Conference:
COMSOL Conference 2015

Boston, MA   October 7-9, 2015

Title:
"The Effect of Resistance on Rocket Injector Acoustics"

Authors:
C. J. Morgan, Jacobs/ESSSA Group

Abstract:

Combustion instability, where unsteady heat release couples with acoustic modes, has long been an area of concern in liquid rocket engines. Accurate modeling of the acoustic normal modes of the combustion chamber is important to understanding and preventing combustion instability. This study evaluates the effect of injector resistance on the mode shapes and complex eigenfrequencies of an injector/combustion chamber system by defining a high Mach-flow form of the convective wave equation (see Eq. 1) in COMSOL Multiphysic's Coefficient Form PDE Mathematics Module. The form of the wave equation shown in Eq. 1 is based off of a similar form derived by Campos in Ref. [1]. The additional terms in Eq. 1 are included by adding source terms to COMSOL's base governing equation.

$$\begin{aligned}\frac{\lambda^2}{c_o^2}\psi - \nabla^2\psi = {} & \frac{2\lambda}{c_o^2}(\vec{v}_o \cdot \nabla\psi) - \frac{1}{c_o^2}(\vec{v}_o \cdot \nabla)(\vec{v}_o \cdot \nabla\psi) + \frac{1}{\rho_o}\nabla\psi \cdot \nabla\rho_o \\ & - \frac{2\lambda}{c_o^2}\psi(\vec{v}_o \cdot \nabla)\log(c_o) + \frac{2}{c_o^2}(\vec{v}_o \cdot \nabla\psi)(\vec{v}_o \cdot \nabla)\log(c_o)\end{aligned} \quad \text{Eq. 1}$$

$c_o =$ Speed of sound
$\rho_o =$ Density
$\vec{v}_o =$ Velocity vector
$\lambda = \alpha + i\omega,$ Complex eigenvalue
$\psi = \psi^r + i\psi^i,$ Complex velocity potential

Background steady-state flow conditions are determined through a NASA Marshall Space Flight Center in-house computational fluid dynamics model, and interpolated onto the COMSOL mesh. Two cases were investigated, one with a small pressure drop (low resistance) and the other with a large pressure drop (high resistance) across the injector. The injector resistance had a significant impact on the acoustic mode shape of the system, particularly at the manifold/injector boundary. For the low resistance case this boundary behaved as acoustically open, while for the high resistance case it behaved as acoustically closed. The knowledge gained through this model can be used during future design cycles to favorably shape the combustion chamber mode shape.

1. L. M. B. C. Campos, *On 36 Forms of the Acoustic Wave Equation in Potential Flows and Inhomogeneous Media*, vol. 60, Applied Mechanics Reviews, 2007, pp. 149-171.