PROPULSION SUBSYSTEM FOR THE EXOMARS ENTRY AND DESCENT MODULE (2016 MISSION DEMONSTRATOR)

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Abstract –
In the frame of the Aurora Exploration Program, ESA and Russia's space agency Roscosmos have signed an agreement to work in partnership to develop and launch two ExoMars missions. The first mission (2016) will study Mars' atmospheric trace gases composition and deliver a Descent and Landing Demonstrator Module (EDM), achieving Europe's first landing on Mars and validating key technologies needed to prepare further planetary exploration capabilities.

The EDM will be released from the Orbiter on the hyperbolic Mars arrival trajectory, and will proceed with entry and descent phases, during which velocity is decreased through hypersonic aerodynamic braking followed by descent under parachute . The final stage of the Descent (attitude control + breaking) until landing will be performed using pulse-mode firing of 9 hydrazine engines. The firing will last approximately 30 seconds.

Thales Alenia Space Cannes propulsion team has been selected by ESA to design, develop, manufacture and test the ExoMars EDM Reaction Control System (RCS). The RCS meets stringent requirements in terms of mass, compact and efficient accommodation and controllability performance as well as being compatible with the programmatic constraints and Planetary protection regulations. To comply with this challenging performance specification a robust design approach is implemented. A pressure regulated monopropellant hydrazine system has been selected based on the clustering of existing 400N engines. The involved high thrust and mass flows present new technological challenges at RCS level.

A former article was presented in last 2012 conference. This paper presents the Exomars RCS frozen design, validations achieved in the period and the next steps to complete the validation and integration inside the EDM shell. It particularly details the extensive on-ground tests that have been performed at equipment and at sub-system level to validate the performances and behaviour of the propulsion sub-system.

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1. INTRODUCTION

The ExoMars Reaction Control System (RCS) will be a breakthrough in Europe as it is the first propulsion system used as a main component of the Entry, Descent and Landing Demonstrator Module (EDM). In the frame of the Phase C/D, the best suitable propulsion system architecture has been defined to face ExoMars challenging goals. Extensive tests at equipment level and subsystem level were carried out to validate the performances of the RCS subsystem that will be detailed in the present article after a brief recall of the mission phases and the RCS description.

2. EXOMARS ENTRY & DESCENT PHASE

The Entry phase starts when the EDM reaches the EIP (Entry Interface Point), it ends when the parachute is deployed. This phase will last about 2 to 3 minutes. The Heatshield will sustain the aerothermodynamics loads, will guarantee the EDM shape and decelerate it to a velocity compatible with the parachutes system activation.

The descent phase starts with the Parachute (PAS) deployment, in supersonic conditions, at the suitable Mach/Altitude/Dynamic Pressure range. The Parachute will stabilise the EDM shape through unstable supersonic regime and decelerate the EDM through the transonic regime and in the subsonic regime. At suitable Mach number, the Frontshield (FS) will be released and allowed to fall away under the EDM. The parachute then brings the EDM to vertical conditions at a velocity compatible with the activation of the propulsive Reaction Control System (RCS). The back cover is then released under Parachute to separate the Equipped Surface Platform (ESP) equipped with the propulsion module.

From stabilised descent, the final braking through the engine cluster will occur. A precise attitude and velocity control logic will be implemented at EDM level to achieve the drop condition within the crushable landing structure capability range. The descent phase will last few minutes and ends few meters above the terrain when the descent rate and attitude of the ESP are such to be compatible with the landing performances.

Following the final braking through RCS, the ESP will drop in free fall the last meters before touchdown on Martian surface. The crushable structure will absorb the ESP final energy.

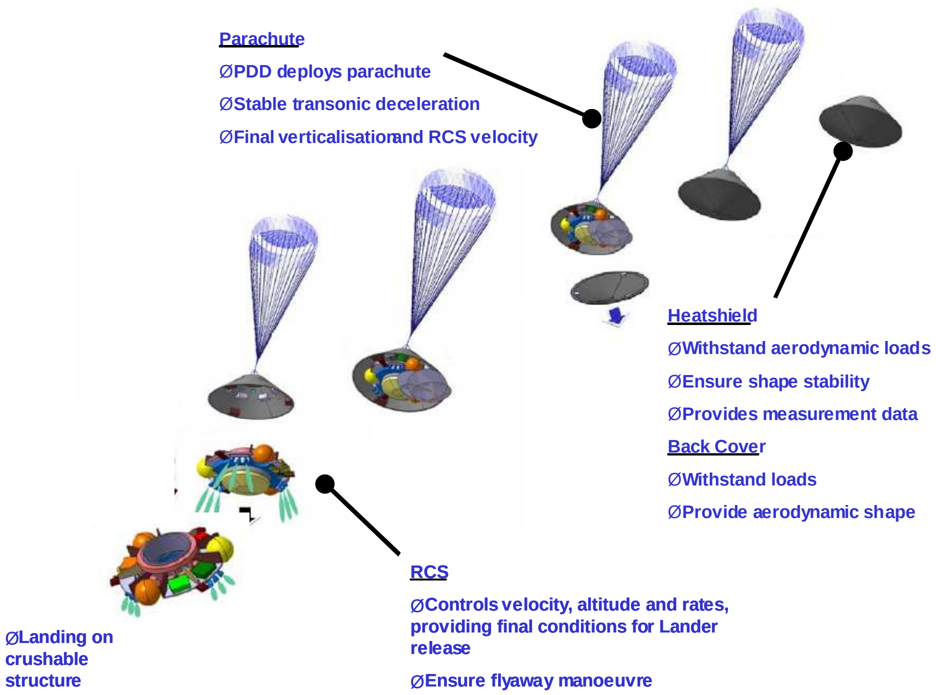

Figure 1 – ExoMars Entry and Descent Phase

3. EXOMARS REACTION CONTROL SYSTEM PRESENTATION

As the RCS is operating after the Parachute and before the crushable structure, the design is optimised to be compatible with operational constraints and to achieve the following functions:

- Ensure braking capability to decrease the Surface Platform vertical speed. The braking phase duration is around 30 seconds.
- Ensure the Surface Platform attitude control.

At the beginning several propulsion architectures have been traded:

- entirely solid fixed propulsion
- solid modulated propulsion based on N2O injection into a solid rocket
- entirely liquid propulsion based on usual spacecraft propulsion architecture
- combination of solid and liquid propulsion technologies.

Thales Alenia Space trade-off outcomes, presented in ref [1], showed that the entirely liquid monopropellant propulsion is the best suitable architecture, considering the following design drivers:

- The mass
- The volume allocation
- The RCS/GNC requirements

- The propellant budget
- The integration complexity
- The fluidic behaviour
- The planetary protection requirements

Several design drivers are not easily compatible together, however, TASF has found an appropriate compromise between each of the design drivers.

4. DESCRIPTION OF THE PROPULSION ARCHITECTURE & PERFORMANCES

The usual space propulsion systems rely on liquid engines with propellant & pressurant storage. This basic architecture can be adapted to each mission. Based on the Thalès Alenia Space France heritage, several trade-offs, relying on heritage and new technologies, were performed on this configuration to identify the most relevant design.

The propulsion system architecture is based on monopropellant engines. This concept is used on Mars Polar Lander & Phoenix (pulse engine) and on Viking & Mars Science Laboratory (throttleable engine). Hydrazine is a self-sterilizing liquid so it will prevent bringing contamination on Mars. Moreover it avoids bringing carbonate species, which could jeopardize the scientific researches. External surfaces or others equipments, not in contact with hydrazine, will be sterilized through dry-heat microbial reduction process or IPA wiping.

For the architecture, TAS-F decided to implement independent propellant lines, in order to secure the performances and ease the development plan. These propellant branches include a by-pass derivation with calibrated orifice in order to limit the water-hammer phenomenon that occurs at priming event. The propellant branches are connected to a single pressure regulation branch.

A pressure regulation system has been chosen in order to have a high thrust level until the end of the firing phase. This system can deliver up to 10 g/s of helium.

The sub-system is accommodated on the Surface Platform that will land onto Mars surface.

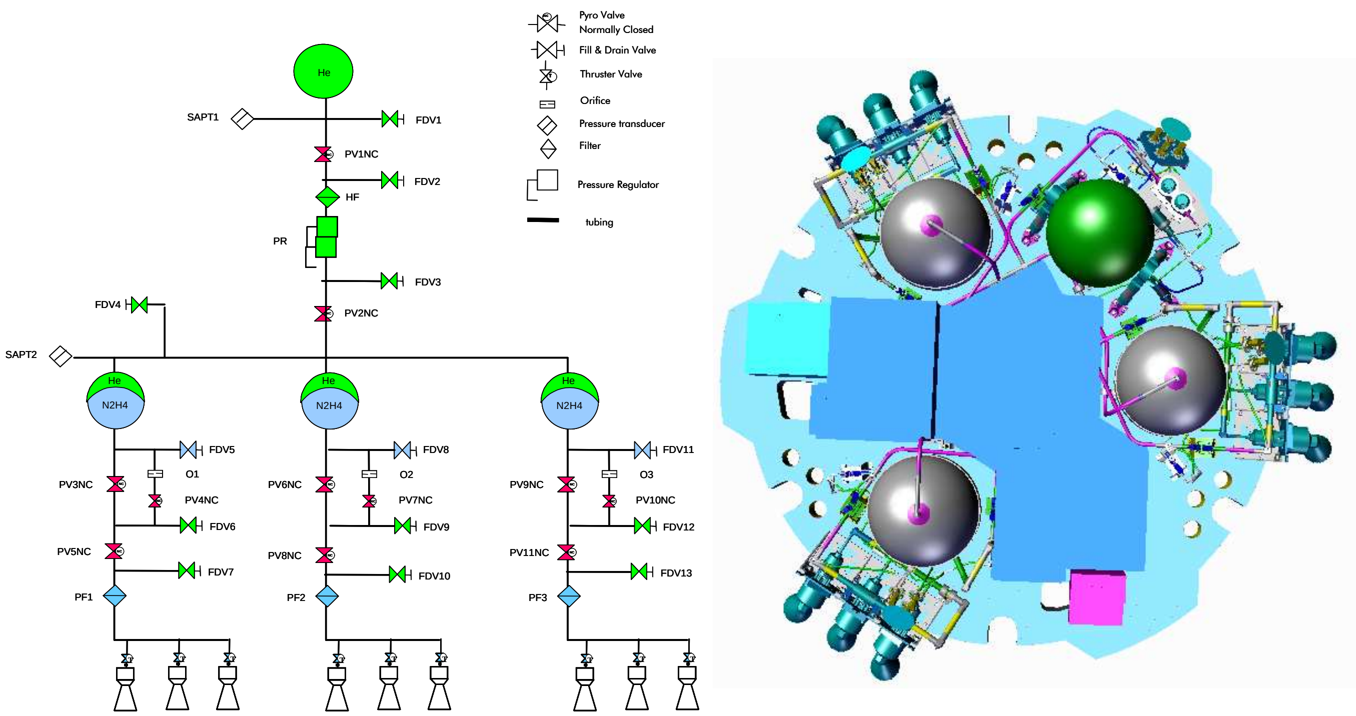

Figure 2 – propulsion architecture & accommodation on the Surface Platform

The RCS system is based on reliable technologies. Major fluidic components are not redunded due to too large volume and mass impacts. Fluidic analysis, run with ECOSIMPRO, have confirmed that this architecture was compatible with the ExoMars mission requirements. Two test campaigns have been performed to correlate the fluidic behaviour (see ref [4] & ref [5]) and make some reliable flight predictions.

For the thrust delivery, a configuration of three clusters of three engines has been selected. Each engine has a maximum thrust level of 440N. Engines can be operated independently on pulse mode at 5Hz, ensuring efficient attitude controllability. Radar doppler and accelerometers will be used by the On Board Computer to define opening and closing time of each engines. The total propellant mass consumption is between 30 and 40 kg. The associated propellant mass flow for one branch is around 700 g/s.
The total thrust delivery is around 3600N in order to decelerate the 300kg of Surface Platform mass. Engine nozzles are canted wrt the vertical axis. This will reduce the plume to terrain interactions effects on the Surface Platform. Moreover each engines have a tilt angle and are located adequately in order to limit plume to plume interactions to avoid thrust losses. Tilt angle also enables also attitude control capability.

The operational sequence of the RCS starts with the priming. It means that the Pyrovalves on the propellant part are fired to enable the hydrazine to fill the lines up to the engine inlet. This is performed before the entry phase.
Then the pressurisation of the propellant tanks is performed during the entry phase. The Pyrovalves on the helium side are fired in order to provide helium flow rate and to reach the operational pressure in the propellant tanks.
When the RCS is fully operational, engines are fired.

Some equipments were selected through ESA Invitation To Tender (ITT) process. Others, Off-The-Shelf products, were directly procured to usual Thales Alenia Space suppliers. The major ones are presented hereafter.

The engine for ExoMars mission is the CHT400, from Airbus DS. This is a pulse mode engine previously used on Ariane 5 for the roll control at beginning of flight. A delta-qualification is still ongoing. Endurance tests have already been successfully performed.

Figure 3 – CHT400 engine

The ExoMars propellant tank is designed by Rafael. It is a re-scaling in between PEPT 230 and PEPT 420 previous designs, to contain up to 15.4kg of hydrazine.

Figure 4 – Propellant tank

The helium tank is procured to ATK. This tank is a re-use of previous tank design, with however a new qualification.

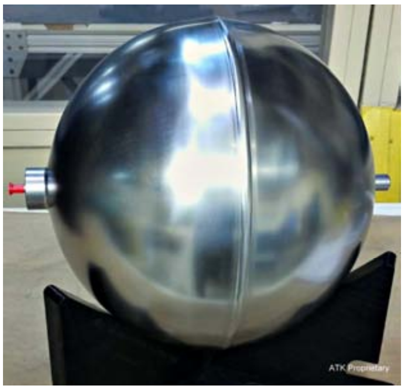

Figure 5 – Helium tank

The pressure regulator is procured to Stanford Mu Corporation (SMC). It allows to have a high pressurant gas flow rate to pressurise the propellant tanks. This regulator is a dual stage regulator in order to have the appropriate reliability for the mission and to minimise the accommodation impacts.

Figure 6 – Pressure regulator

For the others equipments, recurrent Spacebus Off The Shelf (OTS) equipments have been selected and procured.

5. RCS VALIDATIONS

The RCS has successfully passed the PDR in November 2011 and the CDR in May 2013. In between, most of the pieces of equipment have undergone a delta qualification programme (as illustrated by the following matrix and pictures of equipment under test) and the RCS design validation was supported by two Hydraulic Mock-Up (HMU) #1 and #2 test campaigns, run during summer 2011 and summer 2013. All the test objectives have been reached. Two detailed articles presented the fluidic model correlation, see ref [4] and ref [5].

	Engine	Prop tank	Helium Tank	Pressure Reg	½" PV	Propellant filter	Helium filter	SAPT
Heat sterilization					X			X
Centrifuge (QS)		X	X					
Sine		X	X	X	X	X	X	
Random	X	X	X	X	X	X	X	
Shock		X			X	X	X	
Thermal cycling	X	X	X	X	X	X	X	
Operationnal perfo	X	X	X	X	X	X	X	
Pressure Cycling	X	X	X	X		X	X	
Burst	X	X	X	X	X	X	X	

Figure 7 – ExoMars delta-qualifications

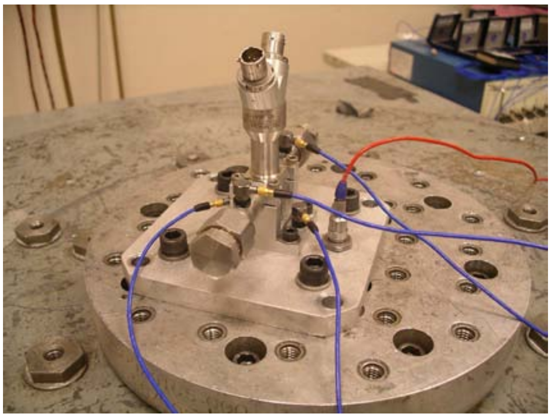

Figure 7 – Pyro-Valve under test

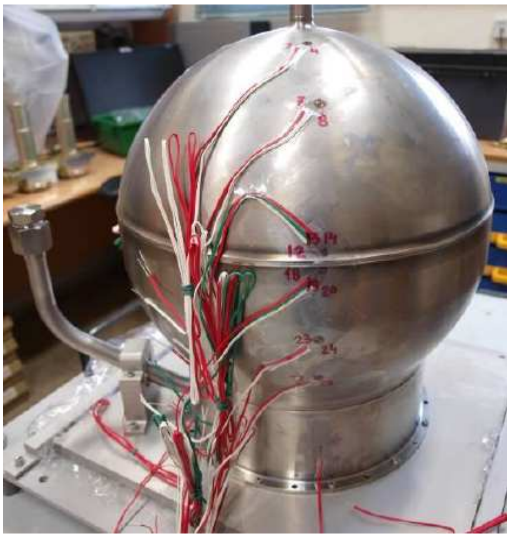

Figure 8 – Propellant Tank under test

Figure 8 – Helium Tank under test

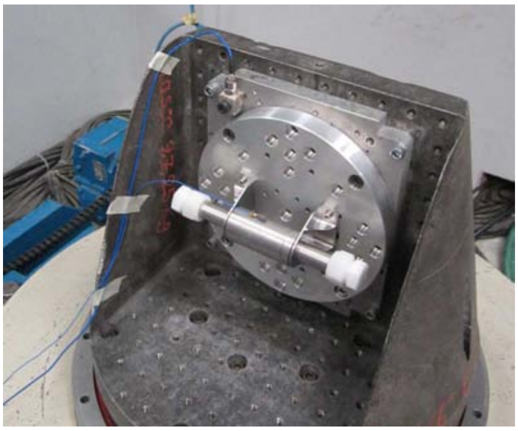

Figure 8 – Filter under test

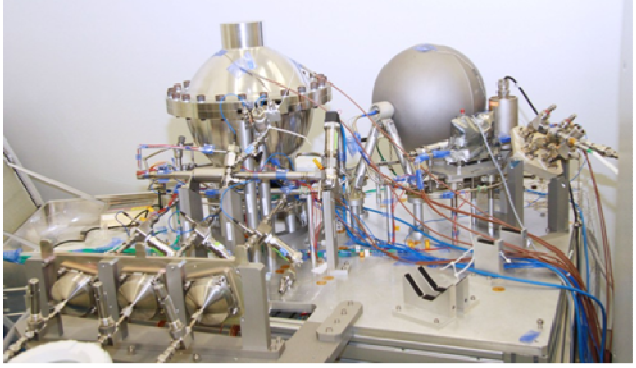

Figure 9 – HMU#2 Mock-Up

Then a Firing Development Model (FDM) will complete the qualification of the subsystem. For this test campaign Thales Alenia Space will re-use the HMU#2 mock-up and will simulate the full operating mission including engine firin with hydrazine. A Qualification Review will state for the flight certification. Final delivery is mid 2014.

6. Conclusions

Thanks to a strong effort of the TASF RCS team, the EDS RCS architecture has been successfully defined and tested at equipment and sub-system levels between 2011 and 2014.
Now the RCS is about to be delivered and the AIV activities will pave its way until lunch in January 2016….

Figure 10 – RCS under integration

7. References

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