PAWSEY supercomputing centre

PARTNER INSTITUTIONS

UNSW AUSTRALIA

PROJECT LEADER
PROF EVATT HAWKES

evatt.hawkes@unsw.edu.au

SYSTEM
MAGNUS

TIME ALLOCATED
7,000,000 HOURS

AREA OF SCIENCE
Turbulent Flows

APPLICATIONS USED
SD3

IMPROVING GAS TURBINES FOR A CLEANER PLANET

Global trends of heightened fuel prices, clean air regulations, biofuels and greenhouse gas awareness are driving scientists to find answers to cleaner energy technologies.

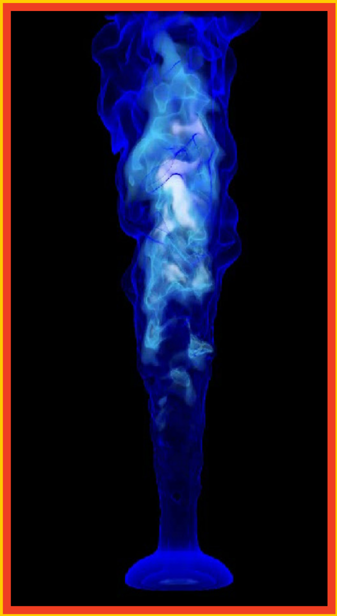
The combined cycle gas turbine is the most efficient and lowest carbon emitting combustion-based power generation system currently available. Prof. Hawkes, from the University of New South Wales, is leading a team of researchers to maximise gas turbine combustion efficiency using the world-class infrastructure at Pawsey Supercomputing Centre.

The gas turbine is a technology used in aviation and for power generation. When used for power generation, it is a technology that enables high penetration renewable energy due to its fast starting capability, providing rapid generation when renewables are not available. Despite this benefit, and the already low CO2 emissions, the technology needs to further reduce CO2 while also limiting other harmful emissions, such as oxides of nitrogen (NOx). To achieve this, new combustion modes are of great interest to gas turbine manufacturers. The thrust of these new combustion modes is to achieve highly diluted, lower temperature combustion in intense mixing conditions, which improves combustion efficiency and radically reduces NOx emissions.

2016

DIRECT NUMERICAL SIMULATIONS OF TURBULENT COMBUSTION

Three-dimensional rendering of vorticity magnitude in a direct numerical simulation of a highly turbulent premixed jet flame. Simulation by Haiou Wang and Evatt Hawkes, University of New South Wales; rendering by Hongfeng Yu, University of Nebraska-Lincoln



Three-dimensional rendering of hydroxyl radical in a direct numerical simulation of a highly turbulent premixed jet flame. Simulation by Haiou Wang and Evatt Hawkes, University of New South Wales; rendering by Hongfeng Yu, University of Nebraska-Lincoln.

THE CHALLENGE

Achieving new combustion modes is a major challenge. Due to lower temperature flames being less stable; they can blow out completely, or be subject to unstable oscillations, which cause system damage. A key barrier in overcoming this challenge is a lack of knowledge of combustion in relevant high-turbulence conditions.

"There is very little understanding of what happens when small turbulent eddies are sufficiently intense that they can penetrate and disrupt the chemical reaction zone of the flame," said Prof. Hawkes. "This project set out to provide the lacking understanding using large-scale computational fluid dynamics models of the flame-turbulence interactions."

Turbulence is a classic example of a multi-scale process which can be thought of as composed of a multitude of vorticies, or eddies, having different length-scales and time-scales. Direct numerical simulations (DNS) of combustion, which resolve all continuum scales of the flow, require very large numbers of grid points and time-steps to compute. In addition, combustion simulations need to compute the chemical reaction rates of many chemical species. As a result, these types of simulations are computationally very expensive.

THE SOLUTION

"Historically, because of the computational expense, typical laboratory flames were long considered out of range for the DNS approach. However, the petascale computing era has changed this situation such that many laboratory flames are now accessible. In this project, we set out to compute a real laboratory flame, which had high turbulence levels such that small scales can penetrate and disrupt the chemical reaction zone of the flame, as they do in a real gas turbine", said Dr Hawkes.

Dr. Haiou Wang, a postdoctoral research fellow in Prof. Hawkes' group identified a candidate flame and carried out the DNS. Dr Wang noted: "This required a significant computational effort. Our simulations had 2 billion grid points, 150,000 time steps, and 28 chemical species, resulting in around 10^{16} degrees of freedom. The simulations conducted ran on 19,200 cores on the Magnus supercomputer, using over 10 M hours and generating around 100 TB of data."

OUTCOME

The massive task of data analysis in Prof. Hawkes' project is ongoing and expected to be active for years. Already published work by Dr. Wang and Hawkes included first-of-a-kind comparisons to experiment and used the DNS to propose new ways to experimentally measure the rate of heat release in the flame. Current submitted work looks at the stability of the flame, which is of great importance in gas turbines.

A completely new direction that this work is enabling is to directly use the data in industry. The research team has been approached by a major international gas turbine manufacturer to employ the DNS data as a validation database for models that are used in their combustor design process. Direct use of these type of data by industry is a completely new direction for combustion DNS, and one which can have significant future impact by providing engineers with the tools they need to design improved, lower emissions combustors.