Case Study

1. Title of Case Study: Modelling Heat Loss Effects in the Large Eddy Simulation of a Lean Swirl-Stabilised Flame

2. Grant Reference Number: EP/R029369/1

3. One sentence summary: Implementation and validation of a low-cost non-adiabatic flamelet approach for simulations of turbulent partially premixed flames in a gas turbine model combustor.

4. One paragraph summary: A sub-grid model for large eddy simulations of turbulent partially premixed combustion in a gas turbine model combustor is extended to include heat loss effects. This case is of interest since the flame is close to blow-off and the flame is stabilised using swirling flows within a complex geometry. The objective of the study is to observe the sensitivity of the flame blow-off to different heat loss modelling. Two simulations are presented that use fixed wall temperature boundary conditions and use adiabatic and non-adiabatic formulations of the sub-grid-scale combustion model. The results are compared to experimental data and to an adiabatic simulation. The heat release rate, lift-off height and the enthalpy deficit within the flame are also analysed.

5. Key outputs in bullet points:

- Development of non-adiabatic unstrained flamelet model for large eddy simulations of turbulent partially premixed flames – theory and software.
- Presented at the 11th Mediterranean Combustion Symposium and the work is published in Flow, Turbulence and Combustion (https://doi.org/10.1007/s10494-020-00192-4).
- Massey, J. C., Chen, Z. X., and Swaminathan, N. (2020). Flame root dynamics and their role in the stabilisation of lifted flames, Book Chapter in "Advances in Energy and Combustion - Safety and Sustainability", Eds. A. K. Gupta and A. De, Springer (In press).
- Massey, J. C., Chen, Z. X., and Swaminathan, N. (2020). Modelling Heat Loss Effects in the Large Eddy Simulation of a Lean Swirl-Stabilised Flame, Flow, Turbulence and Combustion, DOI: 10.1007/s10494-020-00192-4.

6. Main body text

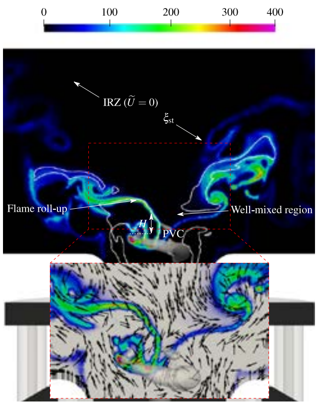

Figure 1: A snapshot of the filtered reaction rate, the stoichiometric mixture fraction (white lines) and the zero axial velocity contour (pink lines) are shown in the mid vertical plane. The inset shows the zoomed in view of filtered reaction rate along with velocity vectors.

Lean combustion is utilised in modern gas turbine combustors to reduce pollutants emission. The stability of lean flames is enhanced through the use of swirling flows, since an inner recirculation zone formed at the centre supplies heat and radical species to keep the flame root alight and stable. However, lean combustion is susceptible to local extinction and flame blow-off. Thus, it is of interest to explore how heat loss effects influence the flame behaviour close to lean blow-off conditions. The chosen test case is of interest due to its resemblance to an industrial gas turbine burner, where complex fluid mechanical processes are present. A snapshot of the flame is shown in figure 1 and the inset shows that the flame stabilisation is closely coupled to the swirling flow field. The results obtained with the non-adiabatic flamelet approach showed that the lift-off height and the volume integrated heat release rate oscillated more in comparison to the adiabatic case and hence, the flame is more unstable with the non-adiabatic flamelet model. Improved statistics are obtained for the temperature in the near-wall regions. The non-adiabatic flamelet case shows the average reaction rate values at the flame root are approximately 50% smaller in comparison to the adiabatic flamelet cases. A higher enthalpy deficit is seen in the near-field regions when the flame root is not present and experiencing some lift-off, suggesting that the flame is more dynamic when the heat loss is included. These are shown in figures 2 and 3. These activities have generated a large data set on flame behaviour under conditions close to blow-off and further investigations are needed to develop closer understanding of conditions leading to flame blow-off and the role of heat loss at the system level. The flame blow-off is a critical phenomenon to understand thoroughly so that it can be avoided through proper design of practical combustors friendlier to the environment.

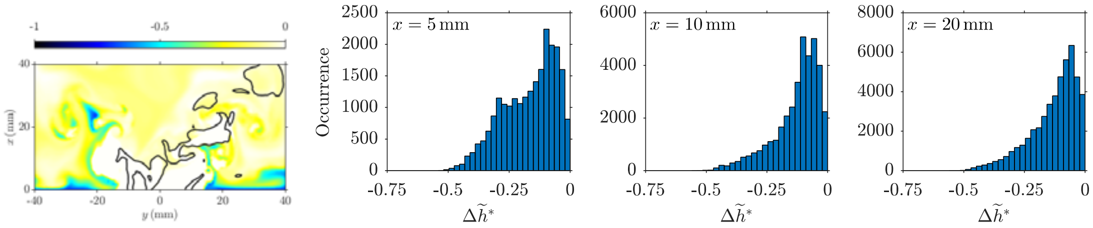

Figure 2: Snapshot of the normalised enthalpy deficit at an arbitrarily chosen time when the flame has an established flame root (left) and histograms of the normalised enthalpy deficit within the flame at different streamwise locations (right).

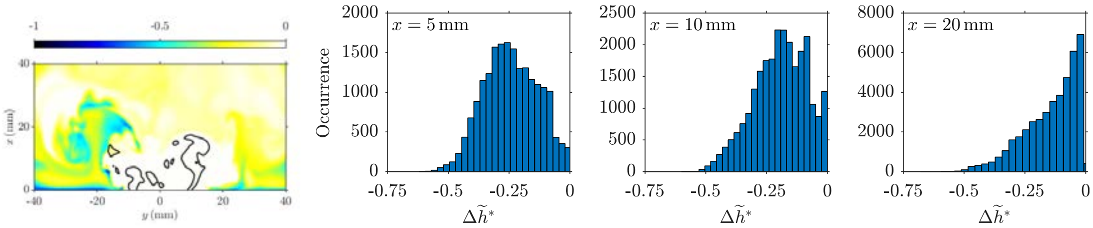

Figure 3: Snapshot of the normalised enthalpy deficit when the lift-off height is at its observed maximum (left) and histograms of the normalised enthalpy deficit within the flame at different streamwise locations (right).

7. Names of key academics and any collaborators:

Dr James Massey, Dr Zhi X Chen and Prof. Nedunchezhian Swaminathan (Department of Engineering, University of Cambridge). Dr. Wolfgang Meier of DLR Stuttgart for the experimental data used for verification and validation.

8. Sources of significant sponsorship (if applicable):

EPSRC DTP scholarship (RG80792), Rolls-Royce plc.

9. Who should we contact for more information?

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10. Please indicate if you would like this case study to be included on the Consortium's ARCHER web-page.

Yes.