FAST Thermal Imaging – Combustion Ignition Studied with a FAST-IR Camera

In the last couple of years, biofuels have become increasingly popular. This growing popularity is mainly driven by factors such as oil price, energy dependency and environmental concerns. However, the biofuels production yield, combustion efficiency and ignition properties are limited when compared to those of fossil type fuels.

In an effort to better understand the interaction between the many parameters affecting biofuel ignition and combustion efficiency in a typical aircraft gas turbine combustor, direct observation to visualize the interaction between the ignition kernel generated by a strong spark and the biofuel droplets reaching the highly energized and ionized region was performed.

This application note presents the measurement results of the internal combustion chamber using a high-speed and high-performance infrared imaging system. The Telops FAST-IR 1500 camera has been designed specifically for such applications with rapidly evolving and highly energetic events.

Introduction

The installation used to demonstrate the benefit of fast infrared measurement for this application is configured with a 75 mm (3 in) sapphire IR optical access window to look directly inside the combustion chamber. The Telops FAST-IR 1500 high-speed infrared camera looks directly inside the combustion chamber through this sapphire window. The experimental setup is presented in Figure 1 and the infrared camera's main control parameters are presented in Table 1.

Parameters	Unit	Value
Distance to combustion chamber	m	1.75
Camera frame rate -Spark analysis: -Gas droplets analysis: -Combustion analysis:	Hz	 5,000 3,000 10,000
Spatial resolution	Pixels	128 x 128
Camera FOV (HxV)	° m	0.1 x 0.1
Camera sensitivity	mK	< 20

Table 1: Infrared camera control parameters

Results and discussion

Biofuel mixtures in the form of liquid injected fuel need to be characterized with respect to their ignition properties. Moreover, characterization must be performed under a large variety of environmental conditions. To characterize

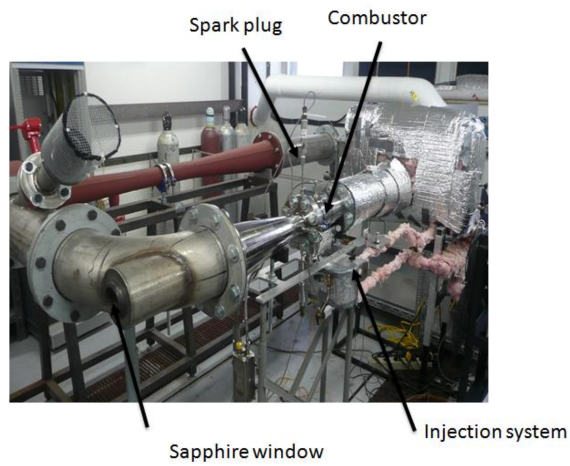

Figure 1: Experimental setup

biofuel mixtures, the effect of the ignition spark, the droplet size and the distribution as well as the flame transient and steady state mode must be understood. The following section describes these elements in greater detail.

Ignition sparks analysis

The ignition system uses a high temperature spark from a spark plug. The sparks are generated at a 3 Hz frequency. The results reveal an unprecedented capability of measuring key ignition characteristics. Figure 2 introduces the step by step temperature signature evolution of the generated spark. The time difference between consecutive frames is 200 microseconds.

One can easily follow the spark dynamic evolution lasting less than 800µs (frame #2 to frame #5). From these measurements, the maximum spark temperature and the temperature distribution, the spark active area and the spark transient evolution can be studied (see Figure 3). One can then derivate the impact of the spark main physical characteristics on the combustion ignition and steady-state mode. For instance, the influence of the spark temperature, active area and physical position in the combustor as a function of fuel mixture and concentration can be optimized.

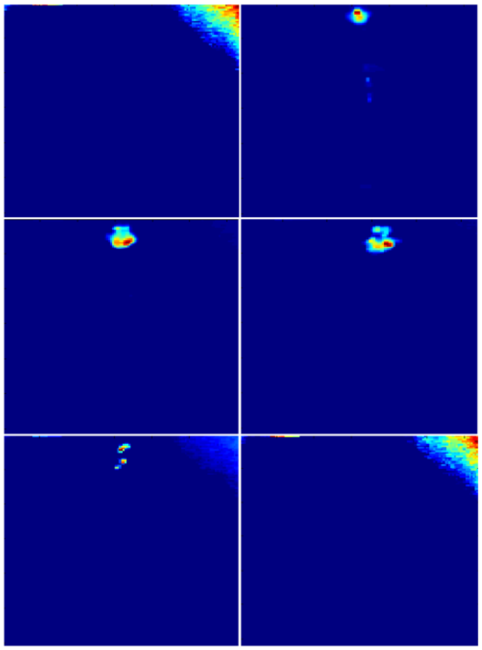

Figure 2: Spark temporal evolution

Injection system analysis

In typical liquid fuel jet engine combustors, combustion instability is highly related to the fuel droplets size and distribution. It is thus vital to understand the injection mechanisms of biofuels. This part of the combustion process can straightforwardly be optimized using high-speed infrared imagery. A good fuel injection system needs to spray the fuel uniformly and continuously into the combustion chamber. The fuel droplets size and distribution into the fuel cloud is key to the efficiency of the ignition and the combustion. Figure 4 illustrates the temporal detection of fuel droplets during a typical steady-state fuel injection process.

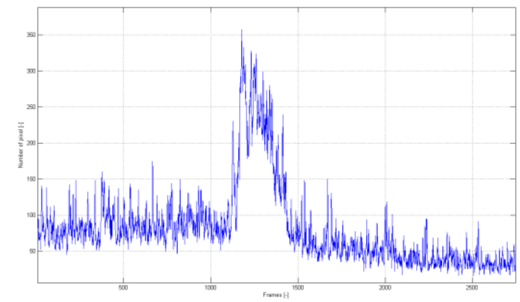

Figure 4: Fuel injection detection.

In steady-state mode (frame 0 to 1000 in Figure 4), fuel droplets are detected in 50 to 100 pixels. The fuel droplet detection counts then increases for no known reason to about 350 counts between frame 1200 and frame 1300. Then the behavior of the fuel injection process drastically changed and only 25 to 50 pixels detected as part of the injection process. Such behavior is an example of anomaly that degrades the combustion efficiency. Figure 5 introduces the dynamics at the beginning of a fuel injection process inside the combustion chamber. As it can be noticed, the fuel droplets are not spayed evenly and uniformly inside the combustion chamber (Red circle in Figure 5). Most droplets are directed toward the bottom half of the combustor. This is a good example of how fast infrared imagery helps to understand and optimize the combustion process.

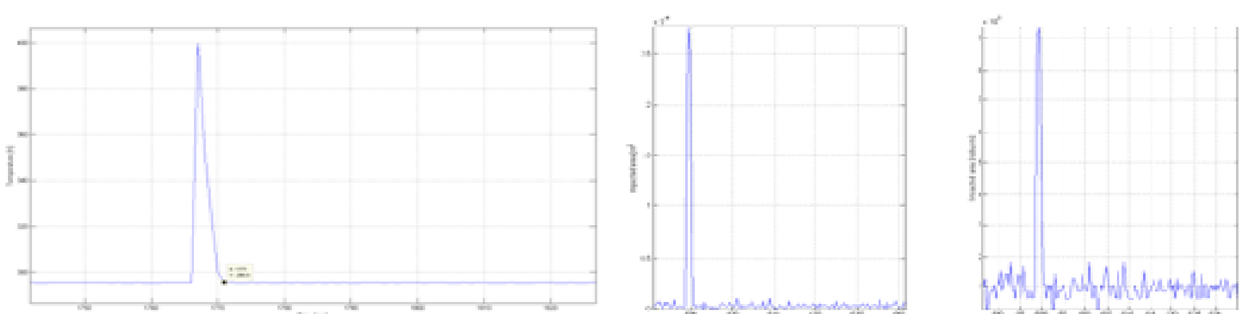

Figure 3: Ignition spark analysis Left) Spark maximum temperature. 2 rights) Spark active area and apparent diameter

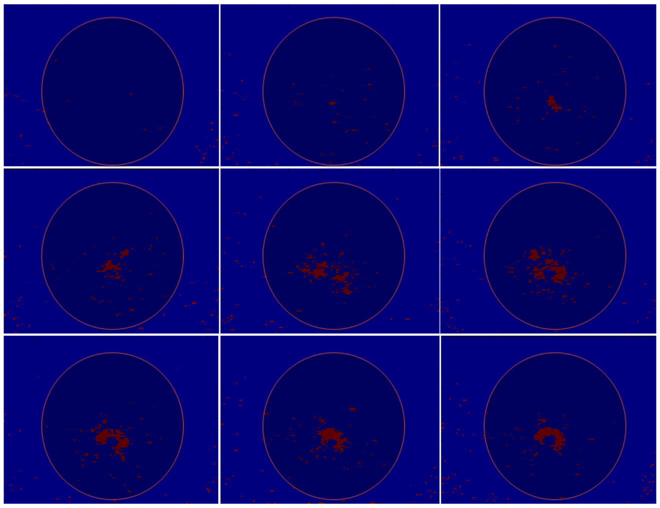

Figure 5: Fuel injection detection from injection ignition.

Combustion Ignition

Finally, a fast thermal camera is useful to study the dynamics of a successful/unsuccessful combustion. The results from the measurements reveal a quasi circular shape temperature distribution in steady-state mode. Figure 6 introduces the spatial temperature distribution approximately 400 milliseconds following the combustion ignition. As expected, the maximum temperature of about 2200 K is located near the center of the combustor. The temperature quickly falls down toward the combustor wall to a near ambient temperature. A sub-sampled sequence of images representing the transient ignition phase is shown in Figure 7. The total elapsed time between the first and the last image is about 100 milliseconds. Large pulsations are easily observed before the steady-state combustion finally gets established for a successful ignition. Another interesting way to analyze the performance of the FAST-IR 1500 infrared camera in this dynamic high-energy application is to look at the progression of the maximum temperature and the total released energy resulting from the combustion active surface area. As shown in Figure 8, the user has direct access to the maximum temperature and to the total emitted energy occurring during the combustion ignition. In fact, the total energy produced by the combustion process peaks around 20,000 W after approximately 0.8 seconds in steady-state mode. Interesting features appears in both the energy and temperature temporal graphs. From this analysis, it is obvious to notice that the ignition was not successful following the first spark. Two sparks were required to successfully initiate the combustion. Also several peaks can clearly be distinguished during the transient phase. As presented in Figure 9 these peaks

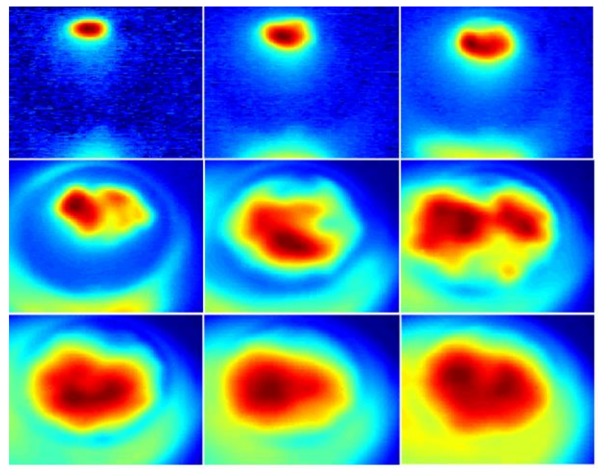

Figure 7: Transient ignition phases

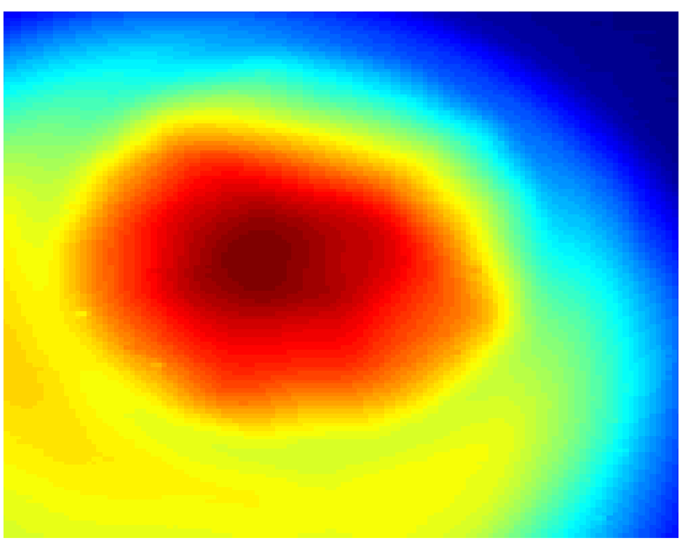

Figure 6: Steady-state successful combustion

do not appear randomly. The most frequent peaks appear at a frequency of 3 Hz and 10 Hz. These frequencies correspond to the ignition spark frequency and to the air injection system respectively. Even in steady-state mode these peaks are affecting the combustion process. The consequences are reduced combustion efficiency, increased noise, and the creation of potential instability inside the combustor.

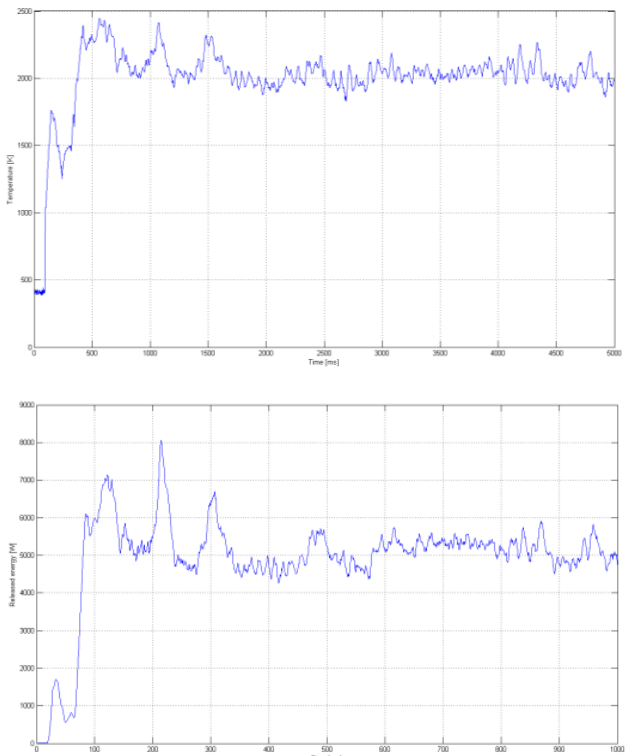

Figure 8: Transient combustion analysis.
a) top maximum temperature. b) Released energy

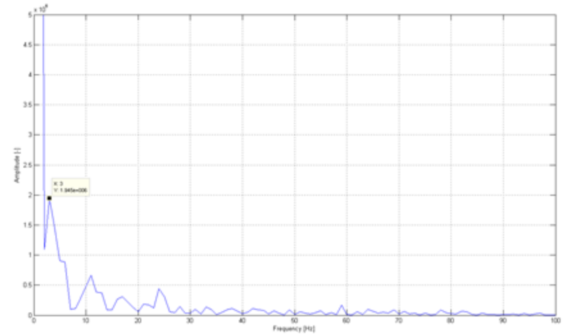

Figure 9: Transient ignition phases

Conclusion

A highly dynamic combustion flow can be analyzed with a fast infrared imager. Important combustion characteristics such as the ignition spark, injection system and the combustion transient and steady-state behavior can be measured. The fast infrared imagery analysis leads to more efficient and stable combustor design. Moreover, the use of Telops FAST-IR 1500 infrared camera for this particular application helps accelerate the use of more lean fuel in standard aircraft combustors.

Telops acknowledges the important contributions of Professor Alain De Champlain from University Laval and Sophie Ringuette from Defence Research and Development Canada (DRDC) – Valcartier that made this research activity possible.

Telops Inc.
100-2600 St-Jean Baptiste ave.
Québec (QC) G2E 6J5
Tel.: 418-864-7808
Fax. : 418-864-7843

.