# Case Study Template

**1. Title of Case Study: Spray response to acoustic forcing of a multi-passage lean-burn aero-engine fuel injector**

**2. Grant Reference Number:**

**3. One sentence summary: Methods of modelling how fuel droplet size is changed when a gas turbine fuel injector is subjected to acoustic forcing have been compared with experimental data.**

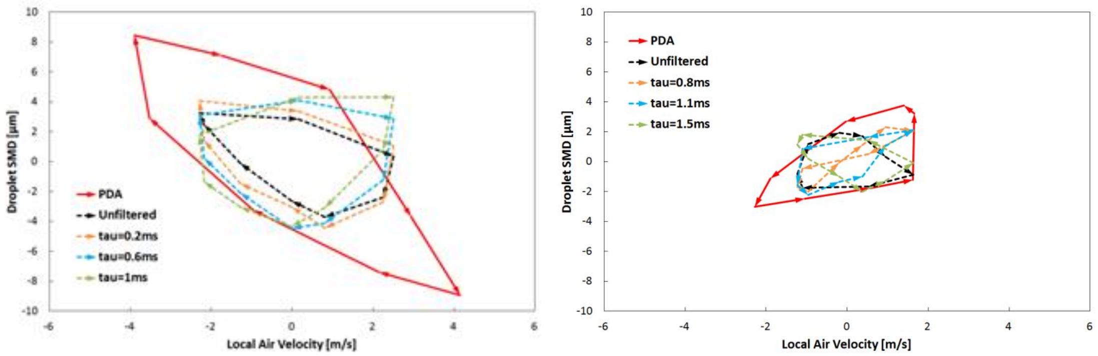
**4. One paragraph summary: The feedback loop caused when acoustic pressure waves from unsteady combustion cause fluctuations in the reactant delivery are a significant issue when developing low emission combustors for aircraft engines. The effect of the acoustic waves on the fuel atomisation is an important element in this. This project looked at ways of including this unsteady atomisation into CFD simulations of a realistic injector at a range of forcing frequencies for comparison with experimental data. It was found that at low frequencies making droplet size a function of instantaneous flow properties was able to reproduce key features of the relationship between droplet size and velocity downstream of the injector. As frequency increases, it is seen that this method is no longer able to capture the correct behaviour, indicating that there is a time delay in the breakup process relative to the acoustic forcing which could play an important role in the acoustic feedback loop.**

**5. Key outputs in bullet points:**

- CFD simulations of two-phase flow with time-varying spray size distributions have been performed over a range of frequencies. These have been compared with experimental data for a realistic acoustically forced injector rather than a simplified model.
- At low frequencies, the methods are seen to reproduce key features of the relationship between droplet size and velocity downstream of the injector. At higher frequency, the agreement becomes less accurate, suggesting the need to include the time delay of the atomisation relative to velocity fluctuation.
- Work carried out in collaboration with Rolls-Royce means this knowledge has been transferred into industry.
- Post-doctoral researcher now working on EU funded project focused on reducing soot emissions from aircraft.

**6. Main body text**

An air-blast fuel injector in an aero-engine plays an important role in the thermoacoustic behaviour of the combustion system. Previous studies have looked at the response of the gas phase to acoustic forcing of fuel injectors, but less attention has been paid to the liquid phase. This project looked at ways of including unsteady atomisation into CFD simulations of an injector at a range of forcing frequencies. A compressible unsteady Reynolds-averaged Navier-Stokes (URANS) method was used to predict the acoustically forced air-flow through the injector. The agreement with experimental data for the air flow response has previously been found to be excellent. Lagrangian spray particles were introduced into the flow with a time varying size distribution determined using existing empirical breakup correlations based on the instantaneous air velocity field. Constants needed for the breakup correlations were calibrated using the data from the unforced and lowest frequency results. Results were then sampled at the same downstream location as in the experiment. Using HPC facilities allowed this to be repeated at a suitable range of frequencies and using different approaches. Baseline results were produced using the instantaneous velocity from the air passages. Simulations were then repeated using an approach where a time filter equivalent to a time delay is used to find the air velocity used in the breakup correlations. Experimental results show a phase difference between the peak air velocity and the Sauter Mean Diameter (SMD) of the particles at the measurement plane. At lower frequencies, the phase shift is captured by the CFD results, as is shown in the figure below. Increasing the delay time used in the breakup model does not improve results indicating that the phase shift, in which the minimum mean diameter is seen some time after the peak velocity, at low frequencies can be explained by the particles travelling to the measurement plane at a slower speed than the air. The higher amplitude of the SMD variation in experiment may be due to uncertainty in the exact acoustic forcing amplitude. As frequency increases, CFD based on the quasi-steady assumption alone is seen to no longer capture the phase shift, indicating that the phase shift in the experiment is not just due to the time of flight of the particles. This is shown for forcing at a Strouhal number of 1.33. At this frequency the experimental phase portrait can be seen to have apparently reversed direction. This can only be reproduced in CFD by including a delay of around 1ms into the breakup model. While introducing a time delay is able to reproduce the phase relationship between local air velocity and mean droplet size for this frequency, it is important to note that the time delay needed to do this changes as frequency changes. Therefore, to create a CFD methodology capable of fully recreating the spray response to acoustic forcing requires further research.




*Phase portraits of Sauter Mean Diameter vs local air velocity at St=0.5 (left) and St=1.33 (right) for different breakup delay times. Arrows show direction of travel around acoustic cycle. Experimental data taken from Phase Doppler Anemometry measurements.*

**7. Names of key academics and any collaborators: Dr Andrew Garmory, Senior Lecturer in Computational Fluid Dynamics, Loughborough University. Dr Jialin Su, Research Associate, Loughborough University.**

**8. Sources of significant sponsorship (if applicable):** £97,000, EPSRC EP/M023893/1, 2016-2017

**9. Who should we contact for more information?** *Dr Andrew Garmory, a.garmory@lboro.ac.uk, 01509227231*

**10. Please indicate if you would like this case study to be included on the Consortium's ARCHER web-page. No preference.**