Consortium for Hall Effect Orbital Propulsion System (CHEOPS)

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Electric propulsion is considered a revolutionary technology for its substantial contribution to the overall performance of scientific and commercial space missions. The ability to replace chemical propulsion with electric propulsion results in significant mass savings and a drastic reduction of the overall cost of the space system (launch cost being roughly proportional to the satellite mass). Another substantial advantage of electric propulsion, particularly Hall propulsion, is its ability to address a whole range of missions, thus stretching the field of possibility.

The CHEOPS project, which started in 2016, aimed to initiate the development of essential and competitive building blocks for the satellite market of the next decades: more specifically, it aimed to develop electric propulsion systems based on Hall-effect thrusters (HET EPS) in three different operating ranges, covering all current and future commercial and institutional space segments.

The CHEOPS EPS each comprise the following subsystems: a thruster unit (TU = anode block + cathode block), a power processing unit (PPU), and a fluid management system (FMS) or a propellant management assembly (PMA). In order to achieve the best system compromise, technical requirements (power, thrust, specific impulse, ergol, and lifetime needs), economic requirements (cost targets) and market forecast (segments and time-to-market) have been gathered from LSI.

CHEOPS low power electric propulsion system

With an operational power range from 300 W to 1 kW, the CHEOPS low power EPS (Figure 1) addresses a large market composed of Earth observation (EO) satellites disposing of low power on-board and of communication satellites on low- / medium Earth orbit (LEO / MEO). It is designed to perform the whole range of propulsive missions, including orbit raising (OR), station keeping (SK) and deorbiting manoeuvres.

Based on discussions with the customers (LSI) and trade-off analyses, the proposed LP EPS consists of a semi-integrated propulsion system; in particular, it provides for two blocks, one of which mechanically integrates the thruster and its fluidic system, leaving the installation of a PPU anywhere on the satellite, mainly for thermal management optimisation reasons.

In order to offer a competitive product, attention was paid to the system's lifetime capacity and propulsive performance (especially efficiency, thrust, and specific impulse). Throughout the design process, a design-to-cost approach was followed to ensure that the product would also meet the expected market price. Consequently, the product includes many low-cost or innovative parts, technologies, and processes, such as off-the-shelf components (COTS) or additive manufacturing (AM).

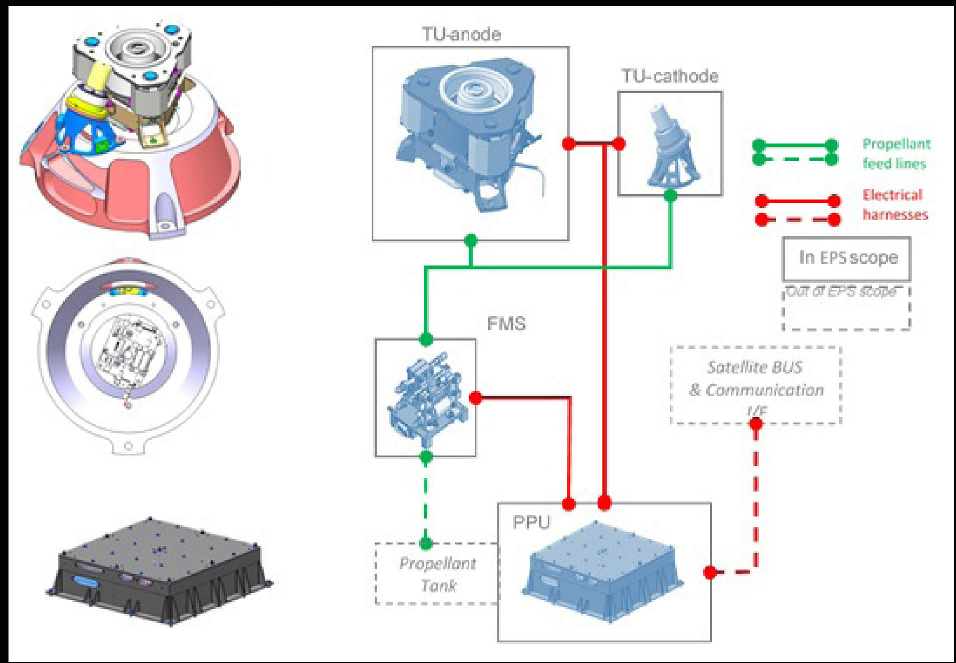


Figure 1: LP EPS design and functional description.

Acronyms, symbols and abbreviations

AD&S
Airbus Defence and Space

AM
Additive manufacturing

CHEOPS
Consortium for Hall Effect in Orbit Propulsion System

COTS
Off-the-shelf components

DDU
Direct drive unit

EPS
Electric propulsion system

E-T
Exploration transportation

FMS
Fluid management system

GEO
Geostationary Earth orbit

GTO
Geostationary transfer orbit

HET
Hall-effect thruster

HP
High power

IOD/IOV
In-orbit demonstration/in-orbit validation

Isp
Specific impulse

LEO
Low Earth orbit

LSI
Large system integrators (AD&S, TAS-F, OHB)

LP
Low power

MEO
Medium Earth orbit

MP
Medium power

NAV
Navigation market

OR
Orbit raising

PMA
Propellant management assembly

PPU
Power processing unit

SK
Station keeping

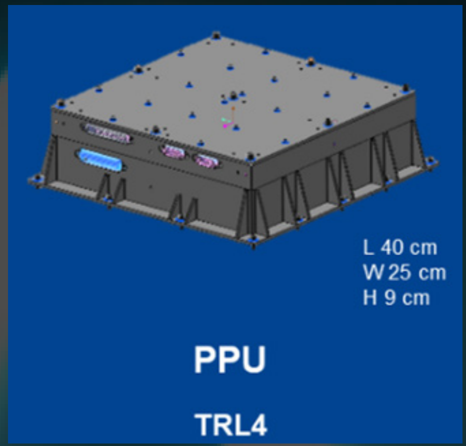
TAS-F
Thales Alenia Space - France

TRL
Technology readiness level

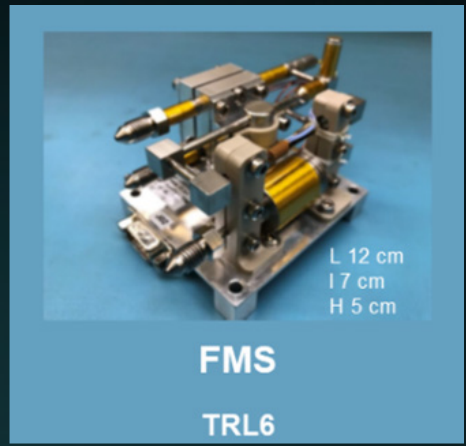
TU
Thruster unit

Minimum performance over life* (Xe)

**demonstrated during endurance on development model*



Communication Protocol CAN
Global efficiency, incl. FMS 90%
Mass Target 3 kg



Nominal Operating power 8,5 W (max)
Valve technology Single coil
Thermal regulation valve
Operating temperature range -5°C/+60°C
MEOP HP=300 bars
LP=10 bars

PPU input power, W	400	500	800	1000	
Thrust, mN	18,8	24	41,6	48	@300V
Isp, s	1 250	1 332	1 490	1 500	
Thrust, mN	16,8	22,3	37,6	44	@400V
Isp, s	1 350	1 413	1 673	1 744	

Figure 2: LP propulsion subsystem technical characteristics.

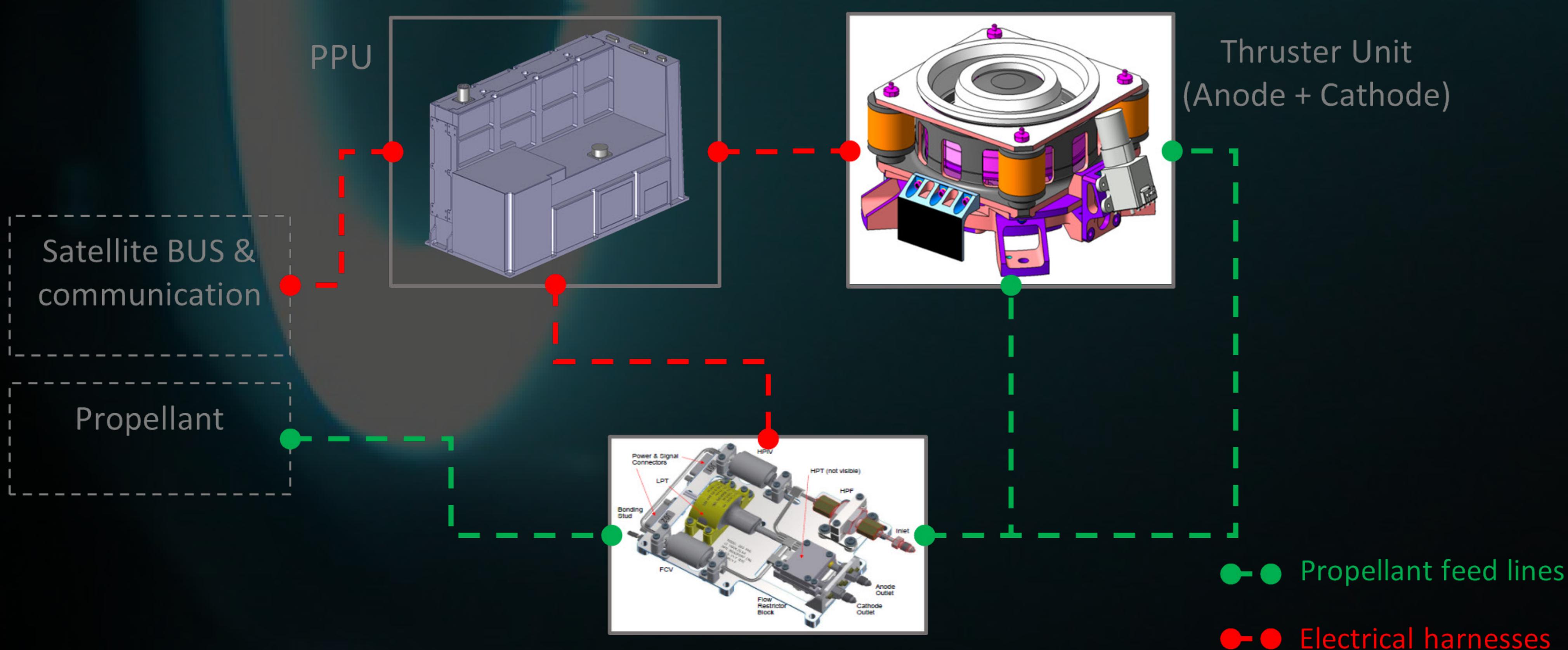


Figure 3: MP EPS subsystem and functional description.

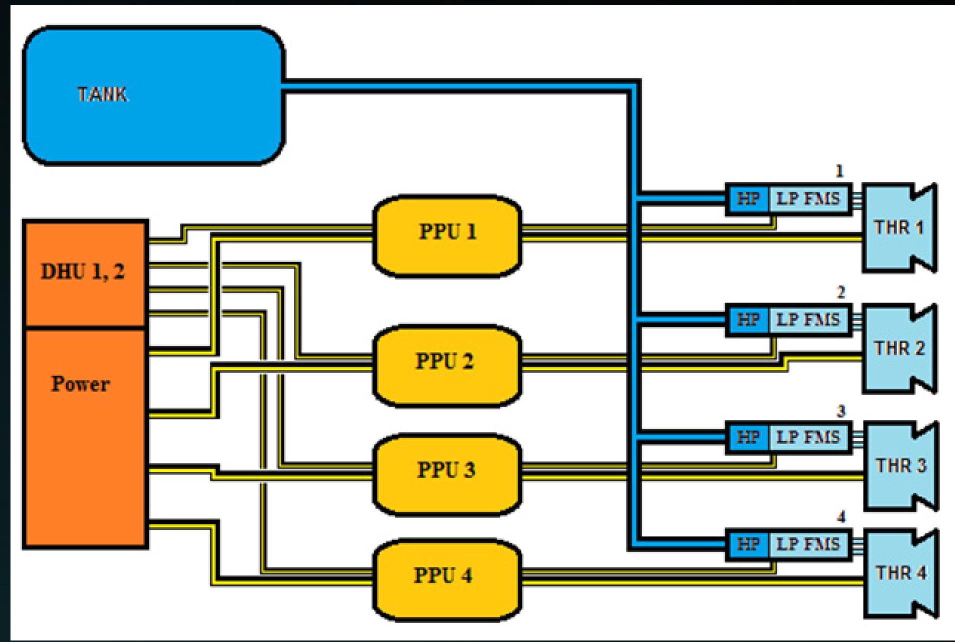


Figure 4: Selected MP EPSs architecture for NEOSAT-like missions (trade-off outcome).

Lastly, the operation of the whole system was demonstrated during a coupled test in late 2020, during which the compatibility with standard and alternative ergols, namely xenon and krypton, was verified.

CHEOPS medium power electric propulsion system

The CHEOPS medium power EPS (Figure 3) is a 5–7 kW-class propulsive system based on a dual-mode thruster and then features high thrust and high specific impulse operating modes, perfectly adapted to propulsive missions needs of the communication and navigation satellites.
In addition, many innovations were brought to the design of the thruster in particular, to allow for an extended lifetime, required for the extension of the application to OR missions, which represents more than ⅔ of the EPS required lifetime. The HET is an evolution of the current PPS®5000, which currently holds the published world record for total impulse. The objective of the CHEOPS upgraded HET is to double the demonstrated total impulse up to 30 MN.s.

Studies have been mainly focused over the course of the phase 1 CHEOPS programme on the optimisation of the system architecture by evaluating several solutions taking into account the system key drivers parameters (mass, complexity – integration constraints, development need and time to market, GTO/GEO transfer duration, propellant need and cost, cost estimation [RD05], reliability estimation).

Each architecture was evaluated with a set of HET solutions (different thrusts, Isp, Dual Mode capability, etc.), FMS (separated HP/LP FMS or integrated FMS), and associated PPU (power range, internal switches). This led to selecting the most promising alternative to the NEOSAT current architecture (Figure 4). Alternative architectures have been identified to answer specific needs or missions other than the NEOSAT-like missions. They will be evaluated in the following phase.

When run at the different operating points, a satisfactory behaviour of the system as a whole was verified during the coupled test performed in March 2021 into the DLR STG-ET test facility. In particular, almost no parasitic oscillations were observed in the discharge path, including the PPU, FMS and TU, when nominal running conditions prevailed.

There were no single events observed during the firing sequences, thanks to the very good outgassing under static vacuum that the TU was exposed to before firing up the first time.

CHEOPS high power electric propulsion system

The CHEOPS high power EPS (Figure 5) is a 15–25 kW-class propulsive system addressing future exploration and transportation applications, for which an improved couple of thrust and Isp performance is necessary to optimise the missions.

The CHEOPS activities mainly focused on the investigation of alternative architectures to reduce the system complexity and decrease the system budgets and the mission costs. The trade-off tests were performed with regards to the thruster architecture (cluster vs monolithic), the electronics system (PPU vs DDU), and the ergol (xenon vs krypton). Given that high performance (> 60 per cent of efficiency) and low erosion are targeted, the 'monolithic – DDU - krypton' architecture was selected due to its significant advantages in transfer time, propellant costs, and total power.

The TU consists of a high power magnetic shielded Hall thruster and one high-current hollow cathode (CAT) to provide the required thrust and total impulse. The FMS comprises an electronic pressure regulator and a flow control unit. Last, the main feature of the DDU is a direct supply of the anode load from a solar array. In a direct drive architecture, the optimal operating condition for the thruster depends on the characteristics of the power generated by the solar arrays. Feedback control of the mass flow to the thruster cannot be handled exclusively by elements inside the EPS. In order to track the peak power point, the mass flow control to the thruster needs to be handled at satellite level, which also needs to gather telemetry from the solar arrays, the power bus and the thruster parameters in order to control the mass flow to the TU correctly.

EPS	Item	Current TRL	Target TRL at the end of the CHEOPS/ASPIRE projects
Low power	Propulsive system	5/6	6/7
	TU	6	7
	FMS	6	7
	PPU	5	6
Medium power	Propulsive system	5/6	6/7
	TU	5	7
	FMS	6	7
	PPU	5	6
High power	Propulsive system	5	6
	TU	5	6
	FMS	5	6
	PPU	5	6

Table 1: TRL and performance achievements and objectives for the three HET EPS.

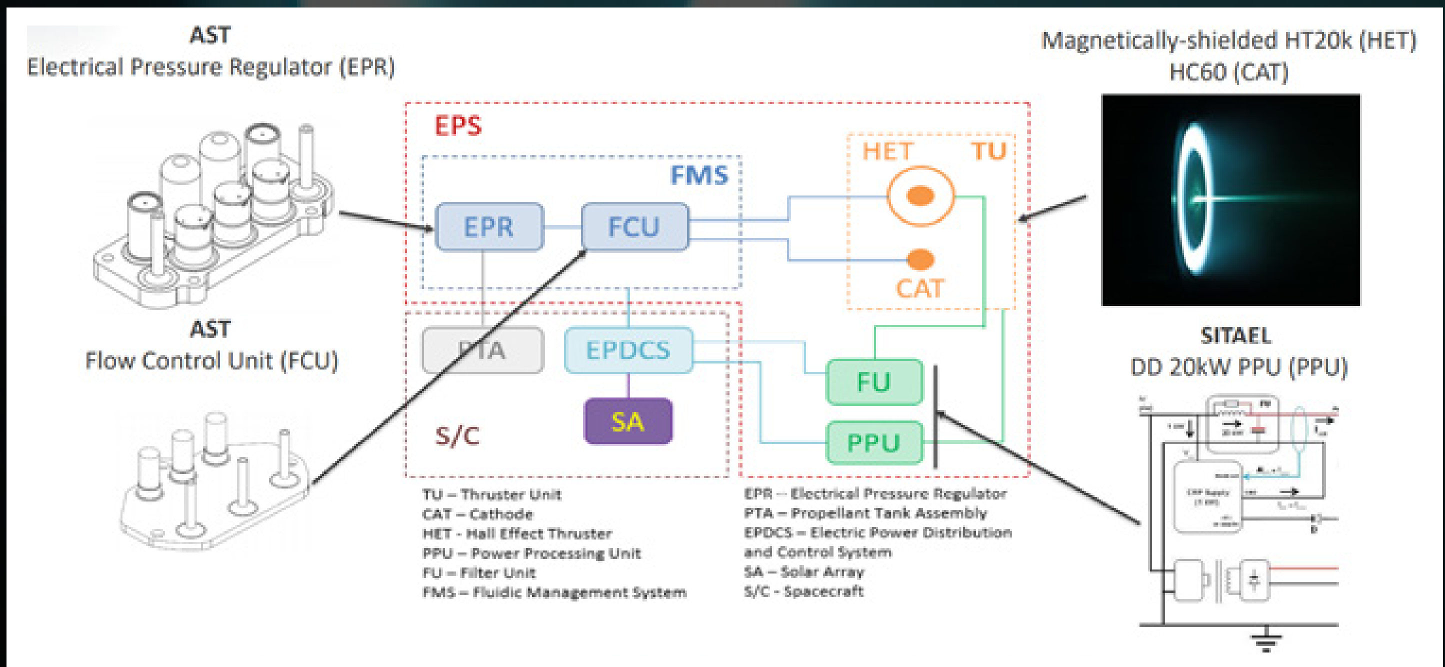


Figure 5: HP EPS architecture (trade-off outcome) (Courtesy of SITAEL and AST).

CHEOPS EPS achievements

In 2021, at the end of the pre-development phase made possible by the CHEOPS programme, the three systems successfully passed their PDR, validating their respective maturity level (Table 1). The work plans to achieve the maturity levels in the upcoming development phase have also been agreed upon. The target levels and associated dates are mentioned in the table.

These objectives are secured through programmes funded by the European Union (H2020 framework). Indeed, in summer 2020, Safran Aircraft Engines was awarded the lead of the CHEOPS Low and Medium Power projects by H2020, and SITAEL the lead of the ASPIRE project, which aims to develop these future products further to permit their application to a wide variety of satellite platforms, payloads and missions.

CONSORTIUM FOR HALL EFFECT ORBITAL PROPULSION SYSTEM

PROJECT SUMMARY

CHEOPS project proposes to develop three different Hall-effect thruster electric propulsion systems (EPS): a dual mode EPS for GEO applications, a low power for LEO applications and a >20 kW high thrust EPS for exploration applications. Each of these EPS are under development according to market needs and drivers applying incremental technology changes to existing EPS products.

PROJECT PARTNERS

The CHEOPS Consortium is led by Safran Aircraft Engines and is comprised of representatives of the biggest European Prime satellite makers (Airbus Defence and Space, OHB System, Thales Alenia Space), the full EPS supply chain (Advanced Space Technologies, Bradford Engineering, German Aerospace Centre (DLR), SITAEL) and supported by academia and research centres (Centre National de la Recherche Scientifique, Chalmers Technology University, SME4SPACE, Universidad Carlos III de Madrid).

PROJECT LEAD PROFILE

Vanessa Vial holds a PhD in plasma physics and a master's degree in energetics engineering from IUSTI. She joined Safran Aircraft Engines Space division in 2007 as technical responsible. After 13 years of experience in development, project management and technical team leadership, she joined the programmes department as head of the R&T programmes on space electric propulsion. She is the coordinator of H2020 CHEOPS project as well as the internal R&T project with space agencies (ESA & CNES).

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