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Innovative Propulsion for CubeSats

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CubeSats and MicroSats have revolutionised Earth observation, space exploration, and communications by offering cost-effective, rapidly deployable solutions …

The small size, modularity, cost-effectiveness, and rapid deployment capabilities of CubeSats make them an attractive option for a wide range of applications, including Earth observation (EO) activities and communications. Unlike traditional large satellites, CubeSats can be built and launched quickly, allowing for the introduction of frequent technological advancements without the long development cycles associated with larger missions.

These satellites are widely used for EO purposes, providing real-time data for a range of activities, including environmental monitoring, disaster response, agriculture, and climate studies. Their ability to capture high-resolution images and sensor data helps scientists track deforestation, monitor ocean health, and predict weather patterns more accurately. CubeSats also support communications, particularly for remote areas where traditional infrastructure is lacking, offering affordable solutions for global internet coverage. In addition to Earth-focused applications, CubeSats are being adapted for deep space exploration missions. NASA notably deployed CubeSats - the Mars Cube One (MarCO) satellites - as part of the 2018 *InSight* mission.[i] ESA is also planning to deploy its first deep-space CubeSats as part of the Hera mission (launched 2024): *Milani*, developed by an Italian-Czech-Finish consortium, and *Juventas*, developed as part of a Danish and Romanian partnership.[ii]

More broadly, CubeSats are driving and supporting innovation in space research and education. Universities, startups, and emerging space nations are increasingly using them as accessible platforms to develop and test innovative technologies. Their affordability and versatility are transforming the space industry, making satellite technology more accessible than ever before.

… but their full potential is constrained by the availability of appropriate propulsion technologies …

Traditionally, small satellites have relied on passive orbital mechanics or simple reaction wheels for attitude control. As their missions grow more complex, however, innovative propulsion solutions are becoming a necessity, particularly in the face of growing regulatory and sustainability requirements.

One of the primary drivers for developing new propulsion systems for CubeSats is the need for precise orbital manoeuvring. The size of a CubeSat means that onboard capacity is limited, thereby necessitating any propulsion system to be small enough to be included within the craft but also leave sufficient room for the satellites payload(s). Additionally, many of these satellites are deployed into low Earth orbit (LEO), often as secondary payloads, limiting control over their initial trajectories. Without propulsion, they are unable to perform orbit raising, station-keeping, or deorbiting at the end of their mission, leading to increased concerns about the accumulation of space debris.

Extending mission lifespans also remains a challenge. Without propulsion, CubeSats are at the mercy of orbital decay and atmospheric drag, especially in lower orbits. Innovative propulsion systems can help these satellites maintain their operational altitude for longer periods, maximising both scientific and commercial returns. This is equally true for deep space missions: as CubeSats venture beyond Earth's orbit to the Moon, Mars, and beyond, they require efficient, lightweight propulsion systems capable of providing the necessary delta-v to navigate interplanetary space.

Future small satellite constellations for EO, global communications, and deep space exploration will require precise positioning and the ability to undertake coordinated movements. Traditional chemical propulsion systems are often too bulky and hazardous for small satellites, necessitating the development of alternative propulsion technologies such as electric, cold gas, solar sail, or iodine-based thrusters.

… necessitating the development of ESA-funded innovative technologies to help usher in a new generation of propulsive CubeSats …

ESA TDE[1] funding for the *Innovative Propulsion for CubeSats* study was awarded to five different teams, supporting the development, testing and validation of a range of innovative propulsion technologies. ESA aimed to identify the most promising European propulsion systems at a conceptual stage, and support their advancement through systematic design,

[1] ESA's Technology Development Element (TDE) is a mandatory programme which explores innovative, 'blue-sky' concepts. It supports all ESA fields of activity across various technical disciplines, serving as the foundation for future technological advancements. All ESA Member States contribute to the TDE on a mandatory basis.

manufacturing, and testing processes. A key objective of this initiative was to advance the selected propulsion systems' Technology Readiness Level (TRL)[2] to at least 3.

Four of the selected projects focused on electric propulsion, whilst the fifth focused on chemical propulsion; all were exploring concepts to enhance CubeSat manoeuvrability and mission capabilities. This approach reflects ongoing efforts to advance both efficiency and performance in next-generation CubeSat propulsion systems, whilst recognising that different satellites will have different propulsion requirements and that no single propulsion unit will be suitable for all CubeSats. All projects received €250,000 in funding through ESA's TDE programme and in-kind access to the propulsion test facilities at the European Space Research and Technology Centre (ESTEC) . The five projects are respectively led by:

ENPULSION SPACECRAFT TECHNOLOGY	Enpulsion, based in Austria, specialises in advanced electric propulsion systems for small satellites. It received funding to develop its field-emission electric propulsion (FEEP) system, the ENPULSION NANO AR[3]. The project aimed to demonstrate active thrust vector control and system performance while identifying necessary developments for a fully qualified commercial product.
T4i	T4i is an established Italian rocket company that develops electrical, chemical, and cold gas propulsion systems for a variety of in-space applications for small satellite platforms and launch systems. The project aimed to design, manufacture, and test a breadboard prototype of the REGULUS-150-Xe electric propulsion system, targeted at enhancing in-space mobility. The project was led by T4i in cooperation with Open Cosmos (UK), University of Surrey (UK), and Tyvak International (IT).
University of Southampton	The University of Southampton, in the United Kingdom, developed the CubeSat de-orbit ALl-printed Propulsion System (Cube-de-ALPS), aimed at designing a standalone de-orbit propulsion system. Using additive manufacturing and printed electronics, the system is designed to shorten a spacecraft's orbital lifetime or enable controlled re-entry and safe recovery of CubeSats. The project was in collaboration with Inkron Oy (FI).

[2] Technology Readiness Level (TRL) is a standardised system used to assess the maturity of a technology before it is deployed in operational missions. Defined by the *European Cooperation for Space Standardization* (ECSS) and aligned with NASA's TRL framework, it ranges from TRL 1 (basic principles observed) to TRL 9 (actual system flight-proven in space). For space applications, TRL progression typically involves rigorous analytical studies, laboratory testing, validation in relevant environments, and demonstration in orbit to ensure reliability under extreme conditions.

exotrail	Exotrail, based in France, specialises in in-space mobility solutions. They received funding to develop a fluidic module of the spaceware™ nano 60W propulsion system, designed for long life and optimised for platforms under 80kg. The project aimed to enhance propulsion capabilities for small satellites but was discontinued, as the company shifted its commercial focus toward higher-power systems.
Università di Pisa	The University of Pisa, in Italy, received funding to develop the CubeSat HTP Innovative Propulsion System (CHIPS), a modular and green chemical propulsion system for CubeSats using hydrogen peroxide (H_2O_2) as propellant. Designed for versatility, CHIPS aimed to provide propulsive capabilities across a wide range of mission scenarios and payload requirements. The project focused on the design, manufacture, and testing of this innovative propulsion technology to enhance small satellite manoeuvrability.

These activities were designed to bridge the gap between research and commercialisation, fostering the development of cost-effective, high-performance propulsion systems. By supporting the progression of European propulsion technology from concept to experimental validation, the ESA TDE-funded studies aimed to enhance the capabilities of small satellites, enabling more advanced and diverse mission applications in both commercial and scientific domains.

… and deliver valuable socio-economic benefits.

Notwithstanding the development of several new types of CubeSat propulsion technologies, these studies also produced important human capital and knowledge benefits, and laid the foundations for potential future operationalisation, and commercial exploitation.

TRL progression of a set of innovative propulsion technologies

ESA TDE funding has enabled the contractors to progress the maturity of their innovative technology to at least TRL 4, i.e., achieving functional verification. The Agency's support played a key role in advancing a diverse set of propulsion solutions for CubeSats, which, together, will be able to meet the wide-ranging needs of different missions in the future.

ESA has adopted a diverse approach to CubeSat propulsion development, recognising that a single solution cannot necessarily meet the wide-ranging needs of different missions. By investing in multiple propulsion technologies - such as those funded as part of this TDE activity - ESA is increasing the likelihood that CubeSats can be equipped with an appropriate propulsion system that meets their operational requirements, from de-orbiting to deep-space travel. Whilst the funded technologies are still in their early stages, and not all may reach full operationalisation or commercialisation, this exploration fosters competition and drives innovation. Having a variety of propulsion solutions within the European toolset not only reduces risk by decreasing dependence on a single technology but also enhances flexibility, enabling mission designers to select the best propulsion system for each specific activity. More broadly, this approach encourages collaboration throughout Europe's space sector, expanding expertise and industrial capabilities across multiple Member States, strengthening the region's leadership in propulsive space technology.

Projects which continued through the TDE development programme were able to achieve key TRL milestones. Enpulsion's NANO AR³ system progressed from TRL 3 to 4, demonstrating active thrust vector control and endurance testing, with plans to reach TRL 8 by 2025. T4i's REGULUS-150-Xe system advanced from TRL 2 to 4, completing a 300-hour endurance test at ESA's Propulsion Laboratory as well as additional testing at partner organisations,[3] whilst the University of Southampton's Cube-de-ALPS system was developed from TRL 2 to 4, with further activities planned to achieve TRL 8 by 2027. The University of Pisa's CHIPS HTP-based propulsion system, meanwhile, reached TRL 4-5, and has secured the opportunity for in-flight testing as part of an Italian Space Agency (ASI) funded mission under the ALCOR programme.[iii]

Enhancing space sustainability

De-orbiting technologies are essential for sustainable satellite operations. Advances in propulsion systems, including cost-effective and sustainable solutions, enhance satellite manoeuvrability, reduce collision risks, and strengthen Europe's leadership in space sustainability.

ESA estimates that there are over 1 million debris objects larger than 1cm in size in orbit, as of 2024.[iv] The growing issue of space debris threatens the sustainability of satellite operations, making the ability to de-orbit spacecraft essential. Regulatory compliance for space-debris mitigation is also increasingly a key factor in satellite deployment, and the technologies developed as part of this activity have the potential to produce cost-effective solutions which meet emerging standards. By reducing the risk of collisions, these propulsion systems have the potential to not only safeguard existing spacecraft, but also to contribute to a more sustainable and commercially viable orbital environment.

All five projects indicated potential uses that contributed to these efforts, whether for deorbiting purposes or in-orbit manoeuvring. The University of Southampton's Cube-de-

[3] T4i reported that partner organisations played a significant role in testing and validation efforts: preliminary verification tests were conducted at the Centre of Studies and Activities for Space at the University of Padova at the beginning of the project whilst integration tests were conducted using Open Cosmos' beeKIT 6U platform, assessing communications between the system and the onboard computer. Thrust measurements were also performed at the University of Surrey, allowing for cross-laboratory verification of measurements.

ALPS project developed an all-printed, lightweight propulsion system designed to enable de-orbiting while minimising mass and cost. Similarly, the University of Pisa's CHIPS project explored a hydrogen peroxide-based propulsion system, providing a compact, off-the-shelf, and readily available orbital manoeuvring and de-orbiting solution for small satellites. Enpulsion, meanwhile, advanced thrust-vectoring propulsion systems to improve satellite mobility and overall manoeuvrability, reducing the risk of debris accumulation. Switching to an iodine-based solution in a follow-up GSTP contract, T4i's REGULUS-150-I2 propulsion system sought to offer a durable, cost-effective alternative to traditional propellants, enhancing the feasibility of long-term de-orbiting strategies.

As regulatory requirements increasingly mandate responsible post-mission disposal, these low-cost propulsion systems provide a commercially viable path for compliance, ensuring that companies can continue to launch satellites without facing legal or financial penalties. In line with ESA's Clean Space initiative[v], the shift towards non-toxic, sustainable propellants such as iodine aligns with broader environmental goals, reducing the terrestrial impact of space activities. In the long term, these advancements will help build a more sustainable foundation for continued commercial activities, providing the means for future missions to operate without adding to the risks posed by uncontrolled space debris, bolstering efforts to meet ESA's Space Mitigation guidelines and ambition to adopt a 'Zero Debris' approach by 2030.[vi]

Leveraging advanced manufacturing and material sciences

Innovative manufacturing techniques are enabling next-generation CubeSat propulsion systems that improve manoeuvrability and enable de-orbiting while reducing costs and failure risks.

Innovative manufacturing techniques - such as additive manufacturing and laser processing - are driving the development of next-generation CubeSat propulsion systems that enhance satellite manoeuvrability and de-orbiting capabilities. For example, the University of Southampton pioneered an all-printed propulsion system, integrating additive manufacturing and printed electronics to create a compact, cost-effective de-orbiting solution.

Similarly, Exotrail and Enpulsion leveraged laser manufacturing and FEEP propulsion technology to improve fluidic control and eliminate mechanical components, reducing failure risks that could contribute to space debris. Enpulsion's approach contributed to material innovation through the development of FEEP propulsion, using capillary forces and specialised emitter arrays to generate controlled ionised particle streams. T4i's switch from xenon to iodine propellant introduced a more sustainable, space-efficient alternative that enhanced propulsion system reliability. Iodine is not only more cost-effective than existing propellent technologies but also enables more compact storage, allowing for better integration into smaller satellite architectures. Moreover, iodine can be stored as a solid propellant, overcoming issues with using pressurised systems. These advancements ensure that even small satellites can be equipped with efficient propulsion, directly addressing the challenge of post-mission disposal.

One of the primary advantages of leveraging these advanced methods is cost reduction: the adoption of additive manufacturing and new propellant technologies have the potential to significantly lower the production costs of propulsion systems, making de-orbiting solutions more attractive to commercial satellite operators. Examples of this cost reduction have already been seen in the US, notably Aerojet Rocketdyne's 3D-printed thruster system which reported a 66% cost saving, as well as a reduction in weight of 67%.[vii] Researchers have also demonstrated the ability to produce flight-ready CubeSat thrusters which can be produced for under €1,000 using 3D printing technologies.[viii] More broadly, leveraging advanced manufacturing techniques enables higher production efficiency, the potential for automation, and the use of innovative and lightweight materials that streamline CubeSat fabrication. As the CubeSat market rapidly expands, increasing manufacturing capacity through more efficient and automated processes could provide companies with the ability to meet growing demand and deliver propulsion units at scale. This not only strengthens European competitive positioning but also allows companies to capture greater market share by offering faster turnaround times and cost-effective solutions.

Harnessing institutional expertise to de-risk innovative technologies

Collaboration with ESA provided project teams with expert guidance and access to specialised testing facilities, enhancing the quality and viability of their propulsion technologies, and helping to align these new solutions with industry requirements and regulations.

Collaborating with ESA provides an advantage for commercial companies and research institutions by de-risking early-stage technology development. With access to ESA's expertise and testing facilities, organisations can develop and refine their technologies without bearing the full financial and technical burden alone. This support is especially valuable for organisations with limited resources, enabling them to advance technologies beyond the proof-of-concept stage and towards operationalisation.

Collaboration with ESA provided all the project teams with access to leading institutional expertise and specialised propulsion testing facilities. Working alongside an experienced ESA Technical Officer and ESA laboratory teams allowed contractors to gain valuable insights and guidance that enhanced the quality and potential applications of their work. Testing played a crucial role in these activities, providing empirical data to validate performance expectations and identify areas for improvement. The Universities of Pisa and Southampton were able to validate their respective propulsion systems, alongside critical components, within a relevant operating environment at ESA's electric propulsion testing facilities. Enpulsion and Exotrail, meanwhile, leveraged ESA's vacuum testing chambers and regulatory insights to refine their own technologies. T4i's design benefited from ESA's strategic guidance, facilitating the transition from xenon to a more cost-effective, sustainable propellant – iodine – as part of GSTP follow-on activities.

By providing access to ESA expertise, testing facilities, and funding, the Agency helped increase efficiency and alleviate the sunk costs typically associated with early-stage propulsion development, such as acquiring specialised equipment and testing infrastructure. This was essential in enabling contractors to develop propulsion solutions that align with evolving requirements and growing market demand.

Supporting and developing early-career professionals

By integrating young professionals into research teams and providing firsthand experience in propulsion development, these projects are helping to build a highly skilled workforce, ensuring Europe remains competitive in satellite propulsion technologies and sustainable space innovation.

These TDE-funded projects have provided opportunities to foster the next generation of space engineers, scientists, and project managers by integrating young professionals into research teams and exposing them to real-world challenges in propulsion development. The University of Southampton, for example, recruited two PhD students specifically for the project. These students transitioned from junior researchers to key contributors, gaining critical skills in additive manufacturing, propulsion system design, mission analysis, and project management.

The University of Pisa similarly engaged students - at both Master's and PhD level - ensuring that early-career researchers gained practical expertise in chemical propulsion and space sustainability. Enpulsion, Exotrail, and T4i, meanwhile, provided young engineers with firsthand experience in ESA's vacuum testing facilities, giving them direct exposure to propulsion system characterisation and performance evaluation. At T4i, young professionals formed much of the project team, supporting each phase of the project's development. One technician, who initially only had laboratory experience, progressed to conducting full-scale propulsion tests at ESA facilities, demonstrating the career growth enabled by institutional collaboration. By integrating young researchers into these activities, these projects are supporting and developing a highly skilled workforce in the propulsion field within Europe.

Enhanced credibility and reputation

ESA backing has boosted credibility by providing technical validation, building trust with investors, customers, and regulators. This support reduces market entry barriers, aligns the developed technologies with regulatory requirements, attracts funding, and enables involvement in larger missions.

Securing institutional backing, particularly from ESA, has significantly enhanced the credibility and reputation of the organisations involved in these activities. ESA's involvement provides a mark of technical validation, reassuring potential customers, investors, and regulatory bodies that the technology meets stringent standards, helping to reduce barriers to market entry and boosting global competitiveness. For three project teams – Enpulsion, the team at the University of Southampton and Exotrail – their TDE activity was the first time that they had worked with ESA. In the case of Exotrail, they noted that they had secured their TDE contract and a General Support Technology Programme (GSTP) contract in parallel.

Institutional support also provides credibility, with Enpulsion and T4i noting that the 'ESA stamp of approval' had strengthened their reputation, attracting potential commercial partnerships, follow-on funding, and investment. Similarly, the University of Southampton suggested that, in addition to increasing the team's visibility within the wider space community, their Technical Officer had helped them to build and develop connections with other companies within the sector. Enpulsion also reflected on their experiences using the testing facilities at ESTEC and highlighted that external visitors - "very senior people, including heads of national agencies" - witnessed their testing activities. They acknowledged that this increased their visibility and exposure, though also noted that this could be a double-edged sword if the testing had failed in front of such high-profile individuals.

Credibility, through partnership with ESA, also allows organisations to secure involvement in larger-scale missions – such as the University of Pisa Chemical Propulsion Research Group securing a place on the ASI-funded *EXtended Cubesat for Innovative Technology Experiments* (EXCITE) mission[4], ensuring continued advancement of their propulsion system and other critical technologies.

[4] The mission is internally developed by the University of Pisa Space Systems Laboratory.

Securing follow-on funding and deployment opportunities

Several projects have successfully leveraged their TDE-funded activities to secure further investment and access to missions, advancing their propulsion technologies, and bringing their systems closer to commercial readiness and market adoption.

Beyond enhanced credibility and reputation, ESA TDE funding has supported jobs and capabilities across the contractors[5], and led to the development of new partnerships[6] – making these organisations better equipped to seek and secure follow-on opportunities. Several projects reported having successfully leveraged their TDE-funded activities to secure further investment, or to gain access to forthcoming missions to further develop and validate their technologies. For example, the University of Southampton progressed from the TDE-funded feasibility study to ESA's GSTP programme, receiving €200,000 to de-risk the technology further. They also received €240,000 (£200,000) from the UK Space Agency to undertake a feasibility study for Active Debris Removal (ADR) activities. T4i have leveraged their TDE experience to secure approximately €600,000 through the GSTP programme, seeking to achieve full qualification of their propulsion system and preparing it for launch in the near future. By securing follow-on GSTP investment, T4i is positioned to commercialise a cost-effective, long-lasting alternative to conventional thrusters by the end of 2027.

Additionally, the University of Pisa's CHIPS project secured a place on its upcoming ASI-funded EXCITE mission,[ix] as part of a broader €3 million project where their propulsion system is one of 5 payloads, further advancing their propulsion system's readiness. Enpulsion, meanwhile, after validating their propulsion system, were able to secure an unspecified funding amount through ESA's Advanced Research in Telecommunications Systems (ARTES) programme, as well as generating commercial interest and new contracts from a client in North America, reinforcing the role of early institutional funding in bridging the gap between R&D and market adoption.

Enhancing European competitiveness and non-dependence

Developing CubeSat propulsion capabilities in Europe strengthens supply chain resilience, reduces external dependencies, and enhances competitiveness in a strategic and fast-growing market.

As highlighted earlier, ESA has strategically funded a range of projects to develop diverse CubeSat propulsion solutions across its Member States, ensuring that expertise is widely

[5] Enpulsion: Core team of 3 engineers; T4i: 10 team members; University of Southampton: 2 members of staff and 2 PhD students; University of Pisa: 2 members of staff, and 3 students; Exotrail: 5 team members directly involved, a further 3 staff supporting the project.
[6] T4i with Tyvak International and the University of Surrey; University of Southampton with Inkron Oy.

distributed, and that Europe possesses technologies to respond to wide-ranging propulsion requirements in the future.

The ability to produce propulsion units at scale strengthens the European supply chain by reducing dependence on non-European components and raw materials, fostering technological sovereignty and enhancing regional competitiveness. It also mitigates the impacts of geopolitical events. For example, the ongoing conflict in Ukraine has highlighted the risks of external dependencies, with Europe's launcher programme being impacted due to the disruption of Ukrainian factories that produced the engines for the Vega and Vega-C rocket systems.[x] Developing European propulsion systems will also ensure unrestricted access to essential technology, overcoming potential export hurdles such as the US International Traffic in Arms Regulations (ITAR).

From an economic perspective, being able to supply reliable propulsion solutions for smaller platforms enhances the competitiveness of European space technology providers, which is particularly valuable as the global CubeSat market is expected to exceed €1.55bn ($1.7bn) by 2033 (growing at a CAGR of ~17% from 2023 to 2033), with Europe expected to grow the fastest during the period.[xi]

Future commercialisation opportunities and spin-outs

While still requiring further maturation, testing, and regulatory alignment before market readiness, the propulsion technologies developed through this activity show early commercial potential through miniaturisation and cost-saving innovations, and opportunities for unique applications.

Though these technologies are currently at a relatively low TRL, there are clear pathways to future commercialisation already emerging. As highlighted earlier, the global CubeSat market is experiencing a period of growth. ESA forecasts that over 6,300 CubeSats will be operational between 2023 and 2032, of which more than 2,300 are estimated to be addressable by the European space sector[xii]. Whilst the number of CubeSats featuring propulsion to date is low, it is expected that this will increase with the rise of mega-constellations and in response to new space debris mitigation guidelines and standards. The increasing size of CubeSats is also seen as a driver.

These TDE-funded projects have developed miniaturised technologies, some of them leveraging additive manufacturing techniques (University of Southampton) and the use of alternative propellants, such as the volumetric efficiency of iodine and 3D-printed technologies (Enpulsion and T4i),[7] making them size- and cost-competitive solutions. Some

[7] T4i estimate that their propulsion units could command a price of approximately €130,000 per unit.

projects also present unique commercial applications. For example, Enpulsion's beam-steering capability offers a novel approach for precise thrust vectoring, whilst the University of Southampton's system could offer significant advantages for ultra-small satellites that lack the space to include propulsive technologies internally. The University of Pisa's propulsion unit, meanwhile, is well positioned to be deployed in mid-sized CubeSats (between 3U to 16U).

The ability to transition from research-driven projects to viable commercial products will be key to ensuring that these technologies reach widespread adoption. The Universities of Southampton and Pisa have notably indicated the possibility of creating spinout organisations to scale up and commercialise their propulsion technologies. However, the University of Pisa suggested that the immediate focus is still on advancing technical development to meet industry demand, and the University of Southampton highlighted that they may license the technology instead due to complexities surrounding spinning-out an academic institution.

Despite the opportunities presented by these technologies, commercialisation will depend on further maturation and testing, in-orbit demonstration and ensuring alignment with emerging regulatory and supply chain challenges, particularly where propulsion components remain dependant on non-European suppliers.

Would these benefits have been realised without ESA?

These activities, funded through ESA's TDE programme, have provided substantial benefits by enabling early-stage technology development and de-risking innovative concepts before commercial investment. By granting access to ESA testing facilities in particular, partnership with the Agency has helped research teams refine their propulsion systems under rigorous conditions, ensuring compliance with high industry standards. Additionally, these activities have supported European non-dependence in propulsion technology, reducing reliance on non-European components and raw materials.

"If we hadn't received funding through ESA, we would have struggled to increase the TRL of this project to the level it is at now." – University of Southampton

"Having access to the ESA testing facilities was great – it also helped their team to better understand the details and functionality of our technology. It's a win-win situation." – Enpulsion

"Having done the TDE activity, we were able to secure an IOD payload position on an ASI-funded mission. No TDE development activities, no payload." – University of Pisa

Several projects have successfully secured follow-on funding through ESA programmes such as ARTES and GSTP. Beyond technological advancements, the activity has provided increased visibility for participating organisations, strengthening Europe's position as an innovator and leader in the CubeSat propulsion sector.

Next steps: Further development, further benefits

The next steps for these projects vary based on their current TRL and objectives, but all share a common trajectory of refining their propulsion technologies, securing additional funding, and moving toward commercial deployment. Further developments will likely focus on optimising performance, reducing overall production costs, and refining solutions to meet the needs of the broader market. Those projects that were being continued into further phases identified their planned next steps:

- **ENPULSION NANO AR³** (*Enpulsion*). The follow-on development under the ARTES programme will focus on the qualification of its thrust-steering technology. Currently at TRL 4, the next steps involve rigorous testing and further refinement to bring the system to market readiness, hopefully within the next 2 years. Enpulsion reported that they have already begun selling early versions of this technology, leveraging a 'New Space' approach to development where customers accept a higher risk in exchange for deploying innovative technologies.

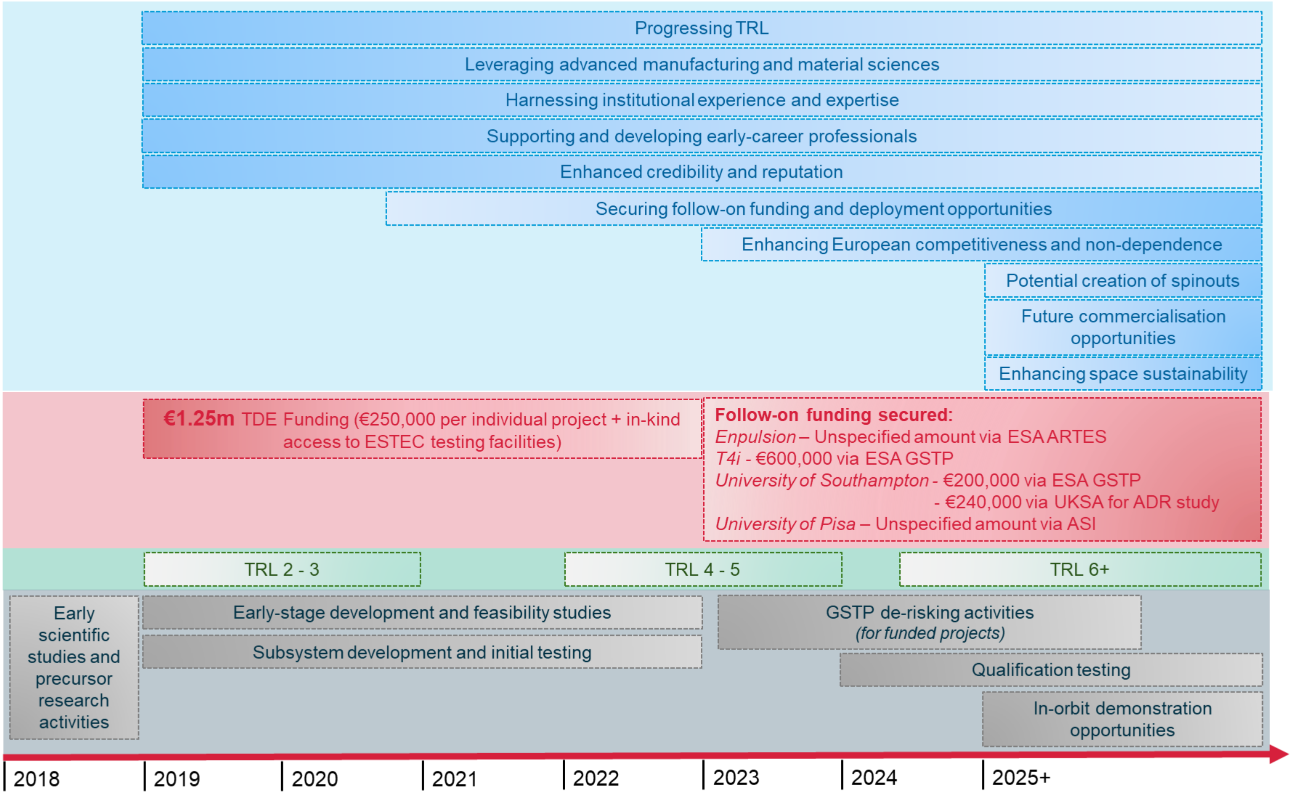
- **REGULUS-150-Xe** (*T4i*). Progressing under GSTP funding, the project has continued to evolve, including transitioning from xenon to iodine (REGULUS-150-I2). The team reports that they are working towards full system qualification and anticipate a commercially viable product to be ready for deployment in 2027. They note that a flight demonstration is essential to secure customer confidence and are actively seeking out potential launch opportunities.

- **Cube-de-ALPS** (*University of Southampton*). The team is prioritising the completion of the GSTP-funded de-risking phase, aiming to raise the system from TRL 4 to 6. They are working to resolve technical issues identified during the TDE phase, with an anticipated timeline of 1-2 years before in-orbit testing.

- **CHIPS** (*University of Pisa*). The next milestone for this project is its inclusion as a payload on an ASI MicroSat mission, which kicked off on 14 February 2025. This is viewed as a key step in achieving TRL 6 and in demonstrating a commercially viable system towards the final in-orbit demonstration.

A preliminary timeline overview of the TDE-funded '*Innovative Propulsion for CubeSats*' project and associated potential benefits is provided below.

Figure 1: Overview of the timeline of the 'Innovative propulsion for CubeSats' project, and potential associated benefits



Source: know.space based on ESA and contractor data

Though each project is at a different stage of development, they collectively represent a significant advancement in the provision of affordable and adaptable next-generation satellite propulsion systems within Europe. The potential long-term benefits of these projects are also substantial. They will enhance mission flexibility, facilitate longer satellite lifespans, enable compliance with emerging space debris mitigation regulations, and allow levels of manoeuvrability previously restricted to larger spacecraft. The ability to provide reliable European-manufactured propulsion systems will also, in the long term, strengthen Europe's position in the global CubeSat satellite industry and reduce dependence on non-European suppliers. Additionally, as these projects advance and enter commercialisation phases, they may stimulate job creation and technical skills development and potentially attract further investment.

Key priority indicators

Programme	Technology Development Element (TDE)
Countries	Austria, Italy, United Kingdom, France, Finland.
Duration	TDE activities were set to be completed within 18 months, but this varied between projects. Though commencing in 2019, some projects were subsequently impacted by the COVID-19 pandemic and were extended.
Lead contractors	Enpulsion (AT), T4i (IT), University of Southampton (UK), Exotrail (FR), and the University of Pisa (IT).
Sub-contractors	Two projects had sub-contractors, or partner organisations: ▪ **T4i:** Open Cosmos (UK), University of Surrey (UK), and Tyvak International (IT). ▪ **University of Southampton:** Inkron Oy (FI).
TRL progression	▪ **Enpulsion:** TRL 3 to 4 ▪ **T4i**: TRL 2 to 4 ▪ **University of Southampton**: TRL 2 to 4 ▪ **University of Pisa**: TRL 2 to 4-5
Spin-out into the space sector	Potential spin-outs from the Universities of Southampton and Pisa.
Jobs supported	▪ **Enpulsion:** Core team of 3 engineers ▪ **T4i:** 10 team members ▪ **University of Southampton:** 2 members of staff and 2 PhD students. ▪ **University of Pisa:** 2 members of staff, and 3 students. ▪ **Exotrail**: 5 team members directly involved, with a further 3 staff supporting the project.
New collaboration with ESA	This was the first time that Enpulsion, Exotrail, and the University of Southampton research team had worked alongside ESA.
Partnerships created	Two projects reported new partnerships or collaborations as part of their activities: ▪ **T4i** with Tyvak International and the University of Surrey ▪ **University of Southampton** with Inkron Oy.

Follow-on funding applied/secured	▪ **Enpulsion:** Unspecified funding amount secured through ESA's Advanced Research in Telecommunications Systems (ARTES) programme. ▪ **T4i:** €600,000 GSTP funding ▪ **University of Southampton:** additional €200,000 GSTP funding to progress from TRL 4 to 6 (expected completion April 2025), and €240,000 from the UK Space Agency to undertake a feasibility study for Active Debris Removal. ▪ **University of Pisa:** Unspecified funding amount from the University of Pisa Space Systems Laboratory as part of the Italian Space Agency-funded EXCITE mission (part of a €3 million project where their propulsion system is one of 5 payloads).

[i] NASA (n.d.). *InSight Lander*. Available at: https://science.nasa.gov/mission/insight
[ii] ESA (n.d). *Deep space CubeSats.* Available at: www.esa.int/Space_Safety/Hera/Deep_space_CubeSats
[iii] Agenzia Spaziale Italiana (n.d.). *ALCOR Program*. Available at: https://www.asi.it/en/technologies-and-engineering/micro-and-nanosatellites/alcor-program/
[iv] ESA (2024). *ESA Space Environment Report 2024.* Available at: www.esa.int/Space_Safety/Space_Debris/ESA_Space_Environment_Report_2024
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