Response Characterization of a LOX-GH_2 Flame to Forced Acoustic Pressure Fluctuations

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Abstract

A key issue during the development process of rocket engines is combustion stability. Combustion instabilities appear if acoustic fluctuations in the combustion chamber interact with the combustion process and yield a fluctuating heat release or evaporation rate. If these fluctuations are in phase with the pressure fluctuations, the Raleigh-integral is positive and consequently, the acoustic fluctuations rise up to levels being dangerous for the entire combustion chamber. At the *Lehrstuhl für Thermodynamik* of the *Technische Universität München*, a numerical tool has been developed to get a better understanding of the physical processes behind these instabilities and finally being able to predict numerically the level of instability in rocket engines. The three-dimensional time domain code solves either the Acoustic Perturbation Equations (APEs) or the Linearized Euler Equations (LEE).

One major problem in the simulation process is the modeling of the feedback mechanism which couples the acoustic fluctuations and the heat release or evaporation rate. The fluctuations of the evaporation rate itself can enforce instabilities. Furthermore, they are closely related to the heat release rate. Simulations of the entire rocket combustion chamber with all injectors resolved in detail will remain numerically too costly for an industrial application even in the near future. As a consequence, only a single injector is used to study this coupling of acoustics and flame response. Appropriate boundary conditions with source terms are used to impose external pressure fluctuations similar to the first transverse mode shape of the entire combustion chamber on the reduced injector domain. Thus, simulations with varying frequency and amplitude can be conducted. The mode shape of the first transverse mode has been chosen as this mode is the most critical one regarding combustion instabilities in rocket engines.

Evaporation of liquid droplets is an important process during rocket engine combustion and is often considered as one important process in the feedback mechanism. In order to determine the flame response to acoustic pressure oscillations, a numerical study of subcritical liquid oxygen with gaseous hydrogen combustion has been conducted using an Euler-Lagrange approach. The gas phase is calculated in a fixed Eulerian frame of reference using URANS equations, while equations of motion are solved for the droplets in a Lagrangian frame of reference. The Shear Stress Transport Model is used for turbulence modeling, and the Eddy Dissipation Model with a single step reaction mechanism is used for combustion modeling. Two liquid sprays with different mean diameters of the Rosin-Rammler distribution for the initial droplet size are analyzed. The setup for the numerical simulations is similar to experimental tests conducted at the Mascotte test bench with a combustion chamber pressure of 10 *bar*.

A large number of different frequencies (2000 Hz – 7500 Hz) and amplitudes (1 % – 20 %) have been analyzed. The results show a dependency of the evaporation rate on the excitation frequency and amplitude. The response is almost solely monofrequent. This means that they have the same frequency as the pressure oscillations. Furthermore, the oscillation in the evaporation rate is in the same order of magnitude as the forced pressure oscillation, resulting in response amplitudes of the order of one and higher. A peak of the interaction coefficient for mid-range frequencies could be determined (see Figure 1). It is also shown that a different spray with decreased mean diameter affects the behavior of the spray evaporation with the peak in the interaction coefficient moving to smaller frequencies. Furthermore, the interaction level of the evaporation rate with the pressure excitation is around twice as high as for the heat release and therefore an

important process in evaluating combustion stability in a rocket combustion chamber. The results clearly show a non-linear behavior resulting in a strong decrease of the response amplitude with an increasing excitation amplitude (see Figure 2).

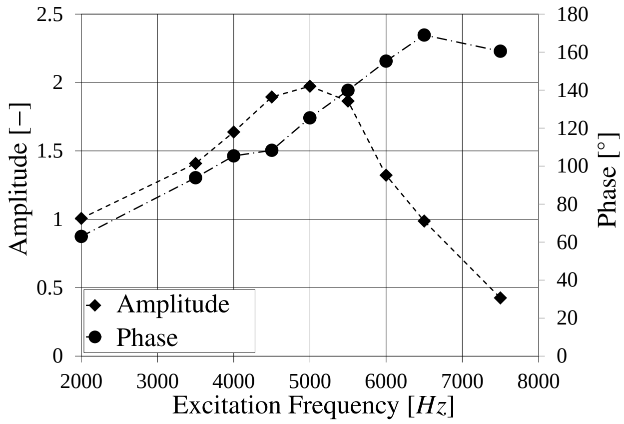

Figure 1: Frequency Characteristic

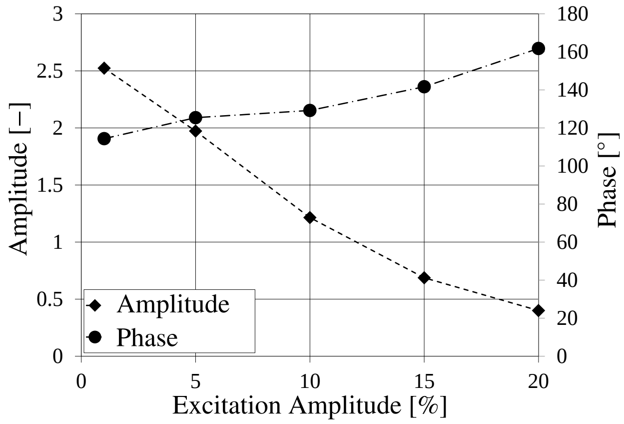

Figure 2: Amplitude Characteristic

An additional analytical analysis using the same evaporation model as the numerical simulations shows that the ratio of saturation pressure amplitude to ambient pressure amplitude is the major influence for the coupling between pressure oscillation and evaporation rate. For single droplets of constant radius the amplitude of oscillation in the evaporation rate is directly proportional to the ambient pressure oscillation. This analysis also reveals the importance of the droplet diameter and the excitation frequency, which influence the fluctuation of the droplet temperature and therefore the evaporation rate.

This study clearly show that the utilized methods and models are applicable for determining the flame response to acoustic pressure fluctuations in the framework of subcritical combustion chamber pressures including liquid propellants. The calculated transfer functions between pressure excitation and flame response (in terms of heat release and evaporation rate) can now be used to simulate an entire combustion chamber with the previously mentioned acoustic solver leading to quantitative conclusions regarding combustion stability. A more detailed validation and comparison with experimental data will be carried out in the future.