Dispersion of entropy waves advecting through combustion chambers

I. Duran, Y. Xia, A. S. Morgans and X. Han
Imperial College London

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Unsteady combustion in modern gas turbines generates large entropy waves, also known as hot spots. When these are accelerated through the stator vanes, they generate acoustic waves via a mechanism known as indirect combustion noise [1]. The upstream-propagating acoustic waves interact with the the flame and can contribute to the thermoacoustic feedback loop [2], while the downstream-propagating waves contribute to the global noise [3]. The strength of each acoustic wave is directly proportional to the amplitude of the entropy wave reaching the inlet of the first stator blade.

Low-order models can be used to predict the noise generated by an entropy wave with reasonable accuracy, and at a fraction of the cost of numerical methods [4, 5]. These analytical models neglect the advection of the entropy wave through the turbulent combustion chamber, assuming the entropy wave arrives at the turbine inlet in the same form as that in which it was generated by the flame. The first computational analysis of the advection of entropy waves through a turbulent flow was performed by Morgans et al. [6]. For a fully resolved turbulent channel flow, they found that the entropy wave was strongly deformed by the shear dispersion of the flow, but all of the entropy was eventually convected downstream of the flow without loss in time-integrated amplitude.

The aim of this work is to extend the study of entropy wave advection to the case of a real gas turbine combustor geometry, whose flow includes far more complex features, such as recirculation zones and swirl. The particular combustor considered is the SGT-100 combustor [8, 9] shown in Fig. 1. Simulations are performed using the ReactingFOAM solver of OpenFOAM [7]. For entropy wave advection, a similar approach to that in [6] is used; the entropy wave is assumed to originate in the areas where mean heat release occurs. It is then advected as a passive scalar with the flow, using either the mean flow velocity or the instantaneous velocity at each point.

Example results, showing the effect of advection by the mean flow, are shown in figure 2. The outlet entropy wave strength indicates that a large amount of entropy is still able to reach the outlet. The flow features typical of industrial combustion chambers do have a significant effect on the entropy waves; in particular the recirculation zone results in an effective loss of entropy wave amplitude. This study will prove useful in deriving entropy wave advection models that pertain to real combustor flows.

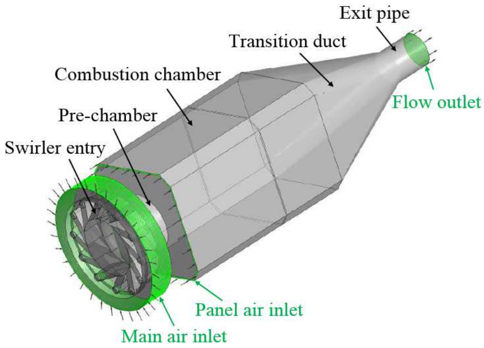

Figure 1: The SGT-100 combustor simulated for the study [8, 9].

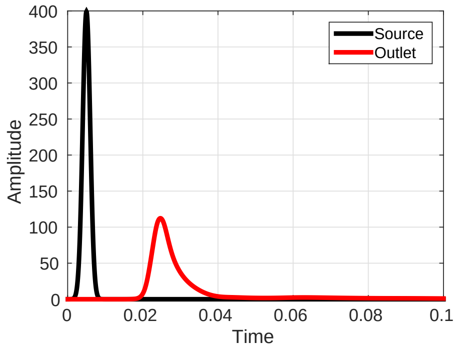

Figure 2: Source term of entropy (black) and entropy at the outlet of the combustor chamber (red).

References

[1] F. E. Marble and S. M. Candel. Acoustic disturbance from gas non-uniformities convected through a nozzle. *J. of Sound and Vib.*, 55:225–243, 1977.

[2] C. S. Goh and A. S. Morgans. The influence of entropy waves on the thermoacoustic stability of a model combustor. *Combustion Science and Technology*, 185(2):249–268, 2013.

[3] N. A. Cumpsty and F. E. Marble. The interaction of entropy fluctuations with turbine blade rows; a mechanism of turbojet engine noise. *Proc. R. Soc. Lond. A*, 357:323–344, 1977.

[4] I. Duran and S. Moreau. Solution of the quasi one-dimensional linearized Euler equations using flow invariants and the Magnus expansion. *Journal of Fluid Mechanics*, 723:190–231, 2013.

[5] I. Duran and A. S. Morgans. On the reflection and transmission of circumferential waves through nozzles. journal of fluid mechanics. *Journal of Fluid Mechanics*, 773:137–153, May 2015.

[6] A. S. Morgans, C. S. Goh, and J. A. Dahan. The dissipation and shear dispersion of entropy waves in combustor thermoacoustics. *Journal of Fluid Mechanics*, 733 R2:1–11, 2013.

[7] http://www.openfoam.com/.

[8] G. Bulat. *Large Eddy Simulations of Reacting Swirling Flows in an Industrial Burner*. PhD thesis, Imperial College London, 2012.

[9] U. Stopper, W. Meier, R. Sadanandan, M. Stöhr, M. Aigner, and G. Bulat. Experimental study of industrial gas turbine flames including quantification of pressure influence on flow field, fuel/air premixing and flame shape. *Combustion and Flame*, 160(10):2103–2118, 2013.