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Effect of Combustion Heat Release on the Stability of Confined Boundary/mixing-layer Confluent flow

Liu Zhiyong[a,]* , Shang Qing[a], Liu Xiaoyong[b], Fei Lisen[b], Liu Fengjun[b]

[a]*China Academy of Aerospace and Aerodynamics, Beijing, 100074, China*
[b]*Beijing Power Machinery Institute, Beijing, 100074, China*

Abstract

The issue of mixing enhancement of the fuel and oxidizer in the combustor of a ramjet has received more and more attention. Various injection ways were designed and justified to improve the mixing process by producing more multiplescale vortex structures. Under the restriction of compact configuration of the combustor in an integral rocket dual combustion ramjet, a better way to enhance mixing is turning the laminar flow to turbulent flow. The present study focuses on the stability analysis of the boundary/mixing-layer confluent flow affected by the combustion heat release in the combustion chamber. Two types of basic flows are formed for linear stability analysis both from a theoretical model and numerical computation. Eigenvalue spectra and eigenfunctions are obtained and compared. The results show that the heatrelease effect stabilizes the confluent mixing flow.

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Keywords: Confluent flow; mixing layer; linear stability; heat release

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1. Introduction

Mixing flows have a number of industrial applications. The mixing of fuel and oxidizer is of great significance to combustion and researchers pay a lot attention to mixing enhancement in power devices, such as engines, fuel cells etc. In the combustor of an integral rocket dual combustion ramjet, the mixing area lies adjacent to the wall thus the

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* Corresponding author. Tel.: +86- 13717770747;.
E-mail address: liuzhiyongtv@163.com

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mixing process is badly affected by the confinement of walls. The present study was incited by this specified application and instability analysis was investigated to explore the mechanism of mixing augmentation.

Many progresses about seeking the mechanism of mixing enhancement in mixing layers have been made in recent decades. Kumar et al. [1] reported an oscillating shock can increase the mixing-layer turbulence levels and thus enhance mixing. Computational investigations [2] have shown that streamwise vorticity induced by baroclinic torques in the mixing layers enables mixing enhancement. While relatively less attention has been paid to the confined mixing layer which is a better model of actual devices, especially combustors. Linear stability theory (LST) and direct numerical simulation (DNS) were adopted by Greenough et al. [3] to study the wall effect on the instability of compressible mixing layers. They found two types unstable modes, i.e. K-H mode and supersonic wall mode. Hu [4] studied the development process of disturbance in confined mixing layers and found that even if the disturbances of two modes propagate linearly and separately, the disturbance energy grow oscillatorily, and periodic structures were discovered. Hudson et al. [5] compared the computational and experimental results of confined compressible mixing layers and reported that the growth rate corresponds well with the experiment in the inlet area, while discrepancy appears downstream. They considered the difference resulted from the wall effect and fluid viscosity. Liu et al. [6] used a boundary layer to model the wall effect and studied the instability features of half unbounded wake/boundary layer confluent flow. Different distances between the wake and the boundary layer were investigated and the best spacing for mixing enhancement was found.

Based on the primary research on the instability of compressible boundary/mixing layers confluent flow in a two-dimensional planar channel [7], the present study focuses on the effect of heat release on the linear stability of the confluent flow. Two mean flows generated both by a theoretical model and numerical computation are considered. The hydrodynamic computation software Fluent® is adopted to conduct numerical simulations and the mixing of ethylene and air is simulated. Detailed stability characteristics are compared and analyzed.

2. Technical approaches

Compressible linear stability equations are adopted under the assumption that the basic flow is locally parallel, and the derivation can be readily found in the literature [7]. The spatial scales in Cartesian coordinate system are nondimensionalized by $\delta=\sqrt{\upsilon_e^* x^* / u_e^*}$, pressure by $\rho_e^* u_e^{*2}$ and other quantities by corresponding free stream values of outer flow. We assume that the viscosity and thermal conductivity satisfy Sutherland's law. The ideal gas assumption is also adopted. Instantaneous flow variables are decomposed into a base and a fluctuation quantity and the disturbances can be written as

$$(u,v,w,p,T)=\left[\hat{u}(y),\hat{v}(y),\hat{w}(y),\hat{p}(y),\hat{T}(y)\right]e^{i(\alpha x+\beta z-\omega t)} \tag{1}$$

(1)

in which α and β are streamwise and spanwise wavenumbers, ω is circular frequency. The boundary conditions can be written as

$$\begin{cases} y=-H, & \hat{u}=\hat{v}=\hat{w}=\hat{T}=0 \\ y=H, & \hat{u}=\hat{v}=\hat{w}=\hat{T}=0 \end{cases} \tag{2}$$

where H is half-width of the channel.

Spatial instability is investigated in the present study and thus ω is real while α and β are complex. A fourth-order-accurate difference method [8] is applied to discretize the stability equations and then a system of homogeneous equations can be got, i.e.

$$F(\alpha)\{\varphi\}=0 \tag{3}$$

Müller method and QZ algorithm are employed to calculate the eigenvalue α, and further the corresponding