Summer 2023

IAF SPACE PROPULSION COMMITTEE

1. Introduction

The Space Propulsion Committee addresses sub-orbital, Earth-to-orbit, and in-space propulsion. All types of propulsion are of interest to the committee: chemical and non-chemical/electric propulsion, but also advanced, unconventional, or air-breathing propulsion. The symposium sessions organized by the committee during the yearly International Astronautical Congress (IAC) include: liquid systems (2 sessions); solid and hybrid systems (2 sessions); electric propulsion (2 sessions); small satellite propulsion; nuclear propulsion and power systems; propellantless propulsion; air-breathing rocket propulsion; disruptive propulsion systems enabling new/visionary space missions.

The committee deals with component technologies as well as complete propulsion systems and their implementation in missions and spacecraft, but also welcomes discussions on dedicated test facilities and diagnostics for space propulsion testing. Special attention is given to New Space developments, including miniaturized propulsion systems for small spacecraft/launchers, or how combined technologies, such as chemical and electric propulsion, can be optimized for extending the range of feasible space missions.

2. Summary - Space Propulsion Highlights

In the **United States**, NASA has successfully launched and completed (November-December 2022) the **Artemis 1** mission. The mission included successful operational demonstration of all propulsion systems of the Space Launch System (cryogenic LOX-LH2 first stage, solid rocket boosters designed as an extended 5 segments version of the 4 segments Shuttle booster, cryogenic LOX-LH2 upper stage), as well as the propulsion system of the Orion Lunar spacecraft, in particular the primary, secondary and RCS engines of the European Service Module developed in collaboration with ESA. The next and first manned flight of the Artemis program is currently scheduled for 2024.

In April 2023, SpaceX performed the first orbital test flight of the Starship program. The test was the first attempt to lift off the Starship fully stacked in its launcher, whose first stage (**Super Heavy Booster**) is powered by 33 LOX-Methane Raptor engines, for a total nominal thrust of more than 71 MN.

Artemis 1 launch
(court. NASA)

In **Europe**, in April 2023 the 116th launch of the **Ariane 5** launcher successfully brought to orbit (in its ECA version) the JUICE mission from ESA. Qualification of the large propulsion systems for the **Ariane 6** (solid booster P120C, Vulcain 2.1 and Vinci cryogenic engines) are now acquired, waiting for the maiden flight expected at the end of 2023. An improved **P160** version of the P120C, with an extra length of 1 m increasing the propellant mass, has been funded by the ESA ministerial conference for flight on A6 Block2 in 2025.

The development of the LOX-Methane **Prometheus** engine is continuing, targeting a “grasshopper flight” on the Themis demonstrator in 2024. Finally, two flights of the **Vega-C** launcher occurred in June and December 2022, with perfect behaviour and flight qualification of the P120C motor, but unfortunately with a failure on the second flight of the second stage **Zefiro 40** solid rocket motor. The development of the **M10** engine (LOX-Methane, 10-t class), for the **Vega-E** version of the launcher is continuing as planned.

Ariane 5 launch of the JUICE spacecraft (court. ESA)

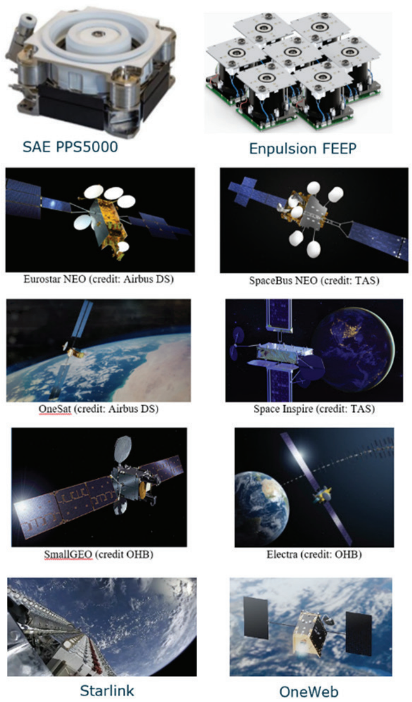
In **Asia**, an attempt for the maiden flight of the new Japanese **H3 rocket** has been done by JAXA in March 2023. The launch has not succeeded due to ignition problems for the second stage of the rocket, which are currently undergoing failure investigation from JAXA toward return to flight of H3. However, the new first stage of the launcher including two LE-9 engines (LOX-LH2, 150-ton class) has fully worked as planned.

The maiden flight of **Lijian 1/Zhongke 1A** (ZK-1A), developed by CAS Space, took successfully place in July 2022. This launcher is using four solid stages (three first stages: P71/P35/P10) with a lift-off mass of 135 tons, height of 31 m, main diameter of 2,65 m., and payload capability of 1500 Kg for a SSO orbit at 500 km altitude. A similar launcher, named Jielong 3 or Smart Dragon 3 and developed by CALT, has been flown in December 2022 from a barge launch pad. It is using the same motors. In the same month, the **KZ-11** launcher developed by CASIC and partly derived from the DF31/41 missile had its maiden flight. This launcher has a lift-off mass of 78 tons, a diameter of 2,2 m and is based on a new P45 carbon case first stage. Unfortunately the 3rd stage solid rocket motor failed during the maiden flight.

The first technological launch vehicle flight of the **HANBIT** launcher developed by the Korean company INNOSPACE took place in March 2023 from Brazilian Alcantara site. The hybrid motor (LOX-paraffin fuel), with 150 kN thrust, worked as expected paving the way for the HANBIT-Nano launcher version.

H3 rocket maiden flight (court. JAXA)

Electric Propulsion has made great technological and commercial progress and is being adopted in a large range of space applications: from Cubesats, through Earth observation satellites in LEO and telecommunication satellites in GEO/LEO, to remote deep space missions. Extensive heritage has been achieved through various mission success and large capability exists within the Conventional and NewSpace sectors with good diversification and maturity readiness. The electric propulsion market is characterized by the presence of many suppliers in Europe, North America, Russia, China, Japan, South Korea, Israel and India. The current market is highly competitive, with all the players competing on price, performance, product reliability and availability.

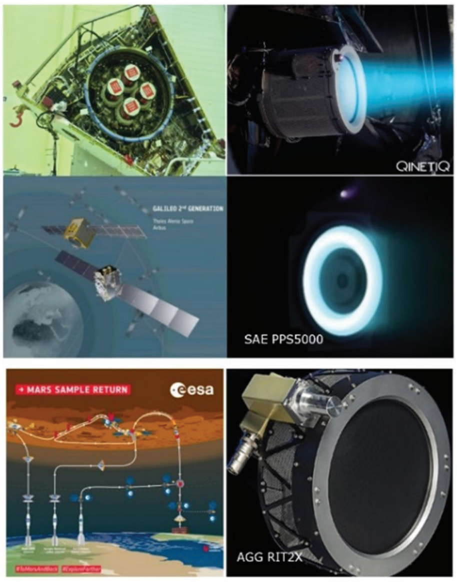


In **Europe**:

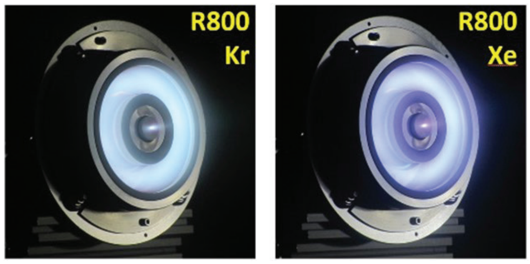
- ESA, the European Commission and National Agencies have heavily invested in developing and maturing European Electric Propulsion technologies, as recently discussed in the EPIC workshop held in

May 2023. **EPIC** (Electric Propulsion Innovation & Competitiveness) is a Programme Support Activity, funded by European Commission as part of Horizon 2020, to enable major advances in electric propulsion for in-space operations and transportation, coordinated by ESA with the participation of several national agencies and two industry associations.

- ESA has launched the **BepiColombo** mission which it is still on its way to Mercury, propelled by 5kW T6 Gridded Ion Engines.



- the 5kW-class HET **PPS®5000** from Safran completed ground qualification with 20000 hours demonstrated on ground and 17 thrusters in orbit.
- the **IFM Nano/AR3/Micro FEEP** from Enpulsion/FOTEC completed ground qualification with 30000 hours demonstrated on emitter and 167 systems in orbit.
- the **GmbH HEMPT-3050** from Thales Alenia Space completed ground qualification with 9000 hours demonstrated.
- Some other thrusters have started their ground qualification, including: AGG **RIT2X**, Sitael **HT100**, Sitael **HT5k**.
- All European Primes are today offering “all-electric” GEO telecommunication platforms using the PPS®5000 from Safran. As examples, Spacebus NEO from Thales Alenia Space and Eurostar NEO from Airbus DS have achieved flight heritage.
- European electric propulsion systems are baseline for the **Galileo 2nd Generation navigation constellation** and the **Mars Samples Return - ERO mission**.
- Rafael’s **R-200TU** and **R-800TU** are in the final stages of ground qualification. R-800TU completed 1000 hours with Xenon and more than 800 hours with Krypton, including tests at high discharge power up to 1.5kW.



In the **United States**:

- NASA has launched the DART mission with the 7kW **NEXT-C** GIEs;
- NASA is developing the **50kW electric propulsion system** for the Lunar Gateway.

Worldwide:

- Electric propulsion has become the standard for LEO large/mega-constellations and thousands of low power (<1kW) HET thrusters are already in operation in the **Starlink** and **OneWeb** constellations.
- Efforts are being put to boost commercialization with competitive price, short lead time, high production volume, high performance and high reliability and to accelerate maturation of innovative/game-changing electric propulsion technologies.

A major boost in the **micro-propulsion** scenario came from the deep-space CubeSats flying with the Artemis 1 mission. All these 10 CubeSats were equipped with a micro-propulsion system, either as orbital maneuvering propulsion, RCS propulsion, or both, including some particularly promising concepts such as: the **AQUARIUS** water resistojet system on the EQUULEUS CubeSat (4 mN thrust, 60 sec specific impulse); the **VACCO MiPS** combined mono-propellant/cold gas system on the ArgoMoon CubeSat (1x 100 mN main thruster, 4x 25 mN RCS thrusters); the **Busek BIT-3** RF ion thruster on Lunar IceCube (solid iodine propellant, 1.1 mN nominal thrust).

MiPS propulsion system (court. VACCO)

In addition, there are several ESA IOD Cubesat missions under development, which are expected to embark Cubesat propulsion systems developed in Europe: GOMX-5, demonstrating large orbit transfer with electric propulsion (1x iodine **NPT30-I2-1.5U** gridded ion engine system from ThrustME); VULCAIN, for stereoscopic imaging of the Earth focusing on Volcanos & coastal areas (1 x iodine **REGULUS HPT** system from T4i); LUMIO, observing meteoroid impact on lunar far side (chemical mono-propellant + cold/warm gas reaction control thrusters); VMMO, observing Moon's water ice in polar region (2 x **IFM NANO FEEP** system from Enpulsion); M-ARGO, demonstrating critical technologies and operation for stand-alone deep-space Cubesats (1 x Gridded Ion Engine system from Mars Space); HENON, for space weather measurement in a Distant Retrograde Orbit with 3-hour advanced warning of solar storms (1 x Gridded Ion Engine system from Mars Space); HERA MILANI Cubesat (cold gas propulsion system from T4i); HERA Juventas Cubesat (cold gas propulsion system from Gomspace); SATIS, for Rendezvous with Apophis two months prior to its close encounter with Earth (1 x Gridded Ion Engine system from Mars Space); e-Inspector, for close observation of large space debris (1 x iodine REGULUS HPT system from T4i.

3. Future Outlook

In the always very active **micro-launchers** sector, interesting developments have been reported by Dawn Aerospace, which has successfully completed several test flights of their rocket-powered Mk-II Aurora spaceplane. The current scaled version of the spaceplane has 5 kg payload capacity and is powered by a 90% H_2O_2-Kerosene engine, providing sea-level thrust of 3.7 kN at sea-level specific impulse of 236 s.

In March 2023, Relativity Space has performed the first orbital test flight of their Terran 1 launcher. This is the first launcher fully built with components built using **Additive Manufacturing** techniques, including its 9 LOX-Methane engines.

In Summer 2022, during a comprehensive test campaign by the NASA Marshall Space Flight Center in cooperation with IN Space, LLC and Purdue University, **Rotating Detonation Engines** (RDE) were successfully tested for use as rocket engines, specifically for lander configurations. Two differently cooled annular combustor configurations were used, which were additively manufactured from different copper-based alloys and each had a plug nozzle. Both designs were successfully ignited with LOX/GH_2 and LOX/Methane propellants and operated both water-cooled and partially regeneratively cooled using methane. A total of 18 starts and 802 seconds of burn time with and without visual confirmation of the existing detonation waves were achieved in 28 test runs. Likewise, hot gas tests were demonstrated up to 133 s until the thermal steady state was reached. The combustion efficiency was equivalent to that of a conventional thrust chamber operated at constant pressure, with the characteristic combustion chamber length being an order of magnitude smaller.

ESA has initiated a Cross-Cutting Initiative on **Innovative Propulsion technologies**, which are considered as propulsion technologies which bring significant positive benefit in terms of mass, performance, cost and flexibility, are at low TRL yet enough (>TRL2) to be engineered and demonstrated in a medium term, that enable new missions or applications, facilitate the creation of new markets and enhance reliability and competitiveness. A workshop will take place in June to address: High Efficiency Atmospheric-Breathing Electric Propulsion for VLEO application, Advanced Airbreathing Propulsion, Rotating and Pulse Detonation Propulsion, Water Propulsion, Long Term Storability and Operation of Hydrogen Peroxide, Innovative Aerodynamic Surfaces, Long-term In-space Cryogenic Propulsion and ISRU Propellants, Space tethers, Beamed Energy Propulsion, Metallic Propellant for Chemical Propulsion, Advanced High Altitude Platform Systems, Innovative Propulsion on Non-Terrestrial Bodies. A second workshop will be organized in 2024 on Nuclear Electric and Nuclear Thermal Propulsion.

4. Committee Activities

The committee is currently made of 45 members from 15 countries, including 8 female members and 10 young professionals, with good distribution among geographical areas and categories (industry, Academia, agencies). In the first half of 2023, one new member has been welcomed in the committee: Saroj Kumar (University of Alabama in Huntsville).

The committee is not only active in the organization of the International Astronautical Congress (IAC), but also fosters synergies with other relevant space propulsion conferences, such as the EUCASS (European Conference for Aeronautical and Space Sciences) and the biennial 3AF/ESA Space Propulsion conference.