Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: PROPHY / CFDMPS / STUDENT
Corresponding author: Musa Onur ÖZTÜRKMEN
e-mail of corresponding author: onur.ozturkmen@metu.edu.tr
Type: Oral
Status of corresponding author: Student
For student corresponding author: student member of one of the following:

Stability Characteristics of a Single Injector Combustor through Acoustic Solutions with Large Eddy Simulated Heat Sources

Musa Onur ÖZTÜRKMEN [1,2], Yusuf ÖZYÖRÜK [3]*

** Corresponding author*
[1] PhD Candidate, Middle East Technical University, 06800 Ankara, Turkey, onur.ozturkmen@metu.edu.tr
[2] Lead Engineer, Roketsan Missiles Inc., 06780 Ankara, Turkey, oozturkmen@roketsan.com.tr
[3] Prof. Dr., Middle East Technical University, 06800 Ankara, Turkey, yusuf.ozyoruk@metu.edu.tr

Abstract

Thermoacoustic instabilities have long been known and studied in propulsion systems such as rockets. The combustion chambers are designed to operate under steady conditions. However, the likelihood of non-steady behavior in the combustion chambers is high. The pressure inside the combustion chamber of a rocket engine varies in an oscillatory manner due to many reasons, such as flow turbulence and fluctuations in atomization process, and from the propellant supply lines in the case of a liquid propellant engine. Thermoacoustic instability begins to develop when the oscillations in chamber pressure are coupled with unsteady heat release and the net rate of energy addition resulting from unsteady motions is greater than the rate of losses resulting from various mechanisms, including heat transfer, viscous action, and acoustic emission through the nozzle. The stability characteristics of the chamber are investigated through an in-house acoustic solver, which solves the non-homogeneous wave equation. Methods that rely on the solution of the nonhomogeneous wave equation, i.e. the Helmholtz equation, are widely used in the literature to decrease computational requirements [1, 2, 3]. The Helmholtz equation for a combustion chamber is obtained following the same procedure as in classical acoustics. The discretization of the wave equation with frequency-dependent source terms due to heat release and impedance boundary conditions results in a nonlinear quadratic eigenvalue problem. While the solution of the standard linear quadratic eigenvalue problem can be obtained directly, the nonlinear one requires some linearization procedures to reduce it to the standard general eigenvalue problem. Different linearization procedures are utilized to obtain the standard general eigenvalue problem and the convergence behavior of the utilized methods is investigated. An experimental test case from the literature [4-6], known as CVRC (Continuously Variable Resonance Chamber), is considered for the validation study. A coaxial injector is used to introduce the fuel and oxidizer into the combustion chamber. The fuel composition is pure gaseous methane, and the oxidizer is a gaseous mixture composed of 42% oxygen and 58 % water in terms of mass fraction. The CVRC has a variable oxidizer injector length between 8.89 cm and 19.05 cm, and due to variable injector post length, the combustion chamber exhibits different stability characteristics through acoustic and combustion interactions. Two different oxidizer post lengths are selected for the current study, which are 12.06 cm and 13.97 cm. Note also that both oxidizer post lengths show unstable behavior according to experimental data [6]. Large eddy simulations (LES) are conducted for these cases in order to determine the heat release distribution accurately inside the chamber. The LES studies are carried out axisymmetrically and the chemistry is modelled with a reduced reaction set of BFER [7]. The reaction set includes 2 step reaction with 5 species (CH_4, O_2, H_2O, CO, CO_2). The effects of the combustion are incorporated into the acoustic solver by using a flame transfer function obtained from the simulations with proper impedance boundary conditions. The flame transfer function is defined based on the axial velocity fluctuation at the injector exit. The obtained results are compared to literature data and LES simulations. Overall the present results agree the available other simulated results.

References

[1] F. Culick, ‘Unsteady motions in combustion chambers for propulsion systems’, AG-AVT-039 (2006).
[2] F. Nicoud, L. Benoit, C. Sensiau, T. Poinsot, ‘Acoustic modes in combustors with complex impedances and multidimensional active flames’, AIAA Journal 45 (2007) 426–441.
[3] J. Pieringer, T. Sattelmayer, F. Fassl, ‘Simulation of combustion instabilities in liquid rocket engines with acoustic perturbation equations’, Journal of Propulsion and Power 25 (2009) 1020–1031.
[4] K. J. Miller, ‘Experimental study of longitudinal instabilities in a single element rocket combustor’, Master’s thesis, Purdue University (2005).
[5] Y. C. Yu, L. A. O’Hara, J. C. Sisco, W. E. Anderson, ‘Experimental study of high-frequency combustion instability in a continuously variable resonance combustor’, 47th AIAA Aerospace Sciences Meeting, Orlando, Florida, 2009.
[6] J. C.Sisco, Y. C. Yu, V. Sankaran, W. E. Anderson, ‘Examination of mode shapes in an unstable model combustor’, Journal of Sound and Vibration 330 (2011) 61–74.
[7] B. Franzelli, E. Riber, M. Sanjos ́e, T. Poinsot, ‘A two-step chemical scheme for large-eddy simulation of kerosene–air flames’, Combustion and Flame 157 (2010) 1364–1373