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A combustion-driven facility to study phenomenologies related to hypersonic sustained flight

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Abstract. This paper reports on the development of a new Blowdown-Induction Facility driven by two different Oxy-Fueled Guns. The facility is conceived and realized to simulate different phenomenologies and flow conditions related to hypersonic sustained flight.

Introduction

Plasma Guns used in the context of Thermal Spray are often engineered versions of similar devices originally designed for aerospace research; for these applications the plasma gun is particularly relevant because it couples the reliability of an industrial device with the desired operating conditions, i.e. very high temperatures and very low pressures of the considered gas (heated by the electric arc). Nowadays however, new applications emerging in the general fields of Aerothermodynamics and Propulsion require (a) lower temperatures and higher pressures, (b) different process gases (Methane or Hydrogen) and (c) different operational modes (combustion instead of electric arc) respect to those generated by plasma torches. All these requirements call for the design and development of facilities with combustion-driven Thermal Spray Guns, and the present study may be regarded as a relevant effort along these lines; in particular, here we describe the development of a new facility based on two different Oxygen-Fueled guns (DJ2700 and 6P-II) that exhausts into a low pressure ambient. Unique properties of this facility are its ability to simulate different phenomenologies and flow conditions related to hypersonic sustained flight.

Experimental apparatus

Figure 1 shows the overall Vacuum Oxy-fueled Facility (VOF).

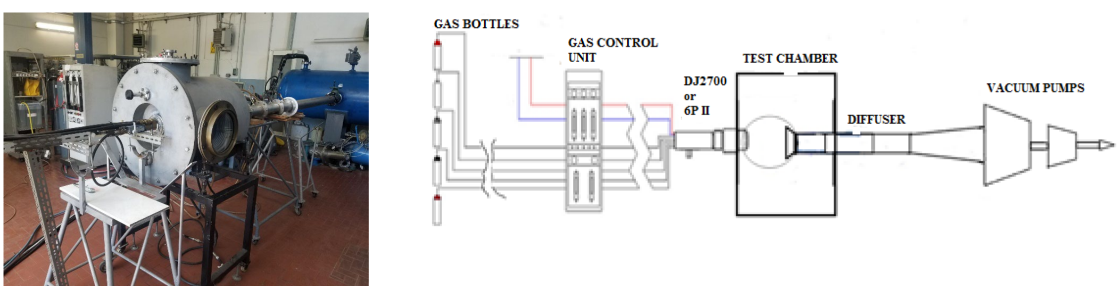

Figure 1 – VOF –Picture (left) and Layout (right).

Main facility components can be listed as:

1. Gas Supply Systems
2. Gas Control Units
3. Hybrid HVOF gun (DJ2700) / LVOF gun (6P-II)
4. Test Chamber and Diffuser

5. Vacuum Tanks and Vacuum Pump System

Gas Supply System

The details of the gas supply systems are shown in Fig. 2. In both systems Nitrogen is used only to prevent melting of the powder injectors in the guns.

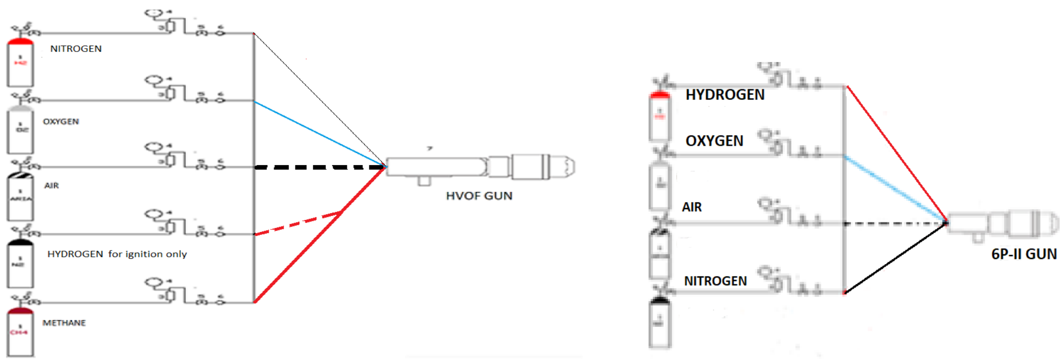

Figure 2 – Layout of the gas supply system for DJ2700 (left) and 6P II (right).

For the DJ2700 gun the gas flow requirements are: Oxygen 340 NLPM at 12 bar - Methane 200 NLPM at 7 bar - Air 439 NLPM at 7 bar - Nitrogen 18 NLPM at 12 bar - Hydrogen 8 NLPM at 10 bar. For the 6P-II gun the gas flow requirements are: Oxygen 45 NLPM at 2.6 bar - Hydrogen 170 NLPM at 2.4 bar - Air 50 NLPM at 6 bar - Nitrogen 15 NLPM at 5 bar.

Gas Control Units

A sketch of the Gas Control Units is shown in Fig. 3, with some relevant details being made evident through the associated legend. Both the units are realized in the laboratory.

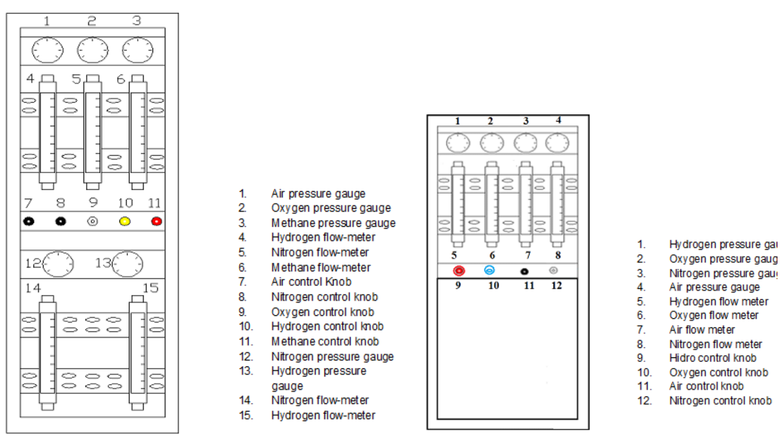

Figure 3 – Gas Control Units Front Panels for DJ2700 (left) and 6P-II (right)

HVOF gun (DJ2700) and LVOF gun (6P-II)

The Sulzer-Metco Diamond Jet (DJ) 2700 has been chosen as HVOF gun, the reader being referred to Figure 4 for a detailed sectional drawing of the gun. The DJ gun relies on a combination of oxygen, fuel and air to produce a high pressure annular flame, which is characterized by a uniform temperature distribution. The exhaust gases, together with the air injected from the annular inlet orifice, expand through the nozzle to reach a supersonic state. The air cap is cooled by both water and air to prevent it from melting.

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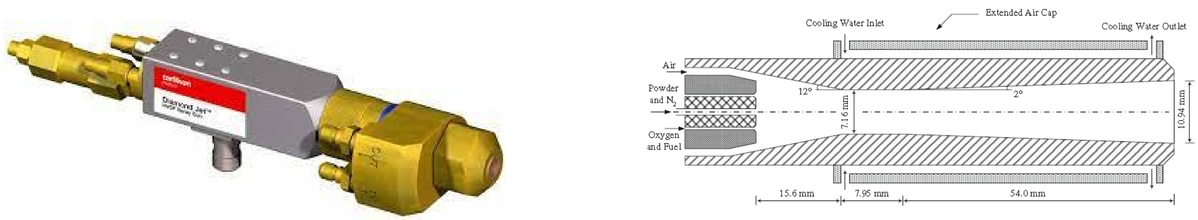

Figure 4 – DJ 2700 Hybrid Thermal Spray torch.

The Flame Spray Technology 6P-II has been chosen as LVOF gun, the reader being referred to Figure 5 for a detailed sectional drawing of the gun. The 6P-II can be used with Hydrogen as fuel gas. A siphon plug system mixes fuel and oxygen in precise volumetric proportions at the gun to provide consistent operation and prevents the possibility of backfire. A reversible air cap is used to create a parallel air flow to cool the gun or as a convergent pinch air flow.

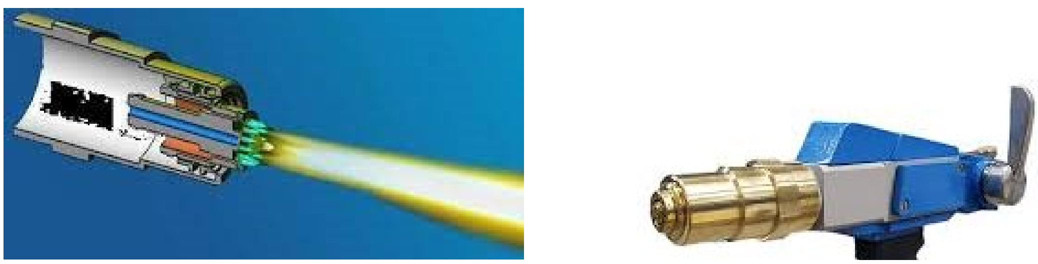

Figure 5 – 6P II Flame Spray torch.

Test Chamber and Diffuser

The test chamber is a iron cylinder with a diameter of 600 mm (Fig. 8), flanged at the ends and hosted inside the first section of the supersonic diffuser, Figs. 6(left) and (right).

Figure 6 – VOF Test Chamber (left) and Diffuser (right).

Vacuum Tank and Vacuum Pumps system

Vacuum pumps are a Stokes Microvac 212H (220 m^3/h) and a Edwards E2M275 (292 m^3/h); they evacuate the facility and the tank in a relatively brief time -5 minutes about - up to100 (Pa) ultimate pressure.

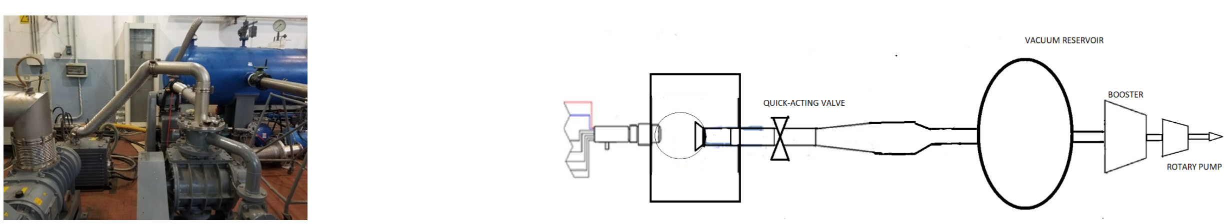

Figure 7 – Vacuum System: Rotary pumps (left) and system layout (right).

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Applications and preliminary results

DJ2700 – HVOF

The HVOF gun (DJ700) produces a supersonic, overexpanded flow at atmospheric pressure (p ~ 0.7 (bar) at nozzle exit) of residual exhaust gases from Methane-Oxygen combustion; this flow is suitable for simulating the jet at the exit of a supersonic combustor (e.g. ramjet) if added with air and brought to the correct expansion conditions by means of a particular starting procedure of the facility set up in [1], see Figure 8.

Figure 8 – HVOF gun at ambient pressure (left) and in the VOF Test Chamber (right).

6P – II LVOF

As for the 6P-II gun, this device produces a subsonic, high velocity flow in which Hydrogen and Oxygen burn generating thermal energy (and a residual water vapour), which heats Air (flowing in the cooling cap) and Nitrogen (flowing in the injector); by correcting the composition with Oxygen in the right percentage, Air at high temperature and atmospheric pressure is therefore obtained which can be used as a source for a hypersonic tunnel of the blowdown-induction type (see figure 7, right side). At the time of writing this paper ignition tests with hydrogen have begun and great precaution is needed.

References

[1] A. Esposito, C. Allouis, M. Lappa "A new facility for hypersonic flow simulation driven by a high velocity oxygen fuel gun" - ICAS 2022, 33rd Congress of the International Council of the Aeronautical Sciences, Stockholm Sweden 4 -9 September 2022.