CHALLENGES IN MODELLING GAS TURBINE COMBUSTION

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ABSTRACT

Challenges in modelling turbulent combustion in land based gas turbine combustors will be discussed in an overview, with historical perspective. The lean premixed technology and its implications for modeling will be addressed. This includes turbulence modelling for strongly swirling flows and different approaches for modelling turbulence-chemistry interaction. In this context, turbulence modelling approaches such as URANS and LES, combustion models such as LFM and EDC will be addressed. Simulation results will be presented and compared with measurements for different applications. Challenges related with alternative fuels such as biogas and syngas will also be addressed.

INTRODUCTION

Since several decades, one of the main goals in gas turbine combustion has been to reduce Nitrogen Oxide (NOx) emissions, while retaining high combustion efficiency. This has led to the development of lean premixed technology, which is the state of the art in modern gad turbine combustors. This technology, however, puts special demands on the modelling such as the predictability of turbulent premixed combustion, and predictability of higly swirling turbulent reacting flows. An additional important issue in this context is thermo-acosutics, which, however, will not be addressed in the present lecture. The present lecture aims to provide an outline of the issues related with the modelling of turbulent combustion for premixed flames, and turbulence for swirling flows in gas turbine combustors.

In flame stabilization, swirl plays a central role for has turbine combustion systems. The predominant effect of swirl on the turbulence structure is to create a strong non-isotropy, which can strongly overburden the state of the art RANS (Reynolds Averaged Numerical Solutions) based turbulence models that assume an isotropic turbulence structure as implied by a scalar turbulent viscosity [1]. A further feature of swirling flows is that an increase of the swirl number beyond a critical value leads to the the so called sub-critical flow state [2], which is characterized by a quasi-deterministic low frequency unsteadiness, leading quite often to the so-called “precessing vortex core” (PVC), and exhibiting a strong sensitivity to the downstream conditions. These features put additional demands on the computational modelling. In the modern lean premixed combustion technology, the applied swirl numbers are quite high, for being able to stabilize the flame under lean conditions, which especially necessitates an adequate modelling strategy for the swirling flow, as far as the turbulence modelling is concerned. To this purpose, a series of investigations have been performed. A series of tutbulence models such as RANS, URANS (Unsteady RANS) [3], DES (Detached Eddy Simulations) and different versions of LES (Large Eddy Simulations) [4] have been applied to different experimental configurations. The results will be discussed and assessed in the lecture.

In land based gas turbines, the lean premixed combustion [5] was established as the main technology for achieving low NOx emissions. Compared to the more conventional non-premixed combustion, the premixed combustion puts stronger demands on the modelling, since the turbulent flame speed needs an accurate modelling, which was not relevant for the non-premixed case. Furthermore, for being able to adequately face the currently important challenges, such as emissions, stability, fuel flexibility, it is quite often not sufficient to consider the main species, but work with a reaction mechanism, which contains information on a large number of species. Since additional transport equations need to be solved for the species, this, coupled with a turbulence modelleing strategy such as LES, may end up in extremely high demands on computer resources. Thus, finding an acceptable trade-off between accuracy and economy is a further challenge as far as the modelling of turbulent premixed combustion is concerned.

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In this context, two different combustion modelling strategies, namely the EDC (Eddy Dissipation Concept) and the LFM (Laminar Flamelet Method) are used. In LFM, limitations of the standard non-premixed approach, based on the mixture fraction and the scalar dissipation rate, for lifted flames like the present one, is overcome by adding the progress variable as an additional dimension to the flamelet libraries. The predictive capability of the models will be assessed by comparisons with experiments.

Finally, combustion of alternative fuels such as biogas and syngas, as well as the phenomena of flashback [8] are addressed.

EXAMPLES OF NUMERICAL RESULTS

Figure 1 shows the contourts of temperature in a plane through an industrial gas turbine combustor, as well as the isosurfaces of high vorticity, at an instant of time. As turbulence model, the Reynolds Stress Model (RSM) within URANS framework was used, wheras the combustion model was based on the EDC. In this apparently sub-critical flow state, a PVC can be observed which extends from the burner to the turbine inlet nozzle guide vanes.

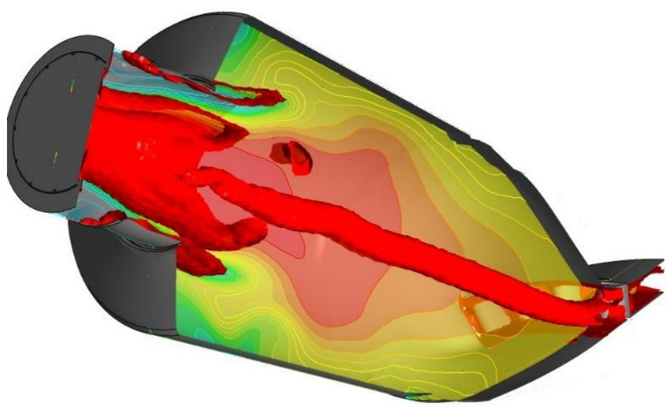

Figure 1. Temperature contours as well as isosurfaces of high vorticity in gas turbine combustor.

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REFERENCES

1. Pope, S. B., 2000, *Turbulent Flows*, Cambridge University Press, Cambridge, UK.
2. Escuider, M. P., 1988, Vortex breakdown: observations and explanations, *Prog. Aerosp. Sci.*, **25**, pp. 189-201.
3. Durbin, P. A. and Reif, P. B. A., 2011, *Statistical Theory and Modeling for Turbulent Flows, 2nd Ed.*, Wiley, Chichester, UK.
4. Sagaut, P., 2006, *Large Eddy Simulations for Incrompressible Flows*, Springer, Berlin, Germany.
5. Poinsot, T. and Veynante, D., 2005, *Theoretical and Numerical Combustion, 2nd Ed.*, R.T.Edwards Inc., Philadelphia, USA.
6. Magnussen, B. F., 1981, On the structure of turbulence and generalized eddy dissipation concept for chemical reactions in turbulent flow, *Proc. 19th AIAA Aerospace Meeting, January 12-15, 1981, St. Louis, USA, pp. 1-6*, DOI: 10.2514/6.1981-42.
7. Peters, N., 2002, *Turbulent Combustion*, Cambridge University Press, Cambridge, UK.
8. Benim, A. C. and Syed, K. J., 2015, *Flashback Mechanisms in Lean Premixed Gas Turbine Combustion*, Academic Press, Oxford, UK.