OVERVIEW OF ROCKET TESTING AT THE WESTCOTT TEST FACILITY (2022/2023)

GLASGOW / 20-23 MAY 2024

James Macfarlane[1], Edward Moore[1,2], Iain Waugh[1], Adam Greig[1], Alistair John[3], Jack Coghen-Brewster[4], Matt Escott[4], and James Sadler[5]

[1] *Airborne Engineering Ltd., Westcott Venture Park, Aylesbury, UK*
[2] *Corresponding author: ed@ael.co.uk*
[3] *University of Sheffield, Sheffield, UK*
[4] *Protolaunch, Westcott Venture Park, Aylesbury, UK*
[5] *URA Thrusters, Westcott Venture Park, Aylesbury, UK*

ABSTRACT

Westcott Venture Park (formerly the Rocket Propulsion Establishment) is home to a growing number of propulsion and propulsion service companies. This paper gives an overview of recent activities by some of them. Airborne Engineering Limited report commissioning work on their LOX/LCH4 test facility and further test work on their VTVL rocket. Protolaunch report a number of developments in thruster technology in the 20N-500N range with a variety of propellants. URA Thrusters have been developing a very diverse range of electric propulsion options for in-orbit use. Finally, the Race to Space initiative was launched, supporting hands-on propulsion training for students from UK universities. This was supported by Airborne Engineering and Protolaunch who hosted hot-fire engine tests for the students, and European Astrotech who assisted with cold-flow testing.

1. INTRODUCTION

Westcott Venture Park (formerly Rocket Propulsion Establishment Westcott) in Buckinghamshire, England, has been at the centre of UK rocket propulsion development for over 70 years. The site is now home to a growing number of propulsion companies who are working on a diverse range of technologies, both in chemical and electric propulsion. Westcott is the home of the National Space Propulsion Test Facility, owned by the UK Space Agency and operated by Nammo UK.

Previous papers have summarised recent rocket testing and development at Westcott for the years 2016-2021 [1, 2, 3]. This paper gives a brief overview of the facility upgrades, rocket test programmes and other developments undertaken over the last two years (2022/2023) at three Westcott-based companies: Airborne Engineering, Protolaunch and URA Thrusters, the latter brining electric propulsion into the reported activities for the first time.

This paper also reports on the “Race to Space” competition for student rocket engines, organised by Sheffield University and supported by Buckinghamshire Council, the Satellite Applications Catapult and the UK Space Agency, with test firings taking place at Airborne Engineering and Protolaunch. This new initiative aims to encourage student design and testing of rocket engines in a safe but exciting manner, by providing access to industrial test facilities and industry mentors.

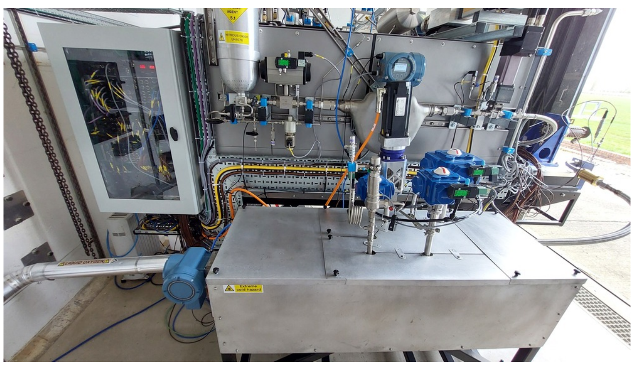
Figure 1: Westcott Venture Park (UK).

2. AIRBORNE ENGINEERING

Airborne Engineering Ltd (AEL) have undertaken a variety of projects focused on facility upgrades, rocket engine additive manufacturing processes, fundamental combustion research and the testing and control of challenging fluid systems.

2.1. LOX/Methane Test Facility

Test facility upgrades have included the commissioning of the liquid oxygen (LOX) subsystem of a 30kN scale LOX/methane test rig, funded by the European Space Agency. The facility can liquefy methane in-situ from high purity gaseous feedstock using a pressurised liquid nitrogen cold source, which is also capable of subcooling propane.



(a) LOX valve enclosure, which includes the massflow meter and throttle valve

(b) Firing bay, with LOX delivery hose attached to a back-pressure choke for commissioning tests.

Figure 2: LOX system components in the J1 firing bay.

Figure 3: LOX cold flow in the J1 facility.

The LOX subsystem has a 200L high pressure tank, fed from a 2000L low pressure bulk tank. Figure 2 shows the installed LOX run table in the firing bay. The run table includes the Coriolis massflow meter, throttle valve, run valve, secondary run valve, and chilldown valve. Figure 3 shows one of the cold flow LOX tests, which are part of the test rig commissioning activities, testing flowrates up to 7kg/s.

2.2. Additive Manufacturing Research

Additive manufacturing research has included investigating the benefits of using green-lasers with copper alloys. After optimising the process and testing small samples, a 20kN class LOX/LCH4 demonstrator combustion chamber (Figure 4) is being manufactured from GRCop-42 and will be tested later this year. The chamber incorporated a novel compliant firewall geometry in order to increase lifetime. This is reported in more depth in another paper at the SP2024 conference [4].

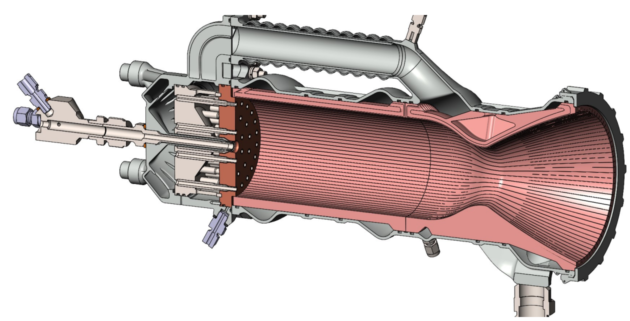


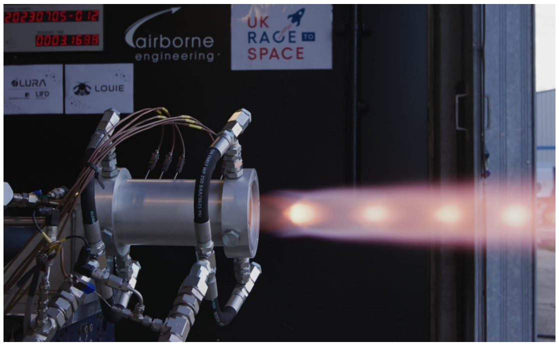
Figure 4: Combustion chamber demonstrator design, which uses two GRCop-42 slip liners that are separately cooled by LOX (chamber) and LCH4 (nozzle). The structural jacket and injector head are printed from IN718, with conventionally machined and brazed injector components.

Figure 5: AEL VTVL rocket tethered test, take-off and landing from ground.

2.3. VTVL Rocket flight testing

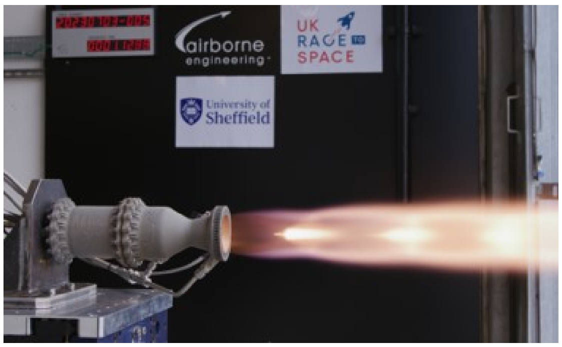
AEL's vertical take-off, vertical-landing (VTVL) Gyroc 5 vehicle has now undergone a concerted flight test programme. Most of the tests employed drop-away legs for the take-off phase, with "landing" being achieved by throttling down to letting the vehicle hang from the tether. See [5]. However, recent flights (Figure 5 have demonstrated take-off and landing from the ground, proving the vehicle is ready for free-flight tests.

Modifications have been made to the vehicle to enable remote telemetry and remote safety shutoff. The first free-flight is planned for early summer 2024, which will enable testing of larger distance flights and more dynamic manoeuvres. These flights will guide the subsequent design of a larger vehicle, suitable for carrying experimental instrumentation payloads. AEL wishes to thank ESA and UKSA for their support of the test programme.

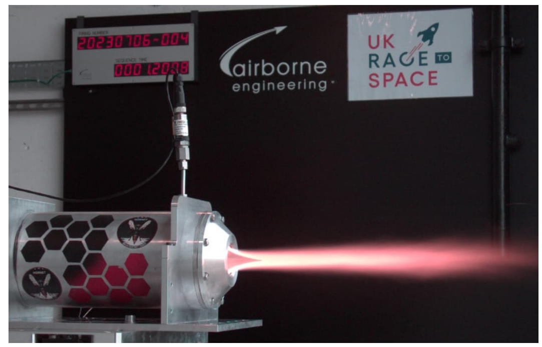


(a) Leeds University

(b) Southampton University



(c) Sheffield University



(d) Bath University

Figure 6: Some of the Race to Space 2023 engine firings.

3. RACE TO SPACE

3.1. Introduction

The Race to Space initiative was launched last year with the goal of developing an integrated space propulsion training infrastructure within the UK by connecting rocketry education activities to produce a 'pipeline of talent' and build industry and academia relations, encouraging knowledge exchange, mentoring and networking.

3.2. Race to Space 2023

In July 2023 the first Race to Space National Propulsion Competition took place. This was a large success, involving 10 university teams from across the UK coming together to test-fire rocket engines for the first time. The teams received mentoring from industry experts throughout the academic year, before heading to AEL, Protolaunch and European Astrotech at Westcott to hot-fire the engines (Figure 6.) All of the hot-firing took place over an intensive four days of testing, with additional cold flow and pressure testing also carried out.

Before this week, just one student built bi-propellant engine had been tested in the UK. Seven of the eight teams were able to successfully achieve a hot-fire test, quadrupling the number of student-built bi-propellant engines successfully fired in the UK. This may well have set a record for the number of different hybrid/liquid engines fired for the first time in one week on one site. Details of the engines hot-fired are given in Table 1.

On the final day of the event, a Student Rocketry Symposium was held at Westcott with over 100 attendees, providing an opportunity for student teams to present their results and network with industry.

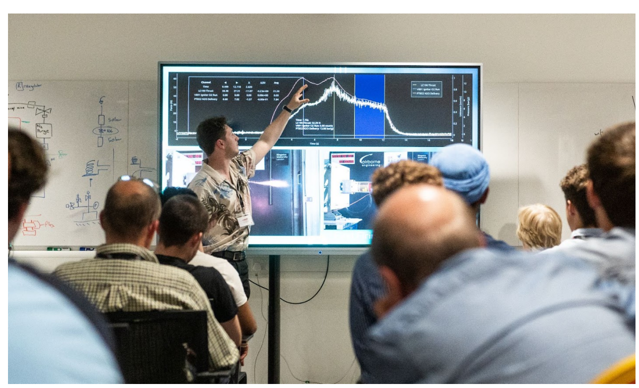


Figure 7: Race to Space 2023 Symposium.

Universtiy Team	Engine Type	Details	Propellants	Design Thrust [kN]
Southampton	Bi-prop	Ablative phenolic	IPA/N2O	1.5
Leeds	Bi-prop	Water cooled	IPA/N2O	2
Sheffield	Bi-prop	AM Inconel	IPA/N2O	3.5
Kingston	Hybrid	Grain regression sensor	N2O	0.2
Glasgow	Hybrid	HDPE	N2O	0.5
Bath	Hybrid	Epoxy resin	N2O	1.5
Cranfield	Hybrid	HDPE	N2O	0.3

Table 1: R2S-23 Hot Fired Student Engines.

3.3. Race to Space 2024

The 2024 Race to Space competition will be held in July this year. We have seen a large increase in universities entering the competition, meaning it will be a busy few weeks of testing. The teams are receiving mentoring and sharing knowledge, advice and offering support to each other through meet-ups and online interaction throughout the academic year. Documentation from the 2023 competition is available, and all documentation produced by the students will be shared online via the website. Details of this year's entries are below in Table 2.

3.3.1. Summary

The initiative is enabling students from a range of backgrounds and experiences to get expert guidance, advice and access to testing that would normally be out of reach. This provides students with the chance to dream, push boundaries and apply what they have learned in their courses to design real rocket engine hardware that is safely tested by experts.

Thanks to Airborne Engineering, Protolaunch, European Astrotech, Satellite Applications Catapult, Buckinghamshire council, UKSA, The University of Sheffield and all of the expert mentors who have supported the initiative.

Universtiy Team	Engine Type	Details	Propellants	Design Thrust [kN]
Imperial (ICSS)	Bi-prop	Cold flow only	IPA/LOX	20
Glasgow	Bi-prop	Steel heat sink	IPA/LOX	1
Leeds	Bi-prop	Water cooled	IPA/LOX	2
Imperial (ICLR)	Bi-prop	Aluminium AM regen	IPA/LOX	5
Southampton	Bi-prop	Ablative	IPA/N2O	1.5
Edinburgh	Bi-prop	Ablative	IPA/N2O	0.5
Sheffield	Bi-prop	Aluminium AM regen	IPA/N2O	3.5
Kingston	Bi-prop	Inconel AM regen	IPA/N2O	6
UCL	Bi-prop	Steel / phenolic	IPA/N2O	2
Bristol	Bi-prop	Inconel AM regen	IPA/N2O	5
Cambridge	Bi-prop	Steel	IPA/N2O	1.5
Cranfield	Hybrid	Steel/phenolic/HDPE	HDPE/N2O	0.5
Nottingham	Hybrid	Steel, copper nozzle	HDPE/N2O	1
Manchester	Hybrid	L1 sized motor	HDPE/N2O	0.25
Durham	Hybrid	Watercooled nozzle	Paraffin/N2O	1
Surrey	Hybrid	Paraffin	Paraffin/N2O	0.4
Bath	Hybrid	Aerospike, deep throttle	Paraffin/N2O	4
QUB	Hybrid	Steel, phenolic	Paraffin/N2O	0.5
USW	Hybrid	Steel, phenolic	ABS/N2O	0.5

Table 2: Planned Engines for R2S-24.

Figure 8: Protolaunch Facilities at E-site.

4. PROTOLAUNCH

Protolaunch is a research-intensive space company that specialises in the development of small chemical thrusters and propulsion sub-system components. Protolaunch is highly focused on ‘green’ propulsion and commercialising alternatives to hydrazine systems that improve in-space mobility capabilities.

Established in early 2019, Protolaunch employs a team of seven experienced multi-disciplinary engineers and is headquartered within the space cluster at Westcott Venture Park, UK. The company operates a sea-level chemical propulsion test facility as well as co-located office and lab facilities.

In late 2023 Protolaunch secured external investment to commercialise thrusters in the 1N, 20N and 500N thrust classes that utilise oxygen & methane and oxygen & hydrogen as propellants.

4.1. Upgrades to E-Site Test Facility

Protolaunch operates a containerised sea-level propulsion test facility. The site has been expanded to include precision propellant metering systems specifically for gaseous oxygen & gaseous hydrogen, as well as cryogen capable blowdown systems for Liquid Nitrogen and Liquid Oxygen.

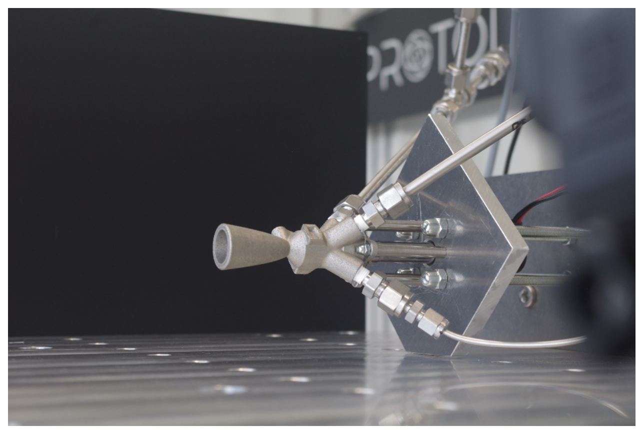


Figure 9: Protolaunch FOx-1.

4.2. FOx-1

FOx-1 is a dual mode thruster designed for water electrolysis systems that utilises gaseous oxygen and hydrogen as propellants. FOx-1 produces 1.4N of thrust in warm gas mode and 20N in bipropellant mode. Significant hot-fire testing of ‘battleship’ hardware has been undertaken investigating various thermal management techniques to address the high temperatures of stoichiometric operation as well as validation of an acoustic resonant ignition technique that enables the rapid heating of gaseous propellants above ignition temperature. Hot-fire testing of a TRL5 representative system commenced in Q1 2024 with continuous operation vacuum testing in the 20N mode scheduled to begin in Q3 2024.

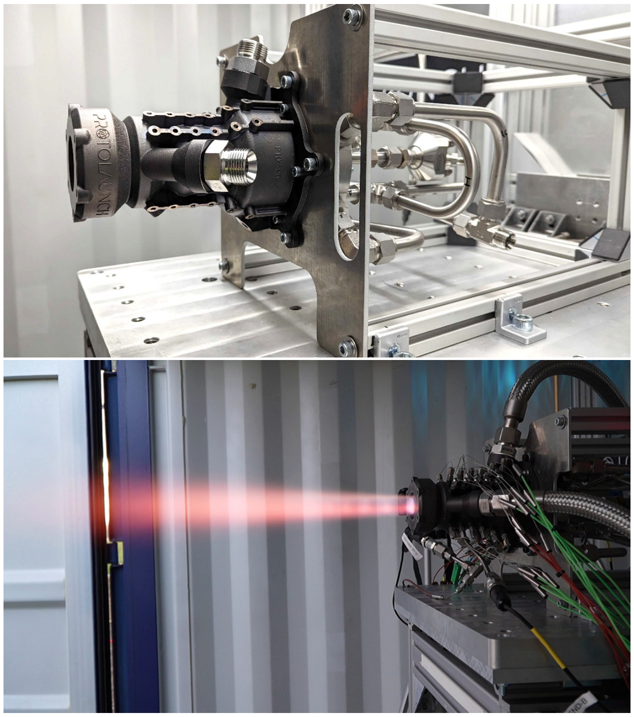


Figure 10: Protolaunch Arctic FOx.

4.3. Arctic FOx

Arctic FOx is a 500N thruster designed to operate using cryogenic propellants, with interest in both oxygen/methane and oxygen/hydrogen variants. A development model using gaseous oxygen and hydrogen as propellants with cryogenic liquid nitrogen in the cooling jacket has undergone extensive hot-fire testing. The data from these campaigns is particularly relevant to understanding multi-phase flows in cooling jackets with applications for autogenous pressurisation modes of operation. A follow-on body of work funded by ESA which focuses on developing a TRL5 variant of the current engineering model is set to kick-off in 2024.

4.4. Cavitating Venturi Flow Control Valves

In 2022 Protolaunch developed a number of cavitating venturi flow control valves under a piece of work funded by the UK Space Agency with relevance to throttling applications for ESA's EL3 mission. These valves demonstrated remarkable repeatability and robustness in providing precise and stable mass flow into a throttling combustion chamber in the face of changing pressure gradients. This performance is detailed in a paper previously presented at Space

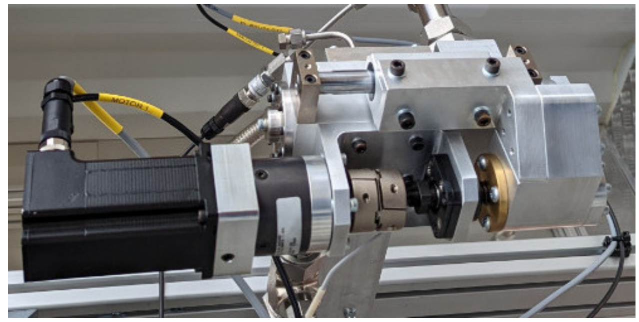


Figure 11: Protolaunch Cavitating Venturi Flow Control Valve.

Propulsion 2022. Since then, Protolaunch has received a number of Requests for Information regarding the suitability of these valves for other lander applications and has undertaken R&D work related to faster actuation capabilities and lifetime testing.

5. URA THRUSTERS

URA Thrusters is a UK SME spun-out from AVS group, created in 2019. URA's vision is to commercialise and democratise the use of water and sustainable propellants for in-space logistics, mobility and transportation, by developing chemical and electric propulsion systems and full plug-and-play propulsion architectures. To achieve this URA is developing one of the widest catalogues of novel in-space propulsion solutions in the world, ranging from electrolysed water chemical propulsion to water electro-thermal and electrodeless propulsion systems. These solutions will enable the use of water for all spacecraft propulsion needs, and a simpler route to in-situ resource utilization for propellant manufacture. URA Thrusters is based in the Westcott Venture park in Aylesbury, with offices and a shared manufacturing & test facilities inside the Westcott Innovation Centre. Westcott Innovation centre is a modern facility designed to facilitate SMEs to develop their capabilities; the URA manufacturing facilities consist of clean assembly areas for hardware assembly, a high voltage PPU assembly and test area, an ISO7 cleanroom for clean assembly of space hardware, and a vacuum chamber that can be used for electric propulsion testing or thermal bakeout. In addition to the facilities in the Westcott Innovation Centre, URA Thrusters also has a second facility, R site, dedicated to hydrogen & oxygen testing, as well as early phase R&D. This facility has a design room used for R&D brainstorming, and test facilities which consist of an electric propulsion test chamber,

Figure 12: URA Test Facilities.

a small vacuum chamber for testing electrolysers, and a large vacuum chamber with a thermal shroud for testing H2 / O2 based thrusters and small propulsion systems. This facility is capable of remote 24 hours running and is set up specifically for hazardous hydrogen and oxygen testing, with access to large banks of hydrogen and oxygen gas cylinders for lifetime testing of thrusters.

URA's product portfolio consists of several early phase developments focussed on the thruster technology required to address introducing sustainability to the space propulsion industry. In addition our roadmap includes developing a complete propulsion system level capability to be able to supply sustainable propulsion modules to the worldwide market. URA has 5 main propulsion technologies they are developing at varying level of TRL.

5.1. AQUAMET - Microwave Electrothermal Thruster

Microwave Electrothermal Thrusters (MET) offer a high specific impulse and significant lifetime increases when compared to Resistojets and Arcjets. The technology scales up and down to suit a range of satellite platform sizes. It is also propellant agnostic and compatible with a range of gases, as well as water and ammonia. The MET systems under development at URA Thrusters (Figure 13) allow for operation at a wide range of input powers and mass flow rates, leading to a corresponding wide range of specific impulse and thrusts. URA is currently working to develop a demonstration model of a MET running on water at 9.3 GHz and 350W thruster input power. It is expected to achieve a specific impulse in the range of 500 to 800s and 10-30mN running on water vapour.

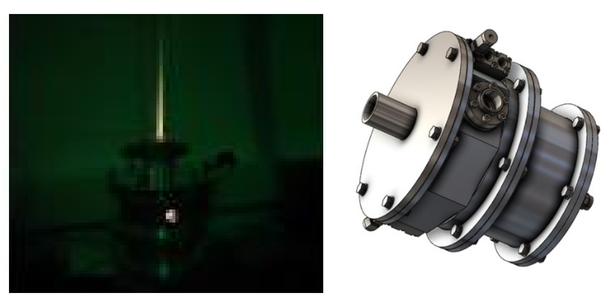


Figure 13: URA Aquamet Thruster.

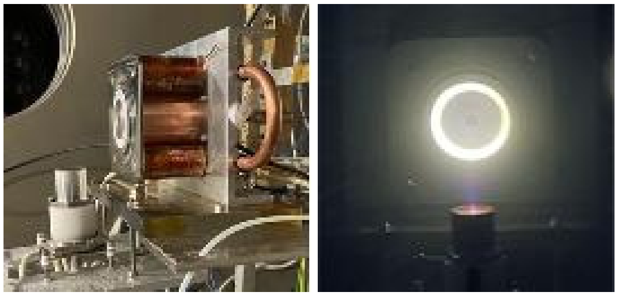


Figure 14: URA Aquahet Thruster.

5.2. AQUAHET – Hall Effect Thruster

Under a project called Hydra, URA are developing the full system architecture of a hybrid water propulsion system based around a 5 kW Hall-effect thruster using electrolysed oxygen / hydrogen for the anode / cathode respectively. This technology also utilises a range of developments from the ICE product family including electrolysers, chemical thrusters and water tanks. Hall-effect thrusters (HET) are the most flown type of electric propulsion. At URA, we are developing a family of Hall-effect thrusters (Figure 14) that operate at 2kW and 5kW nominal thruster powers. The predicted thruster performances are as follows:

- Discharge power: 1.5-2.5kW, Isp: up to 3000s, Thrust: up to 42 mN
- Discharge power: 3.5-7kW, Isp: up to 3000s, Thrust: up to 120 mN

5.3. ICE – Electrolyser Water System

ICE propulsion offers a game changing high thrust propulsion system ideal for satellites of all sizes. It is an attractive replacement for hydrazine, capable of providing high thrust in combination with the natural high specific impulse of hydrogen/oxygen catalytic combustion. Beyond this, advanced manufacturing techniques enable both mass, and low-cost construction ideal for constellations. The system utilises water as a propellant. This enables a high storage density, as well as a significant reduction in cost and complexity of launch site activities when compared to heritage chemical propulsion devices such as hydrazine. Hydrogen and oxygen can then be manufactured in orbit using an electrolyser, this manufactured hydrogen and oxygen are then fed into a thruster, which combusts the hydrogen and oxygen to produce thrust. URA Thrusters are developing a range of thrusters encapsulating a wide range of thrusts from 10 mN to 1 N at

Figure 15: URA ICE System.

>300 seconds ISP. We have also developed a modular electrolyser technology that can scale from 80W to 240W to fit whatever power budget is needed for the propulsion system. In combination with a range of tank sizes, this enables an endless combination of total impulse, peak thrust, and power availability suitable for any platform.

5.4. AQUAMAG – Water / Metal High Hybrid Rocket

One of the current drawbacks of electrolysed water propulsion that prevent it from being adopted for a wider application is its inability to provide a sustained long duration thrust for something like deorbitation. To help overcome this drawback URA is working on low TRL studies to explore water / metal hybrid rocket fuel combinations. These studies are specific to testing novel fuel grain designs and are focussed at showing whether these new concepts for fuel grain design could enable a sustained thrust using water as an oxidiser and metal as a fuel.

5.5. PET – Porous Electrospray Thruster

PET uses an inert and non-toxic energetic ionic liquid, which is fed to Additive Manufactured porous emitter tips, where a high-voltage drop extracts ions from the liquid, generating thrust to the spacecraft. URA's unique feed system design means the amount of liquid and number of emitter arrays are scalable to suit all mission needs. PET is scalable up to 400W to support satellites platforms with greater power requirements. The specific impulse of thrusters in the PET family ranges from 2000 s and have TTPR in range of 20 – 40 µN/W.

6. CONCLUSION

This paper has reported on a very diverse range of design and testing work carried out at Westcott over the last two years (2022/2023) and the site continues to grow, both in terms of the number of propulsion companies based here and the capability of the facilities they offer.

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