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DATA ACQUISITION SYSTEM DEVELOPMENT FOR A SUPERSONIC COMBUSTION TEST BENCH

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Abstract. *To develop aerospace vehicles, it is necessary to do several ground tests, simulating the same conditions of the real flight, to study all the phenomena involved before doing a flying test. For the first flight of the 14-X, the hypersonic vehicle that is being developed in the Institute for Advanced Studies (IEAv), the supersonic combustion inside its combustor is being analyzed using a direct-connected supersonic combustion test bench. This ground test facility consists basically of a vitiated air generator (VAG) unit and a nozzle directly coupled to the supersonic combustor to be tested. The flow at the exit of the test facility simulates the air conditions behind the oblique or conical shock waves formed ahead of vehicles flying at hypersonic speeds. These are the same conditions at a scramjet (supersonic combustion ramjet) combustor entrance and it is a high temperature supersonic flow. To simulate this flow on the test facility, oxygen enriched air is heated by combustion inside the VAG and then accelerated through the nozzle, generating the "vitiated air" containing the desired flow properties plus the heating process combustion products, while keeping the same atmospheric oxygen content. The objective of this work is to propose a practical data acquisition method using the commercial software LabVIEW (Laboratory Virtual Instrument Engineering Workbench) to measure and verify if the conditions of the flow at the nozzle exit are the ones required for the test and act on the fuel and the oxidant flow, at the entrance of the VAG, to control with this the flow test conditions.*

Keywords: *vitiated air generator, ground test facility, data acquisition system.*

1. INTRODUCTION

Before flight tests, aerospace vehicles must be tested on the ground in order to confirm the necessary parameters for its development. For the 14-X's first flight, which is being developed by IEAv, one of the most important steps is to study the supersonic combustion inside its scramjet combustor. For this, besides the Shock Tunnels, the Supersonic Combustion Test Bench is used to simulate the aerodynamics conditions of the air flow inside the combustor, where the fuel, for the supersonic combustion, is injected. The objective of this paper is to propose a data acquisition system using LabVIEW software in order to confirm if the VAG is providing the air under the project conditions and, if not, to operate the test bench input parameters so that it meets the project conditions.

1.1 The 14-X project

Nowadays rocket engines are used to place objects into orbit. Their main characteristic is that they have to store, besides the fuel, the oxidant required for operation their engines. Because of that, much of its mass of the vehicle is constituted by oxidant, limiting its payload and the design of its structure, as well as its high cost (Griffiths, 2005).

The recent intensification of international efforts to develop hypersonic propulsion with supersonic air breathing indicates that it may be an efficient way to reach space in a future not too distant. Aware of these efforts, the Defense and the Science and Technology Ministries (2003) had elected two research areas, among others, as a strategic priority for Brazil: air breathing propulsion and hyperspeed. These priorities are intended to ensure Brazil to be in technological equality with the rest of the world, allowing the country to attend as a partner in the development of advanced propulsion systems.

The IEAv, one of the Institutes of the Department of Science and Aerospace Technology (DCTA), is developing an Hypersonic Aerospace Vehicle, the 14-X, shown in Fig. 1, using waverider technology, which provides lift to the vehicle, and scramjet technology, which is an air breathing propulsion system based on supersonic combustion.

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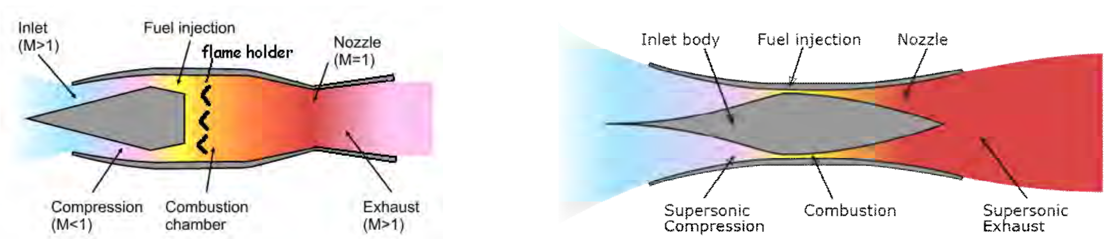
Figure 1. 14-X's artistic conception.

1.2 Scramjet motors

Scramjet is an acronym of Supersonic Combustion Ramjet, that is, a ramjet-type motor with supersonic combustion.

Ramjet and scramjet engines are air breathing propulsion systems that have no moving parts to compress the air, using the vehicle own geometry to obtain the required compression through the oblique or conic shock waves that are created in front of it when flying at hypersonic speeds, thus creating the necessary conditions (temperature and pressure) for combustion within the combustor (Leite et al, 2007; Rolim, 2009).

The main difference between ramjet and scramjet engines is the air flow speed that runs through the combustor, as shown in Fig. 2.



(a) (b)

Figure 2. Basic diagram of a ramjet engine (a) and scramjet engine (b) (Wikipedia).

Inside the combustor, the fuel (hydrogen or a hydrocarbon) is injected into the supersonic flow, where it mixes and burns after the injection nozzle, as shown in Fig. 3. The hot gases are expanded through the supersonic nozzle at speeds greater than the ones of the input, generating thrust.

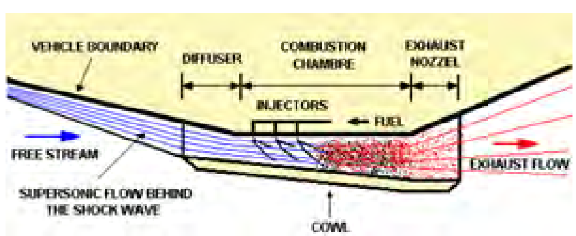


Figure 3. Schematic scramjet engine working diagram (Curran, 1996).

1.3 Vitiated Air Generators

The direct-connected supersonic combustion test bench consists basically of a Vitiated Air Generator (VAG) and a supersonic nozzle directly coupled to the combustor being tested. Thus, this device simulates the air flow conditions inside a scramjet combustor in flight, which is a supersonic high temperature flow.

According to Leite (2006), in order to simulate the high temperature airflow required for testing the 14-X's combustor, oxygen enriched air must be heated inside the VAG and then accelerated through the nozzle, generating the "vitiated air" with the desired properties of the flow plus the combustion products and the same atmosphere's oxygen level. Figure 4 shows a schematic drawing of a VAG with its supersonic nozzle.

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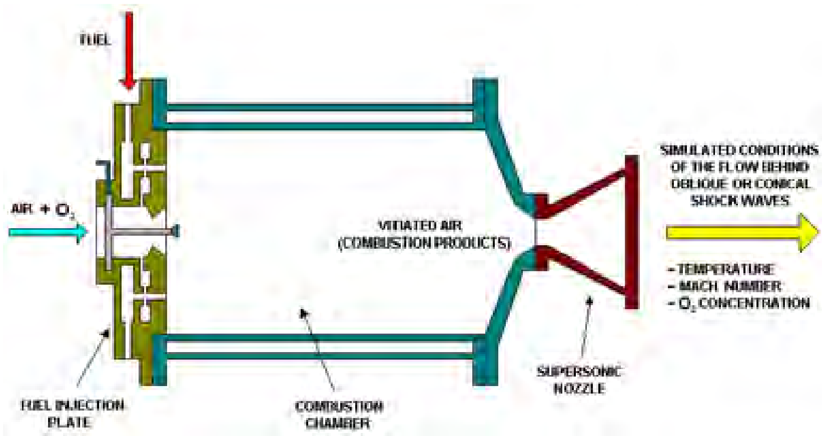


Figure 4. Schematic drawing of a Vitiated Air Generator with its supersonic nozzle (Leite *et al*, 2007).

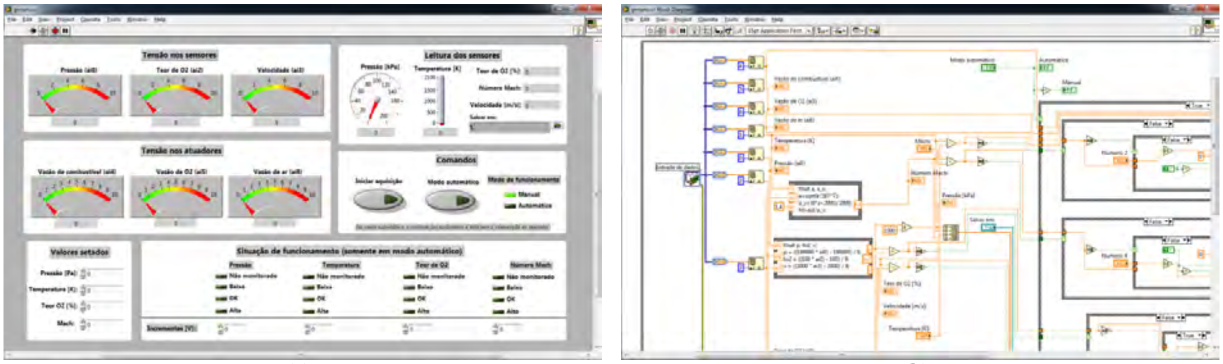
1.4 The LabVIEW software

LabVIEW (Laboratory Instrument Engineering Workbench) is a commercial graphical design software that provides users a tools required to create and deploy measurement and control systems via hardware integration using the concept of Virtual Instrument (VI).

Through a VI it is possible to use a personal computer to simulate real measuring devices, allowing users to buy only the converters and use the software to perform the measurements, instead of buying the tools and their accessories.

Furthermore, it is also possible to adjust the systems because, in addition to taking measurements (through input devices), LabVIEW allows to act on the measured signals and provide a feedback signal to control or even set the system's parameters.

Figure 5 shows the front panel and the block diagram, which are environments where measures are carried out and the code is programmed, respectively.



(a) (b)

Figure 5. Front panel (a) and block diagram (b).

2. OPERATIONAL REQUIREMENTS

Because scramjet engines make use of compressed heated air generated by shockwaves, the combustor's drawn air has some particularities, such as:

- Temperature higher than the environment: the generated shock wave is caused by air compression, which makes the air temperature to rise.
- Supersonic flow speed: the air coming into the combustor is at supersonic speeds.

To heat the air to the desired temperature, inside the VAG it should be burned methane (CH_4) with air. However, doing this, the oxygen (O_2) of the atmospheric air is consumed, so to keep the same initial air properties in which the combustor is in when flying, the air must be enriched with oxygen, in order to the resultant flow, at the nozzle exit, presents the same temperature and oxygen rate originally planned.

Additionally, after passing through the supersonic nozzle, the air is accelerated and, with that, the flow temperature decreases so it is necessary to check if there was chemical recombination of the dissociated species due to the high

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temperature in the entrance of the nozzle. Figure 6 shows the IEAv's Vitiated Air Generator, which is still being assembled.

Figure 6. Vitiated Air Generator's overview.

3. DATA ACQUISITION SYSTEM METHODOLOGY

Figure 7 shows a sketch of the combustor that will be tested at IEAv in the Supersonic Combustion Test Bench. This picture also depicts the shock wave reflections that enter the combustion chamber.

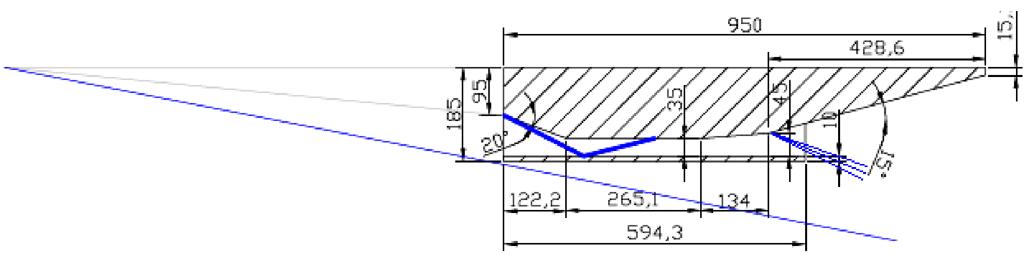
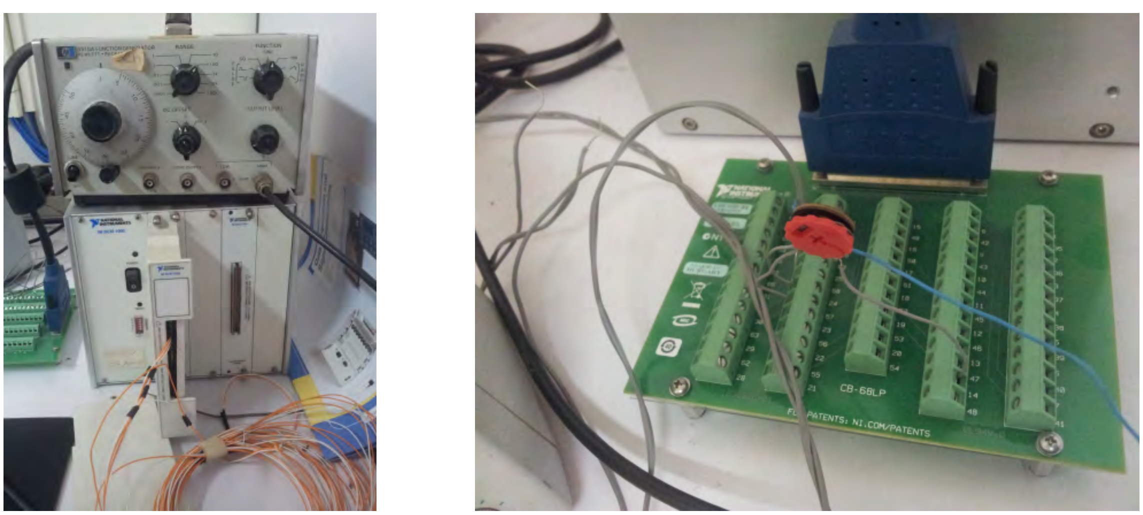


Figure 7. Sketch of the model to be tested (Moura, 2009).

The parameters being measured in the VI were simulated using signal generators and variable resistors.

The board used in this work was the NI PCI-6024E and the sensor interface was CB-68LP. Note that, as the project advances, those may be changed to ones that suits better. Equipments used are shown on Fig. 8, where it is possible to see the signal generator and the sensor interface.



(a) (b)

Figure 8. Signal generator (a) and sensor interface (b) used in data acquisition.

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Figure 9 shows the complete data acquisition system at the workbench.

Figure 9. Data acquisition system.

When programming the VI, it is necessary to set the parameters to be monitored. Also, it was expected that they may adjust the system, i.e., changing the input parameters so that the project conditions keep the same as desired, allowing corrections faster than when operated manually.

The VI measures the following parameters of the gas that enters the combustor:

- Pressure.
- Temperature.
- Oxygen rate.
- Flow speed.

These are the parameters that must be controlled because they have to be the same of the atmosphere in which the aircraft is flying.

Moreover, for the VI act to correct any deviation shown by the gas that enters in the combustor, it was also decided to monitor some parameters of the equipments responsible for the Vitiated Air Generation functioning:

- Fuel flow.
- Air flow.
- Oxygen flow.

Besides, in order to allow the effective control of the output conditions, the VI acts controlling the fuel, air and oxygen flows, so that the combustor's input parameters may be changed in a way that they keep the designed properties.

3.1 VI operation

The VI front panel shows essential information for monitoring and controlling the air flow conditions at the 14-X's combustor entrance (the exit of the supersonic combustion test bench nozzle). The screen is split in 6 parts, as follows:

- Sensors voltage: responsible for providing the operator the voltage values on pressure, oxygen content and speed sensors.
- Sensor readings: by converting the voltage measured at the sensors, the direct reading of the thermocouple and using some calculations, this subscreen shows the operator the effective air properties values entering the combustor (pressure, temperature, oxygen level, speed and Mach number). Also, these information are written to disk for registration and further analysis.

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- Actuators voltage: as well as "Sensors voltage" subscreen, this subscreen shows the voltage values that power the actuators where, via these values, it is possible to get the fuel, oxygen and air flow flowing into the VAG.
- Controls: this subscreen is responsible for starting and stopping all the measurements, as well as let the system operate in manual mode (only the parameters are monitored) or automatic mode (the VI monitors and acts in order the make the output parameters meet the values set at "Set values" subscreen).
- Set values: this subscreen is intended to be used only when the VI operates in automatic mode. This is where the operator must set the air desired properties at the entrance of the combustor being tested.
- Operation conditions: this subscreen is also intended to be used only when the VI operates in automatic mode because, with it, it is possible to get a glimpse if the air properties at the entrance of the combustor being tested are higher, lower or equal to those set at "Set values" subscreen. Section "Increments" indicates how much increment or decrement must be done if it is necessary to act to change the vitiated air properties.

When the system is in automatic mode, as well as monitoring and recording the vitiated air properties, the VI acts actively on the VAG's input parameters, allowing the operator set the air properties in the program itself, and the system makes the adjustments to achieve and maintain these values;

When the system is in manual mode, the VI only monitors and records the air properties flowing into the combustor to be tested. When it is necessary to change some property the operator must do it manually, as the system will not interfere.

3.2 Operation in automatic mode

In automatic mode, the VI continuously monitors the air properties that enter the combustor to be tested and, if any of the properties is different from the set ones, it acts in order to correct the GAV's input parameters. Figure 10 shows a simplified flowchart of the system in automatic mode.

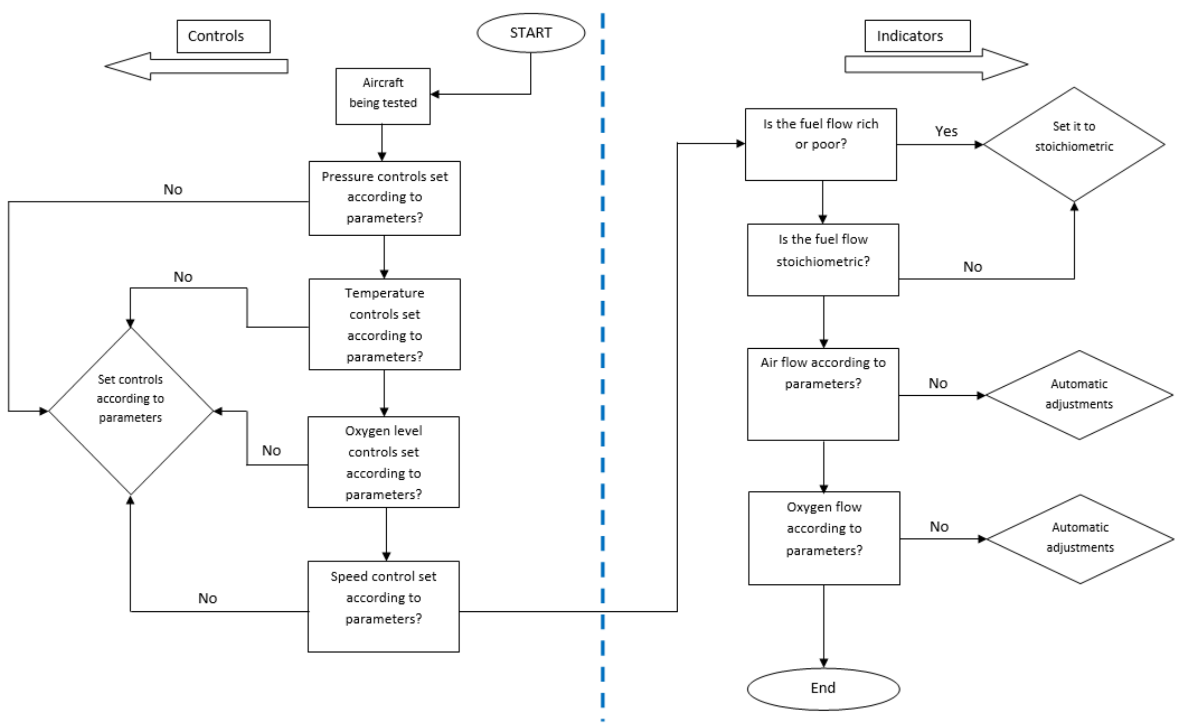

Figure 10. Simplified flowchart of the VI operation in automatic mode.

When the system detects that any parameter is different from the set one, the VI increase or decrease the voltage at the fuel, air and/or oxygen alimentation, changing its flow rate as appropriate. This increase/decrease is done in increments or decrements as set in the "Increments" section at "Operating conditions" subscreen.

Which parameter must be changed to adjust the vitiated air conditions depends on which property is different, and this do not necessarily involves changing all the VAG's alimentations voltages. This increase/decrease process continues until all properties match the set ones.

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4. CONCLUSIONS AND FUTURE WORKS

Despite being used simulated values with signal generators, it is noted that the system behaves as expected and it will be a great tool for the study of the supersonic combustion at 14-X's scramjet engine. It is good to notice that, as it is a project still in development, several sensor and component's parameters and configuration may be changed as the work progresses, however, because of LabVIEW versatility, the VI will not be affected and should only have its input and/or output components changed at Measurement & Automation program (this software comes with LabVIEW), setting them according to the new sensors and actuators.

After setting the air properties to test the combustor, it must be defined which sensor will be used and how the actuators will be controlled (fuel, oxygen and air alimentations).

With the data acquisition system developed in this work, it is possible to do a new verification and analysis of the new parameters and the equipment to be used because it is always possible to add new parameters to be monitored and refine the code presented in this work.

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6. RESPONSIBILITY NOTICE

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