Current Research in Combustion

A Forum for Research Students and Early Career Researchers

12 September 2023
West Park Teaching Hub,
Loughborough University, UK

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IOP Institute of Physics

Programme

9:00 AM - 10:00 AM	**Registration and Refreshments**
10:00 AM - 10:15 AM	**Welcome from the IOP Combustion Physics Group** Room: WPT.0.03 (ground floor)
10:15 AM - 12:20 PM	**Oral Presentation Session 1** Room: WPT.0.03 (ground floor) **Hassan Ahmed** (10:15AM – 10:40AM): Flame Surface Evolution and Machine-Learning Classification of Topology in Turbulent Premixed Flames **Atanu Dolai** (10:40AM – 11:05AM): Assessment of combustion dynamics of co/counter-swirl flames at varied momentum ratios and oxygen concentrations **James Harman-Thomas** (11:05AM – 11:30AM): Autoignition Study of Methane and Methane/Hydrogen Blends in CO2 **Qichi He** (11:30AM – 11:55AM): Simultaneous two-plane flame front detection using defocusing based PIV **Aanantha Balaji Murugavel** (11:55AM – 12:20PM): The effect of pressure on the mixing and combustion characteristics of Jet in Crossflow
12:20 PM - 1:30 PM	**Lunch and Posters**
1:30 PM - 2:45 PM	**Oral Presentation Session 2** Room: WPT.0.03 (ground floor) **Tarek Rashwan** (1:30PM – 1:55PM): Elucidating the impacts of heat losses on applied smouldering combustion systems **Maxwell Williams** (1:55PM – 2:20PM): Laser Imaging Turbine Engine Combustion Species (LITECS): An Overview **Thomas Howarth** (2:20PM – 2:45PM: Flame structure and stabilisation mechanism of a high-pressure hydrogen micromix combustor
2:45 PM - 3:30 PM	**2023 'Huw Edwards Award' Lecture: Professor Paul Ewart** Room: WPT.0.03 (ground floor)
3:30 PM - 4:15 PM	**Afternoon Break and Posters**
4:15 PM - 4:30 PM	**Presentation of Prizes and Close** Room: WPT.0.03 (ground floor)
6:00 PM - 10:00 PM	**Dinner at Caravelli** To celebrate the presentation of the Huw Edwards prize for services to combustion, a dinner will be held in Paul Ewart's honour. Pre-booking was required prior to the conference. Make your own way to the restaurant, located in the centre of town. The Old Manor, 11 Sparrow Hill, Loughborough, LE11 1BT.

2023 ‘Huw Edwards Award’ Lecture

New light on an old flame - using lasers to study combustion

Professor Paul Ewart[1]
[1]Oxford University, United Kingdom
2023 ‘Huw Edwards Award’ Lecture: Professor Paul Ewart, September 12, 2023, 14:45 - 15:30

The invention of lasers with frequency-tunable output revolutionized spectroscopy in the second half of the 20th century. New techniques were developed to exploit the properties of laser light and these were soon applied to study combustion. Research in fundamental atomic and molecular spectroscopy also stimulated new techniques for measuring important combustion parameters and development of new kinds of lasers. This talk will take a historical tour, from a personal perspective, of how this field developed from studies of fundamental atomic physics to applications in combustion chemistry and engineering.

Oral Presentations

Assessment of combustion dynamics of co/counter-swirl flames at varied momentum ratios and oxygen concentrations

Atanu Dolai[1], R.V Ravikrishna
[1]Research Associate, Loughborough University, Loughborough, United Kingdom

Oral Presentation Session 1, September 12, 2023, 10:15 - 12:20

Combustion dynamics of co/counter-swirl flames is studied using simultaneous measurement of pressure (50 kHz) and high-speed OH*-chemiluminescence (5 kHz) by varying momentum ratios (M) and O2 concentrations (XO2) using low calorific value syngas as a fuel. The main objective of the study is to understand the coupling between heat release rate, combustor noise and combustor geometry. For all studied momentum ratios, the frequency spectrum obtained from pressure have a dominant peak around ~280 Hz, which is close to the fundamental axial mode of the combustor. However, the global luminosity obtained from high-speed chemiluminescence reveals two kinds of motions. One represents the global fluctuation of the heat release rate, and another indicates the rotational motion of the heat release zone. The frequency of global fluctuation is ~280 Hz, suggesting that the periodic epochs in the pressure originated from this motion and are the source of combustion instability. Interestingly, the frequency representing the rotational component (frequency ~600 Hz) of the heat release zone is absent in the pressure. The global fluctuation of the heat release rate reduces when M increases. However, both motions are found to be completely suppressed when the oxygen concentration is reduced to 13.13%, indicating that low oxygen combustion can be an effective strategy to mitigate combustion instability.

Autoignition Study of Methane and Methane/Hydrogen Blends in CO2

Dr James Harman-Thomas[1,2], Mr Touqeer Anwar Kashif[3], Dr Kevin Hughes[2], Prof. Mohamed Pourkashanian[2], Professor Aamir Farooq[3]
[1]Uniper Technologies, Ratcliffe-on-Soar, United Kingdom, [2]University of Sheffield, Sheffield, United Kingdom, [3]King Abdullah University of Science and Technology, Thuwal , Saudi Arabia

Oral Presentation Session 1, September 12, 2023, 10:15 - 12:20

The combustion of hydrocarbon fuels to provide heat and power has been the backbone of human society for thousands of years and the catalyst for large-scale industrial development. As we drive towards clean-energy solutions, combustion will play an essential role in this transitionary period to prevent compromising humanities growing energy demands. Direct-fired supercritical CO2 (sCO2) combustion offers high-efficiency power generation from the combustion of fossil fuels in a way that captures 100% of the CO2 emissions. The Allam-Fedvedt cycle is the most advanced of these power cycles and has a combustion chamber that operates at 300 bar and CO2 dilutions of up to 96% and a high-purity stream of oxygen. By combusting fuel in pure oxygen and CO2, the CO2 produced is readily captured and thus there are no harmful emissions released to the atmosphere.
Despite the potential direct-fired sCO2 power cycles, the chemical kinetics of combustion in large CO2 dilutions and pressures up to 300 bar is poorly understood and there is limited data for mechanism validation. Following on from previous work creating a mechanism tailored for combustion in CO2 (UoS sCO2 2.0), the present work investigates gaps in the ignition delay time data (IDT) for methane and methane/hydrogen blends. Five different fuel mixtures were studied at 20 and 40 bar over a large temperature range to identify key reactions and areas for future mechanism development. This study produces the first IDT data for methane/hydrogen combustion in a pure CO2 dilution of 85%.

Simultaneous two-plane flame front detection using defocusing based PIV

Qichi He[1], Dr Christopher Willman[1], Professor Benjamin Williams[1]
[1]Department of Engineering Science, University of Oxford, Oxford, United Kingdom

Oral Presentation Session 1, September 12, 2023, 10:15 - 12:20

An inexpensive and compact image splitting device is proposed to extend a standard single-camera single-plane particle image velocimetry (PIV) system to simultaneous measurement of the turbulent premixed flame front on two depth-offset planes. The method places images from the two planes onto the two halves of a camera sensor by using image splitting optics with variable optical path lengths. A shallow depth of field is achieved to ensure only one plane is in focus on each half of the sensor. By using a high-pass filter and a novel two-step filter we have devised, the out-of-focus particle images are effectively removed, while the in-focus particle images remain, allowing the turbulent flame fronts on two planes to be detected simultaneously. This method was successfully applied to measure the two-plane flame front in an optically accessible internal combustion engine. To investigate the feasibility of measuring turbulent flame displacement speed, a laminar flow rig test was performed to quantify the velocimetry uncertainty caused by out-of-focus image crosstalk. Our image splitting approach could be combined with conventional polarisation/wavelength discrimination methods to achieve simultaneous multi-plane flame front reconstruction with similarly high in-plane spatial resolution to standard single-plane measurements, and is suitable for practical combustion devices with limited optical access.

Flame Surface Evolution and Machine-Learning Classification of Topology in Turbulent Premixed Flames

Mr. Hassan Ahmed[1], Professor Stewart Cant[1]
[1]University of Cambridge, Cambridge, United Kingdom

Oral Presentation Session 1, September 12, 2023, 10:15 - 12:20

In turbulent premixed flames, the balance between flame area generation and its destruction dictates the overall burning rate. Flame area generation is promoted by turbulent straining while area destruction results from mutual annihilation of adjacent interacting surfaces. The local topology of the flame surface plays a vital part in determining the subsequent evolution of flame area. In this work, canonical flame topologies are investigated using a 3D DNS dataset of a methane-air premixed flame in an inflow-outflow configuration. The principal topologies of interest are classified as reactant pocket, tunnel closure, tunnel formation, and product pocket at critical (isosurface interaction) points in the reaction progress variable field. A spatial correlation is established between the different topologies which shows that most reactant pockets have a neighbouring tunnel closure while product pockets are generally close to tunnel formations. This suggest that the coupled topologies can morph into one another, resulting in substantial reduction of flame surface area near the interaction site. The local classification is supplemented by a machine-learning model with the potential to track local topological evolution dynamically. This method, which uses a convolutional neural network to classify surface topology, has an overall classification accuracy of 77%. The main advantage of the machine-learning approach is its potential in tracking the evolving topologies resulting from isosurface interaction. Moreover, flow properties such as turbulent straining can be accounted for with the new method thereby improving the understanding of surface evolution in turbulent flames that will result in more robust stretch and burning rate models.

Flame structure and stabilisation mechanism of a high-pressure hydrogen micromix combustor

Thomas Howarth[1], Dr. Mark Picciani[2,3], Prof. Edward Richardson[4], Dr. Marcus Day[5], Dr. Andrew Aspden[1]
[1]Newcastle University, Newcastle-upon-Tyne, United Kingdom, [2]Reaction Engines Ltd., Abingdon, United Kingdom, [3]Sunborne Systems Ltd., Didcot, United Kingdom, [4]University of Southampton, Southampton, United Kingdom, [5]National Renewable Energy Laboratory, Golden, United States of America

Oral Presentation Session 2, September 12, 2023, 13:30 - 14:45

A high-pressure hydrogen micromix combustor has been investigated using direct numerical simulation with detailed chemistry to examine the flame structure and stabilisation mechanism. The configuration of the combustor was based on a NASA design, using numerical periodicity to mimic a large square array. A precursor simulation of an opposed jet-in-crossflow was first conducted to generate appropriate partially-premixed inflow boundary conditions for the subsequent reacting simulation. The resulting flame can be described as an essentially-lean inhomogeneously-premixed lifted jet flame. Five main zones were identified: a jet mixing region, a core flame, a peripheral flame, a recirculation zone, and combustion products. The core flame, situated over the jet mixing region, was found to burn as a fast thin premixed flame and is responsible for 85% of total fuel consumption, whereas the peripheral flame shrouded the core flame and burned at very lean conditions. It was shown that turbulent flame propagation was an order-of-magnitude too slow to stabilise the flame at these conditions. Stabilisation was identified to be due to ignition events resulting from turbulent mixing of fuel from the jet into mean recirculation of heat. Around the location where ignition was first possible, isolated events were observed, which developed into rapidly burning flame kernels that were blown downstream by the bulk flow. Further downstream, near-simultaneous spatially-distributed ignition events were observed, which appeared more like ignition sheets.

Laser Imaging Turbine Engine Combustion Species (LITECS): An Overview

<u>Dr Maxwell Williams</u>[1], Prof Jon Carrotte[1], Dr Andrew Garmory[1]
[1]Loughborough University, Loughborough, United Kingdom

Oral Presentation Session 2, September 12, 2023, 13:30 - 14:45

Low Technology Readiness Level (TRL) experimental combustion facilities, capable of providing elevated temperature and pressure conditions, are crucial in developing novel low emissions combustion systems and for the validation of models of the various physical and chemical processes involved in combustion. To achieve this requires instantaneous and simultaneous measurements of key combustion parameters such as temperature, species concentration and equivalence ratio distributions within the combustor. However, extractive emissions techniques are unable to measure within the combustor due to the harsh conditions and can only provide information at locations downstream of the combustion region. Low TRL experimental combustion facilities provide good optical access and hence techniques, for example laser induced fluorescence or coherent anti-Stokes Raman scattering, have been able to provide information within combustors such as species concentration and temperature. However, they are unable to simultaneously measure these quantities and may only capture information at a single point. Due to the turbulent nature of the combustor, simultaneous and instantaneous measurements over the plane of interest are required to capture the complex processes within. LITECS aims to use tomographic Tunable Diode Laser Absorption Spectroscopy (TDLAS) to measure the temperature and key species concentrations simultaneously within a low TRL experimental combustion facility, over a cross section of the combustor. Initial line of sight measurements of H_2O have been made using TDLAS to prove the measurement concept within a combustor and trials of custom opto-mechanical solutions for use inside the low TRL facility have begun. Continued development of this measurement technique is ongoing.

Elucidating the impacts of heat losses on applied smouldering combustion systems

<u>Dr Tarek Rashwan</u>[1,2], Dr Marco Zanoni[2], Dr Taryn Fournie[2], Mr Seyed Ziaedin Miry[2], Mr Jiahao Wang[2], Dr Gavin Grant[3], Prof Jose Torero[4], Prof Jason Gerhard[2,5]

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Oral Presentation Session 2, September 12, 2023, 13:30 - 14:45

Applied smouldering systems harness waste combustion within porous media to drive thermally efficient environmental engineering processes. These systems use various reactor orientations for a range of purposes, such as: (i) hazardous waste management, (ii) off-grid sanitation, (iii) sludge treatment, (iv) waste-to-energy, and (v) resource recovery. These systems provide unique benefits over other thermal treatment systems due to their broad self-sustaining limits offered by smouldering's resilient combustion characteristics. This combustion resilience stems from local rate-limiting processes, i.e., via oxygen diffusion in the pore space to the fuel surface, which leads to characteristically cool peak temperatures, slow propagation velocities, and gradual heating rates. These characteristics foster a highly energy-efficient thermal treatment process. Practically, this means that smouldering systems can manage traditionally problematic waste streams with a low energy footprint, e.g., those with low-volatilities and high moisture contents. Smouldering is driven by coupled heat and mass transfer along with chemical reactions in porous media. These combined processes lead to a series of distinct smouldering zones characterized by their dominant process, i.e., the cooling zone, reaction zone, and preheating zone.

This presentation presents a collection of targeted analyses and experimental work to better understand the varied effects of heat losses in these systems, primarily within the cooling zone. This work led to valuable insights, such as: (i) the key sensitivities in the global energy balance to system scale, (iii) the impacts of non-uniform air flux due to heat losses, and (iv) the behaviour in smouldering systems that reach a steady-state global energy balance.

The effect of pressure on the mixing and combustion characteristics of Jet in Crossflow

Aanantha Balaji Murugavel[1], Dr. James C. Massey[1,2], Prof. Nedunchezhian Swaminathan[1], Dr. Yusuke Tanaka[3]
[1]Department of Engineering, University Of Cambridge, Cambridge, United Kingdom, [2]Robinson College, University of Cambridge, Cambridge, United Kingdom, [3]Mitsubishi Heavy Industries, Takasago, Japan
Oral Presentation Session 1, September 12, 2023, 10:15 - 12:20

The enhanced mixing abilities of Jet in Crossflow (JICF) are gaining renewed interest, positioning it as a potential fuel injection strategy for highly reactive zero-carbon fuels like hydrogen. Extensive research has delved into the reacting JICF configuration under atmospheric conditions. However, the JICF characteristics at high pressure and temperature conditions, akin to gas turbines, remain unexplored. The study aims to investigate the influence of pressure on fuel-air mixing, combustion and their mutual interactions using the LES paradigm. The numerical predictions are validated against PIV measurements and reasonable comparisons were observed. Mixing attributes are assessed using the uniformity index and mixture fraction decay along the jet centreline. The results indicate enhanced entrainment of air in the jet near-region, leading to an earlier jet breakup and thereby shorter potential core length at higher-pressure conditions. However, in reacting conditions, the flame stabilization plays an important role. At high pressure condition, the flame stabilization occurs relatively closer to the jet exit and along the windward shear layer between the jet and the crossflow. The local heat release then reduces the shear layer vortex roll-up, which impedes the entrainment process and increases the jet penetration depth. The reduced rate of mixing subsequently influences the combustion modes of the multi-regime JICF flames. The presentation aims to provide insights into these key physical processes.

Poster Board Numbers

Poster Board Number	Name	Title
1	Ashley van Bruygom	Application of a Flamelet Generated Manifold Approach to a Dual-Swirl Hydrogen Burner
2	Oussama Chaib	Cellular patterns of turbulent premixed hydrogen/methane/air flames
3	Dere Rojhat	Hydrogen Fuel Technologies for Future Propulsion and Power (HOPE)
4	Aidan Forknall	Modelling combustion flow regimes via a spectral/hp
5	Anupam Ghosh	Assessment of fusion-spliced optical elements in combustion environments: Survivability and optical characterization
6	Ankit Dilip Kumar	Hydrogen enrichment effects on swirl stabilised flames
7	Siyi Qiu	Effect of hydrogen enrichment in methane on the thermoacoustic states of a swirl stabilized combustor
8	Giovanni Tretola	Investigation of turbulence and thermophysical interplay in hydrogen release scenario
9	Daniya Zhumabayeva	Entropy generation rate as a marker for the onset of flame instability

Poster Presentations

Assessment of fusion-spliced optical elements in combustion environments: Survivability and optical characterization

Dr Anupam Ghosh[1], Dr. Aniket Kulkarni[1], Dr. Paul Wright[1], Prof Krikor Ozanyan[1], Dr Maxwell Williams[2], Prof Jon Carrotte[2]
[1]The University Of Manchester, United Kingdom, [2]Loughborough University, United Kingdom
Lunch and Posters, September 12, 2023, 12:20 - 13:30

Qualitative non-intrusive measurement of combustion species concentration inside a gas turbine (GT) engine is challenging due to its optically inaccessibility, hostile environment for instrumentation design. Permanently spliced optical fibre-lens arrangement can be a potential solution to address these issues. However, survivability and optical performance of such a delicate arrangement in a hostile combustion environment is critical. Thus, aim of the current study was twofold: to analyse optical characteristics of spliced optical fibre-lens arrangement and to assess the survivability in GT engine-like conditions. A 50µm solid core optical fibre (fused silica, 0.22 numerical aperture) was spliced with a collimated lens (4.75-mm radius of curvature) using a laser splicing system with a high precision (< 5-micron). First, survivability studies covered laboratory tests as well as in a combustor rig at NCCAT. Laboratory tests were conducted to assess cyclic temperature variations up to 800K temperature. In-combustor survivability tests were carried out in non-reactive, high pressure (max. 6 bar) and temperature (600K) region of the combustor to examine radiative heating, acoustic and vibration loading. Surprisingly, the spliced arrangement survived in both tests. Second, the optical characterization was conducted using a HeNe laser (CW, 633 nm). Laser beam-divergence (half-angle) of 2.2 mrad with at the beam diameter of 1.91mm was observed at a measurement distance of 300-mm. Overall, this study indicates the feasibility and suitability of using a fusion-spliced optical element to deliver laser light to an inaccessible combustion test section for non-intrusive measurement.

Entropy generation rate as a marker for the onset of flame instability

Daniya Zhumabayeva[1], Professor Stewart Cant[1]
[1]University Of Cambridge, Cambridge, United Kingdom

Lunch and Posters, September 12, 2023, 12:20 - 13:30

A comprehensive understanding of the mechanisms of intrinsic flame instability, including hydrodynamic and thermodiffusive instabilities, is necessary for the safe and efficient implementation of combustion processes. This is becoming more important with the move towards greater reliance on hydrogen as a zero-carbon fuel. While being extensively studied, certain features of instabilities, such as their onset, are defined mainly by qualitative measures in both numerical and physical studies. This work proposes a quantitative marker to identify the onset of intrinsic flame instabilities derived from the statistics of the entropy equation. Direct numerical simulations were implemented for the two-dimensional laminar premixed planar methane-air flames, with varying amounts of hydrogen addition up to 50% by volume. Entropy generation mechanisms were analysed based on their contributions resulting from heat conduction, viscous dissipation, mass diffusion, and chemical reaction. Hydrogen addition was found to impact the flame dynamics, as evidenced by the entropy generation due to the chemical reaction becoming stronger further into the reaction zone. Hydrogen addition also resulted in earlier instability onset characterised by increased data dispersion in all entropy generation terms. The dispersion was quantified by their statistical range, which increased for all progress variable values as the flame transitioned into instability. The entropy generation due to viscous dissipation was much smaller in magnitude compared to other mechanisms, but it was found to be the most sensitive indicator of instability onset. The present entropy-based analysis shows potential for characterising different instability types, which can have interdependent contributions to global flame statistics.

Modelling combustion flow regimes via a spectral/hp element reactive flow solver

Aidan Forknall[1], Jialin Su[1], Andrew Garmory[1]
[1]Loughborough University, United Kingdom

Lunch and Posters, September 12, 2023, 12:20 - 13:30

In this project combustion modelling methods will be implemented into the framework of an existing spectral/hp element solver, Nektar++. The aim is to create a reactive flow solver capable of accurately modelling combustion flow regimes at low Mach numbers. The study investigates how the high-order resolution of a mixing flow field translates to modelling of turbulent
diffusion flames, in regard to both cost and accuracy. First, a non-reacting pseudo-compressible flow solver has been developed based on the Incompressible Navier-Stokes code, using a low Mach variable density approach able to simulate mixing between fuel and oxidizer streams. For
modelling of reactive flow, results of a 1D flamelet generated manifold (FGM) formulation dependant on mixture fraction, Z, are tabulated and coupled into the solving process. Validations are presented with turbulent cold flow mixing and canonical reacting flow cases, including
combustor relevant geometry such as Sandia Propane-Jet flow and Sandia Piloted CH_4/Air Flames.

Hydrogen enrichment effects on swirl stabilised flames

Ankit Dilip Kumar[1], James C Massey[1,2], Isaac Boxx[3], Nedunchezhian Swaminathan[1]
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Lunch and Posters, September 12, 2023, 12:20 - 13:30

The effects of hydrogen enrichment on thermoacoustic and helical instabilities in a swirl-stabilised flame is studied using large eddy simulation. The sub-grid reaction rate is modelled using unstrained premixed flamelets and a presumed joint probability density function approach. Two partially premixed cases undergoing thermoacoustic oscillations at ambient conditions are studied. The addition of hydrogen leads to period-2 thermoacoustic oscillations. The amplitude of the fundamental thermoacoustic mode increases with the addition of 20% hydrogen by volume. The second pressure mode associated with the chamber mode is also excited with the hydrogen addition. Intermittent single, double and triple helical instabilities are observed in the pure methane case, but are suppressed substantially with hydrogen addition. The results are analysed in detail to shed light on these observations. The feedback loop responsible for the thermoacoustic instability is driven by mixture fraction perturbations resulting from the unequal impedances of the fuel and air channels. It is shown that hydrogen addition increases the flame's sensitivity to these perturbations, resulting in an increase in amplitude. This higher amplitude thermoacoustic oscillation, along with a higher local heat release rate in the presence of hydrogen, is shown to considerably modify the flow structures, leading to a suppression of the helical instabilities.

Effect of hydrogen enrichment in methane on the thermoacoustic states of a swirl stabilized combustor

Mr Siyi Qiu[1], Dr Efstathios Karlis[1], Dr Chaoxu Chen[1], Professor Alex Taylor[1], Professor Yannis Hardalupas[1]
[1]Imperial College London, United Kingdom

Lunch and Posters, September 12, 2023, 12:20 - 13:30

As hydrogen gets increasing attention in power generation industry, we investigate the effect of hydrogen enrichment in methane on the thermoacoustic states of a lab-scale swirl-stabilized combustor. The combustor was operated lean with pure methane and methane-hydrogen blend. The thermoacoustic state was characterized by sound pressure measured by a microphone and global CH* chemiluminescence by a photomultiplier. Two high speed cameras were synchronized to the sound pressure signal and capture the combustion dynamics in the axial-radial and the cross-sectional plane of the combustor. The results show that for pure methane, as the equivalence ratio Φ increased from 0.65 to 0.75, the combustor went through four thermoacoustic states. These are: a quiescent state where the flame is lift-off, a quiescent state with combustion noise of larger amplitude and the flame attached to the centrebody, an intermediate state where the flame is largely attached while giving off intermittent bursts, and a limit-cycle state where the flame is oscillating. For methane-hydrogen blend, no attached state was found. As the mole fraction of hydrogen was increased from 10% to 25% while keeping Φ constant at 0.6, the combustor went from a quiescent, lift-off flame, to an intermittent flame that switches between the lift-off and oscillation state, to a full limit cycle state. In our previous study, the intermittent state was found to be associated with a centre mode of the swirl flow. This is further compared with proper orthogonal decomposition of the dynamics of the flame for both the pure methane and methane-hydrogen cases.

Investigation of turbulence and thermophysical interplay in hydrogen release scenario

Giovanni Tretola[1], Konstantina Vogiatzaki[1]
[1]University of Oxford, Oxford, United Kingdom

Lunch and Posters, September 12, 2023, 12:20 - 13:30

In refuelling station, hydrogen is stored at cryogenic condition to reduce the volume occupancy. An accidental release of hydrogen can have severe consequences, as the mixing with air can lead to hazard conditions such as flammable clouds. Thus, a proper prediction of the leakage scenario is crucial.

During hydrogen leaks, turbulence fluctuations can lead to peaks in pressure or temperature than will ignite the mixture. To predict hazard conditions, it is important to predict these peaks. The hydrogen jet, stored at cryogenic and high pressure and released in standard conditions, will transition from subcritical to supercritical condition. The role of turbulence during this transition is not entirely clear, with a lot of open question especially about the interplay between the thermo-physical condition and the turbulence, translated in uncertainty in modelling strategies.

In this work the interplay between turbulence and thermophysical properties on compressed hydrogen jets at cryogenic conditions is evaluated. Large Eddy Simulation (LES) of cryogenic hydrogen round jets, performed through a tailored numerical solver for cryogenic jets, are showed. Hydrogen is released at 50 K and 5 bar from a circular nozzle of 1 mm diameter, mimicking the undesired release of stored hydrogen in refuelling station. Turbulence characteristics are analysed, along with main results like centreline and radial profiles of hydrogen concentration, velocity, and temperature. This to improve the understanding of the turbulence role, often neglected in experimental studies, to evaluate the impact of different modelling strategies and to provide guidelines for similar applications.

Cellular patterns of turbulent premixed hydrogen/methane/air flames

Oussama Chaib[1], Prof Simone Hochgreb[1], Prof Isaac Boxx[2,3]
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Lunch and Posters, September 12, 2023, 12:20 - 13:30

Lean hydrogen-rich methane/air flames are subject to thermo-diffusive (TD) instabilities induced by sub-unity Lewis numbers which alter the characteristic shapes of turbulent flames. At sufficiently low Lewis numbers, a number of cellular structures (cusps, throughs, fingers) appear on the flame front as a result of the instability. The varying stoichiometry along the front results in an enhancement of local consumption speed (and an occasional super-adiabaticity) in positively curved structures (convex towards reactants) and, conversely, a decrease in consumption speed in negatively curved structures (concave towards reactants) resulting in elongated flame fingers. A robust correlation between curvature and flame consumption speed has been demonstrated in numerous DNS investigations of TD-unstable laminar and turbulent lean hydrogen-air flames, while weak correlations were found in methane-air flames due to quasi-unity Lewis numbers.
In this work, we examine these correlations experimentally from high-speed OH planar laser-induced fluorescence images of turbulent premixed hydrogen-enriched methane/air flames. Correlations between gradients of OH intensities in the normal direction to the flame front and curvature are investigated using signal processing tools (cross-correlation, power spectral density). We show that weak correlations exist in methane-air flames while a transition to positive correlations is observed as hydrogen is added to the mixture. Profiles of OH gradients and curvature across the curvilinear coordinate of the flame front appear to follow the same trend and exhibit comparable cellularities with increasing hydrogen content. Finally, we discuss the morphology of the 70% hydrogen flame featuring local extinctions at negatively-curved structures.

Application of a Flamelet Generated Manifold Approach to a Dual-Swirl Hydrogen Burner

__Miss Ashley Van Bruygom__[1], Duncan Walker[1], Andrew Garmory[1]
[1]Loughborough University, United Kingdom

Lunch and Posters, September 12, 2023, 12:20 - 13:30

The poster presents current work being undertaken based on the HYLON burner (Hydrogen Low NOx), using a Flamelet Generated Manifold (FGM) combustion model. HYLON is a dual-swirl hydrogen burner intended for use in the aviation sector. For combusting simulations, FGM is commonly used in the gas turbine industry as it is cheaper than solving detailed chemistry as part of the simulation. The aim is to examine the ability of the modelling approach to reproduce experimental results using the commercial code, Simcenter STAR-CCM+. In previous work, a best practice modelling approach was defined and has been implemented in this study. The current study is conducted using Large Eddy Simulation turbulence modelling and a 1D freely propagating combustion modelling approach used to generate the FGM table. Experimental Particle Image Velocimetry (PIV) results of the velocity field are presented for two flame archetypes, lifted and attached. Cold flow and reacting PIV is compared to simulation results and show a strong agreement for the velocity field. Flame location and temperature is analysed with temperature probe data and through scalar scenes. This work is ongoing and shows that the prediction of the flame lift-off is difficult and could be caused by the combustion modelling or thermal boundary conditions, requiring further investigation.

Hydrogen Fuel Technologies for Future Propulsion and Power (HOPE)

Rojhat Dere[1]
[1]University College London, United Kingdom

Lunch and Posters, September 12, 2023, 12:20 - 13:30

Due to the growing interest in lean hydrogen combustion as a potential solution for reducing emissions in various sectors, including power generation and aerospace, further investigation of flame behaviour, stabilisation characteristics, and emissions performance of hydrogen combustion is necessary. Fuel-air mixture preparation is of primary importance when investigating hydrogen flames, as it affects the flame dynamics and post-combustion gases. The current work uses a pilot-stabilised, single-nozzle partially premixed hydrogen burner, where the hydrogen is introduced in the air stream in a jet-in-cross-flow configuration. In order to understand the effect of fuel-air mixing, a few different geometric configurations will be tested, including varying the distance of the hydrogen injector upstream of the combustor entrance, the angle of hydrogen injection, and the number of hydrogen injection ports.

To characterise the flame, advanced diagnostic techniques are being utilised, including high-speed OH planar laser-induced fluorescence (PLIF), OH* Chemiluminescence for integrated heat release measurements, dynamic pressure measurements in the plenum and combustor, and exhaust NOx measurements, Particle Image Velocimetry (PIV) and Laser-induced breakdown spectroscopy (LIBS). The operability and stability regime of each burner configuration is mapped, including lean blow-off limits. It is expected that the insights from the single-nozzle experiments will help design the multi nozzle configuration.

Current Research in Combustion:
A Forum for Research Students
and Early Career Researchers

12 September 2023

West Park Teaching Hub, Loughborough University, UK

IOP Institute of Physics