Commissioning of the Aerospazio's vacuum facilities with Safran's Hall Effect Thruster

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Abstract: Safran thruster models PPS®1350 and PPS®5000 have been tested at Aerospazio Tecnologie. Thrusters were characterized with respect to performance and plume properties at different operating points for the PPS®5000 thruster and a single operating point for the PPS®1350. Measurements show a slight deviation of PPS®1350 and PPS®5000 performances due to effect of the pressure in the vacuum test facility. Indeed, the pressure in the Aerospazio's vacuum test facilities is lower than the reference pressure initially set in the Safran's facility. Today, thanks to the successful tests facilities commissioning, Aerospazio Tecnologie is the partner of Safran for the qualification of PPS®1350E QM thruster and the acceptance of the PPS®5000 flight model.

Nomenclature

EM	=	Engineering Model
F	=	Thrust (N)
g	=	Gravitational acceleration (9.80665 m/s^2)
HET	=	Hall Effect Thruster
I_d	=	Discharge current (A)
I_{sp}	=	Specific Impulse (sec)
LVTF2	=	Large Vacuum Test Facility 2
mt	=	Total mass flow rate (mg/s)
MVTF1E	=	Medium Vacuum Test Facility 1 Extended
η	=	Efficiency (%)
P_{vacuum}	=	Pressure in the vacuum (mbar)
PPS	=	Propulseur à Plasma Stationaire
θ_{90}	=	Divergence (degree) at 90%
Ucrp	=	Potential (V)
U_d	=	Discharge voltage (V)

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I. Introduction

THE development of electric propulsion systems based on Hall Effect Thrusters (HET) expanded significantly since the first demonstration in flight on the soviet satellite Meteor in 1972. The reliability and performance of 1.5kW-class HET have widely been demonstrated on-board numerous spacecrafts, particularly on communication satellites. As a result a significant heritage in terms of HET physics and technologies has been produced worldwide for more than 40 years.

At Safran a wide experience has been acquired since 1992 through numerous research activities carried out on HET from few hundreds of watts up to tens of kilowatts. The obtained results participate to the improvement of the 1.5kW-class PPS®1350G and the 5kW-class PPS®5000 competitiveness.

During the thruster PPS®1350-G life test qualification achieved between 2003 and 2006 the thruster completed 10532h of operation at 1.5kW and 7309 cycles with no decrease in performances during the whole lifetime, corresponding to a thrust of 89 mN, specific impulse of 1700 sec and efficiency of 50%.[1] The thruster also ensured the success of the SMART-1 probe journey to the moon by achieving a world record of operation with 4960 h and about 800 cycles[5]; it covered more than 100 million of km consuming only 82 kg of propellant (Xe).[2] These highly successful ground and flight tests led to the selection of the PPS®1350-G for north/south station keeping on the European Alphabus high power telecommunication platform.[3]

Nowadays, Hall-Effect Thrusters (HET) are used worldwide mainly for spacecraft orbit control and station keeping. It is expected that their application extend significantly in particular to variety of missions. The full electric satellite need versatile operating points to insure both orbit transfer on high thrust mode and also orbit and control on high specific impulse mode.

Safran is developing the PPS®5000 thruster that will be able to handle both orbit raising and station keeping throughout its lifetime. This thruster has been selected by OHB, Airbus Defence and Space and Thales Alenia Space for the new generation plateforms ELECTRA and NEOSAT of Airbus Defense and Space. More recently this product has been selected by Boeing company. The qualification testing over 3 years at Safran test facilities and the simultaneous production phase request to commission Aerospazio test facilities.

II. Aerospazio Test setup

The test was performed in the Aerospazio facilities LVTF2 for the PPS®5000 and MVTF1E for the PPS®1350.[4]

The MVTF1E chamber is constituted by two cylinder (diameter 1.3 and 2.1m, total length is 6.5m). The facility is equipped with a system diagnostic (19 Faraday probes and RPA) and a thrust balance on the principle of the null reading. The distance between the diagnostic and the thruster exit plane is 54 cm.

The LVTF2 chamber is a cylinder 3.8m x 12.5m, equipped with a system diagnostic made of 34 Faraday and a thrust balance on the principle of the null reading. The distance between the center of the diagnostic and the thruster exit plane is 1m.

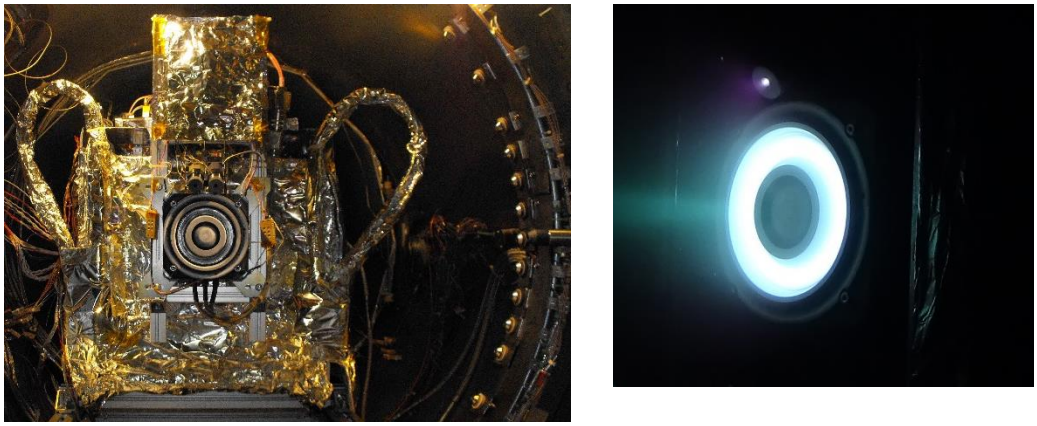
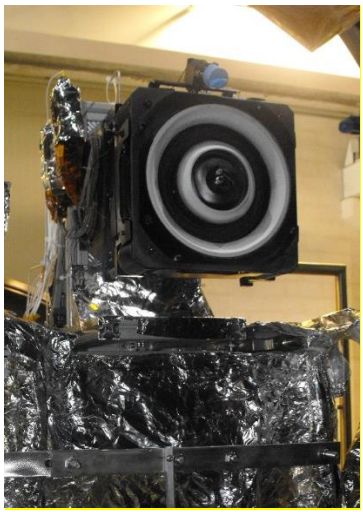


Figure 1 – The PPS®1350 Hall Effect Thruster on the thrust balance in the MVTF1E facility.



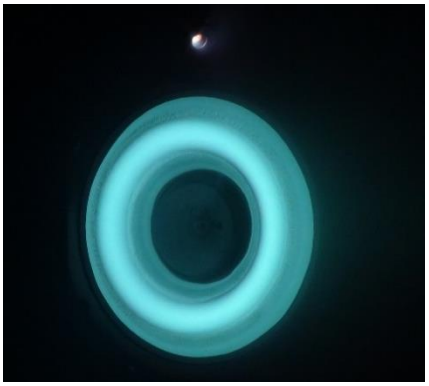


Figure 2 – The PPS®5000 EM Hall Effect Thruster on the thrust balance in the LVTF2 facility.

III. PPS®1350 Results

The PPS®1350 is the Flight Model of the Safran 1.50kW-class HET. The nominal operating point was chosen at discharge current Id (4.28A) and voltage Ud (350V). The thruster has been designed and manufactured by Safran.[1]

Figure 3 shows results for thrust (F), xenon mass flow rate, specific impulse I_{sp}, efficiency η, discharge current vs cumulative operating time during the test dedicated to verify the vacuum test facility and diagnostics with the PPS®1350.

Specific impulse and efficiency are defined as follows:

$$I_{sp} = \frac{F}{\dot{m} * g}$$

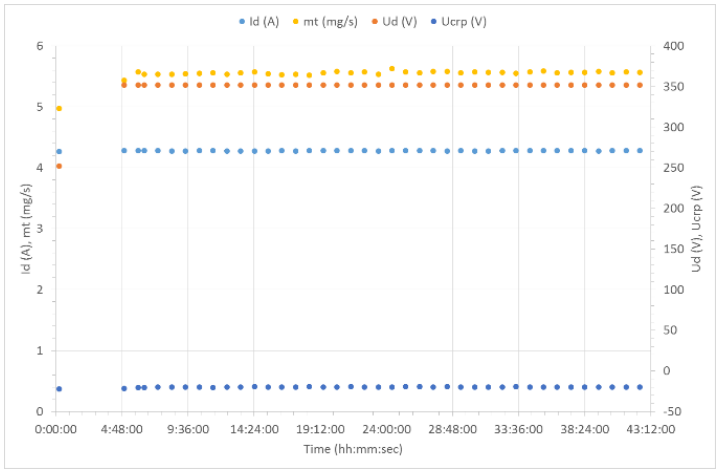
$$\eta = \frac{F * I_{sp} * g}{2 U_d I_d}$$

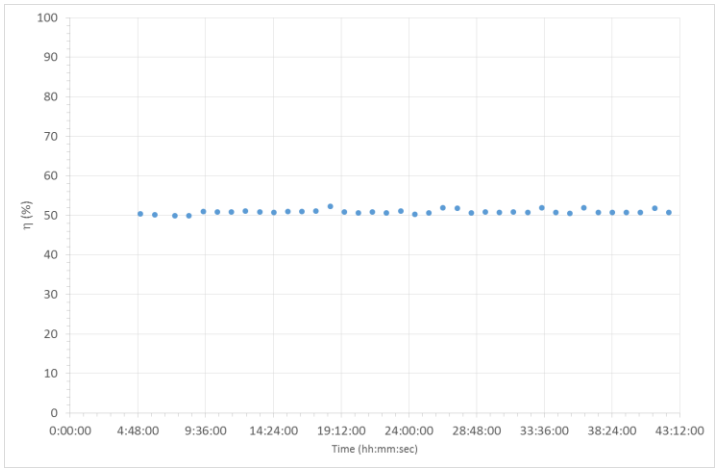
where g is the gravitational acceleration (9.80665m/s^2), Id is the current discharge and Ud is the discharge voltage. Note the equation of efficiency includes the magnet voltage.

Thrust measurement uncertainty is dominated by the calibration of the thrust balance and estimated to be +/-2.5%. The specific impulse measurement uncertainty is obtained by uncertainties of the thrust and the xenon mass flow rate, and estimated to be +/-3.5%.

During the test campaign, the pressure in the vacuum test facility was 7.9 10^{-5} mbar during nominal operation. The performance assessment at nominal operating point is based on previous results obtained during the qualification test and the acceptance test of the flight model.

Figure 3 shows the repeatability of the thrust and the discharge parameters. Repeatability of the thrust and discharge parameters are estimated to be, respectively, 0.60% and 0.4%.


Id (A)
mt (mg/s)
Ud (V)
Ucrp (V)
Id (A), mt (mg/s)
Ud (V), Ucrp (V)
Time (hh:mm:sec)
0:00:00
4:48:00
9:36:00
14:24:00
19:12:00
24:00:00
28:48:00
33:36:00
38:24:00
43:12:00


η (%)
Time (hh:mm:sec)
0:00:00
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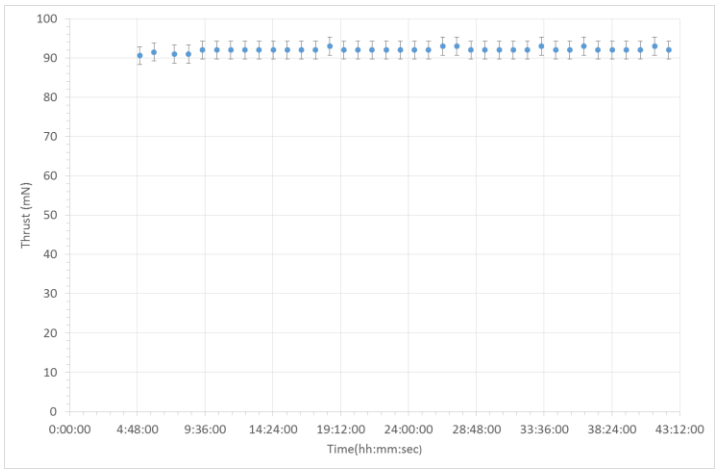
33:36:00
38:24:00
43:12:00


Thrust (mN)
Time(hh:mm:sec)
0:00:00
4:48:00
9:36:00
14:24:00
19:12:00
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28:48:00
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43:12:00

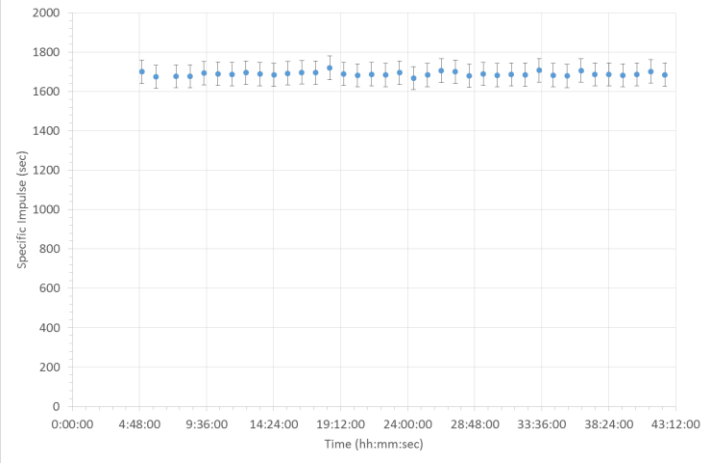

Figure 3 – Performance and discharge parameter at 7.9 10^{-5}mbar.

Table 1 synthesizes the results obtained in the two different vacuum chambers. The results show a good agreement with those obtained in the Safran facility. Nonetheless It can be noted that the pressure level affects the thruster operation.[5,6,7] Indeed, differences are evaluated at 1.90% for the thrust, 6.50% for the xenon mass flow rate and 2.6 degrees for the divergence of the plume. A low pressure results in a greater total mass flow rate to have the same discharge current, due to the fact that the gas-electron collisions are less likely.

	Pvacuum (mbar)	Id (A)	Ud(V)	m (mg/s)	U_{CRP} (V)	Thrust (mN)	Isp (sec)	η (%)	θ_{90} (°)
Safran (acceptance)	1,52 10^{-4}	4,28	351,4	5,23	-16,70	93	1818	56	40,6
AER	7,9 10^{-5}	4,28	352,08	5,57	-20,45	91,50	1674	50	38

Table 1 – PPS®1350 performance at nominal point in the two differents facilities and diagnostics

These results allowed to validate the test vacuum facility with these diagnostics. Safran decided to entrust the qualification of the PPS®1350E QM at Aerospazio Tecnologie. The qualification of the thruster at 2.45kW began in 2017.

IV. PPS®5000 Results

Safran is developing a 5kW thruster that will be able to handle both orbit raising and station keeping throughout its lifetime. The PPS®X000 technical demonstrator and the engineering models (EM) PPS®5000 have accumulated more than 5000 hours of testing.[8] The PPS®5000 Engineering Model has been used by Aerospazio Tecnologie to validate the diagnostics and the LVTF2. The PPS®5000 has been operated at 9 points covering the application needs.

Figure 4 shows xenon mass flow rate and discharge current in the Safran and Aerospazio facilities.

Thrust measurement uncertainty is dominated by the calibration of the thrust balance and estimated to be +/-2.5%. The specific impulse measurement uncertainty is obtained by uncertainties of the thrust and the xenon mass flow rate, and estimated to be +/-3.5%. During this campaign, the pressure in the vacuum test facility varied between 2 10^{-5} and 6 10^{-5}mbar.

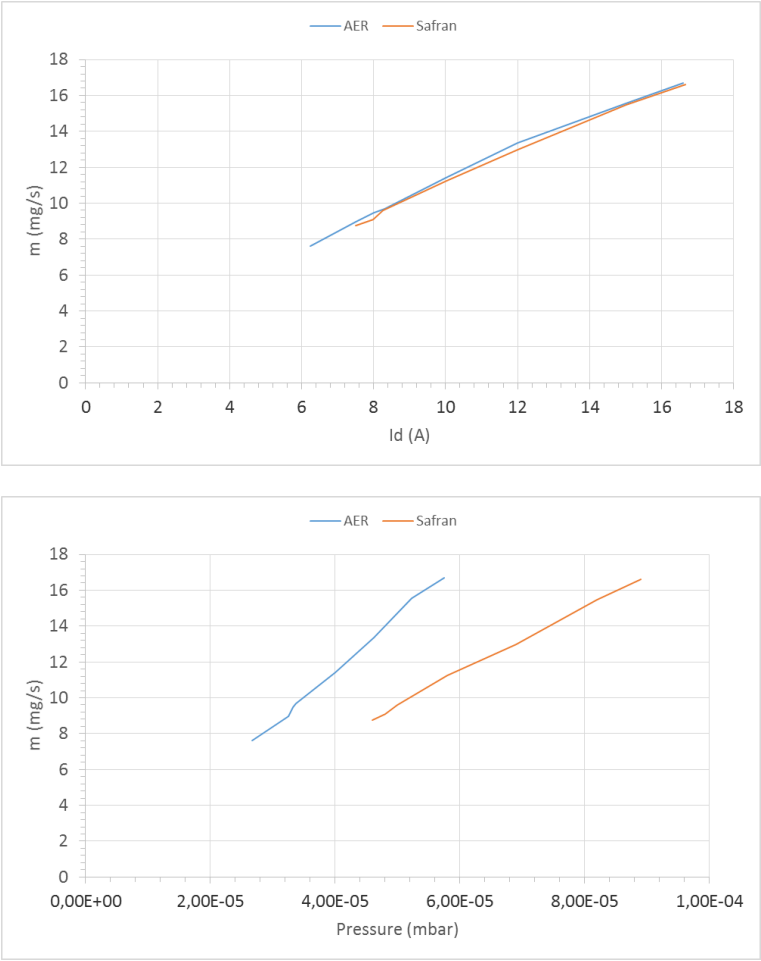

Figure 4 – Mass flow rate and discharge current

The results obtained are in good agreement with those obtained in the Safran facility. The deviations are of the order 2% for the thrust, 4% for the xenon mass flow rate, 4% for the efficiency and the impulse specific varies between 0 and 45sec. The deviations are due to the effect of the pressure in the vacuum chamber, the effect pressure impact the discharge parameters, the thrust, the efficiency, the specific impulse and the divergence of the plume. The measurement of the divergence shows a divergence lower than 40° for all operating points.

V. Conclusion

The test campaign carried out at Aerospazio Tecnologie for the PPS®1350 and PPS®5000 thrusters showed a good agreement with measurements at Safran. Tests were successfully concluded after confirming positive results. Thruster performance and plume properties were measured at a variety of operating points for the PPS®5000 thruster and at a single operating point for the PPS®1350. The effects of a slightly lower pressure on the thruster operation show:

- A slight decrease of thrust (2%), specific impulse (< 40sec) and efficiency (4%).
- A slight increase of xenon mass flow rate (4%).
- A slightly increased plume divergence (0 to 5°).

These results are in accordance with previous pressure sensitivity tests performed with PPS®1350[6] and PPS®5000, and mastered for qualification or production tests.

Today, thanks to the successful tests facilities commissioning, Aerospazio Tecnologie is the partner of Safran for the qualification of PPS®1350E QM thruster and the acceptance of the PPS®5000 flight models.

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