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ORIGINAL ARTICLE

Flow dynamics in low aspect ratio dump combustor

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Abstract This paper reports an experimental investigation of the flow field inside a low aspect ratio dump combustor. The length of the combustor studied was less than the reattachment length for the separated flow. The exit of the combustor is tapered which supports the flow reversal from the exit section. The flow field behaviour in the combustor is evaluated from pressure and velocity measurement studies. The velocity, stream function and pressure distribution inside the combustor are used to elucidate the presence of recirculation and flow reversal from the exit section of the combustor for different Reynolds numbers. A small variation in U_{rms} velocity was observed in axial direction while in the radial direction it was quite high. Two recirculation zones are recognized and the strength of the recirculation was seen to increase with flow Reynolds number. The turbulence intensity in the recirculation and shear layer zone was seen to be higher than the potential core.

1. Introduction

The flow field in a dump combustor is very complex, relating the turbulence mixing of fuel and air, reattachment, flow separation, recirculation and the chemical reactions, etc. A significant amount of research have been performed on re-circulating flow field in a dump combustor and the role of shear layer's large scale structures in mixing processes and noise generation. The large scale coherent turbulent structures and acoustic waves are excited in the combustor cavity that represent large, rather well-organized lumps of fluid motion and display their own dynamic behavior in turbulent flows [1]. Drewry [2] has discussed the flow in a dump combustor and suggested four distinct regions in the flow field, namely, imbedded vortices, flow reattachment, recirculation region, and a fully developed flow inside the combustor. Schadow et al. [3] have showed

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Nomenclature

e_{acq}	fixed error in data acquisition
e_{cal}	fixed error induced during instrument calibration
e_{red}	fixed error in data reduction process
e_{U_j}	maximum probable value of the fixed error
h	step height (unit: m)
I	turbulence intensity
N	number of the observations of one quantity U_j
P_{in}	mean pressure at inlet of the combustor (unit: Pa)
P_{rms}	root mean square of the pressure (unit: Pa)
P_w	mean pressure inside the combustor (unit: Pa)
r	radial distance from the center of the combustor (unit: m)
rms	root mean square
R	radius of the combustor (unit: m)
Re	Reynolds number
s	constant for confidence level in the measurement
SPL	sound pressure level
u_r	velocity along radial direction of the combustor (unit: m/s)
u_x	velocity along the axial direction of the combustor (unit: m/s)
u'	velocity perturbation (unit: m/s)
U	flow velocity (unit: m/s)
$\overline{U}$	mean of flow velocity (unit: m/s)
U_{in}	mean velocity at inlet of the combustor (unit: m/s)
U_j	individual measurement of velocity during calibration
U_{rms}	root mean square of the velocity perturbation (unit: m/s)
x	axial distance from inlet of the combustor (unit: m)
ψ	stream function
σ_{U_j}	standard deviation of an individual measurement U_j
$\sigma_{\bar{U}_j}$	mean value of standard deviation
$\delta U_{0.95}$	total uncertainty with 95% confidence level

that the recirculating eddies provide low velocity regions inside the combustor, thus, improving the stability of the flame. Usui and Sano [4] have used the space time correlation to determine the recirculation velocity of the large eddy. In their experimental studies they observed the large recirculation eddies near the wall of the combustor due to flow reversal from the combustor exit. Forrester and Evans [5] have studied the effect of expansion ratio, Reynolds number, chamber length-to-diameter ratio and chamber exit geometry on the length, strength and wall pressure profile for the re-circulating zone formed downstream of an expansion and also compared the confined jet expansion with that of a free jet. Teyssandier and Wilson [6] have studied the effect of sudden enlargement in pipe flows and have concluded that the full pressure recovery occurs if the length of the chamber is larger than the reattachment length. Ahmed [7] has discussed the reattachment length and the recirculation region behaviour for swirl and non-swirl combustors through stream function distribution. The length of the reattachment and the corner recirculation region decreased with the swirl. Therefore, the flow recovered shortly after the reattachment. The turbulence energy production, convection, diffusion, and dissipations are reported higher in the swirling flow. Hammad et al. [8] have discussed the effect of flow Reynolds number on the reattachment length, development length, and recirculating flow strength in the laminar axisymmetric sudden expansion flow. The reattachment and development length downstream of reattachment are reported to be linear function of the Reynolds number. The recirculating flow strength, defined as the ratio of the minimum stream function value in the recirculation zone to the maximum stream function [8], was reported to be a non-linear function of the flow Reynolds number. The strength of the recirculation becomes weaker as the Reynolds number is increased. Chen and Driscoll [9] have reported that the internal recirculation helps in enhancing the mixing by an increase in the fuel–air contact area because the recirculation zone acts like a large vortex. Joos and Vortmeyer [10] have studied self-excited oscillations of premixed flames behind a step. They have shown that when more than one frequency was excited; an unsteady sound field forms. As a result, the phase position of the sound pressure and the sound particle velocity at the flame continually changes. Schadow and his group in their several studies ([3,11–13]) have characterized the large scale structures in acoustically forced ducted flows in dump combustors and have shown control over the combustion instabilities in gaseous combustion using acoustic drivers. They have also extended this study to liquid fuel systems by using pulsating fuel injection. In all their studies, they have shown a strong influence of acoustics on the flow dynamics inside a combustor.

Pressure fluctuations in a turbulent boundary layer are a source of excitation. They may generate acoustic noise and also excite the wall vibration, which can affect the performance of the device concerned. Flow situations involving flow separation through flow restrictions and adverse pressure gradients are more prone to induce noise and vibration problems. Viets and Drewry [14] have observed the strong influence of the inlet velocity profile on the pressure distribution in a dump combustor flow field. Yang and Yu [15] have reported that maximum velocity fluctuation along the centerline occurred immedietly after the racctachment. The shear layer, where the high gradient of mean velocity occurs, is assocoated with high energy level. This high turbulence kinetic energy is transported by both diffusion and convection in and out of the recirculation reagion. Usui et al. [16] have reported high turbulence level in the sudden expansion spray chamber than the free jet or tube flow. The large fluctuation in the chamber was attributed to the unsteady or intermittent nature of the downward jet.

Menon and Jou [17] have studied the interaction between the vorticity and the acoustic component of the flow field in a combustor. The low frequency pressure fluctuation at the