Simulating Acoustic Combustion Chamber Eigenmodes to Facilitate Combustion Stability in Rocket Engines

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Abstract

Airbus Safran Launchers is the market leader in Space Launch services. It produces the Ariane 5 Launch Vehicle and is currently developing the Ariane 6.
Rocket engines are among the most powerful machines that exist. Their power level is comparable to nuclear power plants. The geometric dimensions of rocket engines, however, are relatively small. The core of the Rocket engine is the combustion chamber where in the case of Liquid propellant rocket engines, fuel and oxidizer are injected, mixed and burnt and where, consequently, the energy release takes place. The hot combustion gases are accelerated in a convergent - divergent nozzle to supersonic speed. Acoustically, the combustion chamber represents a fairly closed volume with low dissipation. This in combination with the high power density can lead to thermo-acoustic instabilities. In the case of High Frequency (HF) instabilities, the 3D combustion chamber eigenmodes interact with the combustion process and lead to a self-sustained oscillation which can have detrimental consequences for the engine.
Therefore, the knowledge of the acoustic combustion chamber eigenmodes is important. The knowledge permits to avoid interactions with other components and also facilitated the design of countermeasures, e.g. Baffles or acoustic absorbers.
The simulation of the acoustics of rocket combustion chambers is not trivial due to different reasons. First, the combustion process leads to variable gas properties which either needs to be included into the simulation or a work-around needs to be found. Second, the mean flow is being accelerated to supersonic velocities. This means that this flow has an impact on the acoustic behavior and a low Mach number approximation is not valid.
COMSOL Multiphysics® has been used to model the volume of the combustion chamber. Gas properties and mean values had to be generated using CFD. These values have been imported into COMSOL and the COMSOL acoustic equations have been used to determine combustion chamber eigenmodes.