

Electric Propulsion

Overview, Mission Applications & Future Opportunities

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Outline



- Electric Propulsion: A brief introduction and history
- Mission Applications & Future Trends
 - Telecommunications
 - Science & Exploration
- Interested in Electric Propulsion?
 - Skills & roles in EP
 - My career path
 - Recommendations/Opportunities for the Next Generation of EP Engineers
- Questions & Answers























Chemical Propulsion vs Electric Propulsion



How does Electric Propulsion compare with Chemical Propulsion?

Chemical propulsion fundamentally relies on the nozzle expansion of a gas:

Considering 1-D isentropic compressible flow:

Max. exhaust velocity (into vacuum)

$$v_{ex\ max} = \sqrt{\frac{2\gamma R_0 T_c}{(\gamma - 1)\mathcal{M}}}$$

 R_0 = universal gas constant γ = specific heat ratio

 T_C = chamber (stagnation) temperature M = molecular weight

Effective exhaust velocity < 5 kms⁻¹ Specific Impulse < 500 s

Chemical propulsion systems are considered energy limited

To increase performance further requires a means to accelerate propellant that does not rely on the energy stored within the propellant





$$\Delta v = v_{ex} \ln \left(\frac{m_0}{m_f} \right) = \left(I_{sp} g_0 \right) \ln \left(\frac{m_0}{m_f} \right)$$

Initial mass including propellant, m_0 $g_0 = 9.80665 \text{ m/s}^2$

Electric Propulsion: Overview



- In general, Electric Propulsion encompasses any propulsion technology in which electrical energy is used to produce thrust.
- Electrical energy is used to ionize the propellant (gas, liquid, solid) and accelerate the resulting ions/plasma to very high exhaust velocities (10-40km/s)
- Electric Propulsion is very fuel efficient, but much lower thrust levels (mN) are achievable than for chemical propulsion.
- Depending on the process used to accelerate the propellant, electric propulsion thrusters fall into three main categories.
 - Electrothermal

Resistojets

Arcjets

- Electrostatic

Gridded Ion Engines (GIE)

Hall Effect Thrusters (HET)

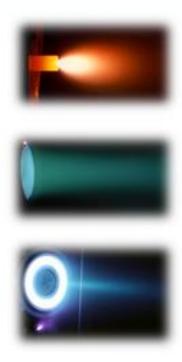
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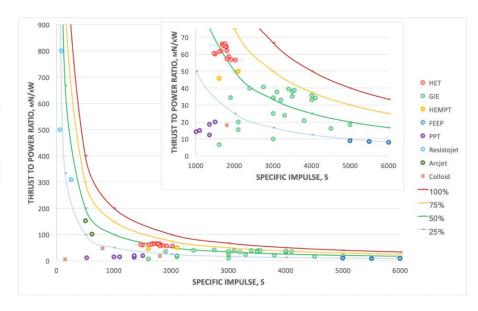
Field Emission Electric Propulsion (FEEP)

- Electromagnetic

Pulsed Plasma Thruster (PPT)

Magneto Plasma Dynamic Thrusters (MPD)

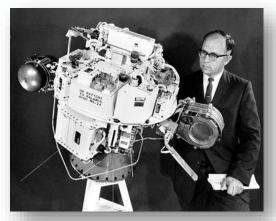




Electric Propulsion: History



First use of electric propulsion in space was in the early 1960s:



Increasing number of EP systems flown from the late-1970's onwards (resistojets, arcjets, ion thrusters, hall effect thrusters).

SERT-1 (US) July 1964 Ion Thruster



Orbit Raising

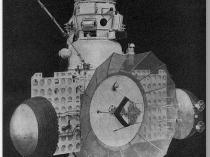
De-orbiting

Drag-compensation



BepiColombo (ESA)

GOCE (ESA)



ZOND-2 (Soviet Union) Nov 1964 Pulsed Plasma Thruster







Electric Propulsion: Ion Thrusters



• The two most widely adopted EP thrusters are Hall Effect Thrusters (HET) and Gridded Ion Engines (GIE). Between them they provide performances matching a wide range of applications.





Characteristic	Hall Effect Thruster	Gridded Ion Engine	Comment
Specific Power	18W/mN	25-35W/mN	Lower number represents improved Orbit Transfer durations for a given power ceiling
Thruster Efficiency	50%	70%	Higher number tends to reduce thermal interface demands for a given power ceiling
Specific Impulse	1500-2500s	2500-4500s	Higher number represents wet mass saving / higher payload fraction
Operating Voltage	300-400V	1000-2000V	Linked to specific impulse, higher voltages are more challenging for power supply design.
PPU Specific Mass	5kg/kW	10kg/kW	Higher number represents increased EP system dry mass penalty
Plume Divergence	45°	15°	Lower number reduces complications of thruster beam interaction with spacecraft appendages (solar arrays, antennas, deployable radiators etc.)
Throttle Range	2:1	10:1	20:1 demonstrated on GOCE (QinetiQ T5) Higher ratio useful for power limited missions (MP-R)

Mission Applications: Telecommunication Spacecraft



Operational Station Keeping

- In 2004, Intelsat 10-02 became the first European developed telecom satellite using EP for STK.
- Since then several satellites have been built in Europe that feature (Russian) SPT-100 thrusters.
- In July 2013, AlphaSat became the first European developed telecom satellite using four SAFRAN PPS-1350G HETs for NSSK.

Orbit Raising

- On telecom satellites, orbit raising to GEO has traditionally been achieved using chemical propulsion in a few days but consumes propellant that amounts to ~40% of the s/c mass. Using EP, orbit raising takes longer (months) but can reduce the propellant consumption drastically, increasing the useful dry mass fraction and reducing launch cost.
- Boeing (US) was the first satellite manufacturer to introduce partial EP orbit raising (orbit topping) on the 702HP platform.

All-Electric Platforms (EOR & STK)

- In 2015, the Boeing built Eutelsat 115 and ABS 3A platforms became the first all-electric commercial satellites demonstrating Electric Orbit Raising.
- Today, all 3 of the main European Large System Integrators (Airbus Defense & Space, Thales Alenia Space, OHB) are developing all-electric commercial satellites.
- HET-based EP subsystems are currently the preferred choice by European LSIs for full-EP platforms.



Future Trends: Large Constellations

esa

- Renewed market interest in LEO/MEO constellations
 - propulsion for orbit acquisition, maintenance and de-orbiting
- <u>LEO</u>: micro- to mini-satellites, power for propulsion up to 300W
 Target price for propulsion subsystems ~30k€ 100k€
 100 500 units per year (excl. mega-constellations of 1000s)
- <u>LEO/MEO</u>: small to medium satellites, approx. 500W 2kW
 Target price for propulsion subsystems ~100k€ 500k€
 100 300 units per year
- Critical: end-of-life disposal strategy >> reliability
- Challenges:
 - Fast innovation and strong competitiveness
 - Drastic reduction of manufacturing costs
 - Standardisation of EP testing
 - IOD of novel propulsion technologies



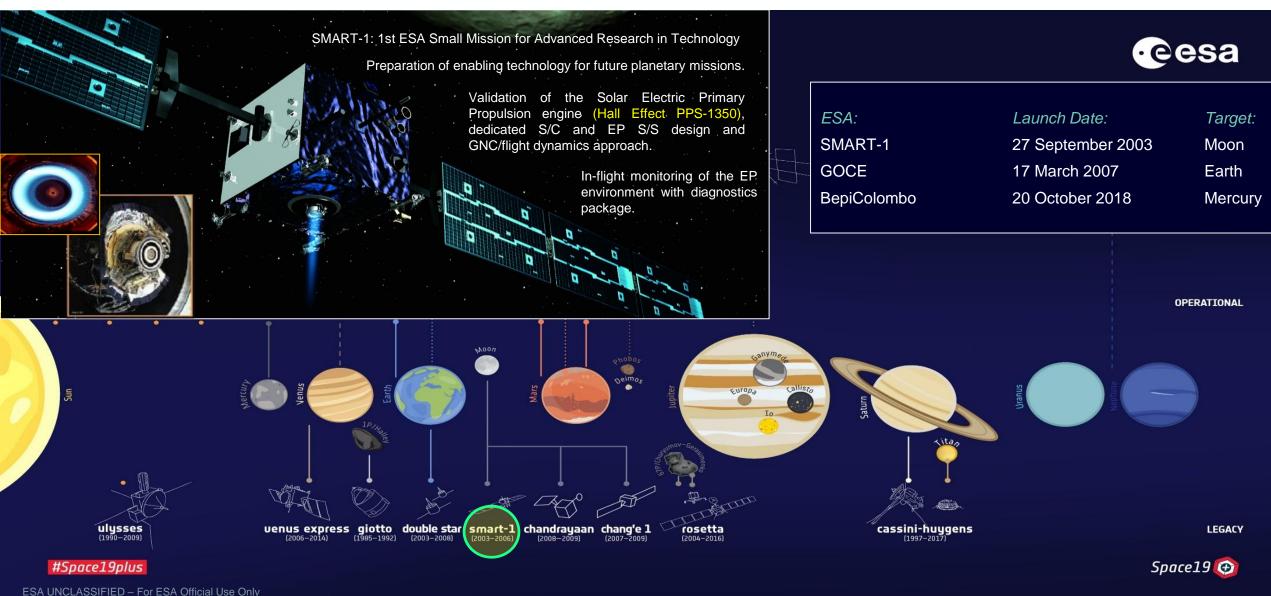
Starlink (SpaceX)	up to 12,000 spacecraft (possible up to 42,000)	
OneWeb	> 700 spacecraft	
Others	ICEYE, GalaxySpace, Amazon (Kuiper)	

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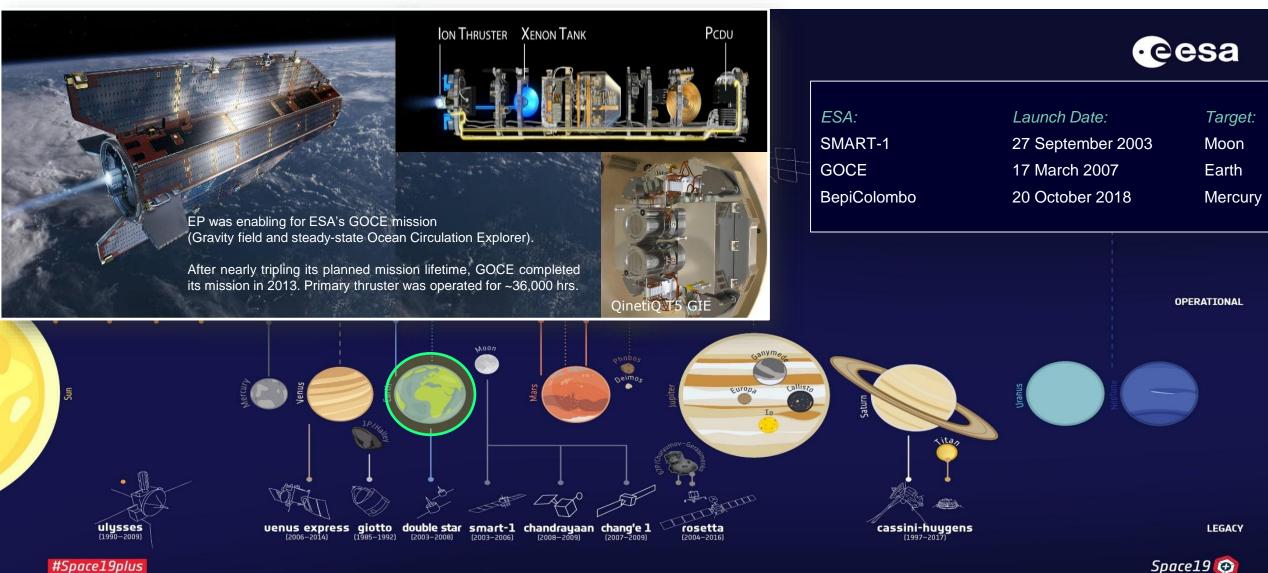


→ THE EUROPEAN SPACE AGENCY





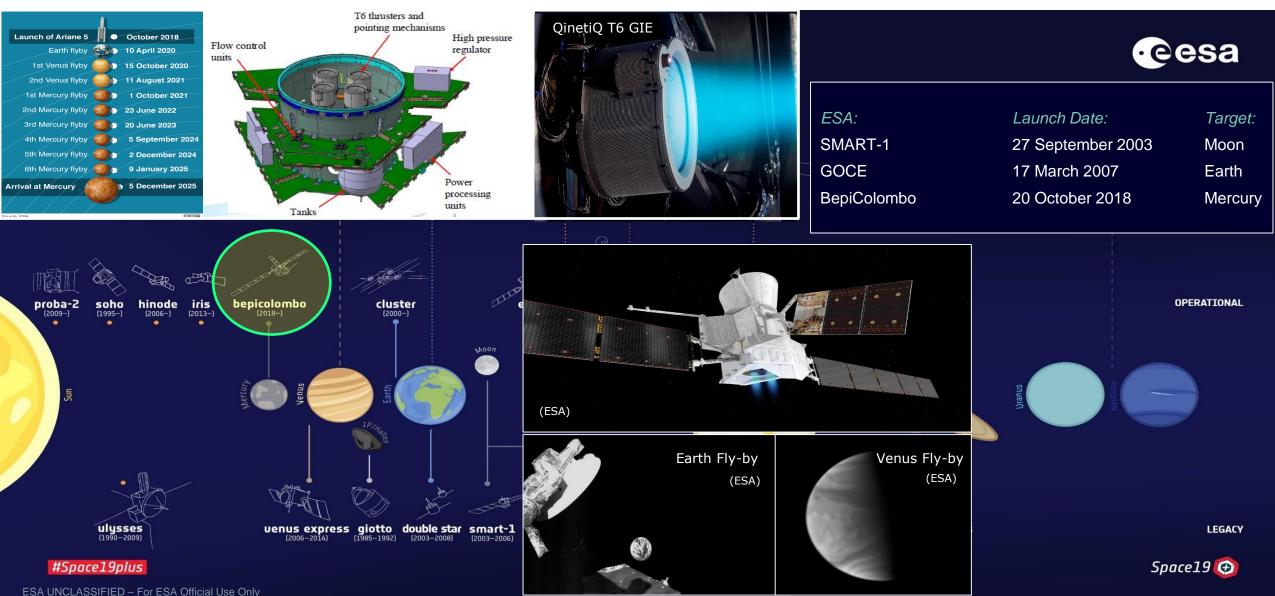




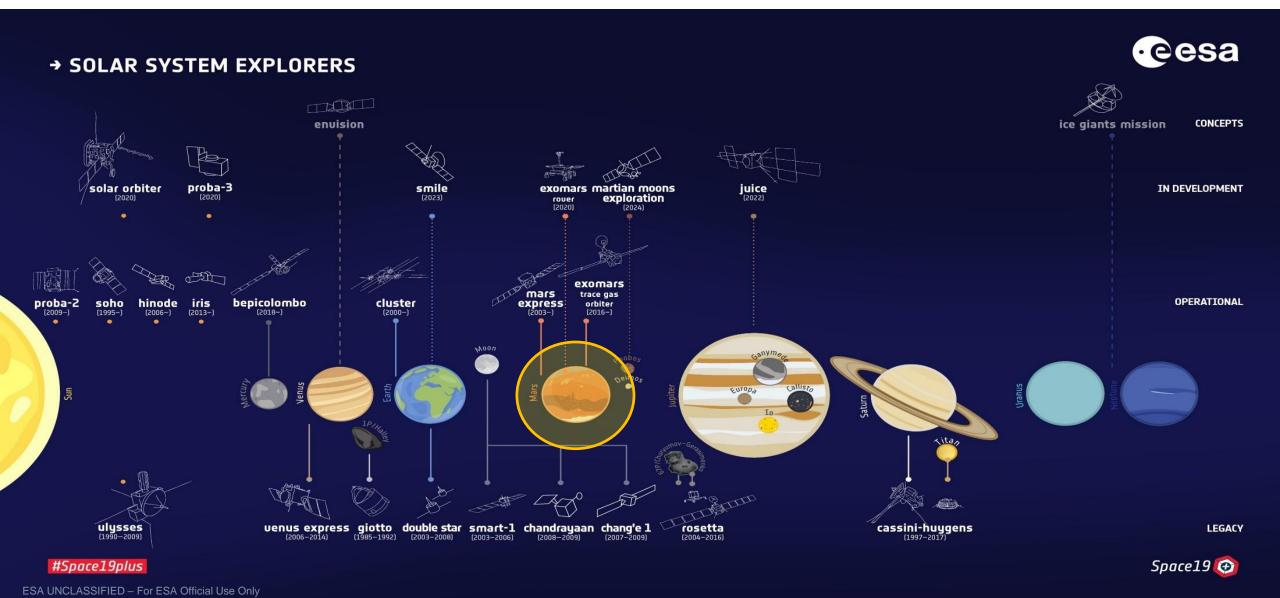
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MSR Earth Return Orbiter - bringing Mars down to Earth

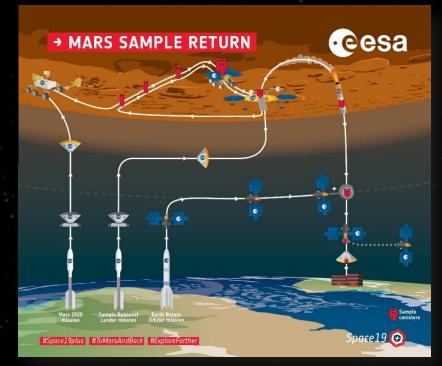
Earth Return Orbiter (ERO) will bring the first ever Mars samples back to Earth by 2031. ERO is ESA's contribution to the final part of the NASA-led Mars Sample Return campaign.



Mars Sample Return will represent a cornerstone in the exploration of the Solar System. The MSR overall campaign architecture is based on three different missions as an international effort.



Bringing its extensive experience on exploration missions like Rosetta, Mars Express, Venus Express, Gaia, ATV and BepiColombo.



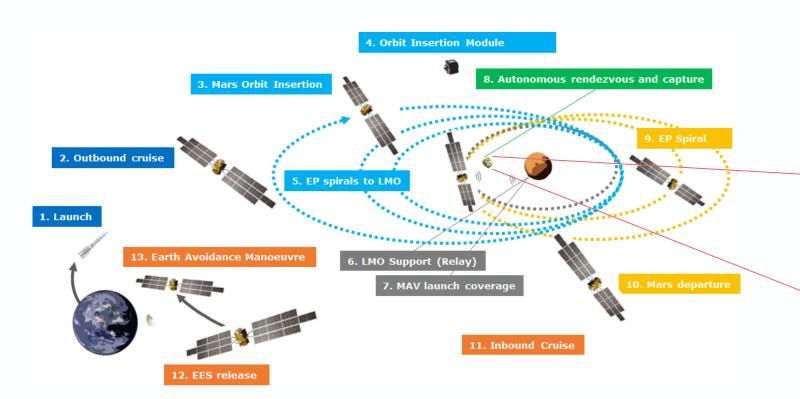
AIRBUS

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Solar Electric Propulsion is considered for the outbound and return cruise phases and orbit lowering/raising at Mars.



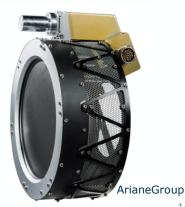




EP Subsystem

3 x EP chains + 1 redundant
Utilising 7.5 kW RIT thrusters
Each thruster:

0.16 – 0.25 N 4000s 15 MNs



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Future Trends: Science & Exploration



- Continued trend in scaling-up and scaling-down of EP subsystems for science and exploration:
- 1. Small-to-medium class, versatile spacecraft for NEO / asteroid intercept and planetary exploration
 - low power, low thrust high Isp propulsion subsystems

Scaling-down for Micropropulsion







N





10 kW - 20 kW0.3 - 1.1 N

2000s - 3800s



- High Power EP Subsystems for space transportation, interplanetary missions, spacecraft servicing
- However, EP as configured today (whether GIE or HET) is limited by spacecraft power generation:
 - Solar Array W/kg and structure size (they can still get quite a bit bigger but there will be a limit)
 - Mass of power converters/distribution

Challenges

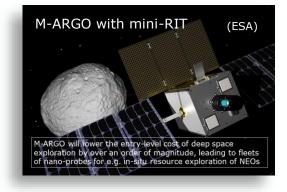
- Improved plasma confinement
- Significant heat loads: accurate thermal modelling becomes more important in the materials selection and qualification process
- Alternative propellants
- Manufacturing of components
- Test facility infrastructure: limited facilities in Europe for testing high power EP subsystems
- · Development of high fidelity numerical models for performance and lifetime that can be used as reliable design tools and to reduce verification overhead (i.e. long duration life tests)





Challenges

- Power Conditioning and control; high power density >> flexible solar arrays
- Thermal design & control; high power density, high dissipation >> deployable radiator panels
- Standardisation of EP testing to reduce verification overhead of low cost subsystems



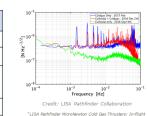
иN

- 2. Space missions with precision pointing/control requirements are driving the need for propulsion subsystems capable of providing very low thrust levels over a wide throttle, with sub-µN resolution and very low noise:
 - interferometry missions (e.g. LISA)
 - formation flying

Challenges

- Extending the throttle range
- Noise verification
- Neutralisation strategy (for low power, high Isp EP subsystems)

	Future Missions
Thrust Range	1-1000 µN
Thrust Resolution	≤ 0.1 µN
Thrust Noise	$< 0.1 \mu\text{N}/\sqrt{\text{Hz}}$ (0.1 mHz - 1 Hz)
Total Impulse	Several 10,000 Ns

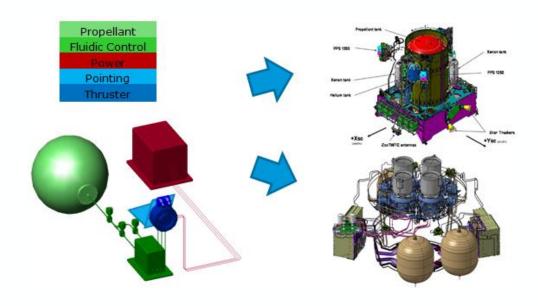


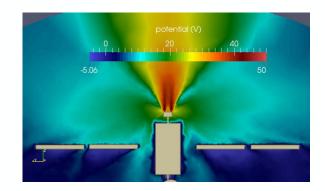
Credit: FOTEC / Enpulsion

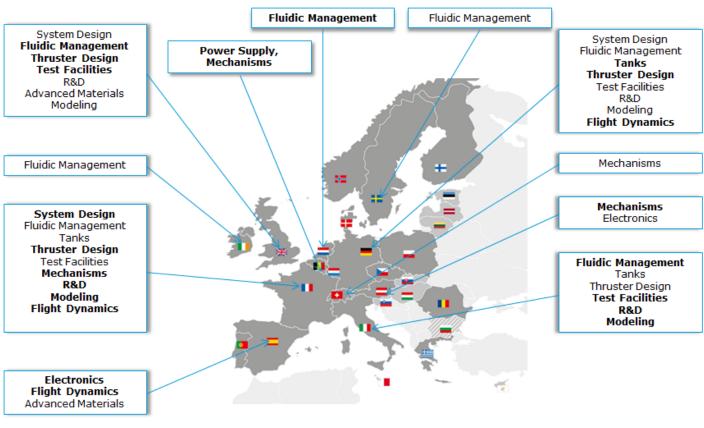


Interested in EP? Skills and Technical Roles in EP















































More information:



Electric Rocket Propulsion Society: http://electricrocket.org/ (contains IEPC Article Repository)

http://www.epic-src.eu



















EPIC Lectures 2019: https://livestream.com/accounts/362/epiclectureseries2019

The European Commission (EC) set up the "In-space Electrical Propulsion and Station-Keeping" Strategic Research Cluster (SRC) in Horizon 2020 with the goal of enabling major advances in Electric Propulsion for in-space operations and transportation, in order to contribute to the leadership of European capabilities in electric propulsion at global level within the 2020-2030 timeframe.

The "Electric Propulsion Innovation & Competitiveness" (EPIC) project is the PSA for the Electric Propulsion SRC funded as response to the H2020 Space COMPET-3-2014 topic.

The R&D is implemented via Calls made by the EC, open to all EU Member States and H2020 participants (future: Horizon Europe)















Next EPIC Workshop and Lecture Series: Cologne, May 2022

See EPIC website (above)

More information:



European Cooperation for Space Standardisation: https://ecss.nl/

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Dankanich, J. et al, "Recommended Practice for Pressure Measurement and Calculation of Effective Pumping Speed in Electric Propulsion Testing", Journal of Propulsion and Power, Vol. 33 (3), May-June 2017

Lobbia, R. et al, "Recommended Practice for Use of Langmuir Probes in Electric Propulsion Testing", Journal of Propulsion and Power, Vol. 33 (3), May-June 2017

Brown, D. et al, "Recommended Practice for Use of Faraday Probes in Electric Propulsion Testing", Journal of Propulsion and Power, Vol. 33 (3), May-June 2017

Sheehan, J.P. et al, "Recommended Practice for Use of Emissive Probes in Electric Propulsion Testing", Journal of Propulsion and Power, Vol. 33 (3), May-June 2017

Farnell, C. et al, "Recommended Practice for Use of Electrostatic Analyzers in Electric Propulsion Testing", Journal of Propulsion and Power, Vol. 33 (3), May-June 2017

Polzin, K. et al, "Recommended Practice for Use of Inductive Magnetic Field Probes in Electric Propulsion Testing", Journal of Propulsion and Power, Vol. 33 (3), May-June 2017

Opportunities in ESA



ESA Programme	Summary	
Internships	3 – 6 months, for students in the last year, or second to last year, of a master's degree. Students from ESA Member States. Advertised around November every year – see: https://www.esa.int/About_Us/Careers_at_ESA/Student_Internships2	
Young Graduate Trainee	1 year, for students in the last year of a master's degree, or recently graduated. Students from ESA Member States. Advertised around February every year – see: https://www.esa.int/About_Us/Careers_at_ESA/Graduates_Young_Graduate_Trainees	
National Trainee	1 year (with possible extension to 2 years) for students in the last year of a master's degree, or recently graduated. Students from Belgium, Estonia, Germany, Ireland, Luxembourg, Portugal, Switzerland, Greece and Spain. See: https://www.esa.int/About_Us/Careers_at_ESA/Graduates_National_Trainees	
Research Fellowship	2 years (with possible extension to 3 years) for recent Postdocs (within 5 years). Postdocs from ESA Member States, European Cooperating States, Associated Member States and Canada (as Cooperating State). Published throughout the year – see: https://www.esa.int/About_Us/Careers_at_ESA/Post_docs_Research_Fellowship	
Co-funded Research	See ESA's Open Space Innovation Platform https://ideas.esa.int/servlet/hype/IMT?documentTableId=45087592960554546&userAction=Browse&templateName=&documentId=d43f47acc4ff42c1a58d463ce4518622	































Thank You

Questions?

https://www.esa.int