OVERVIEW OF ROCKET TESTING AT THE WESTCOTT TEST FACILITY (2021)

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ABSTRACT:

This paper gives a brief overview of the rocket test programmes undertaken at the Westcott (UK) rocket test facility in 2021, in particular those undertaken at the Airborne Engineering and Nammo UK test sites. This encompasses a variety of testing for liquid and hybrid propellant rockets, ranging from fundamental combustion research to qualification testing.

1. INTRODUCTION

The rocket development and test facilities at the Westcott Venture Park in Buckinghamshire, England (formerly Rocket Propulsion Establishment Westcott) have been at the centre of UK chemical rocket science and technology for over 70 years. The UK chemical rocket industry has, like most industries, seen highs and lows over the period of its history with levels of staffing at Westcott reaching as high as 1,100 people during the 1970's and '80's and as low as 15 people around the millennium. A previous paper concentrated upon rocket activities at Westcott in earlier years [1, 2]; this paper concentrates on the year 2021, with a focus on the activities of Airborne Engineering and Nammo UK.

These rocket companies often work together on new technology trials and agency- sponsored research programmes. Each organisation has a set of unique capabilities and expertise that can be pooled together to mutual advantage on such programmes. Together, these capabilities encompass monopropellant and bipropellant thrusters for sea-level and in-space applications, propulsion subcomponents, manufacturing, qualification, test instrumentation and analysis.

There have been some programme delays in 2021 due to the ongoing COVID-19 pandemic, but despite this, there has still been a rise in the presence of UK chemical rocket businesses on the site with a significant number of test firings for liquid and hybrid rockets across a range of different end applications.

2. AIRBORNE ENGINEERING

Airborne Engineering (AEL) are specialists in testing for propulsion and challenging environments. Over 2021 they have undertaken a variety of internal and customer projects focused on fundamental combustion research, rocket engine manufacturing processes or the testing and control of challenging fluid systems. Selected projects are described in the next sections.

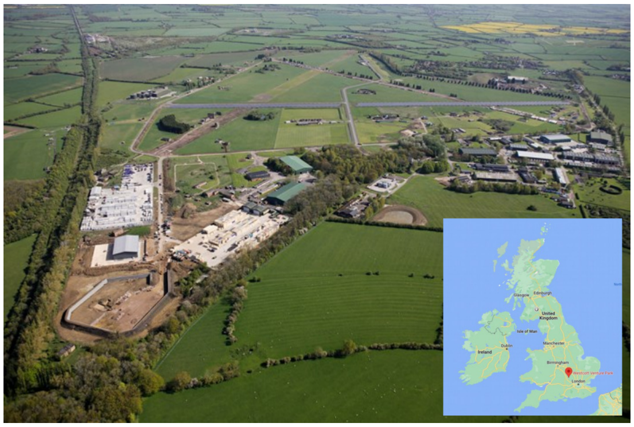

Figure 1: Westcott Venture Park (UK).

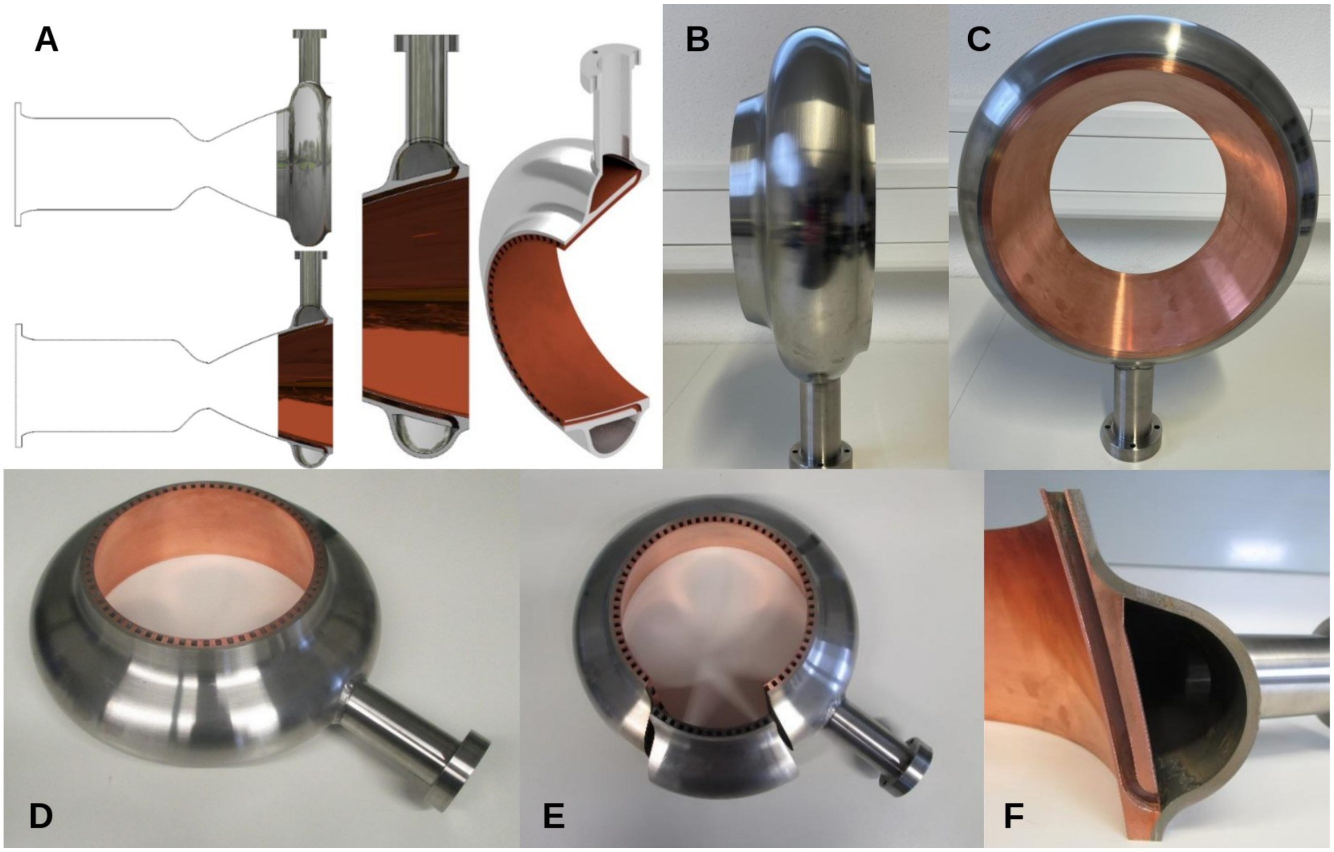

Figure 2: Cold spray additive manufacture (CSAM) bimetallic (CuCrZr/IN625) manifold demonstrator test piece.

2.1. Cold Spray Additive Manufacture

Cold Spray Additive Manufacture (CSAM) involves seeding metal powder into a stream of inert gas that is heated at pressure and then accelerated to supersonic speeds through a nozzle. The powder is sprayed at a target using a robot arm where it deforms plastically and solid-state bonds to form deposited material, which is then post-machined. CSAM can produce high-quality bimetallic parts with no build volume restrictions, and is therefore one of the only contending methods for additive manufacture of high-performance, high-thrust lift engines.

A 20kN demonstrator CSAM combustion chamber was designed by AEL. Sample sections of this demonstrator were manufactured by project partner Impact Innovations GmbH at their research spray-lab. These proved the ability of CSAM to create high aspect ratio coolant channels and to create one-piece structural jackets and manifolds, without requiring high-temperature brazing or welding processes that might degrade the properties of the copper alloy liner.

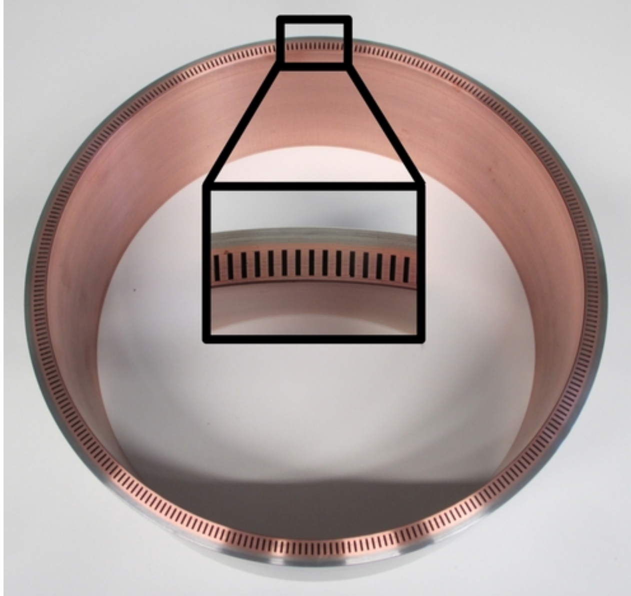

Figure 3: High aspect ratio coolant channel demonstrator piece, with rectangular coolant channels 5x1mm on a part with diameter 280mm.

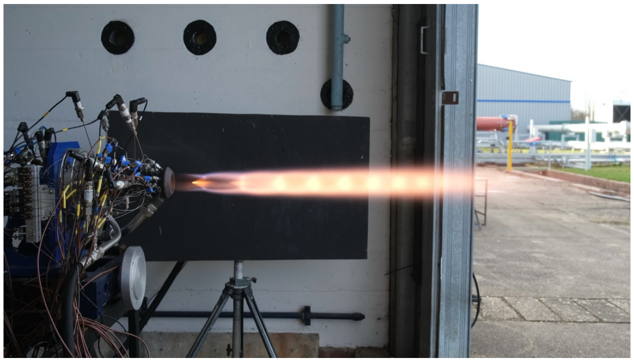

Figure 4: Additively manufactured nickel-based alloy (ABD®-900AM) chamber in AEL's J1 test facility.

2.2. Novel Nickel alloys for additive manufacture

A previous paper described the design of additively manufactured combustion chambers using a novel nickel alloy called ABD®-900AM [3]. The ABD®-900AM alloy has been designed by Alloyed to maintain strength up to 900℃, demonstrating an increase in capability over IN718 of ~100℃, whilst being processable with similar laser parameters.

Initial testing of these combustion chambers was reported in the previous conference [2, 3]. Since the previous conference further testing was undertaken to find the performance limits of the firewall material, raising the chamber pressure (and therefore heat flux) until the firewall developed pinhole leaks. Nitrous oxide and isopropyl alcohol propellants were used for combustion with high-pressure water for cooling.

2.3. VTVL Gyroc vehicle

AEL successfully tested its Vertical-Takeoff-Vertical-Landing (VTVL) demonstration vehicle - named *Gyroc* - for the first time in June 2019 [2]. Gyroc uses non-toxic rocket propellants (nitrous oxide and isopropyl alcohol,) weighs about 20kg and can hover for around 30 seconds [4]. It has a gimballed, throttleable engine whose action is controlled by a custom on-board IMU and flight computer, with feedback control loops for attitude, position and propellant throttling [5]. Recent vehicle upgrades have included a three-antenna, differential-GPS system for tracking vehicle position to centimetre accuracy and for comparing the IMU's estimated position and attitude against direct measurement.

The vehicle is currently undergoing a flight test programme for ESA, aiming to characterise the vehicle dynamics, tune control loops and compare experimental results against a software 6DoF simulator [6]. Advanced control loops are being studied by project-partner Technology for AeroSpace Control (TASC) to provide recommendations for tighter vehicle control. The vehicle is currently being tested on a safety tether, with hovering flights and small lateral translations being investigated. Even with this short tether and therefore small flight envelope, the testing allows end-to-end verification of the complex control system.

Future work will include free-flights on a launch range or within a drone-cage under construction at Westcott. After more testing, Airborne plans to scale-up the vehicle so that it can be used to assist other organisations developing autonomous planetary landing technology and who need a way to perform realistic flight testing.

Figure 5: Gryoc VTVL rocket vehicle tethered hover, to tune control loops and explore system dynamics.

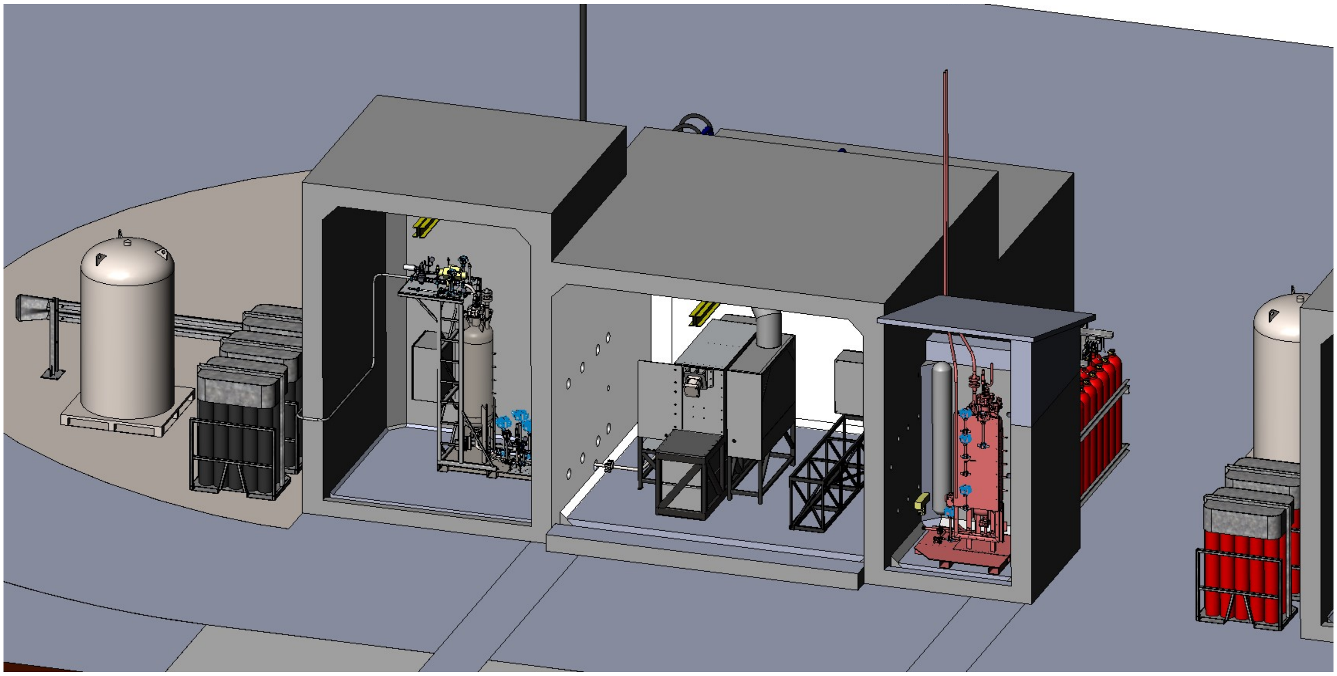

Figure 6: AEL's J1 facility is undergoing major upgrades to install a 30kN level high-pressure LOX/LCH4 feed system. The oxygen bulk tank, high-pressure run tank and pressurant are shown on the left of the central firing bay, with the methane high-pressure run tank and gaseous banks (pressurant and propellant) shown on the right.

2.4. 30kN LOX / LCH4 facility

AEL has begun work on upgrading its J1 test bay with high-pressure liquid oxygen (LOX) and liquid methane (LCH4) feed systems, suitable for engines up to 30kN thrust level.

The liquid oxygen system is capable of a mass flow of up to 7.5 kg/s and a delivery pressure of up to 90-95 bar. The system uses a 200L high-pressure run tank, pressurised with either nitrogen, oxygen or helium gas, dependent on customer cost and purity requirements. The run tank has thermowells for measuring propellant temperature (and thermal stratification) and an internal coil for thermal conditioning of the propellant (e.g. subcooling with liquid nitrogen). The high-pressure line to the engine has valves for chilldown and line priming, instrumentation for temperature, pressure and massflow measurement, and a control valve for feedback control of massflow. This control loop allows specification of arbitrary massflow-time profiles, which can be used for ramping propellants or exploring different operating conditions within one firing. A secondary, smaller massflow LOX delivery line can be used to supply other experimental equipment such as gas generators.

The liquid methane system is capable of a mass flow of at least 3kg/s and a delivery pressure of approximately 145bar. Similar to the LOX system, the LCH4 system has a 200L high-pressure run tank, and a high-pressure delivery line with active massflow control. A secondary, smaller massflow LCH4 delivery line can be used to supply other experimental equipment such as gas generators. The run tank will be pressurised from a high-flow rate gaseous CH4 bank to avoid dissolved pressurant impurities in the LCH4.

Whilst liquid natural gas is widely available and cheap, its methane purity is not constant and even small percentages of longer-chain hydrocarbon impurities can affect engine performance. The liquid methane system is therefore designed to liquefy methane in-situ in the high-pressure run tank, using liquid nitrogen as the cold source. High purity methane gas can therefore be used, which can be 99.5% or 99.95% methane depending on customer requirements, with potential for some of the remaining impurities to be further removed during the liquefaction process using cold traps. A liquid nitrogen jacket will chill-down the high-pressure run tank and line, with the liquid nitrogen pressurised to prevent freezing or over-subcooling the methane.

This LOX/LCH4 feed system was scheduled to be completed in 2021, but due to a funding gap in the schedule and COVID-19 disruption this was delayed. The LOX system is currently mid installation, due to be commissioned at the end of Q2 2022. The LCH4 system long-lead time items are currently in manufacture, due to be commissioned in Q4 2022. Whilst not under the current funded programme, an additional build phase is planned to add a high-pressure room-temperature hydrocarbon feed system to this facility, to support firings with kerosenes or alcohols. The system has also been designed to allow simple upgrades to support gaseous oxygen and methane as propellants.

2.5. Smallspark S4-Hive hybrid engine

SmallSpark Space Systems is working to develop a line of propulsion systems that focus on simplicity and rapid iterability. Their S4-HIVE engine (alongside their S4-NEWT satellite thruster) aims to demonstrate the viability of using non-toxic, safer to store fuel grains that enable high performance at a considerably reduced cost.

The S4-HIVE pathfinder (Figure 7) demonstrated a number of the core principles of the engine design, and serves as a precursor to the S4-HIVE.c, a composite variant of the system that is presently being manufactured, with the aim to begin tests in Q3 2022.

Working with AEL, SmallSpark have performed 3 test campaigns using Nitrous Oxide, and will be continuing to work with AEL once they bring their LOX capabilities online in Q3 2022.

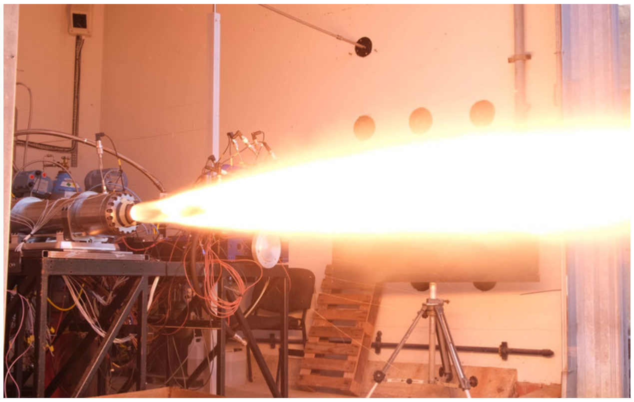

Figure 7: Smallspark S4-Hive hybrid engine in AEL's J1 test facility using N_2O as oxidiser.

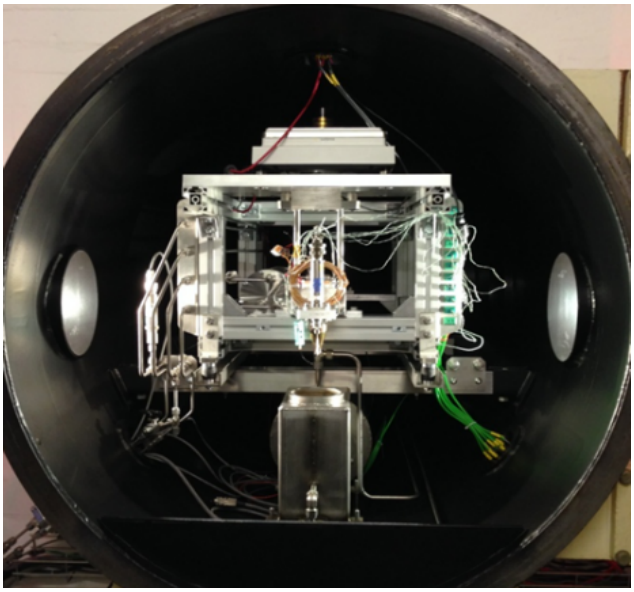

Figure 8: Nammo's MiniHATF Test Facility.

3. NAMMO UK

Rocket engine development and production has continued to increase at Nammo UK. The propulsion teams have a number of hypergolic bi-propellant thrusters and apogee class engines at various stages of development ranging from 100 to 1300 Newtons thrust. The Nammo LEROS range of qualified rockets, thrusters and fluidic components primarily address the 'in-space' sector including commercial Earth orbiting satellites and deep space missions for both NASA and ESA. Increased levels of demand for these products has resulted in extensive utilisation of the F-Site test facilities at Westcott, with future business indicating further increases over the coming years. The MHT 1 Newton hydrazine monopropellant thruster has successfully completed a number of different mission qualification programmes and is being delivered in flight batches. This is keeping the Nammo MiniHATF test facility busy. Also the LEROS 10 thrusters that have been selected by Airbus UK for the Mars Sample Return mission (along with four LEROS 2b apogee engines) are undergoing ATP hotfire testing in the F1 test facility.

The LEROS 4 High Thrust Apogee Engine (thrust range 1000 to 1300 Newtons) is now ready and able to be tested at high altitude in the recently commissioned National Space Propulsion Test Facility (NSPTF) that has been designed to test chemical rocket engines from 100 to 1500 Newtons. The LEROS 4 is gen-

Figure 9: The NSPTF facility during early construction (a) and the pump installation owned by the UK Space Agency (b).

erating a lot of interest from spacecraft manufacturers for Moon landing missions and is baselined for the upcoming ESA EnVision mission to Venus. It is soon to be qualified and flown on a commercial moon lander.

The NSPTF is now open for business to companies with engines and thrusters that need to be tested at high altitude (under representative space vacuum conditions). Initial enquiries and bookings for testing in the facility are being managed by STFC on behalf of the UK Space Agency. Nammo UK, who designed and built the facility, are the appointed service provider for testing services. This state-of-the-art facility includes a novel plume cooling heat exchanger and large bank of mechanical pumps to maintain vacuum during testing. Engines using hypergolic propellants have now performed validation testing in this facility with firing durations exceeding 2000 seconds.

Figure 10: Nammo's F1 thruster facility.

The development programmes that Nammo now have underway also include Moon and planetary orbit insertion and surface lander engines at higher thrust levels up to 7 kN. In order to service these developments through initial proving, a 7.5 kN sea-level capability is being designed and constructed under a UKSA/ESA initiative. In time this higher thrust capability is envisaged to become integrated into the National Space Propulsion Test Facility to provide high altitude testing facilities at these higher thrust levels.

4. CONCLUSIONS

The site at Westcott has a long history of UK propulsion testing, initially for military applications. The site is now home to several commercial companies with a range of rocket testing facilities and skills. These capabilities encompass monopropellant and bipropellant thrusters for sea-level and in-space applications, solid propellants, propulsion subcomponents, manufacturing, qualification, test instrumentation and analysis.

This paper describes some of the varied test programmes undertaken at Westcott in the last year (2021). There is increasing investment at Westcott with several feed systems planned for the next few years, including a 30kN LOX/LCH4 facility and higher-thrust altitude testing facilities, which will further increase UK rocket testing capability.

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