Case Study

1. Title of Case Study:
A numerical method for the prediction of combustion instabilities

2. Grant Reference Number:
EP/K026801/1 and EP/R029369/1

3. One sentence summary:
A computational tool was developed for the accurate simulation of self-excited thermo-acoustic and hydrodynamic instabilities in gas turbine combustion chambers.

4. One paragraph summary:
The present work constitutes one of the first in-depth computational research efforts to study the physical mechanisms associated with self-excited combustion-driven instabilities. A fully compressible large eddy simulation method was developed providing a cost-effective tool in the design process of modern gas turbines; in particular to examine the thermo-acoustic and hydrodynamic behaviour of prospective combustor concepts to confirm their stability or otherwise. EPSRC funding has made this work possible by allowing simulations to be run on the high performance supercomputer ARCHER.

5. Key outputs in bullet points:
- Developed a new technology (CFD code) to assist the design of low-emission gas turbines
- Provided new knowledge on the characteristics of self-excited combustion instabilities
- Established new collaborations within the UKCTRF and with external research institutions
- Trained a new PhD student (ongoing research into gas turbine hydrogen applications)
- Produced 4 high-quality journal papers and 4 peer-reviewed conference papers to date
- Presented research outcomes at several international conferences and expert meetings

6. Main body text
Despite being highly effective in the reduction of environmentally harmful pollutant emissions, modern gas turbine combustors are known to be susceptible to thermo-acoustic and hydrodynamic instabilities. These instabilities are characterised by high-amplitude oscillations of the pressure and heat release rate, and arise when a resonant feedback loop between the combustion chamber acoustics and the unsteady reactive flow field is established. The present work devised an accurate computational tool based on large eddy simulation, capable of predicting the onset of such instabilities.

Two test cases, each involving a lean, partially premixed, swirl-stabilised flame, were chosen to demonstrate the tool's predictive capabilities. The first test case focused on the combined effects of multiple instability mechanisms in a lab-scale combustor. These effects included periodic oscillations of the mass flow rate and local equivalence ratio (Figure 1), as well as interactions between the unsteady flame front and coherent vortex structures (Figure 2). The second test case comprised a full-scale industrial combustor (Figure 3) operated at different elevated pressures of 3 and 6 bar. Both a low-frequency longitudinal mode and a high-frequency azimuthal mode were identified (Figure 4).

Overall, the simulations carried out for both test cases showed good agreement with available experimental measurements and provided new insights into the physical feedback mechanisms underlying combustion-driven instabilities.

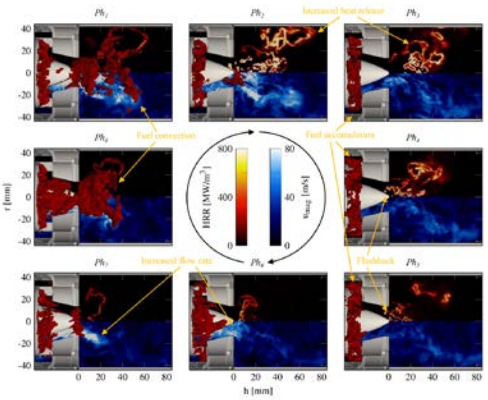

Figure 1: Periodic evolution of the heat release rate, velocity magnitude and reactant mixture composition.

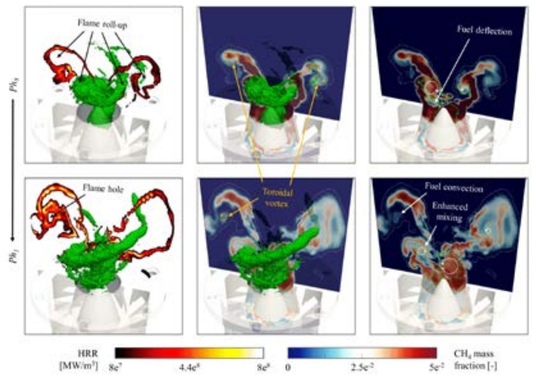

Figure 2: Typical interaction of coherent vortex structures with the unsteady flame front.

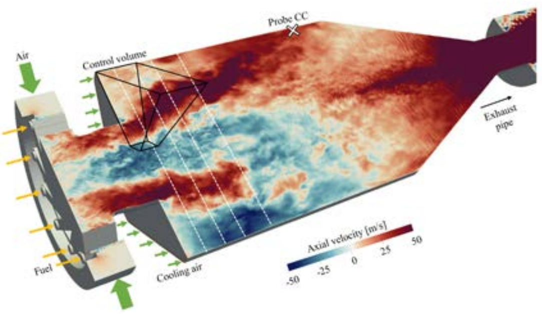

Figure 3: Vertical cut through the combustor with an instantaneous snapshot of the axial velocity.

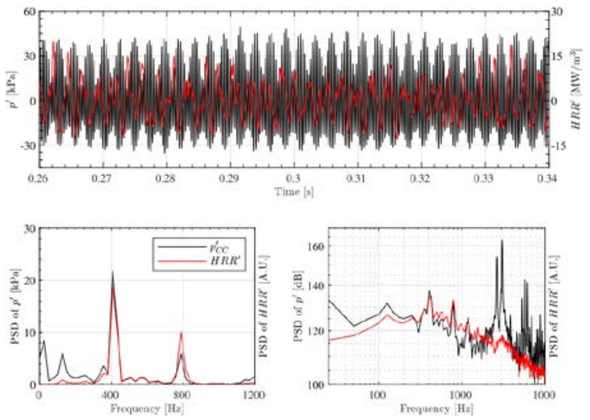

Figure 4: Time signals of the heat release rate and pressure dynamics including their FFT.

7. Names of key academics and any collaborators:

Daniel Fredrich, Imperial College London
William P. Jones, Imperial College London
Andrew J. Marquis, Imperial College London
Yu Gong, Imperial College London

8. Sources of significant sponsorship (if applicable):

Siemens Industrial Turbomachinery Ltd.

9. Who should we contact for more information?

Daniel Fredrich
d.fredrich15@imperial.ac.uk
+447874006635

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

Yes