Analysis of acoustic energy dissipation in a rectangular combustion chamber.

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Abstract:

Acoustic coupling with combustion processes leading to high amplitude and short period pressure oscillations can result in the rapid destruction of a rocket combustion engine. A combustion chamber is critically unstable when less energy is dissipated from the acoustic field than is added by acoustic coupling with the combustion processes. Measurements of acoustic dissipation have thus far been relatively limited to a number studies with sub scale combustion chambers often without combustion. Greater understanding of acoustic dissipation in during combustion at representative conditions is required to improve modelling by accurate application of representative boundary conditions. In addition further understanding of acoustic dissipation will provide guidelines for combustion chamber development programs looking to minimise the probability of combustion instability occurring. The acoustic field and acoustic energy dissipation are investigated for a sub-scale combustion chamber using liquid oxygen and gaseous hydrogen propellants. The acoustic field is forced through the use of a sectored siren wheel allowing the investigation of acoustic energy dissipation and its dependence on operating conditions. A one dimensional model of a harmonic oscillator is introduced and compared to test results.

Introduction:

High Frequency (HF) combustion instability has been observed in rocket development programs since the 1940s and can rapidly lead to the destruction of a rocket combustion engine [1]. Although significant research has been undertaken since then, the extreme conditions under which combustion instability occurs and the complicated nature of combustion processes have limited progress in understanding.

High frequency combustion instability forms from the coupling of the acoustic field with combustion processes. When the coupling results in positive energy addition the acoustic field is driven to oscillations of higher amplitude and can rapidly damage the combustion chamber if dissipation of acoustic energy is less than the energy addition [2].

Sub-scale combustion chambers provide an alternative, cost effective method, for investigating the basic mechanisms of combustion instability and to improve scientific understanding of rocket combustion.

Investigation of acoustic dissipation, often referred to as damping, has been undertaken since the 1970s in the form of acoustic admittance calculations [3, 4]. Since then methods of investigation have become more advanced with the addition of external energy sources (acoustic forcing) but have typically been limited to cold flow checks at close to ambient conditions[5, 6]. One notable exception is the work presented by LeCourt (1987)[7] where pressure traces of a dynamically decaying signal were obtained at operating conditions up to 25 bars. However, results with Lox/GH2 and for pressures up to 60bars (Super critical for Lox) are not yet publicly available.

Materials & Methods:

Investigations were undertaken at European test bench P8 at the German Aerospace Centre (DLR) Lampoldshausen using sub scale combustion chamber ‘H’ (Figure1)[8]. Tests were conducted at three operating conditions; Hydrogen cold flow check (25 bars), and combustion tests at 40 and 60 bars.

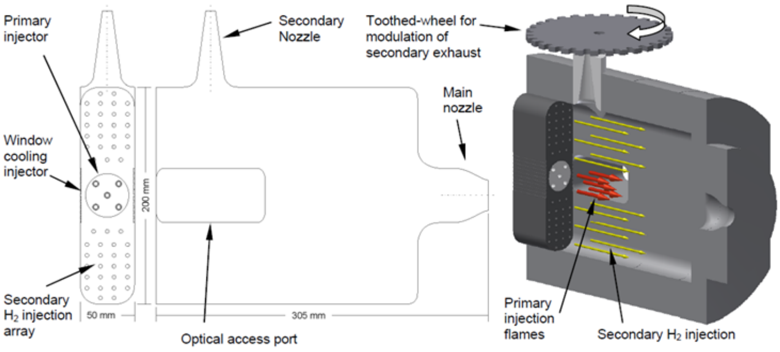

Figure 1: Illustration of the BKH combustion chamber [8]

The tests were conducted by externally exciting pressure oscillations in the combustion chamber by opening and closing a secondary nozzle. A ‘sector wheel’ was used to periodically excite the signal before the secondary nozzle was left open to observe decay in the pressure oscillations.

The dynamic pressure readings flush mounted on the combustion chamber walls were used in analysis of the acoustic field.

Results:

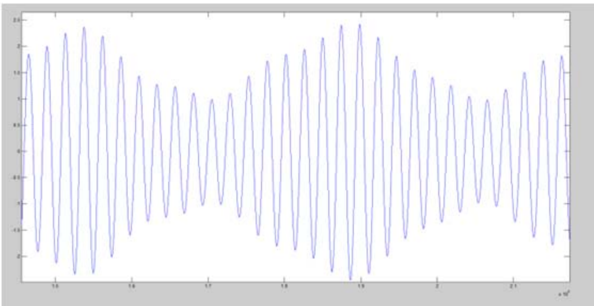

Figure 2: Typical dynamic pressure signal trace after broad band filtering around the 1T mode.

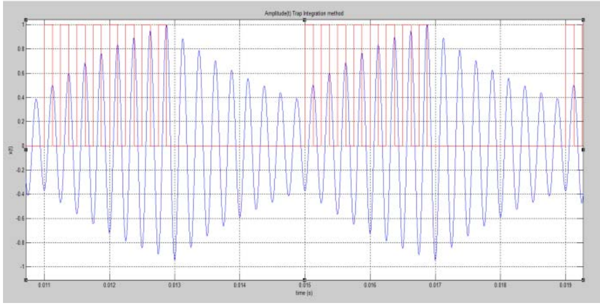

Figure 3: Numerical Solution to the forced damped dynamic oscillator with a damping factor of 500 1/s.

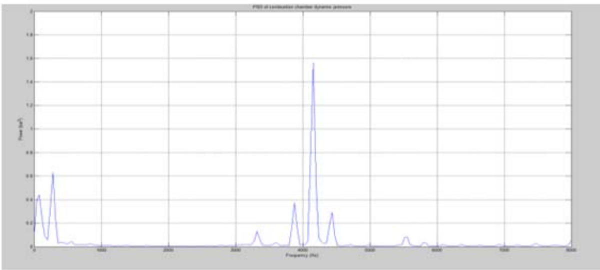

Figure 4: Power Spectral Density (PSD) of combustion chamber spectra for excitation of the 1T mode

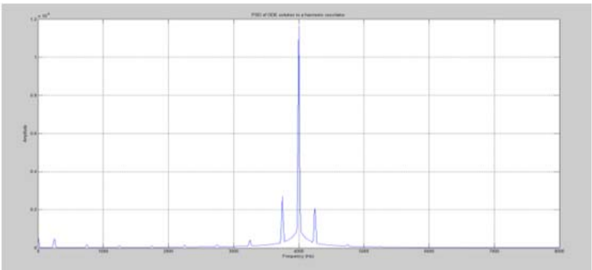

Figure 5: PSD of 1D damped driven harmonic oscillator driven at the 1T mode.

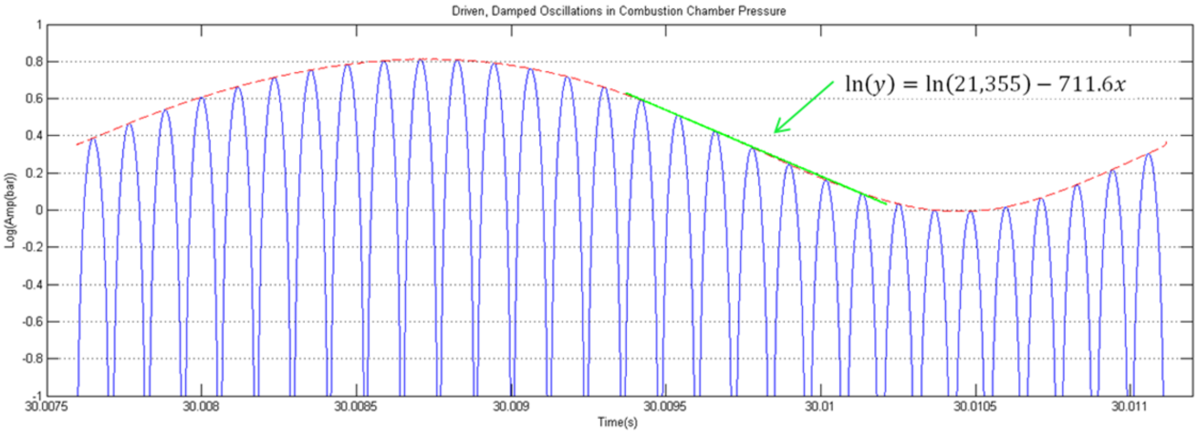

Figure 6: Damped Driven oscillation of the 1T mode during combustion at 40bar chamber pressure.

References:

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