Winter 2024

IAF SPACE PROPULSION COMMITTEE

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 annualInternational Astronautical Congress includes: 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.

Highlights

Liquid Propulsion

Large rocket launchers/space vehicles were in the spotlight at the liquid propulsion sessions in the IAC 2023. In an interesting keynote talk, the Academy of Aerospace Propulsion Technology and the Xi'an Aerospace Propulsion Institute have presented a wide overview of the current liquid rocket engine developments for **heavy launch vehicles in China**, focusing among others on their 500-ton LOX-kerosene engine and the 220-ton and 25-ton LOX/LH2 engines. AVIO (Italy) has shown the latest developments on

Firing test of a 500-ton LOX-kerosene engine (courtesy Academy of Aerospace Propulsion Technology/ Xi'an Aerospace Propulsion Institute)

the **M10 LOX-Methane engine** for the VEGA-E upper stage, including an experimental demonstration over a cumulative operational time of 1200 seconds. JAXA has presented the results of the qualification test campaign of the **LE-9 engine** for the H3 launch vehicle (LOX-LH2, 1471 kN thrust), successfully demonstrated with 61 firings on engineering models and 9 cumulative firings on the qualification model. Finally, ArianeGroup has illustrated the full range of equipment and subassemblies for the **propulsion system of the ORION European Service module**, specifically focusing on the RCS cluster (4x200 N thrusters, operating with MON and MMH as propellants).

Firing test of the M10 engine (courtesy AVIO S.p.A.)

In another interesting contribution from the T(H)RUST team in the Department of Mechanical and Aerospace Engineering of Sapienza University of Rome, examples of test results on high-frequency combustion instabilities, thrust chamber wall heat flux, cooling channels and nozzles were presented, in support to present and future developments in the field of liquid rocket engine propulsion.

During the conference, an overview of the finalization of the **new Rocket and Satellite Propulsion Laboratory Center** in Warsaw (Poland) was presented. The new facility specializes in green space propulsion research allowing green thruster and engine vacuum qualification for thrust levels of up to 500 N (and up to 5000 N for sea level R&D), with 4 hot fire test benches and extensive chemical laboratories. The opening of the center took place at Łukasiewicz – Institute of Aviation in Warsaw shortly after the IAC, in October 2023.

Solid/Hybrid Propulsion

Various experimental and numerical studies on new concepts and breakthroughs in solid and hybrid propulsion systems were presented at the IAC 2023. The Technology Innovation Institute (UAE) presented possible combinations for **in-situ propellant production for hybrid rocket propulsion**, utilizing materials available on Mars and the Moon. The reactive molecular dynamic simulation results presented by the Aeronautic Institute of Technology (Brazil) shed light on the mechanism underlaying the **aluminium particles passivation** process, showing that better understanding of this mechanism could ensure long-term stability and performance of aluminium-based components in solid propellants. CAS Space (China) presented the conceptual design of a **permeable nozzle with thrust vectoring capability**. ISAE-SUPAERO (France) showed the results of the design and testing of a student-developed hybrid rocket engine using **H_2O_2 and 3D-printed ABS** (Acrylonitrile Butadiene Styrene). Alpha Impulsion (France) presented the development of a deeply original **autophage hybrid rocket** engine, revisiting an old concept for various combinations of liquid/powdered propellants and structural plastic propellants. Warsaw University of Technology (Poland) showed the results of the Twardowsky's engine test campaign, leading to flight qualification of a student hybrid rocket engine.

Tohoku University (Japan), in collaboration with ElevationSpace Inc. and other companies, presented the **ELS-R100 mission**, a re-entry technology demonstration from Low Earth Orbit using a hybrid thruster. Finally, Koc University and DeltaV Space Technologies (Turkey) reported interesting results on the **ablation resistance of graphite** and a hot-gas generator system based on hybrid rocket technology.

Electric Propulsion

The electric propulsion sessions at the IAC2023 have been, as usual, rich in presentations and developments in diverse fields. FOTEC (Austria) has presented the results of a 48000hour endurance test campaign on their F**EEP multi-emitter**, conducted under funding and supervision of the European Space Agency, which has demonstrated the viability of operating a FEEP emitter for extremely long durations and paving the way to using this type of propulsion also for very demanding deep-space missions. Berlin Space (Germany) has presented their advanced propulsion system for small satellites based on **2 mN Hall Effect Thrusters**, designed to work with Xenon or Krypton. Results from the first successful test campaign on an interesting concept of **multidirectional plasma thruster** have been presented by Advanced Propulsion Systems LLC (Russia). In the field of **numerical plasma simulations**, the universities of Bologna and Padova (Italy) have presented a novel coupling method for fluid/kinetic solvers, intended for use in the simulation of helicon plasma thrusters. Considering the comparisons presented by the University of Tokyo between on-orbit and ground thrust measurements, as detailed in the next section on small satellite propulsion, numerical plasma simulation results should be used very carefully for propulsion system integral characteristics assessment, such as thrust and specific impulse, since these numerical models are validated predominantly in laboratory environment and might show less accurate results for the actual in-space performance.

Small Satellite Propulsion

The IAC 2023 has confirmed that the small satellite propulsion scenario is extremely dynamic, with many ongoing developments worldwide. Papers have been presented on systems designed for actual missions, such as the **AQUARIUS** water propulsion system developed by the University of Tokyo and JAXA and successfully demonstrated in the EQUULEUS Lunar CubeSat, where it delivered a cumulative Delta-V of more than 17 m/s in multiple maneuvers. The in-space demonstration of AQUARIUS revealed 1.5 times higher thrust than ground test measurements, emphasizing the importance of the conditions under which ground tests are performed, especially for thrusters of small-form factor since their exhaust flow can be significantly affected by the environment in the vacuum test facility. The other system designed for an actual mission is the **IANUS** propulsion system developed and qualified by T4i (Italy) for the Milani CubeSat within the Hera

mission, a 6DOF system based on cold gas thrusters in the 6-26 mN range, operating with R134a as propellant. Other highlights from this session include the results of successful testing at 20-50 W of an **ambipolar plasma thruster** developed by TU Dresden (Germany), the demonstration at 0.17 mN thrust and 2500 s specific impulse of a **porous emitter electrospray thruster** from the University of Southampton (UK), and the first results on a 50 mN **water resistojet** from Sapienza University of Rome (Italy). Finally, Bauman Moscow State Technical University (Russia) presented a study on the efficiency of a Pulsed Plasma Thruster (PPT) utilizing various propellants, showing the perspectives of using **low face carburization propellants** instead of the commonly used PTFE for enhancing the performance of PPT thrusters.

Hypersonic, Air-Breathing and Combined Cycle Propulsion

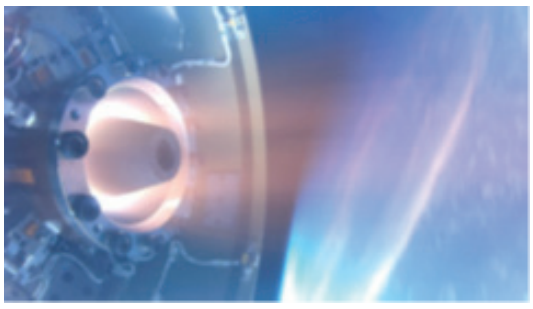
During this session at the IAC 2023, Beihang University (China) presented experimental and numerical results on **ramjet and scramjet** propulsion systems, including solid-propellant ducted rocket fuel supply and mixing. One of these studies dealt, in particular, with the numerical investigation of a **Mach 5 hypersonic ramjet with subsonic combustion**, demonstrating the feasibility of developing such a propulsion system and broadening the operational capabilities in terms of speed and spatial domain of subsonic ramjet engines. The Sapienza University of Rome (Italy) presented an investigation of fluid mechanics and heat mass transfer in the **HIFiRE-2 scramjet**, suggesting the need to investigate new configurations with swirling injectors, different injector's locations and angles and different cavity geometries, to reduce the total pressure losses without decreasing the mixing efficiency. Kyushu University (Japan) reported a numerical design optimization and analysis of **shock-induced mixing and combustion** via data-driven approaches, while Kanazawa Institute of Technology (Japan) proposed a simple numerical method to analyze the flame holder flow field of a typical hypersonic jet engine with minimum computational time.

Nuclear Power and Propulsion Systems, and Propellantless Propulsion

This session, organized jointly between the IAC Space Power and Space Propulsion symposia, hosted a variety of papers with topics ranging from solid-core Nuclear Thermal Propulsion (NTP), liquid-core NTP, Nuclear Electric Propulsion (NEP), solar sails and nuclear fusion propulsion systems. The session featured an interesting keynote from the University of Alabama in Huntsville (USA) describing the current research progress and development efforts on NTP in the United States, with a special focus on the joint DARPA and NASA project **Demonstration Rocket for Agile Cislunar Operations** (DRACO). The University of Alabama in Huntsville also presented a new methodology called Reliability-Driven Design and Test (ReDDT), which focuses on streamlining the nuclear engine test program through design and test planning for a given NTP system level reliability. Kyushu University (Japan) presented the results of a demonstration of **axial pulsed magnetic nozzle** for nuclear propulsion systems, showing some discrepancy between numerical and experimental results which will require further investigation to understand its causes. The Keldysh Research Center (Russia) presented the design and applications of **high-power nuclear-powered propulsion systems** for space transportation to Moon, Mars and outer planets. Finally, Beihang University (China) presented an integrated adaptive control scheme to mitigate the inherent uncertainties of optical models for **solar sail** technology.

Disruptive Propulsion Concepts

In this session of the IAC conference, we mainly focus on systems and technologies which, although in principle they could also be presented in one of the other sessions, show particularly new and possibly disruptive features, making them promise to enable new, futuristic mission concepts. This year's session hosted a very interesting keynote from Nagoya University (Japan), showing the results of the flight demonstration, on a sounding rocket, of the **Rotating Detonation Engine** they are developing in collaboration with JAXA and other Academic partners. The tests were fully successful, demonstrating a thrust of more than 500 N and a specific impulse of 290 s for an oxygen-methane engine operated in space environment.



In-space Rotating Detonation Engine demonstration (courtesy Nagoya University)

Other highlights from this conference session were the developments on **Atmosphere-Breathing Electric Propulsion** of the universities of Bologna and Padova (Italy), who showed their design of a cathodeless radio-frequency plasma thruster; and a renewed interest in

the study of propulsion options for **interstellar travel**, with two different papers on the topic presented during the session.

In the IAC 2023 Late Breaking Abstracts session, Khalifa University (UAE) presented a concept of **graphene-based laser ablation thruster**, including preliminary test results which will require further theoretical and experimental investigation to be confirmed.

Committee Activities

The committee is currently made of 48 members from 15 countries, including 8 female members and 11 young professionals, with good distribution among geographical areas and categories (industry, Academia, agencies). In the second half of 2023, four new members have been welcomed in the committee: Heji Huang (Chinese Academy of Sciences), Jamila Mansouri (European Space Agency), Yuji Saito (Tohoku University), Andrei Shumeiko (Bauman Moscow State Technical University).

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. The committee members are also active in knowledge dissemination to the space propulsion scientific community through the publication of papers and books, such as the handbook on hybrid rocket design published in 2023 by Ashley Karp and Elizabeth Jens.