Experimental studies on injection nozzle flame stability for gas turbines using in-situ combustion applications

Cleopatra Cuciumita
Romanian Research and Development Institute for Gas Turbines COMOTI
Senior Researcher
220 D Iuliu Maniu Bd., sector 6, 061126, Bucharest, Romania
cleopatra.cuciumita@comoti.ro

Daniel Olaru
Romanian Research and Development Institute for Gas Turbines COMOTI
Researcher

Marius Enache
Romanian Research and Development Institute for Gas Turbines COMOTI
Researcher

Florin Florean
Romanian Research and Development Institute for Gas Turbines COMOTI
Senior Researcher

ABSTRACT

This paper presents the experimental results of the test conducted on 3 different geometries for injection nozzles. The objective of these experimental studies was to determine the optimal configuration with respect to flame stability in high velocity flows and aiming for an increase in temperature small enough to be comparable with the decrease in temperature due a subsequent expansion. These conditions are a consequence of the intended application, gas turbines using in-situ combustion. This uses a supplementary combustion in the turbine, intended to best approximate an isothermal expansion that would ensure a better efficiency for the gas turbine. Taking into account the drop in temperature is of approximately 100 degrees after a turbine stage, and the flow velocity is about 100 m/s at the exit of the turbine stage, a suitable solution was sought. The experimental results shown that none of the tested configurations matched the desired conditions, but one of the three geometries had a significantly better behaviour. At the same time, it was concluded that the number and dimension of the injection holes do not play a major role in flame stability in high velocity flows, but rather their shape. The injection nozzles with divergent holes proved to be the most stable and to provide the smallest increase in temperature for high velocity flows.

KEYWORDS: *experimental, flame stability, gas turbine, in-situ combustion*

NOMENCLATURE

Latin

h – Enthalpy

s – Entropy

IR – infrared

M – Mass flow rate

T – Temperature

V – Velocity

Greek

Φ- Equivalence ratio

1 INTRODUCTION

A turbine using in-situ combustion is a turbine in which fuel is injected and combusted, operating on a thermodynamic cycle which is a hybrid between the Ericsson and Brayton cycles [1-3]. The main difference resides in the way the turbine expansion occurs: adiabatic in the Brayton cycle, and isothermal in the Ericsson cycle. By releasing combustion heat inside the turbine, the expansion process departs the adiabatic curve in the enthalpy-entropy plane, and approaches an isothermal, the degree of approximation being a direct function of the capability to burn small amounts of fuel at numerous axial positions along the turbine (Fig. 1).

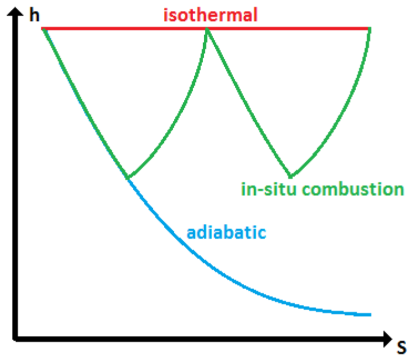

Figure 1: Diagrams of the expansion process in the adiabatic, isothermal, and in-situ combustion with two combustion axial locations

Earlier studies demonstrated the benefits of using reheat in the turbine to increase specific power and thermal efficiency, particularly when the turbine is connected with a heat regenerator [1]. A thermodynamic analysis demonstrates performance gains for turbojet engines with turbine-burners and for turbofan engines with inter-stage stage reheat turbines [2]. A pioneer cycle study by Sirignano and Liu [3] compares the performance of a jet engine using traditional compression together with isothermal expansion. For low flight speeds, it was shown that the turbine burner uses less fuel than an afterburner engine but more than a traditional jet engine. For high flight speeds (above Mach 2.2), the turbine burner shows the best fuel economy.
The turbine burner also enables a reduction in the size and weight of the engine. Previous numerical simulations [4,5] showed that the best location for fuel injection is at the trailing edge of the inlet guide vane. No reliable information exist on the pollutants emission for an aviation turbine-combustor engine model that is mainly due to the lack of the kinetic mechanism. There is, though, one research report that mentioned approximately 15% reduction in NOx normalized emissions for an in-situ reheat ground-turbine [6]. However, the fact that the specific power increases even in the absence of heat regeneration may be turned around and used to reduce the fuel consumption for the same engine power. As a result, the maximum cycle temperature decreases, thus enabling an overall NOx and pollutant emission reduction. By distributing the fuel combustion throughout the turbine, as close as possible to isothermal expansion, such that the overall engine thrust remains unchanged, a smaller temperature variation throughout the combustion process is obtained along with a reduced cycle maximum temperature.
Due to the distributed fuel injection and combustion, both in the main combustor and in the turbine combustor, the amount of fuel to be burned at each location is smaller, thereby allowing a more complete and efficient combustion, decreasing the amount of Unburned Hydrocarbons (UHC) and also the emission of solid particles (e.g. soot), creating the premises for a greener aircraft engine.
On the other hand, when comparing real cycles, for components having same efficiency and if only isothermal expansion is considered, without constant temperature compression, the efficiency of the cycle falls below the Brayton cycle efficiency [7], and efforts for designing better, more thermodynamically efficient turbines must be made in order to compensate this effect. Better said, an increase in the efficiency of the turbine stages, at the same power output, will maintain the initial cycle efficiency.
Turbine combustion is a recent concept, and the amount of work in the field is presently quite limited. An extensive review of recent work carried out in the field is provided in [8], with respect to four related areas: (i) thermodynamic cycle analysis, (ii) reacting mixing layers in accelerating flows, (iii) flame holding in high speed flows and (iv) compact combustors.
Thermodynamic cycle analysis has been carried out for both continuous combustion [9], and for inter-stage combustion [2], using component efficiencies based on typical, real life, values, and demonstrating performance gains related to lower fuel consumption, higher specific thrust, and

enhanced operational speed and compressor pressure ratios for both turbojet and turbofan engines. The results are clearly showing benefits of the technology. Unlike this situation, the three last research areas are facing known difficult problems and only recently developed investigation methods promise to be able to handle them. It explains the current lack of understanding when they are present simultaneously and quantifies the challenge of performing stable combustion in the turbine.

Considering each area separately, we start with combustion in accelerating flows. It has been mainly studied for low Mach number reacting mixing and boundary layers, mostly for laminar [10 - 13], but also some turbulent [14, 15] flows. High speed reacting layers, as is the case of the problem proposed here, are scarcer, but some results on high speed flow combustion have been published [16 - 21]. Theoretical, similarity studies of laminar, two-dimensional, reacting, accelerating mixing layers [22] have shown a decrease of the peak temperature along the mixing layer, with beneficial effects upon the formation of NOx. The work has been extended to non-similar cases using one-step finite rate chemistry in laminar [23] and turbulent [24] flows using the boundary layer approximation. Three-dimensional, full Navier-Stokes numerical simulation studies of accelerating, reacting flows are very limited at this moment, but some simple geometry attempts have been reported [25, 26], also including some limited experimental validation [27]. The key finding of these studies is that fully developed turbulence cannot be assumed in the turbine channels, so RANS based numerical simulations are not suited for the problem, requiring more advanced LES numerical simulations. Numerical simulations [28, 29] on premixed and partially premixed reacting, accelerating and curved flow, aimed at assessing the effect of the centrifugal forces in the rotating part of the turbine, but had limited success due to the two-dimensional approach. Experimental studies [30 - 33] of ignition, stabilization and combustion of liquid fuelled flames in high centrifugal acceleration flows have been carried out in recent years at the Air Force Research Laboratories, in the United States.

For area (iii), the flame stabilization mechanism in high speed flow has been investigated in the light of hypersonic vehicles, for example Scramjet applications [2]. Important contributions originated from the Air Force Research Laboratories featuring liquid injection of fuel into supersonic cross-flow has been studied [34, 35]. Another set of studies [36, 37] aimed at determining the fuel distribution resulting from low angle fuel injection along the solid wall in supersonic, non-reactive flows. Reactive flow experimental measurements were also reported, and the flame stabilization role of a cavity placed on the solid wall has been analysed for various injector designs [38, 39]. Combustion of Kerosene injected in supersonic flows and stabilized using a Hydrogen pilot flame and various cavity patterns, as well as the effect of aeration in conjunction with the cavity geometry and the impact of the flow conditions (temperature and pressure) on the ignition delay were experimentally studied [40, 41], indicating combustion efficiency up to 92 %.

The flame stabilization mechanism in high speed flows, that plays a critical role in turbine combustion, has mainly been studied from the standpoint of supersonic combustion for Scramjets and Ramjets, and differs for the case considered here, even if benefits from the insight gained in those studies are relevant. In particular, the presence of a recirculation region in the flow enables the fuel and the air mixing and burning. Coherent structures, detaching from the recirculation region and containing unburned mixture and burning pockets are carried downstream, further contributing to the complete combustion of the injected fuel [2]. The recirculation region can be created by placing in the flow a cavity [42], or a step [43], creating a sudden flow expansion, and by injecting fuel and, possibly, air, in that reversed flow region. These solutions, generically termed Compact Combustors [2], provide low pressure drop flame stabilization and are already tested for non-accelerating low speed flow.

The Trapped-Vortex Combustor [43] (TVC) was first proposed by the Air Force Research Laboratory and General Electric Aircraft Engines, in the United States, during the last decade. In this approach, the flame is stabilized by means of a vortex trapped in a cavity created on the burner walls, acting as a pilot flame by recirculating the hot burned gas in the cavity, as fuel and air are continuously injected in the cavity. Preliminary experimental [44] and numerical [45, 46] studies have shown that the TVC can not only provide stable combustion, but can also decrease the NOx emissions. Experimental and numerical studies of cavity stabilized, gas fuelled flames in a flow passage resembling turbine stator blades have been reported by Sirignano et al. [2]. Variants or improvements of the TVC include the Ultra Compact Combustor [29] (UCC) and the Cavity Inside Cavity [47] (CVC). The UCC and CVC locate the cavity circumferentially with the idea of allowing for most of the combustion to take place around the turbine shroud. It strongly reduces the axial dimension of the combustion zone [8]. Low pressure experimental measurements on UCC were carried out [48] with promising results regarding combustion

efficiency, combustor compactness, flame stability, especially for lean mixtures, and heat release ratio. It is, however, unclear if the concept performs at higher pressure and how it reacts to higher temperature vitiated air.
Alternative concepts are the Inter Turbine Burning and In Situ Combustor [49]. For the first one, supplementary combustion occurs between the high and the low pressure turbines, acting as a reheating stage in a rough approximation of an Ericsson cycle. The In Situ Combustor is the focus of this paper. Developed by Siemens Westinghouse Power Corporation, the concept proposes fuel injection through the airfoils in order to reheat the expansion cooled gas to increase the cycle efficiency towards the ideal Ericsson cycle efficiency and power output, and to reduce the NOx emissions [2]. However, the ability of achieving stable and complete combustion in the turbine flow channels between the blades and vanes has not yet been demonstrated. In particular, the very short residence time is often lower than the auto-ignition delay, and stabilization requires an additional means, such as a cavity feeding with burn gases.
Since 1960's, several patents have been awarded for different inventions regarding turbine combustion [50 - 52]. Presently, no product or technology exists on the market, and even SIEMENS-Westinghouse, in the early 2000's, has failed in its attempts to test a turbine burner, mostly due to lack of knowledge and understanding the complexity of phenomena taking place in a turbine burner.
One of the main challenges of the in-situ combustion concept is represented by the flame stability. Due to the large flow velocities, significant velocity gradients exist, and the flame is strongly strained as an effect, inducing a significant quenching risk. To avoid this, the flame-local flow velocity must be decreased to value of the same order of magnitude as the laminar flame speed characterizing the flame [53]. In the experiments presented here, this is achieved by using bluff-bodies of various geometries, which also serve as fuel injectors.

2 EXPERIMENTAL SETUP

2.1 Test rig

The experimental program takes into account, at this stage, the flame stability study in high velocity flows. For this purpose, the experiments were conducted in the Combustion Laboratory of COMOTI [54]. The schematics of the testing facility are represented in Fig. 2.

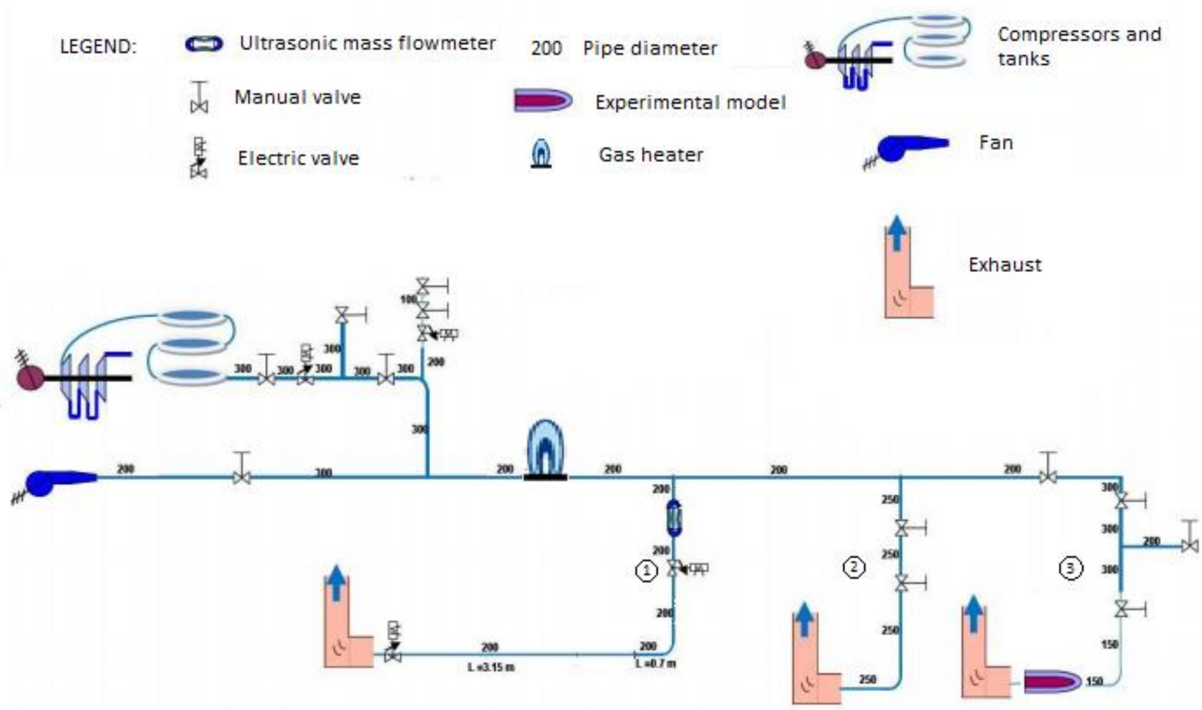

Figure 2: Test rig schematics

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The experiments were conducted on experimental line 3, using air provided by a fan as oxidant, and with no additional heating. The total pressure at the experimental model inlet was 1.05 bara, while the temperature 292 K. The fuel used for the experimental program was methane gas. The main source of methane was the low pressure municipal network, which limited the pressure to a maximum value of 3.5 bara.

2.2 Experimental model

Taking into account the main objective of the experiments, the study of flame stability in high velocity flows, the experimental model was configured considering the possibility to monitor the flame, as well as constructive simplicity.

Therefore, the experiments were conducted inside an existing quartz tube, of 125 mm inner diameter. This tube was fitted with a screw nozzle for mounting the injection nozzle. The quartz tube, mounted on the testing line and along with an injection nozzle mounted on it are depicted in Fig. 3.

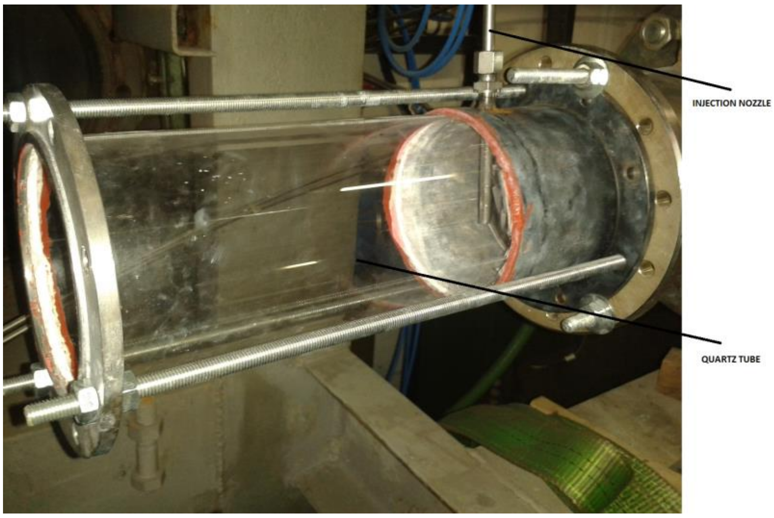

Figure 3: Experimental model configuration

Based on preliminary CFD numerical results, it was decided to manufacture the injection nozzles from stainless steel tubes, having an 8mm outer diameter and an inner diameter of 6mm. These injection nozzles were mounted so that the fuel injection to be performed counter flow and the first injection hole of the nozzle to be positioned in the centre of the quartz tube. Four different injection nozzles were tested, described further on.

2.3 Instrumentation

The instrumentation of the experimental model took into consideration two aspects. First of all, the instrumentation has to be in accordance with the experimental model construction. Therefore, the measuring instruments were mounted at the outlet of the quartz tube, which has a total length of 345 mm. At the same time, the instrumentation needs to consider the objectives of the project. In this case, the main parameter is the flow velocity. Another important parameter is the temperature at the experimental model outlet, mainly because the required temperature increase is relatively small, approximately 150°C. This increase in temperature is meant to cover for the temperature decrease caused by the gas expansion in an axial turbine stage so that, by means of this supplementary combustion to approach the Ericsson cycle isothermal expansion.

The instrumentation consisted in a mass flowmeter, a Pitot tube adjusted with a type K thermocouple and a flue gas analyser.

The probe of a portable MRU Vario Plus gas analyser was mounted in the centre of the outlet section, capable of measuring in temperature of up to 1000°C. This analyser measures and displays real time values for the following parameters:

- CO, CO2, HC – based on infrared dissipative absorption measurement;
- NOx, SO2, O2 – electro-chemical measurement;
- T-Gas, T-Air, gas velocity.

In addition to the Pitot tube of the gas analyser, another Pitot tube was used, for measurements validation. This Pitot tube had the following characteristics:

- Stainless steel 316 L;
- Measuring range: 0 – 100 m/s;
- Temperature measuring range: 0 - 600°C;
- Maximum static pressure: 2 bar;
- Accuracy: under 1% for a flow alignment error of ±10 °.

For infrared temperature measurements, a FLUKE IR FlexCam Thermal Imager Ti40 was used.

Finally, the methane mass flow rate was measured using a designated mass flow meter, Bronkhorst - F-106BI-AAD-02-V. This has a robust design, capable of both measuring and controlling the flowrate. The measuring range is between 1 and 500 Nm^3/h, up to a pressure of 64 bar.

3 EXPERIMENTAL CAMPAIGN

3.1 Experimental program

The main goal of the experiments was to obtain flame stability in high velocities flows, similar to those encountered in the axial turbines stages. At the same time, aiming for a quasi-isotherm expansion in the turbine, the rise in temperature required is relatively small, respectively 150°C.

The experimental program consisted in testing 4 different injection nozzles and determining the optimal configuration to meet the above mentioned objectives. The four injectors are depicted in Fig. 4. The first two, in the above pictures, have 15 cylindrical, equally spaced injection holes, each with a diameter of 2 mm (upper left), respectively 1 mm (upper right). The third injection nozzle (lower left) has convergent injection holes, with an upstream diameter of 0.5 mm and a downstream diameter of 0.35 mm. The fourth one has the same holes diameters, but they are oriented so that the injection to be made through divergent channels.

Figure 4: The 4 tested injection nozzles

For each of these 4 injection nozzles, the experimental program included:

- Firing the fuel at low air flow velocities;
- Gradually increasing the air flow velocity, correlated with the methane gas, until blow-off, to determine the maximum airflow velocity at which the flame is stable.

3.2 Theoretical considerations

The experimental model geometry used in this experimental campaign determines the flame stability through a typical stabilization mechanism around a bluff body represented, in this case, by the fuel pipe.

One of the main issues posed by designing a turbine with in-situ combustion is obtaining a high enough residence time of the fuel mixture around the high temperature area generated by the sparkplug, so that a more complete combustion in a more compact area to be obtained, in order to avoid flame propagation downstream of the turbine stator. The presence of the injection nozzle creates a recirculation zone which, by returning some of the hot flue gases upstream (containing free radicals able to initiate and maintain combustion), represents a source for maintaining combustion and flame stability. The turbulence, which is produced in the shear layers which delimitate the recirculation area has, also, a favourable effect on the mixing of flue gases with the fresh fuel mixture.

The fresh mixture zone is delimitated by the flue gases by the free shear layers which detach downstream of the bluff body. After separation, they migrate towards the centre of the flow channel and create large scale coherent structures, generating major interactions between the flame front and the viscous eddies from downstream of the bluff body wake. The flame is initiated and sustained in this shear layer. The flame stabilizes at a small distance from the bluff body, because the heat and free radicals losses towards the solid wall stops the flame front from reaching the wall. Blow-off happens when cold unburnt gases penetrate this shear layer downstream of the bluff body and replace the flue gases which should be recirculated upstream to maintain the flame. More generally, it can be said that blow-off f happens when the fresh mixture does not remain long enough in the shear layer to be ignited.

In other words [55 – 58], the blow-off happens when the heat production rate in the flame area is not sufficient to allow a rise in the temperature of the fresh mixture above the auto ignition value.

The flame stability in the case of using a bluff body depends on a number of parameters. It is important to mention that previous experimental studies [59 – 61] showed that the shape of the bluff body does not fundamentally affect the geometry of the recirculation zone and, thus, the flame stability.

A series of experimental studies dating back as early as the mid-20th century [59, 62, 63] focused on determining the limits of flame stability and on the stabilization mechanism involved in this process. These studies provided empirical correlations between the geometry of axisymmetric bi-dimensional bluff bodies and flow parameters associated with the recirculation zone downstream. Amongst others, the effects of the upstream flow velocity, of the blockage ratio (the ratio between the area blocked by the bluff body and the total area of the flow channel), of the chemical composition of the fuel mixture and of the shape of the bluff body on the geometry of the recirculation zone, on the residence time within, on the mean transfer velocity through the shear layer and on turbulence intensity in this shear layer were analysed. The conclusion of these studies show that flame stability is mainly determined by two critical parameters: flow velocity upstream of the bluff body and the equivalence ratio of the fresh mixture. These two parameters have been since used by all scientific literature to define the stability limits for premixed combustion.

Besides these key parameters, previous studies have identified other, less significant, parameters that influence flame stability, such as: the pressure [64, 65] and temperature [66, 67] upstream of the bluff body, turbulence intensity [63, 68 – 70], conditions downstream of the bluff body [67, 68], the bluff body geometry [71] or fuel type [60].

For evaluating the flame stability under different configurations, a non-dimensional stability parameter, can be defined [60], which basically depends on the flow velocity upstream of the bluff body, corrected to take into account the effect of upstream pressure and temperature and the geometry of the bluff body. The graphical representation of the delimiting line between stable and unstable regimes is named, in the scientific literature, the stability diagram. Such diagrams can be simplified and represented directly as a function of the flow velocity upstream of the bluff body.

3.3 Experimental results

For the injection nozzle no. 1 it was found that, irrespective of the equivalence ratio, the flame is unstable and blow-off occurs at flow velocities below 10 m/s. Thus, is was deemed unsuited for current application and discarded.

Tables 1 to 3 and Figs. 5, 7 and 8 present the experimental data. Here, the blue dots represent stable combustion regimes while the red dots represent unstable regimes. The dimension of the dots is proportional with the CO concentration measured for each regime.

The experimental measurements indicate that some of the analysed regimes are stable, in the sense that once initiated, the flame is indefinitely maintained, while others are unstable, flameout occurring moments after the ignition. The stability limit passes, for each of the studied cases, between the blue dots (stable regimes) and the red dots (unstable regimes). It is significant that the curve shape is in accordance with the shape represented in literature [60], which is a validation form for the experimental results.

Both for injection nozzle no. 2 and no. 3, for an equivalence ratio of 0.2, the blow-off point is found to occur for a flow velocity between 15 and 20 m/s. At lower equivalence ratio values, the flame becomes unstable even for lower velocities, of under 15 m/s, as it can be further seen.

Table 1: Experimental results for injection nozzle no.2

Regime	V [m/s]	T [K]	CO [ppm]	M_{CH4} [g/s]	M_{air} [kg/s]	φ [-]
1	10.4	646	2	1.477	0.07228	0.16348
2	15.4	838.4	3	1.1945	0.08247	0.11587
3	17.2	754	3	1.189	0.10242	0.09287
4	14.6	817.7	2	0.831	0.08016	0.08293

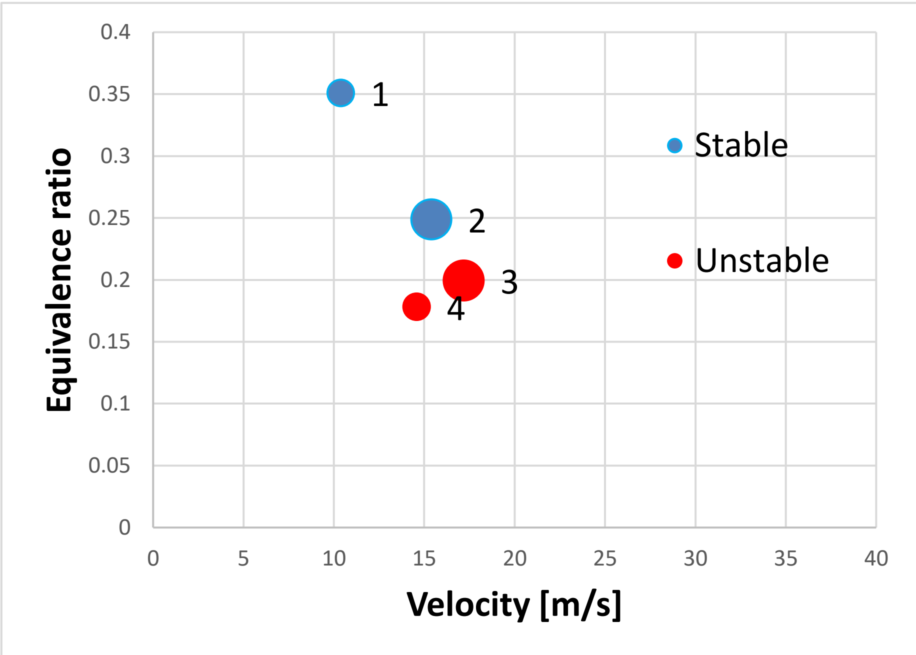

Figure 5: Stability diagram for injection nozzle no.2

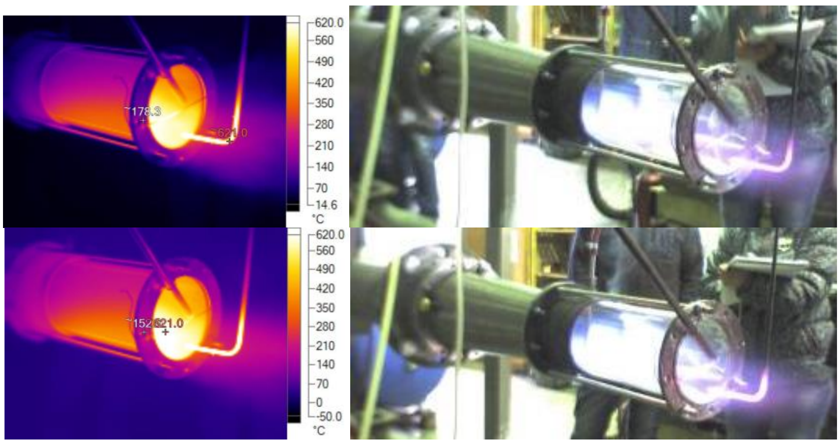

Figure 6: IR and visible light measurements for injection nozzle no.2, regimes 1 (upper) and 2 (lower)

Table 2: Experimental results for injection nozzle no.3

Regime	V [m/s]	T [K]	CO [ppm]	M_{CH4} [g/s]	M_{air} [kg/s]	φ [-]
1	10.5	1084	3	0.7377	0.04349	0.1357
2	14	964	6	0.8711	0.0652	0.10688
3	21	936.9	5	1.2739	0.10063	0.10127
4	20	835	1	1.233	0.10754	0.09173

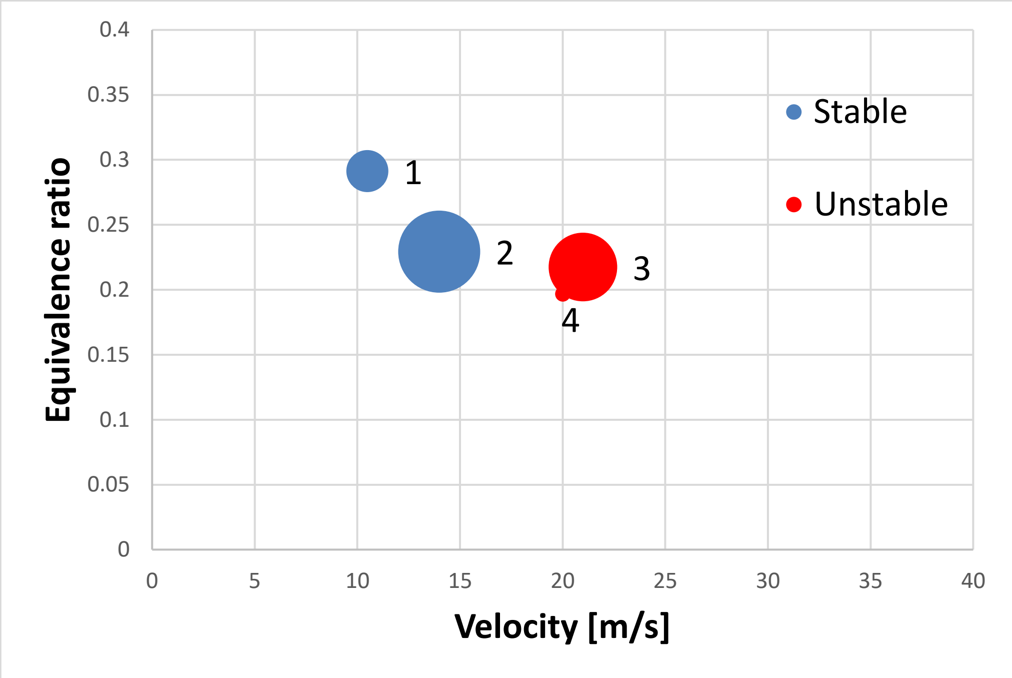

Figure 7: Stability diagram for injection nozzle no.3

The situation is significantly different for the injection nozzle no .4, for which the flame remains stable even for velocities over 33 m/s and for an equivalence ratio way lower, of 0.02. In this case, the blow-off is found to occur at around 35 m/s. This indicates a much better performance of injector nozzle no.4 as compared to no.2 and 3.

Table 3: Experimental results for injection nozzle no.4

Regime	V [m/s]	T [K]	CO [ppm]	M_{CH4} [g/s]	M_{air} [kg/s]	φ [-]
1	7.2	513	3	0.0935	0.06301	0.01187
2	33.4	617	2	0.415	0.24304	0.01366
3	37.1	404.9	1	0.546	0.41138	0.01062

This can be explained if the inhomogeneity of the fuel – air mixture in the experimental model is considered. Due to the fact that the injection is performed counter flow, through the upstream area of the injection nozzle that serves as flame stabilizer, in the vicinity of the flame front the fresh mixture has significant chemical composition non-homogeneities when reaching the combustion area. The geometrical differences between the 3 injection nozzles have an important effect on this inhomogeneity level, leading to large differences in terms of flame stability.

As the performances of injection nozzles 2 and 3 are similar, it can be concluded that the dimension of the injection holes is not relevant. On the other hand, the shape of the injection holes is proven to be critical. Thus, the divergent shape of the fuel feeding channels characteristic to the injection nozzle no. 4 leads to a better dispersion of the fuel jet and to a significantly improved mixing with the surrounding air. This better mixing leads to the extension of stability limits, as it can be seen in Fig. 8.

For all the injection nozzles, for the stable regimes, an increase in CO concentration can be noticed towards the stability limit. This indicates that, although the combustion is stable, its completeness drops when approaching the stability limit.

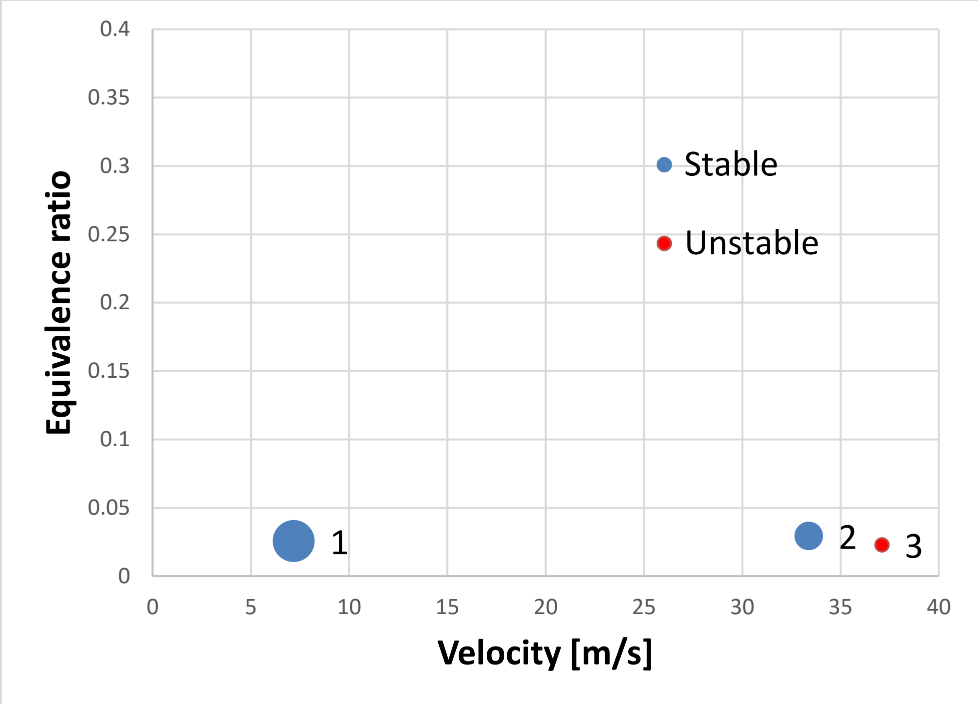

Figure 8: Stability diagram for injection nozzle no. 4

Fig. 9 presents all experimental data in terms of temperature correlated with equivalence ratio. The shape of the dots differentiates between injection nozzles, while the number next to each dot represents the experimentation regime. Red is used, once again, for unstable regimes, while blue for stable ones.

From a temperature standpoint, Fig. 9 presents, as expected an increase of the temperature in the experimental zone, correlated, in general, with the increase of the equivalence ratio. Departures from this trend are, most likely, caused by non-homogeneities of the temperature field in the experimental region. The minimum temperature raise, of 131.9 °C was measured for the injection nozzle no. 4.

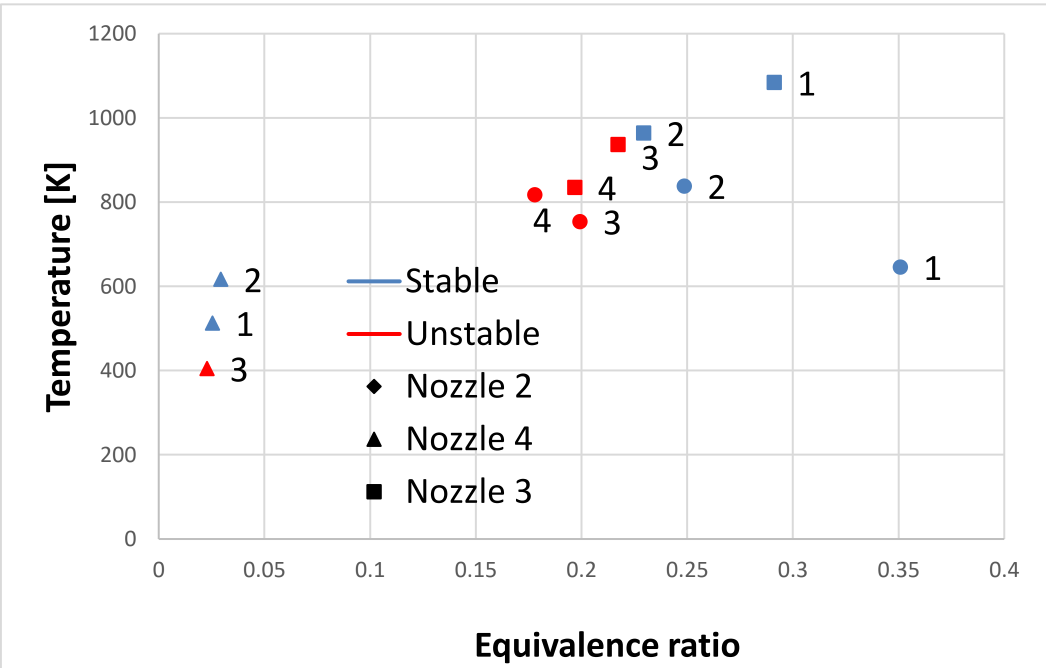

Figure 9: Correlation between temperature and equivalence ratio

4 CONCLUSION AND FUTURE WORK

The goal of the presented experimental measurements was to study the flame stability in high velocity flows, and to obtain the smallest possible temperature rise, around the 150 °C value. To achieve these goals, four different injection nozzles have been tested in the Combustion Laboratory of COMOTI. The tests were carried out with an experimental segment formed by a quartz tube existing in the Laboratory, allowing flame monitoring. The velocity and the temperature were measured using a gas analyser which included a temperature probe, respectively a Pitot tube calibrated for temperatures up to 1000°C.

The results show that the injection nozzles no. 1 - 3 have similar performances, which show the dimension of the fuel channels is not relevant. Conversely, the shape of these channels was found to be a critical parameter. Thus, a divergent shape of the fuel channel, characterizing the injection nozzle no. 4, leads to a faster fuel jet spreading and to a significant improvement of its mixing with the surrounding air. This improved mixing leads to an extension of the stability limits.

The most important result of the experimental campaign presented here is represented by obtaining the experimental proof that the performances of the injection nozzle no. 4 has superior performances, due to a better air / fuel mixing and, consequently, to a better mixture homogeneity in the flame region. For this injector, a stable regime was obtained for the larges flow velocity, of 33 m/s and a minimum temperature rise of 373°C for this flow velocity and a temperature rise of 131.9° C at a flow velocity of 7.2 m/s. Since these two parameters are the main objective of the experimental campaign, it is obvious that this injection nozzle is the best of the four tested injection nozzles.

The validity of the experimental campaign is supported by the shape of the stability curves, confirmed by earlier experimental measurements presented in the literature and cited earlier.

The temperature in the experimental region is generally well correlated to the equivalence ratio, increasing as the latter approaches the stoichiometric value of 1. The completeness of the combustion process, estimated through the CO emission level, decreases as the measured regime approaches the stability limit.

Future work has the purpose of bringing the experimental results closer to the objective of the project, namely the combustion between two axial turbine stages. For this, the next experiments will be conducted with the turbine stator mounted downstream of the injection nozzle area. The presence of the stator vanes should be beneficial to flame stability, since they represent yet another bluff body downstream of the flame. It will be pursued the further increase of flow velocity at which the flame is stable, to values closer to flows at the inlet of turbine stages, namely 100 m/s. At the same time, a goal is to prevent the flame from reaching the rotor vanes, which are highly loaded already. These new experimental data will be then used for comparison and validation of the numerical results obtained by the partners in the project.

ACKNOWLEDGEMENT

The work presented herein is being supported through the PN-II-PT-PCCA-2013-4 research project Gas Turbine with In Situ Combustion (TURIST), contract no. 286/2016.

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