

Pre-Chamber Combustion Evaluation with GT-SUITE

GT-SUITE Conference 2021

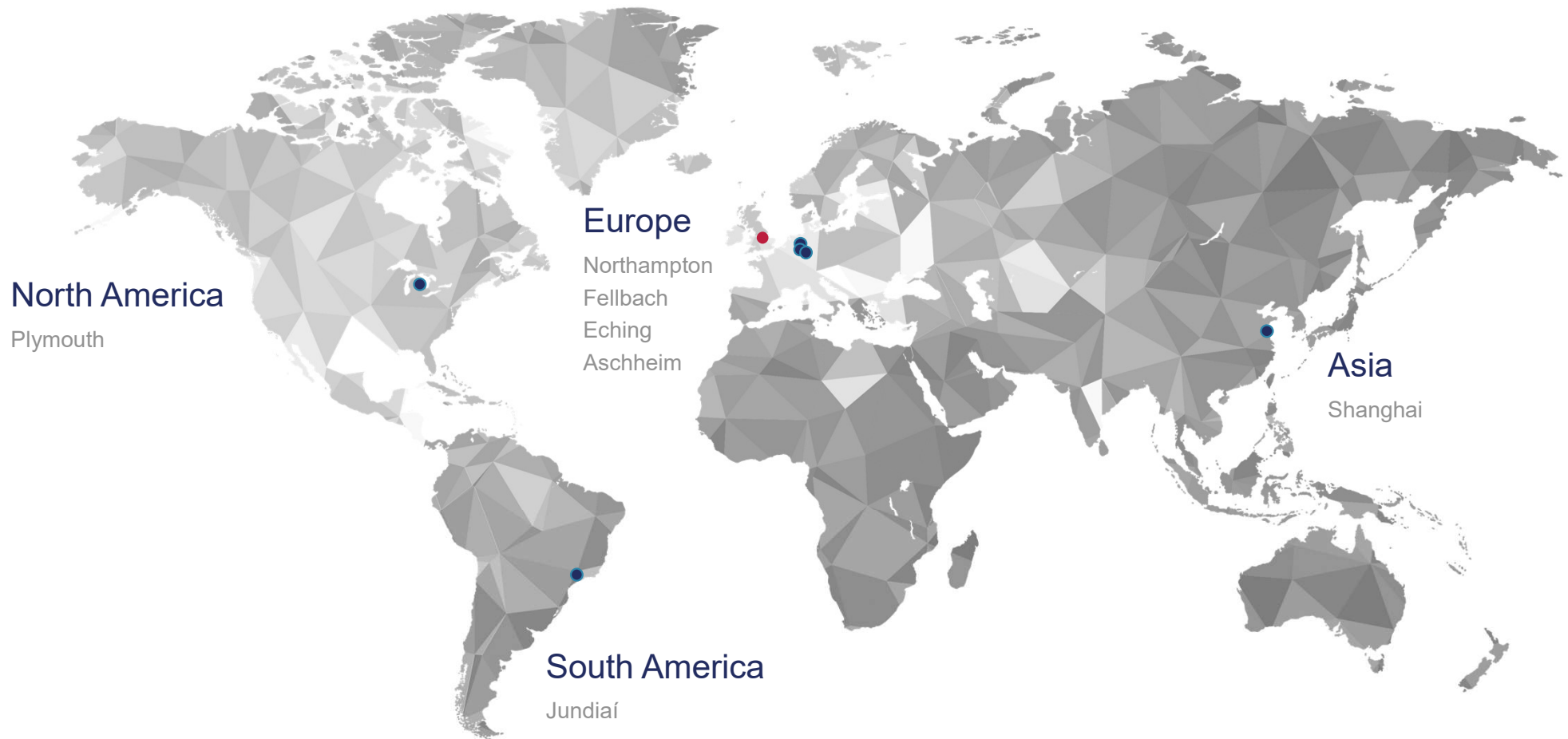
David Gurney | 2021/10/21



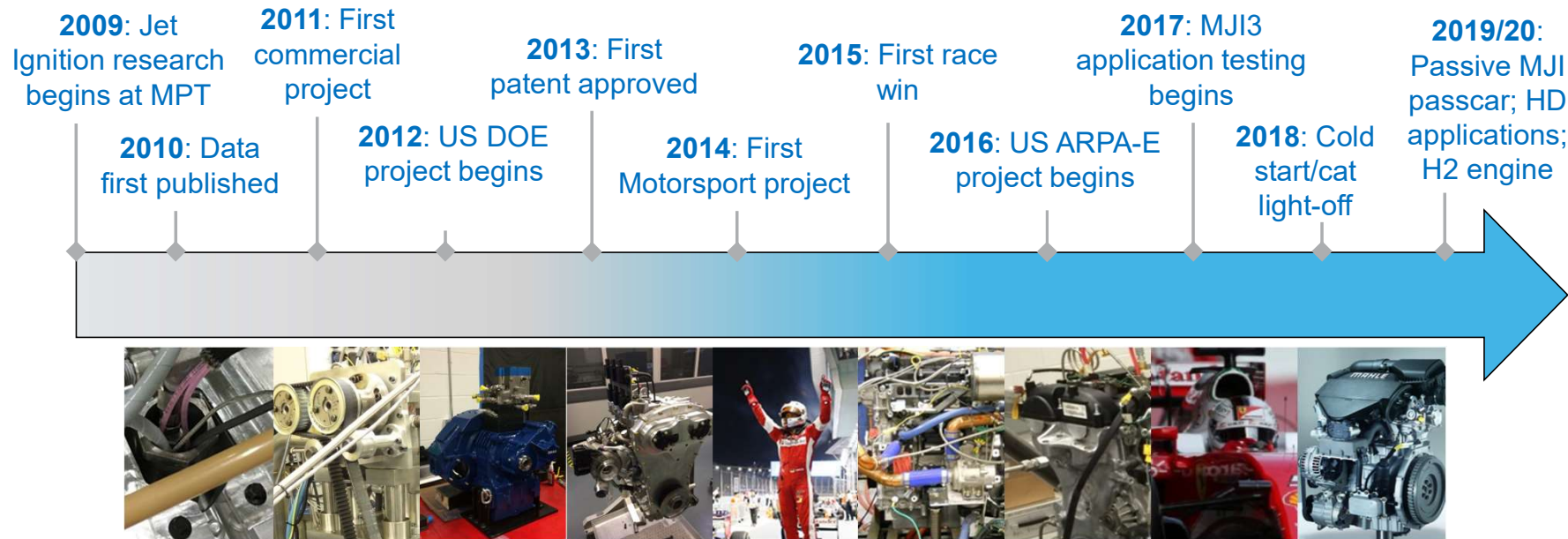
Agenda

1. Introduction to Pre-Chamber Design
2. Benefits of Pre-Chamber Combustion
3. Pre-Chamber Simulation in GT-SUITE
4. Three Pressure Combustion Analysis
5. Applications of TPA
6. Conclusions

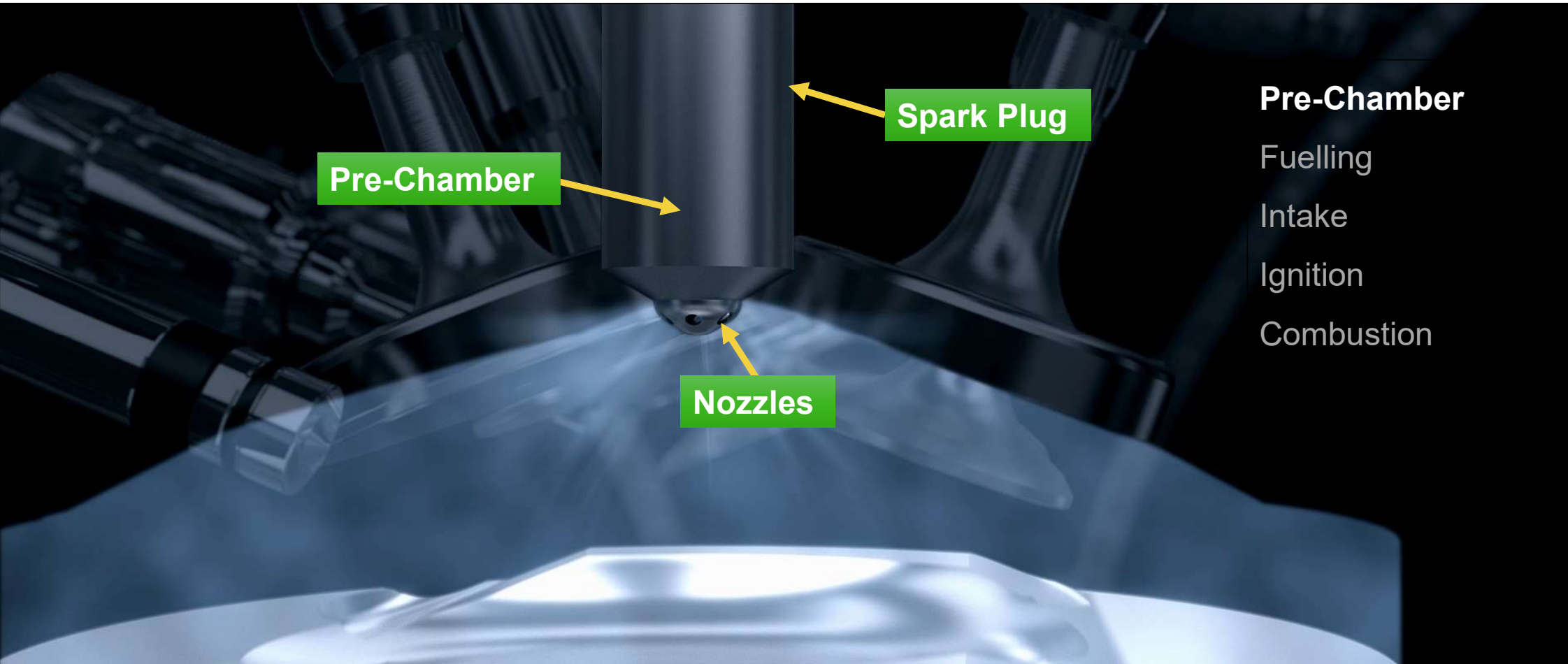
MAHLE Powertrain



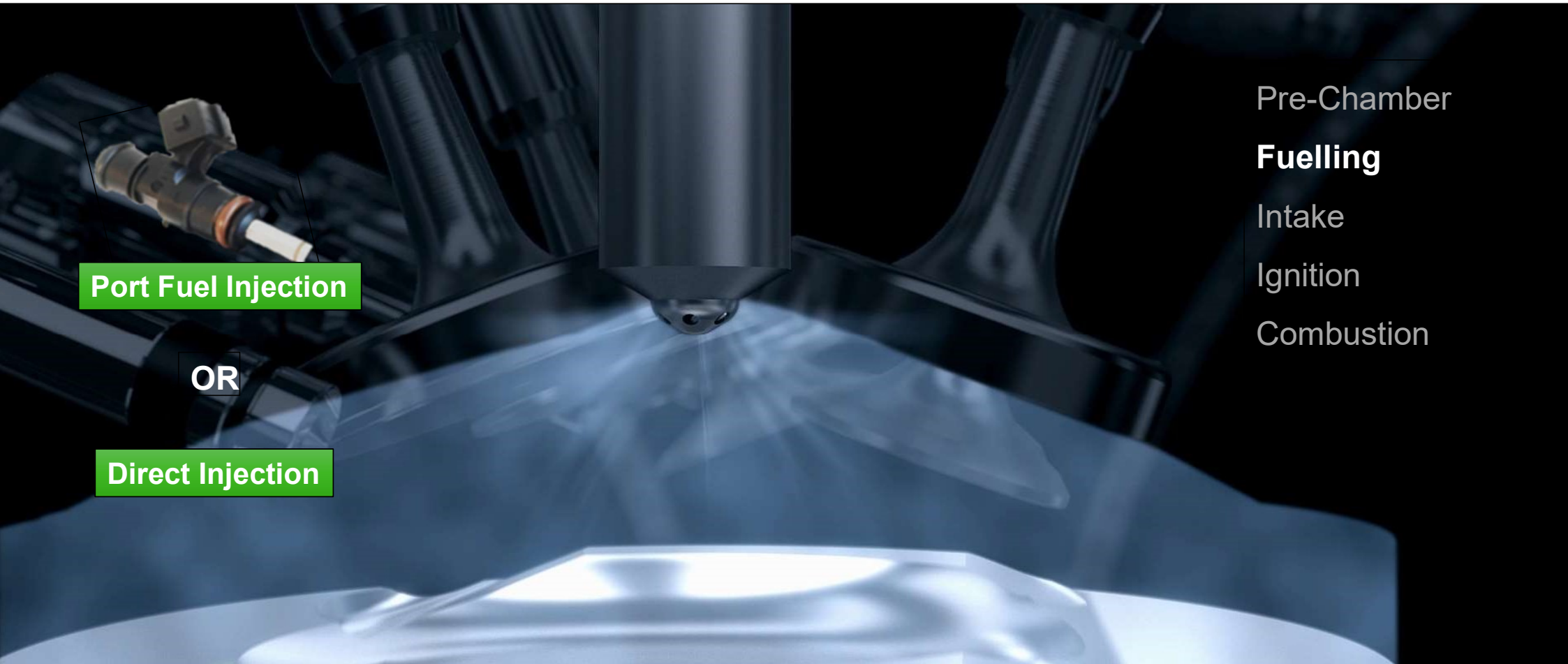
MAHLE Powertrain



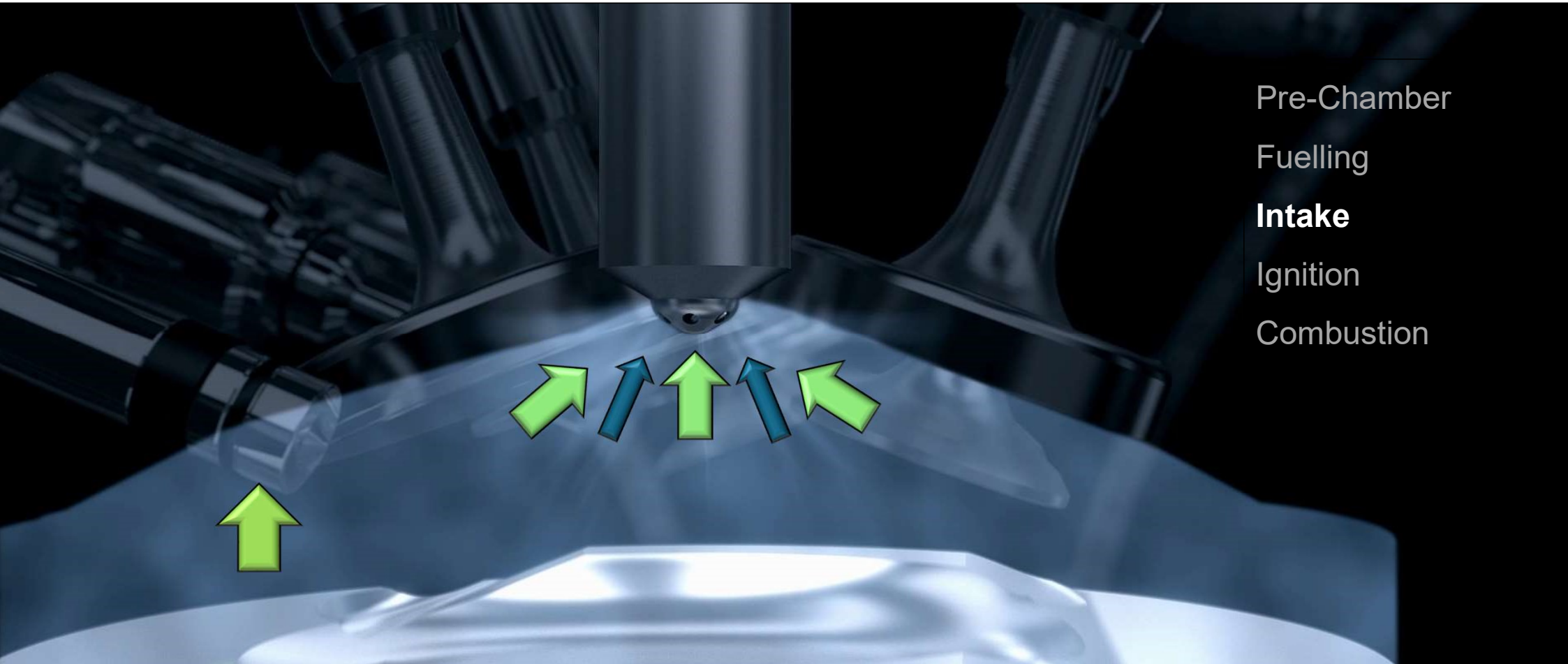
Introduction



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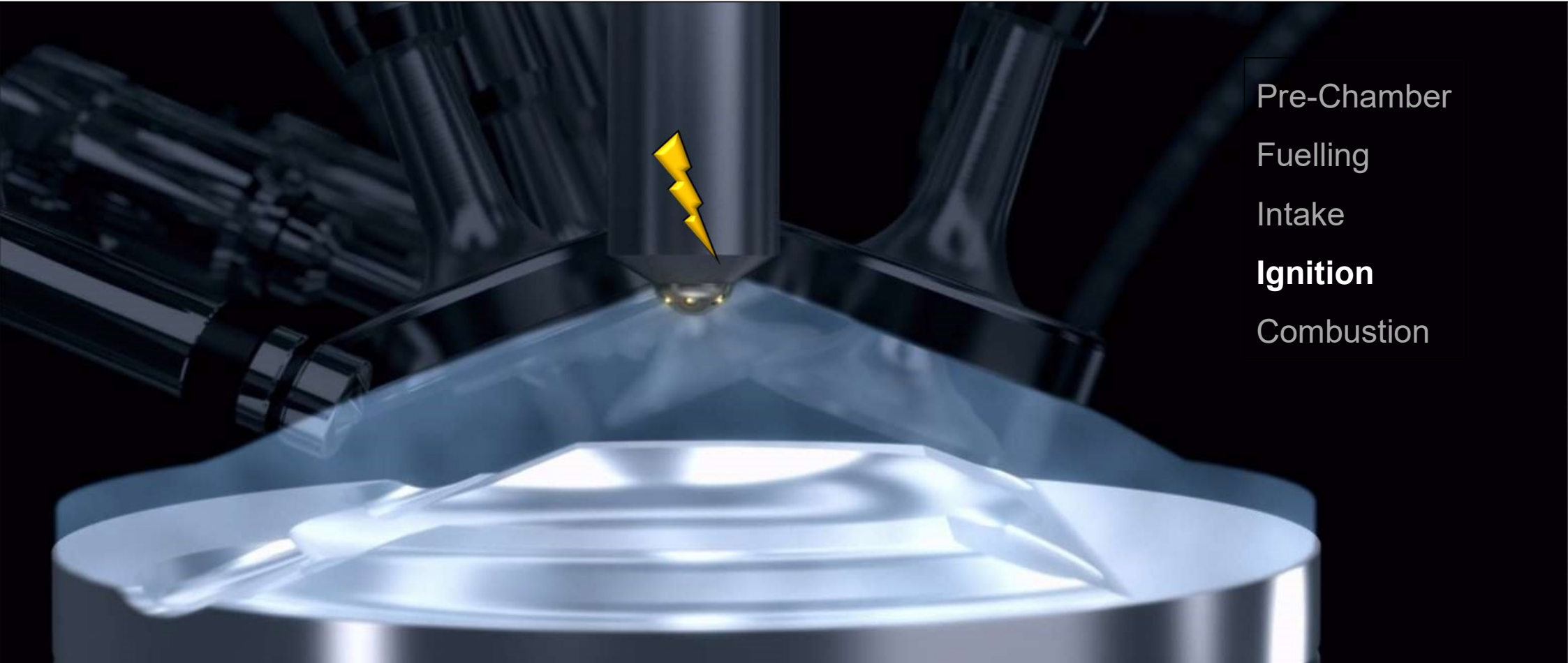


Introduction



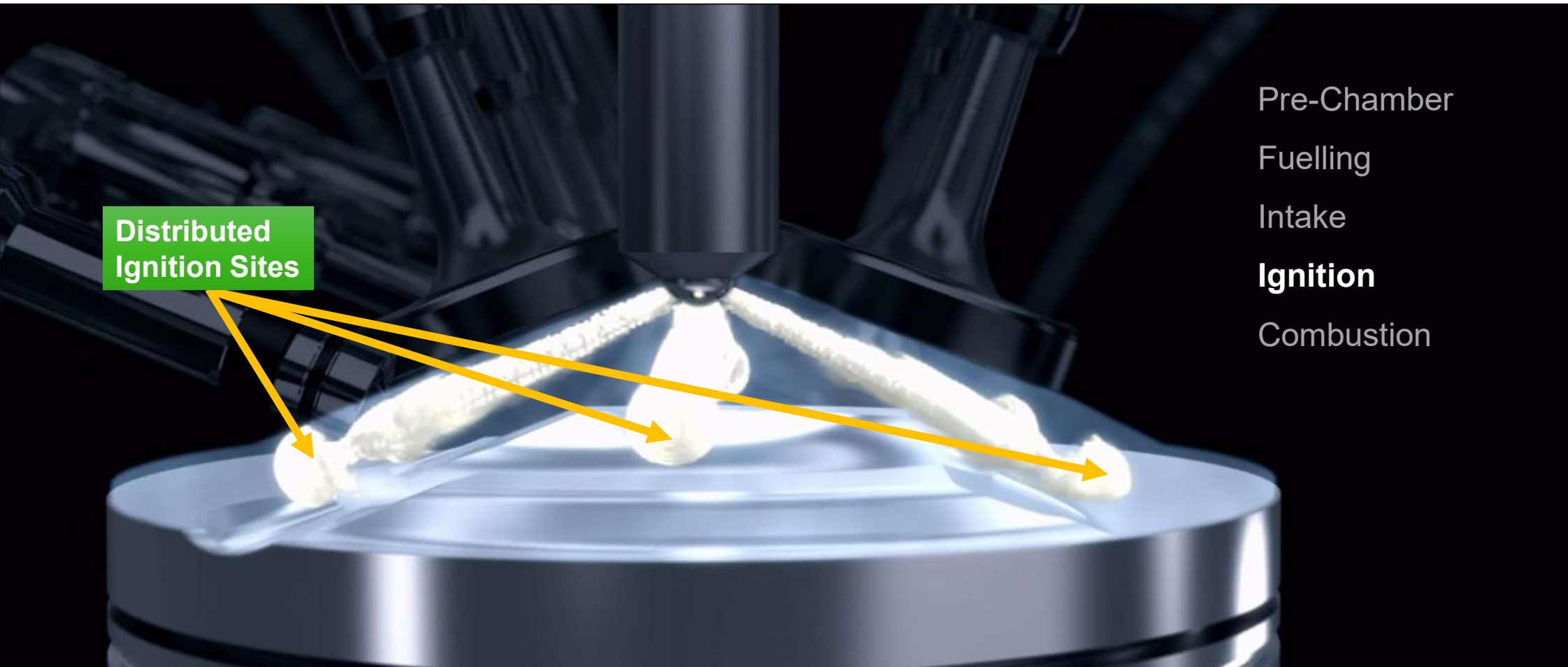
Pre-Chamber
Fuelling
Intake
Ignition
Combustion

Introduction

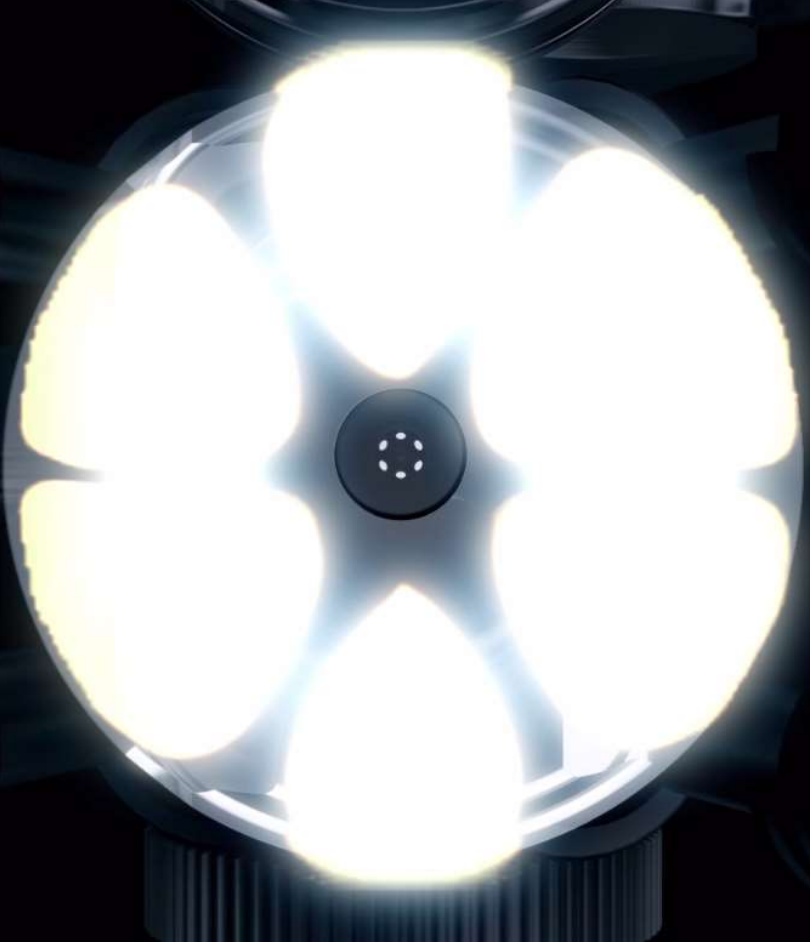


Pre-Chamber
Fuelling
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Introduction



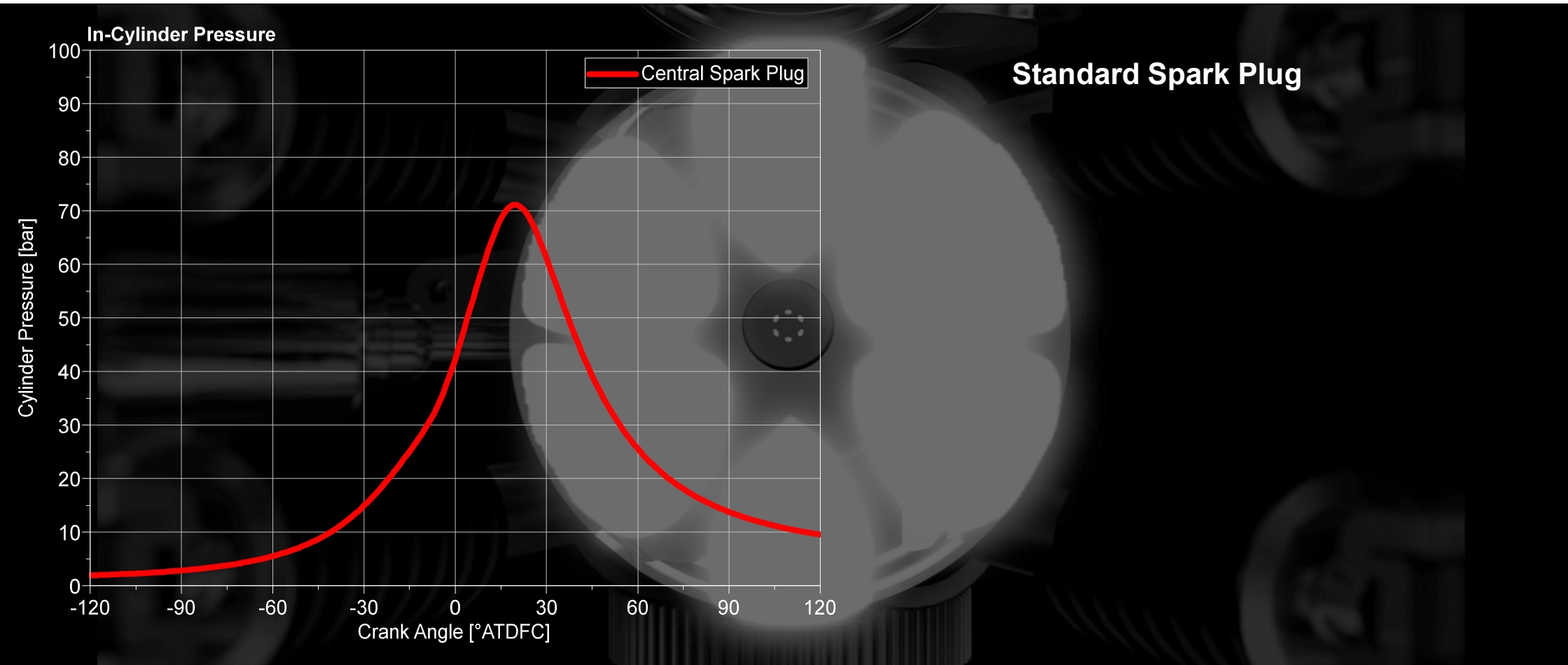
Introduction



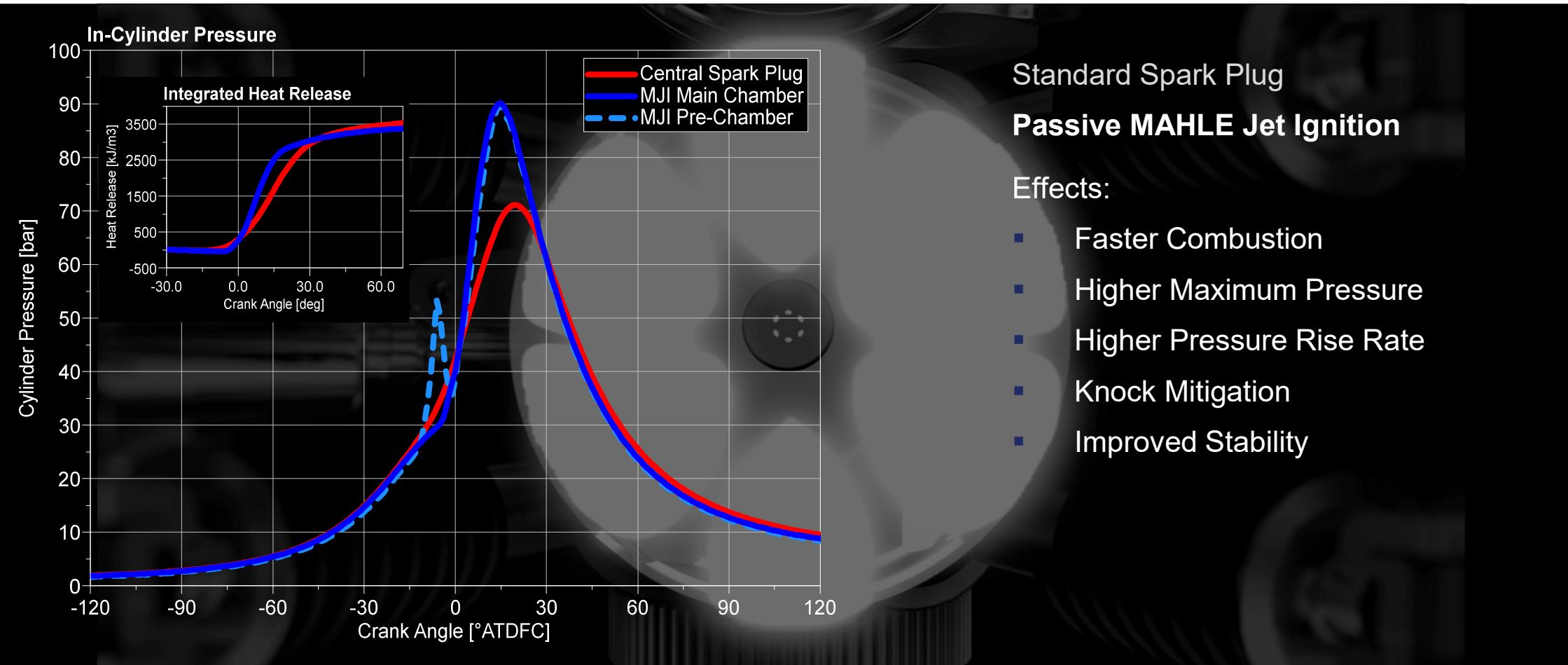
Fast, Stable
Combustion

Pre-Chamber
Fuelling
Intake
Ignition
Combustion

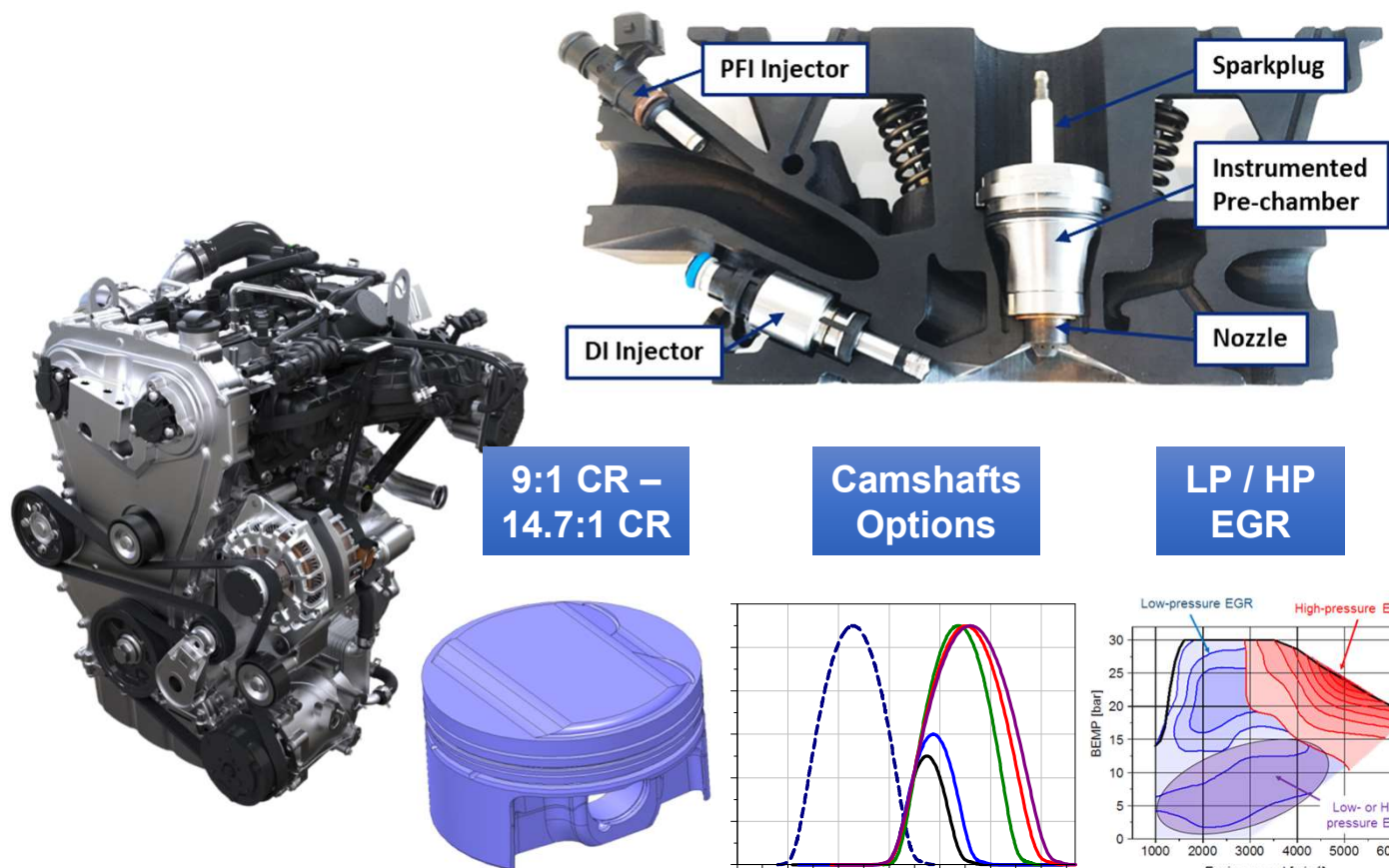
Introduction



Introduction



Benefits of Pre-Chamber Combustion



MAHLE 1.5l 3-Cyl Engine:

- 141kW, 334 Nm
- 37% Peak BTE

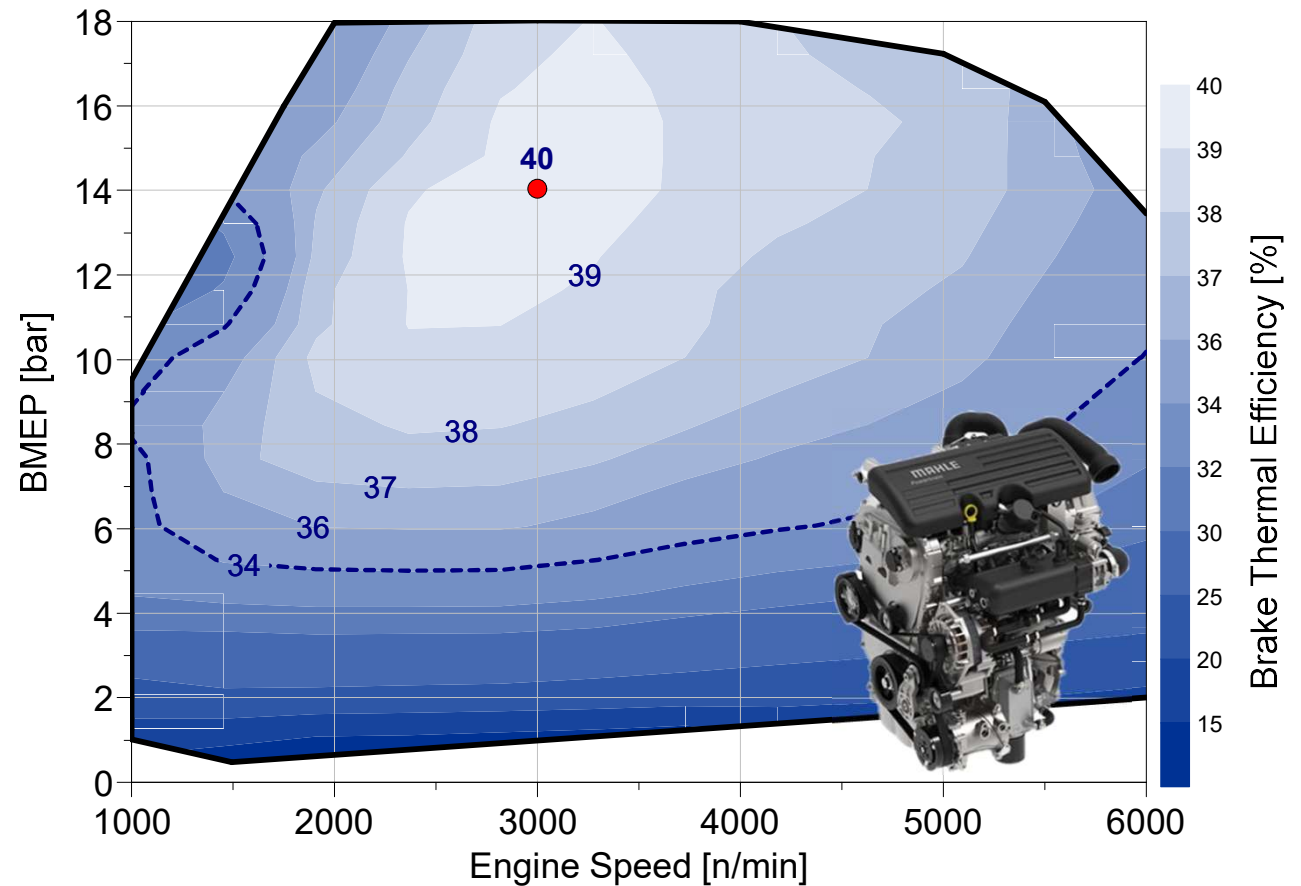
MJI Variant:

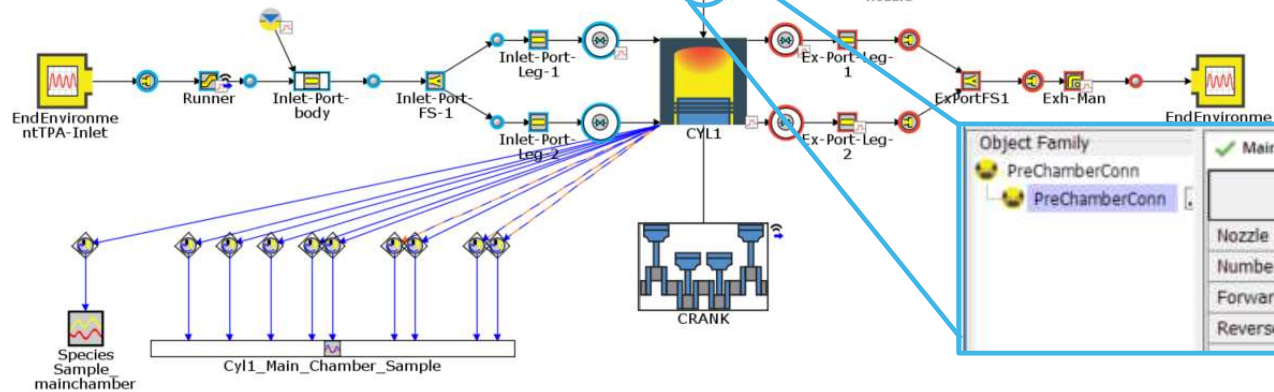
- Passive pre-chamber combustion
- PFI or DI fuelling
- Increased compression ratio
- Miller cycle
- LP or HP EGR

Benefits of Pre-Chamber Combustion

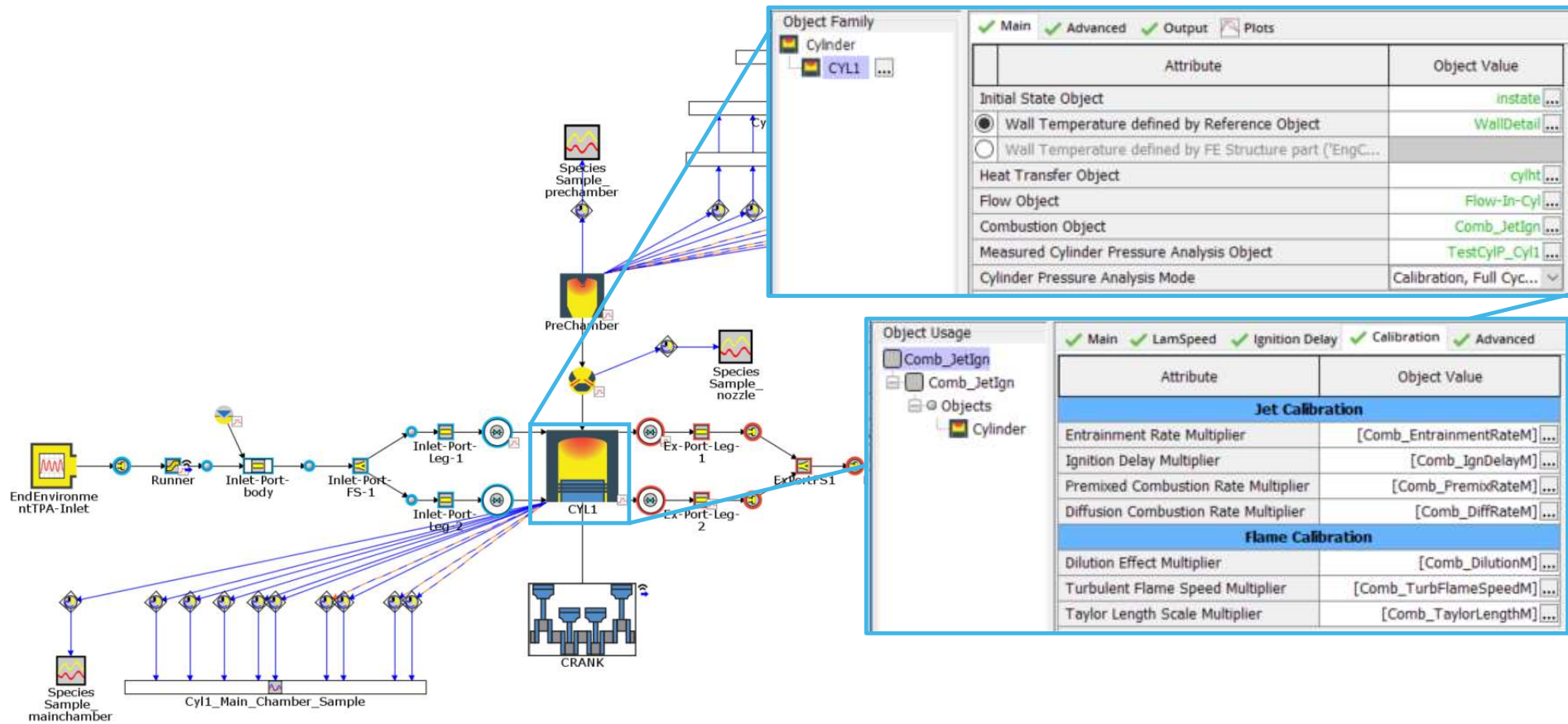
High Efficiency 1.5l:

- Peak Power - 110 kW @ 5500 rpm
- Map at $\lambda=1$ (950°C Pre-Turbine Limit)
- **>40% Peak BTE** (42% Indicated)
- Wide region > 34% BTE



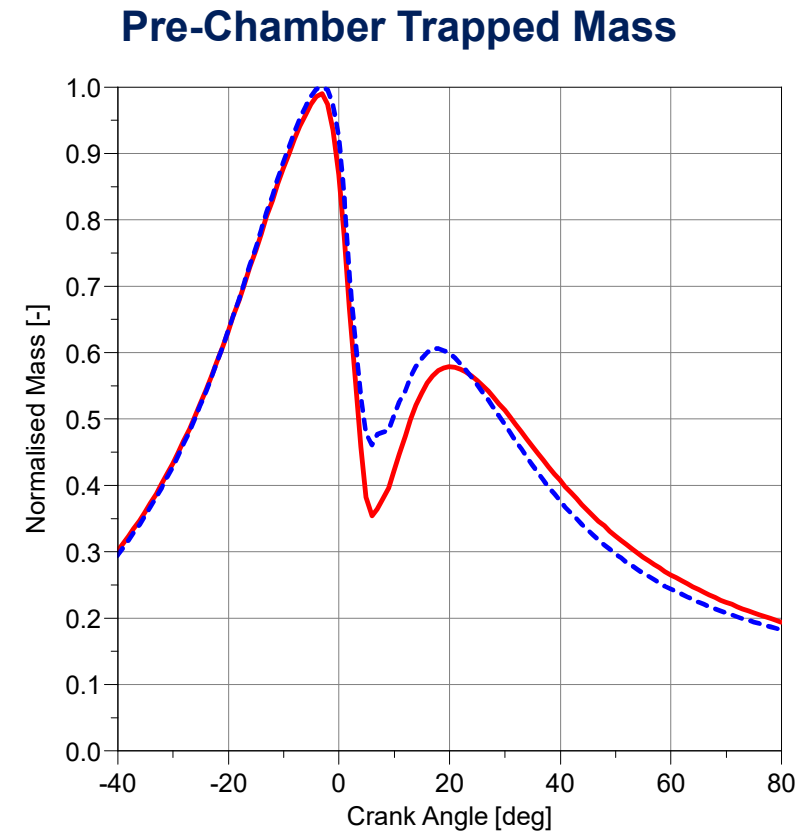
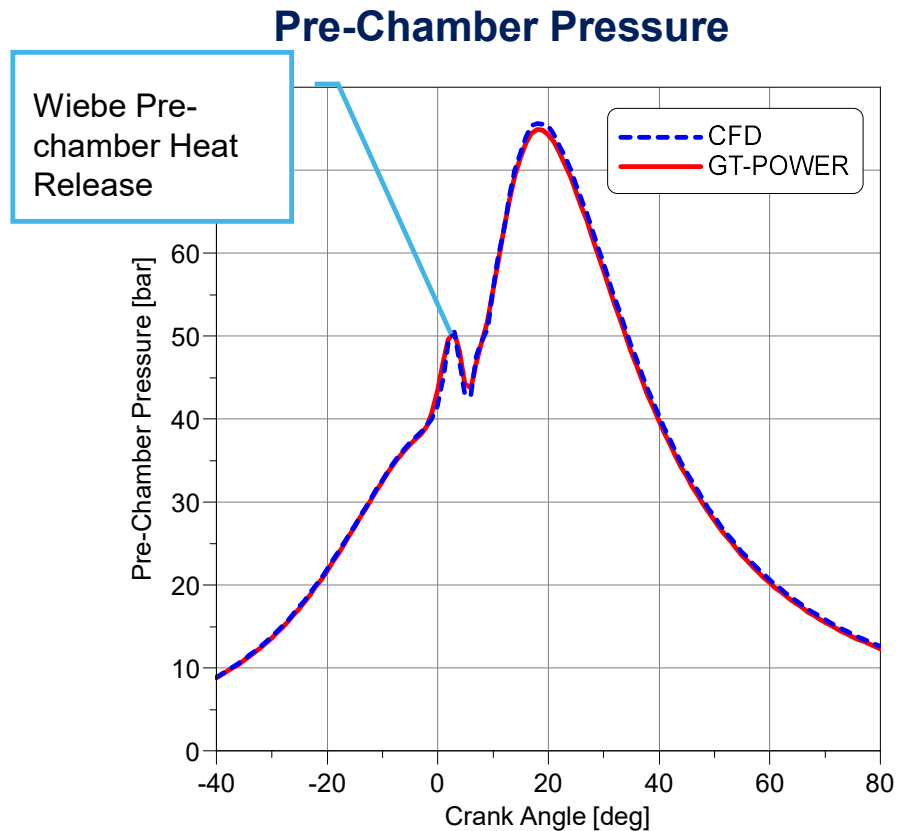


Pre-Chamber Simulation in GT-SUITE



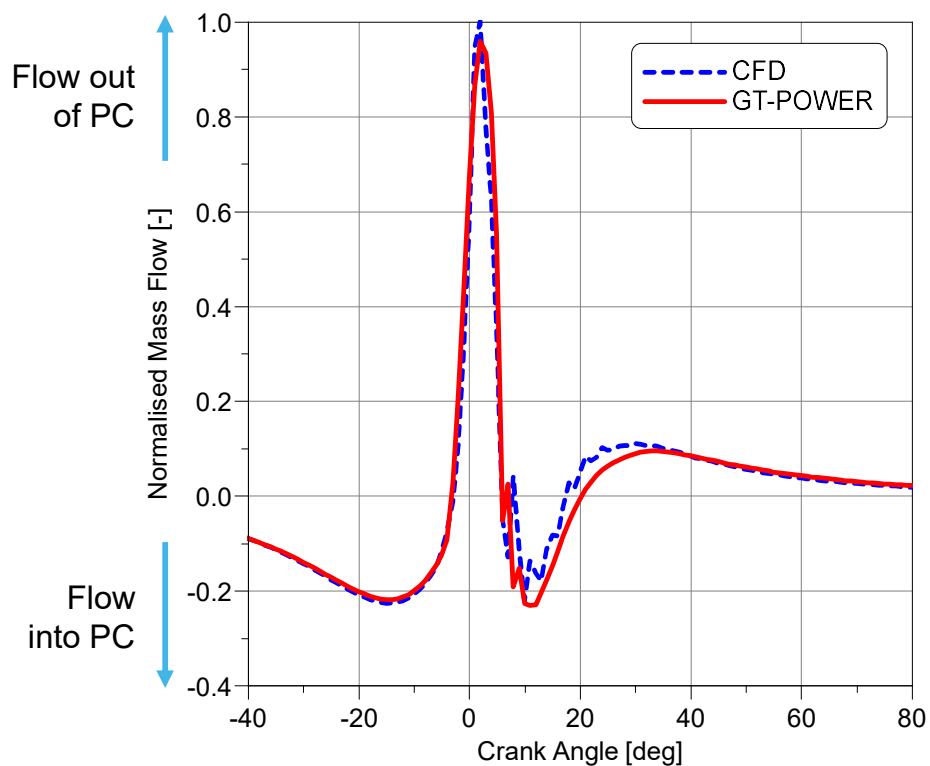
Validation with CFD

Nonpredictive Combustion Models



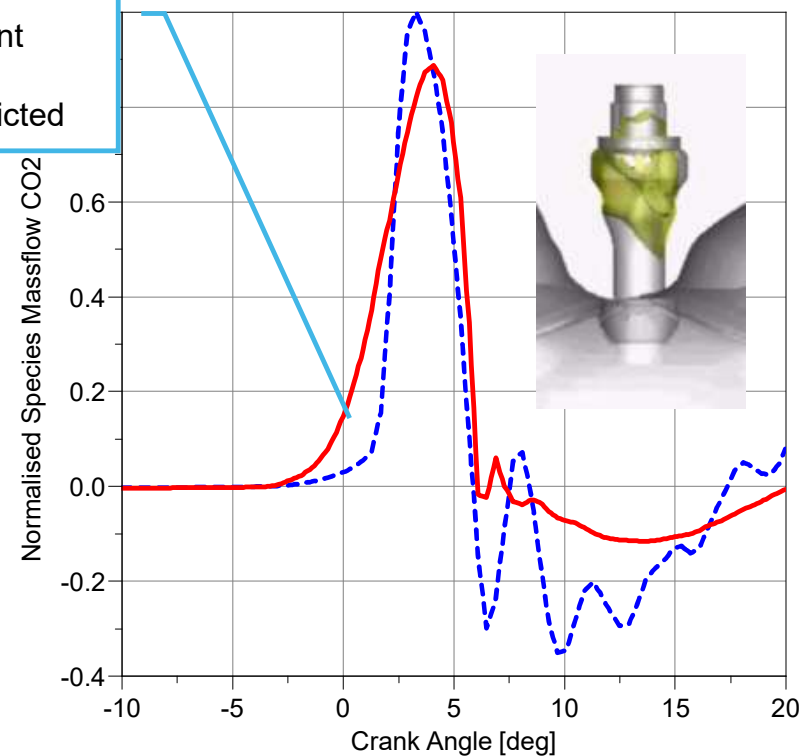
Validation with CFD

Pre-Chamber Nozzle Massflow



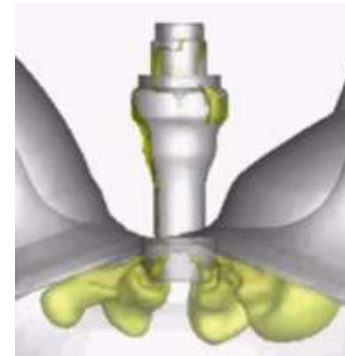
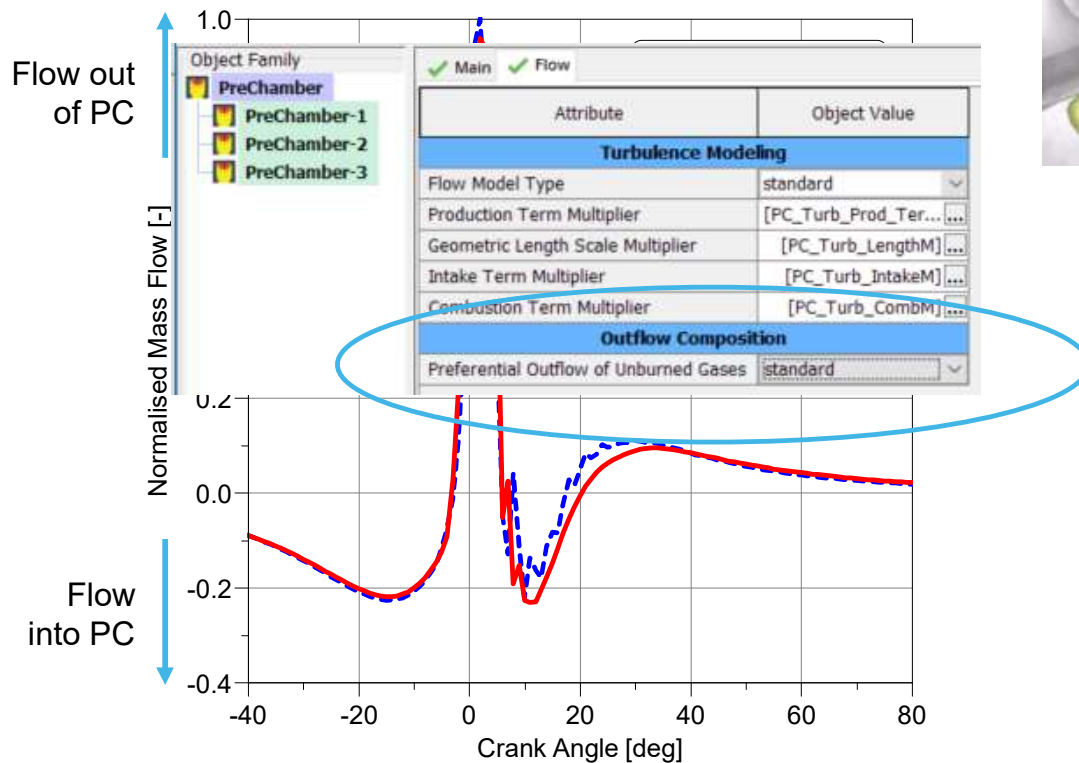
Pre-Chamber Nozzle Species Massflow

Initial Burnt
Massflow
Overpredicted

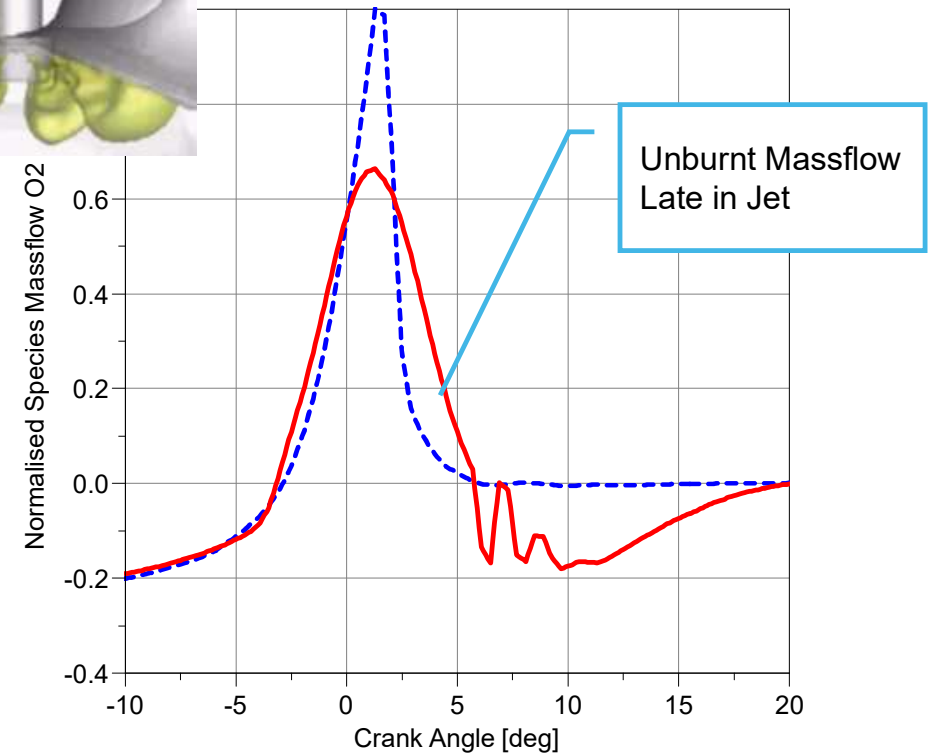


Validation with CFD

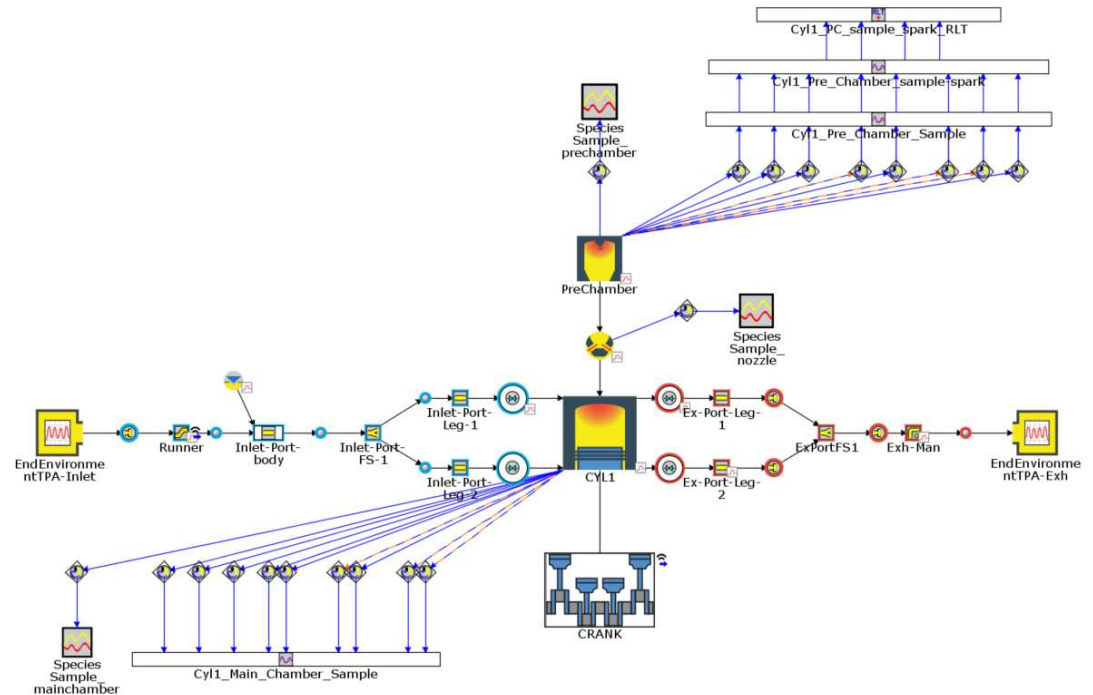
Pre-Chamber Nozzle Massflow



Pre-Chamber Nozzle Species Massflow



- Traditional heat release analysis relies on closed volume during combustion – not valid with a pre-chamber
- GT-POWER used to evaluate measured pressures in pre-chamber and main chamber to determine heat release for both
- TPA heat release analysis used on main chamber
- Non-predictive wiebe curve used for pre-chamber combustion, automatically correlated to measured cylinder pressure using GT optimiser

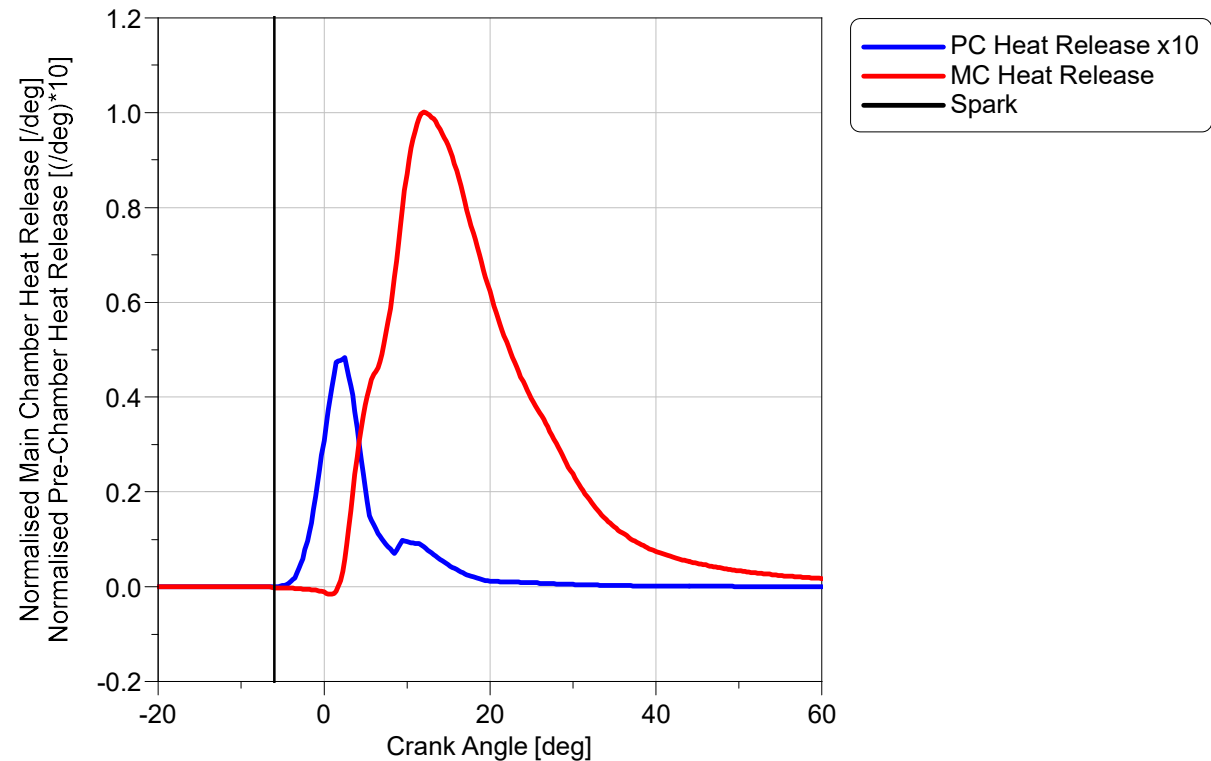


Heat Release Analysis

Typical Results

Simulation Results

- Heat release profiles for pre-chamber and main chamber
- Combustion events timing
- Predicted jet massflow and velocity
- Temperature and gas composition for pre-chamber and main chamber

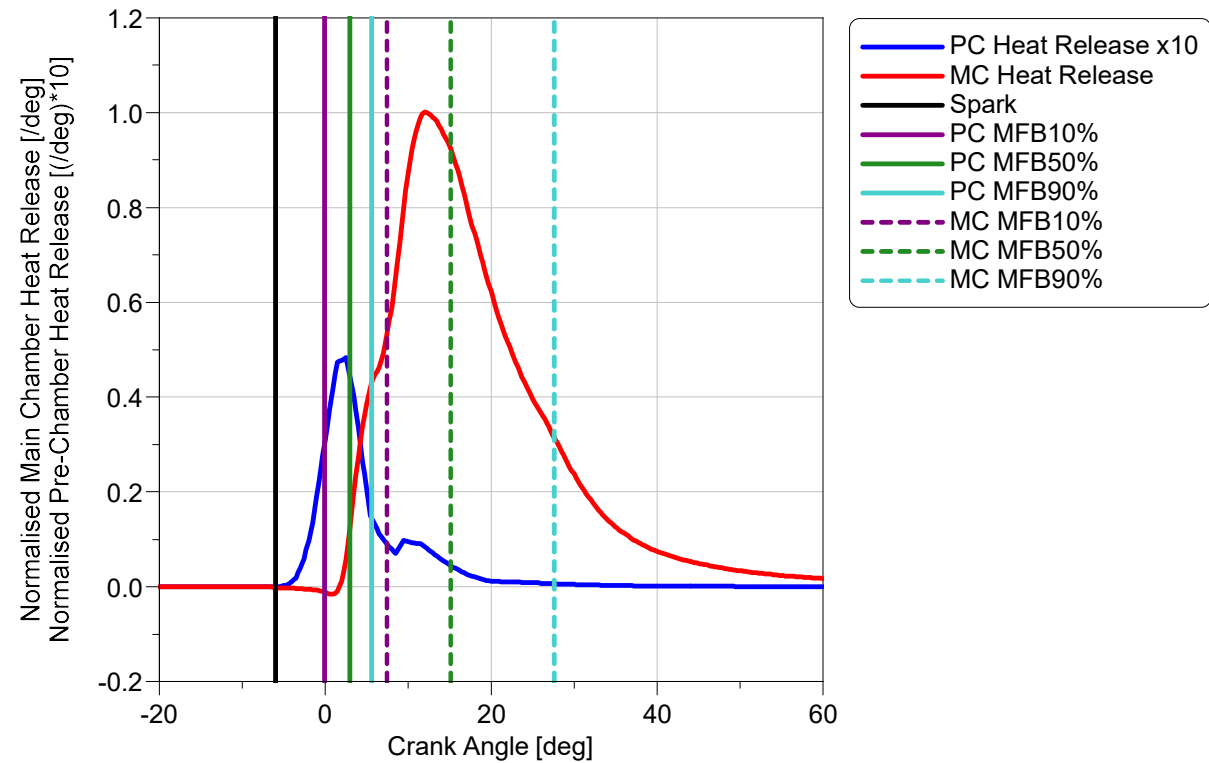


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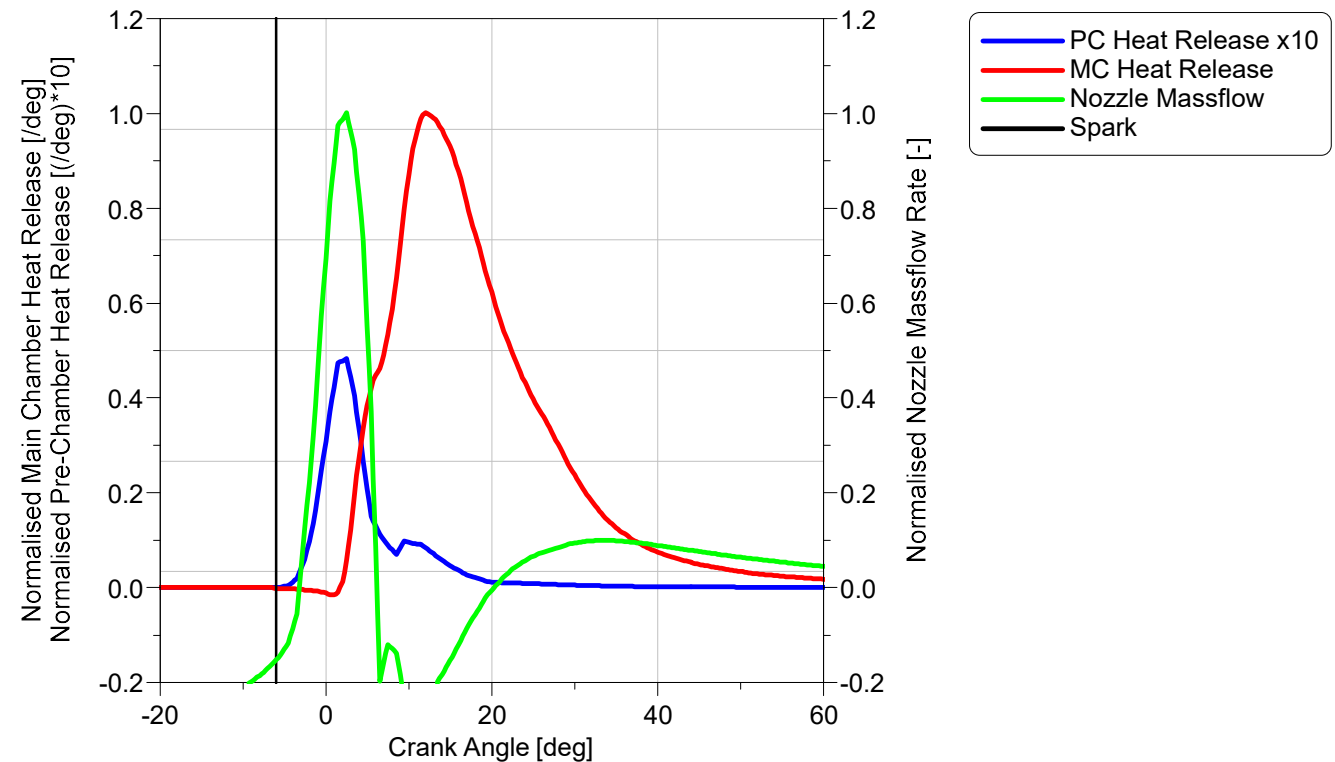


Heat Release Analysis

Typical Results

Simulation Results

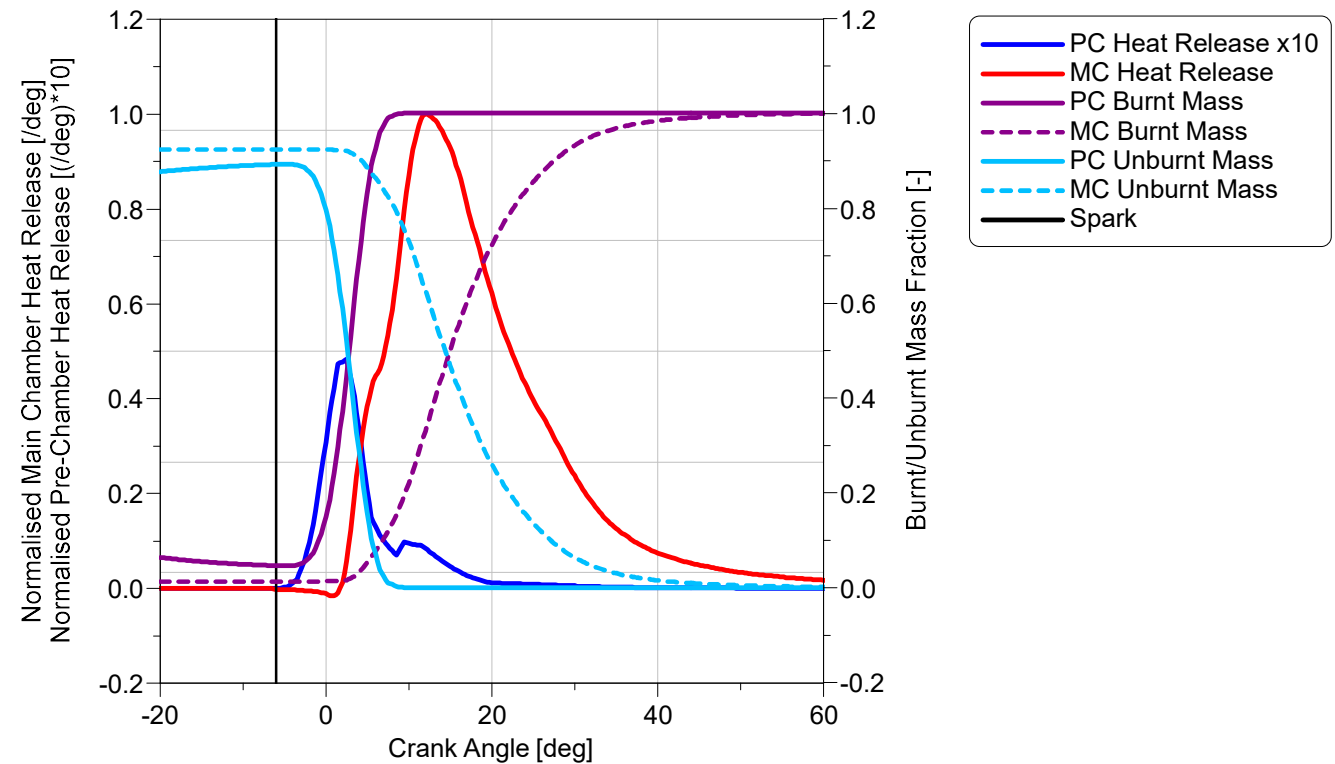
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Heat Release Analysis Typical Results

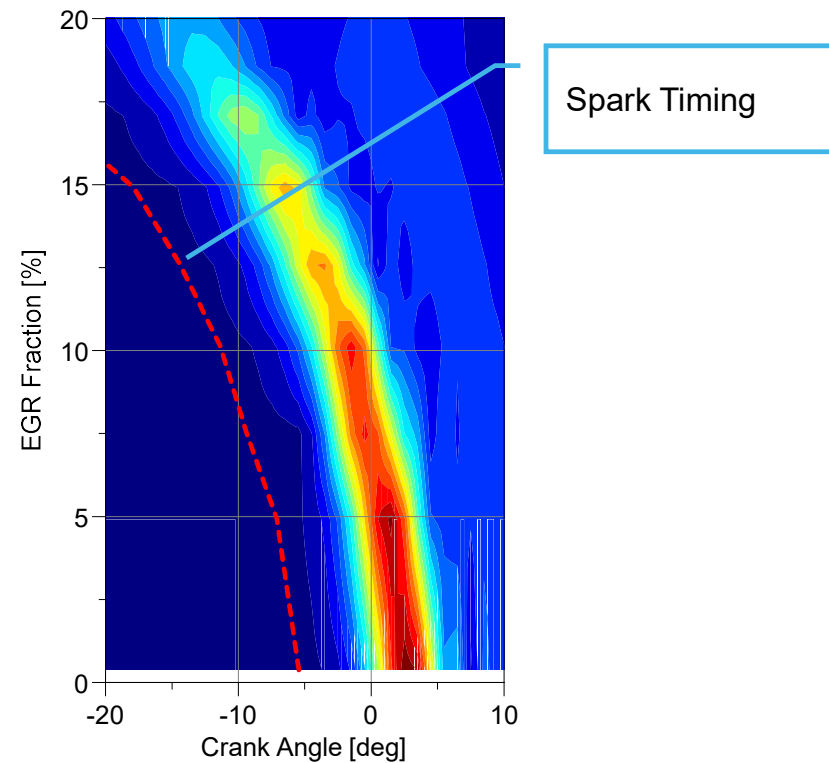
Simulation Results

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Application of TPA Models: Heat Release Analysis: EGR Sweep

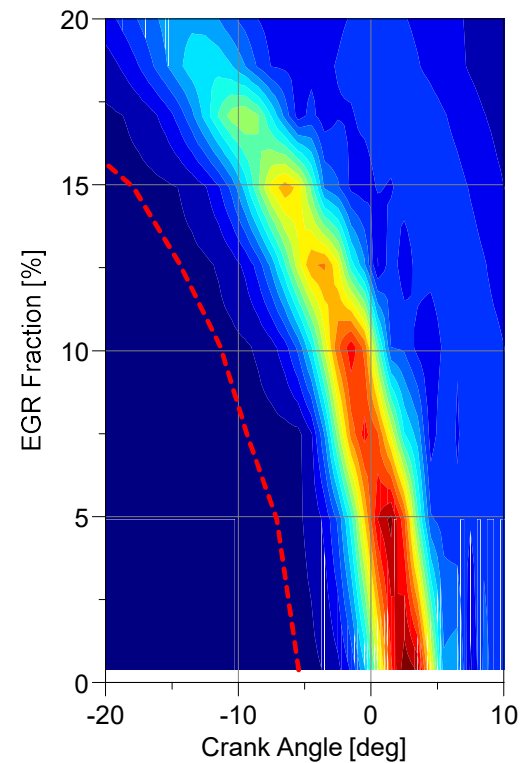
- Increasing EGR requires spark advance
- Slower pre-chamber combustion



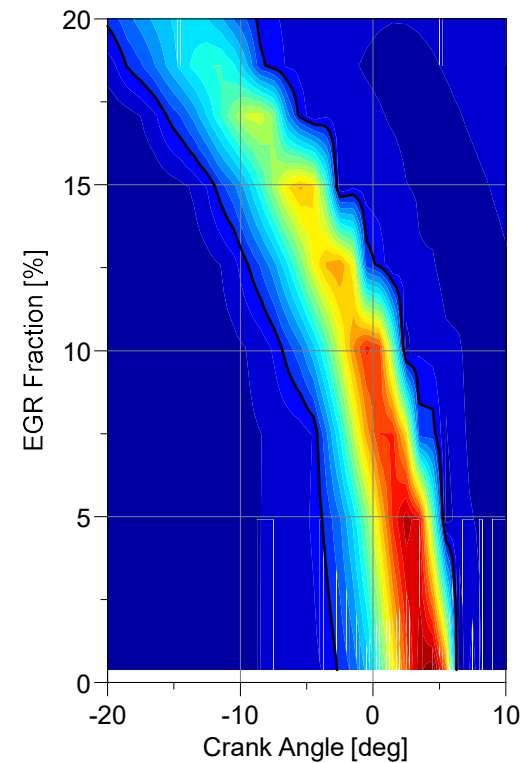
Pre-Chamber Heat Release

Application of TPA Models: Heat Release Analysis: EGR Sweep

- Jet velocity and massflow reduced with increasing EGR



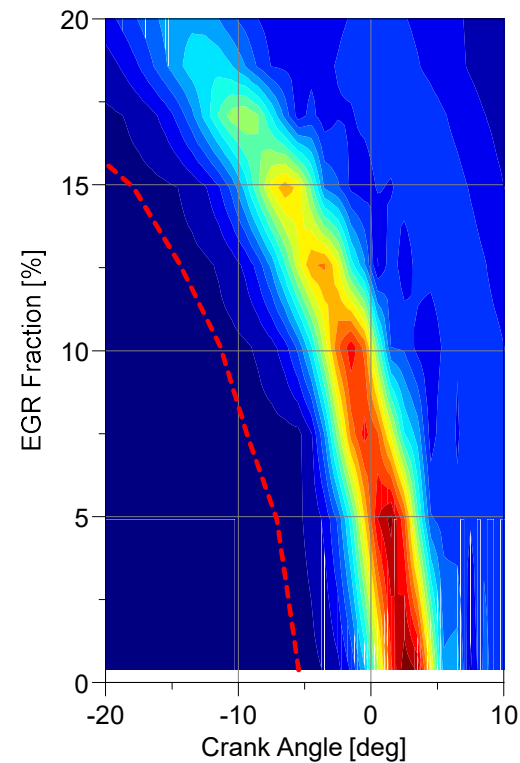
Pre-Chamber Heat Release



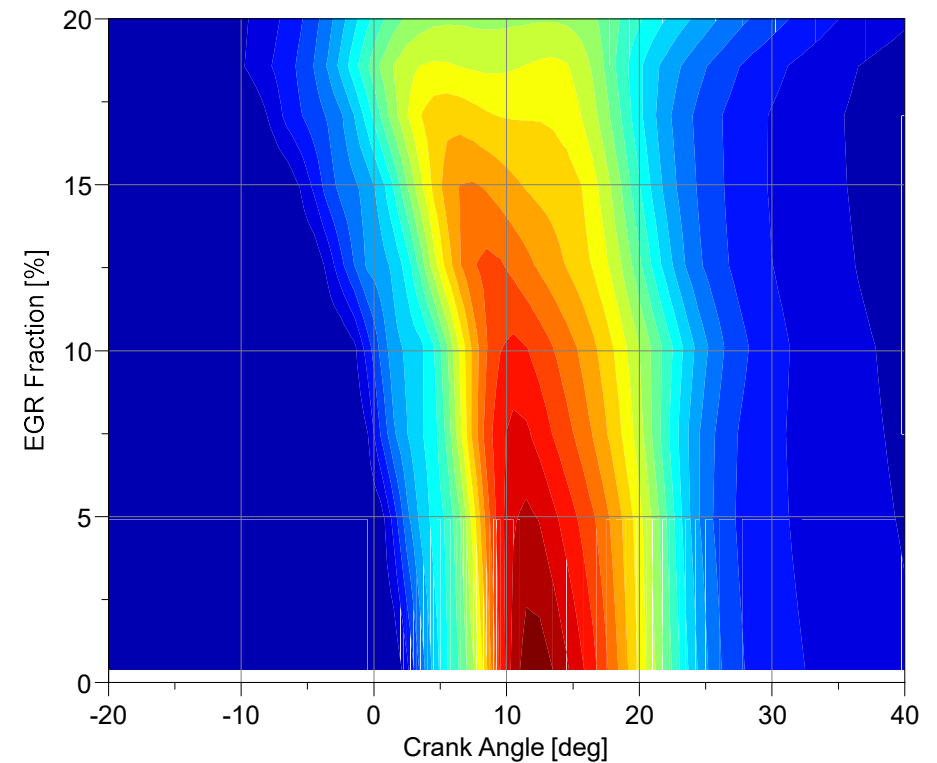
Jet Velocity

Application of TPA Models: Heat Release Analysis: EGR Sweep

- Main chamber combustion timing maintained
- Main chamber heat release slowed only at highest EGR rates



Pre-Chamber Heat Release



Main Chamber Heat Release

Application of TPA Models: Low Load Combustion Stability

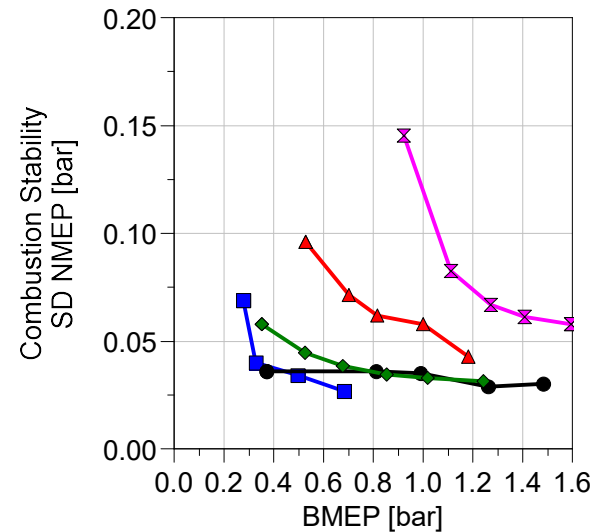
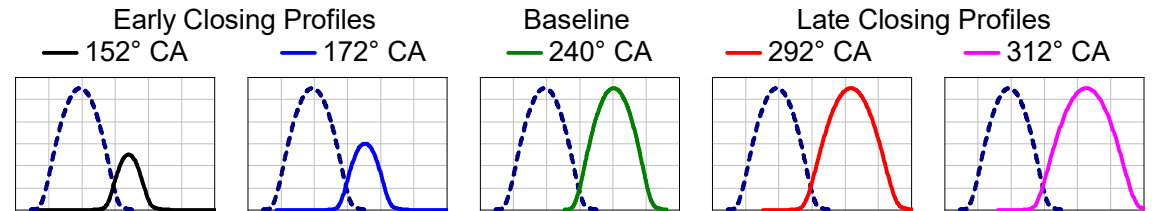
Challenge

- To combine the full load benefits of a pre-chamber with low load stability
- Requires optimised pre-chamber design and gas exchange

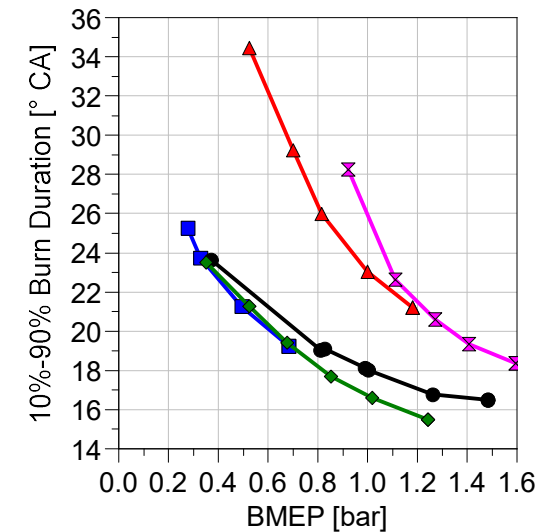
Example: Load Sweep with Early & Late IVC

- Engine tested with 5 different intake cam profiles
- EIVC 152° CA to LIVC 312° CA
- Late inlet valve closing found to cause :
 - Reduced stability
 - Longer burn duration
- Unable to achieve minimum load

TPA performed to understand the cause



Standard Deviation NMEP [bar]

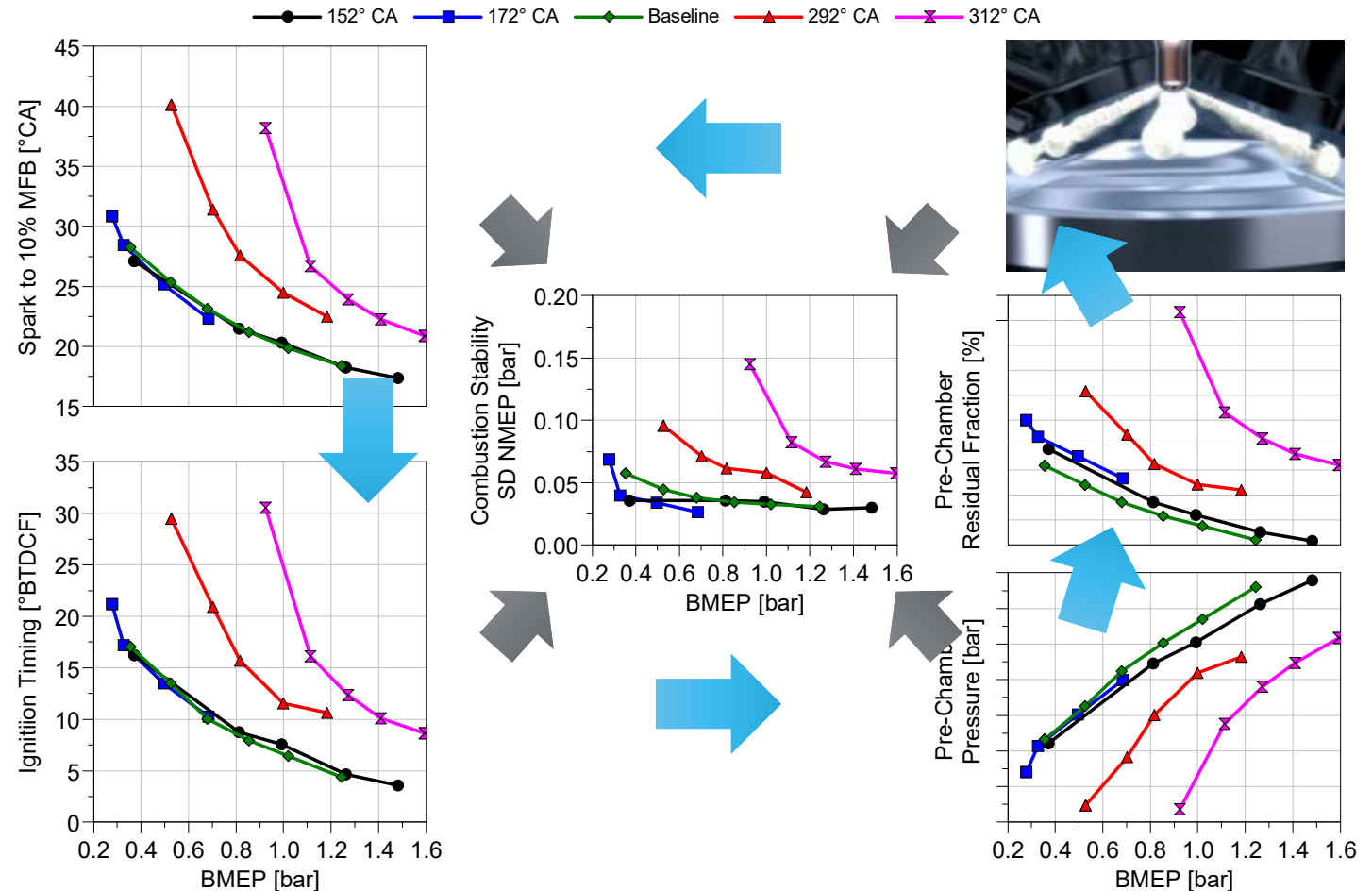


10-90% Burn Duration [°CA]

Low-Load Analysis

Three-Pressure Analysis

- Slower pre-chamber combustion
- Earlier ignition timing
- Reduced pressure & mass of charge
- Higher residual content
- Reduced penetration & effectiveness of jets
- Reduced stability



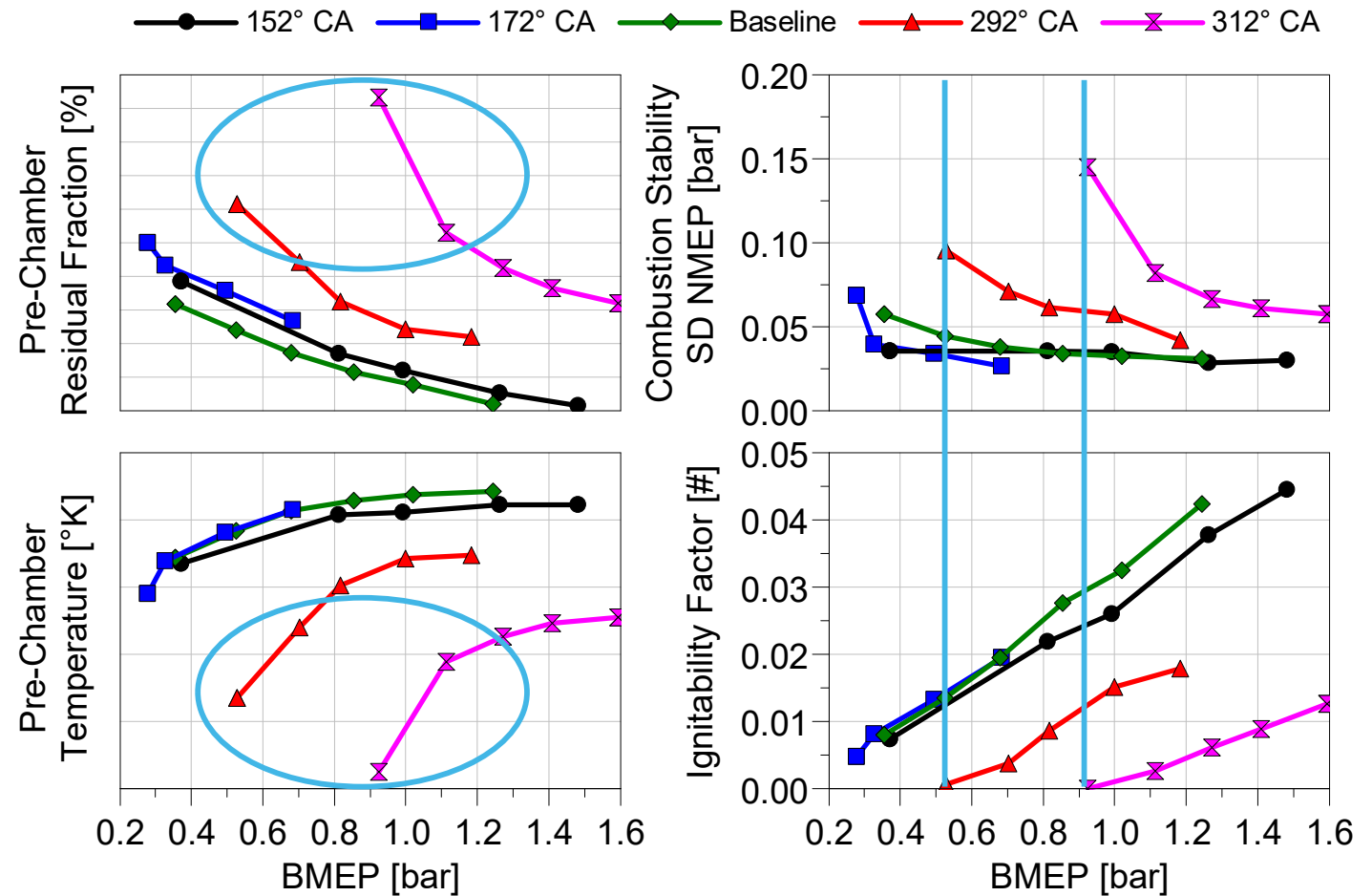
Low-Load Analysis

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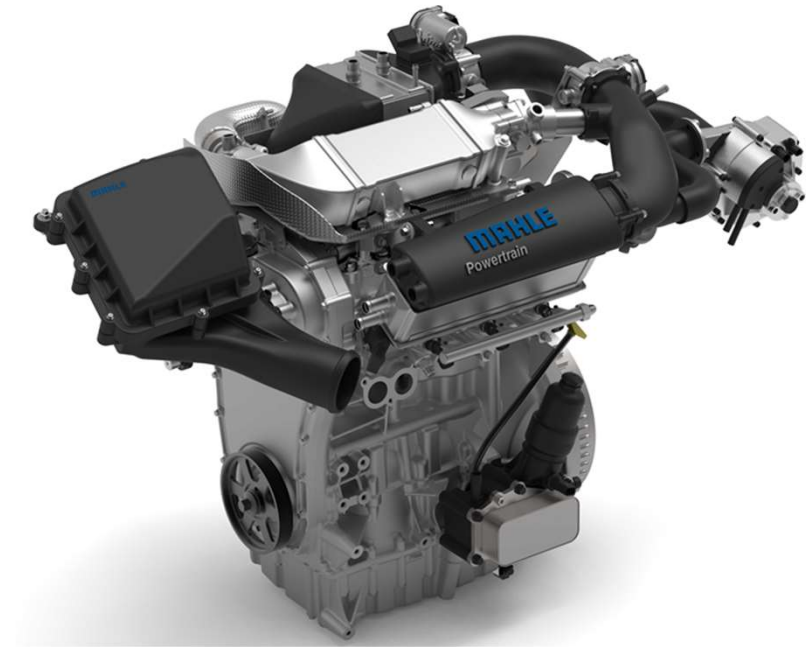
Cause:

- Higher residuals
- Lower temperature
- Combined to give an 'Ignitability factor'
- Indicator of stability limit

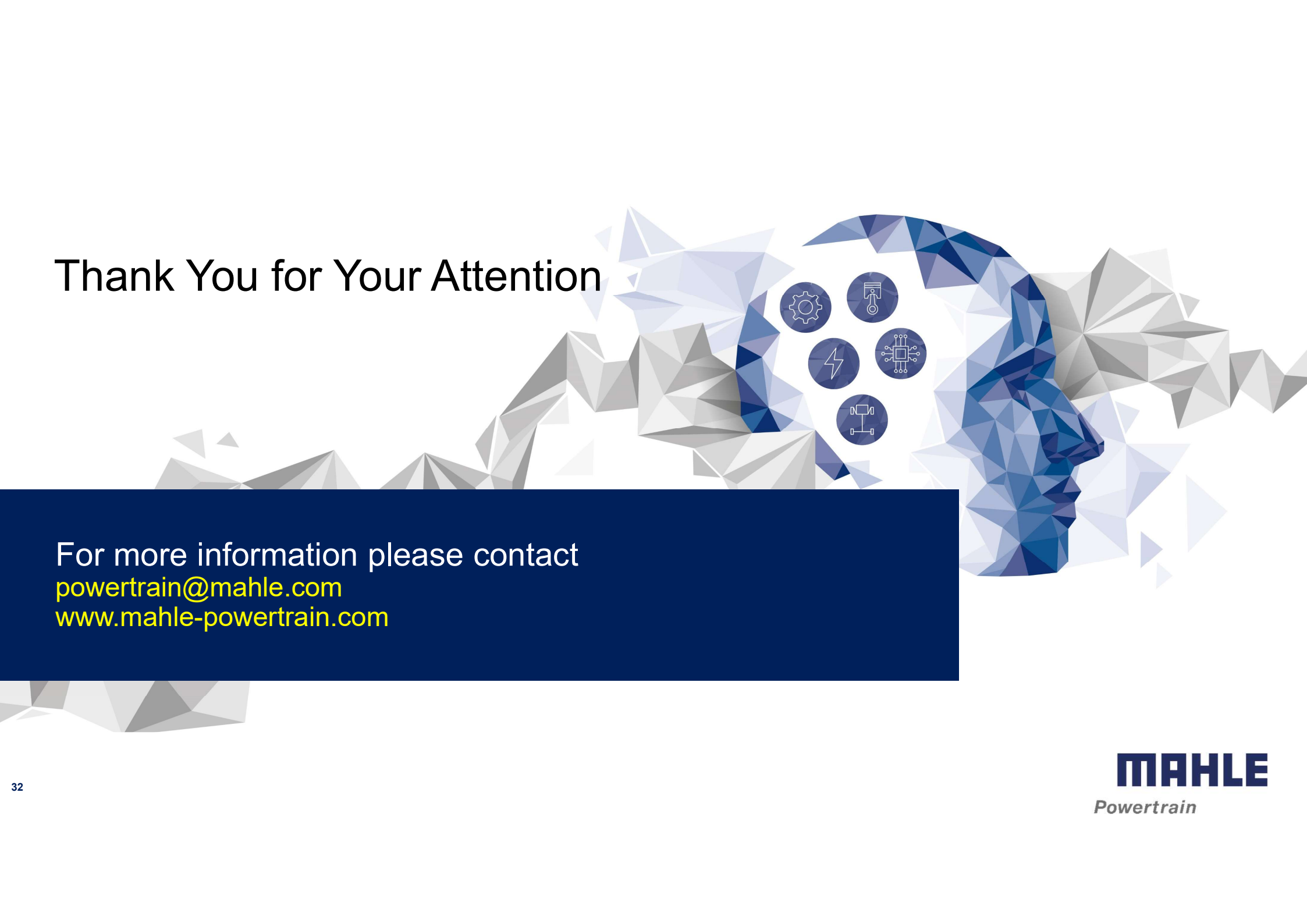


Conclusions

- GT-POWER has been used to perform Three Pressure Analysis of measured cylinder pressure on an engine equipped with a pre-chamber
- Used to determine:
 - Heat release of pre-chamber and main chamber
 - Massflow in and out of pre-chamber
 - Composition of main chamber and pre-chamber at time of spark
- Provides an important diagnostic tool in the evaluation and optimisation of pre-chamber combustion systems



Thank You for Your Attention



For more information please contact
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www.mahle-powertrain.com