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Abstract

This work explores the characteristics of isothermal and reacting wake flows, downstream of a variety of axisymmetric baffle stabilizers. Different inlet mixture conditions and mixing fields are established through staged fuel injection and full or partial premixing with air in an axisymmetric double cavity arrangement, formed along three concentric bluff-bodies. Ignition and flame stabilization is achieved in the downstream recirculation region of the afterbody. The main scope of this work is to enhance our knowledge regarding the impact of the inlet fuel-air mixture regulation strategy in axisymmetric stabilizers. The results are compared with respect to different operational parameters, such as blockage ratio, axisymmetric bluff-body shape and level of inlet mixture stratification. The study helps to distinguish significant differences, similarities and potential weaknesses in the stabilization and mixing performance and to provide useful information for the exploitation of variable inlet mixture profiles under lean operating conditions.

Keywords
Stratified flames, fully-premixed flames, PIV, methane, axisymmetric bluff-body stabilization

Introduction

In the next two decades, the expected continued exponential rise in power generation from fossil fuels, [1], has raised several concerns regarding critical technologies related to the reduction of pollutants such as CO, CO₂, NOx, PM and UHC.

The target of a sustainable and environmentally clean combustion has increased the urgency for innovative combustion systems with higher efficiencies and fuel flexible operation (i.e. gas turbines, industrial furnaces, ICE) without compromising emission levels.

Premixed combustion has been an attractive strategy for the combustion community as it fulfills many of the above goals. Nevertheless, there are certain issues that arise with this combustion mode, such as flame lift-off, sensitive blow out limits, NOx formation, limited operational envelope and instabilities, [2]. In addition, fuel-air premixing raises space and safety issues particularly in practical transportation applications.

As a result, advanced combustion systems operate, either by design or by default, in a mixed-mode i.e. at partially premixed conditions with inlet equivalence ratio inhomogeneities that remain present and affect the main reaction zone [3].

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Recent research works have focused on experimental and computational studies of fully pre-mixed or stratified flames illustrating key concepts and findings regarding flame structure and overall combustion performance [4].

Previous work on axisymmetric bluff body stabilized flame configuration has investigated the effect of a step-wise inlet equivalence ratio distribution on the flame topology with or without swirl [5], [6], [7].

The present work investigates the characteristics of lean stratified flames stabilized in a variety of axisymmetric baffles, formed by a premixer section, and compares their performance against fully-premixed mode of operation. A double cavity, three bluff body, premixer section regulates the wide range of inlet radial, equivalence ratio gradient profiles (from stratified to fully-premixed) that enter the reaction zone.

Isothermal and reacting flow patterns, velocity and turbulence fields are obtained via a 2D-PIV system and are analyzed for a variety of afterbody flame stabilizer geometries. Results are helpful in characterizing flame structure variations, the reacting front topologies and stabilization properties.

**Experimental facility**

The experimental set-up consists of a combustion tunnel and a double cavity premixer-burner, as also reported in [8]. The isothermal and reacting turbulent flow fields have been analyzed for a range of parameters, such as afterbody shape (D, disk or C, cone), baffle width of 25mm or 36mm (Blockage Ratio 0.23 and 0.48 accordingly) and percent of deviation from Lean Blow Off (parameter “d” equals to 5% or 15%).

**Measurement techniques**

**Flowmeters**

The main air was supplied through shop air and it was monitored through a mass flow meter (Bronkhorst F-106AI-HGD-01-V), whereas the main fuel (methane) was supplied by bottles of 99.5% purity. The fuel flow was regulated by Alicat MCR100.

**PIV**

The velocity characterization was performed using a low rate two-dimensional particle image velocimetry (2DPIV) giving the velocity components in the axial and radial directions. The main air flow was seeded with TiO2 particles of 2μm mean diameter. These particles were illuminated using a 15mJ double-pulsed Nd:YAG operating at 532nm. The vertical laser sheet had 1mm thickness at the burner centerline. The time delay between two images in a pair was ranged from 60 to 100 μs in accordance with the total volumetric flow rate. The light scattered
by the seed particles was imaged using a CCD camera (HiSense MkI), with a depth of 12 bit, fitted with a Nikon AF Micro Nikkor 60mm lens (f/4) and a 50mm interference filter centered about 532nm. The 1280×1024px imaged field was 81.5mm wide by 103.2mm tall, with a pixel resolution of 80.6μm/px. The PIV system was operated at 4 Hz and 400 images were recorded for each condition. The measurement process was synchronized and controlled by hard- and software from Dantec. The adaptive correlation method was performed on initial interrogation areas of 64 x 64 and subsequently on areas of 32 x 32 pixels with a window overlap of 75 % with 3 number of passes in the final step.

Preliminary Results

PIV measurements were conducted to investigate the reacting and non-reacting flow field with the following preliminary results:

![Figure 2 Time averaged PIV images of investigated cases](image-url)
• The main thrust of the present study was to describe the time-averaged isothermal and reacting flow characteristics of axisymmetric bluff body wakes. The interaction between the different inlet mixture conditions, stratified or full-premixed, and the recirculation of hot products downstream of a variety of baffle shapes was documented.
• In the recirculation zone, downstream of the smaller diameter disk, the reverse flow strength for the fully premixed cases was higher up to 57% compared to stratified cases at lean conditions.
• The length of the recirculation zone, for disk (D=25mm), for non-reacting cases was 25 mm from burner exit compared to 27.7 mm for the reacting flow under stratification and 37.3 mm in full premixed flames at conditions close to LBO.
• As expected, the cone shape afterbody produced flame configuration with a stronger recirculation with respect to the disk.

References


