

TITLE OF PAPER:

AEROTHERMAL GROUND TEST FACILITIES FOR HYPERSONIC THERMAL PROTECTION
SYSTEM CHARACTERIZATION AT HIGH TEMPERATURE

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The present paper describes the aerothermal tests ground facilities used at Ariane Group for the development and qualifications of space Thermal Protection Systems and Hypersonic vehicles. The different experimental facilities and test configurations are described as well as their potential applications to the requirements. An incremental test logic is exposed. High Temperature measurements techniques are described in order to describe the behavior of the samples during tests.

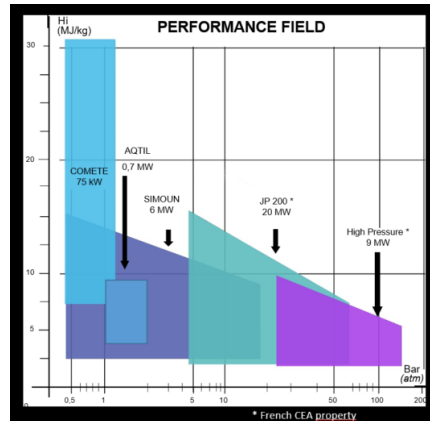
I. Introduction

Since the seventies, Ariane Group has been developing and increasing its knowledge of atmosphere re-entry simulation in order to investigate material behavior of various space vehicles thermal protection system (TPS). Several large power plasma arc heaters test facilities and ground test benches are commonly operated in the Thermal Laboratory located in the Aquitaine site, near Bordeaux, France.

The qualification and design of the TPS system requires the Heat load to be representative of the flight environment. Depending on the space vehicle and its flight conditions, the heat loads can be convective or radiative, and at different pressure conditions and shear stress level. During testing at very different aerothermal conditions, the TPS material can see a wide range of temperatures, from 300°C to 3000°C and above. Those temperatures are up to sublimation conditions of the most common materials. Spaces and hypersonic vehicles are optimized to sustain the thermal conditions and requires also to be weight efficient. Amongst many, critical parameters for this optimization are the absorbed energy and the shear stress seen by the material. Different representative facilities providing the expected flow conditions are described here and their measurement diagnostics applied to those tests cases with the goal to determine surface properties, material recession and behavior.

II. Testing logic

Several facilities are available on the Issac Ariane Group site. The technologies are developed in-house and dedicated to hypersonic vehicles or space re-entry, for civilian as well as military applications. Those differs from the other one only by generating more severe aerothermal heat load and pressures seen on the sample or by the amount of total energy the vehicle has to withstand.



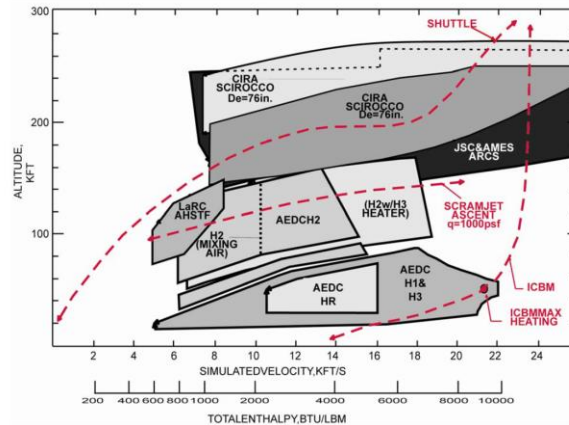
Depending on the requirements, the facility selection for a test campaign depends not only on the aerothermal capabilities. Are also included in the testing logic; the cost, the maturity level of the material to be tested and the maturity level of the program involved. As an example, a low TRL material will of course be tested in subscale screening facilities rather than in facilities dedicated to qualify the designed TPS. In that case, not all the required parameters are compliant but some of them, allowing a selection of the best candidates.

III. Requirements

As described in the following chart, the hypersonic trajectories variety is wide. As a consequence, the aerothermal loads to be reproduced are infinite so as a unique facility will not be able to provide all the characteristics. Several facilities will be of course needed, filling all together the gaps of the trajectory experimental simulation.

The facilities described in the paper aim to cover the spectrum of the material characterization. They do not overcome the aerodynamic facilities where the aerodynamic parameters such as ballistic coefficients are determined at the right Mach and Reynolds number. Most of the time, in those facilities, the testing time order of magnitude is below one second. In the case of qualifying thermal protection systems, if possible, the flight duration is required or at least the duration of the worst conditions to extract- the right erosion parameter vs the heat load.

As can be seen, the flight characteristics will require, in the case of a hypersonic space shuttle, a test bench with a low pressure atmosphere. At the contrary, due to the low pressure, the resulting aerothermal loads will be lower, and thus easier to reproduce on ground.



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IV. Facilities

Several facilities are described here with the objective of demonstrating the variety and potential of those tools to assess the hypersonic vehicle development.

A. Convective flux Plasma Facility

The plasma generator presented here is the AQ-TIL plasma torch. This generator is based on Huels technology which has been used in the thermal test laboratory since the seventies. It is almost daily used at Ariane Group in the field of materials solutions screening. Figure 1. describes the working principle of the heating plasma torch that generates the convective flow over a dedicated sample.

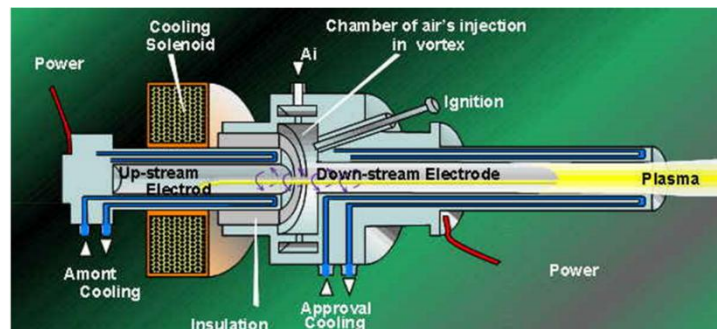


Fig 1: Huels arc heater description

A stabilized DC current is providing electrical power to establish an electrical arc between an anode and a cathode. This arc is mixed with an incoming gas flow in a mixing chamber. As a result, hot plasma expands from the torch with pressure and temperature depending on the applied current and the gas mass flow rate. A deionized water flow prevents the electrodes from melting. An external coil generates a magnetic field in order to generate an arc rotation which induces a better mixing of the plasma gas and also improves drastically the life duration of the electrodes.

The main facility key parameters are described below:

Thermal efficiency	Up to 85%
Enthalpy	5-9 MJ/Kg
Cold Wall Heat Flux	300- 7000 kW/m ²
Shear Stress	20 – 600 Pa

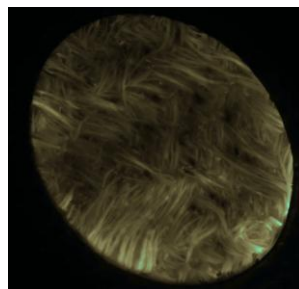
Figure 2. presents the plasma torch during its integration. The flow expanding from the torch is transonic and the cold wall heat flux allow a 50mm size sample. The generator can be used independently with different gas (air, N₂, ...). All the test cases presented were performed with Air gas simulating vehicle motion in earth atmosphere.



Fig 2: Huels arc heater Illustration

Different ways of controlling the aerothermal conditions on the sample are used. The heat load can be obtained by changing the input electrical power, by changing the mass flow rate of the air gas. Those driving parameters change the flow velocity and the flow temperature so different shear stress and surface temperature can be obtained. Those conditions are chosen in order to be representative of the real flight expected conditions. The facility is thus used as a selective screening material test bench, to select the most appropriate material prior to a qualification qualify it.

Working for different hypersonic programs, TPS such as 3D Carbon/Carbon, Carbon/phenolic and Silica/phenolic could be characterized in terms of erosion rate at temperatures over 2000°C. More than the erosion rate, the imbedded thermocouples in the test coupons provide the behavior of the thermal characteristics of the material.



As for example, this tool allow also the screening of preliminary UHTC developments as well as low density TPS material such as CORK, PICA, ZURAM, PROSIAL, ...

Additional Radiative Heat load can be superimposed to the convective one. Indeed, in this hybrid test bench, a laser beam was projected on the sample, adding a radiative heat flux that extends the sample temperature range that can be reached for the same level of shear stress. As a consequence, different material oxidation regimes can be addressed leading to a wider knowledge of the material behavior.

B. SIMOUN

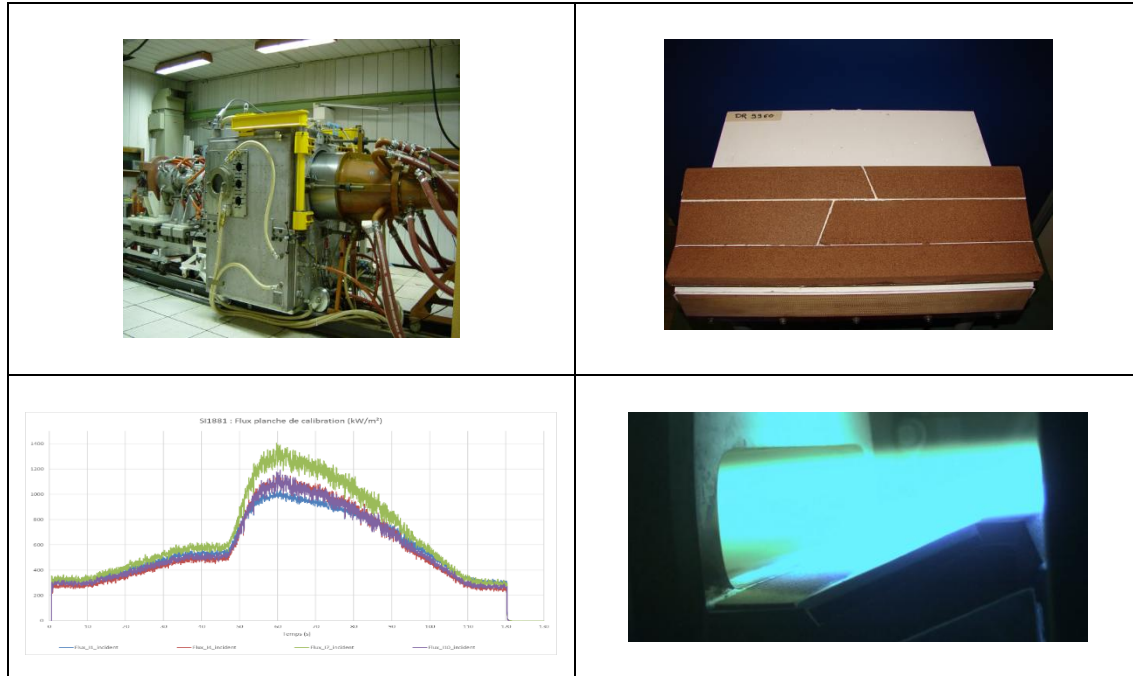
The SIMOUN facility was designed in the eighties for the former HERMES program. This arc heater facility, provide a hypersonic flow under low pressure, able to characterize thermal protections systems working at high altitude or a re-entry within the atmosphere.

The facility general parameters are the followings

Thermal efficiency	Up to 70%
Flow Enthalpy	4-11 MJ/Kg
Cold Wall Heat Flux	150- 1800 kW/m ²
Shear Stress	20 – 450 Pa
Mach	4.5
Test duration	Up to 30 min

The facility did performed about 2000 tests in about 30 years with several great hypersonic programs. The most known are EXOMARS, HUYGENS or ARD but many external customer did some development, including interceptors or classified projects.

Described here below, illustrations present the possibility of performing variable heat loads to provide flow conditions closer to the trajectory. This capability added to the size of the sample give access to qualification tests, a step forward the material characterization of the AQTIL one.



C. Infra Red Flux Facility



Fig 3: Infra-red flux facility

A pure radiative test bench was developed in order to have an academic tool for thermal studies and material behavior tests in controlled flux conditions.

The facility does emit pure radiative heat fluxes through a forty quartz 3000W lamps set up. A reflective cooled gold plated panel holds the lamps while another gold plated cooled panel holds the specimen. A controlled DC voltage can be applied on the lamps. The Heat fluxes that can be obtained from 20 to

900kW/m² thanks to optical multi reflections minimizing loss. This heat load is applied on a 200*100mm² samples for several tenths of seconds up to 300 seconds depending on the lamp voltage. The facility is currently used as a test bench for thermal protection systems materials and does participate in the qualification process of space launchers thermal parts.

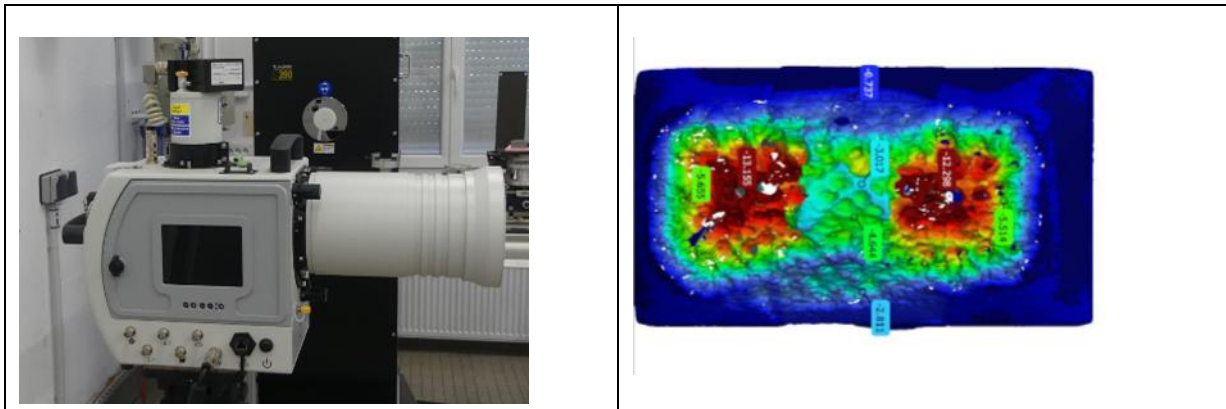
The advantage provided by the equipment is a 100% radiative load that is adapted to design office requirements for the rebuilding of some experiments. Indeed, thermal characteristics of the TPS materials are commonly obtained at low temperature but those characteristics are limited when dealing with real flight temperatures.

A mobile version of this facility give access to perform the heating of thermal protections with other types of testing. Full scale objects could by this way be tested under mechanical or vibration coupled with heating in the critical parts of the vehicle such as winglets.

V. Measurement Techniques

Some test procedures does provide the thermal heat capacity or conductivity when the insulating TPS material is heated. While heating the material within our facilities, very high temperatures are reached. To size and design properly the thermal skin of a hypersonic vehicle, the knowledge of this temperature is critical. Even more interesting, the determination of optical surface properties when the TPS is at high temperature is rare, while needed to predict a proper TPS heat balance.

The Ariane Group Test center is thus equipped with Infra-Red measurement tools. The development of optical measurement techniques to measure, temperature, emissivity or erosion during the tests gives additional value to the data. The laboratory is equipped with infra-red calibration black bodies for temperatures from 50 to 3000°C.



densities silica based materials are generally better thermal insulator but with weaker mechanical strength in front of high pressure flows.

Different aspects of hypersonic vehicles can be addressed through Aerothermal facilities. Of course the TPS is immediately concerned, but antenna behaviors, winglets assessment as well as design architecture and trade off are also of interest.