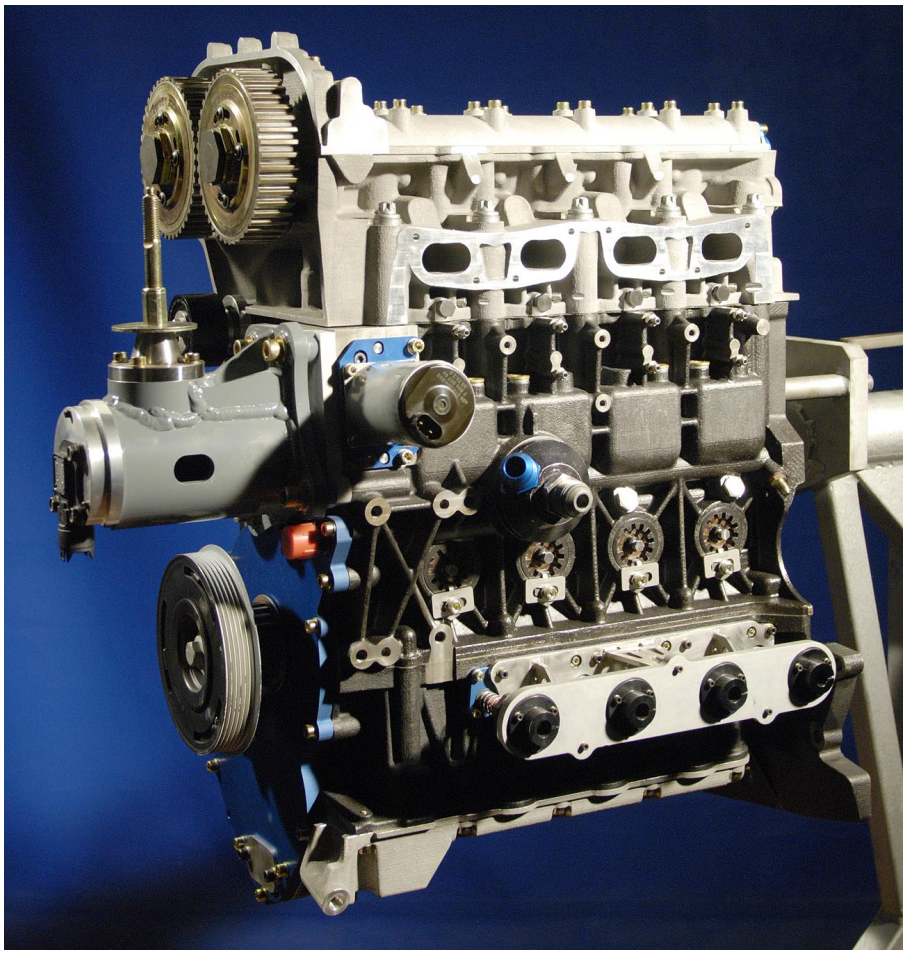
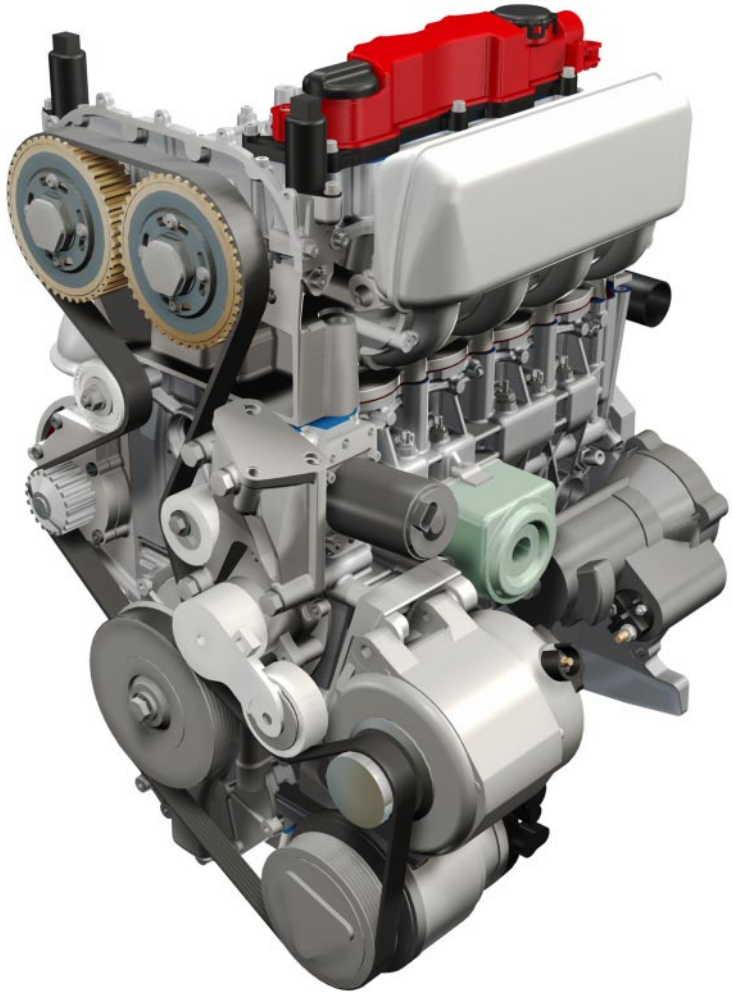
ENGINE EXPO - Stuttgart - 8 May 2007

TURBOCHARGED IN-LINE FOUR-CYLINDER MCE-5 VCR SI ENGINE





Vianney RABHI - Head of Strategy and Development - MCE-5 DEVELOPMENT SA

SUMMARY

A - The objectives of the MCE-5 technology;

B - Brief presentation of the MCE-5 technology;

C - The R&D strategy;

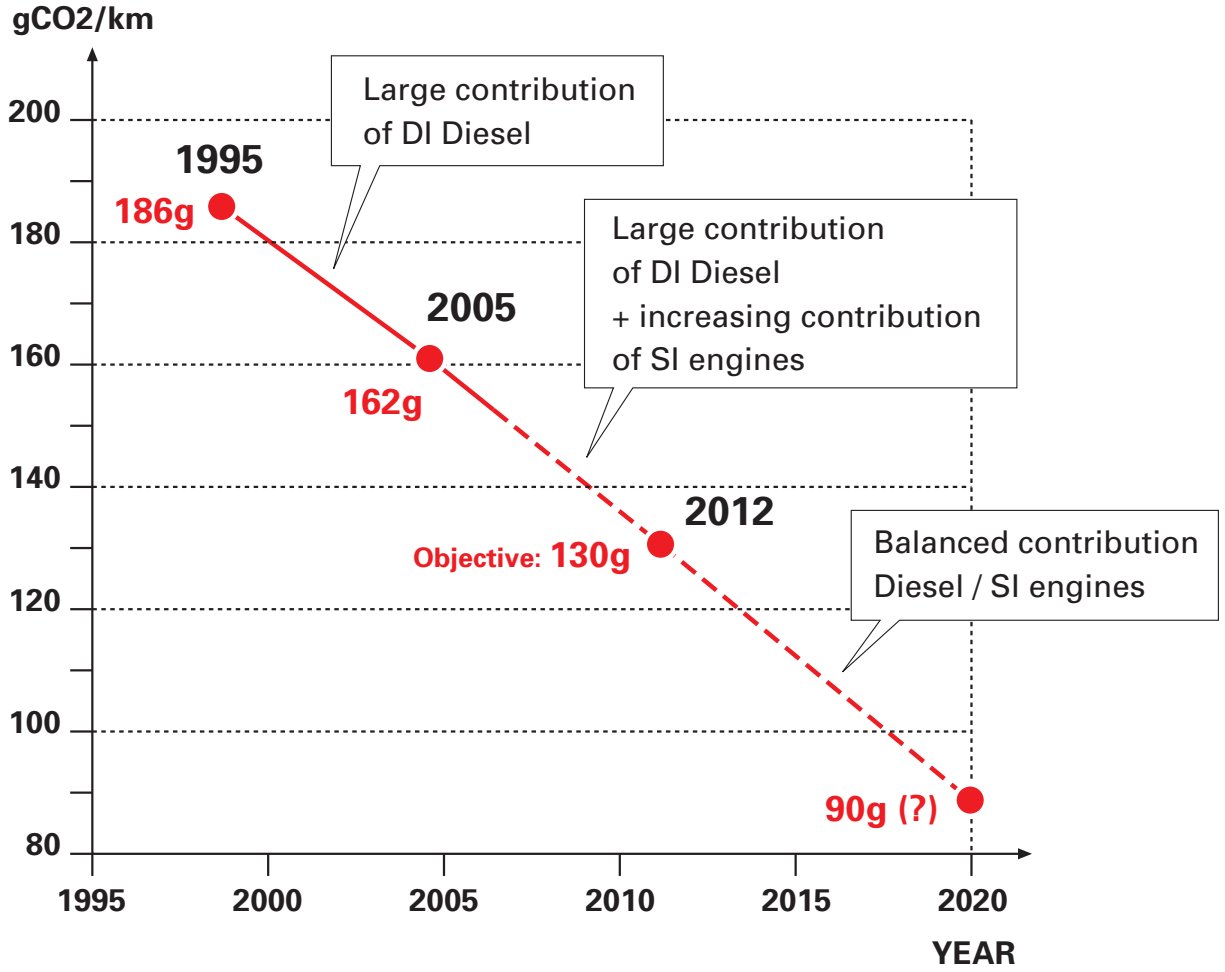
D - Current state of the MCE-5 project and intermediate results;

E - General conclusion.

A - The objectives of the MCE-5 technology

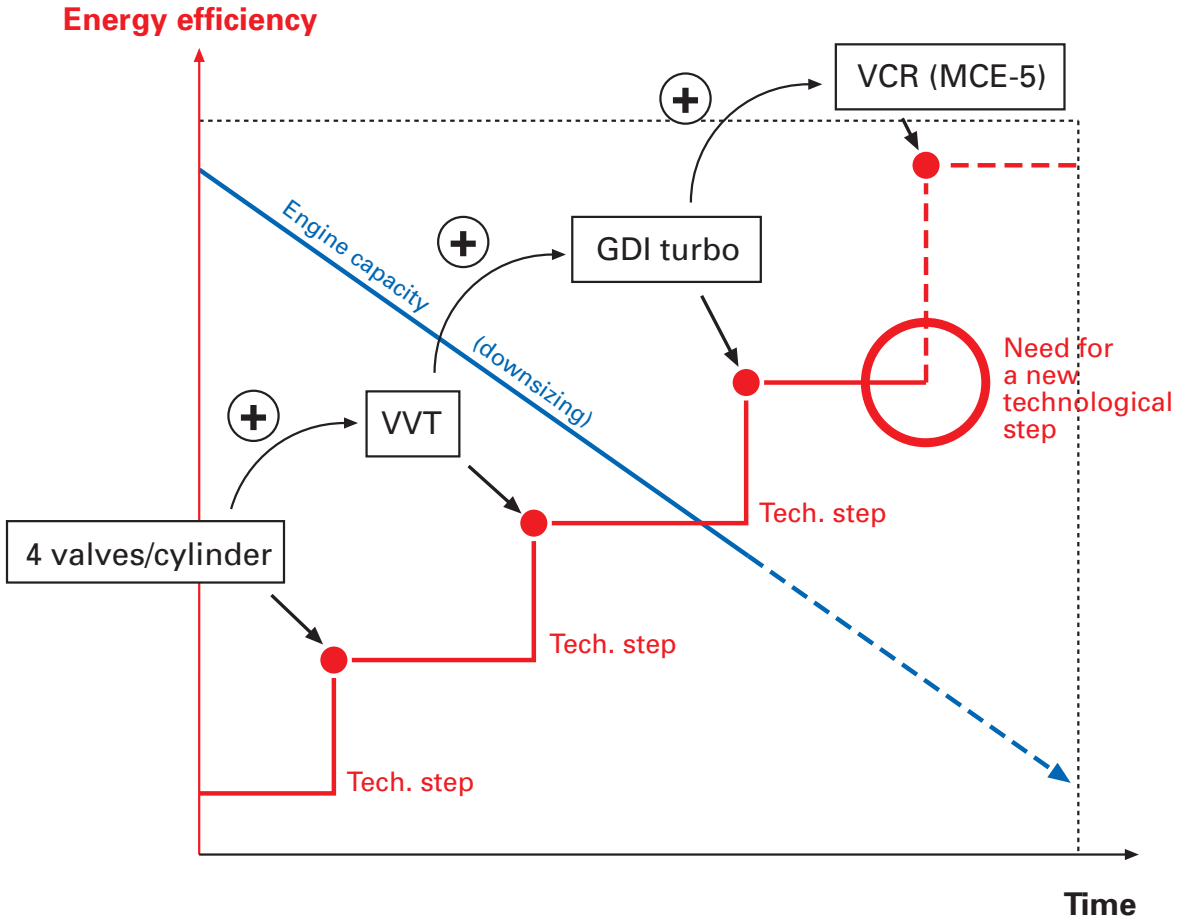
Evolution and objectives for CO2 emissions of passenger cars:

Diesel / SI engines contribution:



The step-by-step evolution of SI engines:

New strategies-technologies are added to previous ones:



The objective of MCE-5 technology is to combine advantages of Diesel and SI GDI turbo:

	SI VVT GDI turbo	Diesel	SI VVT VCR MCE-5 GDI turbo (objectives)
Comparative features			
Low-revs specific torque	++	++	+++
CO2 emissions	+	+++	+++
NVH	+++	-	+++
Additional costs over GDI turbo			
Engine manufacturing	Ref	800 €	≤ 450 €
Additional cost for OxyCat or 3-way catalyst	Ref	0 €	0 €
Additional cost for particulate filter	Ref	500 €	0 €
Additional cost for DeNox (SCR)	Ref	800 €	0 €
Total overcost	**Ref**	**2,100 €**	**≤ 450 €**

General strategy of the MCE-5 technology:

I - Reduction of **friction and pumping losses**:

a) High downsizing;
b) High downspeeding.

II - Improvement of **combustion-expansion effectiveness**:

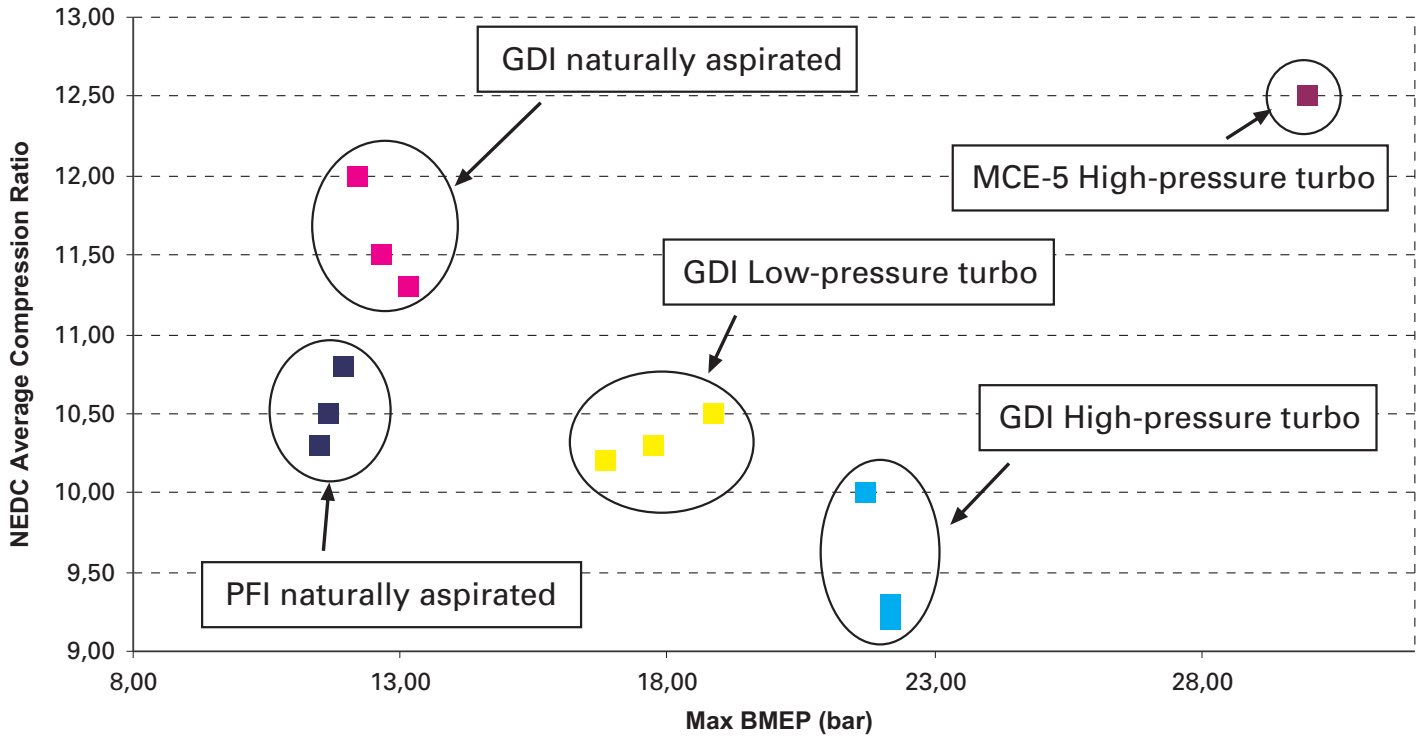
a) All loads optimization of relation between:
- Ignition Advance;
- Compression Ratio;
- EGR.

III - Additional features:

a) Idle speed reduction;
b) Cold starting pollutant emissons reduction;
c) Maximum fuel flexibility (VCR).

General strategy of the MCE-5 technology:

To eliminate the need for compromize between BMEP and Compression Ratio:



Data sources:
selection of mass-produced last generation engines

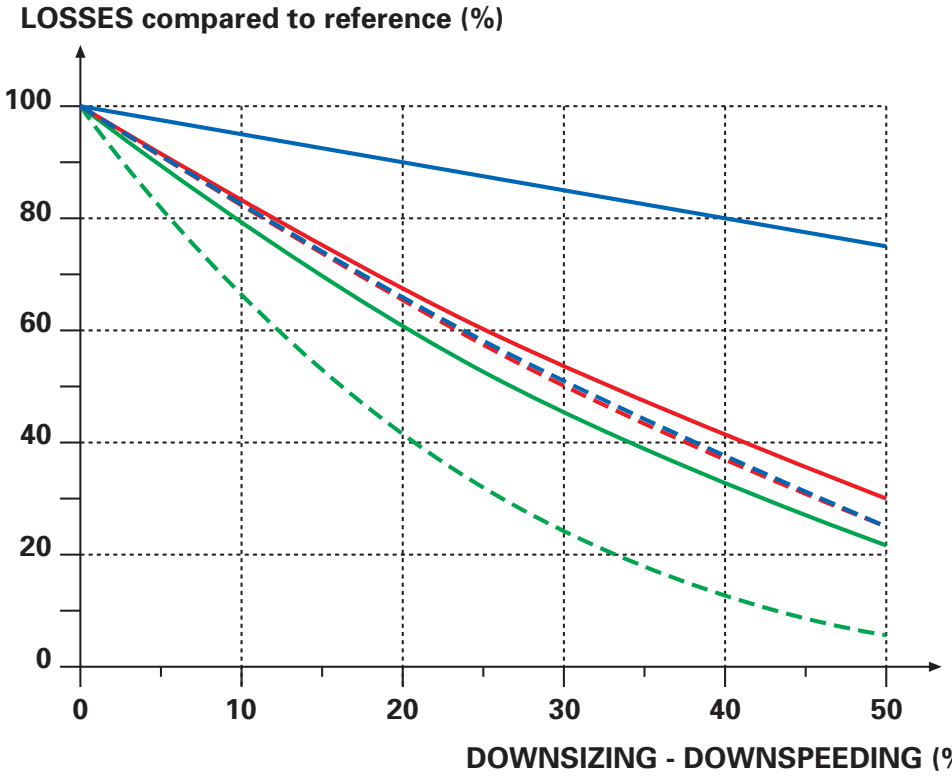
Fixed compression ratio calls for compromize:

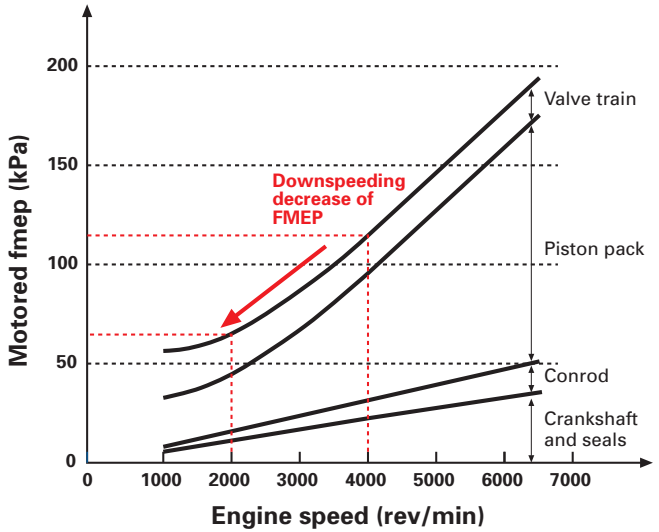
High BMEP (to serve downsizing + downspeeding) penalizes possible max Compression Ratio;
High Compression Ratio (increased expansion efficiency) penalizes possible max BMEP.

The objective of the MCE-5 technology is to combine downsizing AND downspeeding:

As downsizing, downspeeding is a priority objective:

(in broad line)





Sources: Heywood - Stone

Friction - downsizing, same speed
Pumping - downsizing, same speed
Friction - downspeeding, same size
Pumping - downspeeding, same size
Friction - combined downsizing & downspeeding
Pumping - combined downsizing & downspeeding

The objective of the MCE-5 technology is to combine downsizing AND downspeeding:

Downspeeding is more efficient than downsizing for reducing friction losses:

Friction losses reduction: *(in broad line)*

15% Downspeeding is as efficient as **50% Downsizing**

Pumping losses reduction:

50% Downspeeding is as efficient as **50% Downsizing** (same effectiveness)

Notes:

I - If **upspeeding** occurs when downsizing, **FC consumption reduction can be void;**

II - Both downsizing and downspeeding call for **high low-revs torque.**

MCE-5 VCR

The objective of the MCE-5 technology is to combine downsizing AND downspeeding:

The MCE-5 7:1 to 18:1 Compression Ratio control
is set for reaching:

1-stage turbocharging

DOWNSIZING

up to **40%**

x

DOWNSPEEDING

up to **10%**

Together aiming to reduce:

Friction losses by a 1.5 factor (at same FMEP)

Pumping losses by a 3.4 factor

MCE-5 VCR

The objective of the MCE-5 technology is to combine downsizing AND downspeeding:

The MCE-5 7:1 to 18:1 Compression Ratio control
is set for reaching:

2-stage turbocharging

DOWNSIZING		DOWNSPEEDING
up to **50%**	**X**	up to **25%**

Together aiming to reduce:

Friction losses by a 2.2 factor (at same FMEP)

Pumping losses by a 7 factor

The objective of the MCE-5 technology is to combine downsizing AND downspeeding:

MCE-5 downsizing objective: up to **50%**

Low to mid class vehicles: *(in broad line)*

1.5-2.0 L (L4) downsized to --> **1.0 L** (L4; unit capacity = 250 cc)

Power range: ..... from 75 to 110 kW at 5,000 rpm
Max. torque: ..... 230 Nm at 1,800-2,000 rpm

Mid to high-class vehicles:

2.5-3.0 L (V6 or L6) downsized to --> **1.5 L** (L4; unit capacity = 370 cc)

Power range: ..... from 110 to 165 kW at 5,000 rpm
Max. torque: ..... 350 Nm at 1,800-2,000 rpm

High-class vehicles:

4.0-5.0 L (V8) --> **2.25 L** (L6; unit capacity = 370 cc)

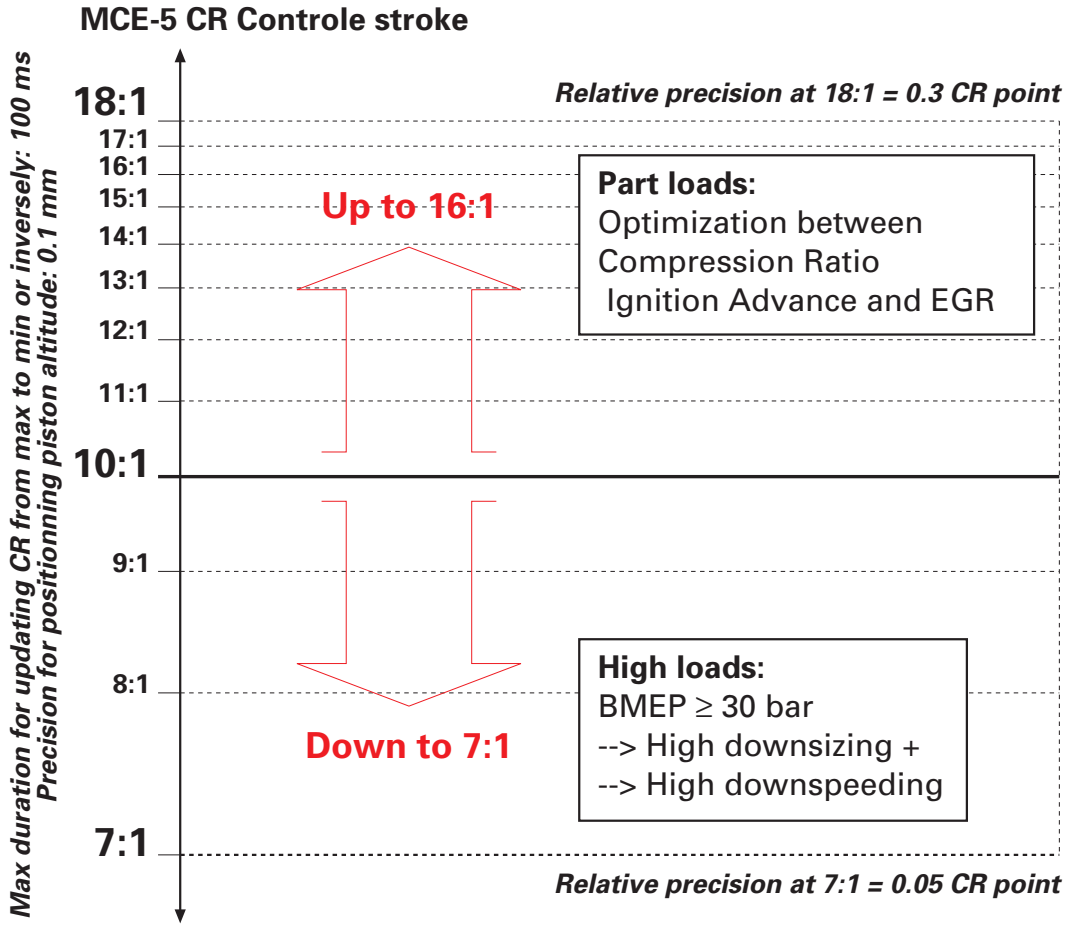
Power range: ..... from 165 to 245 kW at 5,000 rpm
Max. torque: ..... 520 Nm at 1,800-2,000 rpm

MCE-5 downspeeding objective: from **10%** (single stage turbo), up to **25%** (2-stage turbo)

Diesel-like operational speed + extra speed up to 6,000 rpm (max power at 5,000 rpm)

The objective of the MCE-5 technology is to combine downsizing AND downspeeding:

Wide range and high precision CR control is required to meet all objectives:



The objective of the MCE-5 technology is to combine downsizing AND downspeeding:

Extremely low Compression Ratio induces virtuous circles for turbocharging implementation:

I - Ultra-low compression ratio (7:1) permits achieving **extreme low-revs TORQUE;**

II - VCR permits an optimum **engine thermal management.**

LOW CR MANAGES KNOCK SENSITIVITY AT LOW REVS

Knock limit at low revs pushed back by CR reduction
- → High Increase in possible max BMEP at low revs

VARIABLE CR ALLOWS FOR EXHAUST THERMAL OPTIMIZATION

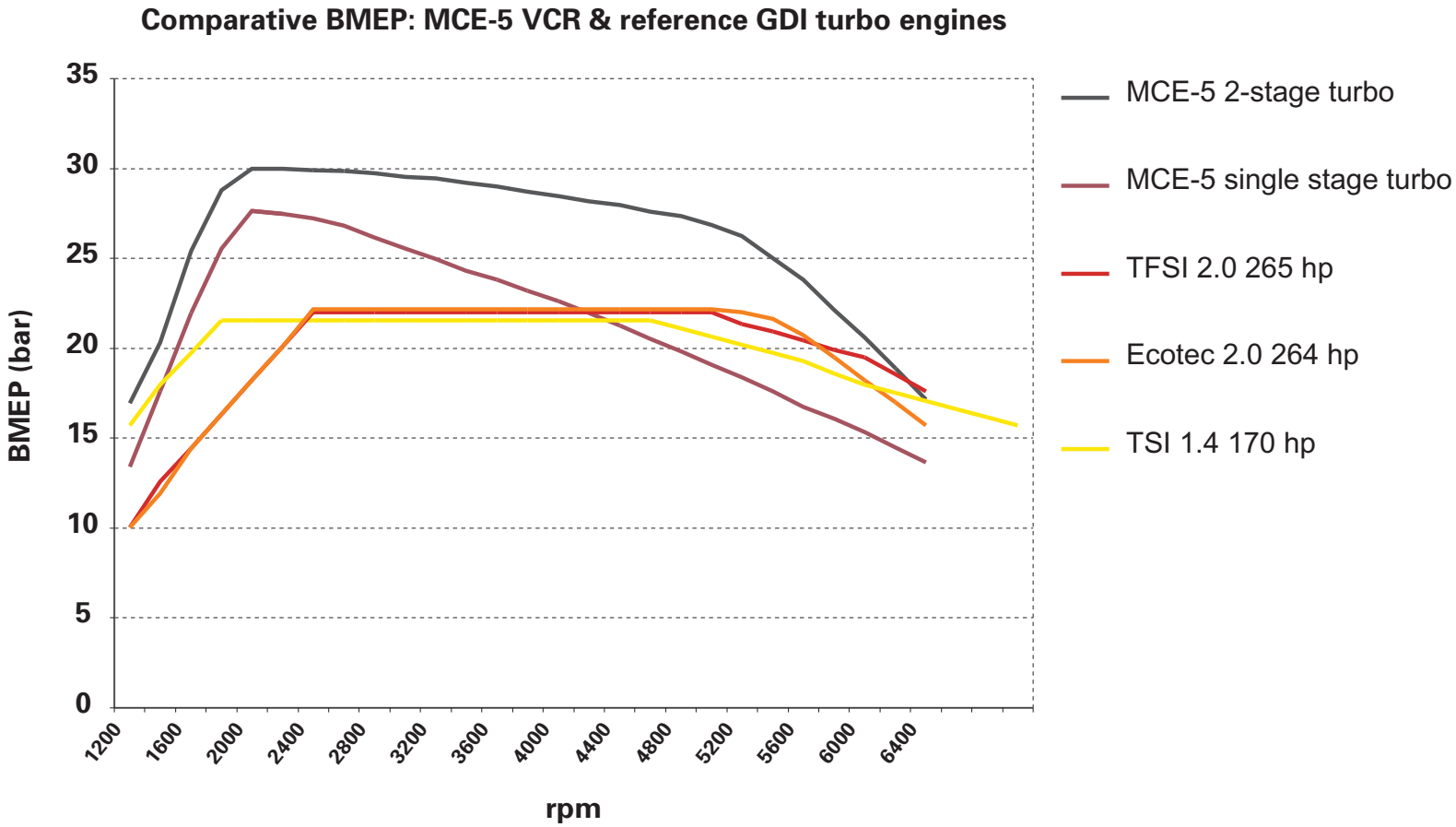
Increase in efficiency by Ignition Advance / CR optimization
(knock threshold increases in parallel to engine speed)
- → Increase in torque
- → Reduction of need for waste gate by-passing
  - → Reduction of exhaust gases temperature
    - → Catalyst overheat prevention
    - → Reduction or elimination of the need for charge enrichment

LOW CR IMPROVES CHARGE SCAVENGING EFFECTIVENESS

Low CR = bigger combustion chamber volume
- → Increased amount of intake gas
  - → Higher torque
  - → Greater energy available for the turbine
  - → Higher engine permeability (cross flow)
    - → Compressor surge limit management
      - → Increase in choice for adaptable compressors

The objective of the MCE-5 technology is to combine downsizing AND downspeeding:

Single or two stage turbocharging permits responding to needs for all passenger cars:



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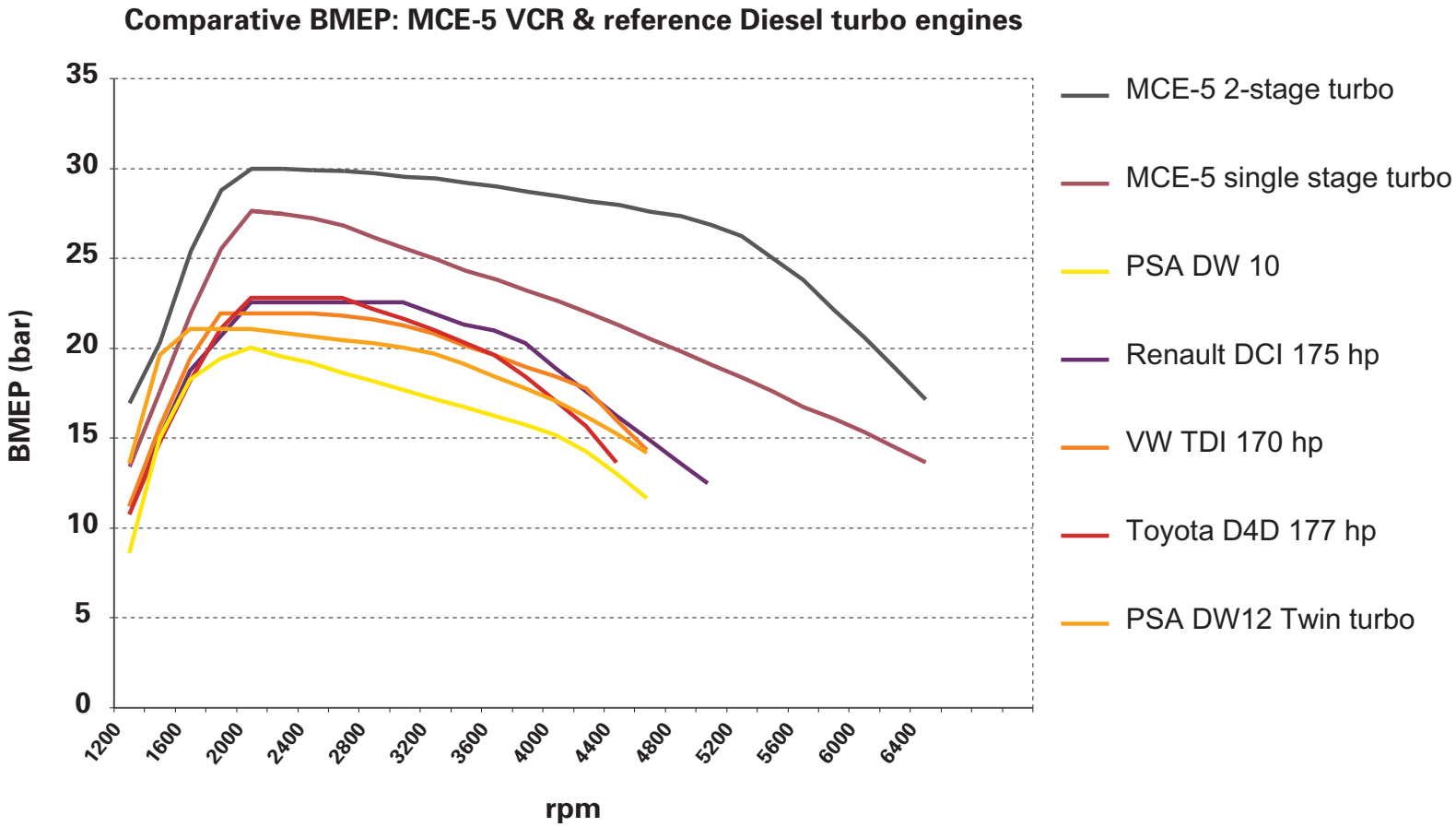
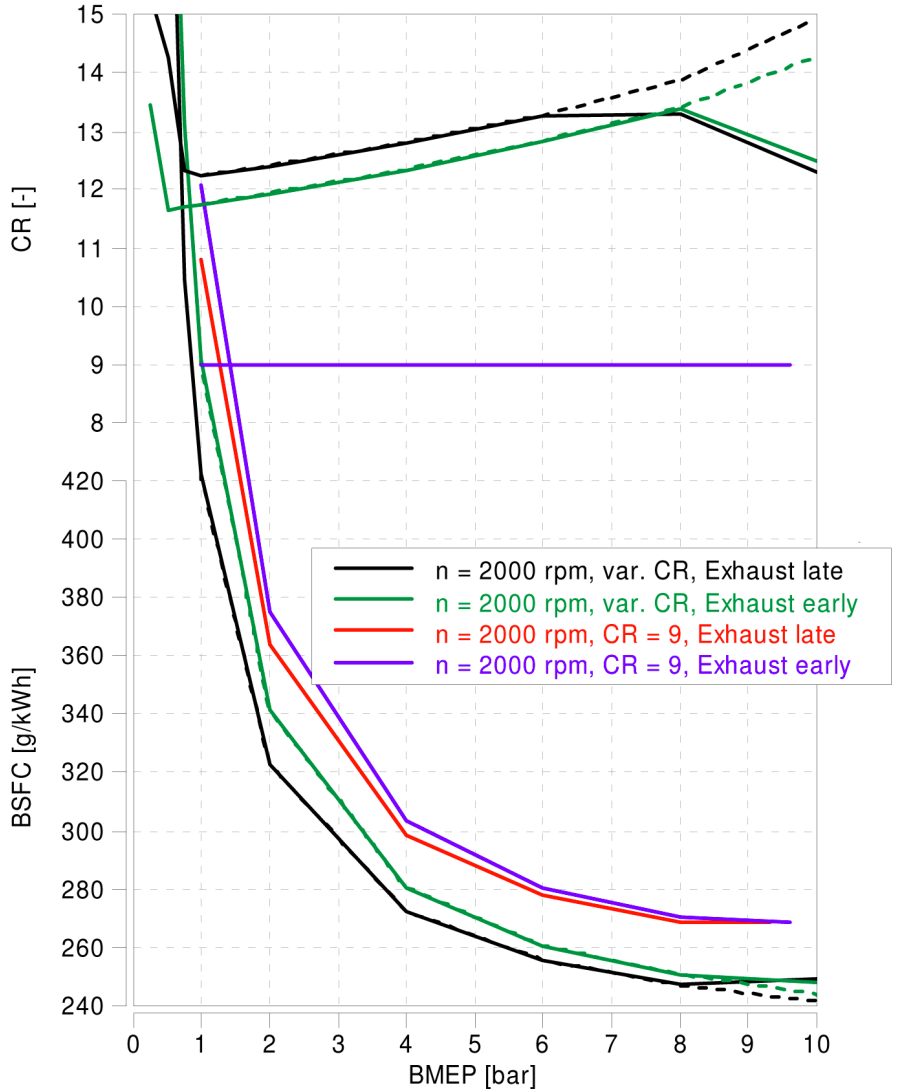


Secondary objective is optimizing combustion-expansion effectiveness at part loads:



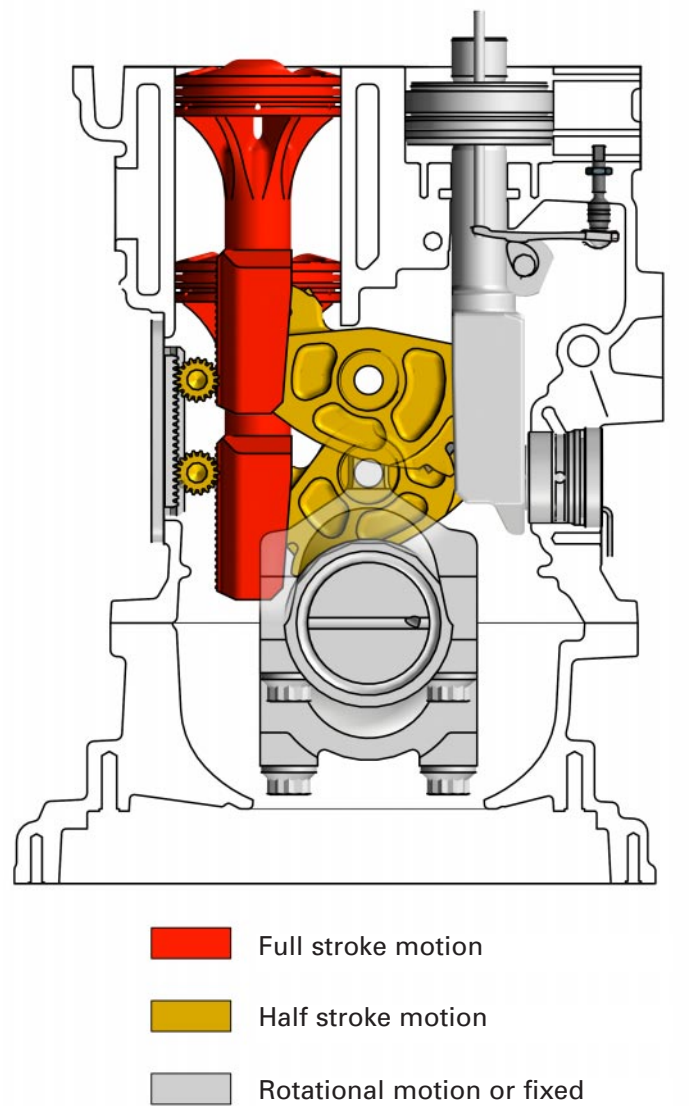
CR / Ignition Advance / EGR optimization:

Between 8 and 12% FC reduction on the entire load range, added to downsizing-downspeeding benefit.

(Boost simulations)

B - Brief presentation of the MCE-5 technology

MCE-5 technology - brief description:



Main features:

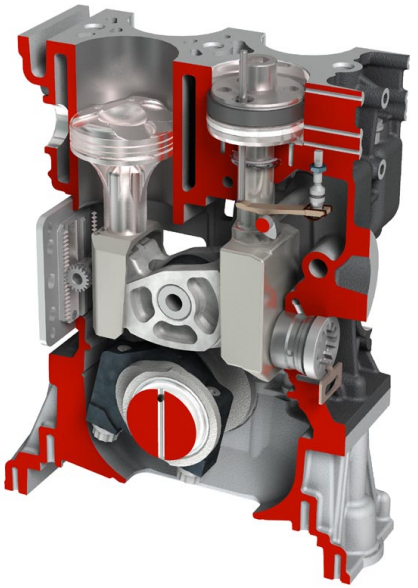
Compression Ratio control:

- Linear CR control from 7:1 to 18:1;
- Reactivity - worst case: 100 ms for min to max;
- Precision: ± 0.05 mm.

Guided piston:

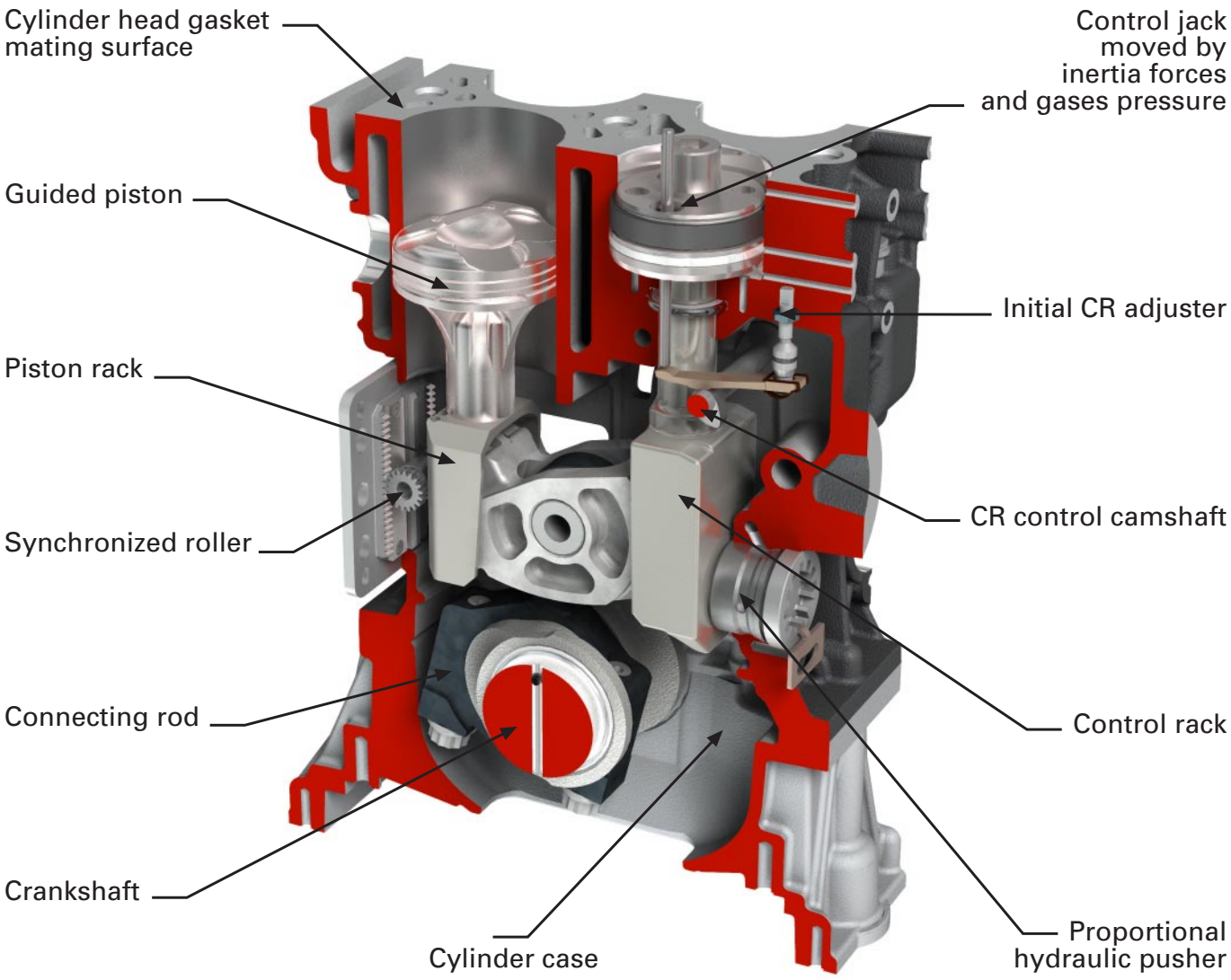
- No slap --> VCR compatible, long cylinder service life;
- Low radial stress (about ten times lower on the average);

Objective: reduction of blow-by, wear, oil consumption and friction.



MCE-5 VCR

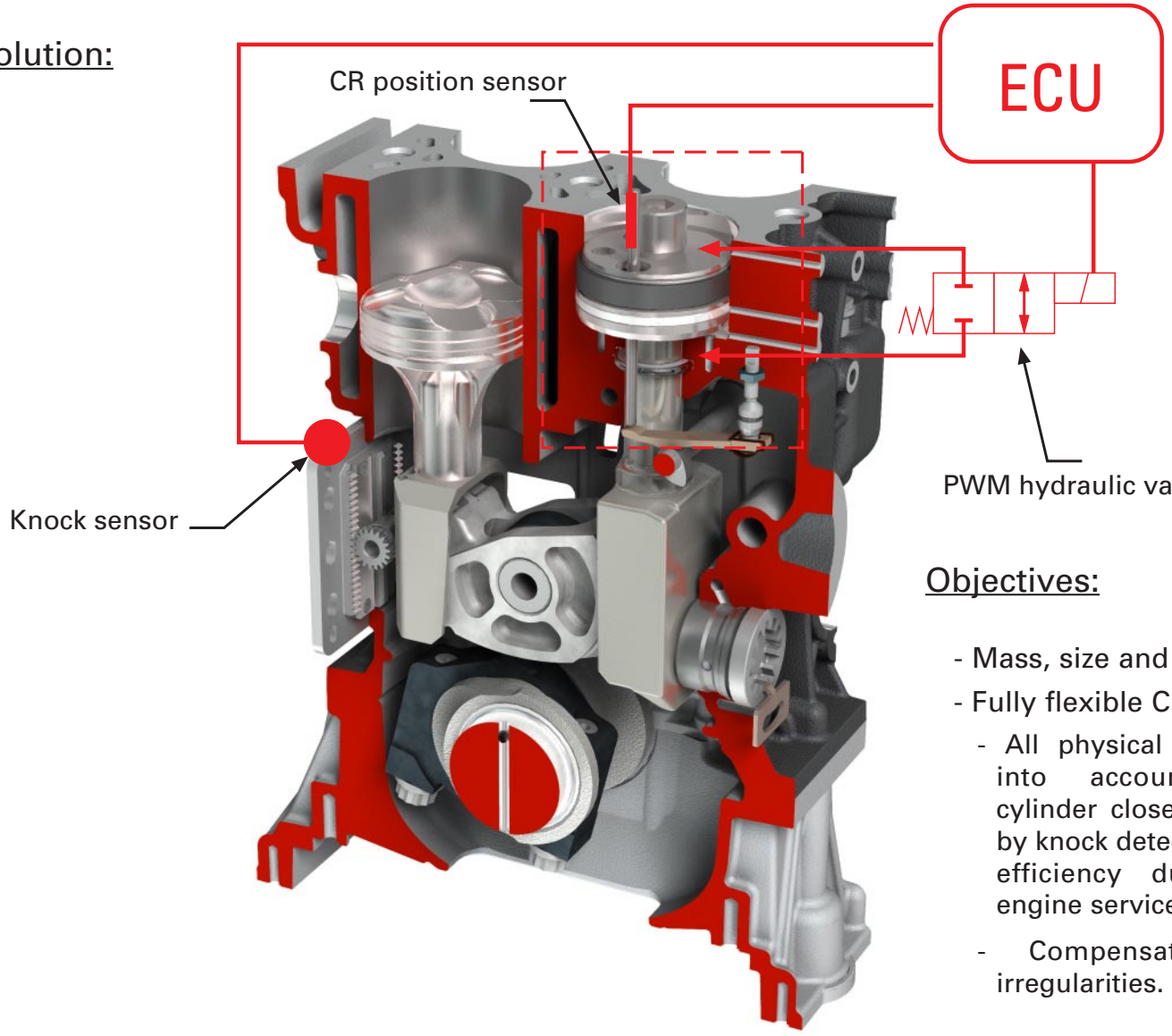
MCE-5 technology - brief description:



MCE-5 VCR

MCE-5 technology - brief description:

Planned evolution:

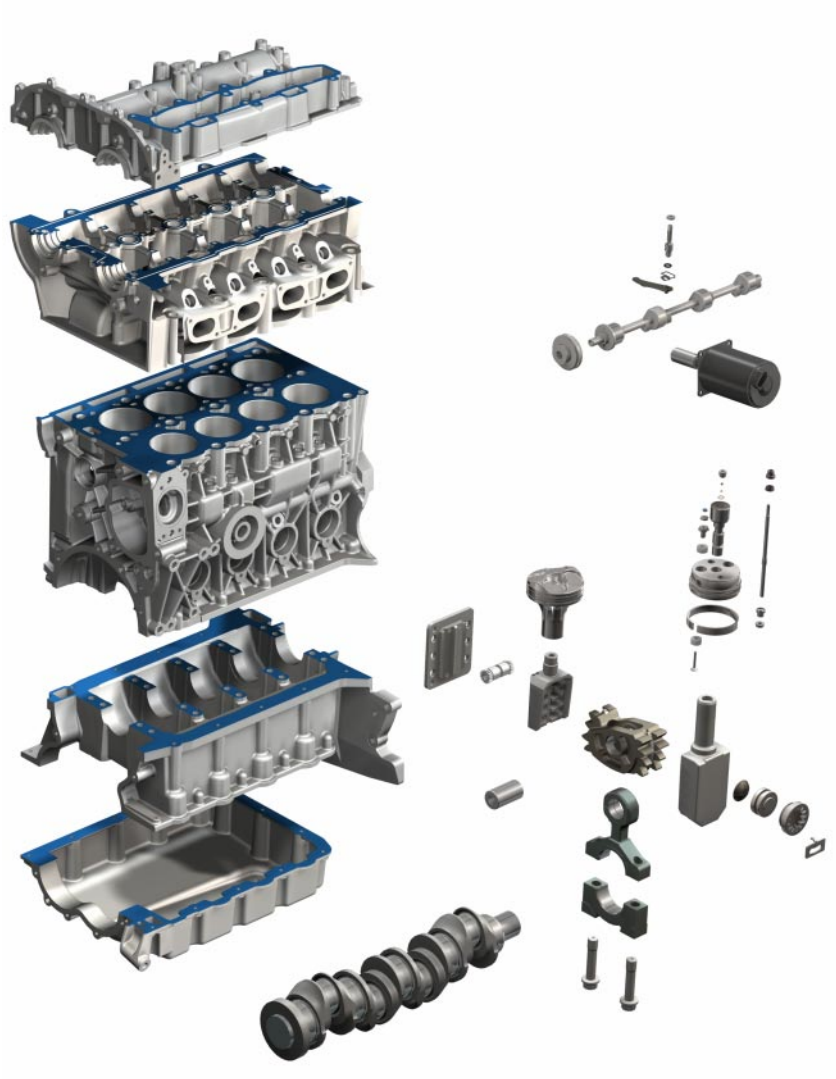


Objectives:

- Mass, size and cost reduction;
- Fully flexible CR control:
  - All physical parameters taken into account. Cylinder-per-cylinder closed loop CR control by knock detection for maximum efficiency during the entire engine service life;
  - Compensation for cyclic irregularities.

MCE-5 technology - brief description:

General arrangement:



C - The R&D strategy

R&D objectives:

Determining factors taken into account:

a) Technical functionalites, flexibility and evolution perspectives;

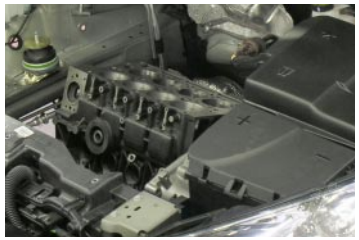
b) Requirements for mass-production;

c) Ability to respond to mass-market demands;

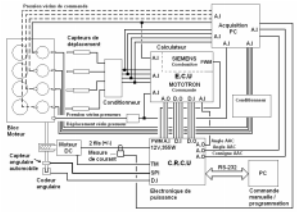
d) Cost/benefit ratio (profitability).

TURBOCHARGED IN-LINE FOUR-CYLINDER MCE-5 VCR SI ENGINE

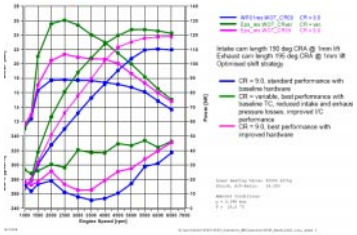
Main R&D tasks:



Vehicle integration



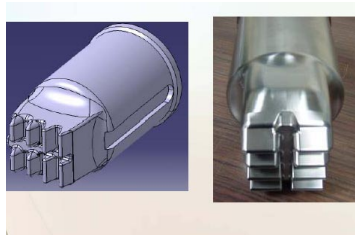
ECUs and engine calibration



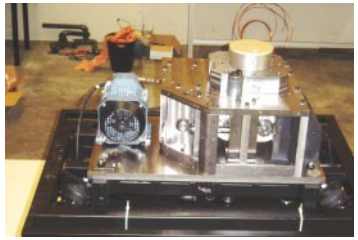
Strategies calculation

Gears

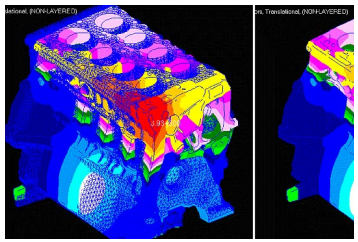
Rod, crankshaft, piston



Mass-production processes

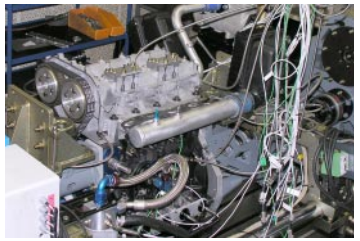


Control jack



Engine structure

Combustion chamber



Performance measurment

Key points being studied:

Conformity to objectives:

Criteria to be considered	**Current situation may 2007**
• Compression Ratio control	○ ○ ○
• NVH	○ ○ ○
• Robustness, durability, reliability	○ ○ ○
• Friction losses	○ ○ ○
• Engine structure, overall size, vehicle integration	○ ○ ○
• Mass production processes	○ ○ ○
• Production cost	○ ○ ○

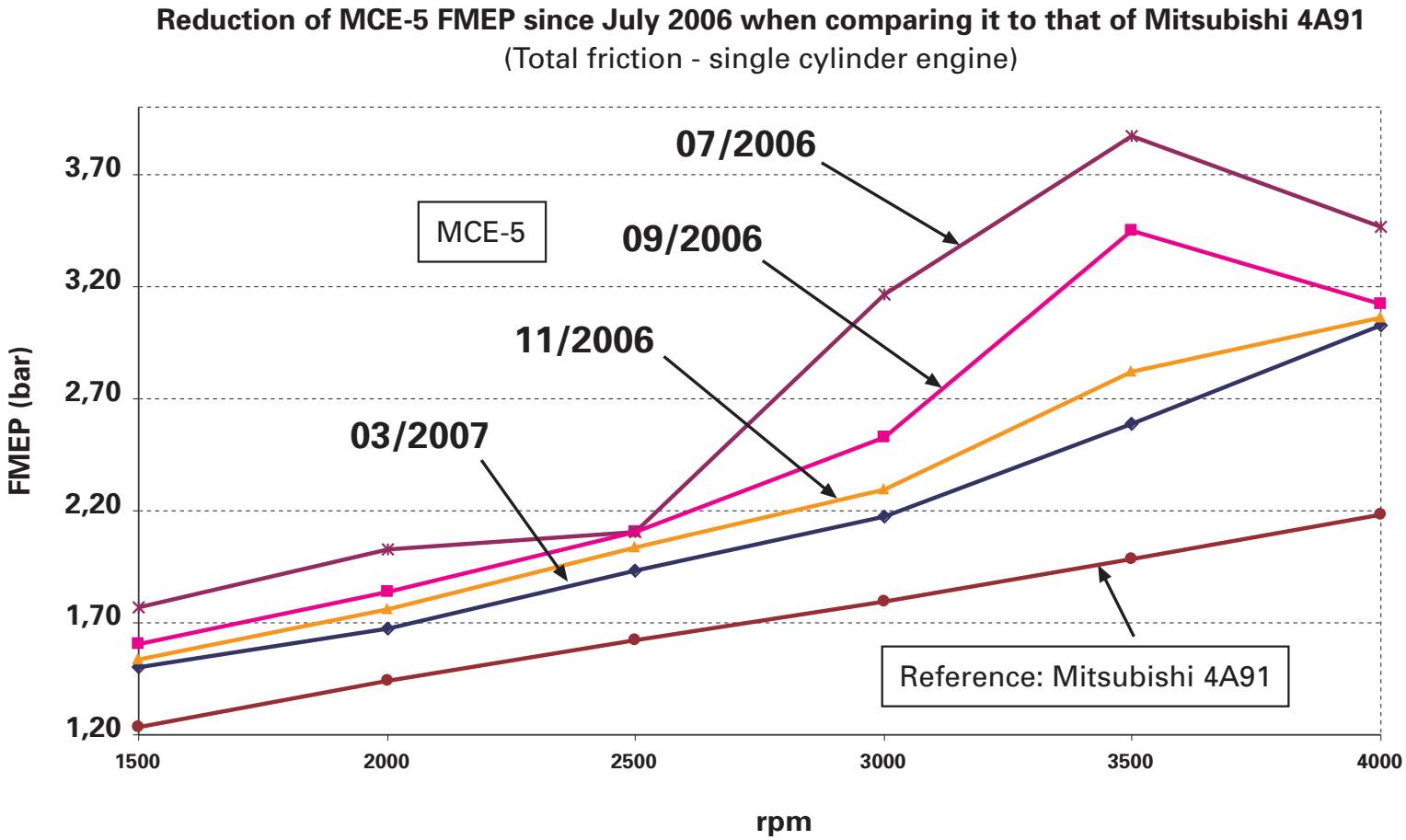
D - Current state of the MCE-5 project and intermediate results

Intermediate results - current situation (in broad line):

Conformity to objectives:

Criteria to be considered	**Current situation may 2007**
• Compression Ratio control	○ ○ ●
• NVH	○ ○ ●
• Robustness, durability, reliability	○ ○ ●
• Friction losses	● ○ ○
• Engine structure, overall size, vehicle integration	○ ○ ●
• Mass production processes	○ ○ ●
• Production cost	○ ○ ●

Friction losses must be further reduced:



Friction losses must be further reduced:

FMEP reduction sources:

a) Piston (FMEP reduction potential: moderate);

b) Gears (FMEP reduction potential: high);

c) Gear wheel pin (FMEP reduction potential: moderate).

MCE-5 gears efficiency has to be improved:

Current calculated-estimated gear efficiency:

About 0.97

Target efficiency for MCE-5 gears:

Between 0.995 and 0.997

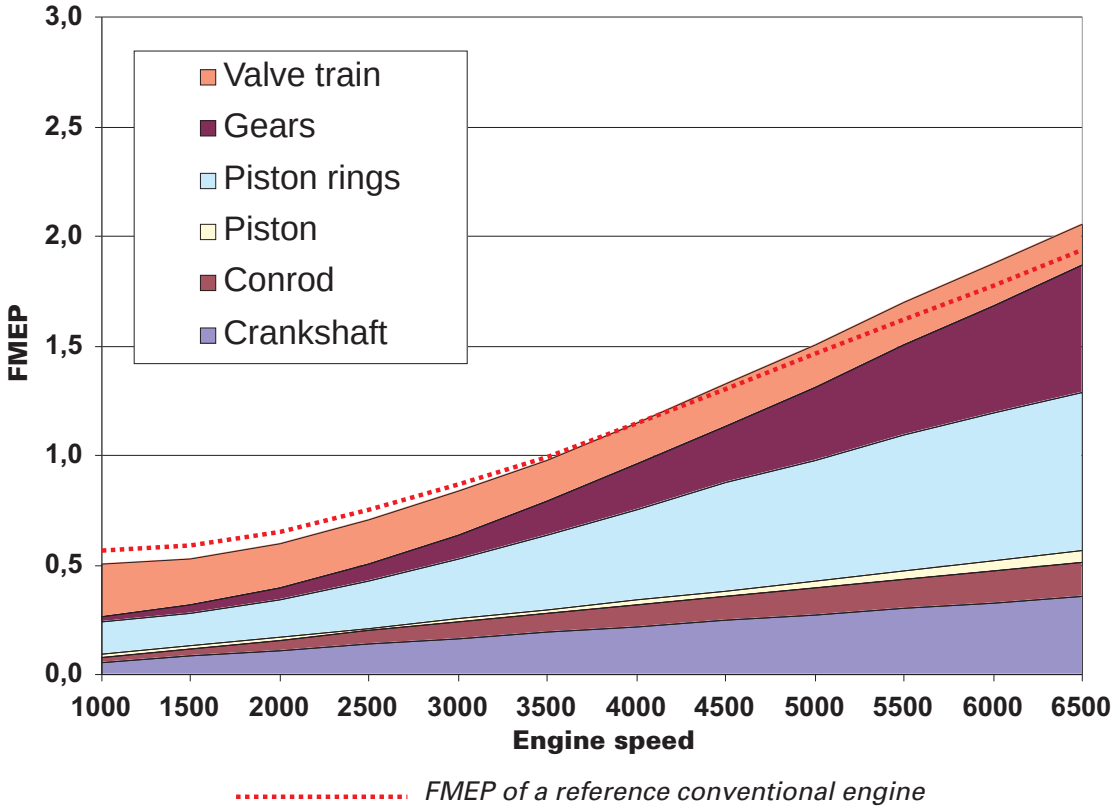
Under study improvement methods:

Method	Effectiveness
Gear module reduction	++++
Gear contact ratio reduction	++++
Gear geometry optimization	+++
Surface roughness optimization	+
Surface treatment (DLC or equivalent)	+

Possible gear friction losses reduction ..... **Between 70 and 90%**

MCE-5 FMEP target:

Objective: a lower FMEP at low speeds:



E - GENERAL CONCLUSION:

1) VCR is a **key technological step** for reaching **high CO2 emission reduction** and energy sources diversification;

2) MCE-5 technology can respond to **all VCR engine requirements**;

3) MCE-5 FMEP remains the last point to be improved to complete the engine conformity to all specifications.

Thank you for your attention