MODELLING FOR SPARK IGNITION IN A GAS TURBINE COMBUSTOR

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The relight problem
The ability to re-ignite an aero-gas turbine across a wide range of flight conditions is a critical operational requirement. Received wisdom tells us that combustors have a large volume, and with a long recirculation time, provide more reliable ignition. A long recirculation time increases emission of oxides of nitrogen however, and the increased volume adds to the overall engine size and weight. The outstanding challenge is to develop predictive computational tools which permit engine designers to ensure that novel low emission and low weight combustor designs are likely to satisfy ignition requirements early in the development process.

Two complementary modelling approaches
Confident prediction of ignition in turbulent partially-premixed and spray burners requires further development of advanced simulation methods, and intensive computing: Large Eddy Simulation (Approach 1) is promising but computationally costly. Inexpensive design tools – for consideration of ignitability in preliminary design studies and optimisation – are still required.

Traditional design correlations for combustor ignitability based on combustor volume and flow rates (cf. Lefebvre) give general information only, and may be applicable to radically new combustor designs. This research has developed a second complementary approach which accounts for details of the fuel distribution and flow patterns in a prospective design, as well as igniter power and location. This initial screening facilitates targeted use of high-fidelity LES.

Approach 1: Advanced CFD for combustor ignition
Spark ignition of a methane jet flame [1] is used as a simple, and challenging, test for ignition prediction. Simulation using Reynolds Averaged Navier Stokes (RANS) coupled with an advanced turbulent combustion model (CMC) [2] fails to capture the interaction of propagation and expansion with large scale turbulence.

Good predictions can be obtained with compressible LES (AVBP), even using relatively simple one-step ‘dynamically thickened flame’ combustion model (Lacaze et al. [3]). Simulations use a new model for spark energy deposition, and 3rd order numerics and efficient massively parallel computation.

The modelling approach has been applied successfully, at CERFACS, to ignition studies of annular gas turbine combustors and rocket ignition.

Approach 2: A tool for rapid assessment of ignitability
The approach developed here [4,5] is to analyse steady-state Reynolds averaged solutions (which can be computed cheaply using RANS) for a combustor at pre-ignition conditions. Ignitability is assessed by tracking Lagrangian particles representing flame elements (originating from the ignitor) using stochastic models for velocity (Langevin) and mixture fraction (exchange with the mean). Particles remain active while their Karlovitz numbers, modelled by: $K_{pa} = 0.157 \left( \frac{\langle u' \rangle^3}{L_{cor} \rho} \right)^{1/2} S_{2p}$, remain below a critical value.

The model indicates to the designer how the burner ignites. An heuristic metric, such as the volume fraction of the burner which gets ignited, can be used to report a qualitative measure of ignition success. Due to stochasticity in the model, the outcomes of multiple trials differ, providing ignition statistics in addition.

Illustration of a gas turbine combustor ignition sequence, superimposed on a combustor image from Stanford CTR.

Unstructured mesh refinement: 2M nodes, 12 M tetrahedra.

Schematic of the turbulent jet ignition experiment showing spark electrodes.

Experimental fast camera images [1] (left) an instantaneous LES temperature fields on a plane through the centre-line [3] (right).

Temperature field in the plane of the igniter for an ignition sequence predicted using LES, Simon Stow (2010).

Ignition sequence predicted using the ignition model (green = active flame elements, red = extinguished elements)

References: