

# “Performance, Efficiency and Combustion Characteristics of a Direct Injection Hydrogen IC Engine for Improved Model Development”

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**IAAPS** 



# Motivation – Hydrogen combustion

**Benefits**   **Challenges**



 **Fast / Hot  
Combustion**

   
*Heat Transfer*

 **NO<sub>x</sub>**  
*Emissions*

 **Diluted  
Operation**

*Flame  
instabilities* 

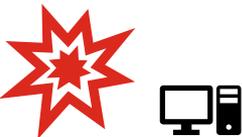
 **Boosting  
Requirements**

  
**Low  
Emissions**

  
**High  
Efficiency**

 **Compression  
Autoignition  
Resistance**

 **Low Ignition  
Energy**

 **Knock / PI**

 **Design  
Challenges**  **Modelling  
Challenges**

  
**High Diffusivity**

  
**Low Density**

  
**Mixture formation**

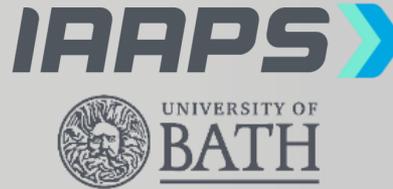
## Project Partners

### Prosperity Partnership with JLR

Engineering and Physical Sciences Research Council funding of ~£5.88M to support Universities of Bath and Oxford



- Combustion system, engine design and development
- Prototype procurement
- Engineering support



- Thermal engine test and analysis
- Development and validation of 1D tools.



- DI Injector supply
- Modelling support for injector position, tumble selection



- Fundamental H<sub>2</sub> flow and combustion experiments
- Optical engine



Digital tool support- StarCCM+



## IAAPS – Designed for collaboration



### University of Bath - Institute for Advanced Automotive Propulsion (IAAPS)/ AAPS Centre for Doctoral Training

Shaping the transition to clean, sustainable affordable mobility.  
Delivering fundamental research and innovation.  
Funded industrial collaborative research projects.  
Training the next generation of leaders and engineers.



### IAAPS Limited

Leading collaborative engagements with industry.  
State-of-the-art physical and virtual research and test facilities.  
Global test centre for propulsion technology.

Today



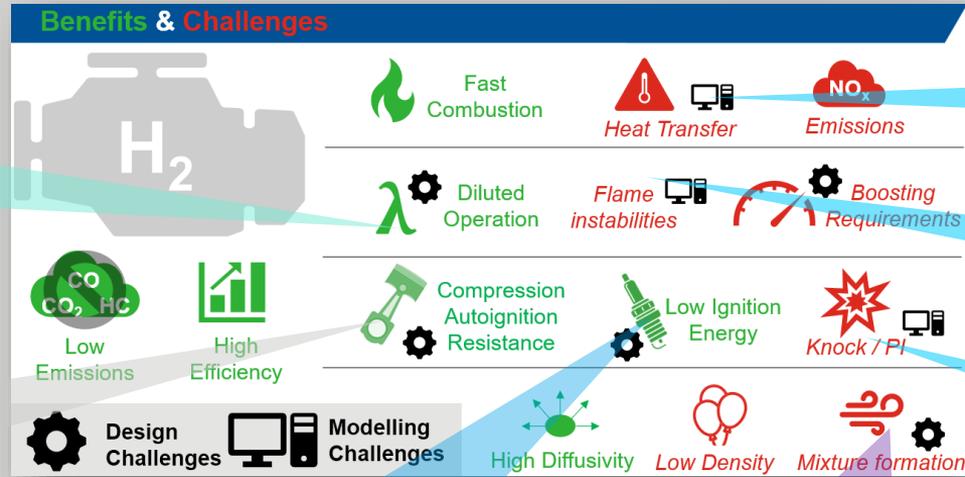
Collaborating with a range of automotive, heavy duty, aerospace and marine organisations and supporting propulsion development programmes across a range of sectors. ISO 9001, ISO 27001, ISO 14001 & ISO 45001 certified

# Objectives – Fundamental Knowledge Gaps To Address

## What knowledge is required to optimise for hydrogen combustion?

**Dilution Strategy**  
*Lean vs EGR*

**Compression Ratio Limits**



**Modelling**

Heat Transfer

Combustion with EGR

Knock / PI

**Ignition**  
Sensitivity to abnormal combustion  
Robustness to H<sub>2</sub>O

**Mixing**  
Tumble vs flow  
Impact of turbulence

## ► Presentation Contents



Thermal engine overview and specifications



Experimental setup



Initial results



Planned / Ongoing Investigations

# Thermal Engine Capabilities Overview

## Tumble Ratio

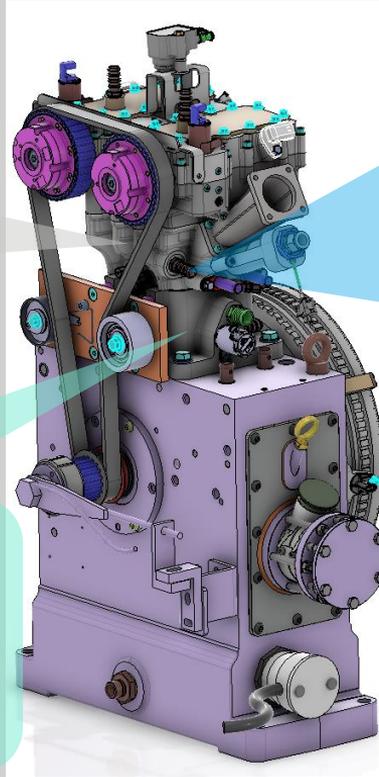
*Low / High*

- Turbulence / Mixing
- NOx Emissions

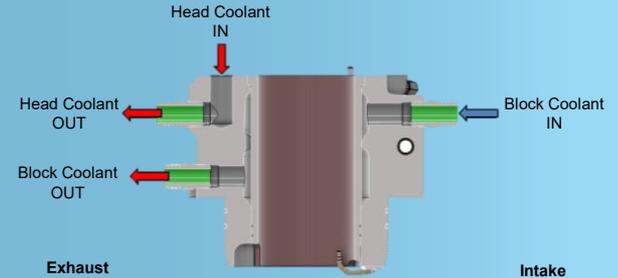
## Compression Ratio

*11:1/12:1/13:1*

- Efficiency / Performance / Knock
- Knock Modelling



## Split Cooling



- Knock and Emissions
- Heat Transfer
- 8 x Thermocouples

## Variable PCJ Pressure

- Heat Transfer
- H2 Emissions – Crevice

## Thermal Engine Specifications

### H2 Single Cylinder Research Engine

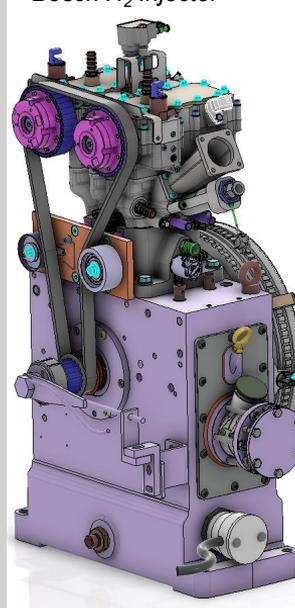
- Ricardo Hydra Diesel Base
- Direct Side Injection
- Central Spark Ignition

#### Engine Specifications

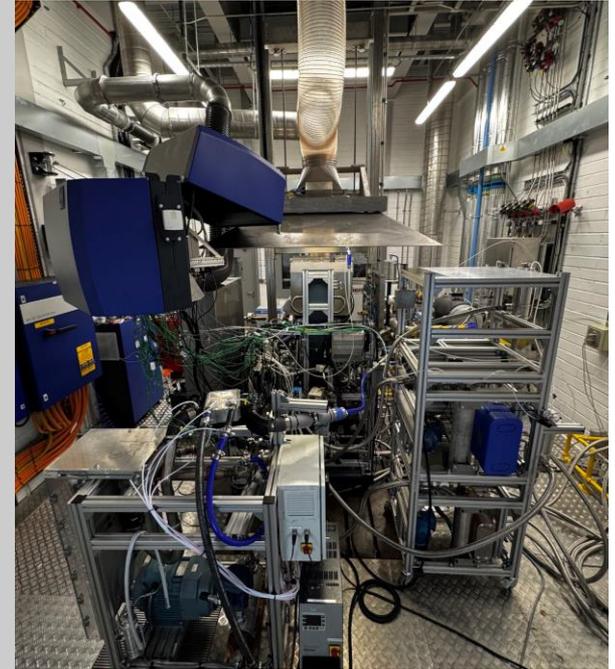
Displacement [cc]	499.44
Stroke / Bore Ratio	1.108
Engine speed [rpm]	1000-4500
Pmax [bar]	185
Pmax mean (300 cycles) [bar]	165
Injection pressure [bar]	10-40
Cam Timing MOP [°CA] BTDC In/Ex	-122 / 120
Cam Phasing Range [°CA] In / Ex	-40 / +40



Bosch H<sub>2</sub> Injector



CAD model of the H<sub>2</sub> SCE



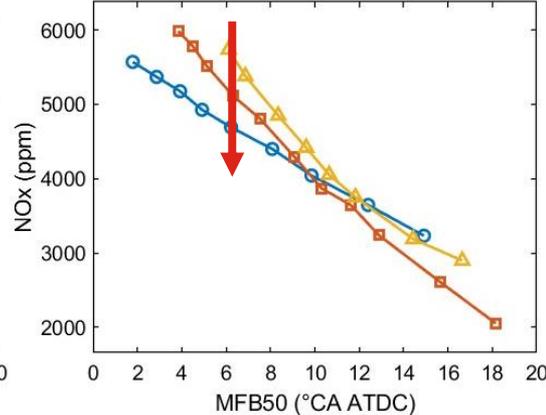
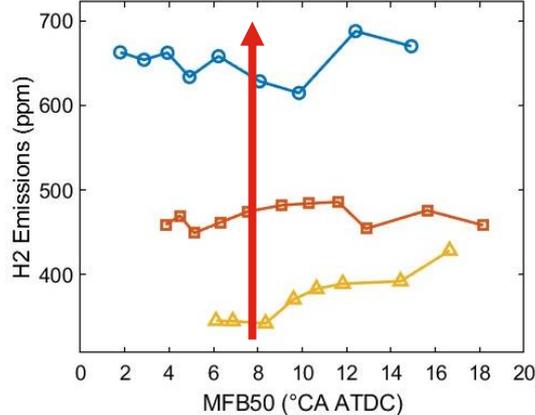
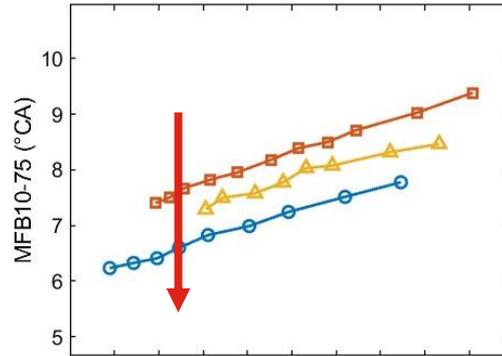
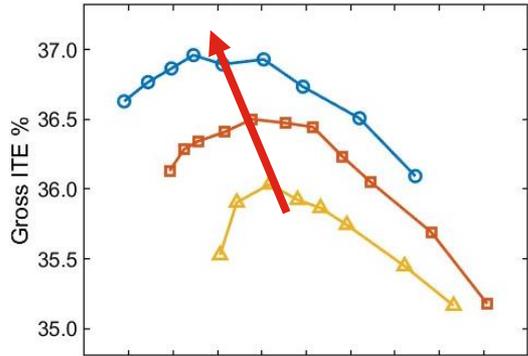
Single Cylinder Research H<sub>2</sub> Engine in test cell at IAAPS

# Fundamental Investigation of Knock Tendency\*

► Spark sweeps with variable SOI: 110/130/150° BTDC

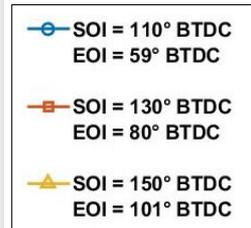
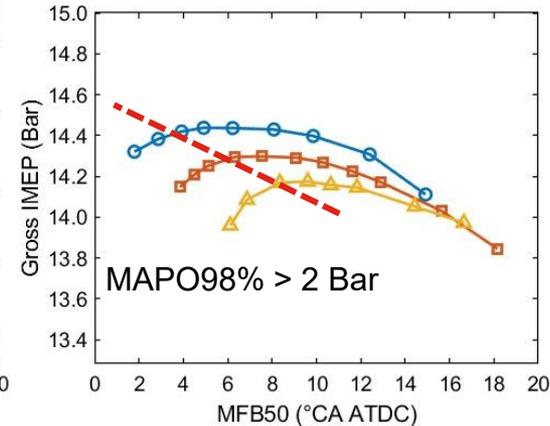
$\lambda = 1.6, 2000\text{rpm}$

1.5 Bar MAP



## Later SOI:

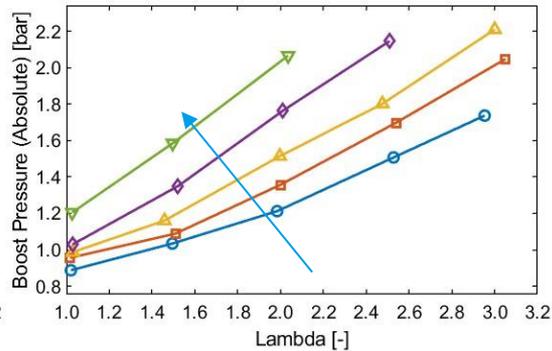
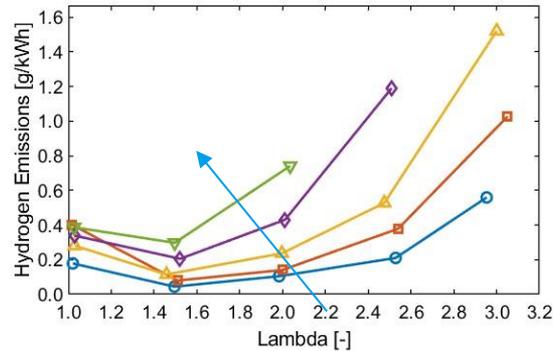
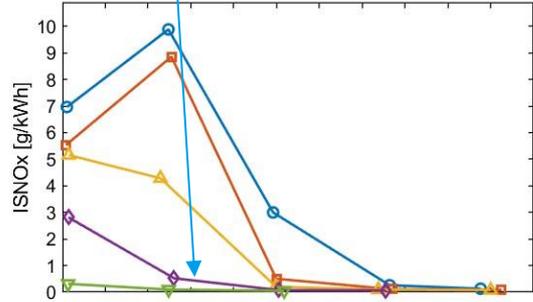
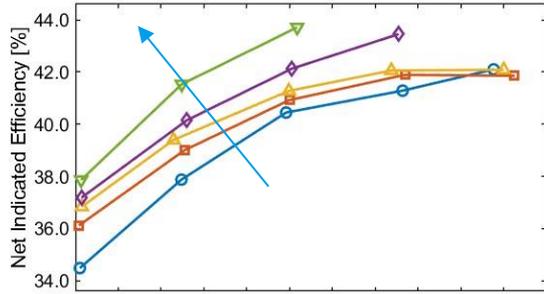
- Higher efficiency
- Shorter burn duration
- Higher H<sub>2</sub> emissions
- Lower NO<sub>x</sub>
- Higher resistance to knock



\* Collaboration with Dr. Alessandro Brusa (University of Bologna)

## Knocking Performance

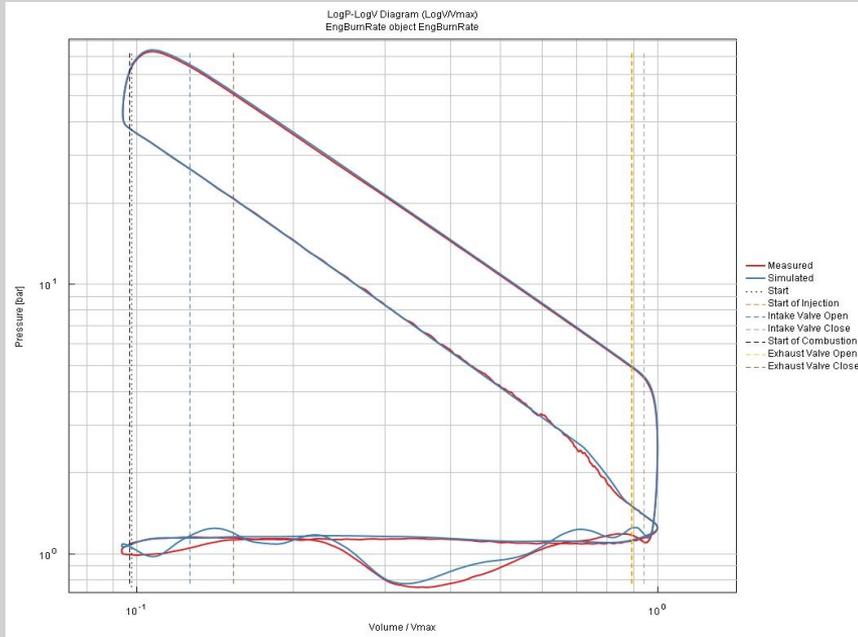
## EGR vs Air Dilution Example @ 15Bar IMEP, 2000rev/min



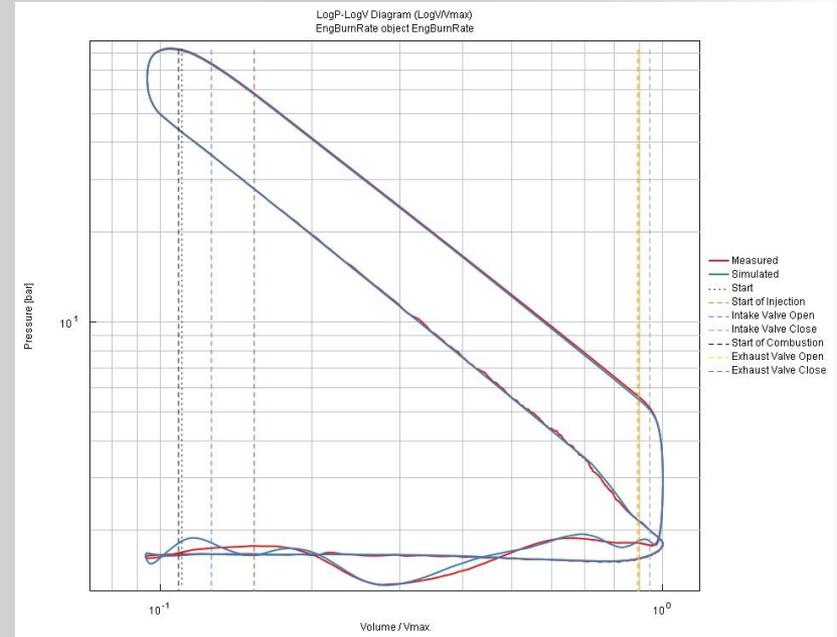
- Increasing EGR improves ITE at equivalent AFR
- EGR drives down Nox emissions
- EGR increases unburned H<sub>2</sub>
- EGR increase boost pressure demand requirements

# 1D Engine modelling correlation

(10 bar IMEP / 2000rpm)

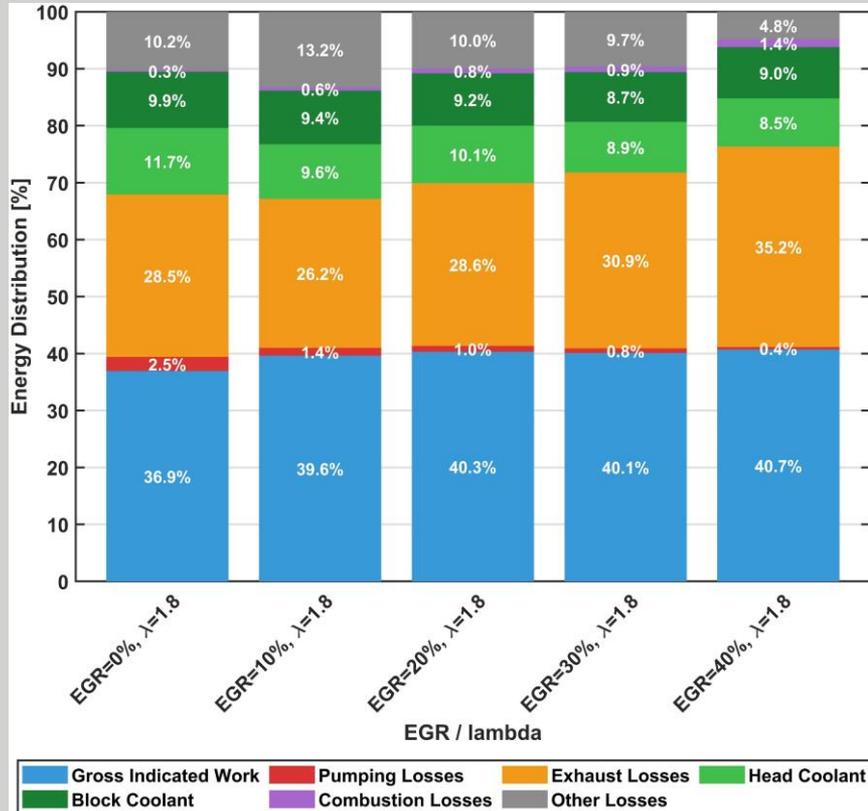


Lambda 2



Lambda 3

## Energy Balance Example- 5bar IMEP, 2000 rev/min



- Increasing EGR improves indicated work
- Exhaust losses help drive boosting system
- Slight increase in combustion losses due to unburned H<sub>2</sub>
- Coolant losses reduced due to cooler combustion temperatures
- Other losses include heat to oil, PCJs etc.

# Improved Heat Transfer Modelling

<https://doi.org/10.1115/1.4067990>

RESEARCH-ARTICLE

## Improving the Predictive Capability of Empirical Heat Transfer Correlations for Hydrogen Internal Combustion Engines

Dominic Parsons, Hao Yuan, Sam Akehurst, Stefania Esposito

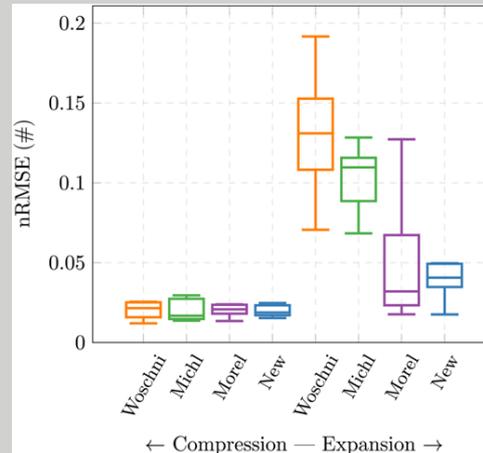
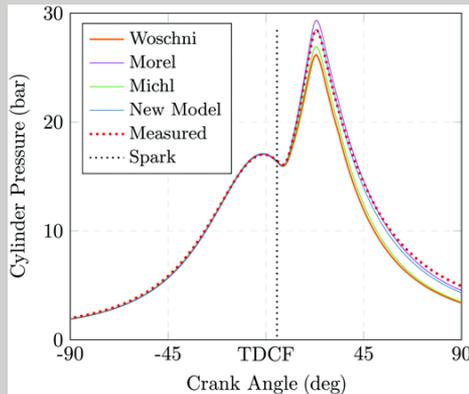


+ Author and Article Information

J. Eng. Gas Turbines Power. Oct 2025, 147(10): 101004 (10 pages)

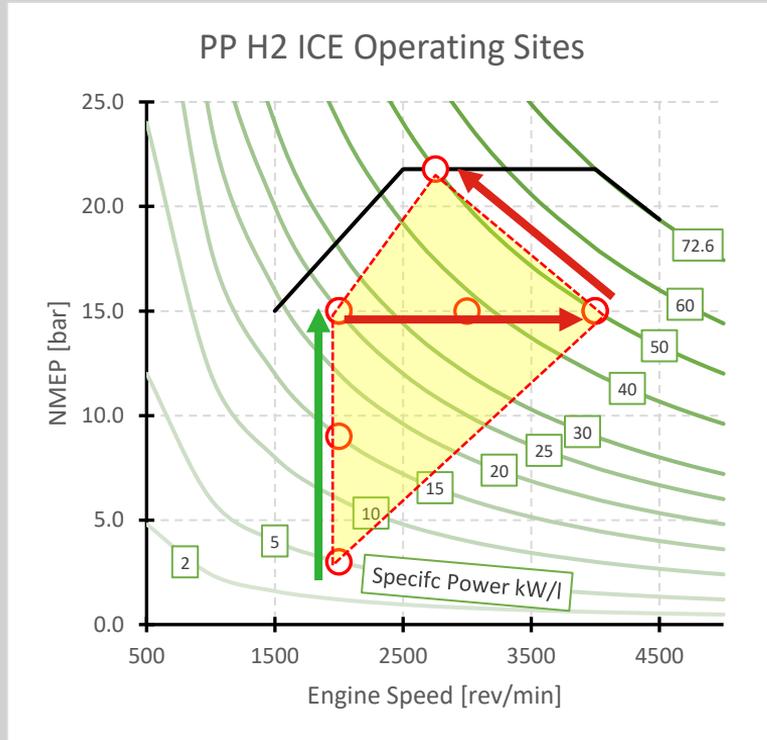
Paper No: GTP-24-1812 <https://doi.org/10.1115/1.4067990>

Published Online: March 18, 2025 Article history



- Development of an improved heat transfer correlation for hydrogen engines based on CFR engine experiments
- Hydrogen low quenching distance typically change local heat transfer correlations
- Different lambda values considered
- Model now being evaluated on latest data sets

## Planned Investigations



Higher speeds and loads

- **Higher Injection Pressure**
  - 25 - 40 bar
- **Low tumble cylinder head**
  - Effect on mixing (Current Build)
- **Higher compression ratios**
  - Thermal efficiency
  - Knock / PI
- **Dilution Study (EGR)**
  - Effect on combustion / emissions
  - Boost requirement
- **AVL VisioKnock**
  - Knock / PI
  - Combustion modelling
- **Heat Transfer**

## Conclusions

- A bespoke single cylinder DI H2ICE research engine has been developed and evaluated at a range of operating conditions to generate robust validation data to improve 1D engine modelling capabilities and demonstrate potential of H2ICE for power density, efficiency and engine out emissions
- A range of data has been collected across speed and load (5, 10, 15 bar IMEP) to study combustion performance
- Both air dilution and EGR have been studied to understand the trade-offs in their influence on combustion performance, emissions and Knock
- Low, near zero Nox emissions have been achieved at lean conditions, with EGR showing to be a significant factor allowing near zero NOx at less lean conditions
- Indicated Thermal efficiencies above 43% have been demonstrated and a number of actions have been identified to improve efficiency further
- A robust TPA model of the engine has been developed in GT-Suite
- Ongoing collaborations to develop predictive
- An improved heat release model taking into account the properties of hydrogen has been developed and integrated in GT-power
  
- Future work will study
  - Lower tumble higher flow head (current build configuration)
  - Changes in compression ratio

# Thank You Any Questions?

## Acknowledgments

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