HPC OPTIMIZATION OF FUTURE DIESEL TWIN-TURBO ARCHITECTURE FOR FUEL ECONOMY
EUROPEAN GT USER CONFERENCE 2019
AIR-FILLING DEPARTMENT / LAURENT JOURNO / 7 OCTOBER 2019
INTRODUCTION & MOTIVATION

- **Upgrade diesel baseline engine for LCV application (Vans):**
  - Master dCi 180 2.3L twin-turbo Euro6d-TEMP

- **Upcoming context:**
  - Euro7 Emission Regulations for LCV applications require more EGR on engine map
  - CAFE standard (LCV 2020 target: 147g CO\(_2\)/km) impose a global fleet CO\(_2\) reduction

- **Advanced simulation study:**
  - Evaluation of new boosting architectures (twin-turbo) available on the market
    - to reduce pumping losses on driving cycles
    - Fuel consumption reduction
    - to improve LP EGR capability for Euro 7
AGENDA

01 FRAMEWORK
   SIMULATION PLAN

02 OPTIMIZATION APPROACH
   METHODOLOGY

03 TWIN-TURBO ARCHITECTURE COMPARISON
   ANALYSIS
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FRAMEWORK

SERIAL TWIN-TURBO ARCHITECTURE

- Compressor By-pass Valve (CBV)
- HP Stage
- Turbine By-pass Valve (TBV)
- LP Stage
- LP EGR Valve
- Exhaust Flap

ICE

- HP Stage
- LP Stage

- Actuators
  - FGT + FGT
  - FGT + VGT
  - VGT + VGT
  - VGT + FGT

- T/C maps provided by 2 major suppliers
- Standard turbo-matching process

Air-Filling Department / Laurent Journo / 7 October 2019
OPERATING POINTS & BOUNDARY CONDITIONS

- 8 operating points with different EGR rates
- Estimation of fuel economy on driving cycles (WLTC, Customer Driving Cycle) with a weighting function
HOW TO SELECT THE BEST TWIN-TURBO ARCHITECTURE?

- Find the best actuators positions to minimize PMEP under EGR constraints
  - Each twin-turbo architecture has 2 or 3 actuators to control boost pressure
  - LP EGR is controlled with 2 actuators (EGR Valve, Exhaust flap)

- 4 or 5 actuators positions as variables on 8 operating points!

What is the best simulation approach?

<table>
<thead>
<tr>
<th>Full Factorial Design of Experiment</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Spatial design discretization</td>
<td>-</td>
</tr>
<tr>
<td>Number of cases</td>
<td>- -</td>
</tr>
<tr>
<td>Waste rate</td>
<td>- -</td>
</tr>
<tr>
<td>Global optimum</td>
<td>-</td>
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<tr>
<td>Computational time</td>
<td>- -</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Direct Optimization</th>
<th>Comments</th>
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<tbody>
<tr>
<td></td>
<td>+ +</td>
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<tr>
<td>Adaptative during optimisation</td>
<td></td>
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<tr>
<td></td>
<td>+</td>
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<tr>
<td>Depending of optimization algorithm choice and settings</td>
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<tr>
<td></td>
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<tr>
<td>Optimisation under constraints helps to reduce waste rate</td>
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<td>+</td>
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<tr>
<td>More confidence to capture global optimum</td>
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<tr>
<td>Optimisation algorithm is efficient to explore the design space and save time</td>
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OPTIMIZATION APPROACH

1D GT-POWER MODEL & OPTIMIZATION SETUP

- **Combustion**
  - Imposed burn rate profile (from dyno tests)
  - Injection mass PID to target load with Air/Fuel ratio and pressure cylinder limitations

- **Twin-turbo**
  - fully parametrized twin-T/C model to switch quickly T/C maps
  - No PIDs to control T/C actuators (rack, WG or TBV)

- **Low pressure EGR**
  - No PIDs to control actuators (valve & exh. flap)

- **Quick convergence (~50 cycles)**

- **Optimization Solver**
  - NSGA-III Genetic algorithm
  - 2 loops of 501 design iterations

- **Single objective**
  - Minimize pumping losses (PMEP) in order to improve fuel consumption

- **Constraints**
  - Load (BMEP)
  - LP EGR rate
  - Max. pressure before turbine (P3)
  - Max. temperature after compressor (T2)
OPTIMIZATION APPROACH

1D GT-POWER MODEL & OPTIMIZATION SETUP

- No T/C and EGR controllers
- Optimizer has direct control on all actuators positions:

<table>
<thead>
<tr>
<th>Twin-turbocharger</th>
<th>LP EGR</th>
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<tbody>
<tr>
<td>Rack HP</td>
<td>CBV</td>
</tr>
<tr>
<td>VGT + FGT</td>
<td>X</td>
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<tr>
<td>FGT + VGT</td>
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</table>
OPTIMIZATION APPROACH

HIGH PERFORMANCE COMPUTING

▪ HPC setup
  - Standalone workstation (44 Cores @2.2GHz)
  - 3 GT-GUI licence for « Optimizer supervision »
  - 44 GT-solver licences for distributed calculations

▪ Number of calculations
  - 3 Architectures x 2 suppliers
  - 8 operating points x 2 bypass conditions (CBV+TBV open/closed)
  - 2 x 501 optimisation iterations

➔ 96192 simulations

▪ HPC performance
  - Speed rate: 3.1 case / min
  - Total duration: 7.2 days (2 optimization loops)
OPTIMIZATION APPROACH

OPTIMUM SELECTION

- **Selection of optimum points using a Python script**
  - Waste rate: Out of constrained data (42%) / Valid data (58%)
  - Invalid points were useful for the optimizer to capture the behavior of system (twin-turbo + LP EGR)

- **Extraction of Pareto Front using a Python script**

![Diagram](image)

1500 rpm / 9 bar

Ranking between 3 architectures changes depending on EGR level

- **Pareto Front PMEP = f(LP-EGR rate)**
  - Pareto VGT + FGT
  - Pareto FGT + VGT
  - Pareto VGT + VGT
  - FGT + VGT
  - VGT + VGT
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03 TWIN-TURBO ARCHITECTURE COMPARISON ANALYSIS
- VGT+VGT is always more efficient than VGT+FGT

- FGT+VGT is more efficient than VGT+VGT with the EGR level increasing

- These results are correlated with the difference of overall thermodynamic efficiency of twin-turbo
Use weighting function to compute an estimation of fuel economy on each driving cycle

Current study shows a fuel economy between [2% ; 4%] for FGT+VGT (vs VGT+VGT) depending on EGR level and driving cycle
CONCLUSION & NEXT STEPS

▪ What is the best twin-turbo architecture? ➔ FGT+VGT but it depends on the context!
  - Current simulation study shows a fuel consumption benefit between [2% ; 4%] for FGT+VGT (vs VGT+VGT) depending on EGR level and driving cycle

▪ Feedback about HPC Optimization with GT-Power
  - Successful Proof of Concept
  - This optimization study gives more information than expected!
    - A powerful and efficient solution to select the best twin-turbo architecture
    - More valuable study by capturing PMEP vs EGR sensitivity (pareto front). Useful to update fuel consumption forecast in a different context.
    - Useful solution to generate T/C actuators maps as pre-calibration for engine tuning activities

▪ Next steps
  - These simulation results have to be confirmed with engine test bench in the future
  - Re-use of optimization dataset to improve predictivity of twin-turbo control using a Neural Network
THANK YOU