Optimizing Brake Performance of a Heavy-Duty, Compression Ignition Engine using Methanol

Erik Svensson, Lund University

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Agenda

- Motivation and Introduction of the work
- Methodology
- Results
- Discussion and Conclusions

Motivation

Motivation
Optimizing the ICE!

Optimize What?

<u>Objectives</u>

Efficiency
- Gross
- Brake

Emissions
- Local
- Global

Noise

Control

<u>Means</u>

Metal Experiments

Optical Experiments

3D CFD Simulations

System Simulations

Motivation
Optimizing the ICE!

Optimize What?

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Efficiency
- Gross
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Noise

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This Work

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3D CFD Simulations

System Simulations

In This Work

Optimize What?

Objectives

Efficiency

- **Gross**
- **Brake**

Emissions

- Local
- Global

Noise

Control

This Work

Means

(Metal Experiments)

Optical Experiments

3D CFD Simulations

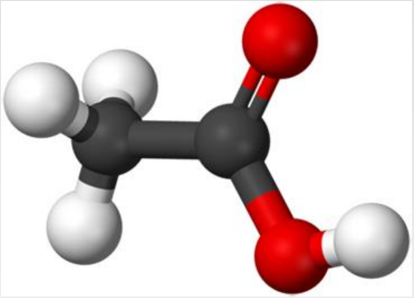
System Simulations

Motivation

Fuel

- Gasoline or Diesel
- Alternative fuels (Alcohols, Low RON Gasoline, H2? etc.)

Methanol



Design of Experiments

What should we look at?

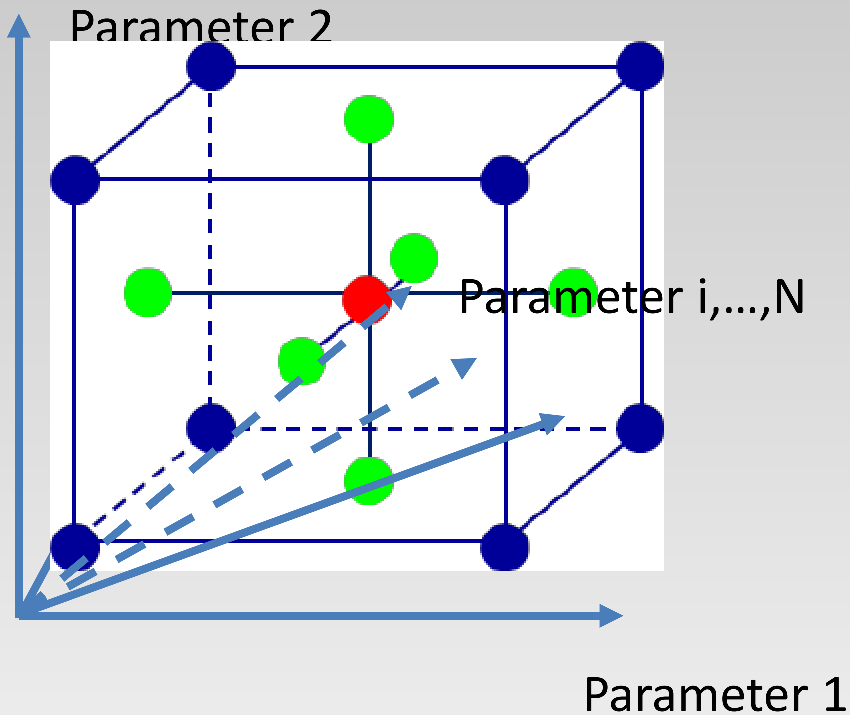
Impossible to sweep every condition

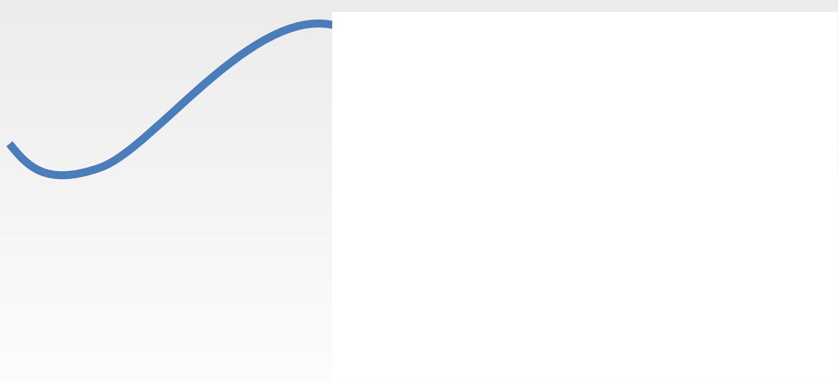
Time consuming

What about Post Processing?

Optimization

- Parameters
    - One Parameter?
    - Two?
    - All?
- Approach
    - DoE
    - Local Optimization
    - Global Optimization
- Objectives
    - Maximize Efficiency
        - Gross
        - **Brake**
- Constraints
    - Peak Cylinder Pressure (PCP)
    - Peak Pressure Rise Rate (PPRR)





Methodology

Modelling Approach
An Overview

Experiments

- Collect and post process experimental data from SCE for model calibration + validation

GTise TPA

- Extract burn rate from GT TPA
  - RoHR != Burn Rate

GTise SCE

- Use existing GT model for B.C. to DI-SRM
  - T_{ivc}, P_{ivc}, IGR, Wall Temps

Loge DI-SRM Validation

- Calibrate and validate turbulence model
  - Six constants

GTise + SRM

- Couple SRM with MCE model and optimize η_{brake}

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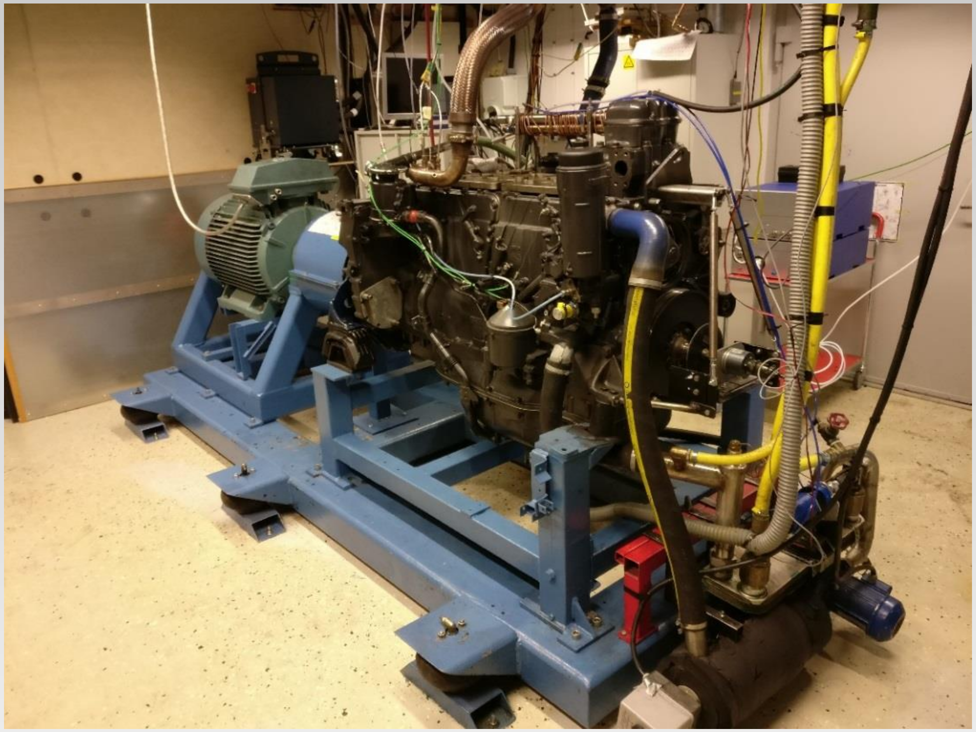
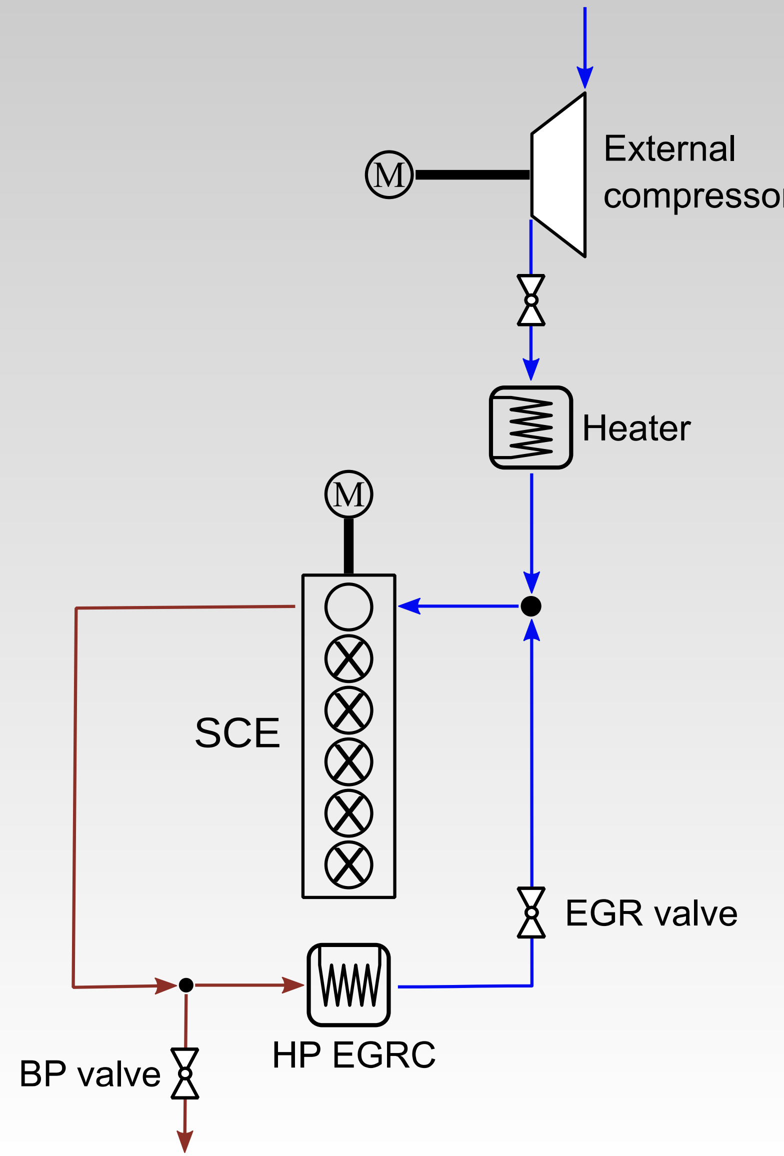
Single Cylinder Engine Experiments



Engine	Scania Single Cylinder
Displacement	2.12 l
Bore × Stroke	130 mm × 160 mm
Connecting rod length	255 mm
Number of valves	4 per cylinder
Fuel	Methanol (100 %Vol)



Experimental Data

- 72 experiments were chosen
- 3 different piston geometries
- 3 different injectors
- Large variety in operating conditions

Geometry

CR (-)	Noz_d (μm)	Noz_h (#)
15, 17, 27	175, 195, 230	8, 10, 12

Operating Conditions

N (rpm)	imepG (bar)	λ (-)	EGR (%)	Tin (K)	#Inj
800 - 1600	5.1 – 15.5	0.9 – 4.1	0 – 55	322 - 455	1-2

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Transfer experimental data to DI-SRM input

- P_{in}
- T_{in}
- $\dot{m}_{\mathrm{fuel}}$
- P_{ex}
- EGR

- P_{ivc}
- T_{ivc}
- $3 \times T_{\mathrm{wall}}$
- IGR
- λ
- $\mathrm{imep}_{\mathrm{G}}$
- T_{exh}
- $\eta_{\mathrm{volumetric}}$
- $x_i \in X_{\mathrm{mole}}$

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LOGE DI-SRM Setup

- PDF Data
  - Mixing model – EMST[1]
  - Mixing time – $k - \epsilon$[1]
- Chemistry
  - Saudi Aramco mechanism 2.0[2]
    - 493 Species and >2700 reactions
  - Tabulated[3]
- Heat transfer
  - Classic Woschni formula with C_1, C_2 based on PPC experiments[4]

[1]Franken, T., Sommerhoff, A., Willems, W., Matrisciano, A. et al., "Advanced Predictive Diesel Combustion Simulation Using Turbulence Model and Stochastic Reactor Model," SAE Technical Paper 2017-01-0516, 2017, https://doi.org/10.4271/2017-01-0516.

[2]http://www.nuigalway.ie/c3/aramco2/frontmatter.html

[3]Matrisciano, A., Franken, T., Perlman, C., Borg, A. et al., "Development of a Computationally Efficient Progress Variable Approach for a Direct Injection Stochastic Reactor Model," SAE Technical Paper 2017-01-0512, 2017, https://doi.org/10.4271/2017-01-0512.

[4]Broekaert, S. "A Study of the Heat Transfer in Low Temperature Combustion Engines." Doctoral Thesis, 2018, https://biblio.ugent.be/publication/8547486

Calibration of DI-SRM

- 8 of 72 cases were chosen for calibration
- Only the mixing time parameters were tuned

$$\frac{\partial k}{\partial \theta} = \left(-C_{den} \cdot \frac{2}{3} \cdot \frac{k}{V_{cyl}} \cdot \frac{dV_{cyl}}{d\theta} - C_{dis} \cdot \frac{k^{\frac{3}{2}}}{l} + \left[C_{sq} \cdot \frac{k_{sq}^{\frac{3}{2}}}{l} \right]_{\theta > TDC} + C_{inj} \cdot \frac{dk_{inj}}{d\theta} + C_{swirl} \cdot \frac{c_m^3}{l} \right)$$

$$\tau = C_\tau \cdot \frac{k}{\epsilon}$$

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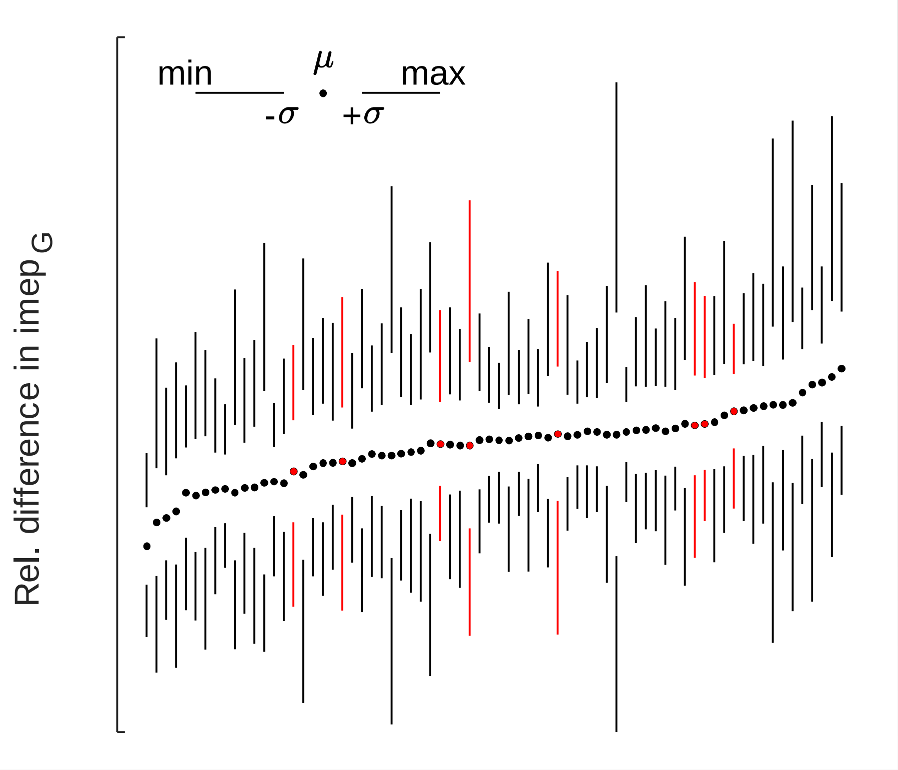
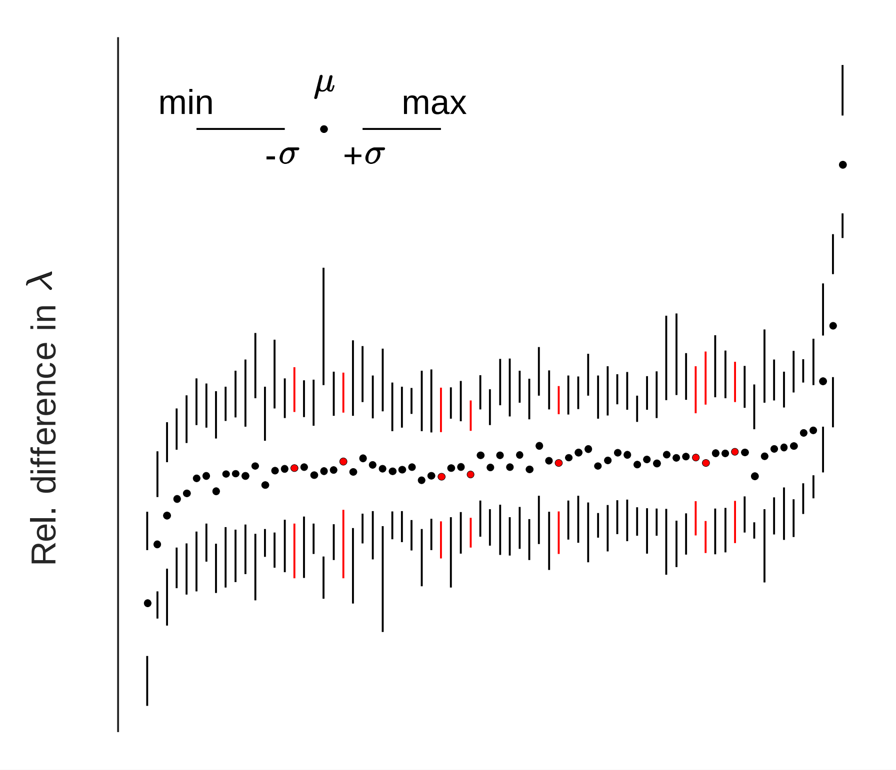
Results

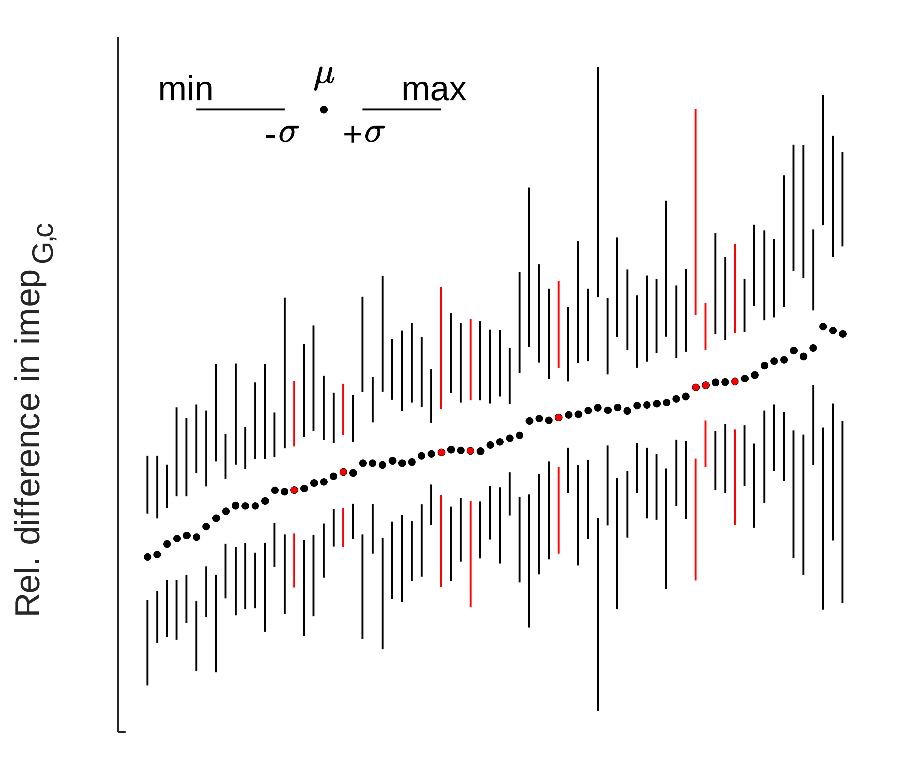
Model Validation

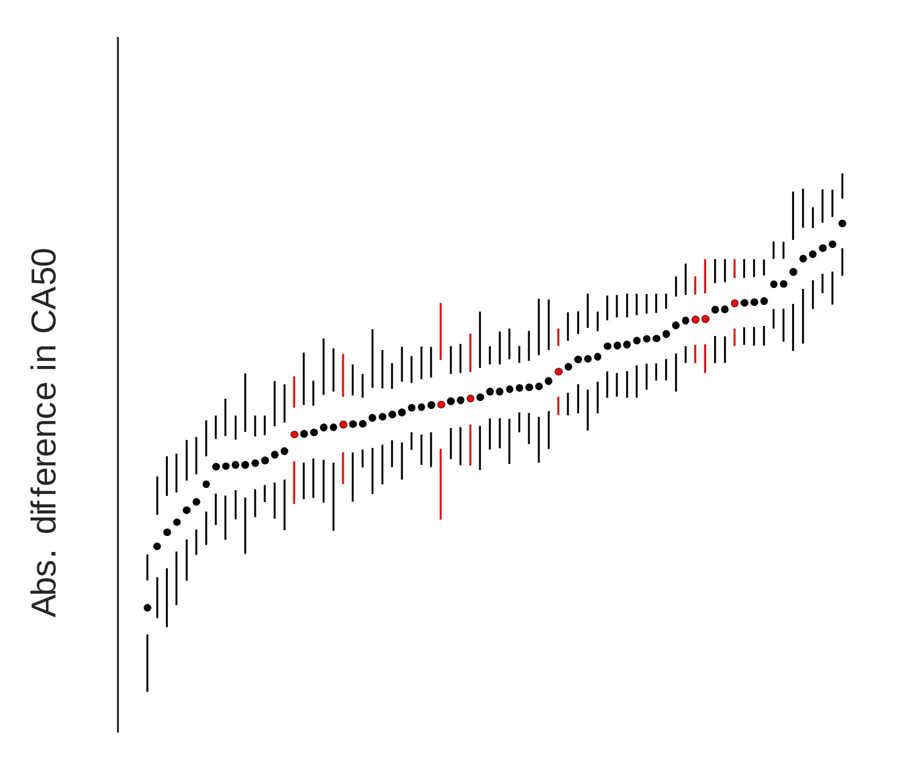
GTP model validation





SRM model validation





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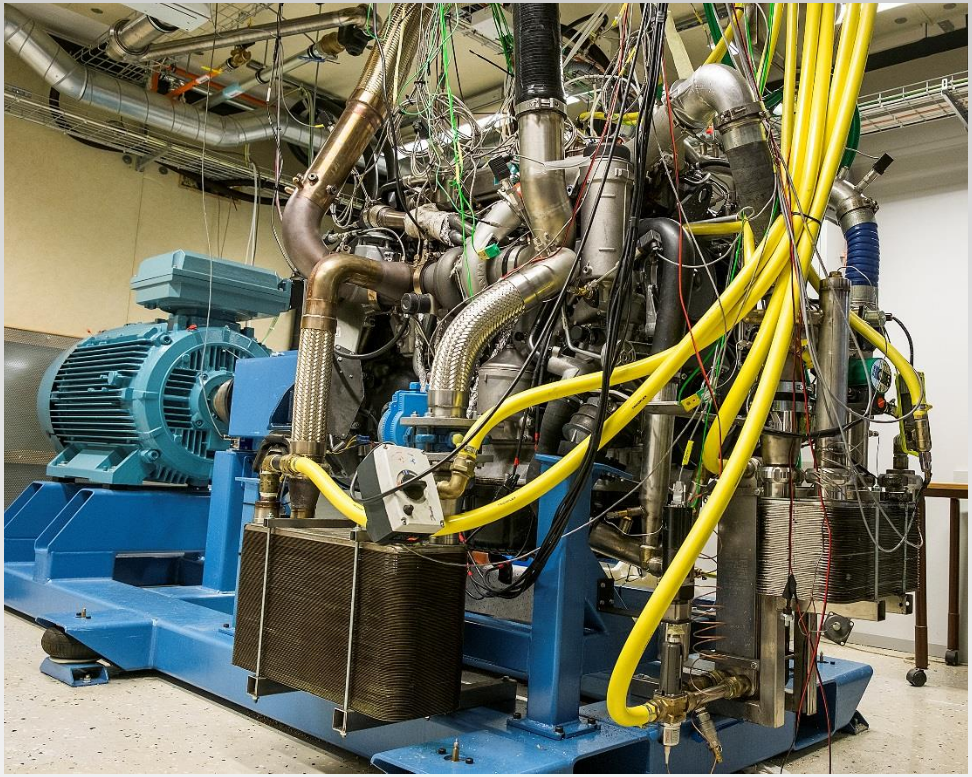
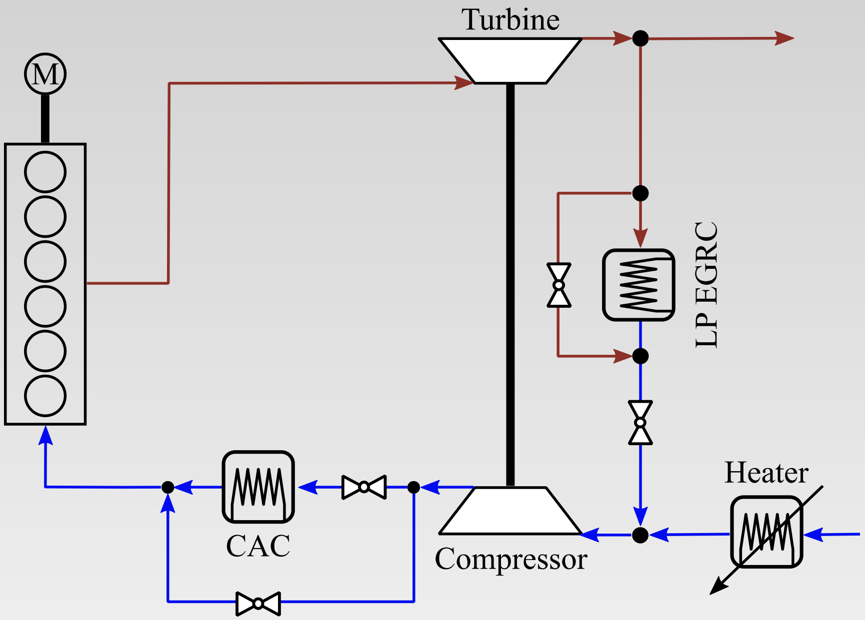
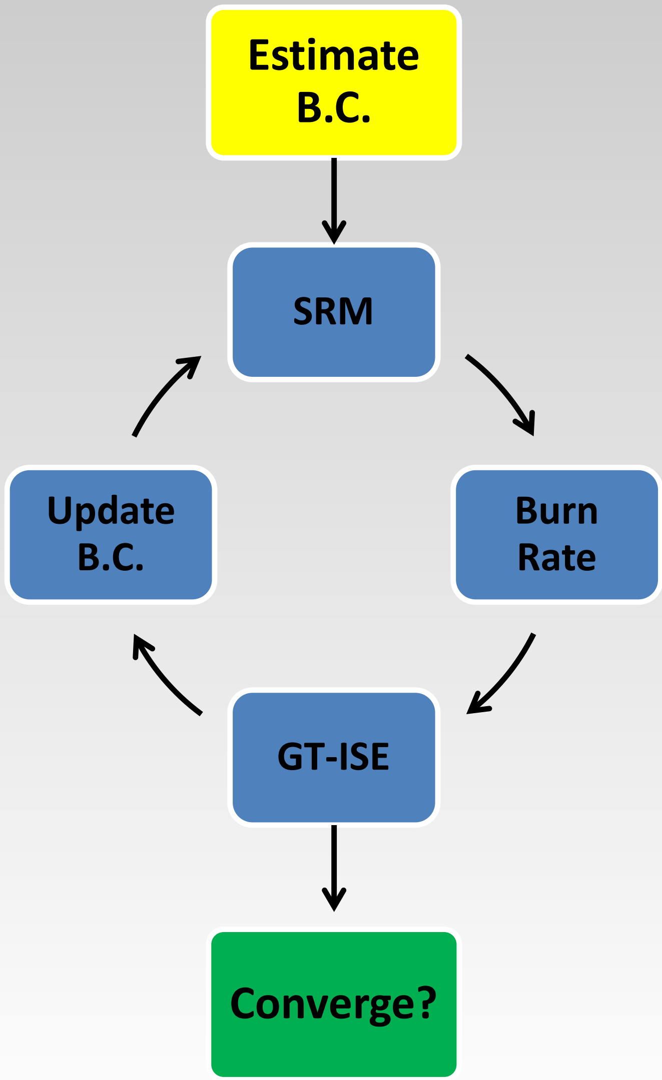
Multi Cylinder Engine – Scania D13, inline 6

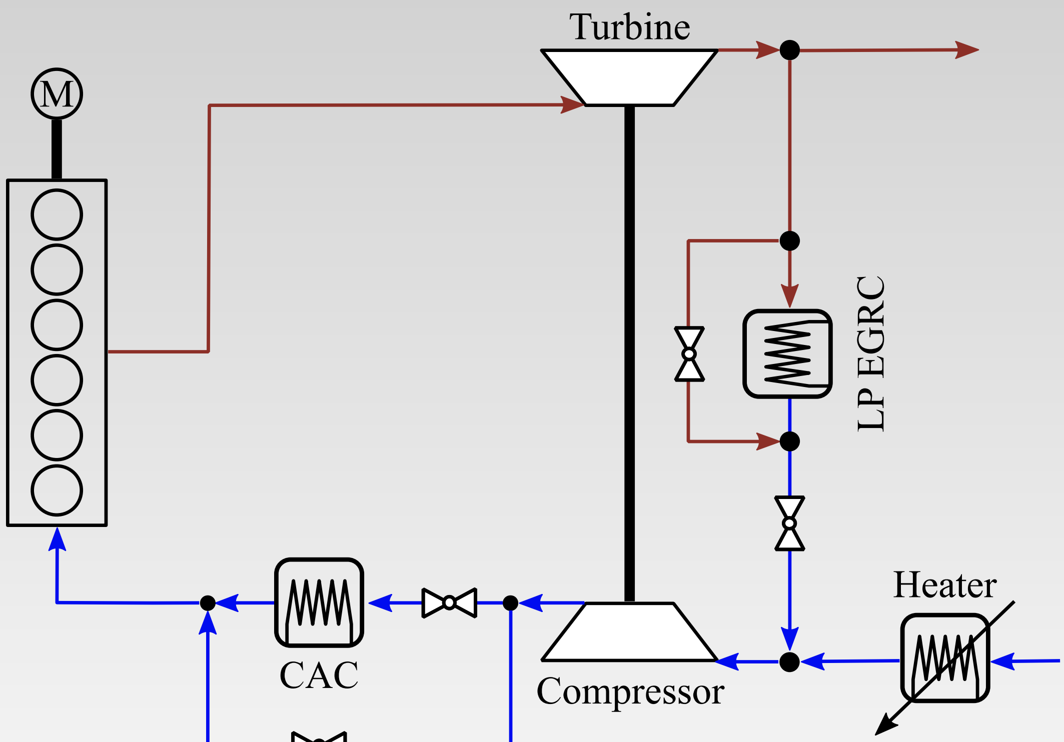




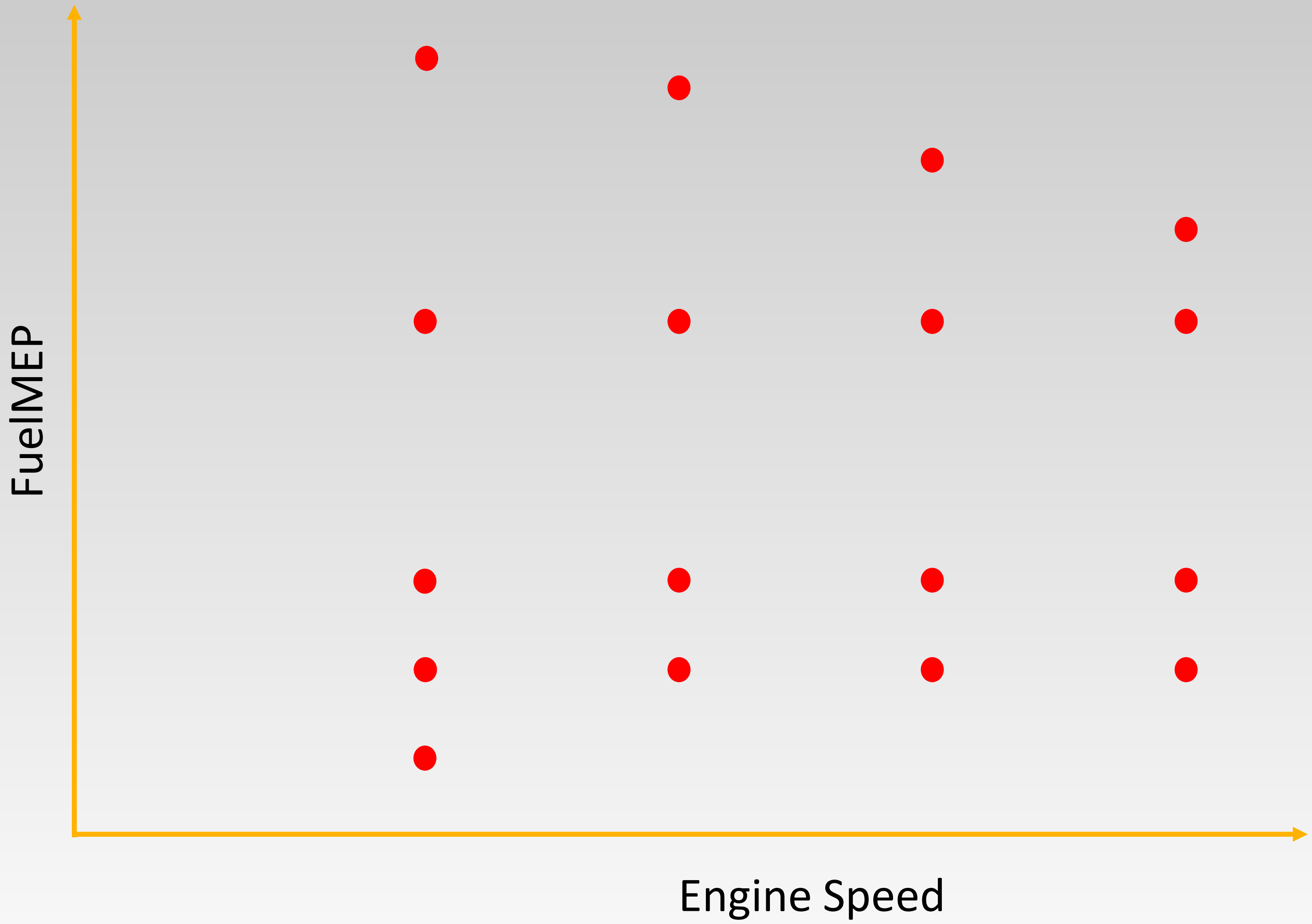
- Turbocharger from BorgWarner
- $\text{FMEP} = \alpha \cdot \text{IMEP} + \beta \cdot \text{N} + \gamma \cdot p_{\text{max}}$

The Methodology
How to simulate the engine





Operating Points



Optimization using a Genetic Algorithm (GA)

- Single objective – Brake Efficiency

$$\max \quad \eta_B(x_i, \ldots, x_N)$$

$$\text{subject to } \left(\frac{\partial p}{\partial \theta}\right)_{max} < limit \qquad \text{And} \qquad p(\theta)_{max} < limit$$

- Which algorithm?
    - Particle Swarm
    - Artificial Bee Colony

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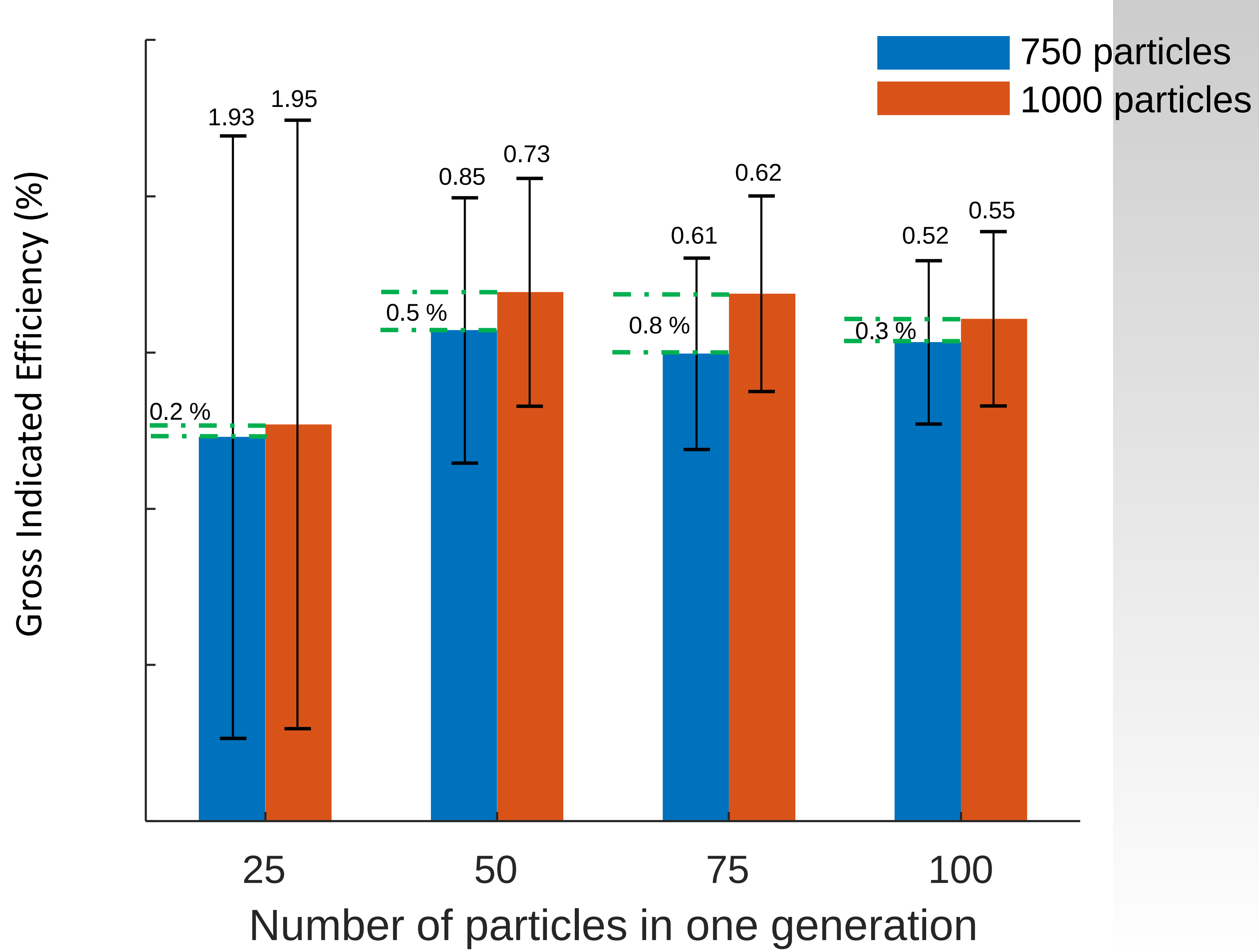
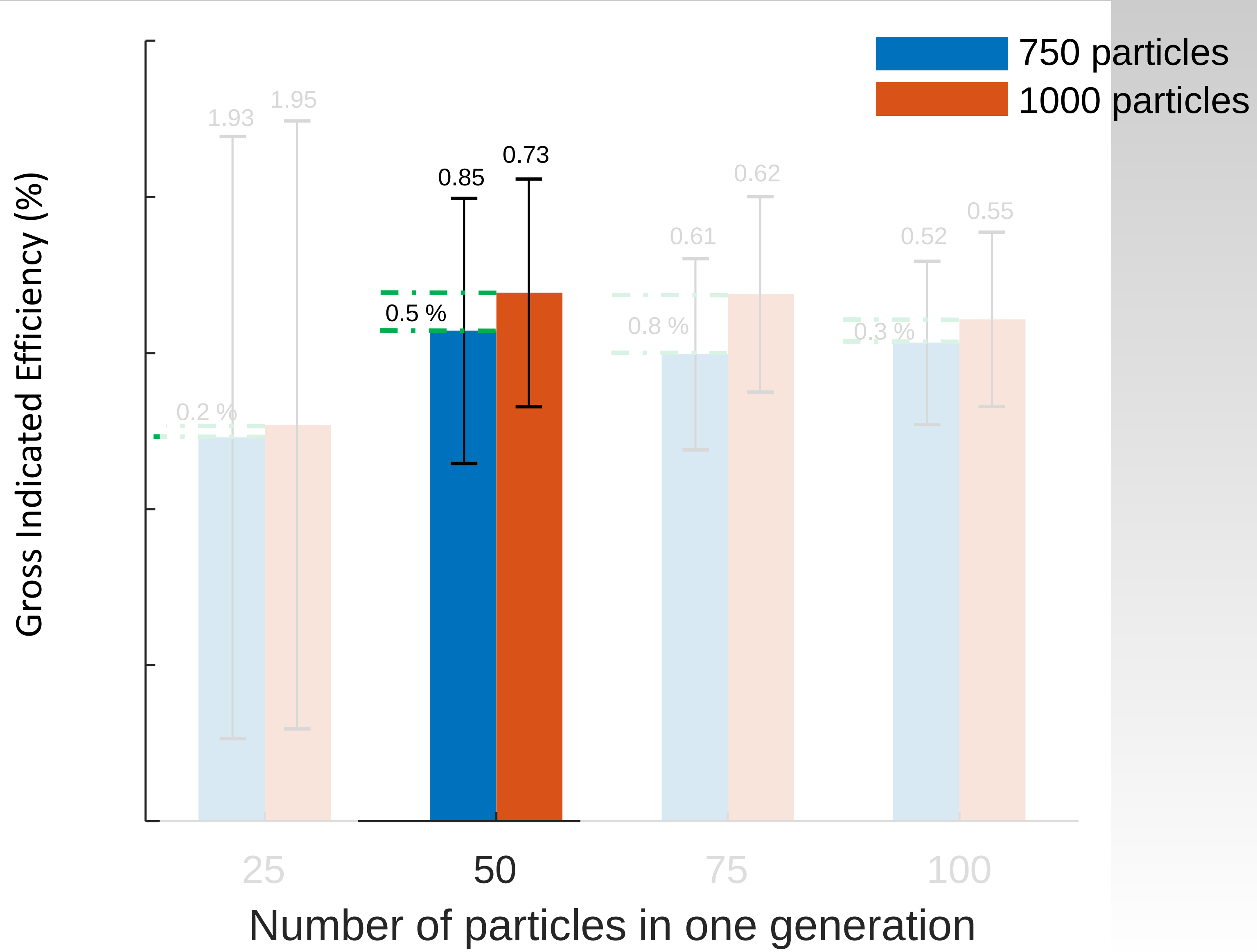
- Which algorithm?
  - Particle Swarm – Significantly Faster
  - Artificial Bee Colony

Particle Swarm Sensitivity



Particle Swarm Sensitivity



Constraint handling

- Single objective – Brake Efficiency

$$\max \quad \eta_B(x_i, \ldots, x_N)$$

subject to $\left(\frac{\partial p}{\partial \theta}\right)_{max} < limit$ bar And $p(\theta)_{max} < limit$

- If constraint is violated

$$\eta_B = \eta_B \times \left(1 - \left(\frac{g_i - \lim_i}{\lim_i}\beta\right)^{\alpha}\right)$$

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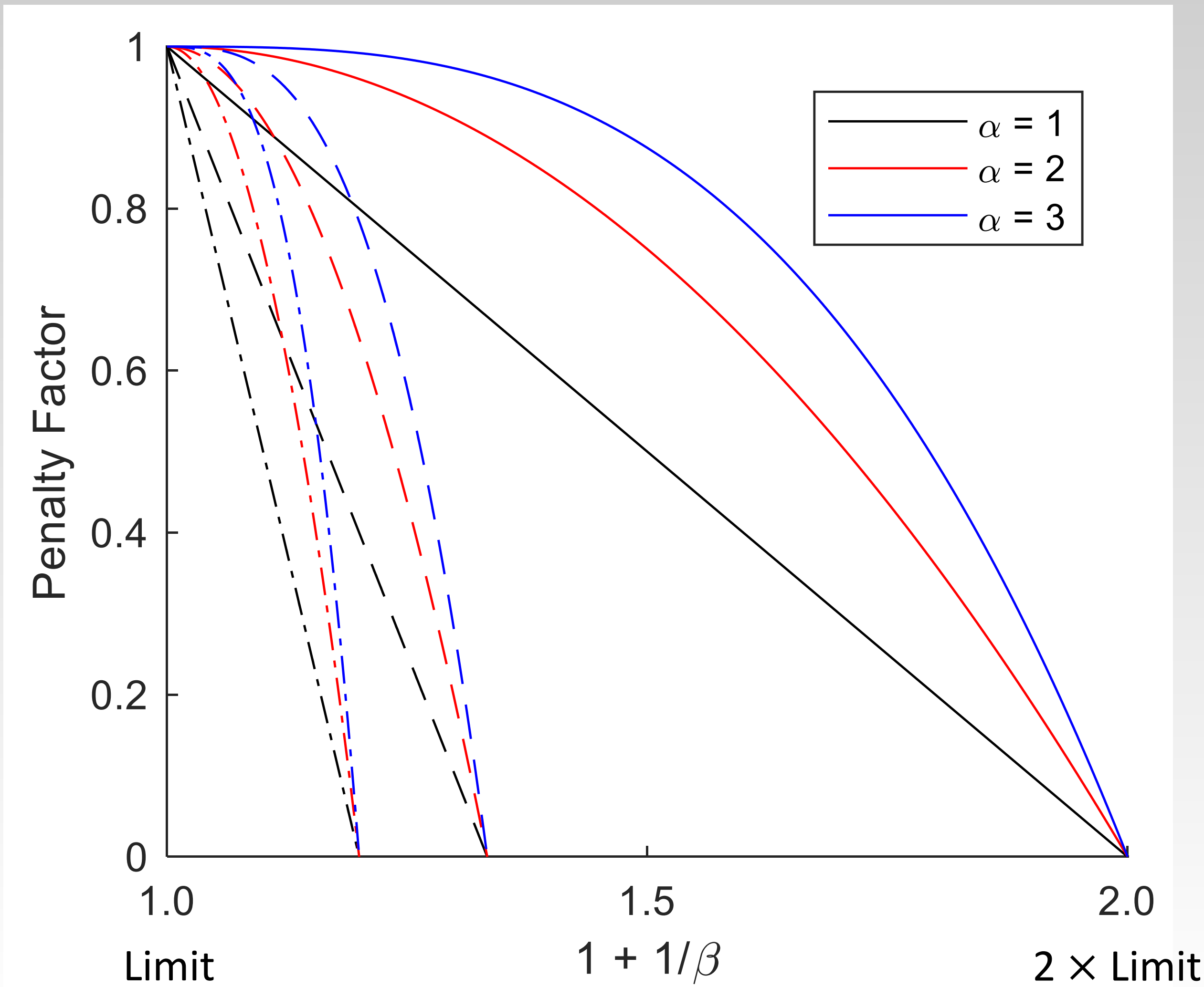

Summary

Summary

- Data from 72 experiments were collected
- B.C. for the DI-SRM were obtain with GT Power
- The turbulence model of the DI-SRM was calibrated
- Finally the DI-SRM was coupled with a MSE model to optimize the brake efficiency of a HD engine running on methanol

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