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Ignition dynamics in an annular combustor for liquid spray and premixed gaseous injection

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Abstract

Ignition is of importance in many combustion applications and raises fundamental and practical issues. The light-round process corresponding to the flame spreading phase in the ignition of annular combustors is examined in this article by performing experiments in a model scale configuration “MICCA-Spray”. This system features 16 swirling injectors each comprising a hollow cone pressurized injector. Experiments are carried out with premixed gases as well as n-heptane and dodecane sprays. The flow, spray and flame are first characterized in a single injector configuration. Propagation from the initial kernel created by a spark plug is then observed using high speed light emission imaging. This provides flame structures at various times during the process and gives access to the time delays for flame merging. With n-heptane and dodecane fuel injection, it is found that the light-round process is similar to the one observed under fully premixed propane/air experiments but the duration of the process is augmented especially for the less volatile fuel. It is also confirmed that the delay is notably influenced by thermal conditions prevailing in the chamber at the moment of ignition, injection process and fuel composition. Making use of a flamelet like model of the combustion process, the relative changes in light-round time delay are found to be, to the first order, proportional to the relative changes in laminar burning velocity induced by the fuel spray in the air flow.

Keywords: Ignition dynamics; Light-round; Spray; Swirling flames; Annular combustor

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1. Introduction

In aircraft engine combustors ignition is critical and deserves considerable attention. Combustion is generally initiated by means of a pair of spark plug igniters, usually diametrically mounted in the chamber. Three stages can be identified in the process: (1) In the first, a spark produced by an

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electric discharge forms a hot gas core, (2) In the second stage, this kernel increases in volume and reaches an injector unit in its vicinity igniting the material exhausted in this region and establishing an initial flame and (3) In the last stage a flame progresses inside the annular chamber and ignites successive injectors, this propagation ultimately leading to combustion stabilization inside the system. This last phase designated as the "light-round" process is considered in this analysis. At this point it is worth reviewing some of the related references. A variety of topics are covered in previous ignition research. Investigations deal with spark characteristics like the minimum spark energy, initial flame kernel size, radical creation for a successful ignition [1–5], gas velocity effects, equivalence ratio, heterogeneity of the flow near the spark gap [2,6–8], ignition probability and turbulence influence [8–11]. Many studies concern the influence of fuel spray parameters [2,12], but most experiments deal with single injector ignition.

Ignition experiments in multi-burner systems are scarce, until recently. Effects of burner separation on gaseous premixed flame ignition and propagation to neighboring injectors in a linear arrangement of 5 swirling injectors were reported in [13,14]. Only a few studies have been carried out in annular combustors under fully premixed or non-premixed conditions [15–17]. It is found that the light-round can be decomposed into five stages and that the delay before flames propagating in clockwise and counterclockwise directions merge is reduced when the injection velocity increases [16]. It is observed that the delay is notably influenced by thermal conditions prevailing in the chamber at the moment of ignition and that it is reduced if the chamber walls are at high temperature.

Progress has also been accomplished with the development of simulation tools which have been mainly used to examine ignition processes in single injector configurations. There is however a notable exception [18] reporting a simulation of a full ignition sequence in an annular multiple injector combustor. More recent LES calculations [19–21] have been carried out in parallel with experiments [16] on a fully premixed swirling injector combustor (MICCA). This has led to high fidelity calculations of the light-round sequence observed experimentally.

At present one finds no experiment concerning the light-round in an annular configuration with liquid spray injection. The objective of this article is to provide such data from systematic experiments and to quantify the differences between a premixed ignition and a spray injection ignition in an annular system. Such experiments provide useful information on the process and the data could be effectively used to guide numerical modeling efforts. The study relies on a laboratory scale apparatus designated as MICCA-Spray having multiple spray injectors and an annular geometry in a configuration which reflects in a simplified geometry the situation prevailing in practical combustors.

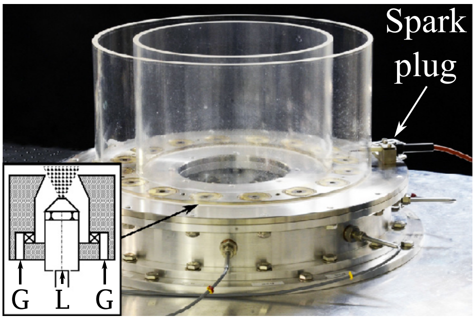

Fig. 1. Photograph of the MICCA-Spray combustion chamber with sixteen liquid injectors and equipped with 200 mm quartz tubes and a single spark plug. An atomizer is sketched on the bottom left where G stands for gas and L for liquid injection channels.

This setup is described in Section 2. Flow and spray are first characterized in a single injector tubular system under cold and hot fire conditions in Section 2.1. Some results of systematic light-round in MICCA-Spray are reported in Section 3 using high-speed imaging. These data are used to examine effects of operating conditions and in particular consider the influence of fuel state -gaseous or liquid- and nature on the light-round delay. A brief interpretation is proposed in Section 4.

2. Experimental configuration

The annular system (Fig. 1) comprises a plenum connected to a combustion chamber by 16 swirling injectors that can be supplied with either gaseous or liquid fuels without changing the geometry and the injection system. The swirled flow is injected into the combustion chamber through a convergent end piece with an exit diameter $d = 8$ mm. Eight channels feed the plenum and, depending on the configuration -gaseous or liquid fuel- these channels deliver a mixture of propane and air or only pure air. Air is injected at ambient temperature. In case of liquid injection, a simplex atomizer is placed after the swirler, 6 mm in recess with respect to the convergent exhaust (Fig. 1) establishing a hollow cone spray in the chamber.

The plenum is terminated by an annular plate holding the 16 injectors. This serves as the backplane to the chamber formed by two cylindrical concentric quartz tubes. The inner and outer quartz tubes are 200 mm long and their diameters are respectively 300 and 400 mm. The ignition process is initiated by a spark plug positioned in front of the camera, located on the opposite side of the chamber. Unlike aeronautical combustors, a single igniter is used so the camera can catch the entire

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