Impact of Axial Gradients on Combustion Chamber Acoustics

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Combustion instability is a major concern in liquid rocket engine combustion processes [1]. It is based on an interaction between combustion chamber acoustics and combustion process. Typically, the basic eigenmodes of the combustion chamber which resemble the eigenmodes of a cylindrical domain (i.e. mostly tangential modes) are excited.
The eigenmodes of a full scale combustion chamber with a long cylindrical section are examined in the present study. In experimental data, an axial dependency of the frequency of the dominant T1 eigenmode is seen.

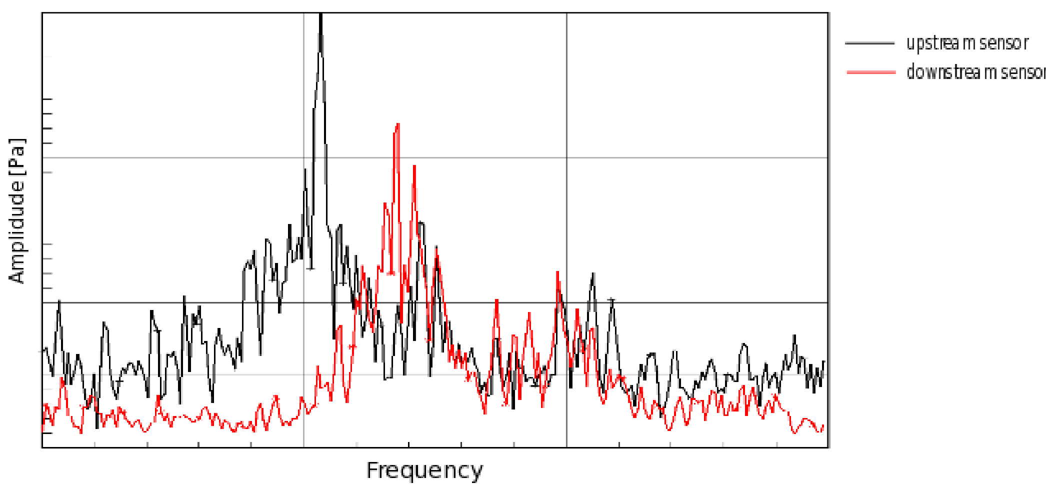

Figure 1: Fast Fourier Transformation around the 1st tangential eigenmode of two dynamic pressure sensors located in the same combustion chamber

As visualized in figure 1, there is a lower frequency first tangential eigenmode (T1) which develops close to the face plate and a higher frequency T1 which develops in the downstream area. The development of two different tangential eigenmodes may be caused by different hot gas properties along the axis of the combustion chamber permitting different tangential eigenmodes to form on different axial locations.
This behavior contradicts basic assumptions used in most low order modeling approaches. These approaches usually assume the combustion chamber to be a perfect cylinder filled with a homogeneous gas. [1].
Since this behavior, as described, can not be modeled using low order approaches, a full 3D simulation of the combustion chamber acoustics is conducted to asses this phenomenon. An axial variation of the sonic velocity is imposed on the mean flow field.

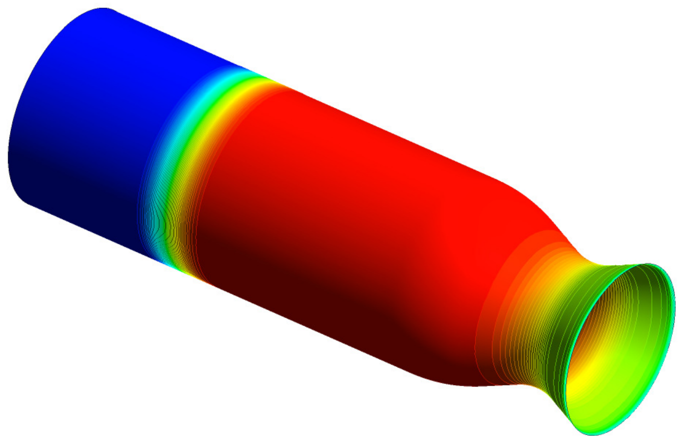

Figure 2: Axial distribution of the sonic velocity in the mean flow field for the PIANO calculation

A perturbation solver, PIANO, which operates in the time domain is used to calculate the fluctuating flow field. This finite difference, high order code solves the linearized Euler, or, alternatively, nonlinear perturbation equations on structured multiblock meshes. The solver permits different sonic velocities to be defined in the computational mean flow field and has proven to be suitable for rocket engine applications [2]. A distribution of the sonic velocity for PIANO is visible in figure 2. Using the PIANO simulation, the shape of the corresponding eigenmodes can be calculated and the data obtained can be compared to the experimental data from the full scale engine. The paper will discuss and evaluate the simulation results in detail.

[1] Harrje, D., Reardon, F. (ed.), Liquid Propellant Rocket Combustion Instability (NASA-SP-194), National Aeronautics and Space Administration, 1972

[2] Kaess, R., Koeglmeier, S., Schmid, M., Sattelmayer, T., Linearized Euler Calculation of Acoustics of a Rocket Combustion Chamber; HF2 Testcase, 2nd REST Modeling Workshop, Ottobrunn, Germany, 2010.