ISSN 2599-8293

European Commission

CORDIS Results Pack on

in-space electric propulsion

A thematic collection of innovative EU-funded research results

June 2024

Research and Innovation

Contents

Editorial

Europe is well on the way to providing its booming satellite market with a cost-effective, highly efficient low-energy electric propulsion system. The result will strengthen Europe's space sector and open up new opportunities in Earth observation, telecommunications, on-orbit servicing and space exploration.

Over the last decade, advances in microelectronics and reduced launch costs have led to an increase in the number of satellites being put into orbit. Tens of thousands of satellites are now planned for launch in the coming years with the aim of improving Earth observation, navigation and communications.

There are currently more than 5 000 satellites in low-Earth orbit (LEO), circling our planet at altitudes ranging from 200 km to 1 600 km. However, LEO satellites are subject to orbital decay, where their distance from Earth gradually decreases, requiring an efficient low-thrust propulsion system for orbital 'station keeping'.

Electric propulsion (EP) is a revolutionary lightweight and highly efficient technology that is uniquely qualified to keep LEO satellites traversing above the globe. This class of space propulsion makes use of electrical power to accelerate a propellant through different possible electrical and/or magnetic means.

The use of electrical power enhances the performance of satellite thrusters compared to conventional chemical thrusters. Unlike chemical systems, EP requires very little mass to accelerate a spacecraft. The propellant is ejected up to 20 times faster than from a classical chemical thruster and therefore the overall system is many times more efficient.

This fact is of particular importance for spacecraft intended for in-orbit servicing and transportation missions. High-power EP systems could also contribute to missions to the moon, Mars and the asteroid belt as their higher power translates into higher thrust values, compared to chemical propellants or solar energy from onboard panels.

EP is a key enabling and strategic technology for the EU Future Space Ecosystem and for ensuring European global leadership in the areas of in-space operations and transportation. Its development will also reduce Europe's dependency on foreign suppliers of critical space technologies, ensuring its independent access to space.

This new CORDIS Results Pack highlights the main achievements of 12 EC-funded Horizon research projects within the Strategic Research Cluster (SRC) on Electric Propulsion. The SRC strengthened European EP research along two complementary technology development lines.

The first focused on incremental technologies like Hall-effect thrusters, gridded ion engines and high-efficiency multi-stage plasma thrusters (projects ASPIRE, CHEOPS LOW POWER, CHEOPS MEDIUM POWER, GIESEPP MP, HEMPT-NG2). The second featured other promising and potentially disruptive technologies in the field of EP, including innovative thruster concepts and new supportive technologies (projects AETHER, EDDA, HIPATIA, iFACT, NEMESIS, PJP). The EPIC2 project supported the European Commission in identifying activities that address research challenges for Europe, and assessed projects' activities and results.

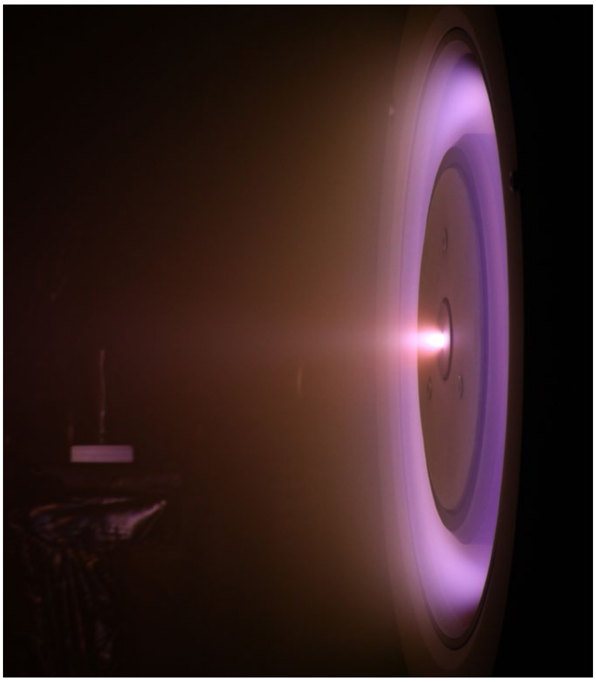
New orbits on the horizon, with air-breathing engines

Powered by the surrounding atmosphere instead of gases carried into orbit from Earth, novel engines open the door to very low earth orbital satellites.

Electric propulsion (EP) thrusters are the future for scientific and commercial satellites. But propulsion is a limiting factor: as soon as the propellant used to create thrust is depleted, the satellite can no longer manoeuvre and reaches the end of its operational lifetime. The EU-funded AETHER project addresses this issue by using residual gases of the upper atmosphere instead of on-board propellant, allowing satellites in very low earth orbit (VLEO) to remain in service for longer and become more cost-effective.

New opportunities in VLEO

Thousands of satellites fill the sky above our heads, particularly in low earth orbit. VLEO is enticing, as it offers enhanced resolution for earth observation and increased speed in telecommunications.



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But satellites at this altitude – roughly 200 km from the Earth's surface – are difficult to maintain. Due to the thin but not insignificant atmosphere, satellites in VLEO must constantly counteract the drag of the surrounding air. This rapidly depletes a satellite's propellant. Using the air itself as a propellant is a game-changer, as it is in inexhaustible supply.

While VLEO represents the most market-ready operative scenario for air-breathing EP engines, interplanetary exploration is also a suitable application, as an atmosphere-breathing EP thruster can be used near a celestial body. Mars, as well as Saturn's moon, Titan, are both good candidates for this.

The RAM-EP thruster

Europe is in the vanguard for developing this technology. In 2017, aerospace leader SITAEL produced and tested on ground the RAM-EP – the world's first air-breathing thruster. According to Stefan Gregucci, head of propulsion at SITAEL: "The aim of the AETHER project was to pave the way for VLEO satellites by concentrating on the air-breathing propulsion system optimisation. The RAM-EP system has been patented within AETHER, thus strengthening SITAEL's position and competitiveness in this very promising segment of the market."

The aim of the AETHER project was to pave the way for VLEO satellites by concentrating on the air-breathing propulsion system optimisation. The RAM-EP system has been patented within AETHER, thus strengthening SITAEL's position and competitiveness in this very promising segment of the market.

While the concept of an air-breathing thruster is straightforward, creating such a system brings many challenges. To produce thrust, the system must collect the incoming air flow, ionise it, and accelerate the produced ions to a speed considerably higher than the orbital velocity.

In the harsh environment of VLEO altitudes, characterised by strong atomic oxygen corrosion, materials are put under a great deal of stress. This aspect adds to the intrinsic complexities of the RAM-EP functional design. Matteo Ciolini, propulsion engineer at SITAEL, states: "The aim for improved ionisation capabilities led to critical thermal and electrical design constraints, forcing us to explore new ceramic materials, unconventional shapes of the intake and also advanced manufacturing processes."

Replicating the environment

AETHER built on and improved the RAM-EP design in multiple ways. The team designed two novel acceleration stages and tested one with atmospheric propellant. To mitigate the effects of the environment, engineers designed and tested a compact radio frequency cathode. Based on numerical flow simulations, the intake thruster was significantly redesigned. Finally, AETHER employed a particle flow generator to simulate the atmospheric composition and velocity a spacecraft faces in VLEO.

The next steps in developing this disruptive technology involve testing the improvements made during the course of the project. The ultimate goal will be designing a spacecraft which incorporates the RAM-EP system. Air-breathing EP engines in VLEO satellites are still on the horizon, but AETHER has advanced the technological readiness level of this exciting innovation in space propulsion.

PROJECT
AETHER - Air-breathing Electric THrustER

COORDINATED BY
SITAEL in Italy

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/870436

PROJECT WEBSITE
aether-h2020.eu/

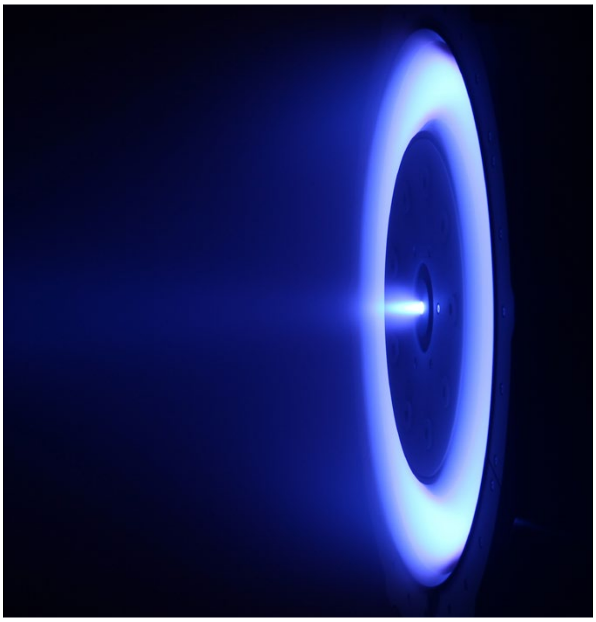
High-power thrusters fuelling future spaceflight

High-power electric propulsion is the key to revolutionising space exploration and transport, tackling orbital debris and enabling new robotic and crewed missions. ASPIRE paved the way for powerhouse electric engines as the prime technology for these advancements.

Traditional chemical propulsion methods – which rely on burning fuel to generate thrust – are being gradually overshadowed by electric propulsion systems (EPSs), particularly those based on Hall-effect thrusters. Leveraging an electromagnetic field to ionise and accelerate a gas, EPSs offer a substantial improvement in specific impulse over their chemical counterparts, providing spacecraft with a considerable mass advantage.

The path to high-power electric propulsion systems

After extensive research and development, electric propulsion has become a reality, with low-power systems already being used in space missions. However, the demand for high-power thrusters is growing, driven by the needs of future space exploration and transport missions, and the deployment of versatile service platforms like the space tug for in-orbit servicing and debris removal.



High-power EPSs, particularly those in the 20 kW class, are pivotal to these platforms, offering the ideal balance of operational flexibility and thrust-to-power ratio. However, the path to qualifying such advanced systems for use in space has been hindered by prohibitive costs and extensive testing times.

A significant advancement in the technology maturity and an alternative qualification strategy proposed by the EU-funded ASPIRE project sought to overcome these challenges. By performing a coupling test at system level and then by integrating advanced numerical modelling with targeted test campaigns, ASPIRE's strategy sought to deliver a cost-effective and methodical pathway for developing and qualifying high-power Hall-effect thruster systems.

Unprecedented achievements in thruster testing

The team started with various application scenarios that could benefit from such powerful EPSs, establishing high-level requirements. Leveraging the experience gained from working on lower-power EPSs, the researchers advanced the design of various subsystems and components, including the thruster unit, the fluidic management system and the power architecture. Each of these subsystems underwent separate testing phases before the team undertook the most challenging task of integrating and testing the complete EPS at a system level.

The final test of the integrated EPS was executed at the SITAEL's IV10 facility, one of the largest vacuum chambers for electric propulsion testing worldwide.

"During our groundbreaking tests, the thruster was ignited multiple times, successfully operating within the desired power range of 12.5 to 25 kW, using both xenon and krypton as propellants," highlights project coordinator Matteo Angarano. "This phase allowed us to explore various aspects of EPS operation in direct-drive mode and high-voltage conditions. The direct-drive architecture allows to significantly reduce the mass and increase the efficiency of the power electronics."

"A groundbreaking aspect of ASPIRE is its consideration of krypton as a propellant. Traditionally, xenon has been used, but krypton offers a cost-effective alternative, reducing the qualification costs by at least an order of magnitude," adds Angarano. "Moreover, even if not originally foreseen, we also decided to test the thruster with argon. Argon is recently being considered an even more economical alternative to krypton for electrical propulsion. This was the first successful test worldwide in operating a 20 kW thruster with argon."

Researchers studied pertinent plasma phenomena and developed simulation codes to evaluate the performance of the thruster over time and across different operating conditions.

Pioneering the future of space exploration

No other EPS above 12.5 kW has yet reached the qualification stage, positioning ASPIRE's system among the forefront of advancements poised for qualification and an in-orbit demonstration. This leap is partly due to ASPIRE's innovative strategy, which leverages predictive numerical tools – a first on a global scale – to streamline the qualification process.

"It was a challenging project, but ultimately the results rewarded our efforts. I am looking forward to soon seeing an electric thruster propel a spacecraft to Mars and beyond," concludes Angarano.

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PROJECT
ASPIRE - Advanced Space Propulsion for Innovative Realization of space Exploration

COORDINATED BY
SITAEL SPA in Italy

FUNDED UNDER
Horizon 2020-LEIT-SPACE

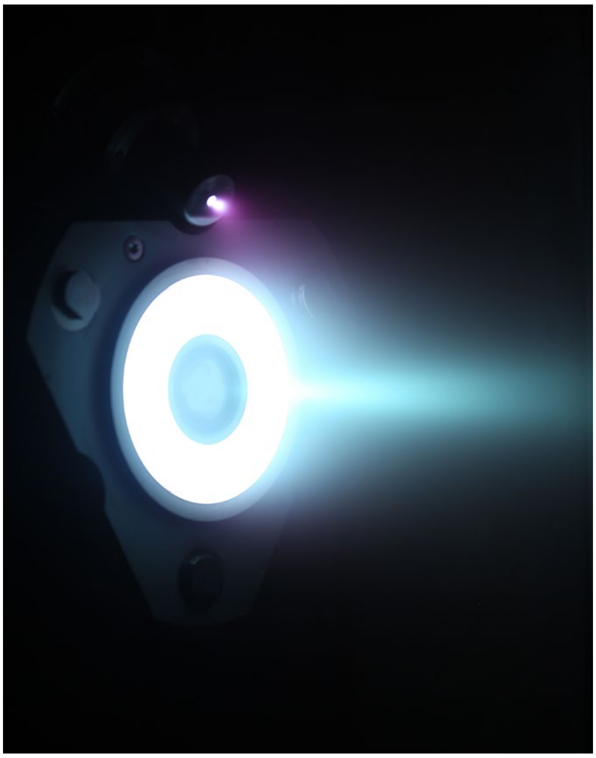
CORDIS FACTSHEET
cordis.europa.eu/project/id/101004366

PROJECT WEBSITE
aspire-h2020.eu/

Improved low-power electric propulsion holds promise for future satellite networks

Low-power electric thrusters, essential for satellite constellations, open new possibilities for global communication, navigation and environmental monitoring. An EU-funded project is redefining their design to extend their lifespan, lower production costs and introduce flexible fuel usage.

The satellite industry is rapidly evolving, especially in the low and medium Earth orbit (LEO/MEO) sectors, pushing Europe to innovate swiftly to enhance its strategic position globally.



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Achieving high performance, compatibility with mass production, quick adaptability and competitive prices are crucial for Europe's success in the satellite market.

To cater effectively to this target market, low-power electric propulsion systems need to be highly flexible, capable of operating with both xenon and krypton propellants across a wide power range, up to 1 kW.

The dawn of low-power thruster systems

Building upon the successes of CHEOPS I, the EU-funded CHEOPS LOW POWER project aims to bring incremental advancements to the first European low-power electric propulsion system by early 2025. The research focuses on key components such as the Hall-effect thruster unit and the fluid management system reaching technology readiness level (TRL) 7, as well as the power processing unit achieving TRL 6.

"We seek to overcome challenges related to compactness, modularity, extended service life, low costs and high production rates, and flexible propellant management," notes project coordinator Vanessa Vial. "We also target the introduction of a qualification strategy for the thruster unit to lower recurring costs through a standardised approach for all customers."

To achieve these goals, CHEOPS LOW POWER is adopting a design-to-cost strategy, using commercial off-the-shelf components and implementing lean production approaches. It intends to leverage new technologies and develop advanced numerical design tools for electric propulsion to better predict thruster performance and behaviour in its operational environments. Moreover, researchers will seek to standardise Hall-effect thruster diagnostics, laying the groundwork for its upcoming in-orbit demonstration.

Accelerating innovation in low-power electric propulsion

By the end of the first project phase, functional and mechanical tests have confirmed that the thruster unit, power processing unit and fluid management system are compatible with both xenon and krypton propellants, achieving up to 1 kW power. Their performance met or even surpassed current benchmarks in the field. A major milestone was reached with the successful completion of the functional design review of the low-power electric propulsion system in 2023. Coupling tests are on the agenda for mid-2024, with the qualification status review planned for the end of this year.

Researchers have also enhanced HYPHEN-2, a multi-thruster simulation platform, by implementing new algorithms that more accurately represent plasma discharge, thruster design and boundary conditions. The improvements expanded the tool capabilities to evaluate alternative propellants and estimate thruster system lifetime. They also achieved a significant reduction in simulation time by 33 %.

Diagnostic methods have been refined and expanded to further understand and analyse plasma parameters within the thruster system. Optical emission spectroscopy combined with a collisional radiative model has proved effective during test campaigns. Test results were compared with those from Langmuir probe measurements, revealing a high degree of similarity in the internal plasma parameters obtained. "Such findings underscore the value of optical emission spectroscopy as a non-invasive diagnostic tool. Its implementation in testing facilities and in-flight monitoring holds promise for the real-time detection and monitoring of critical parameter shifts," explains Vial.

Moreover, time-resolved laser-induced fluorescence has been instrumental in correlating transient or oscillatory behaviour of the thruster unit with the underlying physics which cause instabilities or oscillations.

"By 2025, CHEOPS LOW POWER is set to revolutionise the LEO/MEO satellite markets worldwide, particularly the satellite constellation sector. Over time, the initiative aims to transform the satellite design and manufacturing sector by pioneering an approach that integrates industry capabilities and client needs right from the outset," concludes Vial.

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PROJECT
CHEOPS LOW POWER - Consortium for Hall Effect Orbital Propulsion System – Phase 2 covering LOW POWER needs

COORDINATED BY
SAFRAN SPACECRAFT PROPULSION in France

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004331

PROJECT WEBSITE
lp.cheops-h2020.eu/

Medium-power electric thrusters reach new heights

An EU-funded project is advancing satellite technology with improved medium-power electric propulsion systems using cutting-edge thrusters. The initiative addresses the complex requirements of upcoming space missions, ensuring precise orbit-raising and reliable station-keeping.

Our activities involve perfecting the system to operate efficiently in both the high-thrust mode for orbit-raising and high-impulse mode for station-keeping, while also ensuring low fuel consumption and compatibility with both xenon and krypton propellants.

To keep pace with the evolving demands of next-generation large satellite deployments, Europe is committed to providing its space industry with a highly competitive and reliable propulsive solution.

The EU-funded CHEOPS MEDIUM POWER project focuses on the development of a medium-power electric propulsion system (EPS) leveraging Hall-effect thruster technology, which is poised to revolutionise how spacecraft are propelled.

Elevating performance standards

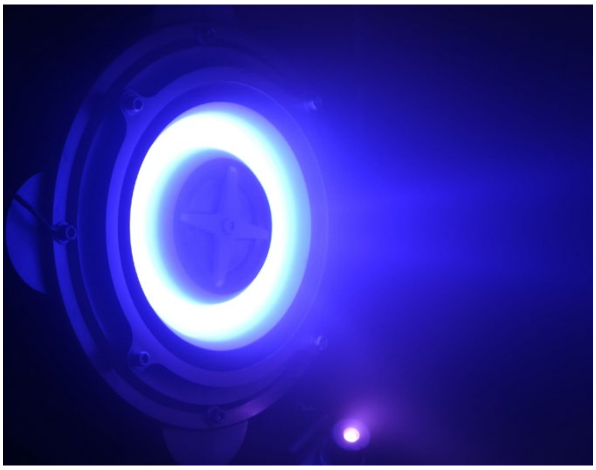
Spearheaded by Safran Spacecraft Propulsion, the consortium aims to achieve a technology readiness level (TRL) of 6/7 for a medium-power dual-mode EPS. “Our activities involve perfecting the system to operate efficiently in both the high-thrust mode for orbit raising and high-impulse mode for station keeping, while also ensuring low fuel consumption and compatibility with both xenon and krypton propellants,” notes project coordinator Vanessa Vial.

Project partners also aim to reduce the total EPS costs by 30 % for satellites in geostationary Earth orbit and navigation configurations. Drawing on extensive experience, they focus on design-to-cost optimisation approaches, streamlining production processes and enhancing system/subsystem functionalities.

Lastly, the project seeks to enhance diagnostic approaches for ground testing and potential in-space applications, aiming to better understand the effects of terrestrial conditions on system performance.

System improvements

To achieve its objectives, project partners focus on incremental developments at system and subsystem levels. “This should enhance the maturity of certain key components, namely the thruster unit, power processing unit and the fluid management system, elevating them to TRL6/7 by 2024,” states Vial.



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Efforts to optimise the power processing unit include streamlining its functions and selecting cheaper yet equally reliable components. The fluid management system will incorporate commercial off-the-shelf products that qualify for space, ensuring it can support a variable number of thrusters per satellite. Furthermore, the thruster unit will cover various missions in the target market segment, significantly reducing the need for new product development with each mission.

Project activities

The project began by designing flexible equipment that could adapt not just to the reference architecture but to various missions. This involved a detailed reliability analysis as well as calculating the balance between power requirements, power-to-thrust ratios and the performance trade-offs necessary for optimising both orbit raising and station keeping.

The second phase shifted focus towards refining the technical specifications of the medium-power EPS, incorporating feedback from large system integrators to enhance both orbit-raising and station-keeping capabilities.

Parallel developments in non-intrusive diagnostics offered insight into thruster performance and internal dynamics, revealing complex oscillations and rotating spokes under specific conditions. The development of the Club Design software and the EP2PLUS-2 code facilitated value cost analysis and accurate plasma plume simulations, respectively.

Hitting new milestones in medium-power electric thrusters

Building on the successes of its initial phase, CHEOPS MEDIUM POWER aims to make the European space industry more competitive. "Our ambition is to introduce worldwide an EPS that offers high thrust and high specific impulse, while also boasting an extended lifecycle. This innovative EPS design should cater to both traditional markets – telecommunications and navigation – and emerging sectors," explains Vial.

CHEOPS MEDIUM POWER also addresses future market demands, seeking to cut both non-recurring and recurring costs across design, manufacturing, testing, qualification and delivery times. "We seek to streamline production processes to achieve shorter fabrication cycles, improved quality, leaner manufacturing, faster assembly lead times and enhanced tolerance management. Ultimately, we aspire to fundamentally transform design and manufacturing practices in the long term, thereby increasing valuable payload and generated revenues," concludes Vial.

PROJECT
CHEOPS MEDIUM POWER - Consortium for Hall Effect Orbital Propulsion System – Phase 2 covering MEDIUM POWER needs

COORDINATED BY
SAFRAN SPACECRAFT PROPULSION in France

FUNDED UNDER
Horizon 2020-LEIT-SPACE

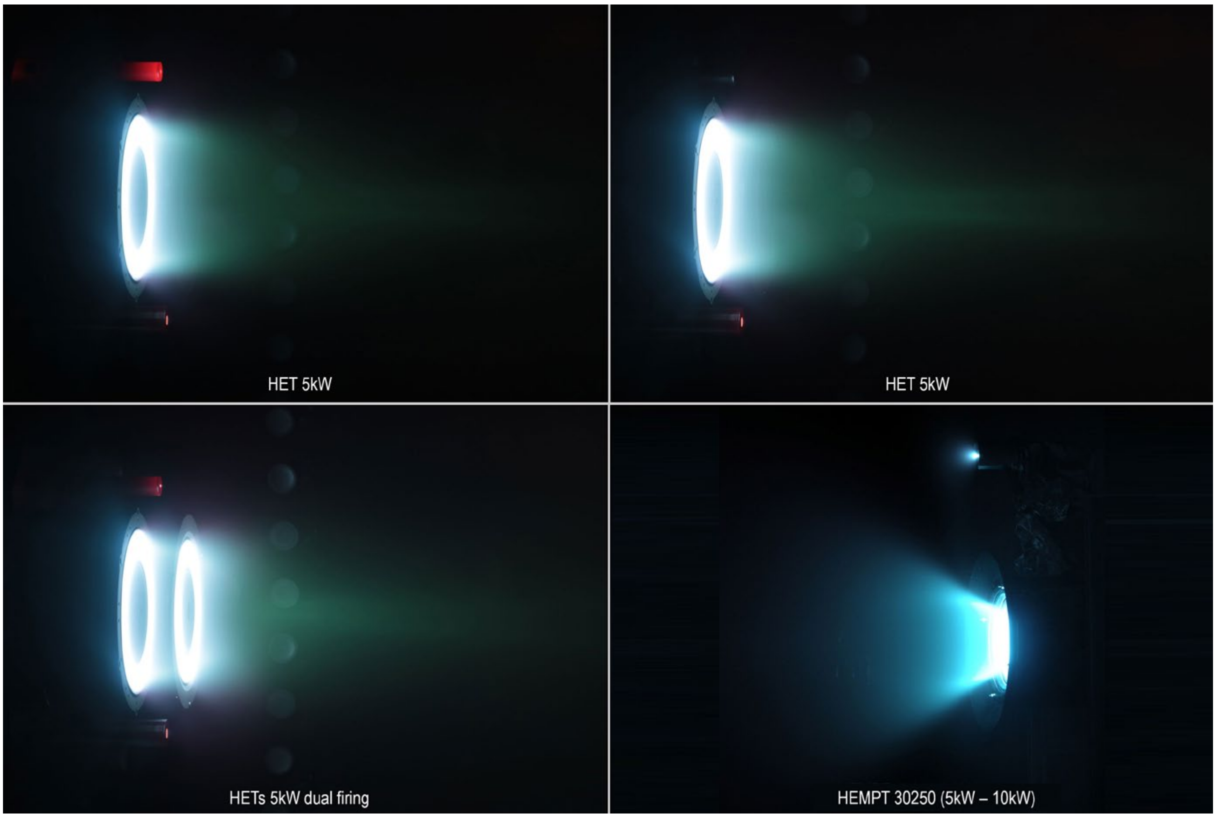
CORDIS FACTSHEET
cordis.europa.eu/project/id/101004226

PROJECT WEBSITE
mp.cheops-h2020.eu/

Direct drive improves solar electric propulsion performances in a spacecraft

Testing how onboard solar arrays deliver electric power to thrusters without the need for a power converter helps develop a game-changing disruptive technology.

Electric propulsion (EP) is key to the future of spacecraft because it provides a large saving in propellant mass. A variety of electric thrusters are on the market, using propellants such as xenon gas, and solar energy from onboard panels to generate electricity. But current technology requires bulky power converters to deliver electricity at a specified wattage. The EU-funded EDDA project tested how direct drive architecture can bypass the need for a power converter in multiple thrusters already on the market by being directly supplied by an onboard solar array at high voltage, up to 400 V.



Thruster performance in simulated space missions

Current technology requires a power converter to boost EP voltage to 250 V and higher to fuel thrusters aboard spacecraft. EDDA analysed several direct drive architectures and tested a new electronic power unit developed by partner Thales Alenia Space in Belgium.

The power unit is designed to work with some existing and future thrusters, such as the Hall Effect Thruster (HET), designed by multiple space companies, including project partner Sitael, and the High Efficiency Multistage Plasma Thruster (HEMPT) built by Thales-D. According to project coordinator Gilles Bouhours: "EDDA integrates electrical power supply and propulsion. Currently, these subsystems are well separated. For EDDA, power management simultaneously controls several thrusters to optimise power and propulsion performances."

Using solar array simulators, different thrusters were tested multiple times, assessing direct drive EP performance in mission simulations related to launch, orbital change and on-station operations. Test results were highly encouraging, with nearly 100 % of power extracted from panels and negligible thermal losses.

Advanced simulations were performed by Universidad Carlos III de Madrid UC3M, where thruster oscillations were analysed in detail. In Extenso Innovation Croissance coordinated the project management.

Applications for direct drive architecture

Spacecraft launches are very costly, and removing power converters from the payload not only reduces cost, but also increases the capacities and capabilities of spacecraft with additional fuel or equipment.

The direct drive architecture has three main market applications. Telecom satellites in geostationary orbit – those at about 36 000 km altitude above Earth – will be well-served by the significant cost and mass reductions realised by faster Electric Orbit Raising, made possible by mature EP technologies.

The ultimate aim of EDDA is to provide a powerful solar electric propulsion system to transport any cargo from one Earth orbit to another, or to another planet.

On-Orbit Services is an emerging market. It allows spacecraft to visit existing satellites and address several needs, such as life extension, spacecraft relocation, maintenance with Orbital Replacement Units and debris removal.

Direct drive EP enables deep space exploration. Missions to the moon, Mars and asteroids require transport of massive payloads. For cargo with EP, this requires a large amount of power to provide propulsion, and direct drive solutions help to meet that need. As Bouhours says: "The ultimate aim of EDDA is to provide a powerful solar electric propulsion system to transport any cargo from one Earth orbit to another, or to another planet."

Project partners come from five companies and one university across Belgium, Germany, Spain, France and Italy. By coordinating with the makers of the most prevalent thrusters used in space, EDDA has positioned direct drive technology for rapid uptake.

PROJECT
EDDA - European Direct-Drive Architecture

COORDINATED BY
Thales Alenia Space in France

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/870470

PROJECT WEBSITE
edda-h2020.eu/

Paving the way for electric propulsion in space

A roadmap for supporting advancement in propellant technology boosts the competitiveness of European space industries on the world stage.

Look overhead on a clear night and it isn't only stars that you will see. Also on display are satellites, which are essential to telecommunication and scientific research. To keep costs low, space industries are on the hunt for technologies that maximise embarked payload while reducing the mass of the service platform. Electric propulsion (EP) is key to achieving this. Coordinated by the European Space Agency (ESA), and with major European Space Agencies as partners, the EU-funded EPIC2 project provides support for a strategic research cluster of operational grants focused on EP.

A masterplan for programme support activity

Space research is costly, and EPIC2, a continuation of the EPIC grant initially funded in 2014, targets both innovation and competitiveness. A defining feature of the project's actions is support for both incremental and disruptive technologies.

Incremental technologies are those that build within existing systems and offer small but market-ready improvements. In the context of EP, this includes advances made to Hall-effect thrusters (HET), radio frequency ion thrusters (RIT), and high-efficiency multistage plasma thrusters (HEMPT). According to project coordinator Jose Gonzalez Del Amo: "Electric propulsion in Europe has grown enormously thanks to EPIC. Several EU companies are now world leaders."

Electric propulsion in Europe has grown enormously thanks to EPIC. Several EU companies are now world leaders.

European competitiveness is demonstrated by the Hall-effect thruster made by Safran, which is now a world leader in the telecommunication and navigation market. Also noteworthy is the HEMPT built by Thales Ulm which is baselined for several constellations of satellites. Baselining has occurred for RIT and Cubesat EP for several ESA missions as well.

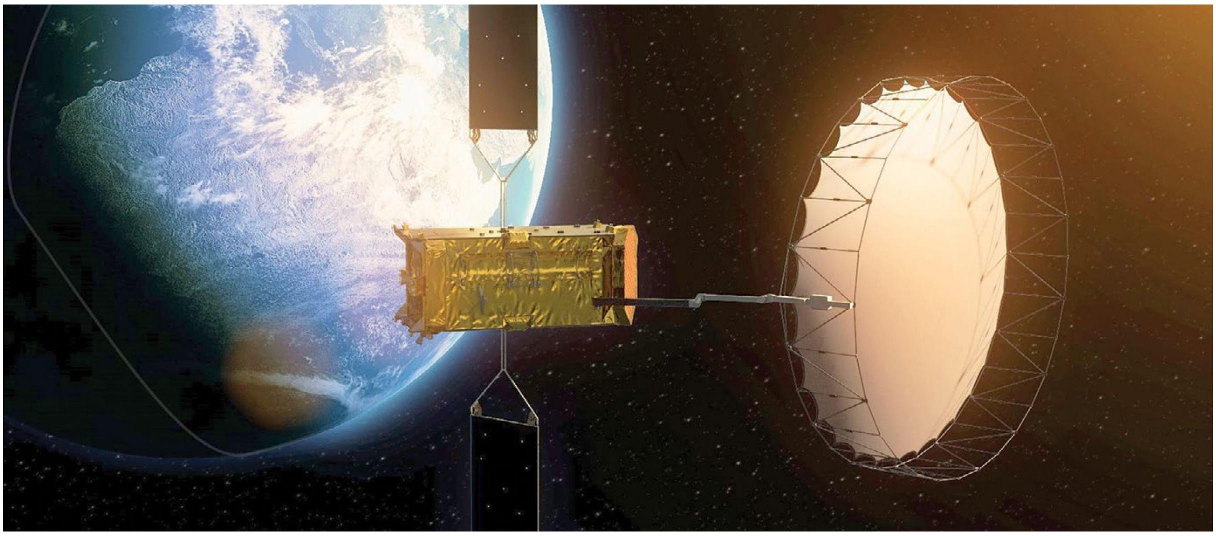
Disruptive technologies change the status quo by replacing a dominant technology with something that offers radical improvement. In the early stages of development, disruptive technologies often underperform compared to well-established technologies. For this reason, a programme support activity grant such as EPIC2 is essential to give nascent disruptive technologies a fighting chance.

Coordination, coherence and conclusions

The European Commission (EC) recognises that supporting EU space industries requires teamwork and is aware of the challenges of getting competing companies to collaborate. As Del Amo says: "It is very difficult to coordinate the effort of different countries interested in electric propulsion due to the competition between their products. A big effort was made, as everything had to be done by consensus."

The EPIC2 consortium ensured coordination among projects in several ways. They identified activities needed to address project challenges and assessed projects' activities and results. As needed, EPIC2 updated the roadmap for realising European competitiveness in global space industries and disseminated results through presentations and conferences.

EPIC2 also advised the European Commission, making sure the institution had the most up-to-date information to guide its policies and decisions. The consortium recommended that the Commission support emerging space companies by providing financial support and securing access to space experts and facilities when needed. EPIC2 also encouraged the exploration of new propellants, as xenon, the market standard, is too expensive.



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The heavens overhead are rapidly changing. EP-powered Cubesat satellites – no larger than two kg – are growing by the thousand, and interplanetary missions are no longer the stuff of science fiction. By supporting the technical development of operational grants in a strategic research cluster, EPIC2 is sharpening the edge of European competitiveness in space.

PROJECT
EPIC2 - Electric Propulsion Innovation and Competitiveness 2.0 (EPIC2)

COORDINATED BY
European Space Agency in France

FUNDED UNDER
Horizon 2020-LEIT-SPACE

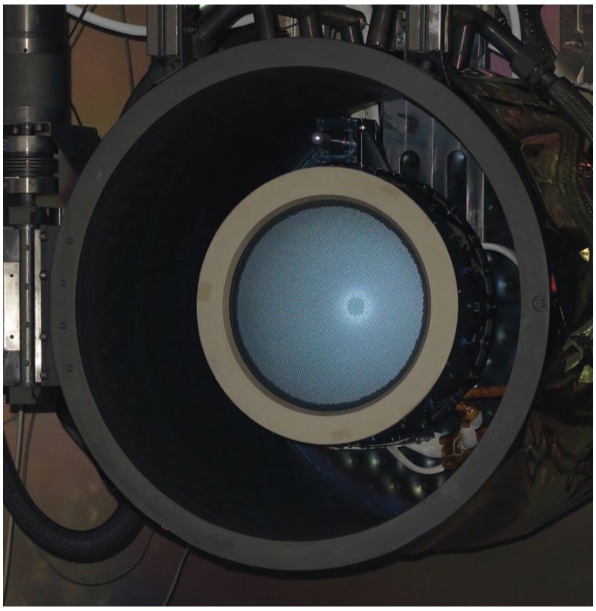
CORDIS FACTSHEET
cordis.europa.eu/project/id/872002

PROJECT WEBSITE
epic-src.eu/

Giving plug-and-play gridded ion thruster technology its moment in the spotlight

In the framework of the European research and innovation programme, industrial actors and researchers are advancing and standardising electric propulsion systems that use grids to speed up ions and generate thrust. Designed as plug-and-play solutions, these systems should offer satellite providers flexible, tailored options for medium-power applications.

The market of commercial communication satellites is undergoing a radical transformation. As the cost per gigabit per second for communication services drops, the ability to quickly bring services to market and reduce service lead times is becoming increasingly crucial.



In this evolving market, electrical propulsion systems offer the opportunity to increase fuel efficiency by an order of magnitude compared to traditional chemical propulsion systems. However, electrical propulsion systems could take longer to reach their final orbit.

Gridded ion technology rising in electric propulsion

Gridded ion thruster technology has already demonstrated its capability to significantly boost the efficiency of electrical propulsion systems with very high specific impulse. Now, the ArianeGroup propulsion solution boosts the thrust to a new level.

The EU-funded GIESEPP MP project is pushing forward the gridded ion thruster technology of medium-power applications. By advancing this technology, the initiative aims to increase the competitiveness of geostationary Earth orbit (GEO) and medium-Earth orbit (MEO) satellite platforms.

Boasting a dual-mode capability, ArianeGroup's RIT2X thruster is a shining example of this effort for advancing GEO and MEO applications. "This feature provides superior efficiency in the low-thrust operating regime – ideal for tasks such as station keeping – and competitive thrust levels for high-thrust operations like orbit raising," notes GIESEPP MP project coordinator Christian Knorr.

"Thanks to its dual-mode capability, the RIT2X is set to empower new communication platforms and offer superior performance for scientific exploration missions," adds Knorr.

Setting a new standard for the industry

GIESEPP MP will create the first European plug-and-play standardised electric propulsion platform based on gridded ion thruster technology that can operate ArianeGroup's ion engines, with the flexibility to incorporate alternative thrusters. At the heart of this platform is the ArianeGroup RIT2X thruster, complemented by a radio-frequency generator, an Airbus Crisa power processing unit and an Airbus DS fluid management system. All of these elements are not only designed to deliver top-notch technical performance but are also created with cost efficiency and industrial standards in mind, paving the way for high volume production.

The project approach ensures that in parallel to the development of the platform components, there is focus on establishing the necessary industrial production capabilities. This is crucial for meeting the ambitious economic objectives set by Airbus Defence and Space.

On the technical front, project activities will conclude with a critical design review for the major components, followed by component-level verification tests. After these stages, all elements will be assembled in a common set-up for a coupling test. This test is pivotal for validating how the components operate together within the electric propulsion system. Thanks to the collaboration with partners from academia and industry, all tests will be performed in environments that closely mimic real-space conditions.

Europe's first plug-and-play electric propulsion system

The ArianeGroup RIT2X thruster should be the first industrialised contemporary European gridded ion thruster. This plug-and-play standardised electric propulsion system maintains the flexibility for providers to choose individual electric propulsion components while also building their own customised electric propulsion systems.

"Our project is bundling the experience and expertise of Europe's top electric propulsion actors, offering a competitive, industrial-grade plug-and-play electric propulsion solution to the market while keeping the flexibility for individual solutions," concludes Knorr.

Our project is bundling the experience and expertise of Europe's top electric propulsion actors, offering a competitive, industrial-grade plug-and-play electric propulsion solution to the market while keeping the flexibility for individual solutions.

PROJECT
GIESEPP MP - Gridded Ion Engine Standardized Electric Propulsion Platform - Medium Power Solution

COORDINATED BY
ArianeGroup GmbH in Germany

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004349

PROJECT WEBSITE
gieseppmp.eu/

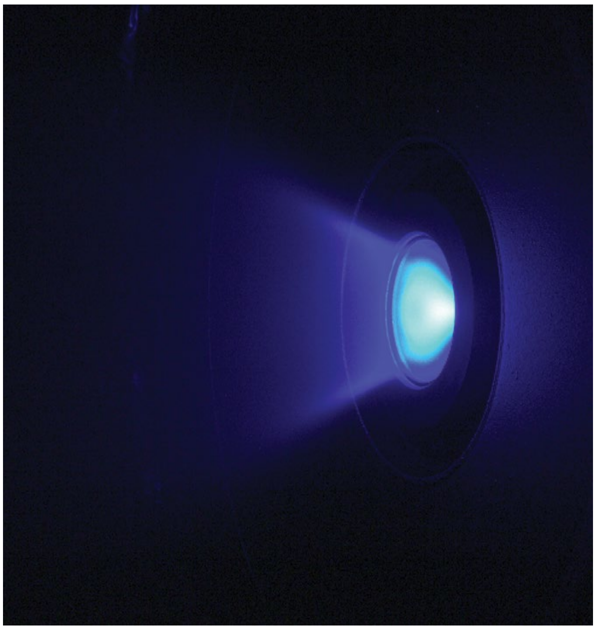
Next-generation electromagnetic thruster for satellites in low Earth orbit

A high-efficiency multistage plasma thruster reduces electric propulsion system cost while boasting dramatically increased propulsion efficiency and system lifetime.

Growth in the global market for small satellites in low Earth orbit (LEO) is accelerating rapidly, with increasing deployment in constellations. About 3 000 small satellites were launched around the world from 2011 to 2020, and another 2 304 in 2022 alone, about a 30 % increase from the previous year. Innovation in propulsion technologies will play a key role in increasing Europe's independence and competitiveness in this socioeconomically important sector.

While chemical propulsion of small satellites has historically been the most common, electric propulsion technologies are increasingly used and are garnering widespread attention. Among the key objectives of next-generation electric propulsion systems are reducing their cost and complexity while increasing their operational lifetime.

The EU-funded HEMPT-NG2 project addressed both objectives with its advanced electromagnetic thruster. Its important advantages relative to currently available electrostatic propulsion systems – a drastic reduction in propellant consumption, longer lifetime and minimal complexity – could boost European competitiveness in the small satellite market.



Advancing a state-of-the-art plasma thruster

The project's high-efficiency multistage plasma thruster is designed to move a satellite by ionising and accelerating a propellant via the combined action of electric and magnetic fields. It will enable satellites to correct their position in orbit (station keeping) or to change orbit (orbital manoeuvring).

HEMPT-NG2 focused on advancing the maturity of the plasma thruster, which was developed within the context of the HEMPT-NG project. To achieve the project's objectives, researchers employed a combined simulation and experimental campaign. This was supported by the design of targeted testing tools implemented in the assembly, integration and test (AIT) procedures.

Increased efficiency and lifetime at lower cost

Essential to the high-efficiency thruster's ion propulsion technology are its permanent magnets for plasma confinement. According to project coordinator Peter Holtmann of Thales (Germany): "Its magnetic cells, arranged in a cusped mirror configuration, enable efficient entrapment of plasma electrons. This prevents the electrons from contacting the discharge channel walls, reducing erosion and extending the thruster's lifetime and operational stability."

In addition, the efficient electron confinement enables a high ionisation efficiency and negligible electron (current) loss. The small starter electron current from the cathode is amplified by an 'ionisation avalanche' so the plasma is sustained with minimal electrical power input. The plasma thruster's high acceleration voltages enable a higher specific impulse (a measure of how efficiently the energy in the propellant is converted to thrust), drastically reducing propellant consumption and thus the propellant mass that must be stored on board.

Furthermore, "the flexible high-efficiency multistage plasma thruster supports multiple different space tasks with the same thruster and it can operate with both conventional xenon and much less expensive krypton propellants," adds Holtmann.

The high-efficiency multistage plasma thruster's magnetic cells, arranged in a cusped mirror configuration, enable efficient entrapment of plasma electrons. This prevents the electrons from contacting the discharge channel walls, reducing erosion and extending the thruster's lifetime and operational stability.

Paving the way to the LEO satellite constellation market

Altogether, the HEMPT-NG2 advances led to a robust design with high efficiency and reduced overall electric propulsion system cost. The universal LEO thruster module was optimised for mass production and a market analysis was performed, paving the way for commercialisation of the high-efficiency plasma thruster and boosting Europe's competitiveness in the small satellite sector.

PROJECT
HEMPT-NG2 - High Efficiency Multistage Plasma Thruster - Next Generation 2

COORDINATED BY
Thales in Germany

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004140

PROJECT WEBSITE
hempt-ng2.eu/

Advanced helicon plasma thruster propulsion moves closer to market

Disruptive electric propulsion leveraging an electromagnetic radiofrequency field to ionise a gas will serve non-geostationary satellite constellations and other small spacecraft.

There are currently more than 5 000 satellites orbiting the Earth at a relatively close distance. These low Earth orbit (LEO) satellites are very useful for Earth observation, serving purposes from climate monitoring to telecommunication and defence, while demand is growing rapidly.

Mass production of hundreds of LEO satellites for mega-constellations will place stricter requirements on manufacturing time and cost, as well as on operating cost and lifetimes. Disruptive helicon plasma thruster (HPT) technology – an advanced type of electric propulsion (EP) under development – could meet these requirements.

The EU-funded HIPATIA project has advanced HPT technology and delivered a complete propulsion system, moving the promising thruster closer to market and to space.

Electric propulsion without electrodes and complex electronics

All propulsion systems rely on Newton's third law of motion: ejecting something in one direction to move in the opposite direction. Conventional chemical propulsion relies on combustion. The ejected exhaust jet moves the satellite, but this requires significant propellant, meaning not only weight but increased risk as the propellant is highly flammable.

Newer electric EP systems use much less propellant but face other challenges. Electrostatic thrusters currently ionise noble gases via electrostatic discharge. Ejection of the ionised particles produces thrust, but ionisation requires electrodes that are difficult to manufacture and operate, as well as complex electronics to produce high voltages.

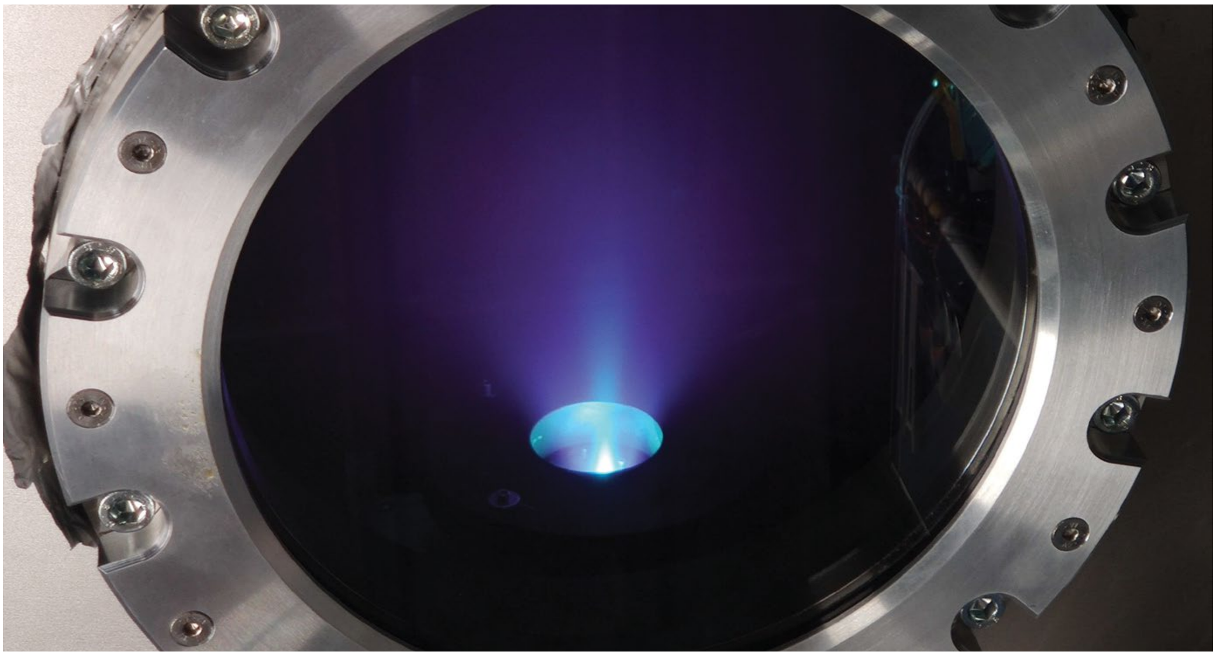
"Helicon plasma thruster technology ionises the propellant to produce hot plasma using an electromagnetic radiofrequency field created by an antenna and magnets. Gone are the electrodes and complex electronics, simplifying the system and enabling a longer lifetime while making it easier to produce, and cheaper and faster to integrate," explains project coordinator Mercedes Ruiz of Sener.

Advances and new developments enable integration and testing

HIPATIA started with an HPT developed to an intermediate technology readiness level (TRL). The rest of the components of the propulsion system – critical to its functionality – had not been considered.

HIPATIA led to two successful coupling test campaigns of the complete helicon plasma thruster propulsion system, bringing it much closer to market application.

A combined modelling and test campaign enabled the consortium to advance the TRL of the helicon plasma thruster and develop and integrate critical components. The propellant control unit controls propellant pressure and mass flow. The radiofrequency generation and power unit ionises the propellant and accelerates the plasma to leave the thruster at high velocities. "HIPATIA led to two successful coupling test campaigns of the complete helicon



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plasma thruster propulsion system, bringing it much closer to market application," says Ruiz.

Propelled to market, accelerating innovation and new missions

"I am very proud of the HIPATIA Team: Sener, UC3M, ADS, CNRS and AST. Despite starting the project during the COVID-19 pandemic, we worked together very well to move forward and fulfil the project's objectives," notes Ruiz. Not only did they advance the TRL and system integration level significantly but "the advanced modelling, simulation and testing deepened understanding of the physics behind this type of plasma device. It has led to new routes to increase efficiency that are the basis of a new thruster design we are currently characterising," says Ruiz.

HIPATIA's developments bring radiofrequency thrusters closer to market. They will provide the aerospace industry with simpler and more versatile EP systems, potentially paving the way to new missions.

PROJECT
HIPATIA - HelIcon PlasmA Thruster for In-space Applications

COORDINATED BY
Sener in Spain

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/870542

PROJECT WEBSITE
hipatia.uc3m.es/

Xenon loses ground to more cost-efficient satellite fuel competitor

In the near future, simple and robust electric thrusters will help small telecommunication satellites blast off into space at low cost using iodine as fuel.

The number of small satellites orbiting Earth has been steadily increasing over the past decade thanks to tiny electronics and reduced launch costs. In the coming years, satellite operators such as OneWeb and StarLink plan to launch tens of thousands of satellites into orbit to enhance internet coverage and improve earth observation.

Typically, the electric propulsion systems powering these small satellites comprise complex electronics and rely on gas propellants like xenon or krypton, which are expensive and in short supply.

An abundant, cost-efficient alternative to standard satellite fuels

The EU-funded iFACT project introduced novel thruster architecture and the use of a cheaper propellant alternative to increase competitiveness in the electric propulsion market.

Researchers turned to iodine as a viable replacement for xenon, an element that is found naturally in soil and the ocean. Its use as a propellant greatly simplifies the propellant feeding subsystem architecture, leading to significant cost savings. Although it has roughly the same mass as xenon, its storage density is three times higher, which helps decrease the mass of the feeding subsystem.

Project coordinator Franz Georg Hey states: “We have developed and demonstrated key building blocks to foster the use of iodine as propellant for electric propulsion. Since 2020, three different iodine-fed thrusters have been built (with powers ranging from 10 W to 1 000 W) and one has been successfully coupled with a CubeSat platform designed by Endurosat.”

Iodine-optimised architecture

Designed by Airbus, the advanced cusp field thruster (ACFT) is a promising electric thruster that runs on iodine. The thruster, which consists of a pair of magnets, two pole shoes, a magnetic anode and a dielectric discharge chamber, can be easily ignited and maintains a stable plasma discharge.

“The 300-W ACFT has operated more than 3 000 h in a dedicated iodine-compatible vacuum facility developed by project partner Aerospazio Technologie in Italy. This is a very important achievement for iodine propulsion, demonstrating the possibility of feeding multiple kilograms of iodine on a single thruster,” remarks Georg Hey.

At the edges of the anode, the propellant is fed into the discharge chamber of the thruster. At the thruster exit, a hollow cathode emits electrons to neutralise the extracted ion beam and maintain the plasma discharge. The project team designed

Calcium-aluminate (C12A7) is a promising cathode material that is likely to be compatible with iodine. The positively charged iodine ions, which are accelerated by an electric field, provide the thrust. After leaving the engine, the positively charged iodine ions are neutralised again by adding electrons to the current to prevent a negative electrical charge on the satellite.

hollow cathodes that provide electrons for both plasma generation and beam neutralisation.

Generating high amounts of plasma, hollow cathodes self-heat and adjust their voltage drop to provide the internal heating necessary to produce the desired ion discharge.

The project team experimented with different cathode materials to test compatibility with iodine. "Calcium-aluminate (C12A7) is a promising cathode material that is likely to be compatible with iodine. The positively charged iodine ions, which are accelerated by an electric field, provide the thrust. After leaving the engine, the positively charged iodine ions are neutralised again by adding electrons to the current to prevent a negative electrical charge on the satellite," explains Georg Hey. Moreover, the material has a smaller work function than the commonly used lanthanum hexaboride (LaB6).

Ultimately, the project team has demonstrated that at low partial pressures, iodine causes no degradation to the satellite and is therefore safe for use as a propellant.

iFACT activities provided sufficient data on how iodine behaves with the materials used in the propulsion system. Researchers hope that iodine use will not only help reduce fuel costs and volume, but also lead to significantly smaller and lighter propulsion modules.

PROJECT
iFACT – Iodine Fed Advanced Cusp field Thruster

COORDINATED BY
Airbus Defence and Space GmbH

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/870336

PROJECT WEBSITE
epic-ifact.eu/

C12A7:e- in cathodes and neutralisers improves electric propulsion

An inexpensive, abundant and locally available ceramic could provide European independence in the manufacture of advanced electric propulsion systems for low Earth orbit satellites.

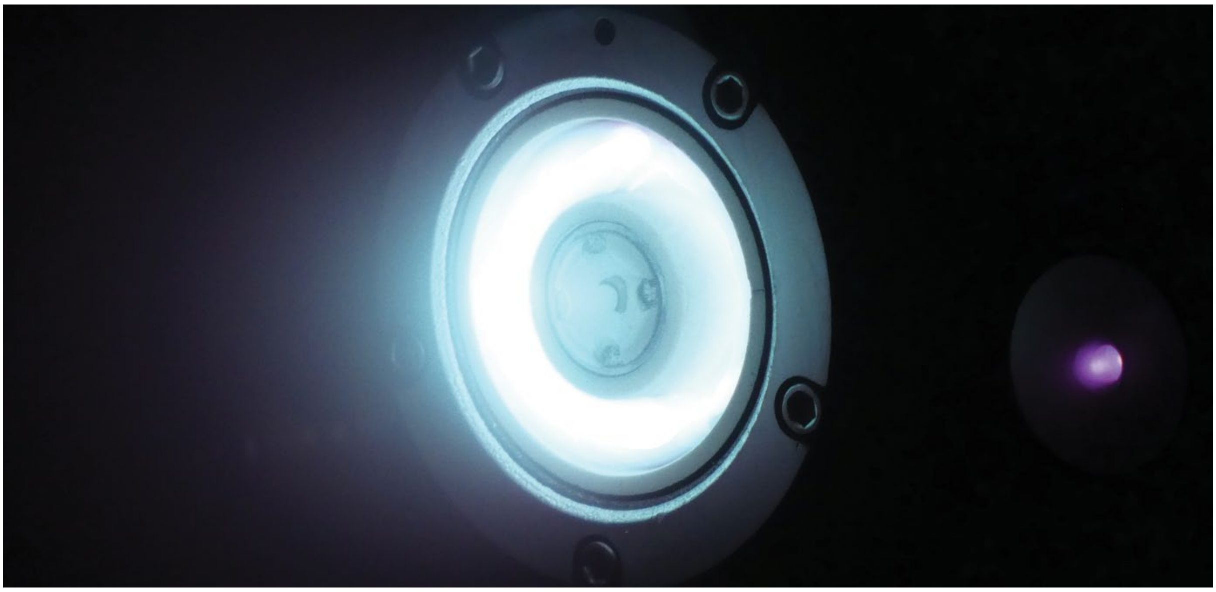
In recent years, electric propulsion (EP) systems have gained tremendous traction over chemical ones for low Earth orbit (LEO) missions. LEO satellites are subject to orbital decay – a gradual decrease in their distance from Earth. As a result, they need efficient low-thrust propulsion systems for 'station keeping'. Smaller satellites also need less bulky and lighter components.

Electric propulsion checks both boxes. However, main challenges arise from the fact that state-of-the-art EP systems use scarce and expensive materials for their cathodes and propellants. The EU-funded NEMESIS project addresses both issues with a disruptive cathode material that can be produced cost-effectively in Europe from inexpensive, locally available and abundant precursors.

C12A7:e- as an alternative electron emitter

Cathode materials serve two purposes. They provide electrons to bombard propellant gases, to produce positive ions that are accelerated and ejected to push the vehicle forward. Then, as this process charges the vehicle positively, additional electrons are required to neutralise the positive charge.

"Most electric propulsion cathodes and neutralisers currently use lanthanum hexaboride (LaB6) as the electron emitter and xenon as the propellant gas. Both lanthanum and xenon are scarce



We overcame the most difficult issue with C12A7:e-, namely sparks and instabilities caused by charge accumulation at the thin dielectric layer on the material's surface that cause malfunction and even melting. Our solution – charge coupling techniques through pulsed polarisation of the material – has been patented.

and expensive – both issues exacerbated by the war in Ukraine," explains Ángel Post of Advanced Thermal Devices and NEMESIS project coordinator.

NEMESIS targeted a novel ceramic material, C12A7:e-, that is not only inexpensive and abundant but requires a lower temperature to begin emitting. This means a lower energy requirement and less induced thermal stress to the rest of the satellite components and subsystems. The researchers expected it to be more chemically inert than LaB6, allowing operation with other propellant gases.

Pulsed polarisation solves electron generation instabilities

The consortium confirmed all expected benefits and exceeded them. The operational temperature was reduced to about 200-250 °C from 800-1300 °C for alternative electron emitters. This eliminates the need for an external heat source, expensive heat-resistant materials in subsystems and thermal radiation shields. Researchers demonstrated operational compatibility with many alternative propellant gases including argon, krypton and even ammonia, in addition to conventional xenon. NEMESIS operated novel cathodes over thousands of hours in total, with consistent and repeatable results in multiple labs.

Importantly, "we overcame the most difficult issue with C12A7:e-, namely sparks and instabilities caused by charge accumulation at the thin dielectric layer on the material's surface that cause malfunction and even melting. Our solution – charge coupling techniques through pulsed polarisation of the material – has been patented," notes Post. Furthermore, pulsed polarisation provided twice as much emitted current, and allowed the consortium to start electron emission at temperatures even lower than those reported in the literature.

Several prototypes have been developed and successfully tested using xenon, argon, krypton, iodine and ammonia propellants. These were successfully coupled with commercial Hall-effect thrusters and achieved high-performance figures of merit.

European independence in cost-effective satellite propulsion

NEMESIS raised awareness within the European space industry via 24 presentations at 9 international conferences and workshops as well as 8 peer-reviewed publications, fostering early adoption and competitiveness. Three follow-on projects have been awarded since project completion and two industrial collaboration agreements have been signed. Europe is on the road to provide its booming small satellite market with cost-effective, low-energy, high-performance electric propulsion, enhancing competitiveness in a growing global market.

PROJECT
NEMESIS - Novel Electride Material for Enhanced electrical propulSIon Solutions

COORDINATED BY
Advanced Thermal Devices in Spain

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/870506

PROJECT WEBSITE
nemesis-space.eu/

Novel Plasma Jet Pack boosts tiny space satellite agility

The PJP project's Plasma Jet Pack, with pulsed electrical thrust thanks to a solid metallic propellant, could improve manoeuvres of nanosatellites in space orbit, offering increased flexibility for a wider range of missions.

Tiny satellites, known as nanosatellites, are typically only a few decimetres long and weigh less than 50 kg each. They are currently used for a variety of purposes, including telecommunications, Earth observation, navigation and positioning, and even interplanetary exploration. Often arranged in constellations, they diversify the capabilities of space infrastructure.

As Luc Herrero from Comat puts it: "Nanosatellites have democratised access to space, enabling a wider range of players, from start-ups to educational institutions, to participate in space research and activities."

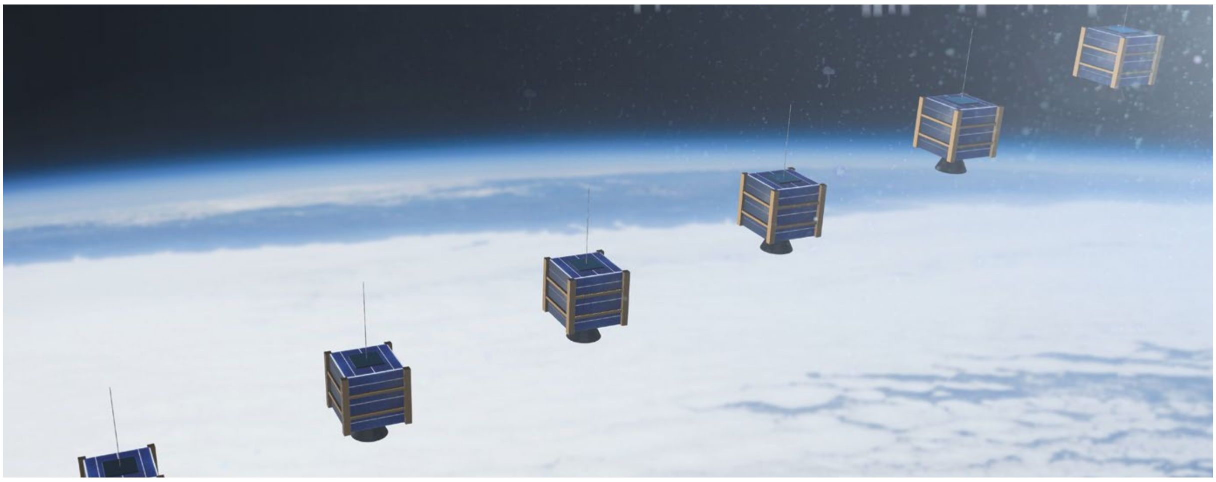
But challenges remain with the complexity of their propulsion and operations, both on the ground and while in orbit, reducing efficiency, cost-effectiveness and safety.

The EU-funded PJP project, coordinated by Herrero, investigated electric propulsion as a solution to the current processes which require nanosatellites to be launched on dedicated rockets.

Using specially designed methods and probes, the project successfully characterised its pulsed plasma solution, developing simulation tools to investigate the underlying physics and leading to a modularised demonstrator, building on previous versions.

Electric propulsion

PJP's electric propulsion technology is based on vacuum arc physics. Here, high-speed ions are created from a solid metal propellant when an electrical discharge is released in



Our combination of plasma characterisation methods and simulation tools deepened our understanding of vacuum arc physics, resulting in one of the most innovative technologies in this field.

a vacuum between two electrodes: the cathode (solid propellant) and the anode (passive electrode). The electrons' energy is transferred to the ions thanks to their cooling process which creates an intense electric field. The PJP solution ejects a quasi-neutral plasma at very high speeds of up to 50 km per second, generating thrust.

"Our device can generate on-demand thrust in space, transferring momentum to the satellite for manoeuvrability, while storing propellant compactly and safely, avoiding the toxic or pressurised tanks and valves needed by conventional electrical or chemical-based versions," explains Herrero.

The team characterised over 30 different geometries of arc discharge chambers using in-house diagnostic methods, which informed the design of a simulation tool to explore a variety of system configurations.

"Our combination of plasma characterisation methods and simulation tools deepened our understanding of vacuum arc physics, resulting in one of the most innovative technologies in this field," notes Herrero.

The modular design led to the creation of three building blocks: the Arc Discharge Chamber, Plasma Generator Unit and Power Propulsion Supply and Control Unit. After qualification by the team, these were combined to create a Plasma Jet Pack 30 W demonstrator, also compatible with 80 W and 150 W versions. This demonstrator builds on previous, more basic versions predating the project.

"While we found that most of the parameters we tested met market needs, more work is needed to avoid electrode erosion and improve thrust duration," says Herrero.

The first flight of the project's modular PJP30 concept is planned for 2024, to demonstrate its directional thrust capabilities.

A range of applications

Alternatives to chemical-based propellants support the EU's sustainability ambitions and with a more local supply chain also align with the EU's aims to be more self-reliant.

Likely applications – such as environmental monitoring, improved communication networks and safer space exploration – will also benefit the European economy, creating jobs while boosting Europe's technological leadership credentials.

The team is also currently developing a new building block with improved thrust capabilities for a broader range of missions.

PROJECT
PJP - Plasma Jet Pack

COORDINATED BY
COMAT in France

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/870444

PROJECT WEBSITE
plasmajetpack.com/

CORDIS Results Pack

Available online in six language versions: cordis.europa.eu/article/id/451366

Published
on behalf of the European Commission by CORDIS at the
Publications Office of the European Union
L-2985 Luxembourg
LUXEMBOURG

cordis@publications.europa.eu

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This Results Pack is a collaboration between CORDIS and the European Health and Digital Executive Agency (HaDEA).

Print	ISBN 978-92-78-44163-0	ISSN 2599-8285	doi:10.2830/530407	ZZ-AK-24-015-EN-C
HTML	ISBN 978-92-78-44164-7	ISSN 2599-8293	doi:10.2830/370710	ZZ-AK-24-015-EN-Q
PDF	ISBN 978-92-78-44161-6	ISSN 2599-8293	doi:10.2830/814207	ZZ-AK-24-015-EN-N

Luxembourg: Publications Office of the European Union, 2024

Solar system exploration

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