Very High Energy Density (VHED) Engine
Design & Development

Analytics based design & development from baseline high energy density engine

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VHED Engine Design: Challenges & Constraints

- **Material Pressure & Temperature Limits**
  - Peak firing pressure \( P_{\text{mat}} \)
  - Exhaust temperature \( T_{\text{mat}} \)
  - Exhaust Pressure \( EP \leq EP_{\text{max}} \)

- **Performance target**
  - Cold start (Compression ratio (CR) > \( CR_{\text{min}} \))
  - Performance at very high altitude
  - Very High Power & Torque

- **Engine Hardware Constraint**
  - Keep major components as Block, Head, Crankshaft ... same as baseline HED Engine
  - Same swept volume as of HED engine
  - Same Common Rail setup

- **Engine Hardware Alteration** (required to manage challenges and constraints)
  - Injector
  - Piston Bowl
  - Turbocharger
  - Cooling System
  - Lubrication System
**Design methodology: Scaling-Up Approach**

Scaling-up Air Flow Rate in proportion to Brake Mean Effective Pressure (BMEP) up-scaling

<table>
<thead>
<tr>
<th>Baseline HED Engine</th>
<th>New VHED Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>High BMEP</td>
<td>Very High BMEP</td>
</tr>
<tr>
<td>$m_{\text{air}}$ kg/h</td>
<td>$1.6m_{\text{air}}$ kg/h</td>
</tr>
</tbody>
</table>

**Inferences: to achieve design criteria from scaled up approach for VHED Engine**

1. Reduce air flow rate (Reduce Boosting Pressure)
2. Reduce Compression Ratio

**Conditional Motoring $P - \theta$ for VHED Engine with CR same as baseline HED Engine**

- $1.2P_{\text{mat}}$
- $0.8P_{\text{mat}}$

**Ruled-out the simplest approach**

Baseline HED Engine

New VHED Engine

$\pi_{\text{CR}}$

$\pi_{\text{CR}}$

$\frac{m_{\text{air}}}{\text{motorizing}} = \frac{m_{\text{air}}}{\text{rated power}}$
Design Methodology: Advanced approach

Input (Geometry & Design parameters)

Is DOE Cycle End?

1D GT-Power Engine Thermodynamic Simulation

Conditional Motoring Simulation

Torque = (Torque)Target

Combustion Simulation

Air flow rate, Fuel flow rate, SOC (Injection Profile)

3D CFD Star ES-ICE In-Cylinder Simulation (Closed Cycle)

Is work done in 3D = work done in 1D for same crank angle?

Output

1D Simulation Close cycle Simulation for Burn Rate Profile

Is Pmax ≤ Pmat?

Pmax ≤ Pmat

Alter Compression Ratio

Alter Fuel Mass

Alter Start of Combustion (SOC) Angle

Alter Boosting

Input / Output

Trigger Parameters

Measures

Tools & Process

TOOLS Used for Modeling
1D Modeling : GT-POWER
3D In-Cylinder : STAR-CD
1D Thermodynamic Model: Representative View
Observations: $P - \theta$ Plot

**Observation:** Peak firing pressure for rated power and torque condition is within material limit.
**Observation:** Exhaust temperature of VHED engine increased by ~80°C as compare to HED still keeping it below material limit.

**Observations: Temperature and BSFC Plots**

*Engine-Out Temperature*

*In-Cylinder Temperature*

*BSFC*
Injection profile and droplet break up baseline model calibrated to match P-theta

<table>
<thead>
<tr>
<th>Calibration</th>
<th>Variation (\frac{\Phi_{\text{test}} - \Phi_{\text{CFD}}}{\Phi_{\text{CFD}}} ) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicated Work around Combustion Phase (-10 TDC – EVO)</td>
<td>0.5</td>
</tr>
<tr>
<td>Peak Pressure [bar]</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Conclusions

- Achieved the Designed Target Conditions
- Attained the Peak firing pressure for rated power and torque condition within material limit
- Realized Exhaust temperature of VHED engine below material limit
- Developed VHED engine without much alteration in baseline HED engine hardware