Dr Robert Bastiaans is leading an assortment of projects aiming to develop understanding on lower emission gas turbine technology. Here, he provides a background to combustion technology and gives an insight into the future of energy conversion.

Could you provide an overview of your background and key research interests?

I am Associate Professor at the Eindhoven University of Technology (TU/e) in the Netherlands and a member of the Combustion Technology Group. My research focuses on modelling turbulent combustion in computer simulations of gas turbines, mainly used for electricity production. I am also Chairman of the Dutch Section of the Combustion Institute, as well as the task-group on Fuel Flexibility of the European Turbine Network (ETN).

My early research focused on aeroacoustics (sound produced by flow instabilities) and led onto modelling turbulence (the last unsolved problem in classical mechanics). Later, I was drawn to the simulation of turbulent combustion problems on very large computer systems. In the initial stage of my study I was amazed that cloud movement could be described mathematically and solved on a computer to a high degree of accuracy – as we know from the ‘highly accurate’ weather predictions.

How might combustion play a role in energy in the years ahead? Do you see fuel supply changing in the next decade or so?

Conversion of fuels – chemical energy to thermal energy, through to combustion – will remain a critical part of our energy future for at least the next 50 years. Thermal energy can be used for thrust to drive electrical energy generators, or directly, as being the case in aeroplanes. The next decade, however, will bring significant changes in fuel supply and tighter regulations on emissions from combustion devices as well as efficiency requirements.

What turbulent combustion problems do you seek to solve?

I’m aiming to solve turbulent combustion in gas turbines with large throughput, at high pressure – especially for new fuels that contain large amounts of hydrogen. Here, all kind of instabilities can occur that are difficult to represent. In experiments, we observed anomalous results in which flame blow-off (an unwanted phenomenon) was observed at decreasing blowing velocity.

The combusting flow can be calculated using big computer simulations, which also determine efficiency, as well as the emissions of any species the user wants to discover. Conditions or geometry can be changed to uncover optimal results.

To this end, can you describe some of the technologies you are developing?

In developing our simulation techniques we are looking at probability density descriptions of the likelihood of certain events occurring. This is on a scale we cannot resolve. In this case the statistical nature of turbulence is very important.

We also have hardware to accurately measure the 1D laminar burning rate. It is called the heat flux method (HFM), because we use a clever way in which the energy radiated by the hot laminar flame to a burner surface is exactly conducted back to the cold fuel mixtures. This means that it stays adiabatic (no heat loss).

Can you give an insight into the principal goals of two of your current projects,
Simulated combustion

With efficiency and emissions regulations looming for energy conversion technology, a group of scientists at the Eindhoven University of Technology, Netherlands, is using computer simulation to better understand and optimise gas turbine combustion.

CONVERSION OF FUELS into energy through turbulent combustion is predicted to remain an integral part of the world’s energy future for at least another 50 years. Continued reliance on gaseous fossil resources as a primary fuel compounded with requirements to reduce greenhouse gas emissions has raised demand for reliable, low-emission, cost-competitive energy production technologies. These tighter regulations on emissions and efficiency requirements for combustion devices, as well as changes in fuel supply and composition, are set to arrive within the next decade, and new combustion technology must be developed in order to adapt. This is the work being undertaken by scientists at the Eindhoven University of Technology (TU/e) in the Netherlands.

A main point of investigation is turbulent combustion, an inevitability in large-scale energy conversion. To convert large amounts of energy, like in electricity production, or aeroplane engines, the process must be intensive. This means that chaotic motion must be employed through high pressures, densities and velocities.

ALTAS

Gas turbine combustion is an important form of energy conversion in the world today; for most aero applications gas turbines are the only way to achieve the required thrust. Throughout the ALTAS project, new CFD is developed to gain knowledge in modelling combustion processes with alternative fuels. The ultimate goal is to predict the complex combustion process of gas turbines using these fuels, with the inclusion of complex physical real fuel phenomena (e.g. temperature-traverse, preferential diffusion, thermo-diffusive effects, soot, ignition and extinction).

The project is supported by Siemens Power Generation (SPG) in the US and Rolls-Royce Deutschland (RRD) in Germany, with both companies contributing to the research effort. At SPG, Reynolds-averaged Navier-Stokes (RANS)-based CFD is used with simple combustion models. One of the aims is to enhance the CFD capabilities to support the design of future combustors. At RRD the research is orientated towards the implementation and application of
Virtual validation

Dr Robert Bastiaans is currently helping to prepare ViTurb, an international project that aims to develop and validate a virtual testing tool for industrial gas turbines.

**THE EINDHOVEN UNIVERSITY** of Technology (TU/e) was invited to participate in the project based on their expertise in turbulent combustion modelling. The group plans to develop a software tool that simulates the behaviour of an entire gas turbine. This includes the performance of the compressor, combustor and expansion sections for flow and chemistry, as well as strength and heat transfer in solid parts.

The strength of such a model is that all parts are coupled with internal boundary conditions with known values. This approach is consistent and prevents design uncertainties, originating from large ranges of parameter variation studies on single components. The whole project is dependent on the compilation of computer code for different parts that have shown potential.

The combustion chamber is the vital part of the turbine where chemical energy is released in the form of kinetic energy and heat. Kinetics is efficiently handled by the use of the flamelet-generated manifold technique, while small-scale turbulent statistics are taken into account by introducing probability density functions. The overall approach has been made possible by using the processing power afforded by modern supercomputers in conjunction with these modelling methods, which were first developed at TU/e.

The tool would allow simulations leading to performance predictions, aeromechanical response, and thermal and heat transfer predictions in one single simulation. Utilising existing experience of large-scale modelling of entire engine components, including the entire compressor and turbine, the model could be used to investigate new cycle architectures, particularly those aimed at efficient carbon capture and storage, as well as use of biofuels or syngas.
MoST is utilising computational and experimental research methods. For the experimental part of the research, the group will attempt to find resonant mixing conditions within a low swirl turbulent burner with variable aspects like swirl, flow and inflow conditions. The CFD side of the research will involve the exploration and development of large-eddy simulation (LES) and direct numerical simulation (DNS) methods. This will use the experimental results as a reference when modelling combustion conditions and allow the subsequent development of optimal fluctuations under said conditions.

**FUTURE HYDROGEN-BASED FUELS**

The natural gas network is expecting an injection of hydrogen in the near future, as the addition of hydrogen to natural gas (the main constituent of which is methane), forming hythane, allows for leaner operation of premixed combustion at lower temperatures and leads to reduced NOₓ, CO and CO₂ emissions, and higher efficiencies of engines and turbines.

In another research arm, ‘Flameballs, cells and cusps in ultra lean hythane air mixtures’, the team is overcoming important challenges in this area. The inclusion of hydrogen (having small molecules) changes the nature of the combustion, making it more volatile and increasing the rate of turbulent combustion. The researchers identified anomalous combustion and detected flameballs that were only predicted at zero gravity, and in inverted flame cases it was found that flames were stable at high velocities but were blown off at small blowing velocities. The TU/e group aims to develop computational models capable of representing these effects at high temperatures and pressures, furthering their understanding of how combustion technology reacts to such a fuel. In the near future gas turbine design and optimisation will be performed on the basis of detailed simulation of flow and combustion, with valuable tools that are currently developed by research groups like TU/e.

![Change in normalised burning rate with a change in turbulent deformation, at changing Lewis number. Realisations from simulations, dots and straight line for theory of methane.](image)

**THE PROJECT WAS** established based on projections that there will be a significant injection of hydrogen into the natural gas network in Europe in the near future. This addition of hydrogen will contribute to reduce the emissions of greenhouse gases.

However, while existing networks for gas storage and delivery can accommodate such amounts of added hydrogen, conventional domestic appliances, such as heating boilers, kitchen stoves, and combined heat and power (CHP) systems cannot automatically do so.

Recent studies have demonstrated that the addition of hydrogen to methane can drastically impact flame stabilisation behaviour due to specific effects related to the high mass diffusivity of hydrogen: so-called preferential diffusion effects. Better understanding the effects of preferential diffusion on flame stabilisation behaviour at conditions typical for burners used in such appliances is therefore vital.

Funding in the Netherlands working in the field. The Group has a strong international reputation based on achievements in theoretical and experimental study of laminar and turbulent combustion systems, eg. engines, gas turbines, microturbines, burners and boilers. Having been active in fundamental and applied combustion research since 1990, CTG is responsible for the most advanced analytical models for flame stretch effects developed to date.

This current project is based, in large part, on concepts established in the earlier STW project ‘Flame balls, cells and cusps in ultra-lean hythane-air mixtures’. The main goal is to generate fundamental knowledge and understanding of preferential diffusion effects on the flame stabilisation/combustion behaviour of hydrogen-enriched natural gas, and to translate this knowledge into new design rules for fuel flexible burners that can handle natural gas with a broad range of compositions.

If successful, the researchers’ findings could lead to innovative new ideas to improve flame stability in gas turbine burners.