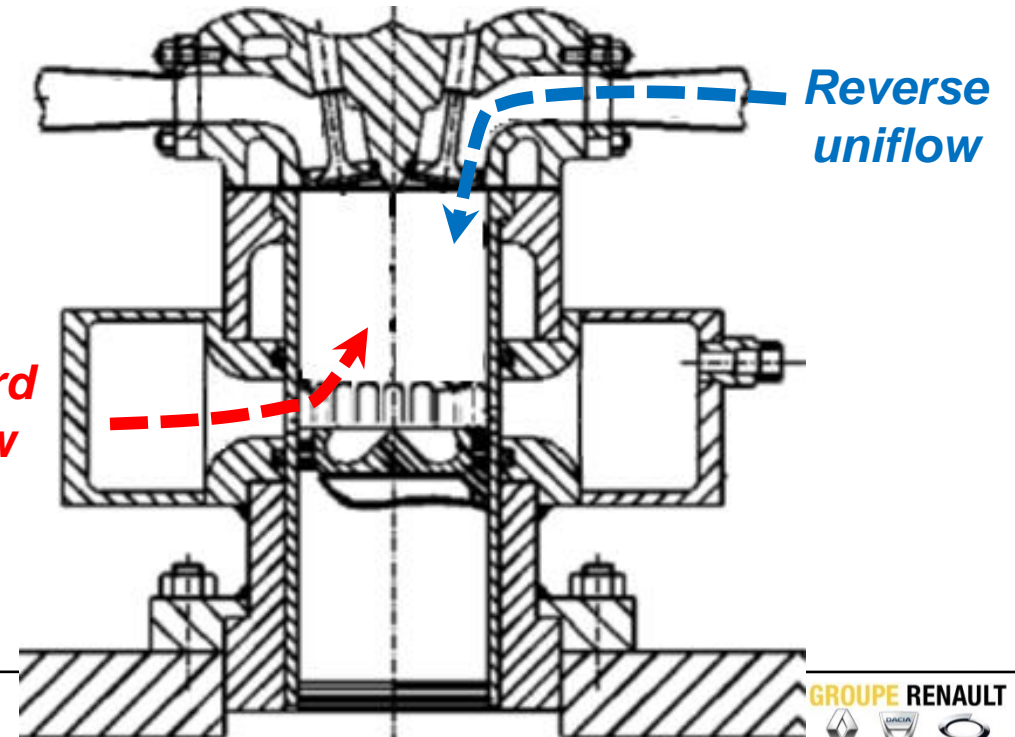
Reverse uniflow
Intake by valves
Exhaust by ports



Question 2 = Which conf. provides the most efficient scavenging ?

- Geometries upstream the cylinder differs strongly between both configurations
- Effects on the scavenging ?
- 3D CFD simulations
 - CONVERGE CFD 2.2
 - Several geometries tested

Standard uniflow



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4. MAIN CONCLUSIONS & PERSPECTIVES

Purpose

- Benchmark between standard and reverse uniflow on 3 operating points
 - 3000rpm x 11bar (FL)
 - 2000rpm x 7bar
 - 1500rpm x 4bar
- Comparison based on Fuel consumption
- No assessment of the emissions

Engine configuration

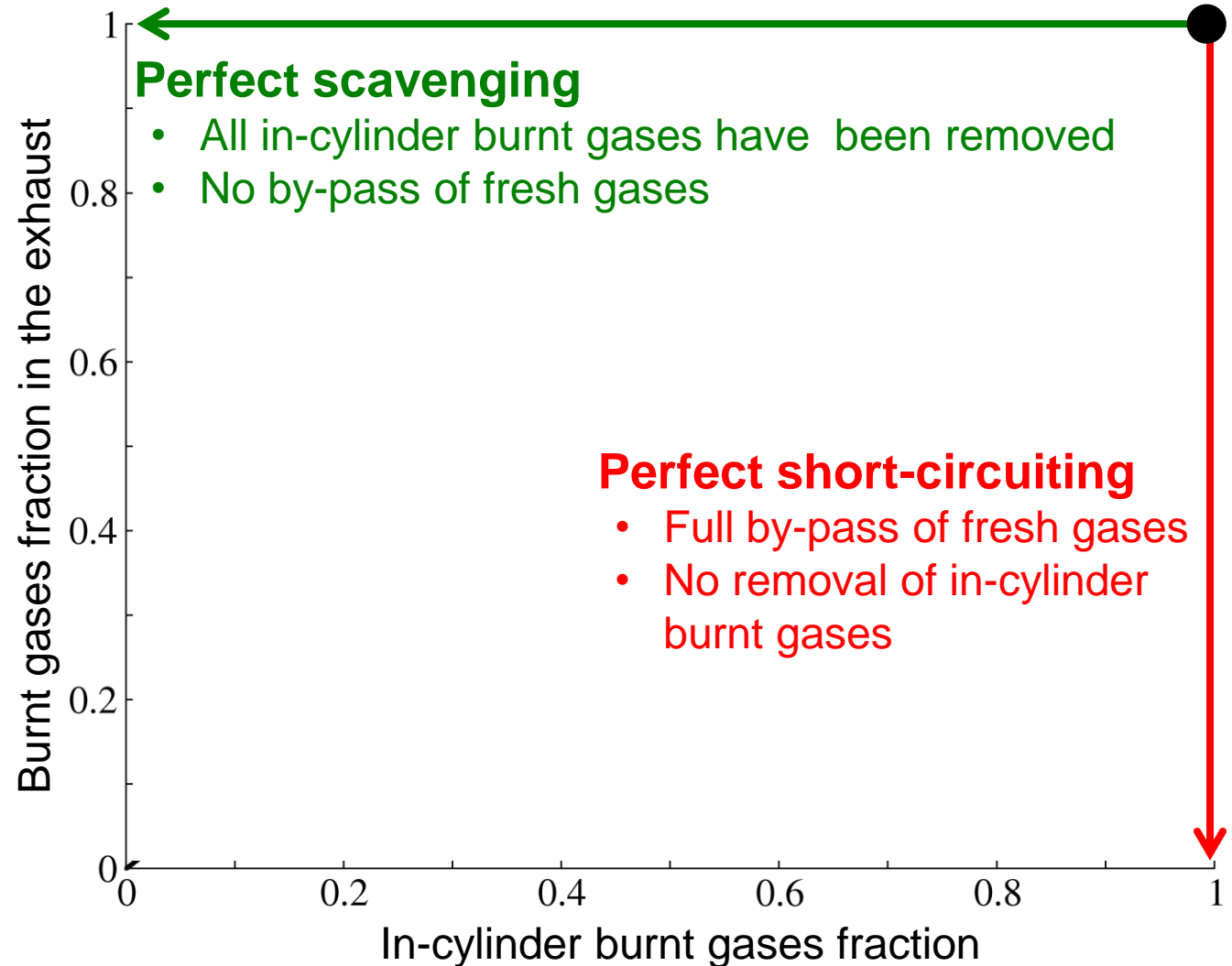
- Based on a Renault K9K engine
 - 4-stroke
 - 4 cylinders 1,460cm³
- and adapted to the study
 - SCE
 - Supercharger added



Displaced volume	400 cm ³
Stroke	76 mm
Bore	88 mm
Connecting Rod	180 mm
Geometrical compression ratio	16.0
Numbers of valves / ports	4 / 12
Supercharging	Turbocharger and supercharger

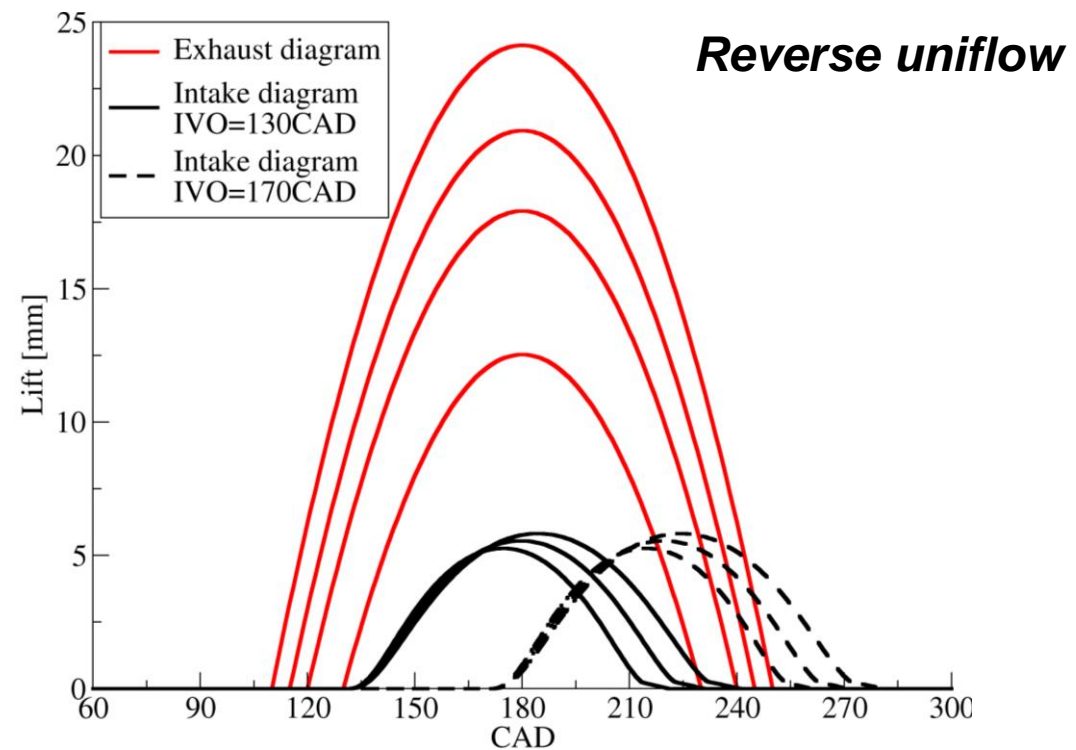
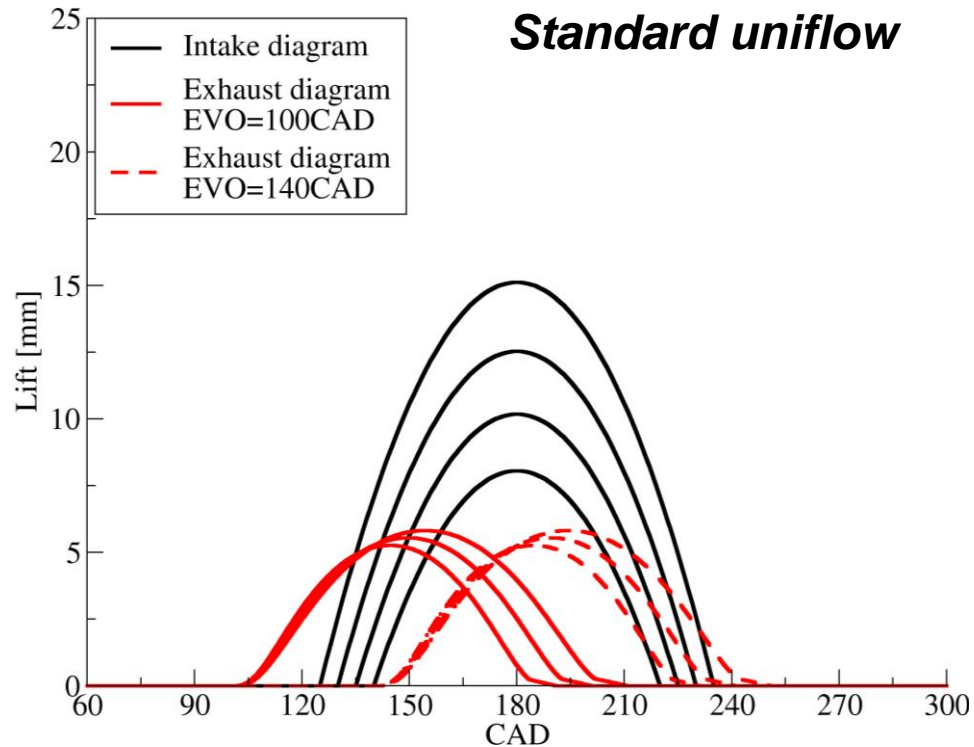
Fixed parameters

- $P_{\text{intake}} - P_{\text{exhaust}}$ fixed per operating point
- Combustion law
 - Dual Flame Model (IFP drive lib.)
 - CA50 = 10 CAD after TDC
- Fixed turbocharger and mechanical compressor efficiencies
- Scavenging curve (hypothesis)



Variable parameters

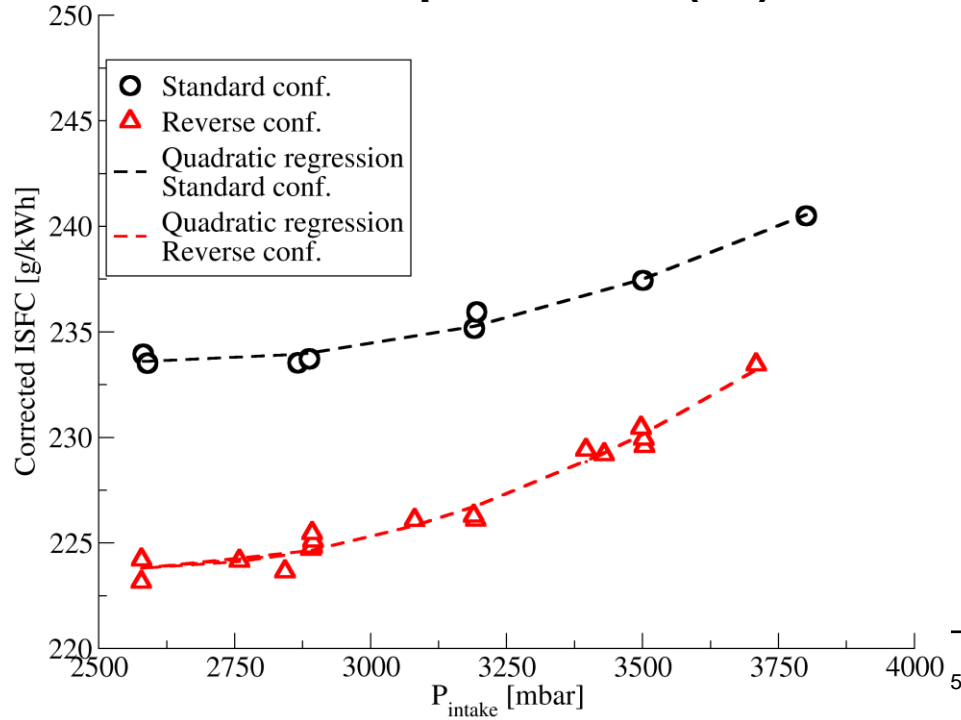
- Several combinations intake/exhaust diagrams investigated
- Intake pressure P_{intake} ($P_{\text{intake}} - P_{\text{exhaust}}$ is kept fixed)



Corrected ISFC

- ISFC + penalty due to the supercharger work
- Most promising combinations intake/exhaust diagrams plotted
- Corrected ISFC \nearrow when $P_{\text{intake}} \nearrow$ due to the supercharger
- 10g/kWh benefit for the reverse configuration
- Large ISFC \Rightarrow pre-design study, optimizations not yet performed

3000rpm x 11bar (FL)



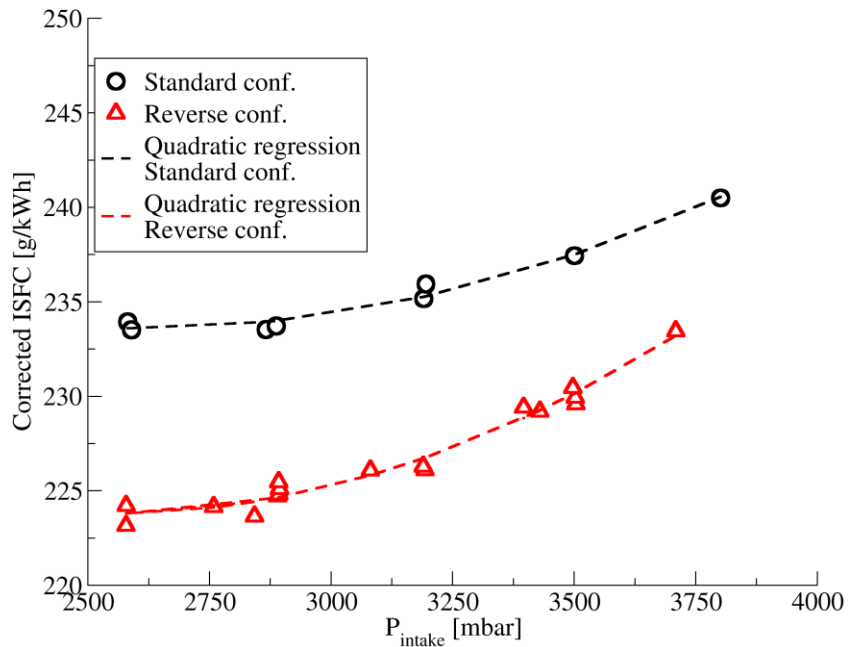
SYSTEM SIMULATION ANALYSIS

RESULTS

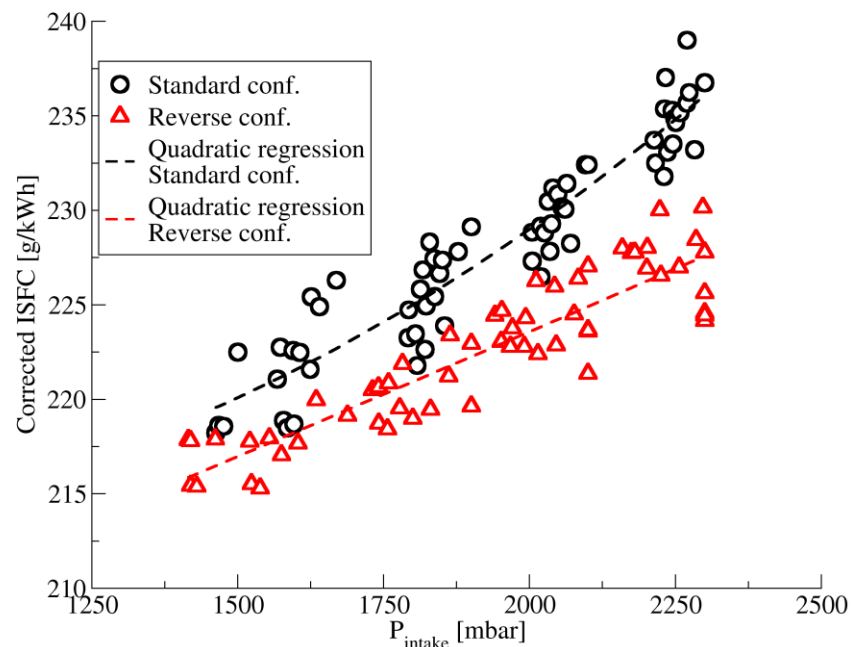
Corrected ISFC

- 3000rpm x 11bar \Rightarrow 10g/kWh benefit for the reverse configuration
- 2000rpm x 7bar \Rightarrow small benefit for the reverse configuration (>5 g/kWh)
- 1500rpm x 4bar \Rightarrow negligible benefit

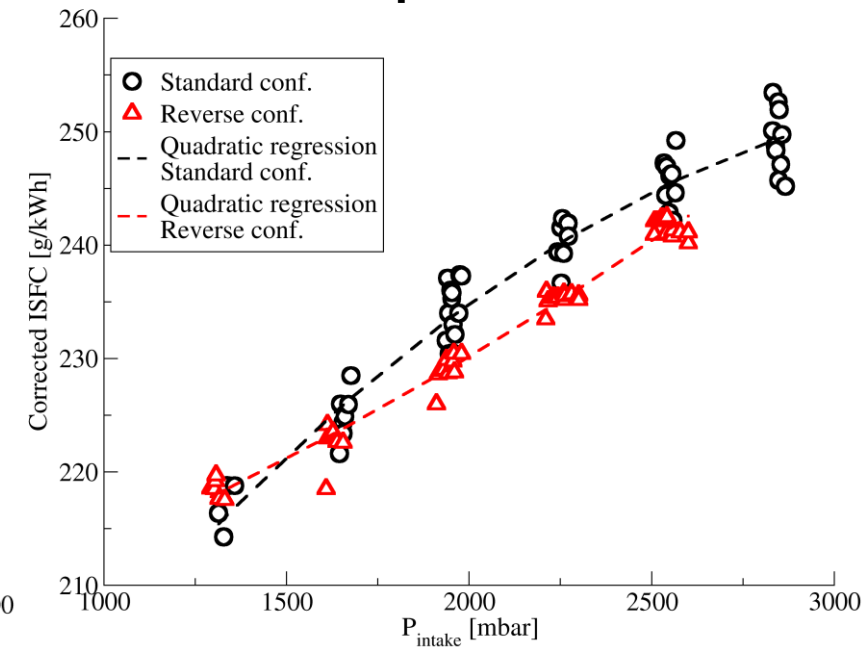
3000rpm x 11bar (FL)



2000rpm x 7bar



1500rpm x 4bar



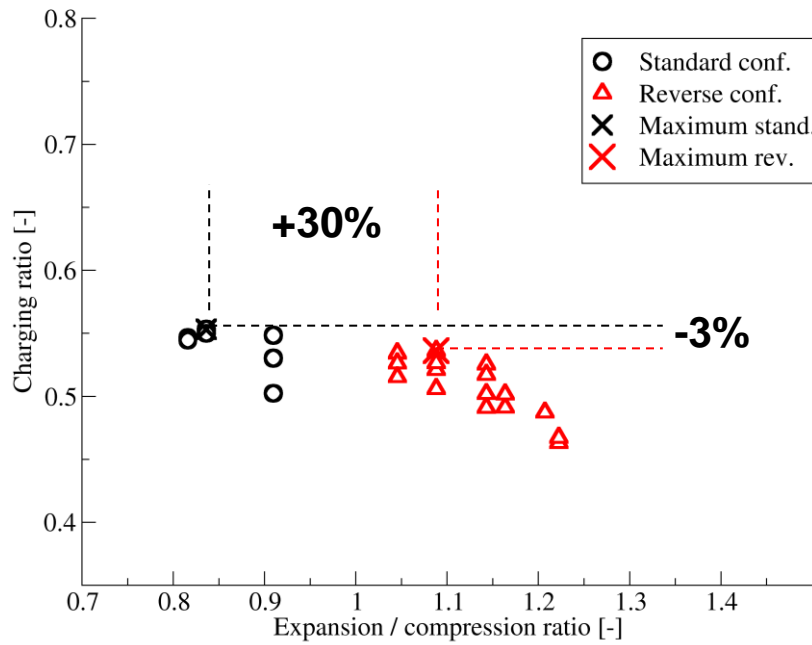
SYSTEM SIMULATION ANALYSIS

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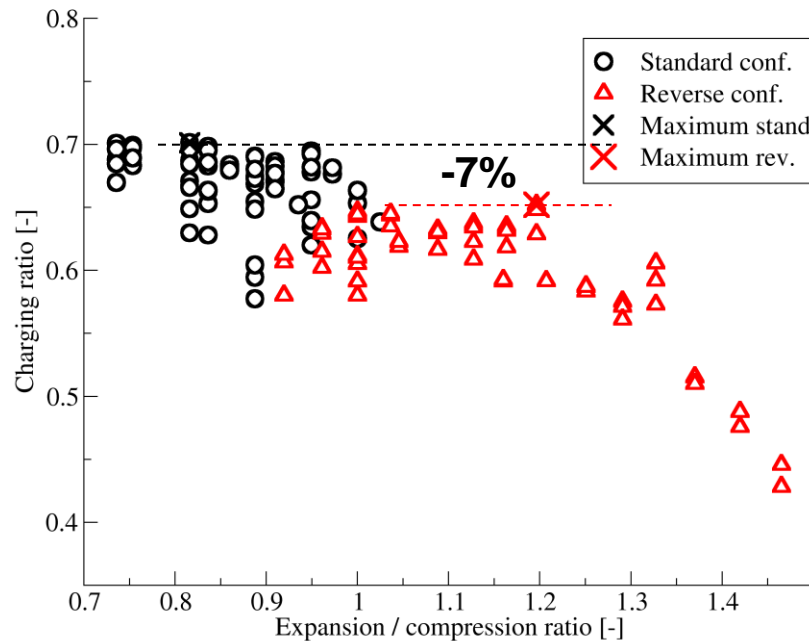
Analysis of the fresh gases masses

- Charging ratio = mass of trapped fresh gases / reference mass based on the intake conditions
- Expansion / compression ratio = $V_{\text{cylinder}} @ \text{exhaust opening} / V_{\text{cylinder}} @ \text{intake closure}$
- Larger expansion for the reverse configuration
- Penalty on the charging ratio \Rightarrow but penalty $\div 2$ for the FL point
- Compensation of expansion benefit and charging penalty

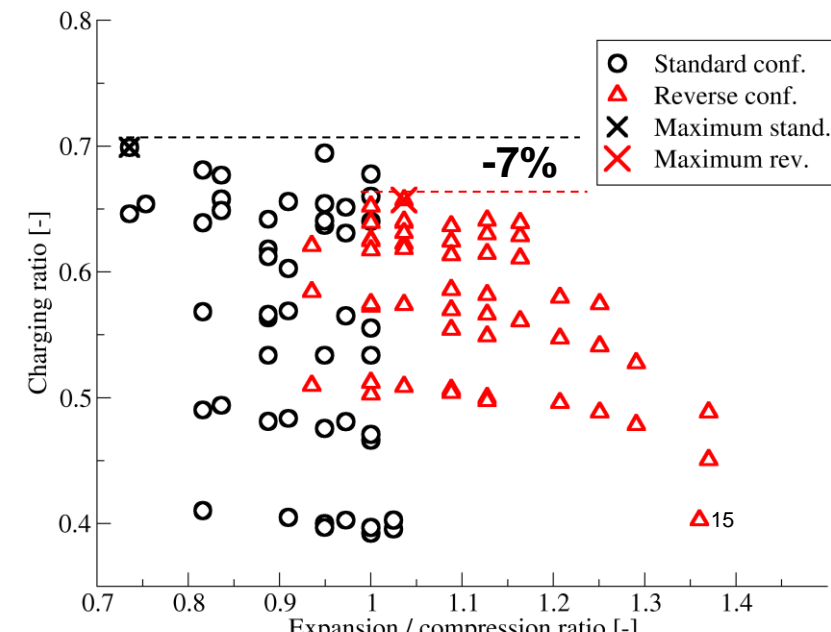
3000rpm x 11bar (FL)



2000rpm x 7bar



1500rpm x 4bar



Clear benefit of the reverse uniflow for the full load point \Rightarrow -10 g/kWh

but the advantages are negligible at low loads/speeds

- Reverse configuration allows a larger expansion but there is a penalty of the trapped mass
- For the full load point, the penalty is small compared to the expansion benefit
- For the other mid-load points, both effects compensate

Conclusions drawn by assuming the same scavenging between both uniflow configurations

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Purpose

- Study of the efficiency of the scavenging for the standard and reverse configurations
- CONVERGE code
- Comparison of the
 - Scavenging curves
 - Charging, trapping ratios
 - Swirl
- Single operating point 3750rpm x 11bar
- Single intake/exhaust diagrams issued from the previous study

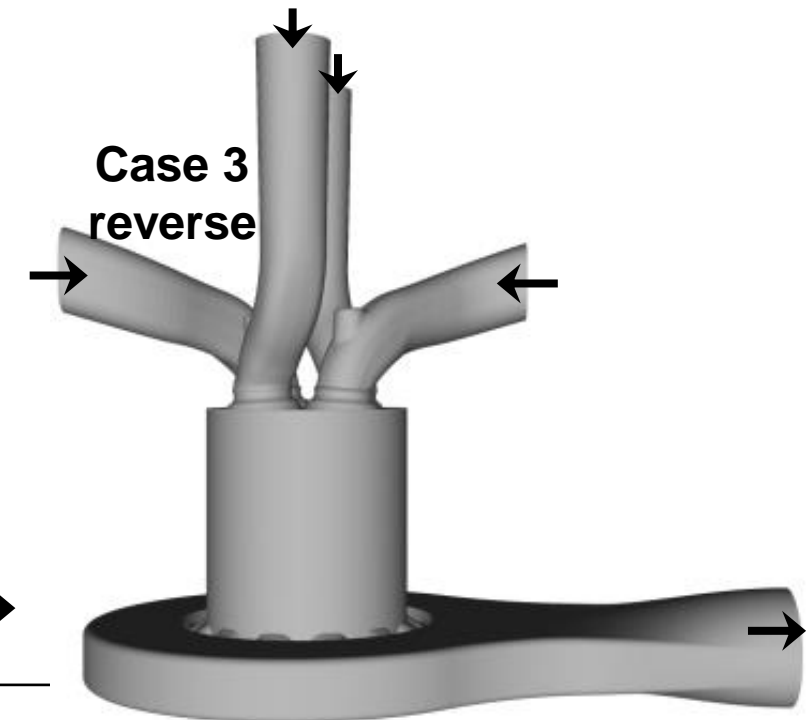
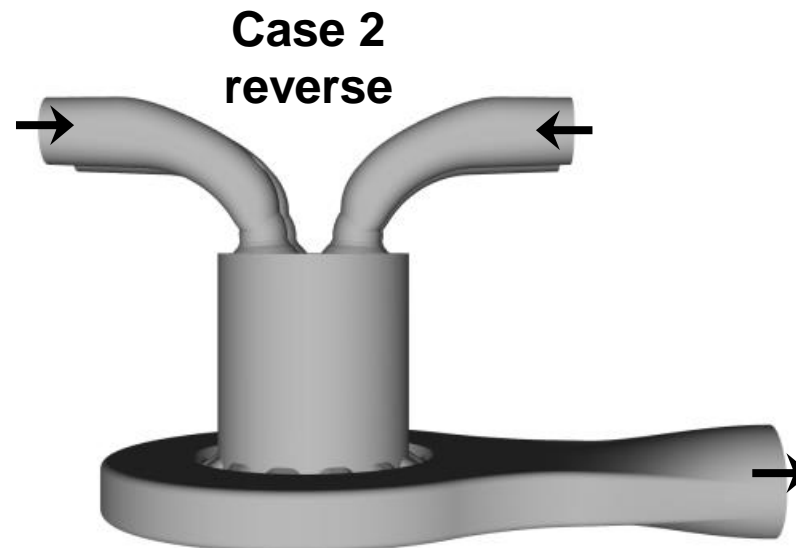
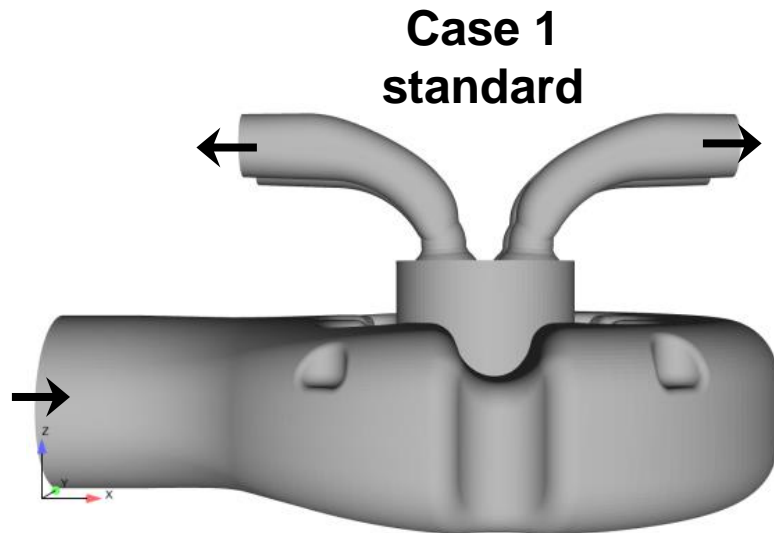


Engine configuration

- Same as previously

Three investigated cases

- Benchmark of the uniflow configurations
 - Case 1 : standard uniflow
 - Case 2 : reverse uniflow with intake ducts typed for enabling filling
- Benchmark of intake ducts in rev. uniflow
 - Case 2 : reverse uniflow with intake ducts typed for enabling filling
 - Case 3 : reverse uniflow with intake ducts typed for enabling swirl



Methodology

- From the end of the expansion to the beginning of the compression
- Best intake and exhaust diagrams issued from the previous study

Automatic grid generation

- Base size = 4mm
- Refinement up to 0.5mm
- 750,000 cells

Numerical setup

- $k-\varepsilon$ RNG
- No-slip hydraulically smooth walls with a standard law-of-the-wall
- $CFL_{convective} < 1$
- $CFL_{acoustic} < 50$

1 day on 64 Intel Xeon E5 @ 2.60GHz

	Standard Uniflow	Reverse Uniflow
Intake duration	125 CAD	100 CAD
Intake opening	117 CAD ATDC	150 CAD ATDC
Exhaust duration	95 CAD	120 CAD
Exhaust opening	105 CAD ATDC	120 CAD ATDC

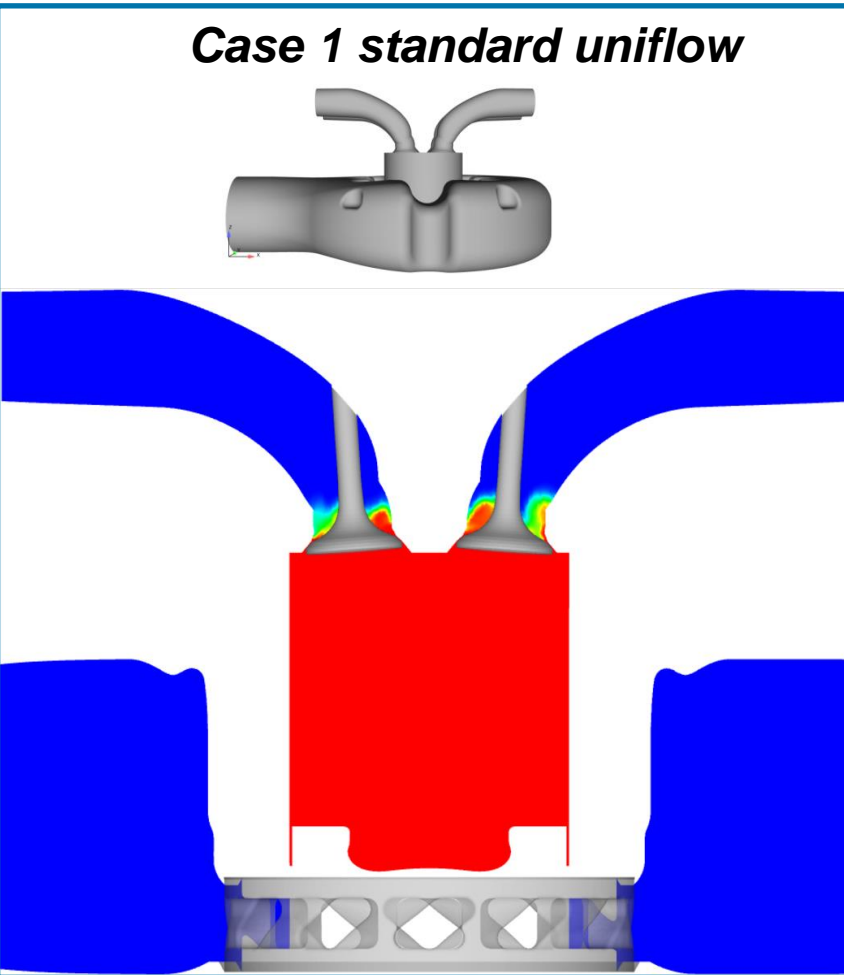
3D CFD ANALYSIS

QUALITATIVE RESULTS

Qualitative results

- In-cylinder tracer fields
- Center slice

Case 1 standard uniflow



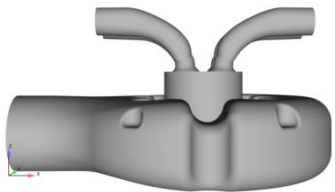
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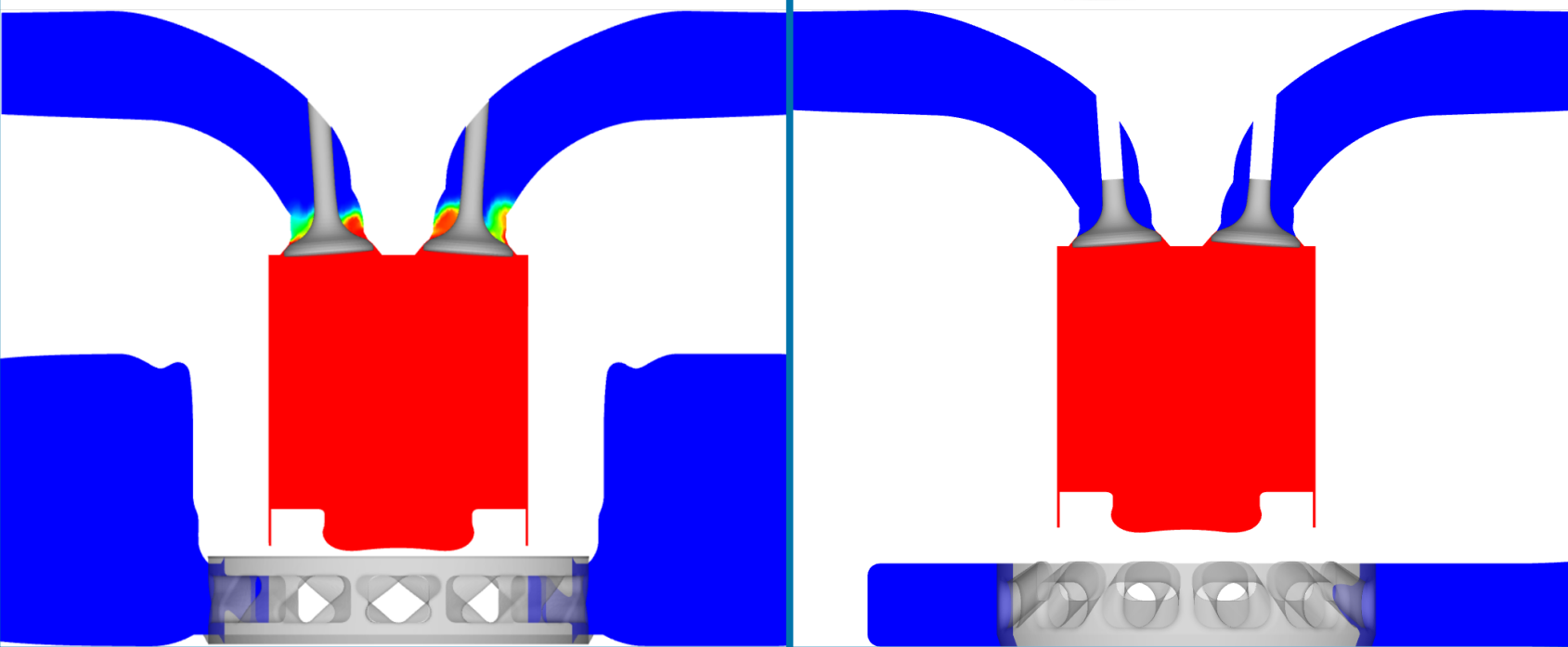
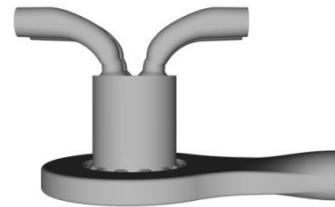
Qualitative results

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- Center slice

Case 1 standard uniflow



Case 2 reverse uniflow



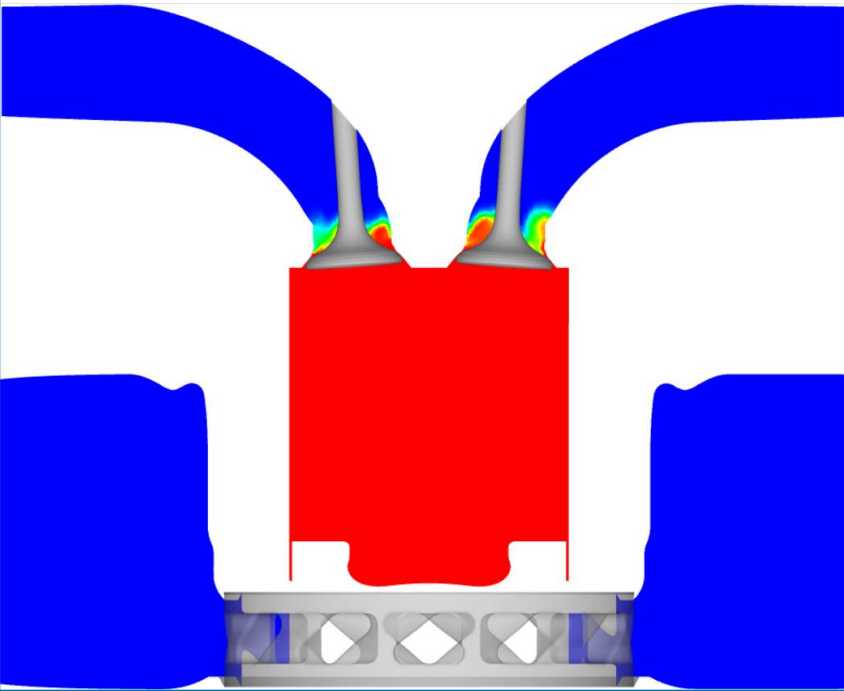
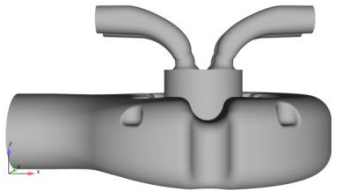
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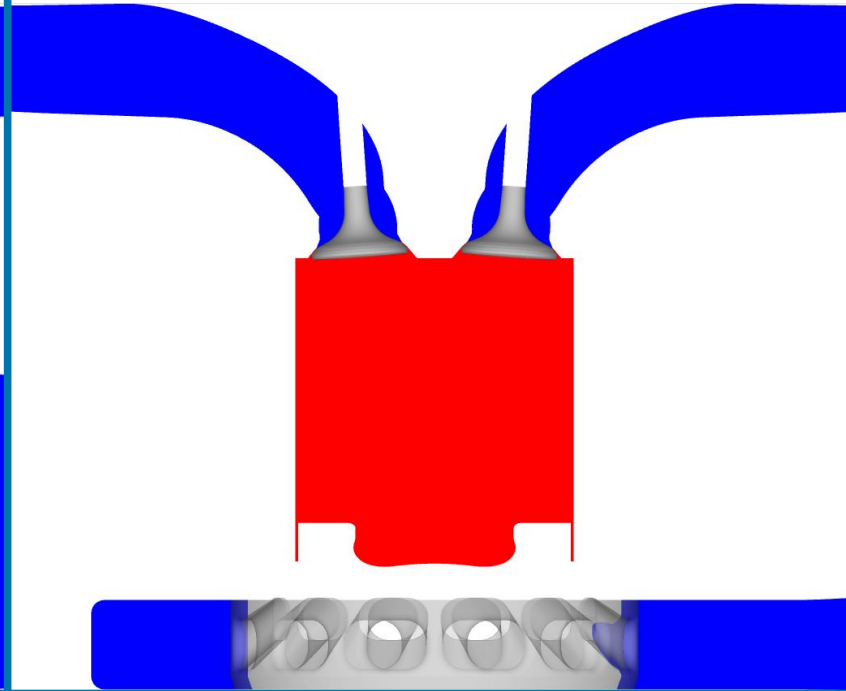
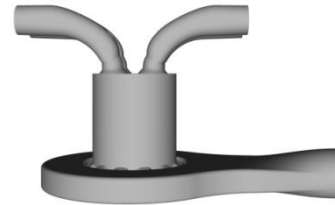
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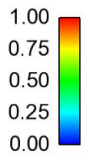
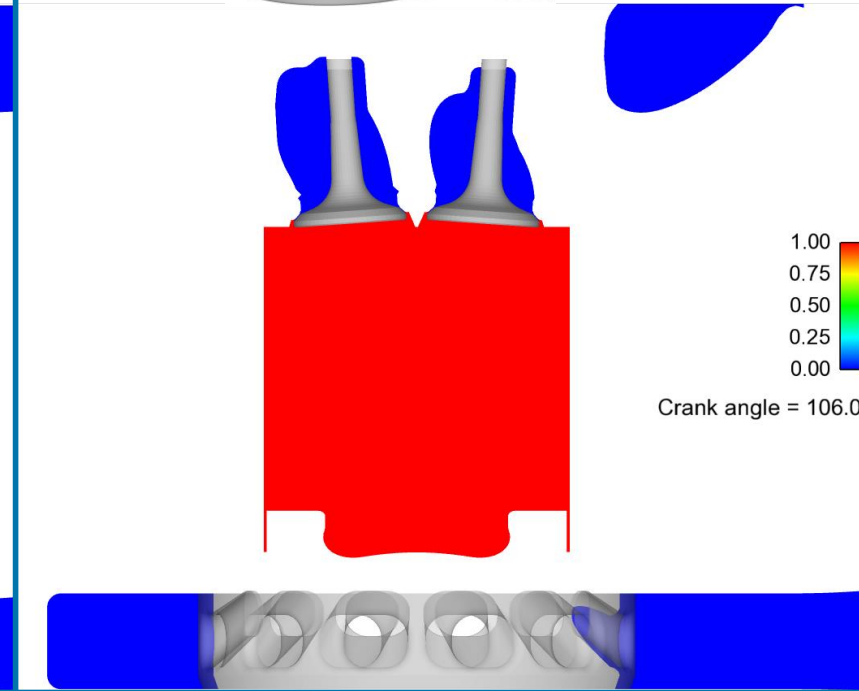
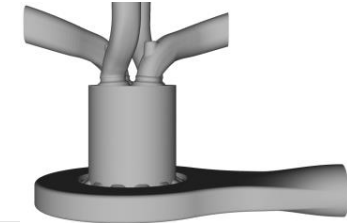
Case 1 standard uniflow



Case 2 reverse uniflow



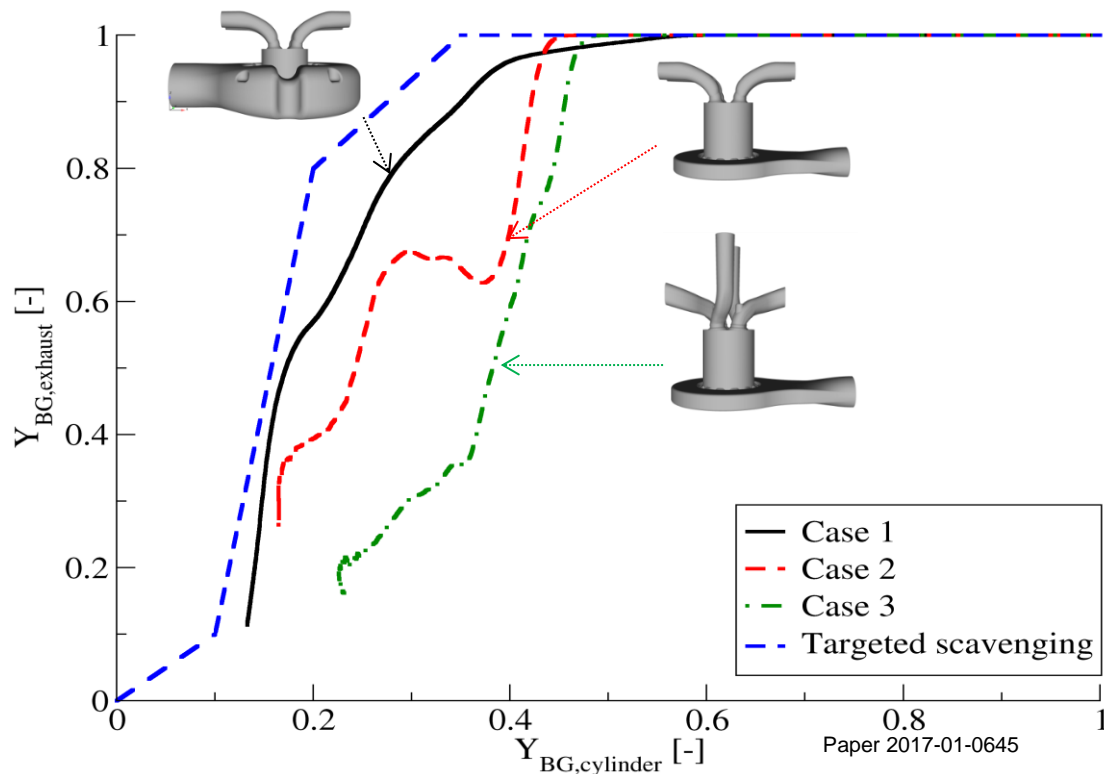
Case 3 reverse uniflow



Crank angle = 106.0

Quantitative results

- Best scavenging for the standard uniflow (case 1)
- For the reverse uniflow, swirl penalizes the efficiency of the scavenging
- Scavenging characteristics
 - $\text{Charging ratio} = \text{mass of trapped fresh gases} / \text{reference mass based on the intake conditions}$
 - $\text{Scavenging ratio} = \text{mass of trapped fresh gases} / \text{total in-cylinder mass of gases}$



	Case 1 Standard	Case 2 Reverse	Case 3 Reverse
Trapping ratio	91%	82%	68%
Scavenging ratio	88%	83%	77%
Swirl number	1.0	0.2	2.4

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Conclusions

- Development of an efficient 2-stroke Diesel engine for medium passenger cars
- First step of the project = choice between standard or reverse uniflow

- Corrected ISFC assessment
 - 10 g/kWh benefit for the reverse conf. for the full load point
 - Benefit vanishes for mid-load points

- Feasibility of the scavenging
 - More efficient scavenging for the standard configuration
 - Previous ISFC benefit potentially lost in the scavenging

⇒ **The standard uniflow is preferred**

Future steps

- Choice of the best suited stroke-to-bore ratio
- Optimization of the transfer ports geometry
- Definition of the combustion system
- Experimental test campaigns on SCE
- Extrapolation of the fuel consumption/emissions in normalized driving cycles

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IGR axial distribution at intake closure

- Case 1 = homogeneous distribution
- Case 2
 - Pockets of IGR in the piston or close to the head
 - Increasing ΔP or delaying slightly exhaust closure \Rightarrow Possibility to pursue the scavenging with a minimal cost on the trapping ratio
- Case 3 = homogeneous distribution

