Commissioning of Aerospazio Test Facilities for PPS®5000 Qualification Programme

IEPC-2017-477

Presented at the 35th International Electric Propulsion Conference
Georgia Institute of Technology • Atlanta, Georgia • USA
October 8 – 12, 2017

Damiano Pagano[1], Leonardo Sestini[2], Elisa Bonelli[3], Simone Scaranzin[4], Gianfranco Meniconi[5] and Fabrizio Scortecci[6]
Aerospazio Tecnologie srl, Rapolano Terme (SI) ,Italy

and

Giovanni Coduti[7], Vanessa Vial [8] and Olivier Duchemin[9]
Safran Aircraft Engines, Vernon, France

Abstract: The aim of the commissioning tests carried out on Aerospazio facilities in the framework of the collaboration with Safran Aircraft Engines was to demonstrate and validate the fulfillment of the test requirements in terms of general facilities capabilities (static and dynamic vacuum, safety systems, etc.) and test specific capabilities (thrust balance measurement range and accuracy, plasma diagnostics, thermal set-up performances to condition the thruster and the XFC in the required temperature ranges). In particular, the commissioning activities carried out on the vacuum facility and test set-up to be used for the PPS®5000 acceptance campaign, for the PPS®5000 Cathode lifetime campaign and for the PPS®1350E qualification test are summarized.

Nomenclature

EM	=	Engineering Model
FM	=	Flight Model
LVTF2	=	Large Vacuum Test Facility 2
MVTF1E	=	Medium Vacuum Test Facility 1 Extended
PFM	=	Proto Flight Model
PPS®	=	Propulseur à Plasma Stationaire
SVTF4	=	Small Vacuum Test Facility 4
TRP	=	Temperature Reference Point
XFC	=	Xenon Flow Controller

[1] Researcher, damiano.pagano@aerospazio.com.
[2] Researcher, leonardo.sestini@aerospazio.com.
[3] Researcher, elisa.bonelli@aerospazio.com.
[4] Researcher, simone.scaranzin@aerospazio.com.
[5] Researcher, gianfranco.meniconi@aerospazio.com.
[6] Technical Manager, fscortecci@aerospazio.com.
[7] Research Engineer, Electric Propulsion Engineering Department, giovanni.coduti@safrangroup.com.
[8] Research Engineer, Electric Propulsion Engineering Department, vanessa.vial@safrangroup.com.
[9] Head of the PPS®5000 thruster, Electric Propulsion Engineering Department, olivier.duchemin@safrangroup.com.

I. Introduction

THIS paper summarizes the activities carried out to demonstrate the fulfillment of the requirements of the test facilities to be used in the framework of the Safran PPS®5000 acceptance campaign (including the cathode lifetime test) and of the PPS®1350 qualification campaign. The commissioning activities involved the MVTF1E (Medium Vacuum Test Facility 1 Extended) to be used for the PPS®1350 qualification test, the LVTF2 (Large Vacuum Test Facility 2) to be used for the PPS®5000 PFM and FM Acceptance Campaign and the SVTF4 (Small Vacuum Test Facility 4) to be used for the PPS®5000 Cathode Lifetime Test. The first objective of the commissioning campaigns was to demonstrate the fulfillment of the test requirements in terms of vacuum performances (static and dynamic). The second aspect concerned the demonstration of the capability of Aerospazio to operate the test article by means of reliable systems. The third point concerned the capability to provide reliable measurements in terms both of thruster electrical parameters and thruster performances measurements (thrust, plume characterization). Finally, the fourth point concerned the performances of the thermal set-up to in terms of conditioning temperatures range.
In the following the arranged test set-ups are described.

II. PPS®5000 Acceptance Campaign Commissioning Test

The PPS®5000 PFM and FM campaign requires the measurement of the thruster performances in terms of thrust and beam parameters (divergence, thrust vector direction) including cold starting. In order to optimize the testing times, a full integration between the performance measurement set-up and the thermal set-up (cold box) has been implemented. However, the commissioning test was carried out in two separate phases because of the test article used during the commissioning test. During the first phase the diagnostic system performances have been demonstrated by performing a complete characterization on the PPS®5000 EM operating the thruster at different operative points. During the second one, the cold box performances have been demonstrated by exploiting a mock-up plate and an heater to simulate the heat load produced by the thruster during its normal operation.

A. The Large Vacuum Test Facility 2

The Aerospazio facility[1-3] chosen for the PPS®5000 Acceptance Campaign was the LVTF2 (Figure 1) whose main characteristics are summarized in table 1. The facility is equipped with a control system allowing recording all vacuum facility data (pressures and temperatures). Redundant vacuum systems and an alarm system allowing minimizing risks and rest time in case of failure are also implemented.

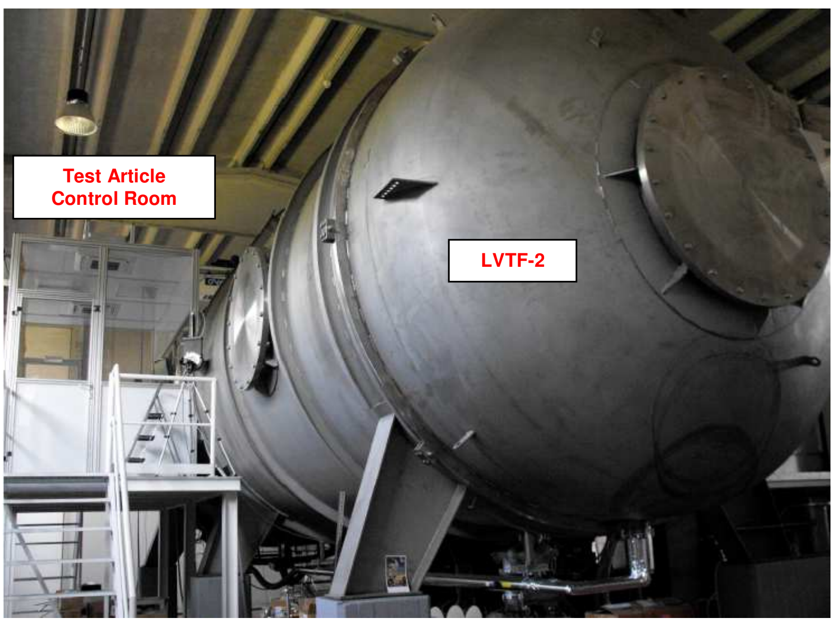


Figure 1. View of LVTF-2 Vacuum chamber.

TEST FACILITY	LVTF-2
Vacuum Chamber	
Internal Diameter	3.8 m
Total Length	12.5 m
Internal volume	140 cu.m.
Graphite lining (Ø x L)	3.7 m x 8 m
Chevron beam target cooling	Water/GN2 (LN2 optional)
Preferred test set-up	
Free firing length	8 m
Free firing diameter	3.7 m
Free firing volume	86 cu. m
Pumping System	
1st stage	Dry Rotary pump and Booster pump
2nd stage	Magnetic lev. Turbomoleculars + dry rotary
3rd stage	Cryopumps
4th stage	Cryoheads + LN2 shroud
Vacuum performance	
Static vacuum	~ 1 x10-7 mbar (w/o bakeout) ~ 3 x 10-8 mbar after bakeout
Dynamic vacuum	> 180.000 l/s on Xe
Vacuum Diagnostics	
Low Vacuum Gauges	3 Pirani
High Vacuum Gauges	3 Ionivac
QMS	1 x 200 Amu

Table 1. LVTF-2 Vacuum Chamber Characteristics

B. The Test Set-up

1. The Test Power Supply (TPS) and the Xenon Feed System

The test set-up include all the equipment necessary to provide electrical power to the thruster, to provide xenon and to perform the test according to Safran requirements. The electronics required to operate and acquire the discharge parameters of the thruster is located in a breadboard rack (Figure 2a) called Test Power Supply (TPS) consisting of a control computer and a set of high accurate power supplies. The TPS provides the power also to the flow control units enclosed in the mass flow panel (Figure 2b). If the XFC is present in the test configuration only one line in the mass flow panel is used and the mass flow controller is replaced with a mass flow meter to measure the total inlet xenon flow to the XFC. Pressure sensors are also installed to provide the requested inlet pressure to the XFC.

2. The Performance Measurement apparatus

The measurement of the thruster performances during the acceptance campaign was intended to exploit two elements of the test set-up. The first one is represented by the plume diagnostic apparatus[4] consisting of a rotating boom equipped with different types of plasma probes. The vertical rotation axis of the boom lies on the plane drawn by the thruster exit plane, thus allowing to scan the semispherical surface in front of the thruster by means of the 34 Faraday probes[3] installed on the boom. The second element to fully characterize the thruster behavior at the different operating points is represented by the thrust balance that exploits the null reading principle in order to improve the accuracy of this kind of measurements. Figure 3 shows the complete test set-up for characterize the PPS®5000 performances.

a)

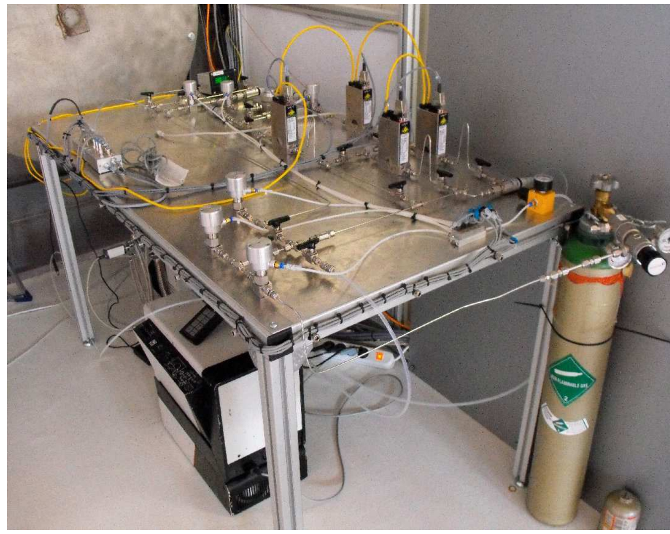
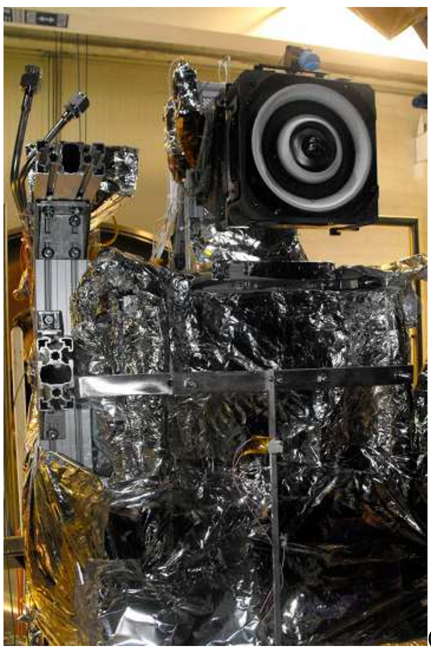
b)

Figure 2 – Test Power Supply (a) and Xenon Feed System (b).

(a)

(b)

Figure 3. SAFRAN PPS®5000 EM installed on the thrust balance.
Front view (a). View of the diagnostic boom (b).

3. The Thermal Shroud

The last element of the test set-up used for the PPS®5000 acceptance campaign is represented by the thermal shroud (cold box) to perform cold ignitions. The cold box must be compatible with the thrust balance in order to make possible performance characterization and thermal cycling without chamber re-opening. It means that only radiative cooling of the thruster is allowed. The compatibility of the cold box with the thrust balance must be both mechanical and thermal. From the mechanical point of view the thruster must be installed on the thrust balance and it must move freely inside the box without contact with it. Thus the cold box is constituted by an aluminium box internally black painted in order to maximise the radiative heat transfer to the thruster. The thermal compatibility of the cold box with the thrust balance concerns two aspects: the first one is related to the good operation of the cold box itself. It means that the thruster must be enough thermally isolated from the thrust balance to be able to achieve the target temperature. To this end the mock-up plate is mounted on the thrust balance interface by means of four plastic insulating rods. Four holes are made on the backplate of the box through which the four insulating rods can move. The second thermal compatibility aspect concerns the effect of the cold box operation on the thrust balance drift. Thus the MLI covering all the external surfaces of the thermal shroud has a double function: it minimises the heat dispersion by radiation allowing a higher cooling efficiency of the cold box and on the other hand reduces the effect of the cooling and heating of the thermal shroud on the balance. The box is closed by a motorised shutter not actively cooled. On the external walls of the box there is the cooling line supplied by liquid nitrogen.

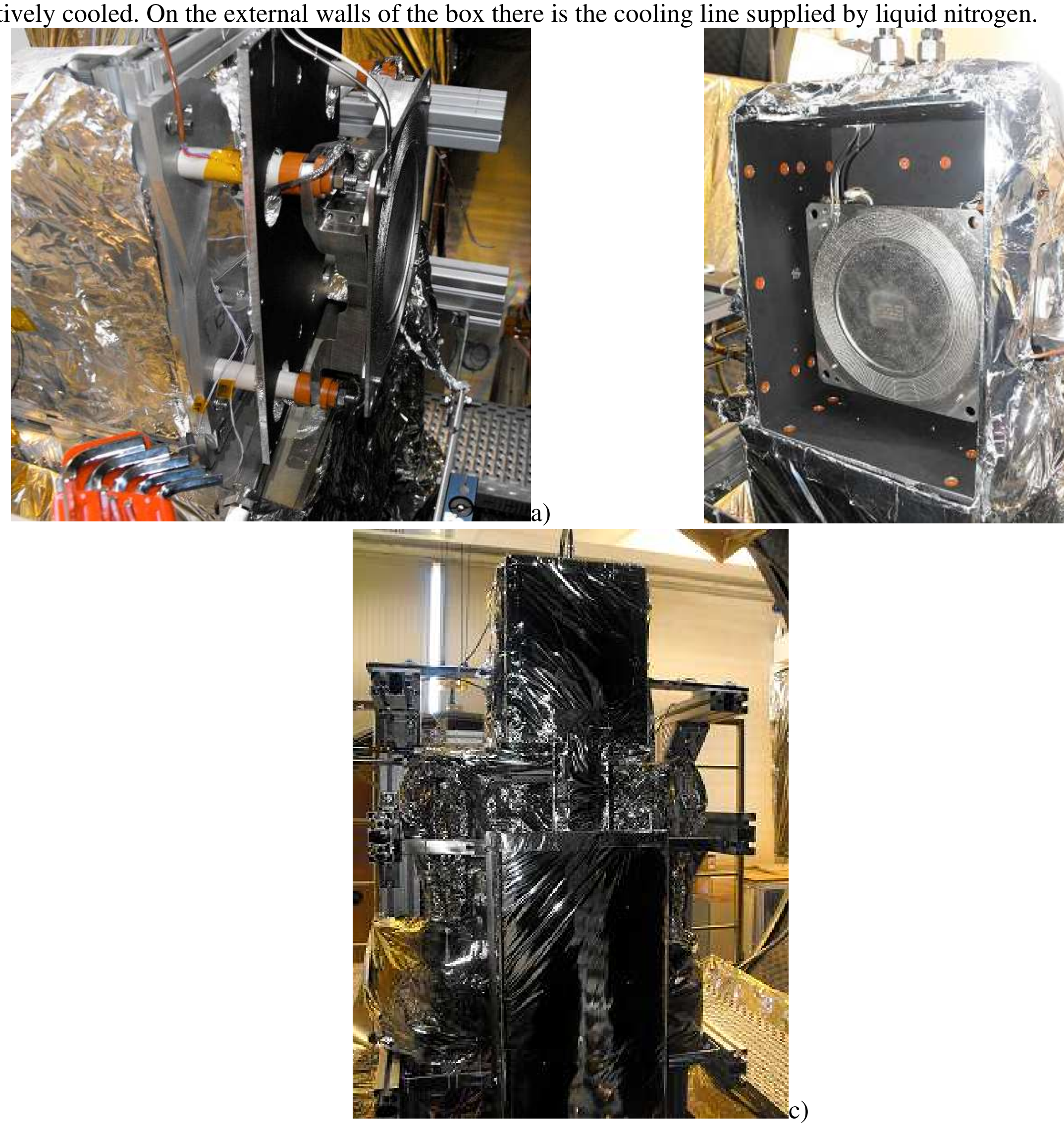

a) b) c)

Figure 4. Installation of the mock-up plate and the thermal shroud on the thrust balance.

C. PPS®5000 Acceptance Commissioning Test Results

The commissioning test carried out on the PPS®5000 EM at the different operating points showed the full agreement with the expectation in terms of measured thrust and beam characteristics (divergence, thrust vector). For what concerns the thermal test, the collected data indicate the capability of the arranged integrated (thermal + performance) set-up to reach target temperature on the thruster TRP for the cold start without affecting the thrust measurement.

III. PPS®1350-E Qualification Campaign Commissioning Test

The activities to be performed in the framework of the Safran PPS®1350-E qualification campaign will include two performance measurement sessions interspersed by a thermal cycling test. While for the PPS®5000 acceptance campaign a combined performance and thermal test was possible to implement due to the radiative heat transfer required, in this case it is necessary to use two independent test set-up.

A. The Medium Vacuum Test Facility 1 Extended

The PPS®1350-E qualification test will be carried out in the MVTF1-E vacuum chamber whose main characteristics are summarized in table 2. The chamber is constituted by two cylinders of different diameter joined together. The first one is 1.3 m in diameter and 3 meters long and inside it the thrust balance and the diagnostic boom are located; the second one is 2.1 m in diameter and 3.5 meters in length and constitutes the free expansion volume for the plume. The vacuum chamber control system is similar to that of the LVTF2.

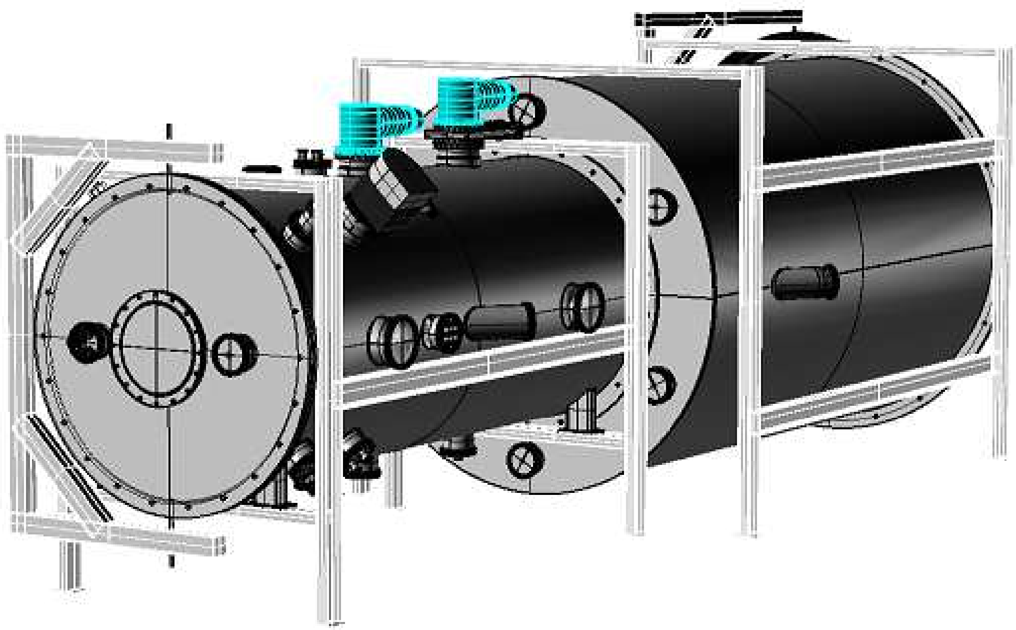


Figure 5. Pictorial view of MVTF-1E Vacuum chamber

B. The Test Set-up

The general architecture of the test set-up for the PPS®1350-E qualification test arranged in the MVTF1-E is essentially similar to that described for the PPS®5000 acceptance test in the LVTF2 for what concerns the vacuum system and the thruster control system. The main differences are in the performance characterization set-up and in the thermal cycling set-up. Two independent set-ups have been adopted due to the necessity to perform the thermal conditioning of the thruster by conductive heat transfer thus preventing to exploit the thrust balance during the thermal cycling test campaign.

For what concerns the performance measurement set-up, the main difference in respect with that adopted for the PPS®5000 acceptance test is in the radius of the hemispherical surface scanned by the probes on the diagnostic boom (55 cm). In this measurement configuration 19 Faraday probes and 2 RPA are installed on the diagnostic boom. The Faraday probes are distributed on the boom with a variable angular spacing from 5 deg in the region closer to the thruster geometrical axis (from 0 to +/-20 deg) to 20 deg for the more external probes. Figure 7 shows the arranged set-up for the performance characterization test. The two RPAs are located one on each side of the central probe (FP10) in redundant configuration in order to determine the ion energy distribution function and the related quantities in the equatorial plane of the plume.

Also in this case the thruster is installed on a thrust balance similar to that used for the PPS®5000 testing with a specifically adapted configuration to improve the measurement accuracy in the expected thrust range and to allow allocating up to 15 thermocouples through it.

TEST FACILITY	MVTF-1E
Vacuum Chamber	
Internal Diameter	1.3 m– 2.1 m
Total Length	6.5 m
Graphite lining (Ø x L)	2.1 m x 3 m
Chevron beam target cooling	Water/GN2 (LN2 optional)
Preferred test set-up	
Free firing length	4 m
Free firing diameter	1.3 – 2.1 m
Pumping System	
1st stage	Dry Rotary pump and Booster pump
2nd stage	Turbomolecular pump + dry rotary
3rd stage	Cryopumps
4th stage	Cryoheads + LN2 shroud
Vacuum performance	
Static vacuum	~ 1 x10-7 mbar (w/o bakeout)
Static vacuum	~ 5 x10-8 mbar (after bakeout)
Dynamic vacuum	> 30.000 l/s on Xe
Vacuum Diagnostics	
Low Vacuum Gauges	2 Pirani
High Vacuum Gauges	2 Ionivac
QMS	1 x 200 Amu

Table 2. MVTF1-E Vacuum Chamber Characteristics

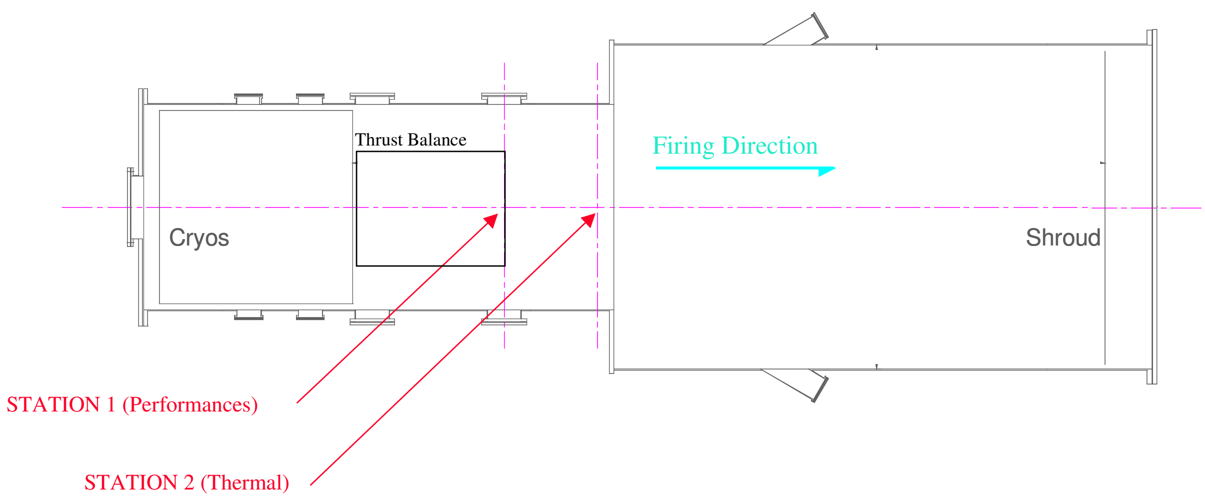


Figure 6. Sketch of the PPS®1350E test stations inside the MVTF1-E for the performance and the thermal cycling test.

The thermal cycling test campaign requires the independent thermal conditioning of the thruster and of the XFC at different temperatures. The thruster shroud is essentially an aluminium box with the internal side walls black painted and an XFC conditioning plate. The thruster is installed inside the box as shown in figure 8. Thus, the thermal regulation of the thruster is performed by both conductive and radiative heat transfer, whereas the regulation of the XFC is carried out only by conductive heat transfer from the plate where it is installed on. The box is closed by a motorised thermal conditioned shutter actuated by a vacuum stepper motor.

The temperature control of the thruster and of the XFC is carried out by means of two independent active temperature regulation systems (cryostats). They allow controlling the box and the plate temperature both during hot and cold cycles.

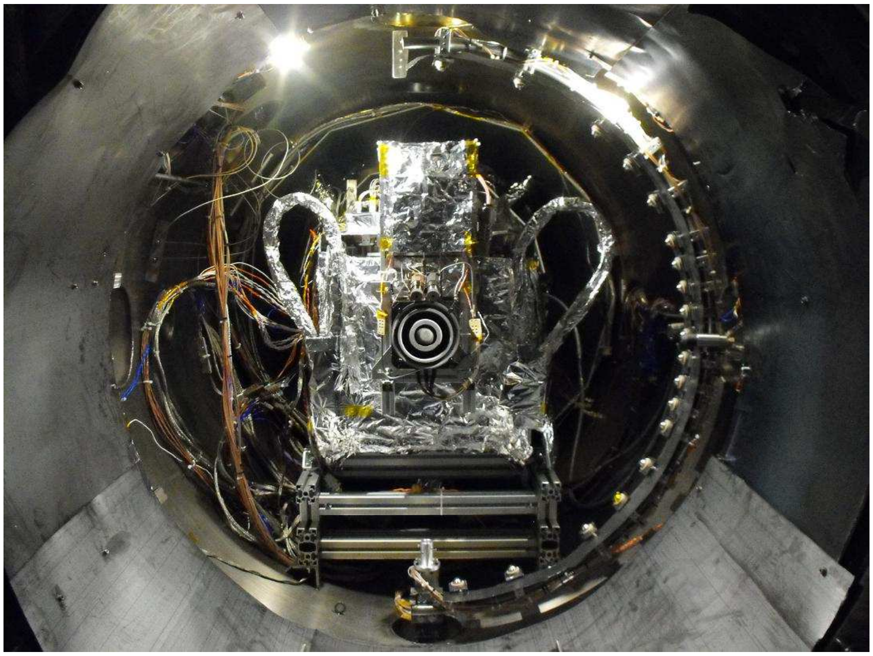


Figure 7. View of the measurement set-up for the performance characterization test during the commissioning campaign with PPS®1350E.

C. PPS®1350E Qualification Commissioning Test Results

Also the commissioning activity, preparatory to the PPS®1350E qualification test, carried out in the MVTF1-E vacuum facility, has indicated the agreement between Aerospazio results and the data obtained by Safran in its Test Facilities in Vernon. For what concerns the thermal test, the capability to cool down and heat up the thruster have been fully demonstrated.

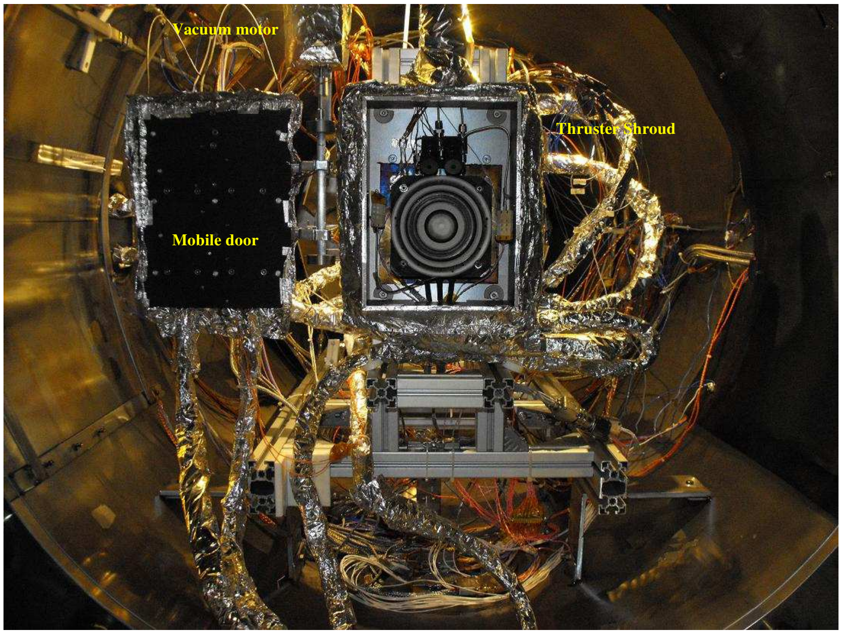


Figure 8. PPS®1350E as installed inside the thermal shroud.

IV. PPS®5000 Cathode Lifetime Commissioning Test

The PPS®5000 cathode lifetime campaign will consist in performing a number of ignition cycles reflecting the number of ignitions that the cathode will undergo during the operative life of the Safran PPS®5000 thruster. In order to reproduce as much better as possible the operative conditions of the cathode an electronic circuit simulating an oscillating load has been developed at Aerospazio so as to simulate the breathing frequency of the thruster and the in-rush during the ignition phase.

A. The Small Vacuum Test Facility

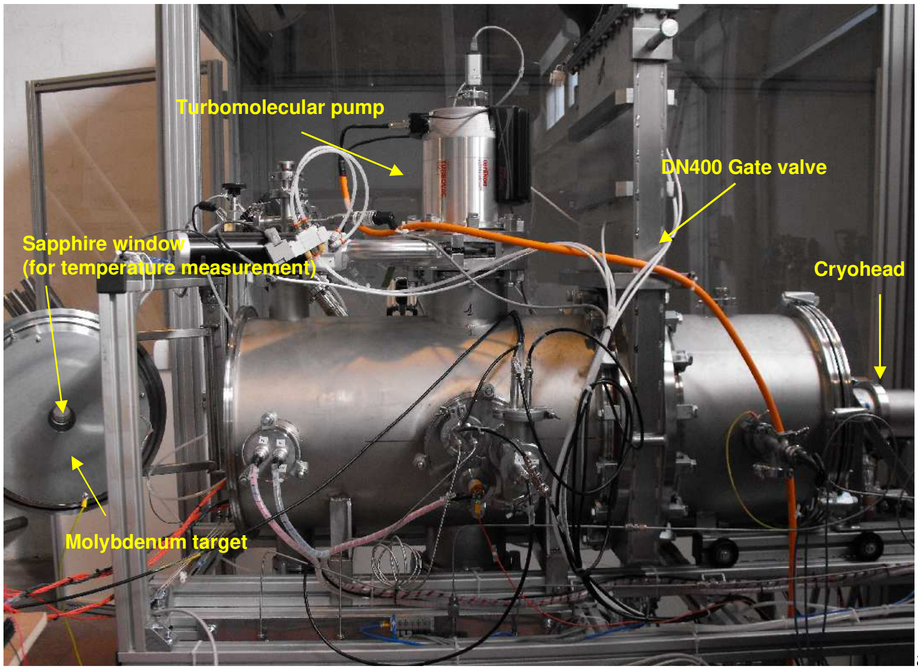
The vacuum chamber to be used for the PPS®5000 cathode lifetime testing consists of a diamagnetic stainless steel cylinder 400 mm in diameter and 108 cm in total length. The chamber is equipped with a dry rotary pump, a turbomolecular pump and a cryohead. The total volume of the chamber is divided in two parts. The first part (the smallest one) is occupied by the cryohead (on the left in Figure 9a) and is not available for customer equipment installation. The second part (on the right in Figure 9a) represents the available volume where the cathode will be installed in. The two sections are separated by a DN400 gate valve that will be closed before regeneration in order to keep the best possible pressure for the cathode. As for the others Aerospazio vacuum facilities, also the SVTF4 is characterized by the possibility to operate the facility both in manual and automatic mode and safety and redundant systems devoted to improve the reliability in operating the test article minimising the risks. In particular a full integration between the vacuum facility and the cathode control system has been implemented. The facility control system acquires and control both the operative parameters of the facility and the operative parameters of the cathode. A sapphire window is located on the chamber door to allow measuring the emitter temperature by means of a pyrometer.

TEST FACILITY	**SVTF4**
Vacuum Chamber	
Internal diameter	40 cm
Total length	108 cm
Pumping System	
1st stage	Dry rotary pump
2nd stage	Turbomolecular pump
3rd stage	Cryohead + turbomolecular pump
Vacuum Performance	
Static vacuum	~ 2 x 10^{-7} mbar
Vacuum Diagnostics	
Low vacuum gauges	2 pirani
High vacuum gauges	2 ionivac
QMS	200 amu

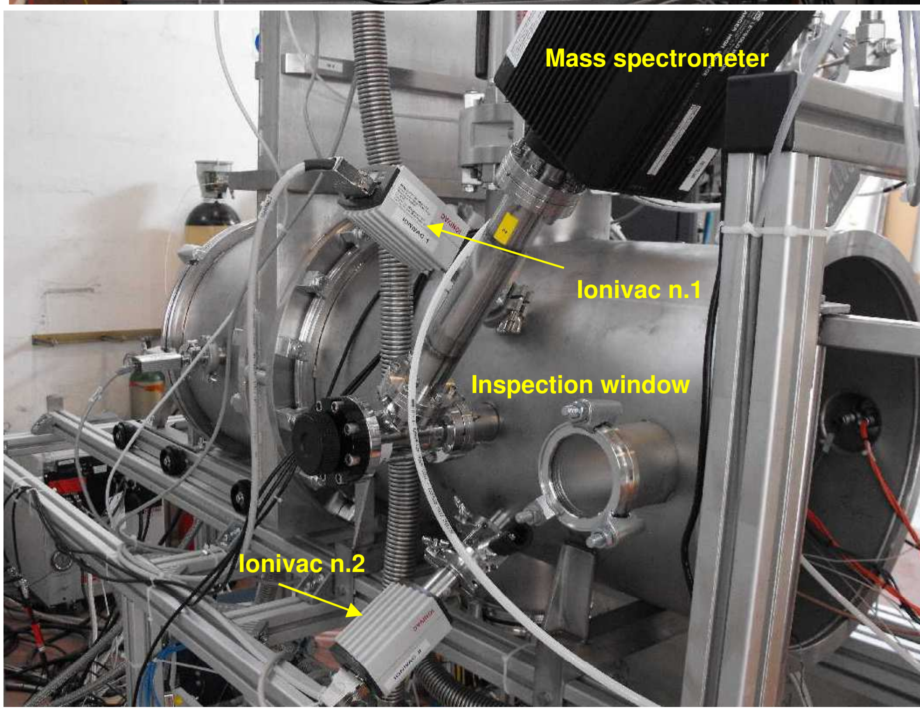
Table 3. SVTF-4 Vacuum Chamber Characteristics

D. The Test Set-up

The test set-up for the commissioning campaign carried out on the SVTF4 vacuum facility is fully representative of the configuration to be adopted for the lifetime campaign. In this test configuration the discharge is ignited between the cathode and a molybdenum target taken at a given distance from the cathode exit plane. In order to reproduce the operative conditions during the thruster life the discharge current is modulated by means of an oscillating load tuned on the breathing mode of the thruster. The system is also able to simulate the conditions during the inrush phase of the discharge. The operative parameters of the cathode are automatically monitored by the control system in order to switch off the cathode in event of failure or if operative thresholds are overcame. The system is able to perform the automatic switching on/off of the discharge according to the set On and Off time.



a)



b)

Figure 9. SVTF-4 right (a) and left (b) side view.

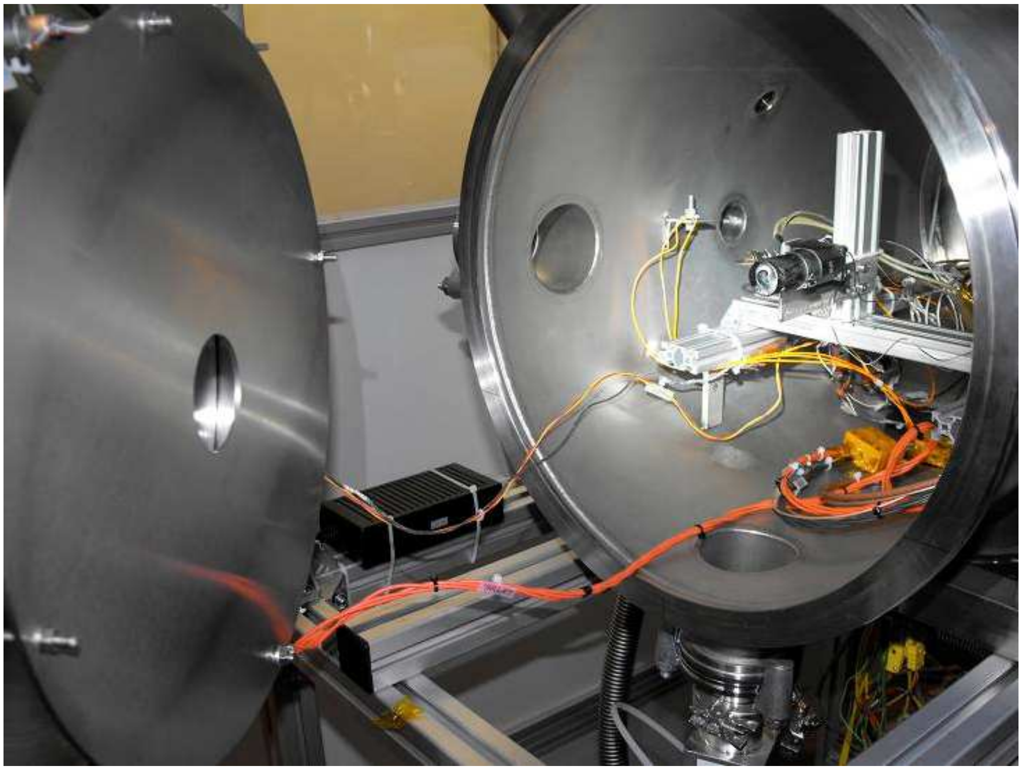


Figure 10. Safran PPS®5000 cathode as installed in the SVTF4 for the commissioning test.

V. Conclusion

The results of the commissioning activity carried out at Aerospazio in the framework of the collaboration with Safran for the PPS®5000 acceptance campaign and the PPS®1350 qualification campaign have shown the capability of Aerospazio facilities to fulfil the test requirements in terms of vacuum performances, reliability, measurement accuracy as demonstrated by the agreement between the results obtained and the Safran expected data for what concern the performance characterization of the two different type of thrusters and by the achievement of the target temperatures both during cold and hot cycling for what concerns the thermal performances.

References

[1]Scortecci, F., Bonelli, E., Michelozzi, B., Saito, F., Scaranzin, S., and Turco, A., "Performance of a large vacuum test facility for spacecraft propulsion testing," *Space Propulsion 2004*, Sardinia, Italy, 2004.

[2]Bonelli, E., Scaranzin, S., Scortecci, F., Saito, F., Killinger, R., Kukies, R., and Leiter, H., "A 3000 hours endurance testing of RIT-22 thruster in the new Aerospazio Test facility," *29th International Electric Propulsion Conference*, IEPC-2005-212, Princeton, NJ, 2005.

[3]Moneti, F., Bonelli, E., Pulcinelli, F., Scortecci, F., Lazurenko, A., and Genovese, A., "The Aerospazio lifetest facilities and diagnostic tools for the HEMPT qualification programme," *Space Propulsion 2016*, Rome, Italy, 2016.

[4]Pagano, D., Coduti, G., Scaranzin, S., Meniconi, G., Scortecci, F., and Kutufa, N., "Performance of Plume Characterization of the SPT-100 B Thruster," *34th International Electric Propulsion Conference*, IEPC-2015-010, Hyogo-Kobe, Japan, 2015.

[5]Coduti, G., Zurbach, S., Vial, V., Duchemin, O., Pagano, D., Sestini, L., and Scortecci, F., "Commissioning of the Aerospazio vacuum facilities with Safran Hall Effect Thrusters," *35th International Electric Propulsion Conference*, IEPC-2017-414, Atlanta, Georgia, 2017.