*Winter 2022*

# 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 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 scheduled in November 2022 a new attempt to launch the Space Launch System for the Artemis I mission, after two previous attempts were aborted, first due to anomalies during the propellant filling procedures, then due to weather risks. The rocket is powered by four **RS-25D** engines (LOX-LH2) and two five-segments solid rocket boosters, both adapted from the Space Shuttle propulsion system, plus a single RL10B-2 engine for the cryogenic upper stage (LOX-LH2), adapted from the Delta Cryogenic Second Stage used in the Delta III and Delta IV rockets.

In August 2022, SpaceX has completed two important static fire tests within the Starship development program: one **Raptor** engine (LOX-Methane) installed in a prototype of the 1st stage Super Heavy Booster; two Raptor engines installed in a prototype of the 2nd stage Starship. The first orbital test of the rocket is expected to happen not earlier than end-2022.

In October 2022 Firefly Aerospace successfully launched its first launch vehicle, which reached orbit. Both stages of the rocket use LOX/RP-1 engines utilizing a tap-off cycle (**Reaver** and **Lightning**), demonstrating the first non-ground and non-suborbital use of tap-off cycle technology up to date.

*Starship SN24 fire test with two Raptor engines (court. SpaceX)*

In **Europe**, while the maiden flight of the **Ariane 6** launcher is currently postponed to 2023, the first test on the upper-stage **Vinci** engine has been conducted in the P5.2 test bench in DLR Lampoldshausen, in October 2022. Meanwhile, the development of the ASTRIS kick stage of Ariane 6 (based on the **BERTA** engine) and of the **Prometheus** engine (LOX-LCH4, 980 kN thrust) are continuing.

The **Vega-C** launcher, based on the **P120-C** solid rocket motor for its first stage and on the **Zefiro 40**

solid rocket motor for the second stage, performed a successful maiden flight in July 2022, bringing seven satellites to orbit. In the meanwhile, in May 2022, Avio has performed a successful first hot-firing test of the **M10** engine (LOX-Methane, 10-t class), which will represent one of the key elements of the Vega-E version of the launcher, targeted to fly from 2026.


*Fire test of the Vinci engine in October 2022 (court. ESA)*

In **Asia**, after a previous failed attempt, South Korea has successfully launched its **Nuri** rocket in June 2022. The first stage of this launcher is powered by four **KRE-075 SL** engines (LOX-Kerosene, 2.9 MN thrust), with the vacuum version of the same engine being used for the upper stage.

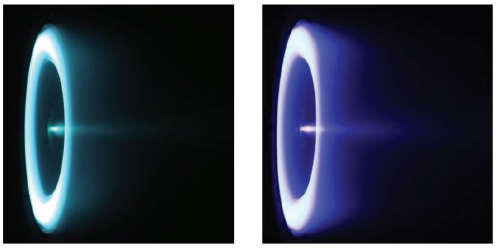
*Maiden launch of the Nuri rocket (court. KARI)*

In China, the ground test of a LOX-LH2 engine (25 tons thrust) was successfully conducted in September 2022. The engine is designed for the third stage of the planned Long **March 9**, a super heavy-lift rocket intended for space exploration missions, such as crewed lunar landing and exploration on Mars. Still in China, the **ZK-1** solid propellant rocket made its maiden flight in July 2022, successfully sending six satellites into their preset orbits. This four-stages rocket, developed by the Chinese Academy of Sciences (CAS), is intended for launching small to medium-sized satellites (1500 kg total payload into 500 km sun-synchronous orbits).

*Test of the LOX-LH2 engine for the 3rd stage of Long March 9*

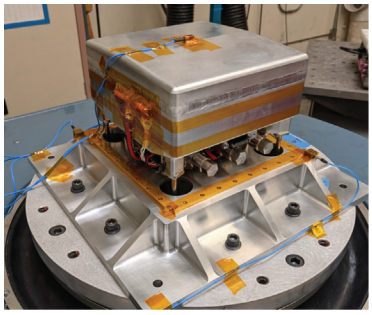
In the **Electric Propulsion** scenario, the crisis due to geo-political situation is implying a general increase of costs for energy and Xenon propellant. Different European developers are facing these issues and alternative low-cost propellants are being considered. The expected market for EP thruster is continuously growing for different applications and, besides existing leader in Europe and US, new companies from the conventional or the New Space market have started to develop EP products in US, Europe and far-East.

In October, SITAEL (Italy) closed a pre-qualification test campaign of its 5 kW Hall Thruster (HT5k) after the completion of a 1500h endurance test, a full performance characterization in the 3-10 kW power range (both with Xenon and Krypton) and an environmental test campaign (structural and thermal vacuum tests).



*HT5k ground tests @SITAEL*

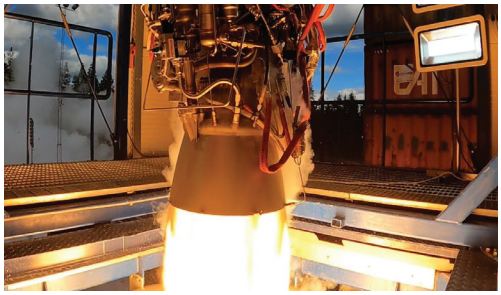
Two major milestones have been reached in the **micro-propulsion** scenario, with the successful launch and operations of two beyond-LEO CubeSats equipped with dedicated propulsion systems: the Italian LICIACube, which witnessed the impact of the DART spacecraft into the asteroid DImorphos, carrying a cold-gas micro-propulsion system (50 mN thrust, 40 s specific impulse); and the US **CAPSTONE** mission, currently on its way to the Moon, equipped with eight mono-propellant hydrazine thrusters (3 N thrust) produced by the company Stellar Exploration, implementing a gear pump system for propellant pressurization.



*CAPSTONE propulsion system (court. NASA)*

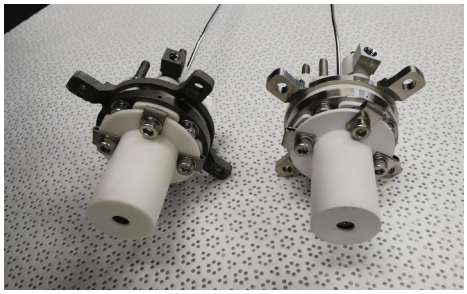
## 3. Future Outlook

Very interesting achievements are being reported in the development of low-cost, reliable rocket engines in the 100 kN-thrust class or below for the **micro-launchers** sector. In July 2022, RFA (Germany) has performed a long-duration fire test of the Helix engine (LOX-Kerosene, 100 kN thrust), consisting of three successive burns of 4 s, 30 s and 40 s. Meanwhile, Pangea Aerospace is continuing the development of their ARCOS 300 kN aerospike engine (LOX-Methane).



*Fire test of the Helix engine in July 2022 (court. RFA)*

With the aim of industrializing its Electric Propulsion products, SITAEL (Italy) consolidated the adoption of **Additive Manufacturing** techniques for the production of key thruster components, like the cathodes and the anodes (which have a complex internal geometry). AM has been successfully applied to different materials, ranging from stainless steel to alumina, and allowed for a significant reduction of costs and production time.



*AM cathode (left) vs. traditionally manufactured cathode (right)*

While several large scale suborbital in-flight **hybrid rocket motor** demonstrations shall be postponed till 2023, the South Korean INNOSPACE plans to launch its Test Launch Vehicle "HANBIT-TLV" in December 2022. The single-staged vehicle will use a 150 kN motor utilizing LOX and a paraffin-based fuel. INNOSPACE revealed more details on its planned family of micro-launch-vehicles with electro-pump feeding systems. Hybrid motors with thrust of 150 kN, 60 kN and 30 kN are to be used. Meanwhile, the sister company of the Taiwanese TiSpace, ATSpace in Australia, is planning two launches of its Kestrel hybrid suborbital rocket. The company confirms work on regeneratively-cooled hybrid rocket motors manufactured using copper alloy utilizing an additive process.

In France, the startup company HyPrSpace has performed some firing tests on a hybrid prototype motor, intended as a first step toward a rocket fully powered by hybrid propulsion.

*Hybrid prototype motor test (court. HyPrSpace)*

Meanwhile, a recent study from Purdue University researchers (https://doi.org/10.3390/aerospace9100581) has assessed the applicability of **Rotating Detonation Combustion** to liquid propellant rocket engines, showing that a 3-14% improvement in specific impulse is theoretically achievable, with especially significant advantages in engines using liquid hydrogen as fuel.

The research vehicle Feitian-1, developed by the Northwest Polytechnical University in China and propelled by a **Rocket-Based Combined Cycle** (RBCC) propulsion system with conventional kerosene-based aviation fuel, has undergone a successful test flight in July 2022. In the first stage of this test flight, an ejector rocket was used to propel the vehicle to the appropriate altitude where the engine could be switched first to ramjet mode and then to scramjet mode, allowing the vehicle to reach hypersonic speed. Finally, a conventional rocket system was used to further raise the altitude.

In the field of **orbital propulsion**, the in-space mobility provider Benchmark Space Systems has been selected by The Exploration Company, a European start-up

developing in-orbit exploration vehicles, to develop the propulsion system for its second demonstrator flight ("Mission Possible", set to launch in 2024, with main goal of performing a safe re-entry of the payload capsule). Benchmark and The Exploration Company will collaborate to develop an innovative propulsion system using High-Test Peroxide (HTP), based on Benchmark's Halcyon Avant propulsion system and on the Ocelot 22 N bi-propellant thruster. In-flight demonstration of this propulsion system will be a crucial step towards the maiden flight of Exploration Company's orbital vehicle Nyx Earth, planned in 2026.

## 4. Committee Activities

The committee is currently made of 50 members from 16 countries, including 8 female members and 8 young professionals, with good distribution among geographical areas and categories (industry, Academia, agencies). In the second half of 2022, two new members have been welcomed in the committee: Marco Di Clemente (Italian Space Agency), William Camilleri (Reaction Engines Ltd).

The committee is not only active in the organization of the International Astronautical Congress, 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.