UNIVERSITY OF LEEDS

Turbulence Induced Cyclic Variation of Combustion

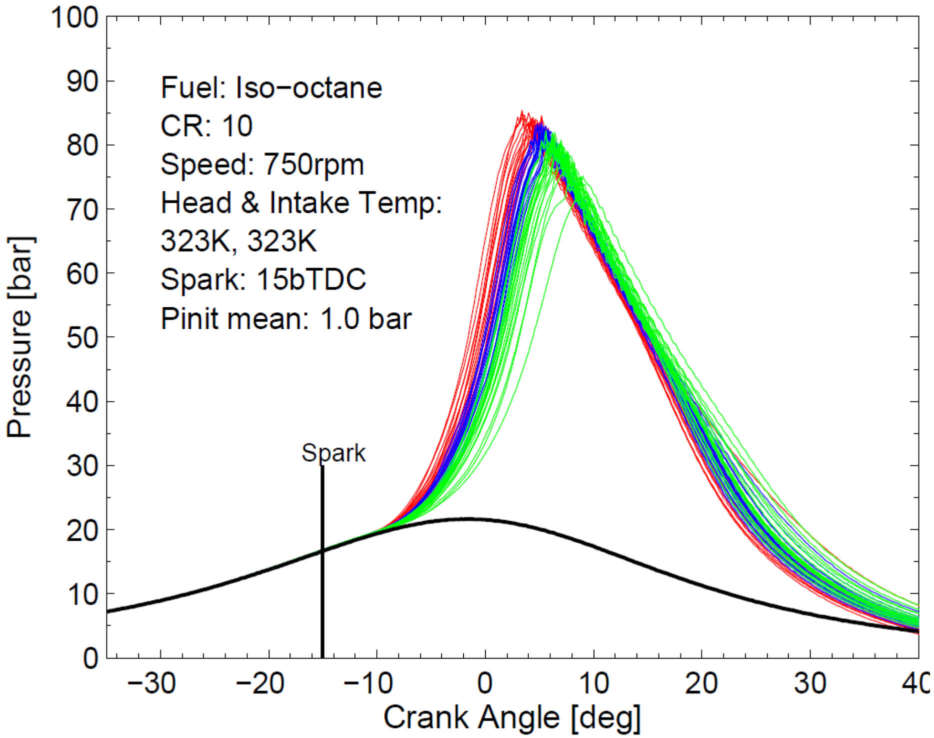
Jeongdo Kim[1], Wankang Zhang[1], Alexey Burluka[2] and Junfeng Yang[1*]
[1] School of Mechanical Engineering, University of Leeds,
[2] Deprt. of Mechanical and Construction Engineering, Northumbria University
Email: J.Yang@leeds.ac.uk

UK Consortium on Turbulent Reacting Flows (UKCTRF) Annual Meeting,
Cambridge University, 12th-13th Sep 2018

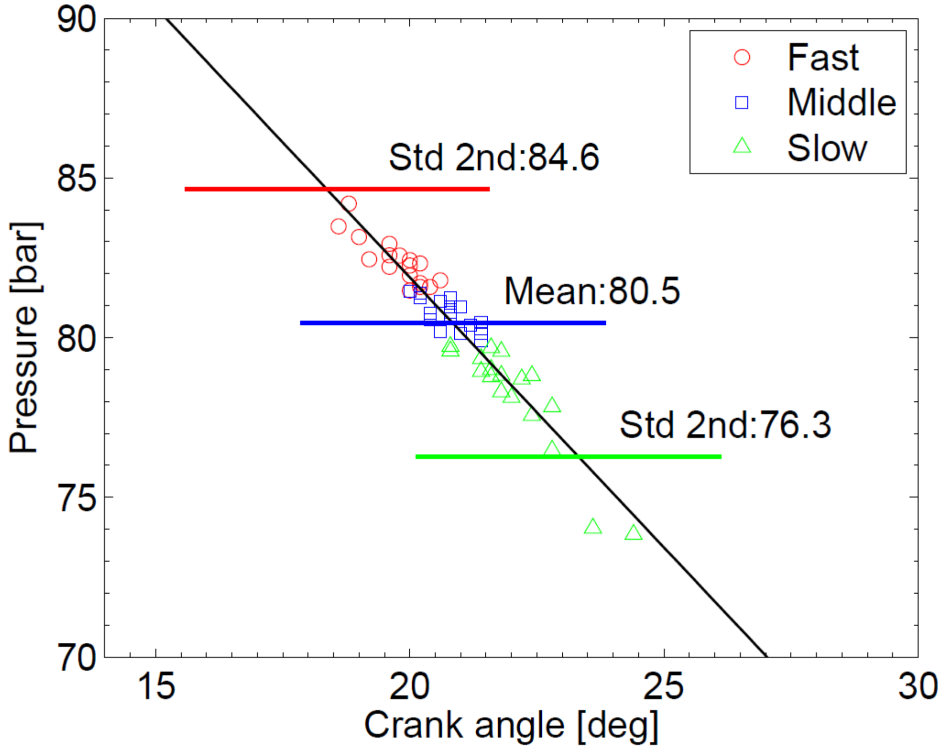
Outline

- Background
- Experimental setup
- Results
- Conclusion
- Future work

Cyclic Variation of Combustion



Pressure traces for a naturally aspirated two-stroke SI engine



Maximum pressure as a function of the crank angle

Hussin, A.M (2012). *New and Renewable Energy: Renewable Fuels in Internal Combustion Engines*, PhD thesis, School of Mechanical Engineering, The University of Leeds

Possible Causes of the Cyclic Variability

- **Variation of the mean flow field**
  - Swirl
  - Tumble
- **Variation in turbulence**
  - Integral scales
  - Root-mean-square velocity
- **Variation of mixture composition**
  - Equivalence ratio of the inhaled fresh charge
  - Amount of the trapped residuals
  - Amount of the recirculated exhaust (EGR)
- **Variation of the flame initiation**
  - Spark energy
  - Composition at the point and instance of ignition
- **Any other thing … …**

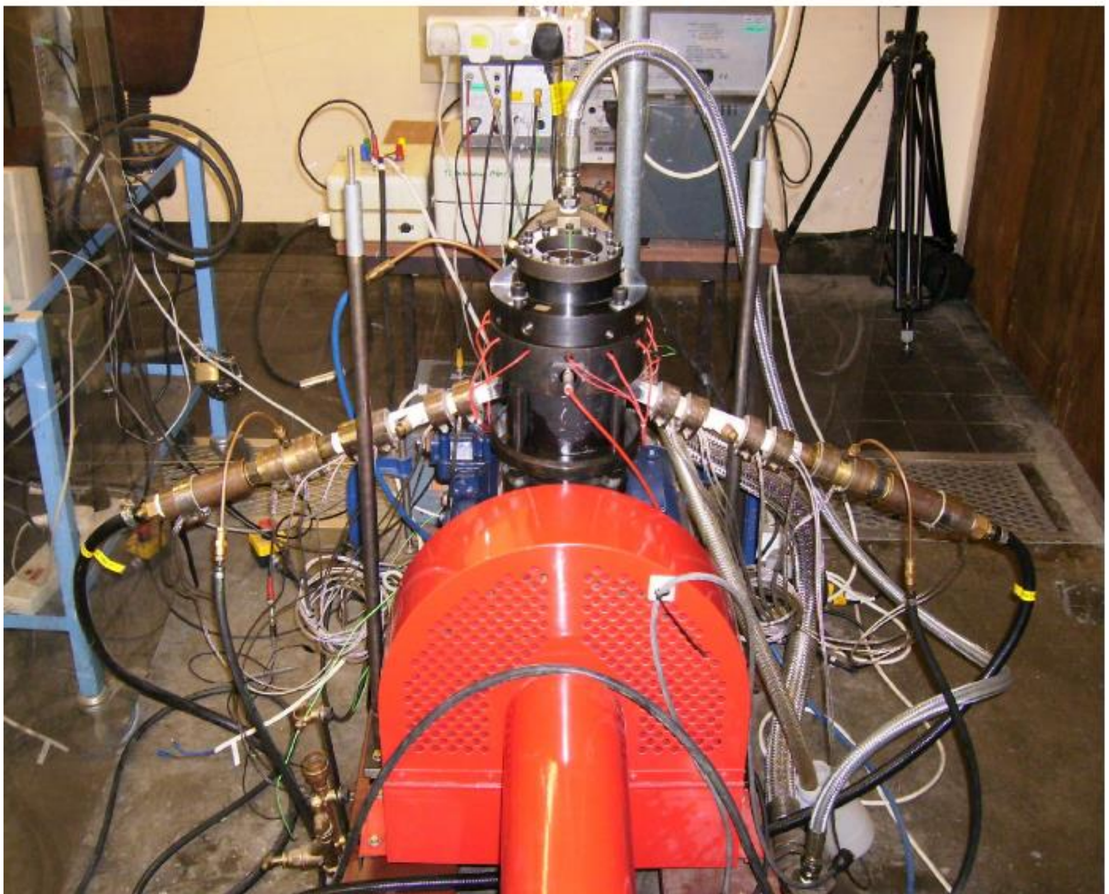
Objectives

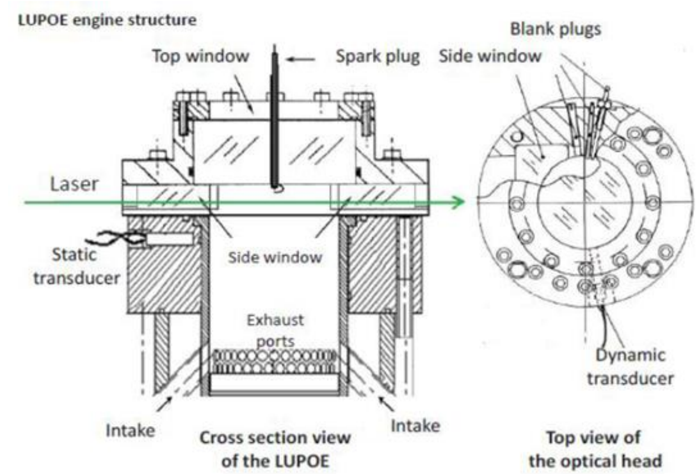
- Investigate the dynamics of turbulent free flame
- Provide closer examination on turbulent premixed flames
- Understand the impact of turbulence on cyclic variation of combustion

Experimental Setup

UNIVERSITY OF LEEDS

LUPOE2D - Leeds University Ported Optical Engine version 2 with Disc-head



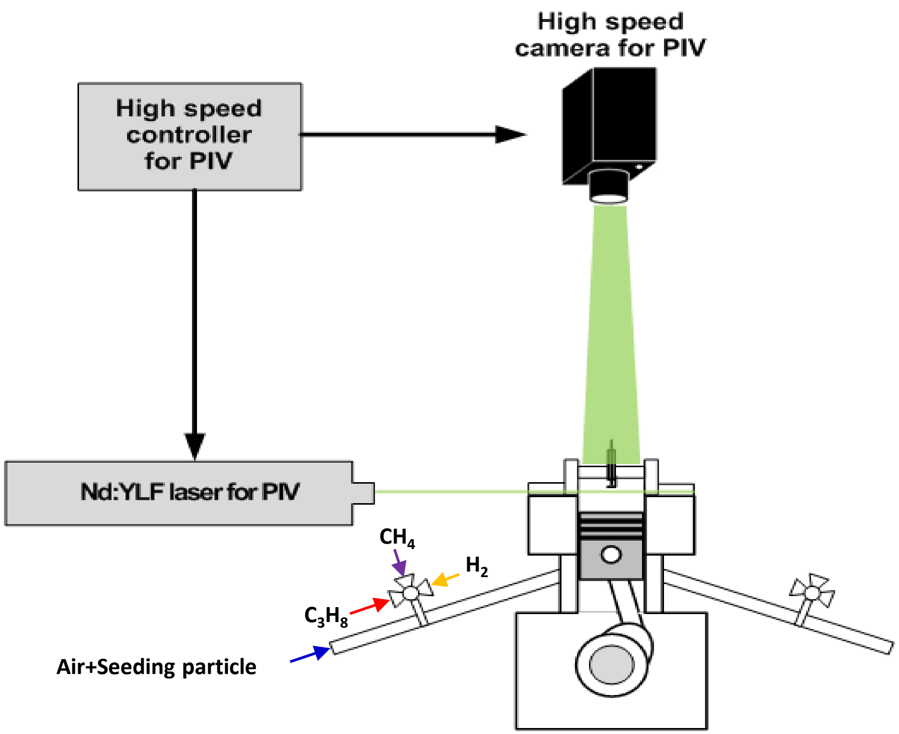


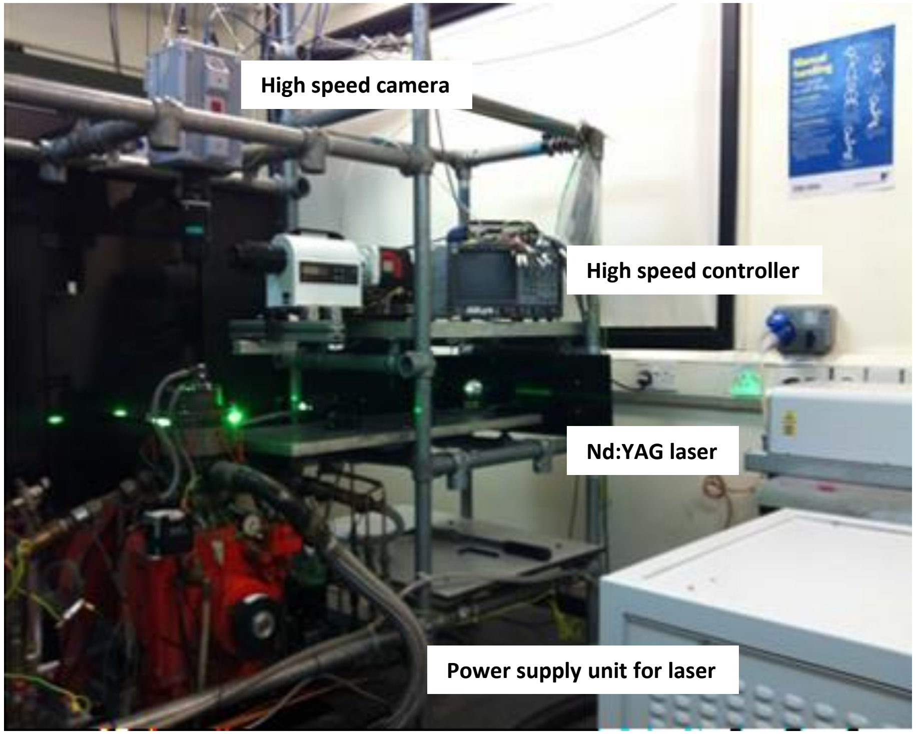
Bore (mm)	80
Stroke (mm)	110
Con Rod Length (mm)	232
Clearance Height (mm)	8
Compression Ration	11.47
Inlet Ports Opening/Closure CA (deg)	101.2
Exhaust Port Opening/Closure CA (deg)	127.6

PIV Setup

UNIVERSITY OF LEEDS

Experimental setup for PIV system to record flame propagation and flow field

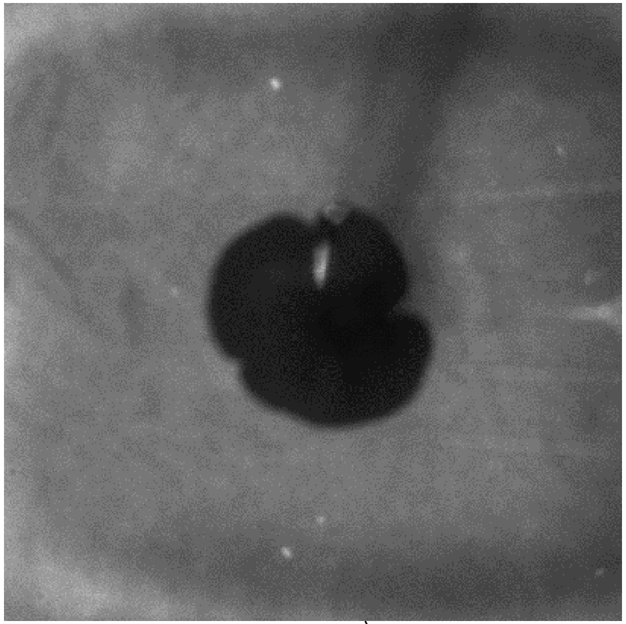




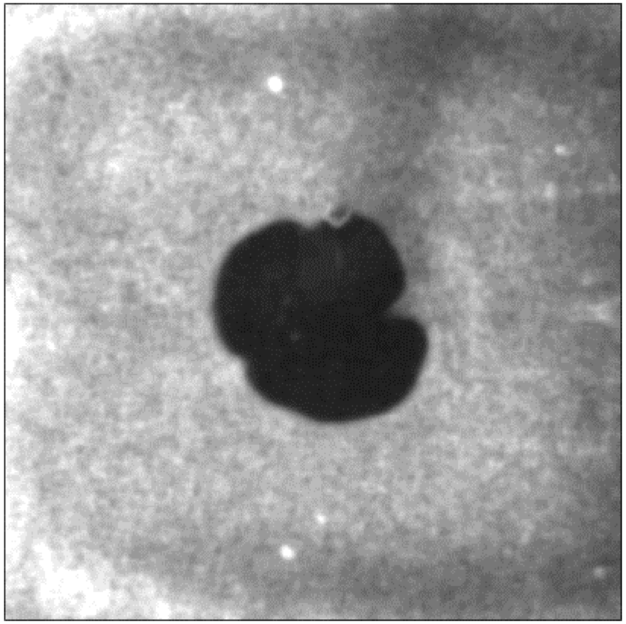
Imaging Processing

UNIVERSITY OF LEEDS

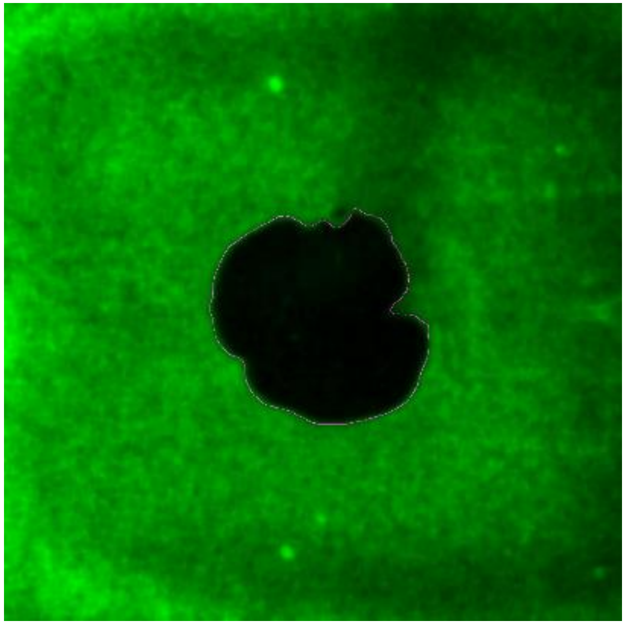
Raw image

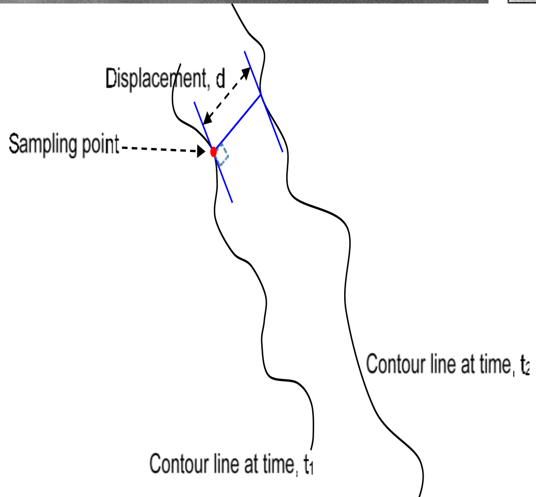


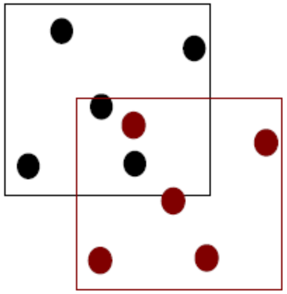
Pre-processed image



Superimposed image







- Flame speed at each sampling point

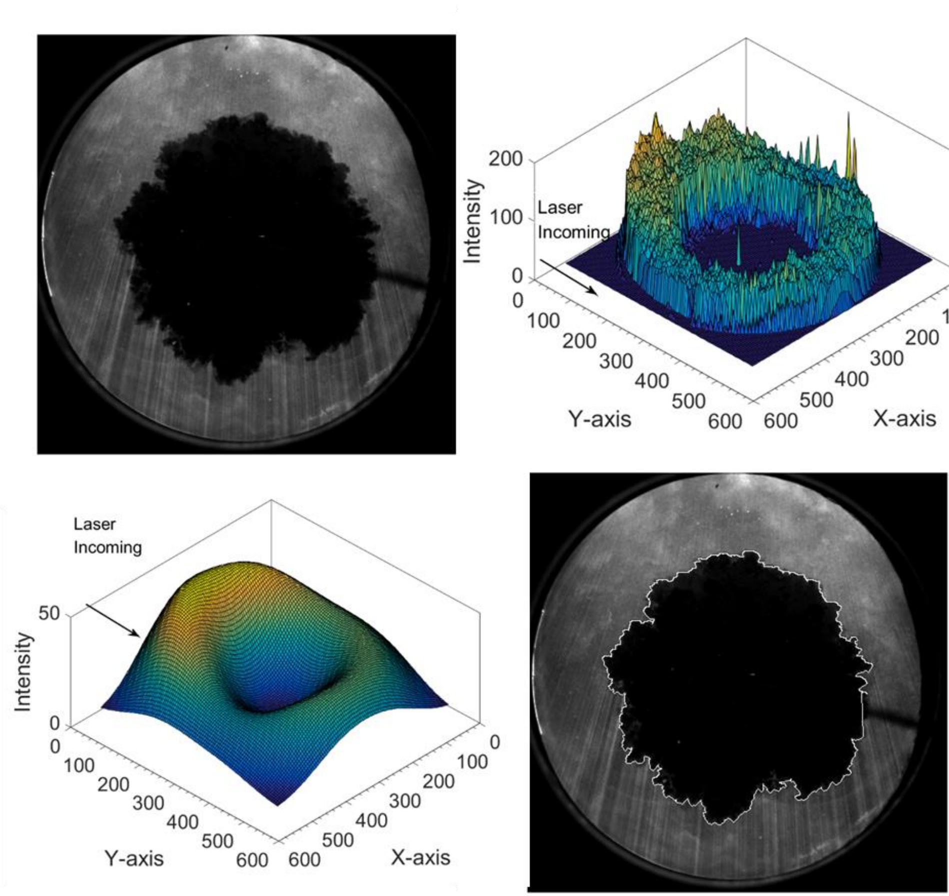
$$S_n = \frac{d}{t_2 - t_1}$$

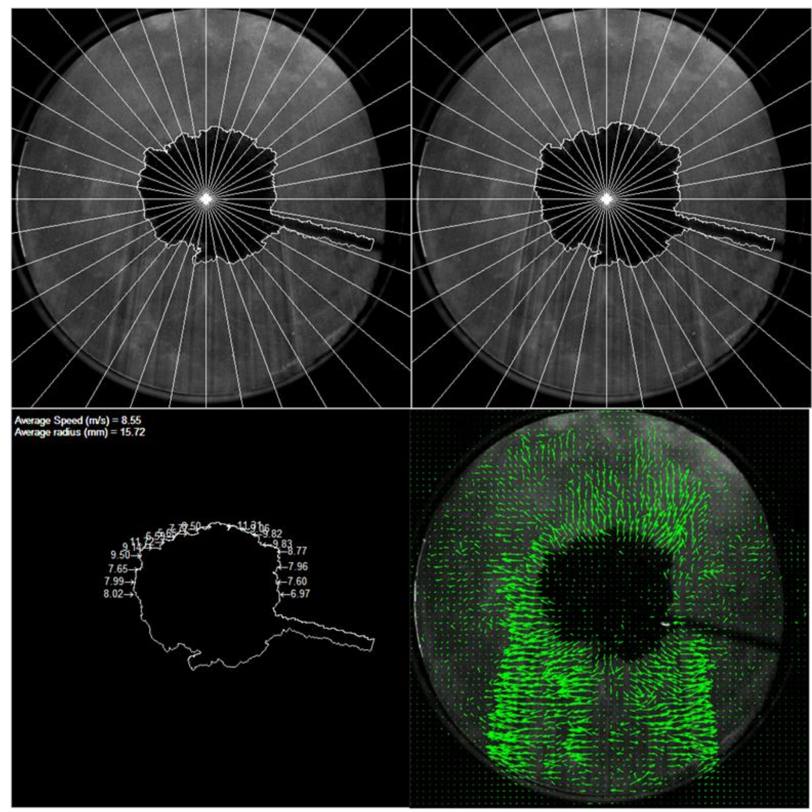
- Mean flame speed at each flame image

$$\overline{S_n}(t) = \frac{1}{n}\sum_{k=1}^{n} S_{n_k}(t)$$

Imaging Processing

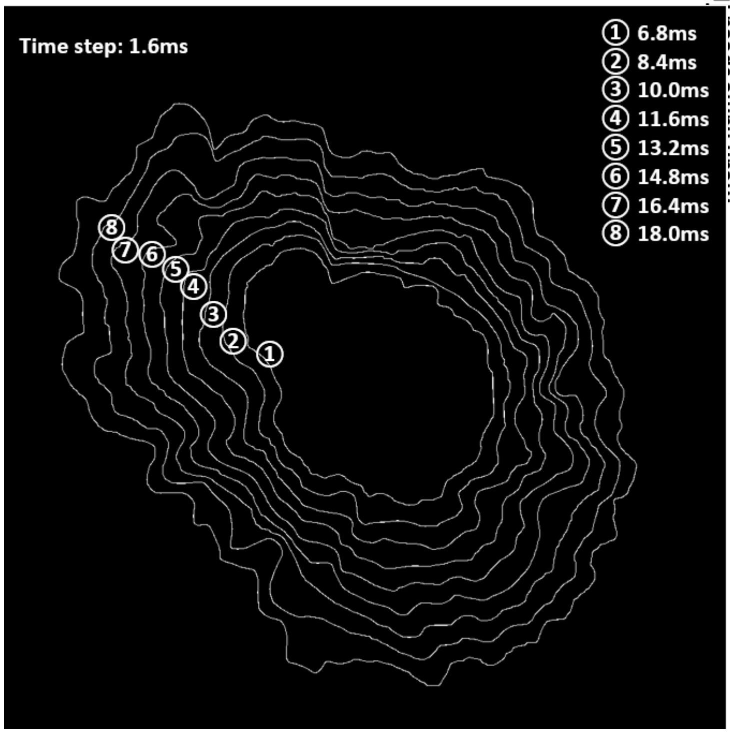
UNIVERSITY OF LEEDS

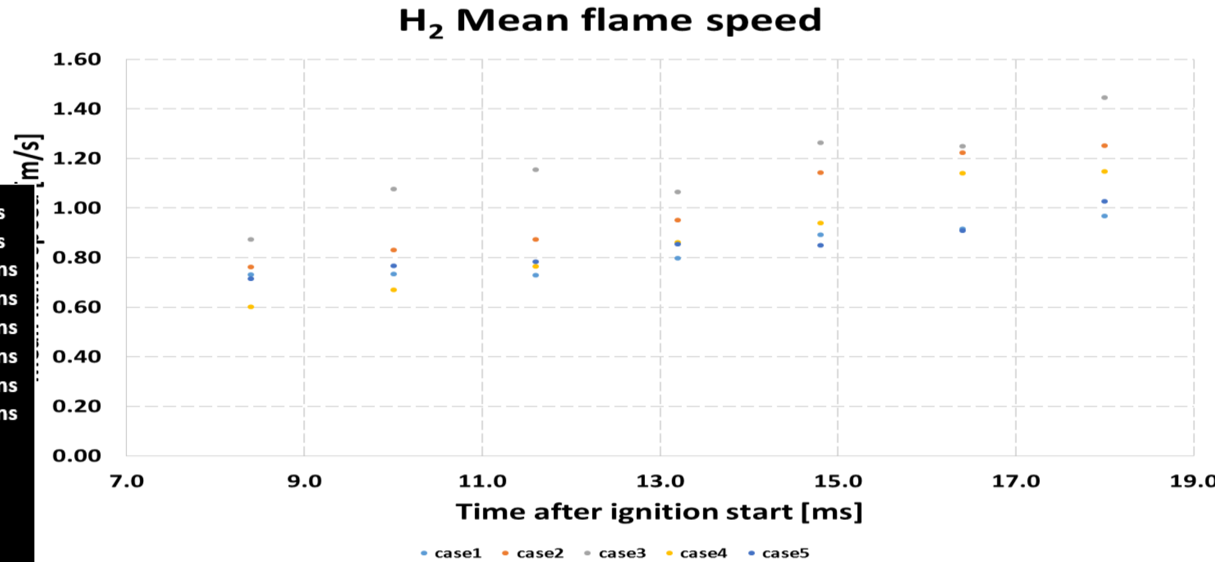


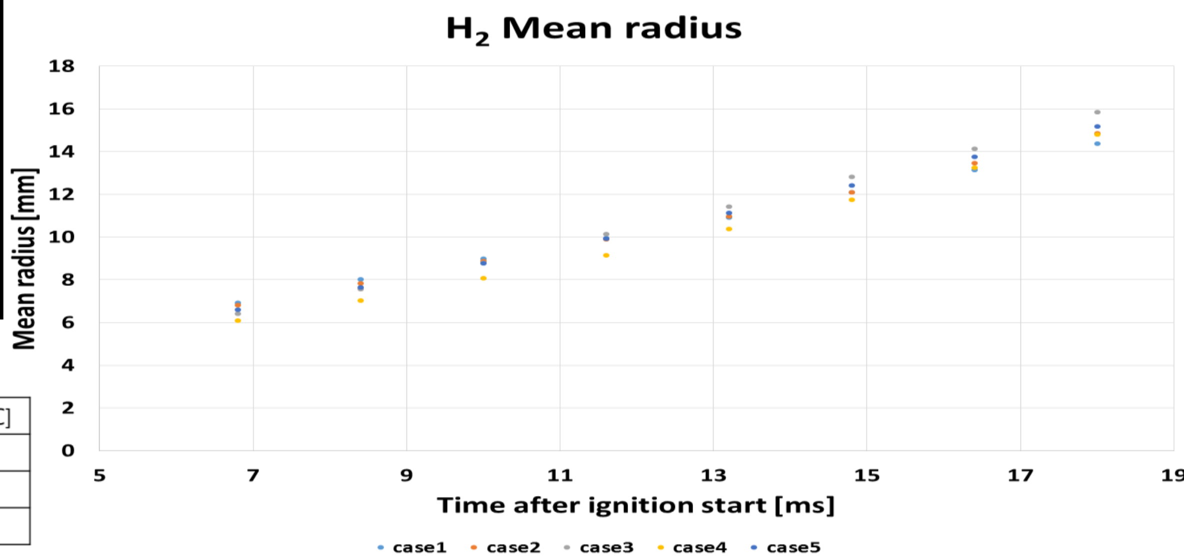


Results : Laminar Flame Propagation

UNIVERSITY OF LEEDS







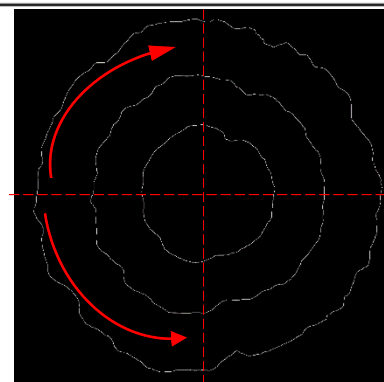
	Pressure [bar]	Temperature [K]	Ignition timing [ºCA bTDC]
Case 1	4	414	36.2
Case 2	5	439	27.6
Case 3	6	460	22.0

Results: Laminar Flame Propagation

UNIVERSITY OF LEEDS

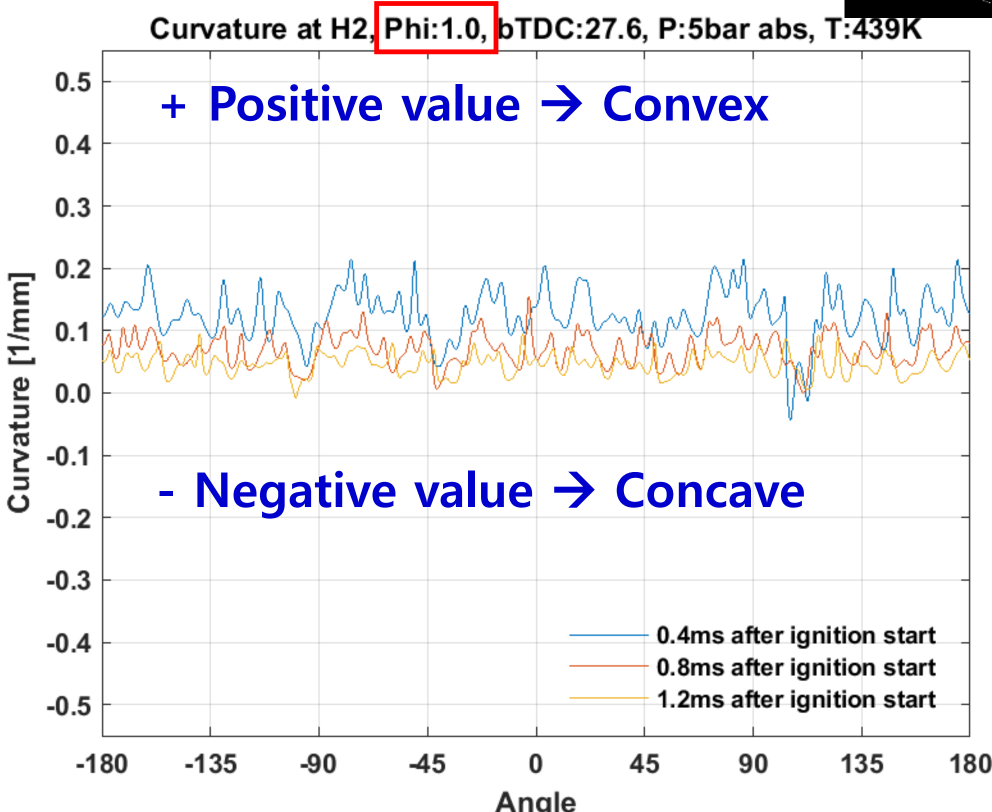
+ Positive degree

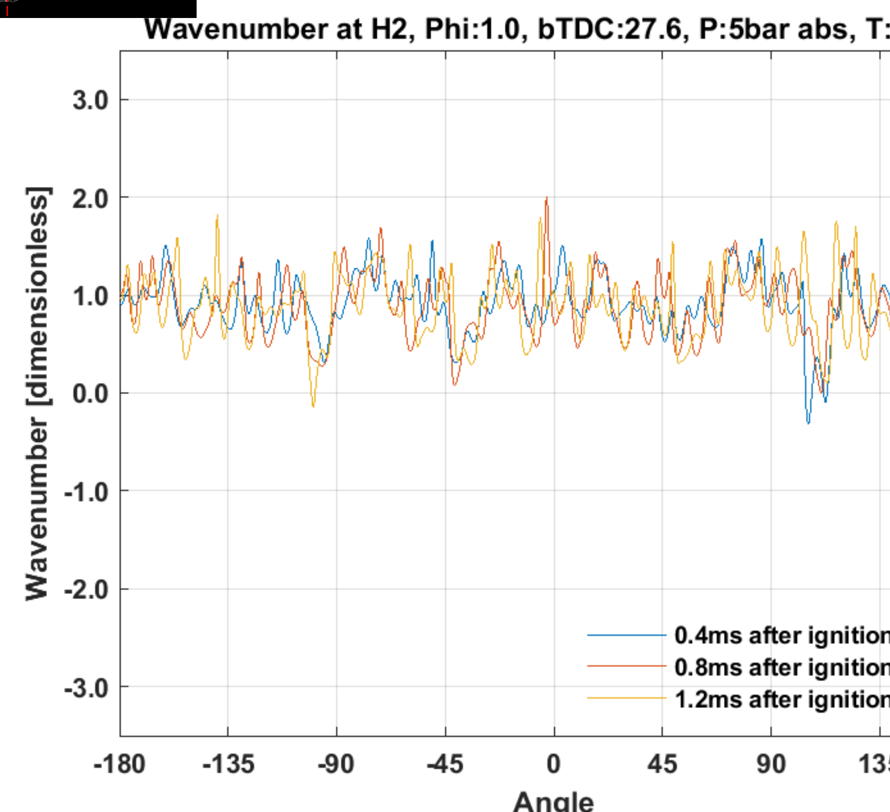
- Negative degree



$$\mathrm{Le} = \frac{\alpha}{D} = \frac{\lambda}{\rho D_{im} c_p}$$

Lewis number, *Le* = 1.08



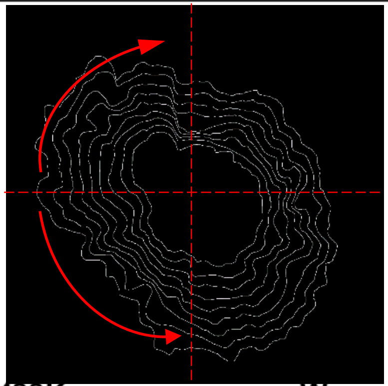


Results: Laminar Flame Propagation

UNIVERSITY OF LEEDS

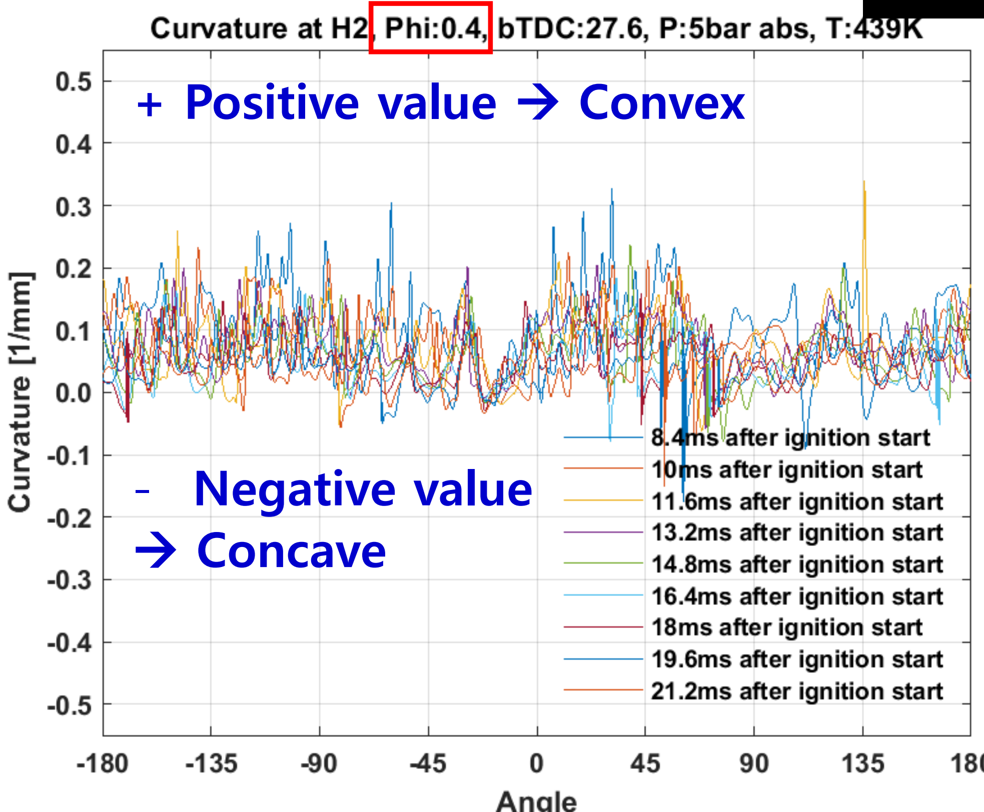
\+ Positive degree

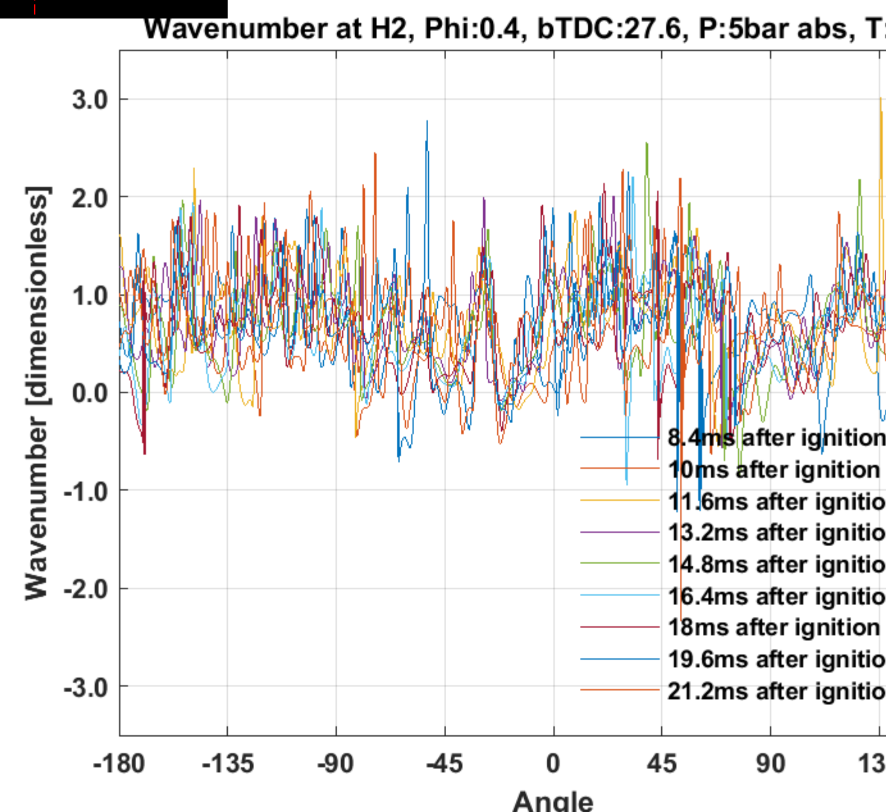
\- Negative degree



$$\mathrm{Le} = \frac{\alpha}{D} = \frac{\lambda}{\rho D_{im} c_p}$$

Lewis number, *Le* = 0.36



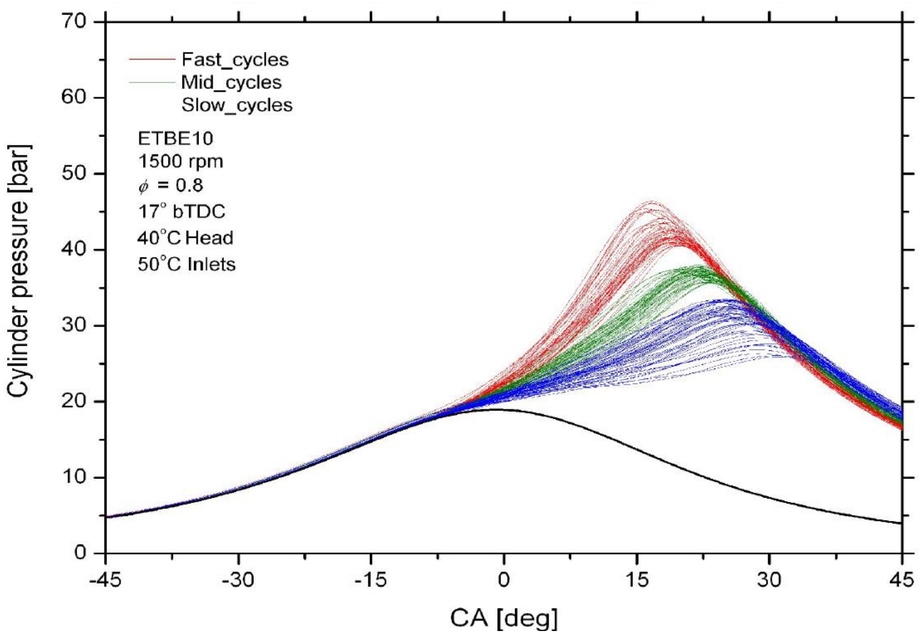


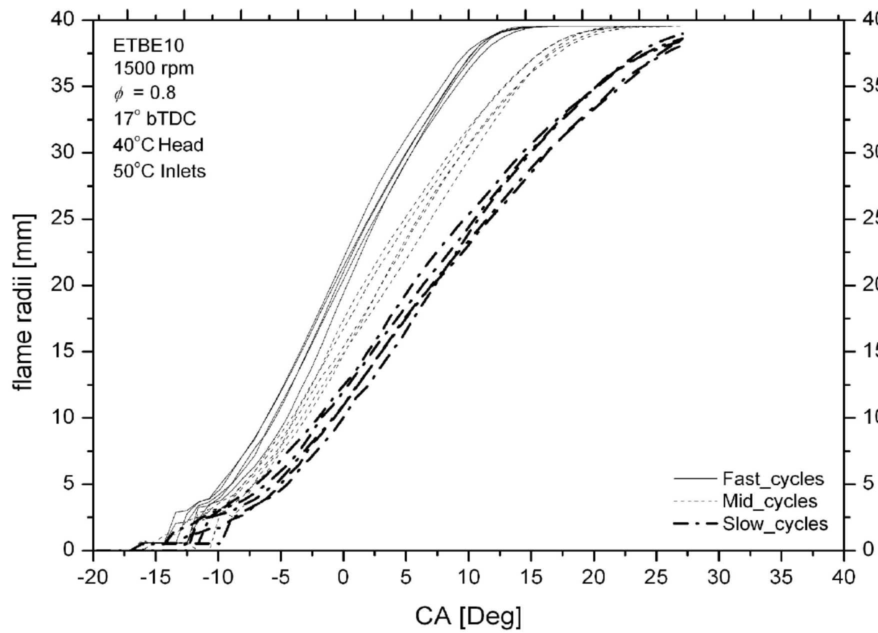
Results: Turbulent Combustion

UNIVERSITY OF LEEDS

Cyclic Variation of Combustion

(Pressure and Flame Radius)

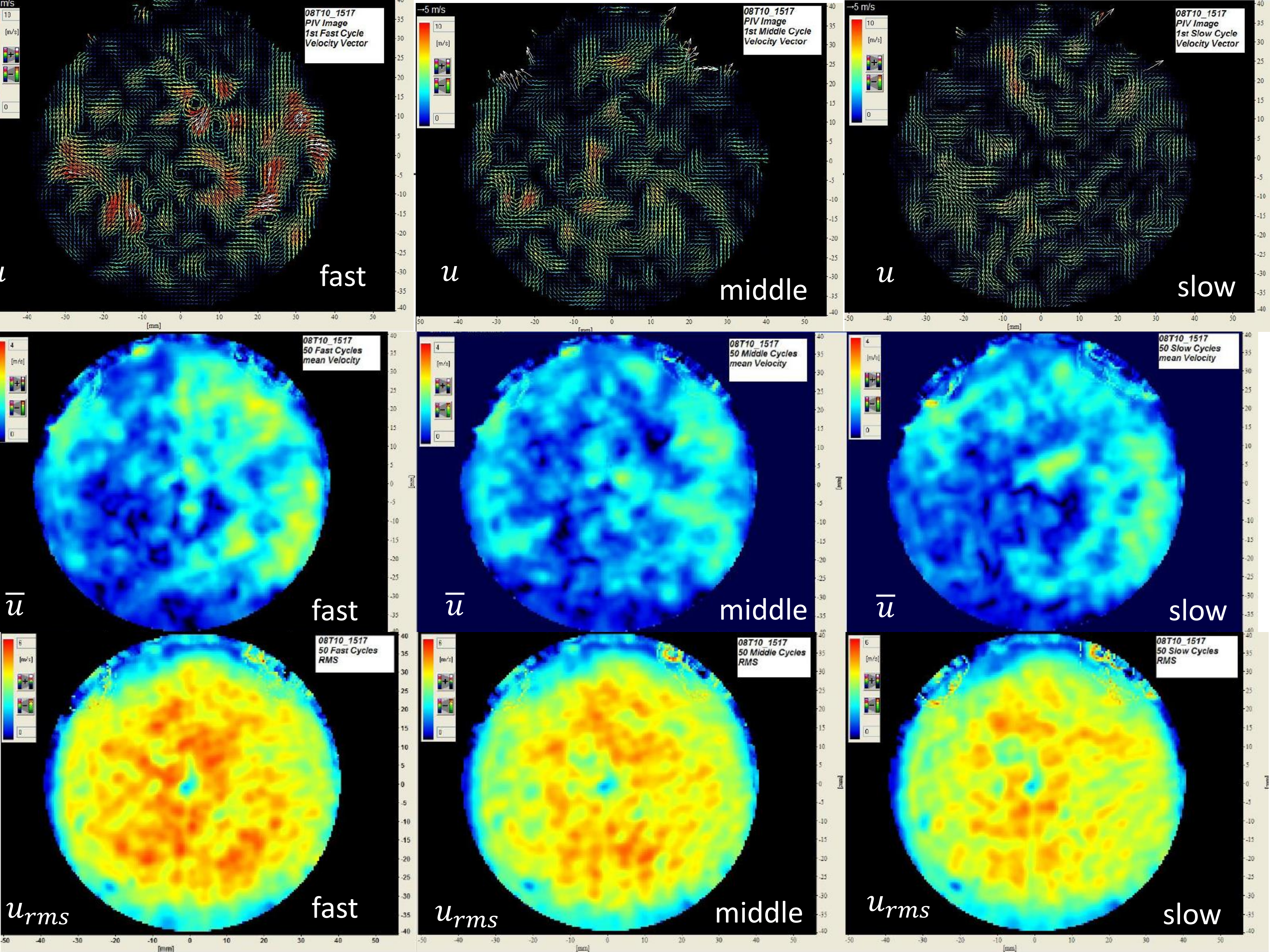




Spread of the crank-resolved **pressure history** of the firing cycle showing 50 samples of fast, middle and slow combustion events

Spread of the **flame radius** of the firing cycle showing 15 samples of fast, middle and slow combustion events

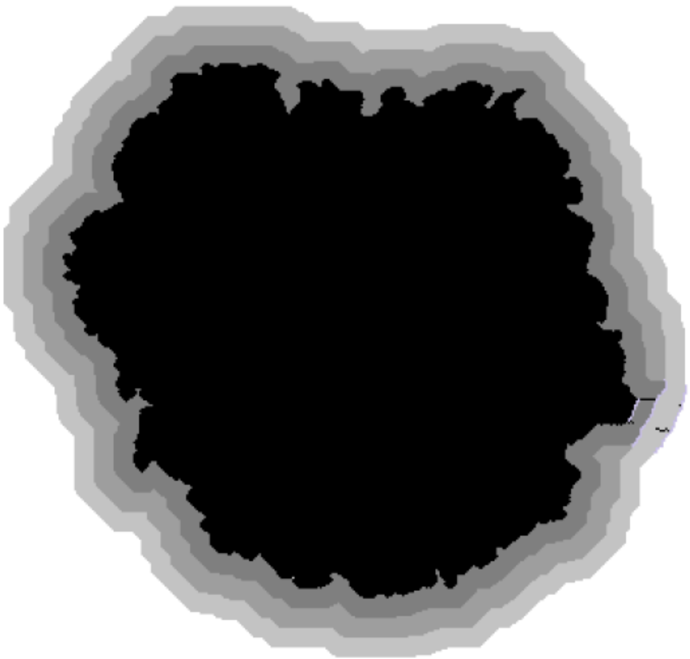
Hussin, A.M (2012). *New and Renewable Energy: Renewable Fuels in Internal Combustion Engines*, PhD thesis, School of Mechanical Engineering, The University of Leeds

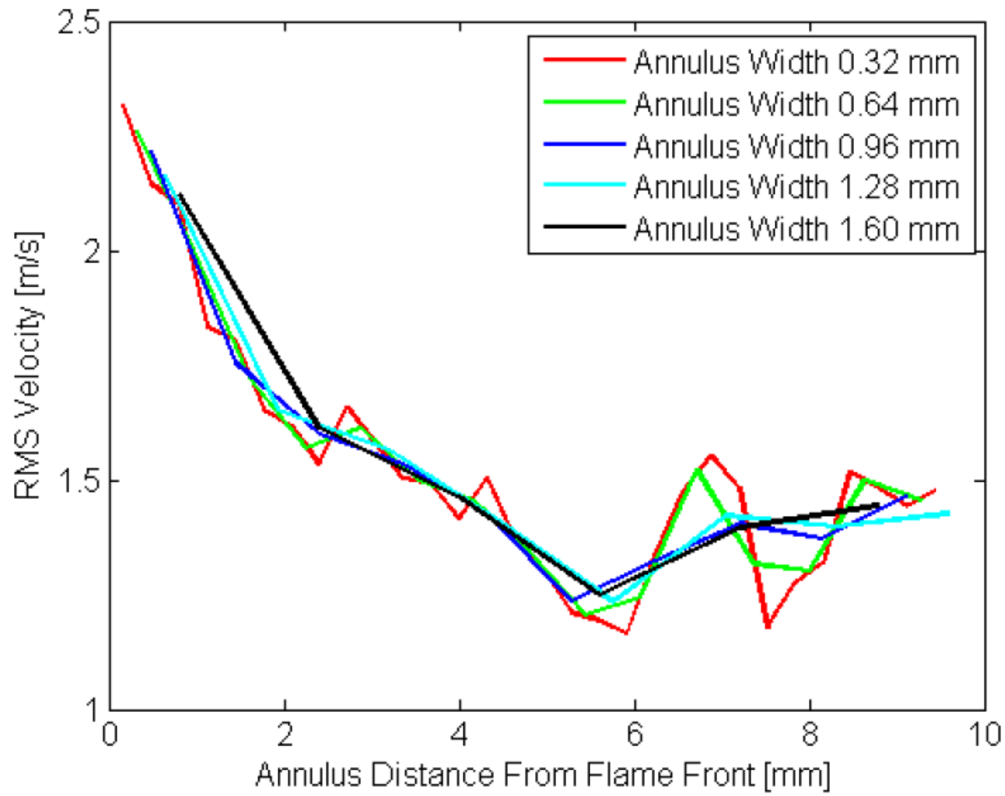


08T10_1517
PIV Image
1st Fast Cycle
Velocity Vector
fast
→5 m/s
08T10_1517
PIV Image
1st Middle Cycle
Velocity Vector
u
middle
→5 m/s
08T10_1517
PIV Image
1st Slow Cycle
Velocity Vector
u
slow
08T10_1517
50 Fast Cycles
mean Velocity
$\overline{u}$
fast
08T10_1517
50 Middle Cycles
mean Velocity
$\overline{u}$
middle
08T10_1517
50 Slow Cycles
mean Velocity
$\overline{u}$
slow
08T10_1517
50 Fast Cycles
RMS
u_{rms}
fast
08T10_1517
50 Middle Cycles
RMS
u_{rms}
middle
08T10_1517
50 Slow Cycles
RMS
u_{rms}
slow
[mm]
[m/s]

Results: Flame Front Unburned Turbulence

UNIVERSITY OF LEEDS

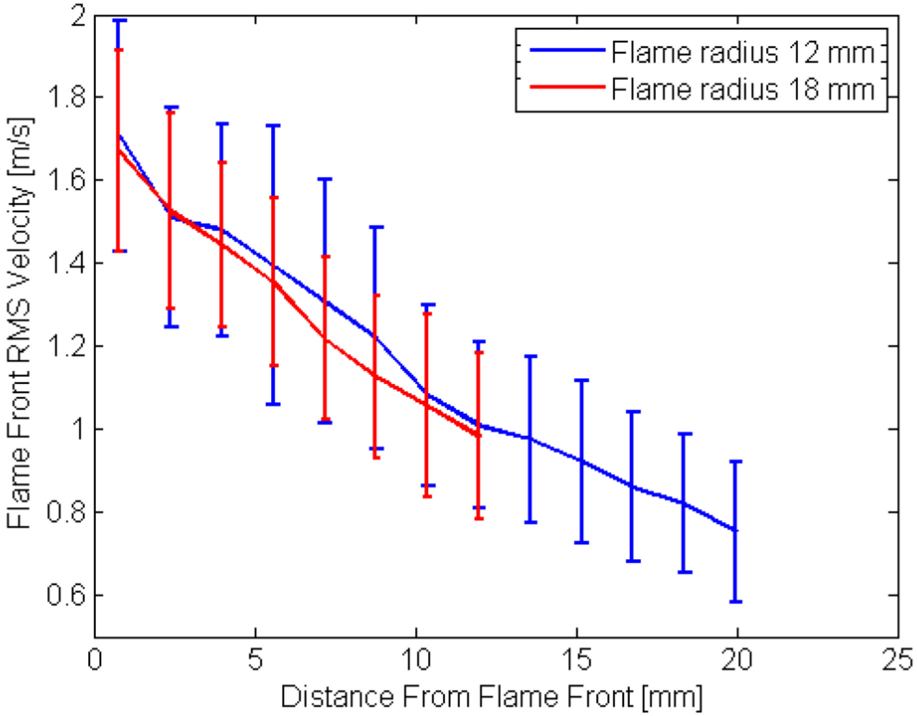




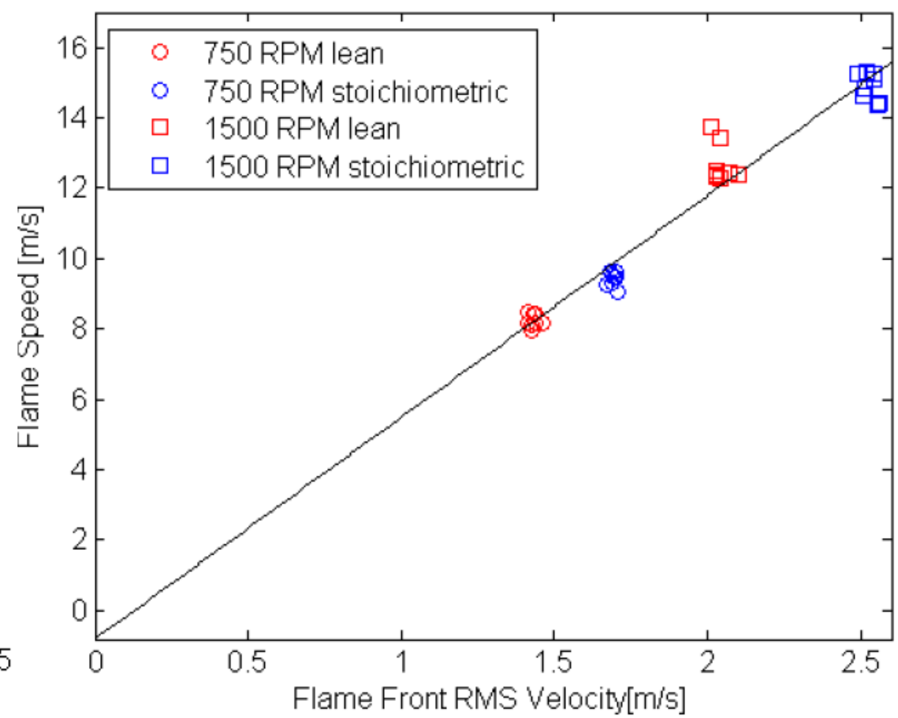
Burned gas (black) and different unburned gas annulus (grey) average flame radius = 23.16 mm and annulus width = 1.60 mm

RMS velocity of fresh gas annulus respect to distance of annulus away from flame front with different annulus width at Stoichiometric Iso-octane/air mixture, 750 RPM average radius = 9.65 mm

Results: Flame Front RMS



Flame front fresh gas RMS velocity (ur ') over first fresh gas annulus next to the flame front as a function of measured distance at averaged flame radius 12 mm and 18 mm at Stoichiometric 750 RPM



Flame speed respect to flame front ur ' at the flame radius from 12 - 19 mm with radius increment of 1 mm

Conclusions

- For turbulent free premixed combustion, the Lewis number indicates that molecular diffusivity dominate the dynamic cellular flame of hydrogen/air mixtures.
- The mean, transient and rms turbulent flow field has been closely exanimated using PIV technique.
- The fluctuating velocity field from one cycle to another causes the cyclic variation of combustion of SI engines.

Future Work

UNIVERSITY OF LEEDS

- Correlate the turbulent burning velocity with the PIV flame speed
- Measure the liquid fuel (gasoline) under laminar conditions
- Experimental data for model development and validation (**WP1**)

UKCTRF WP1: Fundamental research

i. Premixed and non-premixed combustion involving gaseous fuels
ii. Liquid fuel combustion
iii. Combustion involving new fuels (e.g. hydrogen-enriched combustion, etc.)
iv. Detailed chemical mechanisms
v. New combustion regimes
vi. Experimental data for model development and validation