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TEST CAMPAIGN ON HYDRAULIC MOCK-UP FOR EXOMARS EDM PROPULSION DESIGN VALIDATION

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ABSTRACT

In the frame of the development of the new complex propulsion subsystem for the Entry, Descent & Landing Demonstrator Module (EDM) of the Exomars Mission [2] [4] [5], a fluidic test campaign in three big steps is rolled-out. It is composed of two sessions of tests in water (Hydraulic Mock-Up #1 and #2 – HMU#1 & HMU#2) and one session of tests in hydrazine (Firing Development Model – FDM) [3].

The first test campaign (HMU#1) was held on a reduced flight-like mock-up and it was composed of priming and pressure drop tests in water. Its successful completion allowed to conclude on several design trade-offs and to improve the subsystem fluidic numerical models. The results were presented at the Space Propulsion 2012 [1].

The second campaign (HMU#2) was held on a flight-like mock-up representing the final subsystem design and including the pressurant and the propellant stages. It was divided into three parts covering the propulsion operation cycle: priming, pressurization and firing (with water). For each part, several nominal and worst-case parameters were tested.

Its completion allowed to fully validate the final subsystem design and to correlate the associated numerical models. Finally the third campaign (FDM) will deal with the engines performances versus the feeding system. This final step will be carried out with real hydrazine firing.

The article focuses on the second campaign. It first details the proceedings and the results of the tests and then presents the numerical correlation work (using EcosimPro software and the European Space Propulsion System Simulation library – ESPSS).

Exomars and the ESPSS library are programs of the European Space Agency (ESA). EcosimPro is a simulation tool developed by Empresarios Agrupados International.

1. INTRODUCTION

Exomars Entry, Descent & Landing Demonstrator Module (EDM) is a spacecraft which is designed to safely land a science payload on the planet Mars. Therefore it is equipped with a propulsion subsystem designed to decelerate the final descent onto the Mars surface before final touch down [2] [4] [5].

This propulsion subsystem is a hydrazine monopropellant subsystem that operates in regulated mode. It is composed of a single pressurization assembly regulating the pressure of three independent propellant assemblies (Figure 2). Each propellant assembly contains a thruster cluster composed of three 400 N engines.

For the development of this new complex propulsion subsystem, a wide validation plan was necessary to study in detail the fluidic phenomena and to correlate the analyses numerical models [3].

The design validation plan of the EDM Propulsion subsystem is composed of three major tests steps:

- HMU#1, priming and pressure drop tests in water (this activity took place in 2011 and was presented in a previous paper at the Space Propulsion 2012 [1]),
- HMU#2, priming / pressurization / firing tests in helium and water (this activity took place in 2013 and is presented in the current paper),
- FDM, priming / pressurization / firing tests in helium and hydrazine (this activity will be carried out in 2014).

The paper presents HMU#2 activity: mock-up, test sequence, results, correlation and conclusions.

2. HMU#2 PRESENTATION

HMU#1 test campaign focused on the design validation of the propellant lines [1]. When the propulsion subsystem design was defined [5], HMU#2 activity was carried out in order to test the complete flight sequence on a representative mock-up of the propulsion subsystem.

HMU#2 mock-up was built to be as representative as possible of the flight model. Figure 1 shows a picture of the complete mock-up.

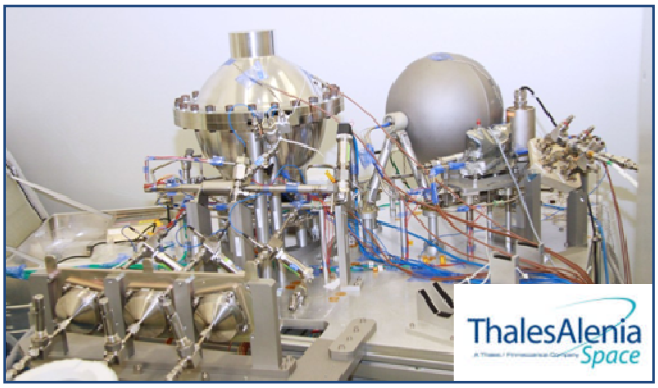

Figure 1: HMU#2 Mock-Up

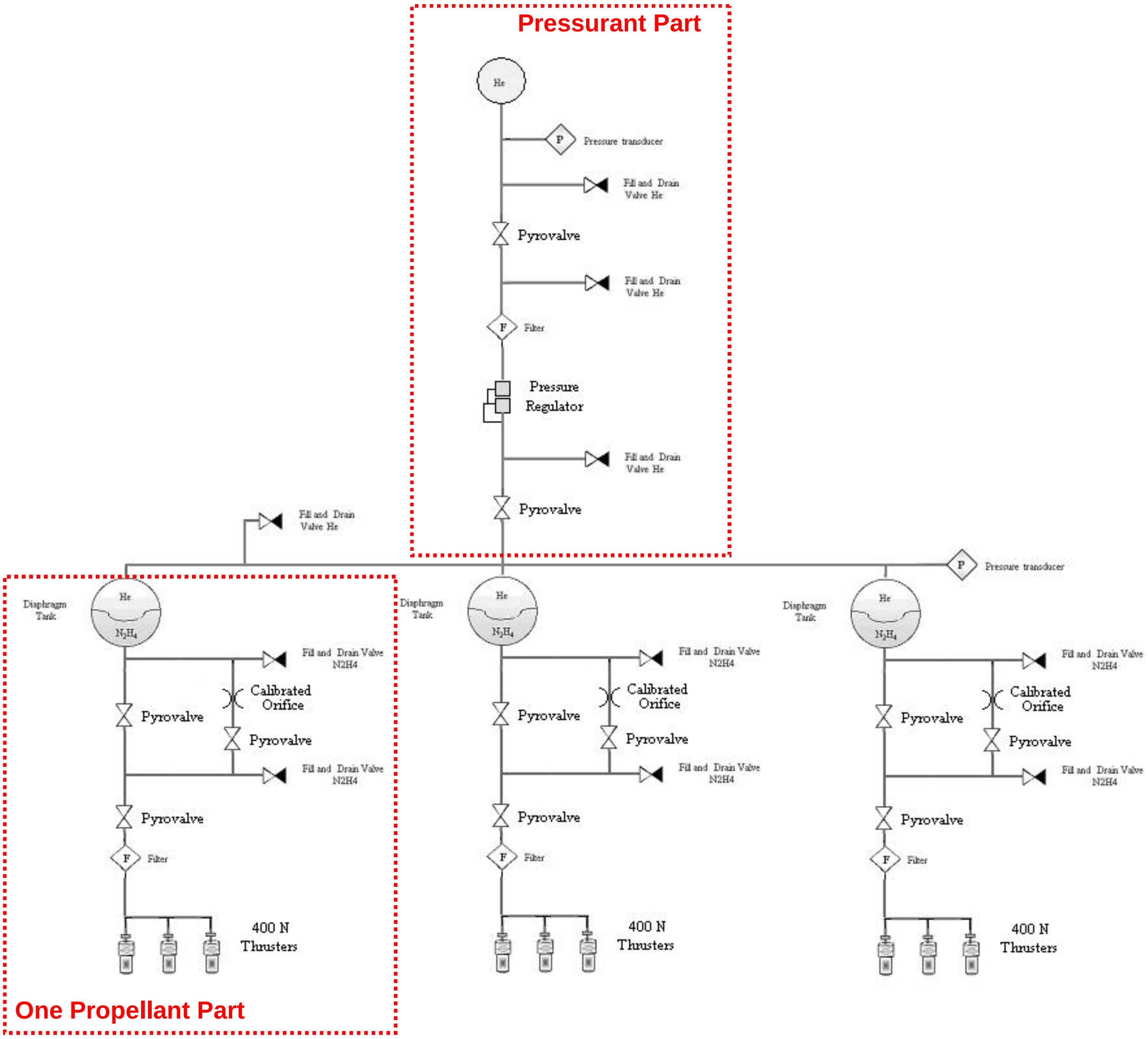

Figure 2: EXOMARS RCS Propulsion Subsystem Schematic

HMU#2 mock-up was composed of the pressurant part and one propellant part (see details on Figure 2). The two other propellant parts were replaced with an equivalent ullage volume for priming and pressurization tests and with a continuous outgoing mass flow for firing tests.

The goal of HMU#2 was to validate the Critical Design Review numerical analyses and to correlate the numerical models (EcosimPro & ESPSS) for further analyses.

HMU#2 mock-up was used in three configurations:

- Priming Configuration (representing the filling of propulsion lines with hydrazine after opening of pyrovalves):

  with closed engines valves and a dedicated rapid opening valve on the by-pass line,

- Pressurization Configuration (representing the initial pressurization of the propellant tanks):

  with closed engines valves and a dedicated rapid opening valve upstream the pressure regulator,

- Firing Configuration (representing the propulsion subsystem flight sequence):

  with flight-like engines valves representing the unsteady firing mass flow rates.

The test campaign was consequently organized into three steps, one on each mock-up configuration:

- Priming (water),
- Pressurization (helium),
- Firing (helium & water).

For the priming tests, the parameters that were studied are:

- generating and residual pressures.

For the pressurization tests, the parameters that were studied are:

- helium and propellant tank initial pressures,
- propellant tank loading with water as simulant.

For the firing tests, the parameters that were studied are:

- firing profile (Steady State Firing, Pulse Mode Firing, worst case firing),
- propellant tank loading with water as simulant.

Each run was performed twice to check reproducibility.

The detailed tested cases are presented in Table 1, Table 2 and Table 3.

Case	Propellant Tank Pressure (bar abs)	Residual Pressure (bar abs)
1	15.1	0.005
2	15.1	0.500

Table 1: Priming – Tests Cases

Case	Helium Tank Pressure (bar abs)	Propellant Tank Water Filling (kg)	Propellant Tank Pressure (bar abs)
1	150	13.0	15.1
2	175	13.0	18.0
3	175	13.0	15.1
4	175	15.4	15.1
5	175	8.0	15.1

Table 2: Pressurization – Tests Cases

Case	Engine Valves Actuation Profile	Propellant Tank Water Filling (kg)
1	PMF1	13.0
2	PMF2	13.0
3	SSF	13.0
4	Elementary	13.0
5	DC	13.0
6	PMF1	15.4
7	SSF	15.4

Table 3: Firing – Tests Cases (*)

(*) The firing engine valves actuation profiles are the following:

- PMF1&2: flight Pulse Mode Firing profiles,
- SSF: Steady State Firing profile,
- Elementary: elementary engines opening and closing profiles,
- DC: duty cycle variations in a pulse period.

3. TESTS RESULTS

The complete test campaign was successfully performed and the tests results were satisfactory. Indeed they showed:

- good consistency between the different sensors for a same test,
- good consistency between the different cases,
- good consistency between the different configurations,
- a consistent physical response for the different studied phenomena.

Results examples are presented in the next figures. Figure 3 shows an example of priming water hammer result (pressure evolution with time for the different dynamic pressure sensors). Figure 4 shows an example of pressure evolution with time in the tanks during pressurization and firing.

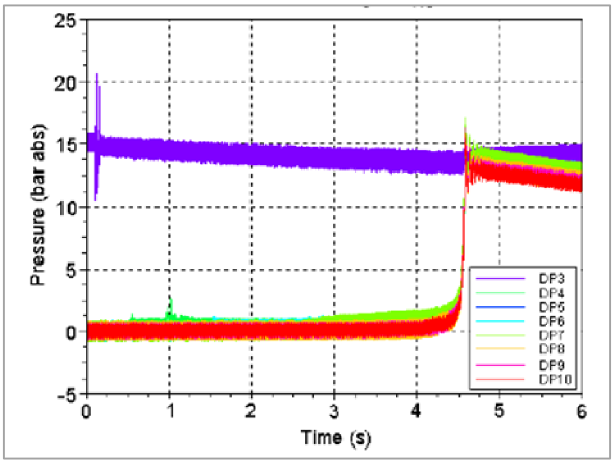

Figure 3: Priming Tests Result Example (Pressure in the subsystem – Case 1)

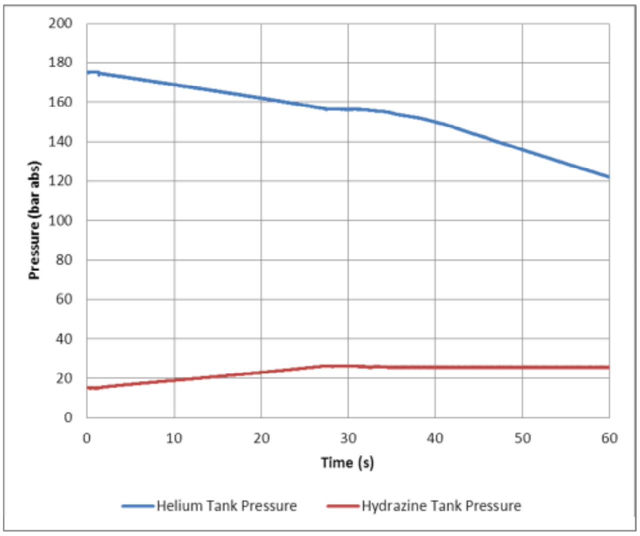

Figure 4: Pressurization / Firing Tests Result Example (Pressure in tanks – Case 3 / Case 1)

The tests allowed to draw some interesting conclusions about the studied phenomena:

- <u>Priming tests:</u>

- The maximum pressure peak is obtained in the deadline located just upstream the valve as a direct result of the sudden flow suction. Indeed, the calibrated orifice located near the valve sufficiently damps the priming water hammer intensity so that no big pressure peak is obtained at the engines inlets.

- The residual pressure in the tested range has a negligible influence. Indeed, because of the calibrated orifice damping effect, the pressure peaks level remains quite low.

  - Pressurization tests:

- The pressure regulator behaviour during slam start can vary between two different test campaigns (e.g. acceptance tests and subsystem tests). Consequently, adequate analysis margins were defined for future use in functional analyses.

  - Firing tests:

- The maximum water hammer pressure peaks are obtained with the pulse mode firing profiles. This is attributed to cross-coupling effects.

4. CORRELATION OF NUMERICAL MODELS

The test results were correlated by numerical simulation with the software EcosimPro and the library ESPSS.

Three numerical models were built corresponding to each test configuration:

- Priming Model: modelling of the propellant part with closed thrusters,
- Pressurization Model: modelling of the pressurant part and of the propellant tanks ullage volumes,
- Firing Model: full modelling of the pressurant and propellant parts.

The numerical models were developed as representative of the mock-up configurations as possible, on the basis of preliminary elementary pressure drop tests (on company internal designed tubing parts – tees, elbows, orifices) and of the acceptance test results of the equipments.

The following general conclusions were deduced from the simulation results:

- the priming simulations globally overestimate the pressure peaks (which is conservative regarding the safety of the phenomenon),
- the firing simulations globally overestimate the line pressure drop (which is conservative regarding the S/S hydrazine and helium budgets).

The tests results were then directly compared to the simulation results. The correlation levels that were obtained are fairly good:

- Priming simulations:

The pressure peaks were correlated with a relative error inferior to 30% on the safe side (overestimation), which represents a good level for such highly intensive phenomena (complex geometries and vacuum conditions) and is improved compared to HMU#1, showing a better accuracy of the model. Figure 5 shows the correlation level obtained on the different dynamic pressure sensors located at the end of lines (DP3 to DP5 are located at the Fill and Drain Valves inlets and DP6 to DP10 are located on the engines cluster).

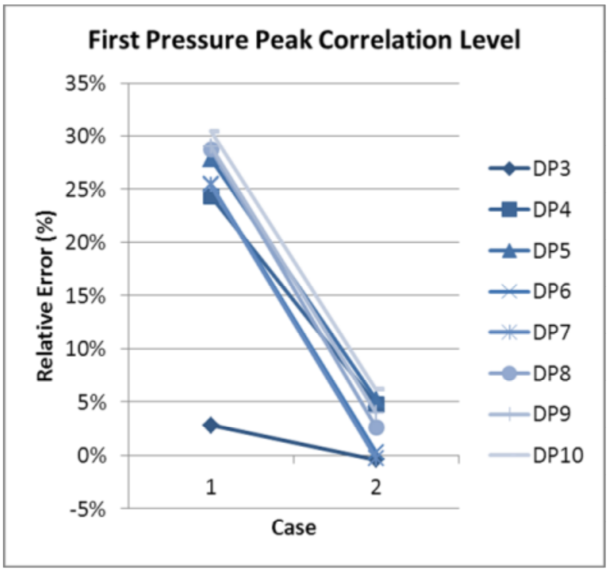

Figure 5: Priming Correlation Level

- Pressurization simulations:

The final helium pressure was correlated with a relative error inferior to 5% on the safe side (underestimation), which represents a very good correlation level. Figure 6 shows the correlation level obtained on the helium tank static pressure sensor (SP1).

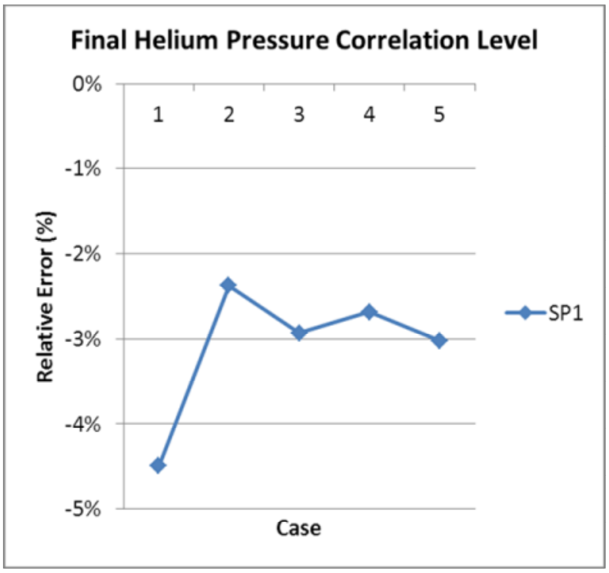

Figure 6: Pressurization Correlation Level

- Firing simulations:

The helium and water consumptions were correlated with a relative error inferior to ±20%, which represents a good correlation level. The pressures along the main line in steady state firing were correlated with a relative error inferior to ±2%, which represents a very good correlation level. Figure 7 shows the correlation level obtained on the helium and water consumption.

Note: For firing correlation, only cases 1 and 3 were studied since they are the most interesting cases to correlate helium and water consumptions. The other cases were tested to study water hammer pressure peaks but the engines model was not accurate enough to allow for a good correlation level and they were not analysed during correlation.

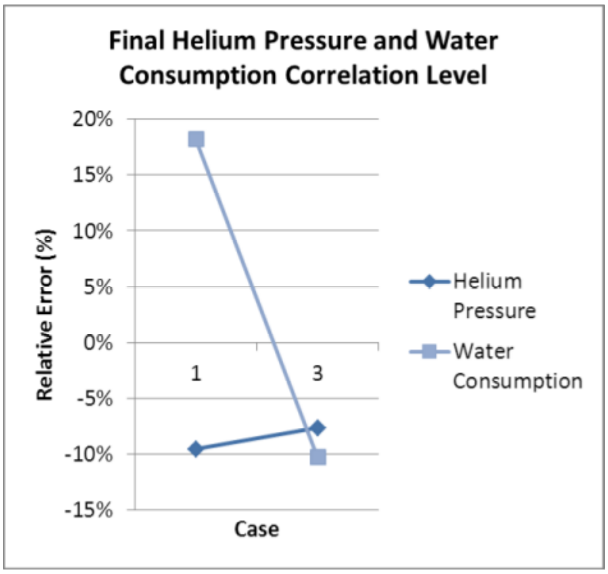

Figure 7: Firing Correlation Level (1)

The correlation level concerning the firing pressure peaks due to the engines pulses was less accurate due to a lack of representativeness in the 400 N engine numerical model. Figure 8 shows the correlation level obtained on the different dynamic pressure sensors located at the end of lines (DP3 to DP5 are located at the Fill and Drain Valves inlets and DP6 to DP10 are located on the engines cluster).

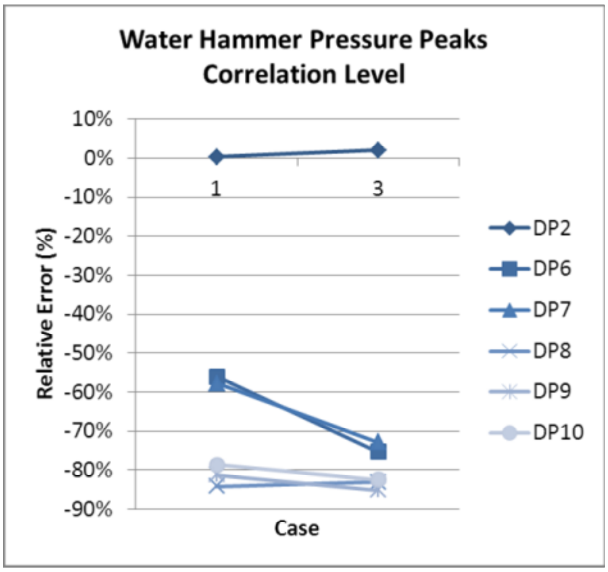

Figure 8: Firing Correlation Level (2)

The lesson learnt from the low correlation level on the firing water hammer phenomena is that despite the good analytical tools that are available these days, real testing is still an essential part of propulsion subsystems development.

Note: Better correlation results were obtained by the engine manufacturer with a more detailed engine numerical model.

5. CONCLUSION

In the challenging development of Exomars EDM propulsion subsystem, the second step of the validation plan – HMU#2 test and correlation campaign – was successfully performed and the results were satisfying. A good global correlation level was obtained with the fluidic numerical simulations on the tested flight phases.

The preliminary elementary pressure drop tests allowed building accurate models of the company internal designed tubing elements (tees, elbows, orifices).

The priming tests confirmed the right sizing of the calibrated orifice implemented to control the priming water hammer with a good confidence level.

The pressurization tests helped studying the pressure regulator behaviour during slam start and allowed defining adequate analysis margins for the subsystem initialization sequence.

The firing tests confirmed the right sizing of the pressurant and propellant budgets and highlighted the cross-coupling phenomena in the water hammer pressure peaks due to the opening/closing cycles of the engines.

The overall test campaign confirmed the usefulness of real testing in propulsion subsystems development.

A final test campaign is planned on HMU2 mock-up refurbished as a Firing Development Model (FDM) in order to perform hot firing tests on a representative mock-up and with flight like engines (hydrazine).

The Exomars EDM team at Thales Alenia Space Cannes wishes to thanks ESA for their support and advice all along the modelling and test activities.

6. SUMMARY

In the scope of Exomars EDM propulsion subsystem development [2] [4] [5], the design validation plan is composed of three fluidic test campaigns in order to help with design trade-offs and to correlate fluidic numerical models [3].

The first test campaign (HMU#1) was presented at the Space Propulsion 2012 [1].

The second test campaign (HMU#2) was presented in this paper. It was composed of fluidic tests in helium and water on a flight representative mock-up. The correlation of these tests showed a global good level: 30% on priming simulations (on the safe side), 5% on pressurization simulations (on the safe side), 20% on the firing simulations budgets (pressurant & propellant consumption) and 85% on the water hammer due to engines opening/closing cycles.

The third test campaign (FDM) will be carried out in 2014.

7. REFERENCES

[1] “Numerical simulations for Exomars EDM propulsion design and operational analyses”, F. Laverty, F. De Dinechin, G. Lubrano, Y. Le-Marchand, A. Iffly, L. Lecardonnel, Space Propulsion Conference 2012 (Bordeaux)

[2] “Definition of the Exomars EDS Reaction Control System for a robust terminal descent phase: propulsion architecture trades”, F. De Dinechin, P. Arfi, L. Lecardonnel, M. Capuano, S. Portigliotti, O. Bayle, F. Caramelli, Space Propulsion Conference 2008 (Heraklion)

[3] “Exomars EDS Propulsion RCS development and validation plan”, G. Lubrano, L. Fontaine, L. Lecardonnel , F. De Dinechin, Space Propulsion Conference 2010 (St Sebastian)

[4] “Description of the propulsion architecture for the Exomars EDL Demonstrator Module (EDM)”, F. De Dinechin, G. Lubrano, D. Lebleu, L. Lecardonnel, L. Fontaine, Space Propulsion Conference 2012 (Bordeaux)

[5] “Propulsion Subsystem for the Exomars Entry and Descent Module (2016 Mission Demonstrator)”, G. Lubrano, P. Capus, D. Lebleu, O. Maillan, P. Garçon, Space Propulsion Conference 2014 (Cologne)