UNIVERSITY OF Southampton
Engineering and the Environment
Aeronautics, Astronautics and Computational Engineering

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 with 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.

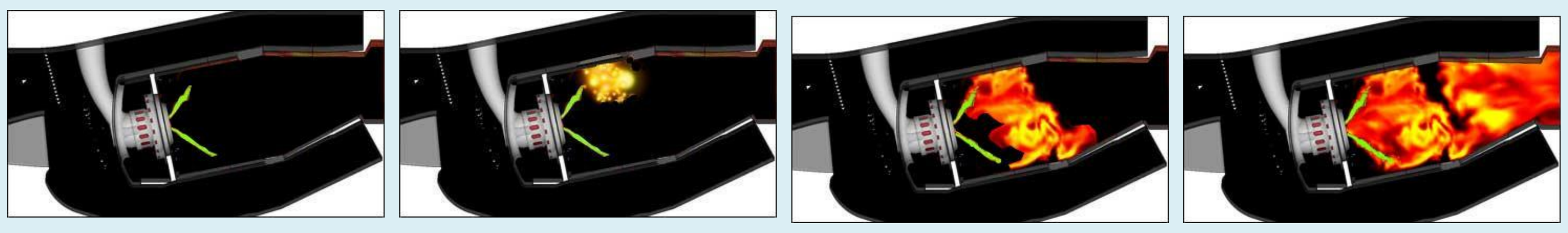
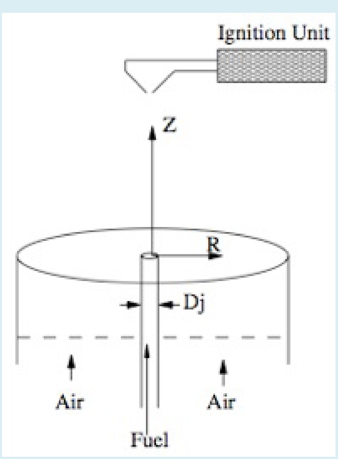


Illustration of a gas turbine combustor ignition sequence, superimposed on a combustor image from Stanford CTR.

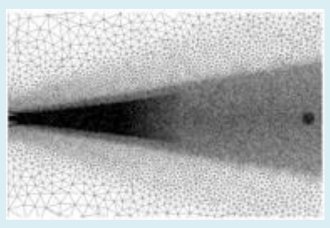
Approach 1: Advanced CFD for combustor ignition

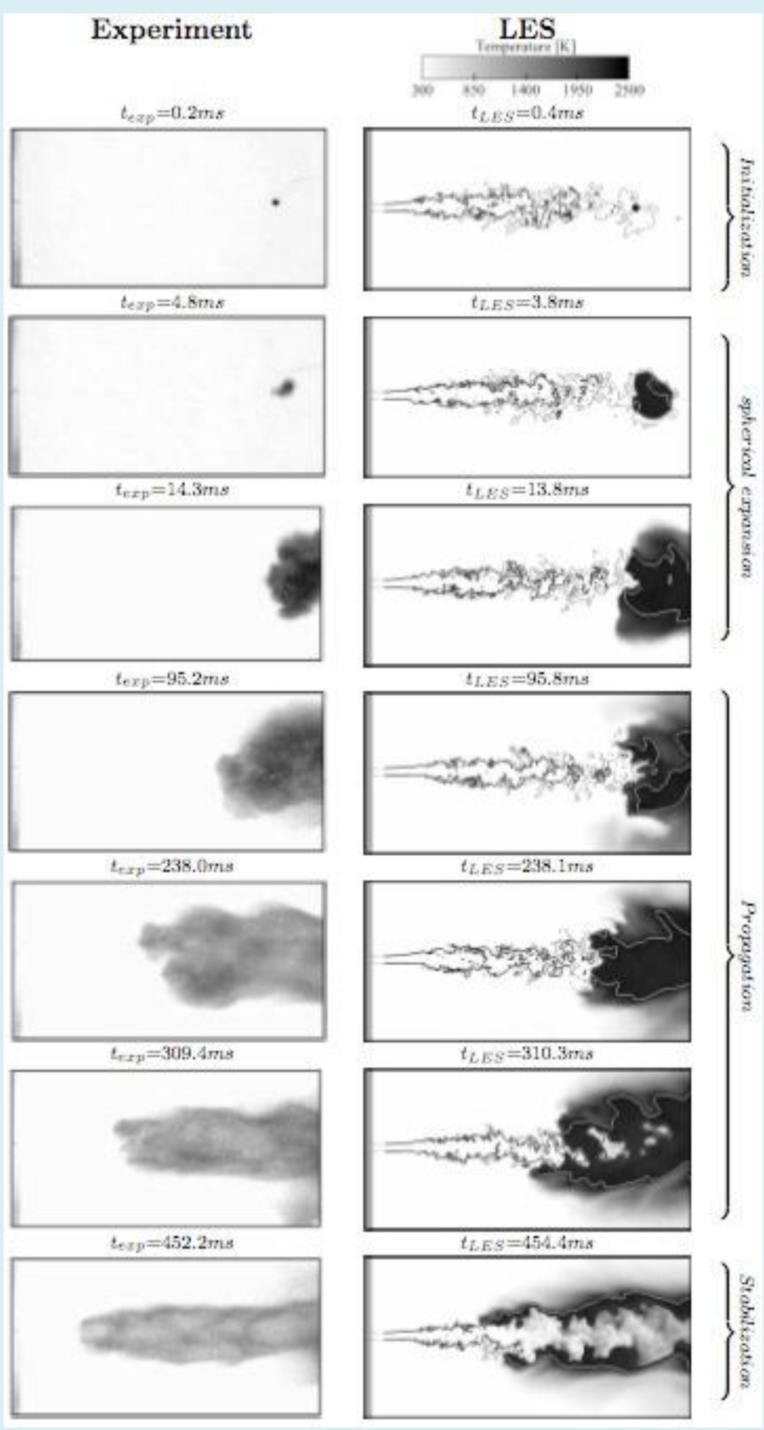
Spark ignition of a methane jet flame [1] is used as a simple, and challenging, test for ignition prediction. Simulation using Reynolds Averaged Navier Stokes (RANS) coupled with an advanced turbulent combustion model (CMC) [2] fails to capture the interaction of propagation and expansion with large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

Schematic of the turbulent jet ignition experiment showing spark electrodes.



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





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

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.

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 inapplicable 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 designs, as well as igniter power and location. This initial screening facilitates targeted use of high-fidelity LES.

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 alight while their Karlovitz numbers, modelled by: $Ka_p = 0.157\left(\nu \frac{(u')^3}{L_{turb,p}}\right)^{1/2} S_{L,p}^{2}$,remains below a critical value.

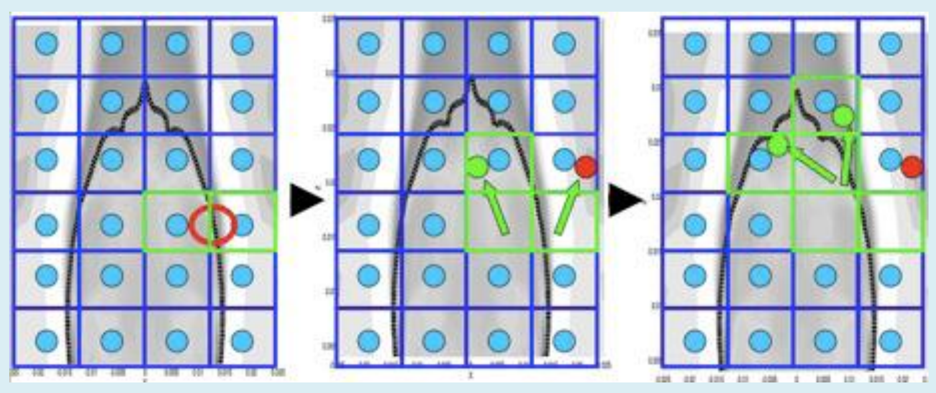
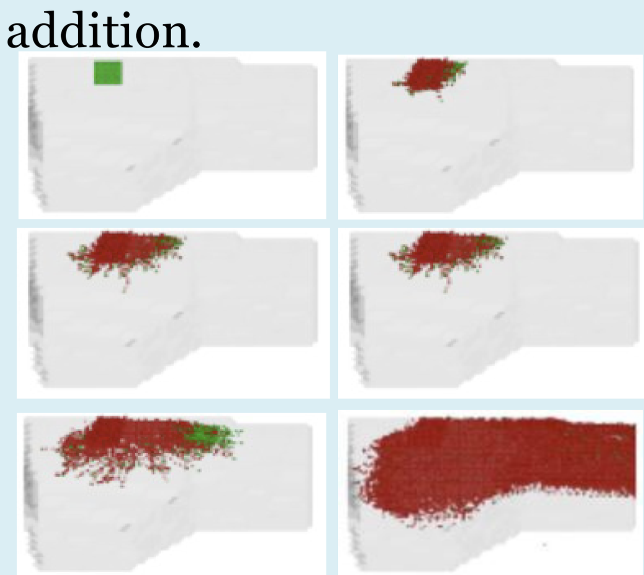
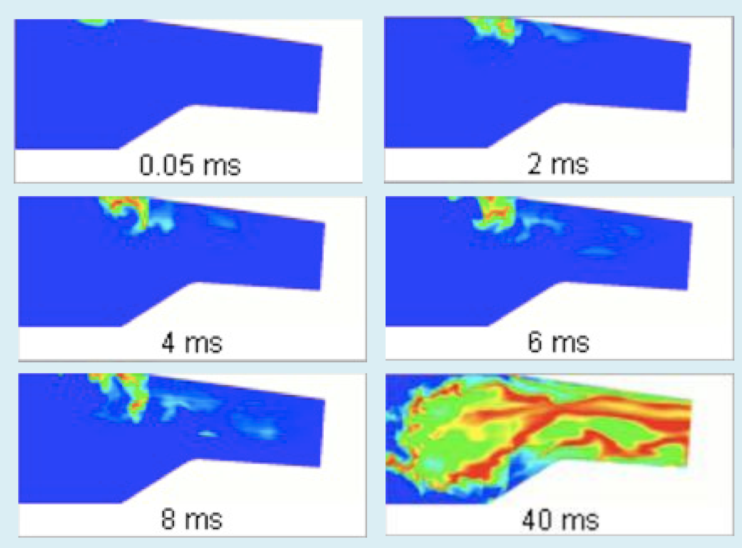


Illustration of the flame tracking scheme: green particles are active flame elements, blue particles await ignition, red particles are extinguished flame. Green cells are ignited, blue cells are unreacted.

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.



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



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

[1] S.F.Ahmed, E.Mastorakos, Combust. Flame (2006).
[2] E.S.Richardson, E.Mastorakos, 3rd European Combust. Meeting (2007).
[3] G.Lacaze, E.S.Richardson, T. Poinsot, Combust. Flame (2009).
[4] Neophytou, A., Richardson, E. S., and Mastorakos, E. *Combust. Flame*. Submitted for publication. 2011.
[5] Neophytou, A., Mastorakos, E.. Richardson, E.S., Stow, S., Zedda, M. 7th *Mediterranean Combustion Symposium* 2011.

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