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Convective-Diffusive Effects in Reactive Flows inside Cavities

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1 Introduction

The flow inside cavities is of considerable complexity contrasting with the simple geometric shape of these objects. Accounting to the particular behavior of such kind of flow there are acoustic oscillations, vortex and flow separation [4].

One of the most important applications of cavities is for flame-holding purposes in Supersonic Combustion Ramjets - Scramjets. Cavities are used in order to increase the time of residence and to provide a pool of radicals which facilitates ignition [1].

This study aims at analyzing the relative contribution of the convective and diffusive effects on the transport of a reactive species (hydrogen) in a Scramjet cavity. Equation (1) presents the non-dimensional transport equation for hydrogen according to [3]. We assume that the diffusion coefficient is constant.

$$\frac{\partial \rho Y_{H_2}}{\partial t} + \left[\frac{\partial \rho u_i}{\partial x_i} - \frac{1}{Pe} \frac{\partial^2 ln Y_{H_2}}{\partial x_i^2} \right] Y_{H_2} = \frac{1}{L^3} \dot{\omega}_{H_2} \qquad \text{em} \quad \mathbb{R}^3 \times [0, \infty), \tag{1}$$

where ρ is the density, Y_{H_2} is the hydrogen mass fraction, u_i is the i component of the non-dimensional velocity vector, x_i is the i non-dimensional space coordinate, L is a characteristic length and $\dot{\omega}_{H_2}$ the non-dimensional combustion reaction rate. Pe is the Péclet number given by $\frac{LU}{D_{H_2-Air}}$. D_{H_2-Air} is the diffusivity of hydrogen into air.

If we are sufficiently far from the flame front, $\dot{\omega}_{H_2}$ can be neglected making of (1) a homogeneous second order partial differential equation. If the Péclet number is large $Pe \gg 1$, the second order term in (1) vanishes. Thus, Eq. (1) becomes hyperbolic and it describes a propagation phenomenum. With this condition, the transport of hydrogen is mainly convective. Conversely, if $Pe \to 0$ the laplacian in Eq. (1) becomes the dominant term. Hence this equation is elliptic in the steady-state ($\frac{\partial \rho Y_{H_2}}{\partial t} = 0$) and parabolic otherwise [2]. Both elliptic and parabolic behavior indicate that the transport of hydrogen occurs by diffusion. Although the later introduces a damping in diffusion with the time.

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2 Numerical Modeling

A Scramjet cavity was modeled with the software of Computational Fluid Dynamics (CFD) CFX. The air-flow at the inlet of the cavity (left side of Fig. 1) was set to Mach = 1.25, static temperature and pressure of 2300 K and 213 kPa and mass-flow rate of 3.3 $g.s^{-1}$. Hydrogen was injected from the upstream wall with a rate of 0.056 $g.s^{-1}$.

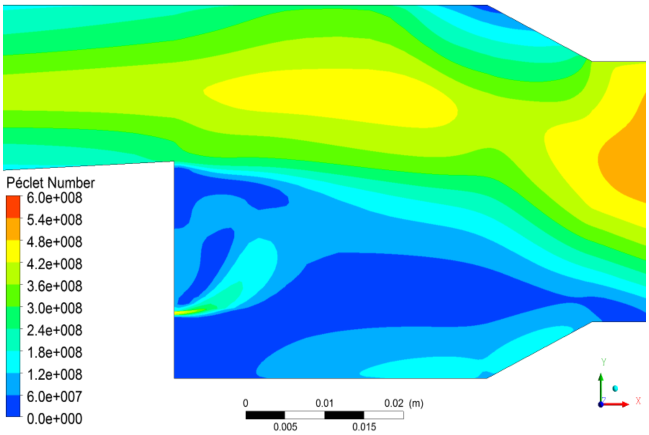

Figure 1: Contours of the Péclet number in the longitudinal plan of the cavity.

3 Conclusions

The species transport in a Scramjet cavity can be accomplished by convective and/or diffusive effects depending on the Péclet number. By the means of CFD we showed that the Péclet number inside a Scramjet cavity is at least one order of magnitude lower than its free-stream value. Therefore, the transport equation for hydrogen is hyperbolic and this fuel is transported mainly by convective effects.

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