Investigation of geometric characteristics on the Non-Reaction supersonic flow inside the channel with the presence of cavities

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ABSTRACT

In the present work, the flow inside a channel with cavity is investigated as a Scramjet combustion chamber. For this aim , the parameters such as L/D (cavity length to cavity depth), H/D (channel height to cavity depth) and varied Mach numbers are studied in the supersonic flow to investigate the effect of geometric parameters on channel flow in non- reacting conditions. In this work, the vorticity is used as mixing parameter. Two-dimensional Navier-Stokes equations are used to solve the steady-state flow. The density based method and standard k-ε Model are employed to numerical simulation. The results show that vorticity of boundary layer and thus mixing in flow is increased with growing of L/D, Mach number and having sweep angle for cavity. Geometries with larger H/D performed better than other geometries in terms of generating vorticity and reducing Total pressure loss. Although the H/D = 1 ratio has a higher recirculation than others, it will not be reliable for all supersonic flow because of its considerable total pressure loss and the survival of the oblique shock in some conditions.

KEYWORDS

Supersonic flow; Cavity; Non- Reaction; Aft Angle of cavity; L/D and H/D Ratio.

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Introduction

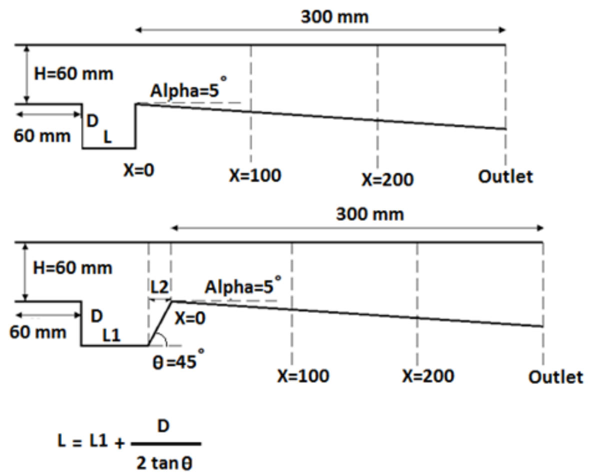
Supersonic flow over cavities has been widely studied for many years because of their significance to aerodynamic configurations. A cavity, exposed to a flow, experiences self-sustained oscillations, which can induce fluctuating pressures, densities, and velocities in and around the cavity, resulting in drag penalties. This problem interested many experimental and computational studies, which have been directed toward improving the understanding of the physics of cavity flows and the means to control their nature[1]. It is generally do open cavities (L/D < 10) could be used for flame-holding while the mixing enhancement could be achieved through the closed cavities[2]. It is noted that there exists an appropriate length of cavity regarding the combustion efficiency and total pressure loss[3]. The most important references used in this work are presented in Table 1.

Table 1. Summarized results of some references mentioned

Author	Year	Mach
Ben Yakar et al.[1]	2001	-
Kim et al.[3]	2004	2.5
Huang et al.[4]	2010	3.2
Luo et al.[5]	2011	3
Lahijani et al.[6]	2020	2.05
Jeyakumar et al.[7]	2016	1.8
Jeyakumar et al. [8]	2016	1.3
Gruber et al.[9]	2001	3
Wang et al. [10]	2019	2.52

Methodology

The geometry and dimensions of the model combustor considered in the present study is depicted in Figure 1. The Geometrical Dimensions and flow conditions of various cavities are presented in Table 2.



$$L = L1 + \frac{D}{2\tan\theta}$$

Figure 1. Schematic representation of geometrical dimensions of combustors in present work

Table 2. Geometrical Dimensions and initial conditions in present work

Parameter	Value
Height of Combustion Chamber	60 mm
L/D	1, 3, 5
H/D	1, 2, 3
Aft Angle of Cavity	45 , 90 deg
Mach	2, 3, 4
P0	690 KPa
T0	300 K

These cases are analyzed using steady two dimensional density based Navier-Stokes equations and a k- ε turbulence model. Figure 2. indicates that Kε Standard can be considered the best option for modeling the case in question.

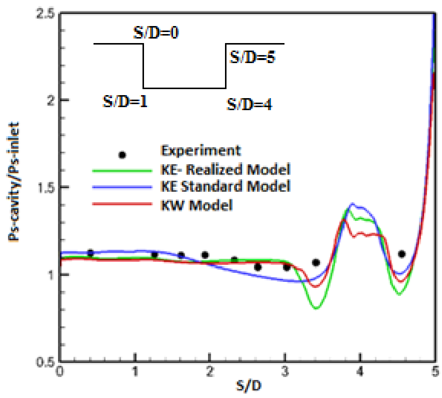


Figure 2. Comparing non Dimensional static pressure(versus inlet static pressure) for various methods of RANS with experimental data[9]

In all CFD simulations performed in this work, the conditions of Pressure inlet, Pressure outlet and Wall are used for the input of the combustion chamber, the output of the combustion chamber and the walls, respectively. Figure 3 showed the wall y^+ is less than 5 at most positions and the difference between the computed inflow and the outflow mass flux drop below 0.0001 kg/s.

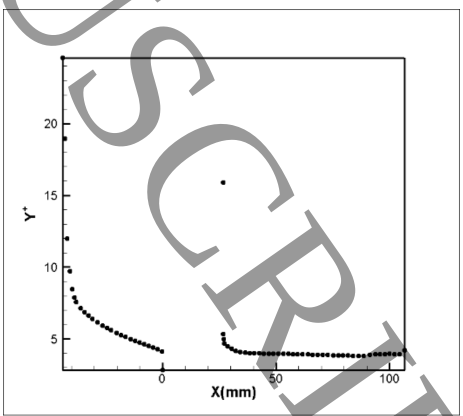


Figure 3. Profile of wall y+ in present geometry

Results and Discussion

The vorticity parameter is the component of the local spinning motion flow near the wall and if not excessive, can enhance the mixing. Also, one of the important parameters in expressing the efficiency of the cavity is the total pressure loss. A minimum total pressure loss as well as maximum efficiencies of mixing and combustion should be considered for the optimization of an overall combustor performance with the cavity configuration[3]. Higher vorticity and lower total pressure loss indicate better performance for every cavity configurations. Figure 4 showed the scaled total vorticity versus various H/D, L/D and Mach numbers at outlet. According to this figure, total vorticity is approximately constant with various H/D parameter at outlet. Figure 5 indicated total pressure loss is decrease by increasing of H/D ratio. Total pressure loss at aft angle of 45 degrees is greater than the rectangle cavity, because of higher pressures acting over the aft wall area.

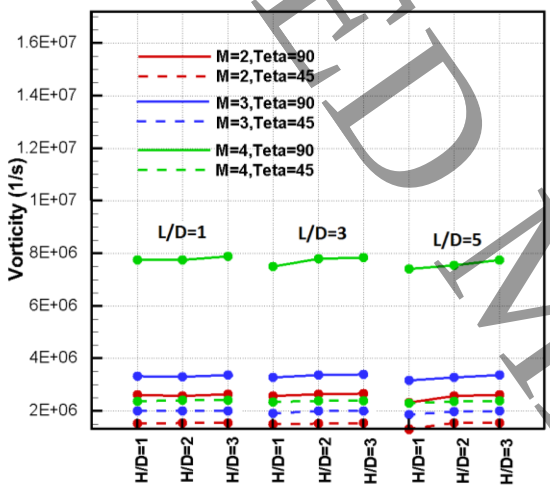


Figure 4. Total local vorticity for various H/D, L/D and Mach numbers at outlet

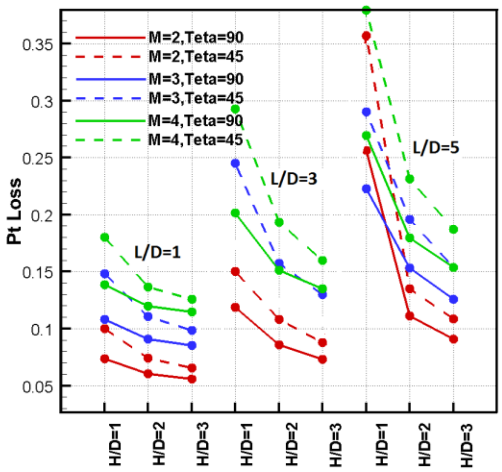


Figure 5. Total pressure loss for various H/D, L/D and Mach numbers at outlet

Conclusions

By increasing of Mach numbers and L/D ratio, and decreasing of H/D ratio, the total pressure loss of cavity case is increased. Also, total pressure loss at aft angle of 45 deg is greater than no angle case.

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