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Overview of the Euclid Reaction Control System and Micro Propulsion Feed Assembly

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ABSTRACT

Euclid is an ESA cosmology mission aimed at mapping the geometry of the Dark Universe. The Reaction Control System (RCS) of Euclid consists of 10 pairs of 20N Hydrazine monopropellant thrusters that will be used throughout the mission for transfer correction manoeuvres and station keeping. In addition, due to the nature of the instruments on-board, exceptional attitude stability is required in order to provide fine pointing. This is achieved by another propulsion system: the Micro Propulsion System (MPS). It consists of 6 pairs of 1-1000µN microthrusters fed with Nitrogen propellant by the Micro Propulsion Feed Assembly (MPFA).

While the spacecraft Prime is Thales Alenia Space Italy (TASI), the design, procurement and AIT activities of both the RCS and the MPFA are placed under the responsibility of OHB Sweden. The Euclid mission is presented herein with a focus on the design challenges of both propulsion subsystems. The synergies between the RCS and the MPFA are discussed, along with innovative solutions considered by OHB Sweden to improve the cost-efficiency for both subsystems.

ACRONYMS

AIT = Assembly, Integration and Test
BOL = Beginning Of Life
CDR = Critical Design Review
CPS = Chemical Propulsion System
EOL = End Of Life
ESA = European Space Agency
FM = Flight Model
MIV = Manual Isolation Valve
MPFA = Micro Propulsion Feed Assembly
MPS = Micro Propulsion System
MTA = Micro Thruster Assembly
PDR = Preliminary Design Review
RCS = Reaction Control System
RCT = Reaction Control Thruster
STM = Structural and Thermal Model
TASI = Thales Alenia Space Italy
WGL = Weak Gravitational Lensing

1. INTRODUCTION

Euclid is an ESA Cosmic Vision Mission aimed at sending a spacecraft in orbit around the Lagrangian point L2 of the Sun-Earth system in order to map the geometry of the Dark Universe (Figure 1). The payload consists of a 1.2m diameter wide field telescope associated with visible and near-infrared instruments sharing a common large field of view. Euclid's main objective is to better understand dark energy and dark matter, estimated to account respectively for 68% and for 27% of the total mass-energy in the universe according to the standard model of cosmology, the last 5% corresponding to normal matter [1].

The first constituent of the so-called Dark Universe is dark energy, which is a form of energy thought to be responsible for the expansion of the universe at an accelerated rate. However, the existence of dark energy cannot be explained with our current knowledge of fundamental physics.

Its second constituent is dark matter, which is a hypothetical substance believed to account for around five-sixths of the matter in the universe. Dark matter exerts a gravitational attraction as normal matter but fails to absorb or emit enough radiation to be detectable with current imaging technology. Although it has not been directly observed, its existence has been theorized from various gravitational effects. While several candidates for dark matter exist in particle physics, its nature remains unknown.

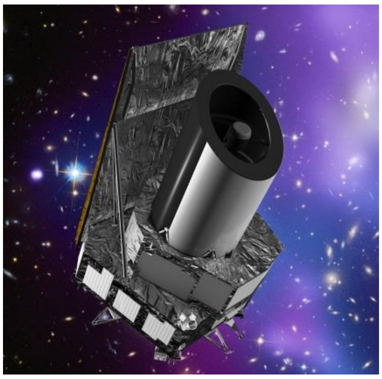

Figure 1 – Artist's impression of Euclid (credit: ESA)

Euclid will create a large and comprehensive map of the Universe around us, simultaneously tracing the distribution of both its luminous and dark components over more than one third of the sky [2]. In order to achieve this survey, Euclid will make use of its two main instruments:

- A visible wavelength camera will take advantage of Weak Gravitational Lensing (WGL) to map dark matter. WGL is a statistical approach quantifying the apparent distortions of galaxy images caused by mass inhomogeneities along the line-of-sight. The amplitude of the distortion can be correlated with the gravitational field, which in turn can be used to map the distribution of matter, and hence of dark matter. A simplified view of the distortion caused by dark matter located in between a background galaxy and an observer is presented in Figure 2.

- A near-infrared spectrometer and camera will measure the redshifts of millions of galaxies in order to provide information regarding the distribution of dark energy and the expansion of the Universe.

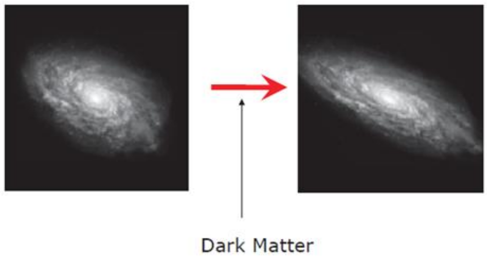

Figure 2 – Galaxy distortion caused by dark matter bending light, illustrating gravitational lensing (credit: ESA)

The Euclid spacecraft consists of one Payload Module with the telescope and the instruments and of one Service Module with among others two propulsion systems, thermal control and AOCS (Figure 3). The propellant tanks define the height of the main part of the Service module. A sunshield protects the whole Payload Module from direct sun illumination and guarantees a stable thermal environment to both telescope and optical bench [3]. Altogether, the spacecraft weights 2.2 tons, is 4.5 metres tall and is 3.1 meters wide.

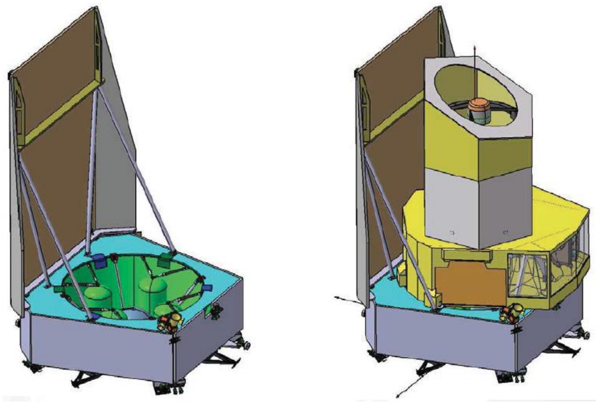

Figure 3 – Simplified view of Euclid Service Module (left) and of Euclid spacecraft (right) (credit: ESA)

Euclid is planned to be launched with a Soyuz rocket from French Guyana in 2020. A direct transfer of approximately 30 days will bring Euclid to L2 where it will follow a large-amplitude orbit during the 6 years of the survey. This orbit allows the spacecraft to have a constant illumination from the Sun, which is advantageous for obtaining a homogeneous data-set. Furthermore, there are no disturbances by the Earth magnetic field, no thermal perturbations, and benign radiation environment compared to an Earth orbit.

2. EUCLID PROPULSION

Euclid has at its disposal two independent propulsion systems located in the Service Module (Figure 4):

- The Reaction Control System (RCS) based on Hydrazine monopropellant thrusters.
- The Micro Propulsion System (MPS) based on cold gas microthrusters fed with Nitrogen propellant by the Micro Propulsion Feed Assembly (MPFA).

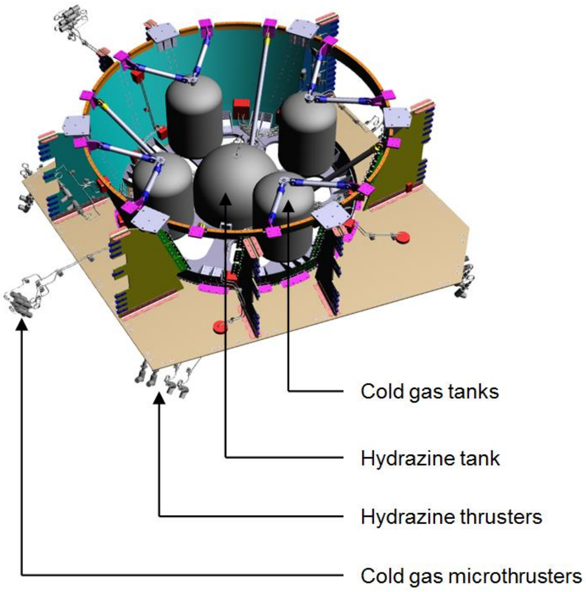

Figure 4 – Open view of the Euclid Service Module illustrating the location of the four cold gas tanks and of the Hydrazine tank (credit: OHB Sweden / TASI)

While the spacecraft Prime is Thales Alenia Space Italy (TASI), the design, procurement and AIT activities (phases B2 and C/D) of both the RCS and the MPFA are placed under the responsibility of OHB Sweden. The PDR for both subsystems took place in January 2016 and the project is now entering phase C/D. The design special features of both propulsion systems are presented in the following sections.

3. REACTION CONTROL SYSTEM

The function of the RCS is to provide the necessary DeltaV for transfer correction manoeuvres and station keeping throughout the mission so that Euclid remains in orbit around L2. It provides also the torques necessary for stabilising the spacecraft attitude after separation from the launcher, for managing the safe mode and for offloading the angular momentum accumulated by the reaction wheels. Additionally, the RCS will deliver the required thrust in order to allow decommissioning manoeuvres at the end of mission.

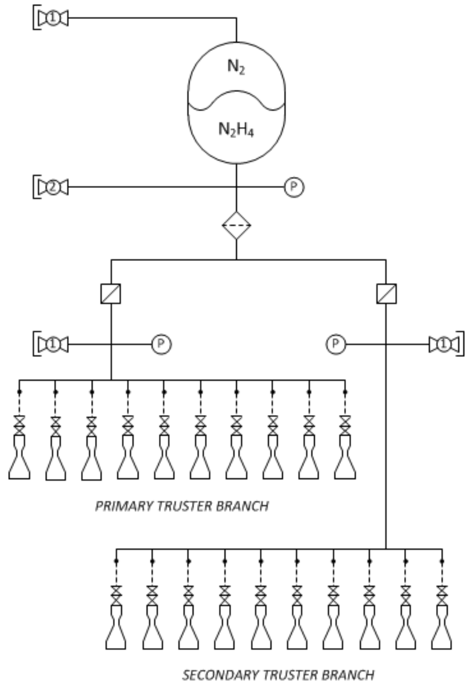

Figure 5 – Euclid RCS schematics (credit: OHB Sweden)

The RCS can be described as a classic blowdown monopropulsion system (Figure 5). Hydrazine is stored in a 173 litres diaphragm tank pressurized with Nitrogen. A filter is placed just downstream in order to reduce critical contamination from the propellant as it flows out from the tank in order to ensure that the propellant meets the system cleanliness requirements. Ten pairs of 20N monopropellant Reaction Control Thrusters (RCT) are distributed between the primary and the secondary thruster branches. The flow control valves of the RCTs feature a double-seat double-coil design. Two latch valves with position indicator are able to isolate the thrusters from the tank during launch and at any given time during the mission. Four service valves judiciously located enable transfer of test fluids, propellant and pressurant in and out of the internal volumes of the RCS during subsystem AIT, system level tests and filling/draining/venting operations. Lastly, three pressure transducers operated with a majority voting logic provide telemetry of the pressure in the propellant lines.

The Maximum Expected Operating Pressure (MEOP) in the RCS is set at 24 bar. The pressurant budget is determined so that for a given propellant loading mass, the pressure in the tank never exceeds MEOP at any time during the mission.

In order to determine the pressure drop from the tank to the RCT inlets at different phases of the mission, the RCS schematics of Figure 5 was modelled in EcosimPro and a pressure drop analysis was subsequently performed. As shown in Figure 6, all the propellant lines from the tank to the ten RCTs of the primary thruster branch have been modelled in the simulation.

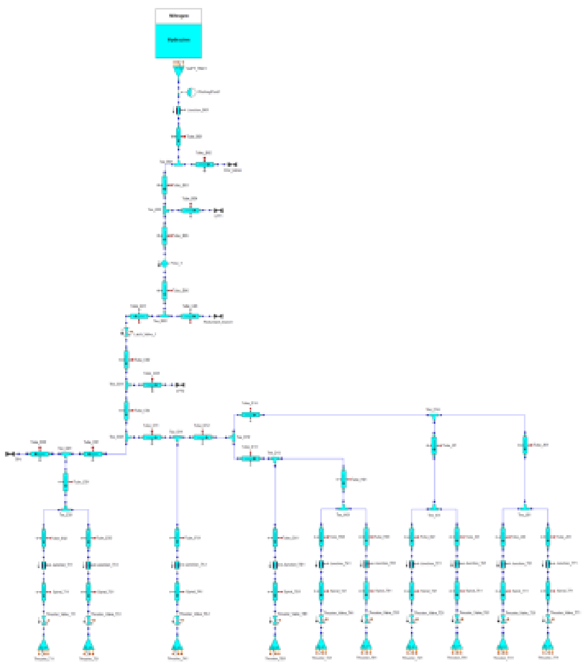

Figure 6 – EcosimPro schematics of the Euclid RCS (credit: OHB Sweden)

Several mission scenarios have been considered with different numbers of thrusters being simultaneously fired and with different system pressures, corresponding to Beginning Of Life (BOL) and End Of Life (EOL) cases. The simulations concluded that the ¼'' tubing layout and the baselined fluidic components are suitable for Euclid since they allow the RCS to meet its thrust requirements throughout the mission.

EcosimPro was also used to simulate the priming of the RCS and to make sure that adiabatic detonation of Hydrazine is avoided during this operation. The priming of the propellant lines, carried out by opening the two latch valves, is performed as soon as possible after separation with the launcher in order to ensure that the spacecraft is able to perform nominal and/or safe-mode operations from an early stage. Factors leading to a higher probability of adiabatic detonation are high pressure spike, high compression ratio and high pressurization rate. Several priming scenarios have been envisioned with the Euclid RCS architecture, with different pressure and media conditions downstream the latch valves; an example is shown in Figure 7.

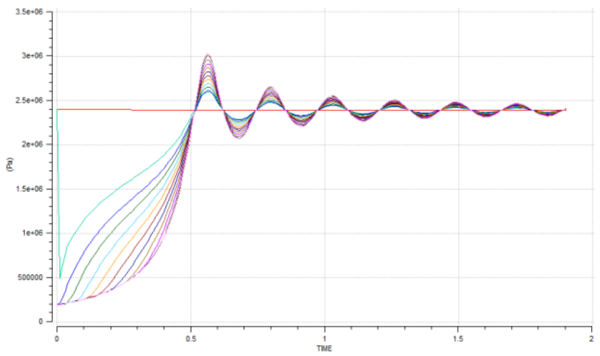

Figure 7 – Pressure in the propellant lines in function of time during Euclid RCS priming (credit: OHB Sweden)

This analysis will be iterated during phase C/D with the selected fluidic units; the priming case to be implemented in Euclid will be chosen accordingly.

4. MICRO PROPULSION FEED ASSEMBLY

Due to the nature of the instruments on-board Euclid, exceptional attitude stability is required in order to provide fine pointing. Conventional reaction wheels were discounted since their noise budget was too high [2]. Instead, fine attitude control is achieved separately by the Micro Propulsion System (MPS). This cold gas propulsion subsystem consists of 6 pairs of 1-1000µN variable microthrusters fed with Nitrogen propellant by the Micro Propulsion Feed Assembly (MPFA). The purpose of the MPS is to produce discrete variable thrust pulses to meet the attitude control requirements through life. The MPFA design, which doesn't incorporates the microthrusters, is placed under the responsibility of OHB Sweden. The rest of the MPS, i.e. the Micro Thruster Assembly (MTA), is placed under the responsibility of TASI.

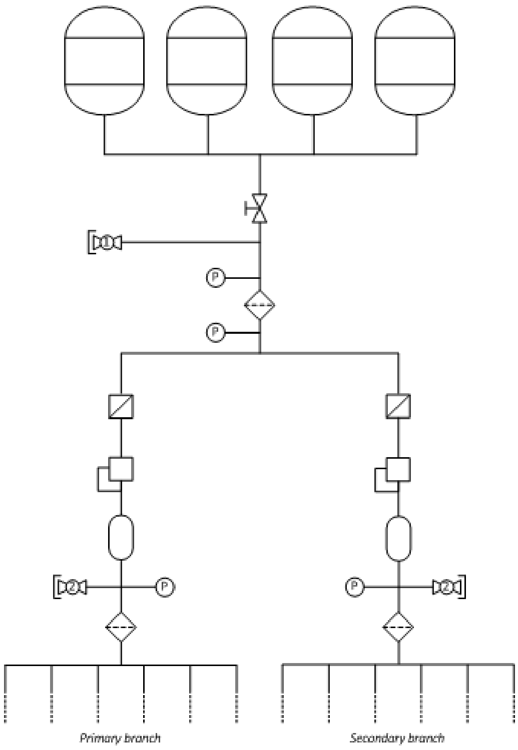

Figure 8 – Euclid MPFA schematics (credit: OHB Sweden)

A Nitrogen propellant load of approximately 70 kg is stored in four gas tanks reinforced with carbon fibre overwrapping, with a total volume of 268 litres. The preliminary design of the MPFA downstream the tanks consists of a Manual Isolation Valve (MIV) to isolate the gas tanks during testing, two latch valves to isolate the thruster branches, one mechanical single stage pressure regulator per branch to regulate the pressure to the desired level for the thrusters, high- and low-pressure filters, high- and low-pressure transducers and service valves (Figure 8). One plenum can be added in each branch if needed for pressure stability, as the MTA, not part of the MPFA, is very sensitive to pressure disturbances.

The MEOP in the MPFA is set at 310 bar on the high pressure side. On the low pressure side, the pressure regulator is reducing the pressure down to 1.5 bar for optimal operation of the microthrusters. The baselined pressure regulator is currently being characterised by test, first at OHB Sweden and then at TASI facilities. This test phase will end with a coupling test with the intention of demonstrating compatibility between the regulator and the microthrusters.

In order to define the regulator set-point with the best accuracy possible, the pressure drop in the lines between the regulator and the microthrusters was determined by EcosimPro fluidic simulations of the low pressure branches (Figure 9). Following this analysis, the regulator set-point is then defined as sum of the microthrusters nominal feed pressure and of the pressure drop in the low pressure lines.

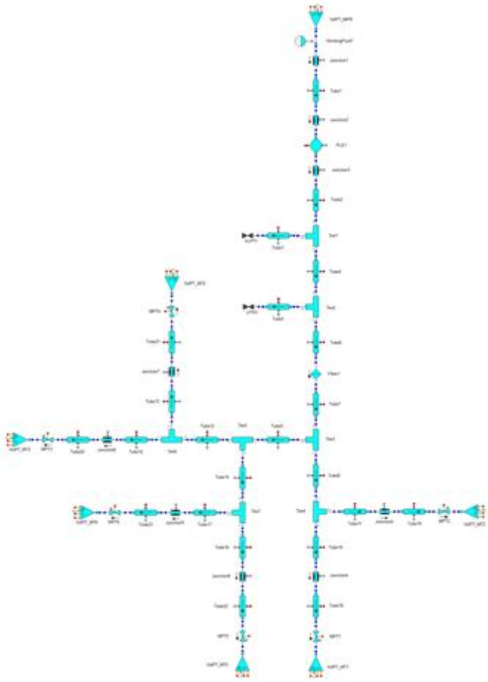

Figure 9 – EcosimPro schematics of the Euclid MPFA, downstream the pressure regulator in one branch (credit: OHB Sweden)

The MPFA design incorporates a manually operated isolation valve to isolate the gas tanks from the downstream high pressure sections of the MPFA. This MIV replaces a pair of normally closed pyrotechnic valves in parallel which would typically be used for the same application. In doing so, a high pressure service valve connected upstream the pyrovalves is no longer needed as the MIV can be opened and closed as required during AIT.

The MIV, with its locking bracket that locks it open for flight, is an off-the-shelf valve that will be qualified by OHB Sweden. It is an all-metal “ultra high purity” high pressure valve, similar to the MIV integrated by OHB Sweden in the electric propulsion system on the telecom platform Small GEO. Not only does the MIV save mass by replacing two pyrovalves, their associated brackets and harness, and a service valve, but also eases the testing phase as it can be opened and closed when needed.

5. SYNERGIES

OHB Sweden is carrying out the design, procurement and AIT activities for both the RCS and the MPFA. This generates synergies between the two subsystems in various areas as diverse as project management, requirements management, procurement, design work and AIT.

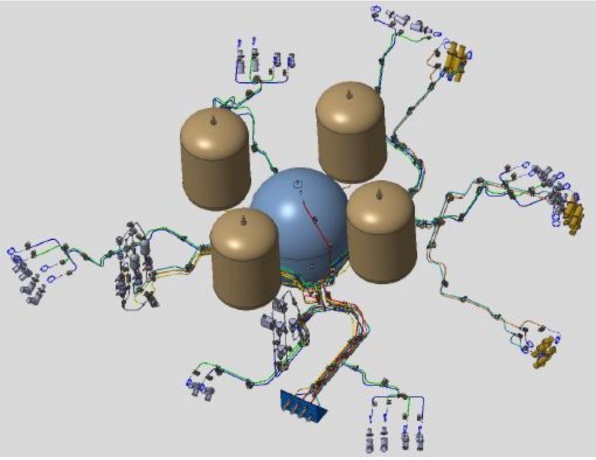

Figure 10 – Euclid RCS and MPFA tube routing from the tanks to the thrusters (credit: OHB Sweden)

Several units common to both subsystems have one unique requirements specification that applies for both the RCS units and MPFA units. As far as practicable, these units are also procured from the same source. For example, the RCS filter and the MPFA filters, even though being subjected to different sets of requirements, have only one requirements specification and are procured from the same supplier. This decreases the number of documents to be generated both at OHB Sweden level and at unit supplier level, decreases the number of reviews and reduces the overall procurement cost.

With regards to the design work, an obvious benefit in having the CAD work being performed by only one team is that the stay-out zones can be defined globally, panel cut-outs can be specified and be used by both subsystems in order to follow the same tube routing paths (Figure 10) and tube standoffs can be shared between the RCS and the MPFA (Figure 11). This last point also leads to mass savings since one shared tube standoff is lighter and more compact than two single ones. Regarding pipe brackets, OHB Sweden is currently developing for future programs a new design of modular tube standoffs aimed at providing more flexibility in the tubing layout.

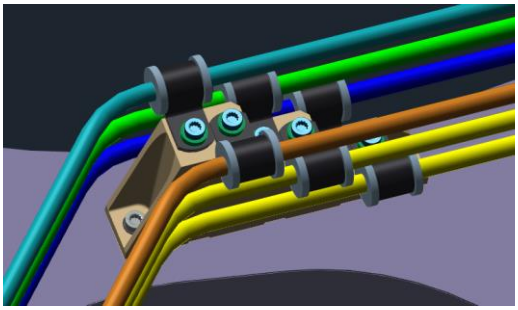

Figure 11 – Tube standoff supporting both RCS and MPFA tubes (credit: OHB Sweden)

Moreover, RCS thrusters and MPS microthrusters alignment requirements are met by using the same alignment spiral design in both subsystems (Figure 12). These spirals designed by OHB Sweden have been qualified within Solar Orbiter, a program in which OHB Sweden is responsible for the detailed design, procurement and AIT of the bipropellant propulsion system.

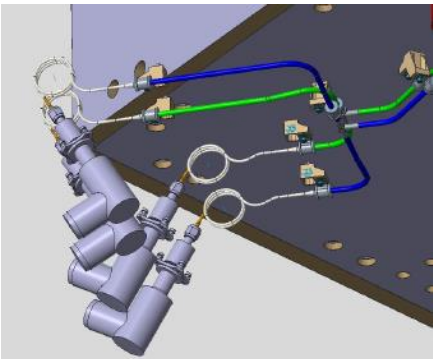

Figure 12 – RCS thruster pairs and associated alignment spirals (credit: OHB Sweden)

Lastly, the AIT work will be greatly facilitated by the fact that integration and tests don't necessarily have to be performed one subsystem after the other, but rather as a combined activity. For example, the proof pressure tests on both propulsion subsystems are planned to be performed simultaneously.

6. CONCLUSION

The propulsion architecture, sizing of key components and equipment layout of the Euclid RCS and MPFA were defined during Euclid phase B2. Following successful RCS and MPFA PDR in January 2016, the project is now entering phase C/D, aiming for subsystem CDR in the end of 2016. OHB Sweden will start the assembly work of the Euclid Structural and Thermal Model (STM) in June 2016 and of the Euclid Flight Model (FM) shortly after CDR. Support will be provided up to launch, with among others simulant loading and unloading during STM and FM environmental tests, health checks and system verification tests during the launch campaign. Euclid FM is, as of April 2016, planned to be launched in 2020.

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