70 MW PLASMA WIND TUNNEL UP-GRADES FOR ESA AURORA TPS TESTING

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ABSTRACT

The SCIROCCO facility is a high enthalpy hypersonic Plasma Wind Tunnel developed by CIRA in collaboration with ESA. With an electrical power available at the arc heater of 70 MW, SCIROCCO is the World's most powerful ground test facility, able to simulate hypersonic air flows encountered during re-entry into Earth atmosphere and to test innovative large scale TPS (Thermal Protection System) for spacecrafts. In the frame of ESA Aurora Exploration Programme, Mars and Earth atmospheric re-entries represent critical issues. Ground tests simulating the reentry conditions encountered by space vehicles are required to validate TPS concepts and to ensure the feasibility of interplanetary missions.

The objective of this work is to identify the necessary upgrades to the SCIROCCO facility to make it able to reproduce hypersonic flows representative of Mars and Earth super-orbital atmospheric re-entries. For the Earth super-orbital re-entry, the work consists in properly changing the configuration of the facility to extend its experimental envelope towards higher stagnation heat flux and pressure values. To reproduce Mars atmospheric entry conditions, the facility must be able to provide a high enthalpy hypersonic flow of a gas mixture representative of the red planet atmosphere; As a consequence, a number of difficulties arise that have been addressed and investigated.

1. INTRODUCTION

This paper summarizes the activities performed in the framework of the ESA AURORA exploration program to extend the SCIROCCO Plasma Wind Tunnel capabilities to deal with Mars atmospheric entry and Earth super-orbital re-entry.

The hypersonic Plasma Wind Tunnel SCIROCCO is a 70 MW arc-heated facility developed to test Thermal Protection Systems of vehicles re-entering the Earth atmosphere. With this facility it is possible to reproduce hypersonic flows on 1:1 scale models with total enthalpies up to 45 MJ/kg and total pressures up to 17 bar.

Figure 1 shows a simplified scheme of the present facility configuration, with the main components.

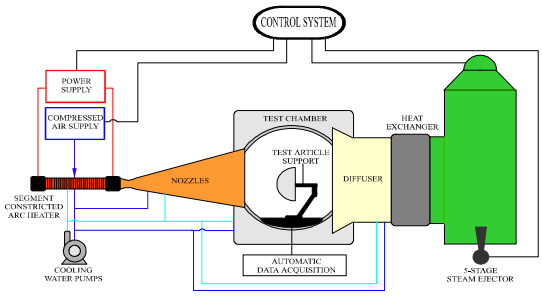

Fig. 1. The SCIROCCO schematic diagram

A number of modification are necessary to upgrade the facility for TPS tests of interest in the framework of the exploration programme.

For an interplanetary mission, the spacecraft that approaches the re-entry has a velocity quite higher than for a "Return From Orbit" one (11-12 km/s instead of 7 km/s). This implies that during the re-entry phase the aero-thermo-dynamic conditions will be more critical due to the higher specific total enthalpy. Moreover, to reproduce the conditions encountered on space vehicles during entry in the atmosphere of the Mars planet, a number of

modifications are necessary to simulate an atmosphere essentially composed by CO_2 (95%).
In this paper we analyze the main results of this feasibility study. Section 2 deals with the requirements and the technical solutions found to simulate superorbital reentry in the Earth atmosphere. Section 3 is dedicated to the feasibility study of the SCIROCCO upgrade with the objective to simulate the aerothermodynamic environment during hypersonic entry in the Mars atmosphere. The conclusions are presented in Section 4.

2. SUPER-ORBITAL EARTH RE-ENTRY

A feasibility study has been carried out to upgrade SCIROCCO in order to reproduce aerothermal conditions of interest for interplanetary return to earth. The facility requirements, the necessary modifications, the new facility performances, the time scheduling are briefly reported in the following paragraphs.

2.1 Requirements

The main requirement for the proposed upgrade is the possibility to reproduce the aero-thermal loads on the TPS materials of the *Earth re-entry Vehicle Demonstrator* during its Earth re-entry phase.
Table 1 summarizes the specific ESA requirements.

Table 1

Test 1			
Stagnation Heat Flux	Stagnation pressure	Test time	Test sample size
18800 [kW/m^2]	130000 Pa	About 6 s	25 mm

Test 2			
Stagnation Heat Flux	Stagnation pressure	Test time	Test sample size
21000 [kW/m^2]	150000 Pa	About 20 s	25 mm

Test 3			
Stagnation Heat Flux	Stagnation pressure	Test time	Test sample size
13900 [kW/m^2]	80000 Pa	About 20 s	50 mm

Test 4			
Stagnation Heat Flux	Stagnation pressure	Test time	Test sample size
8900 [kW/m^2]	42000 Pa	About 20 s	100 mm

All the conditions represented in Table 1 require an extreme design configuration of the facility. In fact, the stagnation point heat fluxes (in the order of 10-20 MW/m2) can be obtained on large models only if the throat section of the facility is directly connected to the Test Chamber. This introduces a number of problems, that will be analyzed in the following paragraphs.

2.2 Facility performances

As discussed in the introduction, the typical velocity of a spacecraft at the atmospheric entry interface, when the vehicle re-enters from LEO is about 8 [Km/s]. For the hyperbolic trajectory described by the spacecraft in the case of direct reentry from an interplanetary mission, this velocity is about 11-12 [Km/s]. Since the stagnation point pressure and heat flux are roughly proportional to the square and to the cube of the velocity, they dramatically increase.
In the present configuration SCIROCCO can be used with different nozzles; indeed the conical nozzle is divided in several parts that, assembled in the correct way, provide different configurations. Figures 1(a,b,c,d) show how the facility is assembled when it is used with the nozzles C, D, E and F respectively.

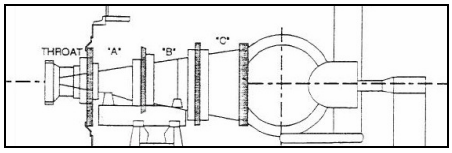

Fig. 1a. Nozzle C

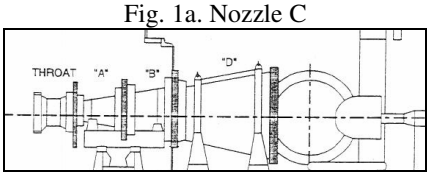

Fig. 1b. Nozzle D

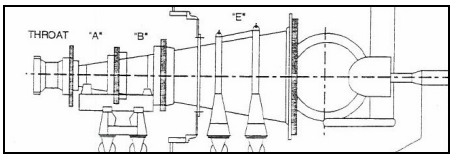

Fig. 1c. Nozzle E

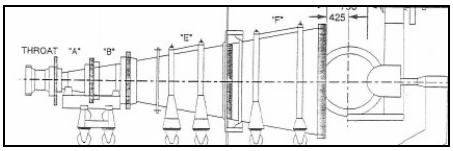

Fig. 1d. Nozzle F

Figures 1 show that it is possible to change the conical nozzle exit area by changing the configuration. Four configurations (C, D, E, F) are now available; however, also other configurations (e.g. throat 0, A, B) have been investigated.

Table 1 shows the diameters of the different exit sections, in mm, and the correspondent geometrical (nominal) *Exit Section-Throat Section* area ratio. The throat section diameter is the same in any case (75 mm).

Table 1

Conf.	**0**	**A**	**B**	**C**	**D**	**E**	**F**
Diam.	187	430	670	900	1150	1350	1950
A/A*	6.2	32.8	79.8	144	235	324	676

For each configuration, the conditions at the nozzle exit section have been computed using one-dimensional theory, according to the equation:

$$\left(\frac{A}{A^*}\right)^2 = \frac{1}{M^2}\left[\frac{2}{\gamma+1}\left(1+\frac{\gamma-1}{2}M^2\right)\right]^{\frac{\gamma+1}{\gamma-1}} \quad (1)$$

Where A is the area of the cross section, A* is the throat area and γ is the specific heats ratio. Experimental data fitting formulas and CFD computations fitting formulas have been utilized to evaluate the stagnation point heat fluxes and pressures on the available hemispherical probe (with radius R=5 cm). This probe is water-cooled and made by copper, so that it is assumed to have a fully catalytic behaviour.
The performances in terms of stagnation pressure and stagnation heat flux are summarized in Figure 2. It is evident that it is possible to meet the requirements of Table 1 only using the configuration "throat 0".

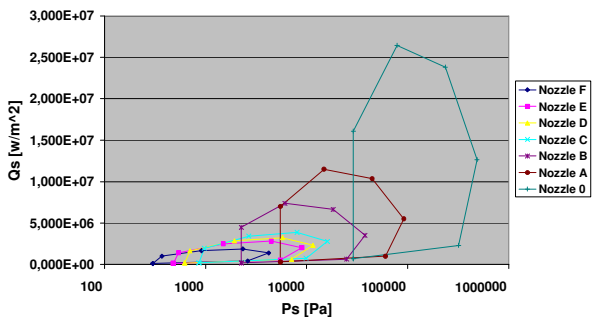

Fig. 2 Facility performances in terms of stagnation point heat flux and pressure

2.3 Description of the modifications

The modifications to make SCIROCCO able to simulate these more critical conditions include modifications to the nozzle (that, as seen before, must be shorter than in the present available configurations), to the test-chamber interface and to the model support system. Indeed, because of the higher stagnation heat fluxes the available calibration probe cannot be used. Moreover, it is not possible to utilize the available model support system, for the reasons explained below.

Test Chamber interface walls

As discussed in paragraph 2.2, the requirements reported in Table 1 can be satisfied only with the shortest configuration of the nozzle (throat 0). In order to use this configuration, a new model support system is necessary to keep the model near enough to the nozzle exit section. In addition, a technical solution is required to connect the throat section to the test chamber. Let us consider Figure 3, where a zoom of the configuration C of Fig. 1a is shown in the region of the Test Chamber interface wall.

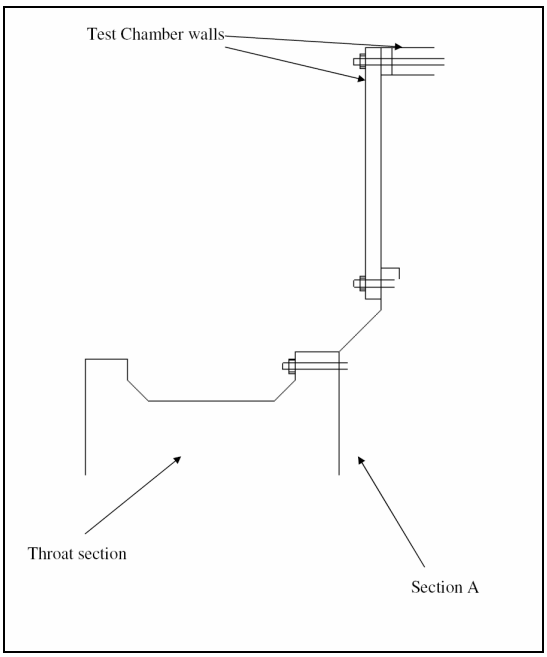

Fig. 3. Present configuration

It is possible to notice how in the present design the section "A" is joined to the test chamber. To directly connect the throat section to the test chamber a new component will be mounted between the test chamber and the throat section, as shown in Figure 4.

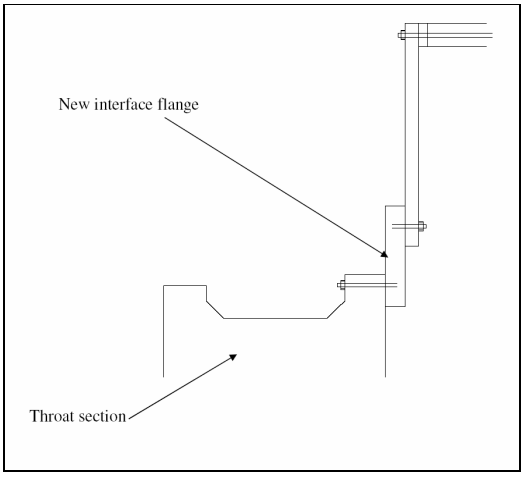

Fig. 4. Future configuration

Model Support System

Figures 1(a-d) show the position of the model in the test chamber in the present configurations. The minimum distance from the throat section is about 2.4 m, for the configuration C (Fig 1a). If the throat section is directly connected to the test chamber, a new model support system is necessary to place the model in the correct position.
Under the assumption of correct flow expansion in the nozzle, so that the velocity downstream the exit section is parallel to the nozzle contour (see Figure 5) the flow properties and the corresponding values of the stagnation point heat flux and pressure on the probe, at different distances from the exit section, have been computed using equation (1). The results pointed out that, in order to satisfy the ESA requirements, the distance from the exit section cannot exceed 3 cm.

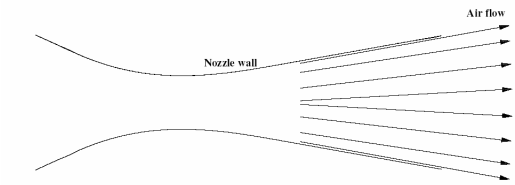

Fig. 4.

Under this assumption the Mach number on the axis, in a generic point not too far from the nozzle exit, can be evaluated through a numerical solution of the equation (1).
Moreover, in order to introduce both the probe and the model during a specific test, the new model support system will be able to sustain simultaneously two different holders that will be translated (along two orthogonal axes) as illustrated in Figure 5.

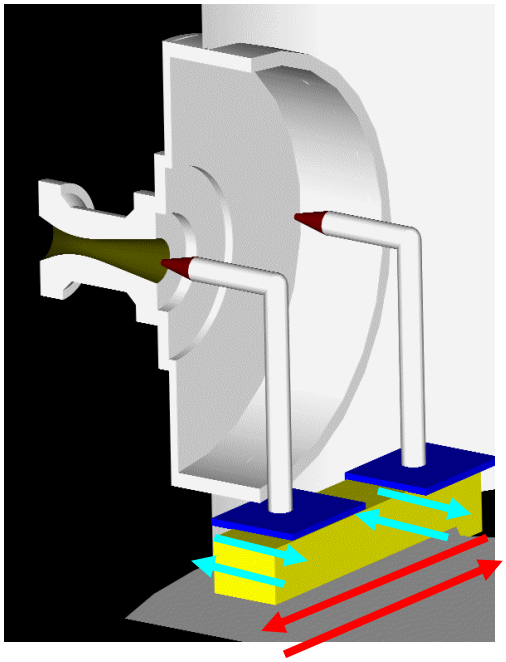

Fig. 5. The new Model Support System

2.4 Instrumentation

The required new instrumentation is related to the higher values of the stagnation pressure, to the higher stagnation point heat fluxes and to the different location of the model. In its present configuration, the facility operates with stagnation point pressures of the order of magnitude of 10^3 (maximum 10^4) Pa, and maximum stagnation point heat fluxes of 3 MW/m^2 on the previously described copper probe. The Gardon Gage cooled sensor is able to make accurate measurements of heat fluxes not exceeding 3 MW/m^2
In the modified configuration of the facility, for the simulation of super-orbital Earth re-entry, the stagnation point pressure will rise to values of the order of 10^5 Pa and heat fluxes will be larger than 10 MW/m^2. For this reason, a new probe will be developed to fulfil the new requirements. The estimated time for design, procurement, manufacturing and verification is 6-9 months.
Moreover, the locations of all the optical diagnostic instruments (thermography, spectroscopy, pirometry) as well as the cameras used for videorecording of the tests are optimized for a field of view centered in the actual Scirocco test chamber. In particular, in the present configuration, a side view of the test model is possible but it is not possible to look at the region very close to the model stagnation point. A number of optical components can be utilized including mirrors optimized for dedicated techniques, i.e. in the visible, in the infrared for pirometry or for thermography, in the UV for spectroscopy. In this

case, a careful analysis for the evaluation of the dependence of the mirror reflectance with temperature is necessary due to the relatively high temperature caused by hot air recirculation and/or radiation from hot model surfaces under test.
Finally, a more precise air mass flow meter will be considered for its importance in the measurement of the specific total enthalpy.

3. MARS ENTRY FEASIBILITY STUDY

In this section, all the modifications needed to extend and/or improve the SCIROCCO capabilities to deal with Mars atmosphere entry are described. The expected facility performances are evaluated and compared to the ESA requirements.

3.1 Facility requirements for Mars atmosphere entry

The upgraded facility should be able to simulate the conditions of the ExoMars mission. The ExoMars capsule is shown in Figure 6 [1]. The stagnation point heat flux and pressure values corresponding to relevant conditions pertaining to two ExoMars trajectories [2], denoted as M1 and M2, are reported in Table 3.

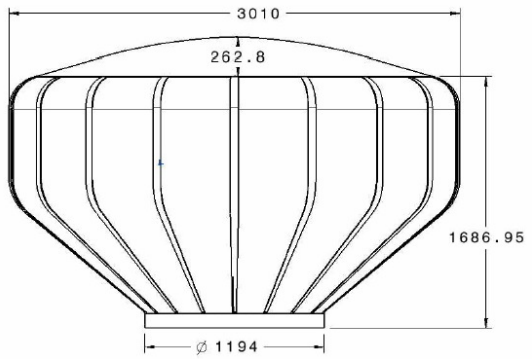

Fig. 6. The Exomars Descent Module

Table 3

Test	Heat Flux [MW/m^2]	Stagnation Pressure [Pa]	Time [s]
M1	2.09	8014	46
M2	1.3	6415	48

The Martian atmosphere mass composition is [2]:

CO_2 = 96.8%; N_2 = 1.7%; Ar = 1.5%

Additional ESA requirements deal with the mass flow rate, the duration of the tests, the refill time and the pressure (Table 4). Assuming that the maximum mass flow rate for the mixture is 2.066 Ks/s, including 2 kg/s of CO_2, 0.035 kg/s N_2 and 0.031 kg/s Ar, the required mass and volume have been estimated.

Table 4

	Species	Mass flow rate [kg/s]	Mass cons. [kg]	Volume cons. [Nm^3]
CO_2	**98.30%**	**2.000**	**1800**	**911**
N_2	**1.70%**	**0.035**	**31.5**	**27**
CO_2 + N_2		**2.035**		
Test duration	**15 minutes = 900 seconds**			
Refill time	**24 hours**			
Pressure	**87 bar**			

3.2 Description of the facility modifications

Based on these system requirements, a number of modifications and changes have been identified that can be summarized as follows:

- Realization and installation of a CO_2 – N_2 gas management system and of an interface to the facility
- Electrical heat tracing of the compressed air system piping
- Reduction of hoses to the arc heater
- By-pass of the DeNOx system
- Realization and installation of a CO combustion system
- Appropriate modification of the control system
- Acquisition of instruments and procedures for people safety

These specific aspects are analyzed below.

CO_2 – N_2 Gas Management System

A feasibility study has been carried out in order to identify a technical solution for the gas management system for the CO_2 - N_2 mixture, since an Argon system is already available at the facility SCIROCCO.
To satisfy the requirements reported in Table 2, two different technical solutions have been investigated:

Technical Solution #1

- 5 m^3 cryogenic tank of liquid CO_2 at 17 bar_g and -25°C
- CO_2 vaporizer
- 160 Nm^3 cylinder pack of gaseous N_2 at 200 bar_g
- N_2 pressure reducer
- CO_2-N_2 mixer at 8 bar_g
- 200 bar_g compressor for 50 Nm^3/h of CO_2-N_2 mixture
- 10 m^3 total capacity tanks of gaseous CO_2-N_2 mixture at 200 bar_g and controlled temperature
- pressure controller

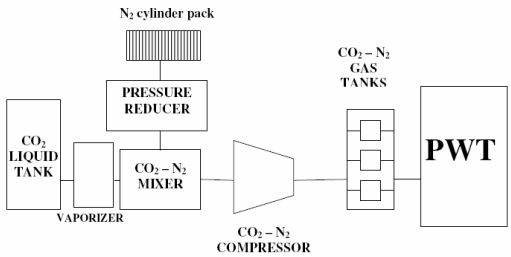

Fig. 7 Technical solution 1

Technical Solution #2

- 10 m^3 cryogenic tank for the storage of liquid CO_2 at 17 bar_g and -25°C
- cryogenic pumping system, designed for mass flow rate of 7200 kg/h CO_2
- CO_2 vaporizer, fed by 1.4 t/h of super heated water steam at 250°C and 28.5 bar_g
- gas delivery pressure (87÷100 bar_g) and temperature (75÷100°C) control system
- 160 Nm^3 cylinder pack of gaseous N_2 at 250 bar_g
- N_2 pressure reducer
- N_2 mass flow controller

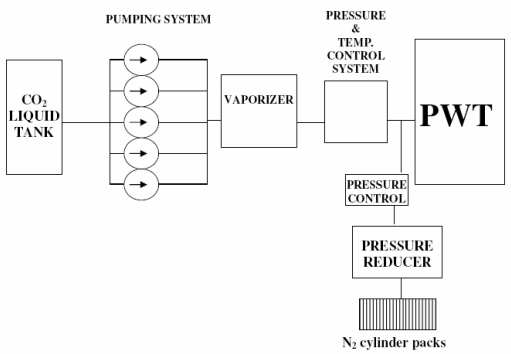

Fig. 8 Technical solution 2

Compressed Air Supply System

The function of the Compressed Air System is to distribute the air to the arc heater. Even if this subsystem is quite complex, it can be simply described with the scheme of Figure9, where we can notice that there are two main valves (PCV-033A and PCV-033B) and downstream three distribution lines, each provided with a distribution valve, up to the column of the arc heater.

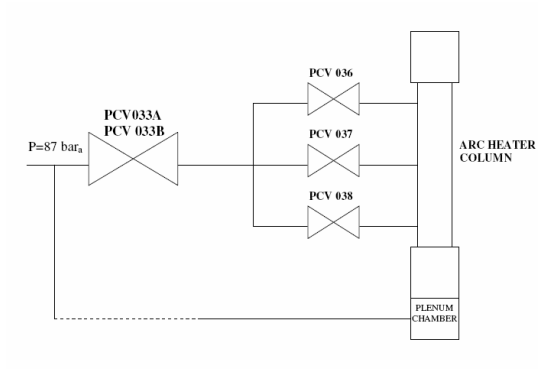

Fig. 9. Compressed air system

Downstream the three distribution valves, and upstream the arc heater, the pressure is high enough to have a choked flow upstream the column, and small pressure drops occur along the three lines. A pressure drop of about 8-10 bar occurs in the three valves PCV 036, PCV 037, PCV 038, and another great pressure drop takes place in the main valves PCV 033A and PCV 033B. Upstream the compressed air supply system a pressure of 87 bar_a is required. The design temperature of the compressed air system is 50 °C; therefore, in order to avoid the CO_2 condensation during its expansion, all the piping must be electrically heat traced, carrying the temperature of the system around a value of 50°C.

Pressure drops in the valves and in the lines, when using CO_2, have been computed and they are of the same order of magnitude compared to the air case. However, when using CO_2, a lower number of gas distribution hoses should be utilized.

The software of the control system should be properly regulated to be used with CO_2 – N_2 mixtures. Moreover, the facility should be able to operate at relatively low specific total enthalpies, because there is the possibility to inject CO_2 – N_2 into the plenum chamber through a line that is positioned upstream the two main valves but downstream arc heater column (see Figure 9). In fact the gas, after its passage into the arc heater, reaches relatively high specific total enthalpy (at least 10 MJ/kg). In order to reduce its specific

energy content cold gas can be injected downstream.

Vacuum System

The vacuum system should be able to properly operate using a gas mixture with the same composition of the Mars atmosphere.
No chemical problems (such as corrosion) are foreseen. The effects of CO_2/CO on the metallic parts of the vacuum system should be negligible. The carbonic acid formed due to the presence of water at the vacuum condenser is in fact less aggressive than the nitric acid formed during usual operations with air.
On the other hand, there are some consequences on the system performances, represented by the "vacuum level" the vacuum system is able to reach, i.e. by the pressure that it is possible to provide. Of course, lower is this pressure, better is the performance. The performances of this system working with air are available, and a preliminary analysis has been carried out for the mixture with the Mars composition, simply scaling the performances with air with the CO_2/air density ratio. The results are shown in Figure 6, where the pressure provided by the vacuum system is reported versus the mass flow rate. The pressure is always higher when using Mars atmosphere in comparison to Air.
Figure 10 includes two curves (red lines) representing the maximum allowed pressures. It is possible to notice that the facility is able to satisfy the requirements.

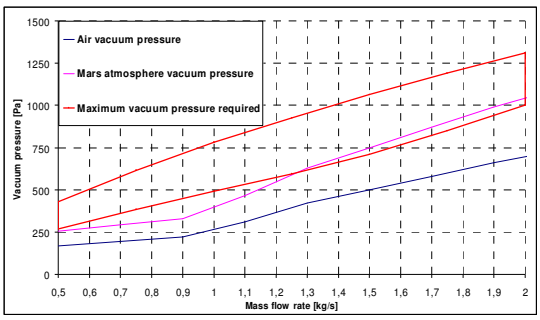

Fig. 10 Vacuum system performances

Carbon Monoxide Combustion System

It is well known that at the very large specific total enthalpy established in the arc heater column, the CO_2 is almost completely dissociated, according to the reaction:

$$CO_2 \rightarrow CO + \frac{1}{2} O_2$$

Other chemical reactions occur between the different chemical components but a large amount of Carbon Monoxide is generally present. The chemical compositions of the different species remain typically frozen in the diverging part of the nozzle, so that they are still present in the diffuser downstream the test chamber, where the flow field slows down from hypersonic to subsonic.
A study developed in [3] has shown, for instance, that in the worst case at the total pressures of 0.001, 1 and 10 atm, at the temperatures of 4000, 5000 and 7000 K, respectively, the equilibrium CO molar fraction is 0.5 and thus its mass fraction is about 0.64. This means 1.3 kg/s of CO emission at the maximum CO_2 mass flow rate of 2 kg/s.
For safety reasons, CO leakages must be prevented in all components of the facility, and a number of CO and CO_2 detectors should be placed in different points of the facility.
In addition, safety procedures and systems will have to be considered and used by people working at the facility.
In order to reduce the CO concentration at the values allowed by the Italian law (10^{-4} kg/ m^3), a combustion system must be installed downstream the vacuum system by-passing the $DeNO_x$ (see Figure 11). The DeNOx system has the function to reduce the NO_x concentration in the gas flow during air operations.

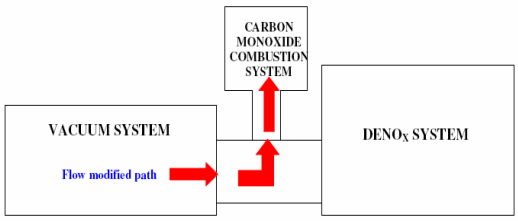

Fig. 11. Carbon monoxide combustion system

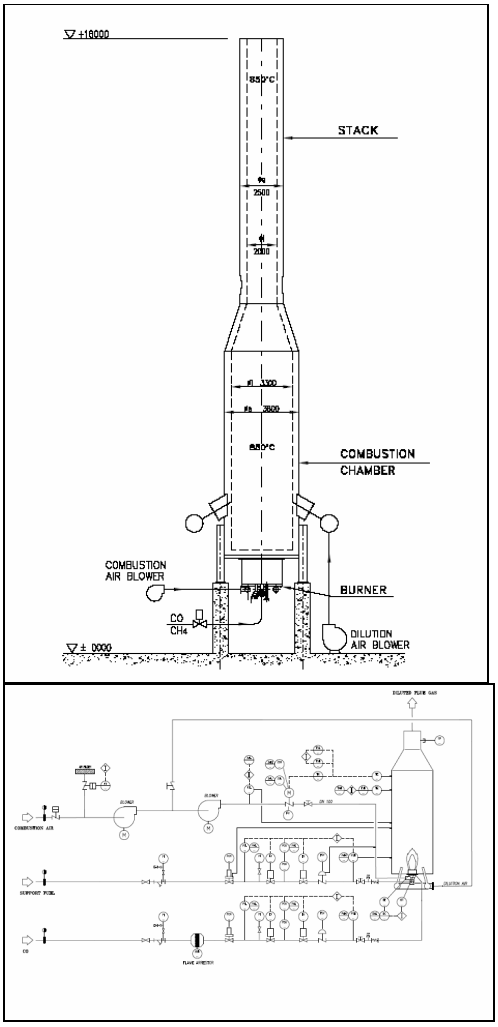

Fig. 12, CO combustion system

When using the facility SCIROCCO with Mars atmosphere, the amount of N_2 in the gas (less than 0.035 kg/s) is negligible if compared with normal operations of the facility with air (up to 3.5 kg/s composed by 77% of N_2); for this reason one can assume that during SCIROCCO operations with Mars atmosphere the concentration of NO_x in the gas flow will be negligible and the DeNOx system will be not necessary.

If we consider the facility working with air, we have, a gas saturated with water steam at a pressure of about 1.06 bar_a and 65 °C. Assuming at the exit of the last condenser of the vacuum system a pressure of 1.06 bar_a, a temperature of 65 °C (typical values for operation with air) a CO concentration of 1 kg/m^3 of discharged gas can be evaluated. Therefore, it is necessary to reduce the carbon monoxide emissions of about four orders of magnitude. A technical solution for this purpose is provided by a dual fuel burner (Figures 12a,b) characterized by a 13.2 MWt carbon monoxide nominal power plus 1 MWt of support methane; to guarantee the required CO reduction it needs a residence time of 2 seconds at a temperature of 850°C; thus the system results to be a 18 m tower made by a 3.8 m diameter combustion chamber followed by a 2.5 m diameter stack. The combustion reaction is sustained by a 3.61 kg/s combustion air fan (30 kWe) and by a 10.55 kg/s dilution air fan (22 kWe).

3.3 Instrumentation

Non intrusive optical diagnostic methods analyzing and describing the chemical-physical properties of the plasma gas are of particular interest in arc-heated wind tunnels, due to the non equilibrium aspects. For this reason the Diode Laser Absorption Spectroscopy (DLAS) is going to be developed in the SCIROCCO Plasma Wind Tunnel. Since its introduction in the mid 90's, the DLAS has been used in hypersonic facilities like ONERA-F4 hot shot facility, DLR-HEG shock tube and ONERA-S4 wind tunnel. This technique is based on measuring the absorption intensity of a fast wavelength tunable laser beam passing through the free-stream (Fig. 13). Velocity, translational temperature and species concentration measurements can be retrieved from the recorded spectral profiles.

The measurements are made at repetition rates up to 10 kHz. Conventional diode lasers in the infrared domain (5 µm) are used to acquire the fundamental and therefore the most intense absorption lines of heteronuclear species such as NO, CO, CO_2 and H_2O. The main advantages of this technique in the context of the Scirocco Arc-Heater Plasma Facility include: a)characterization of the composition of the plasma flow (free stream and shock layer in front the test article); b) cross check with CFD results and possibility to validate and/or to improve the models and capabilities of the CFD analyses; c) optimization of the diagnostic technique, due to the experimentation operation time of Scirocco wind tunnel.

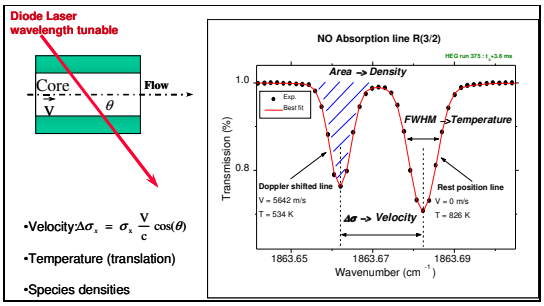

Fig. 13.

The system to be implemented in the SCIROCCO facility is initially optimized to operate with NO. The instrumentation setup can be upgraded in order to make it able to work with CO and CO2 using a dedicated laser source and some properly designed optical accessories such as prisms, mirrors and power meters.
The modification/upgrading of the DLAS technique will require a preliminary design (about 2-3 months), then the procurements of the components (3-5 months) and, finally, the configuration set-up and the modifications to the software (about 5 months)to take into account the new components and the properties of the species under investigation (CO and CO_2).
As discussed at the end of Section 2, an additional, more precise gas mass flow meter will be considered for its importance in the evaluation of the specific total enthalpy. In the present configuration of the facility, this important parameter is measured with a system developed and calibrated only for use with dry air.
As discussed before, in the Aurora projects, different gas mixtures are expected to be used as Co and CO_2. For this purpose a new system will be specifically calibrated for use not only restricted to air but also extended to the additional gas components. This can be realized with a variety of off-the-shelf components now available on the market and specific calibration can be required during the procurement phase.

3.4 Numerical simulation of the SCIROCCO performances with CO_2 flows

Numerical simulations of the aero-thermo-chemical flowfield in the SCIROCCO facility, considering CO_2-based mixtures in thermochemical non-equilibrium, have been carried out. A number of test conditions has been considered to study the flowfield in the SCIROCCO nozzle type "F", and around the hemispherical probe in the test chamber. As discussed before the probe radius is R=5 cm and a fully catalytic material is considered.
Examination of data from literature shows that Air and CO_2-N_2 mixture transport properties (viscosity, equilibrium thermal conductivity, equilibrium specific heats and electrical conductivity, radiation absorption coefficients) are similar at different temperatures and pressures. This suggests that the arc performances should be similar for Air and Carbon Dioxide mixtures, and therefore, in order to evaluate the SCIROCCO performances with CO_2-based mixtures, the same specific total enthalpies and total pressures as in Air (at the same arc electric power and mass flow rate) have been assumed at the SCIROCCO nozzle inlet.
A number of conditions, almost uniformly distributed in the SCIROCCO operating envelope, have been selected (Fig. 14).

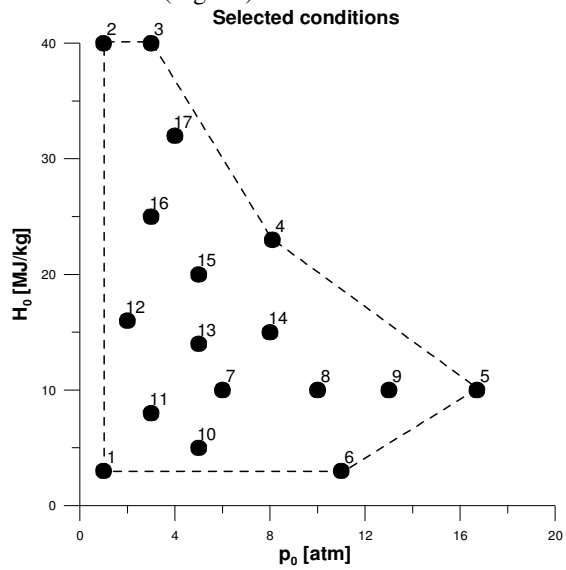

Fig. 14 – Selected conditions in SCIROCCO operating envelope

Thermochemical computations of the equilibrium composition of CO_2-N_2-Ar mixtures have been performed using the validated NASA software CEA2 [4], and, accordingly, only the nine-species with non negligible compositions (Ar, CO_2, CO, C, O, O_2, O, NO , N , N_2) have been taken into account. Each species of the mixture is assumed to behave as a thermally perfect gas where translational-rotational and vibrational-electronic degress of freedom are characterized by different temperatures. Vibrational-translational energy exchanges have been modeled according to the Landau-Teller model and the vibrational relaxation time is derived from the Millikan-White formula, with Park [5] correction for high temperatures. Chemical kinetic model is taken from Park [6-8]. Only the most relevant reactions are taken into account. The fluid-dynamics equations have been numerically solved in the computational domain (nozzle + test chamber). Convective fluxes are computed according to Roe's Flux Difference Splitting scheme. Integration of the equations is performed implicit in time, until steady state is achieved, solving the linearized system of equation by the multigrid technique. The solver has been used in this work in combination with a number of "ad hoc" developed user defined functions to model hypersonic flows in chemical and vibrational nonequilibrium.

The flowfield inside the nozzle type “F” and test chamber and around the hemispherical test model has been computed for all the selected SCIROCCO conditions (see for instance Figures 15 and 16 referring to the condition n. 5 in Figure 14).

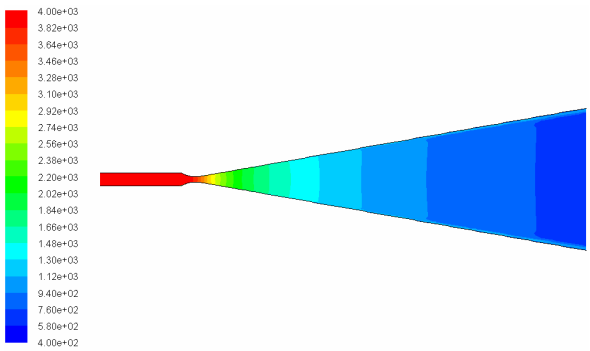

Fig. 15 – Translational temperature distribution in the nozzle (P_0=16.7 bar, H_0=10 MJ/kg)

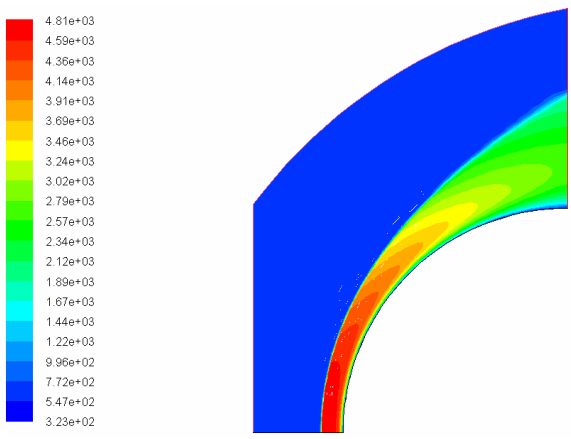

Fig. 16 – Temperature distribution around the spherical model (P_0=16.7 bar, H_0=10 MJ/kg)

The stagnation point pressures and heat fluxes on a fully catalytic test model have been evaluated for each simulation. The numerical results show that including Argon in the mixture does not change the flowfield distribution in an appreciable way. Furthermore, including thermodynamic nonequilibrium effects does not affect the computed surface heat flux distribution on the test model, unless the model wall is assumed to be adiabatic with respect to vibrational energy (Fig.17). In that case, since not all the fluid energy is released to the wall, heat flux can be up to 15% lower.

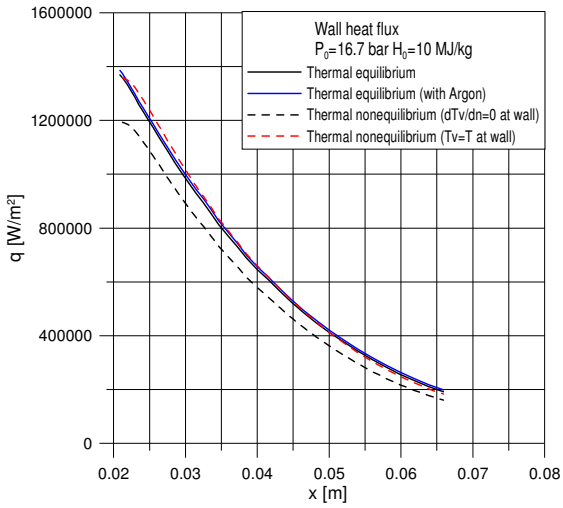

Fig. 17 – Surface heat flux (P_0=16.7 bar, H_0=10 MJ/kg)

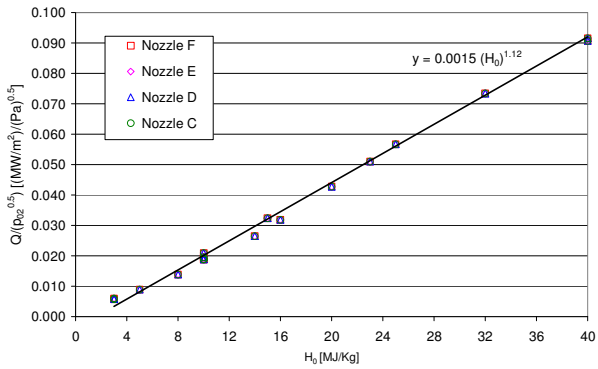

Fig.18 – $Q/p_{02}^{0.5}$ vs H_0 at the exit section of the nozzle F for any selected condition

Suitable correlation formulas have been found for both the stagnation point heat flux as function of the total enthalpy, and for the stagnation point pressure as function of the total pressure, that could be used in future analyses (Figures 18 and 19).
The results have also been extended to the other SCIROCCO nozzles (types “C”, “D”, “E”) by scaling laws.

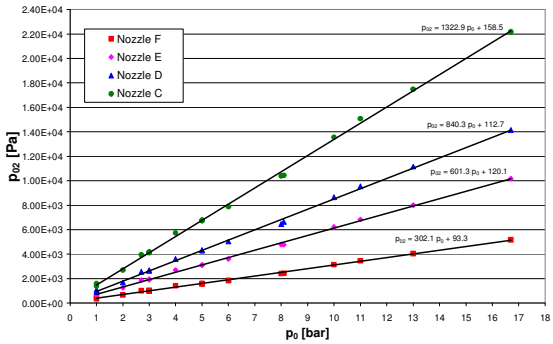

Fig. 19 – p_{02} vs p_0 at the exit sections of the different nozzles for any selected condition

4. CONCLUSIONS

In the present paper, the facility modifications requested in order to have Scirocco Plasma Wind Tunnel ready to be the main on-ground test facility for Aurora ESA Program are presented and discussed. Both goals, i.e. to have a big facility simulating the Mars entry conditions and the Earth super-orbital re-entry conditions, are achievable through a set of engineering modifications and solutions of which the impacts and the costs and the time schedule have been identified.

Actually the ESA Agency is evaluating the feasibility study and results, the relative costs and the schedule. A decision for the following operative phase resulting in the realization of the modification judged necessary and mandatory will be taken within short time.

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