THE OPEN UNIVERSITY'S ALL-AXIS LIGHT GAS GUN FACILITY FOR MMSD RESEARCH

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ABSTRACT

Micrometeoroid and space debris (MMSD) present significant risks to spacecraft. The Open University's Hypervelocity Impact Laboratory (HVI Lab) utilizes a 4.5 mm bore All-Axis Light Gas Gun (AALGG) to study hypervelocity impacts, supporting spacecraft protection and debris mitigation research. The AALGG fires projectiles up to 6 km/s in horizontal and vertical orientations, with in-situ high-speed imaging. Key recent projects include testing the Comet Interceptor's DISC, ODIN Space Ltd's impact sensors, and First Light Fusion's VIPER velocity amplifier. The HVI Lab continues to enhance its capabilities to address critical knowledge gaps in impact dynamics, debris fragmentation, and spacecraft vulnerability, fostering collaborations to improve space sustainability.

1 INTRODUCTION

Micrometeoroid and space debris (MMSD) particles present a significant risk to operational spacecraft and to the long-term sustainability of space activities. Small micrometre sized particles can be capable of degrading spacecraft surfaces [1], whereas mm to cm-sized particles can perforate spacecraft structures, or puncture pressure vessels, leading to the damage or destruction of components or whole spacecraft [2-5]. Consequently, research into spacecraft protection and active debris avoidance, mitigation and recovery have become increasingly topical in recent years.

Light gas guns (LGGs) are powerful experimental tools that have become essential in the study of MMSD impacts to ground test numerical simulations of collisions in a controlled and observable environment [6]. The Open University's Hypervelocity Impact Laboratory (HVI Lab) houses a 5.7 m long 4.5 mm (0.177" calibre) bore All-Axis Light Gas Gun (AALGG) (Fig. 1) [7]. For more than two decades, the AALGG has been used for a variety of hypervelocity impact simulations, for astrobiology, planetary defence, and space exploration optimisation (material endurance and calibration). This paper presents the OU's HVI Lab as a facility for available for upcoming MMSD research.

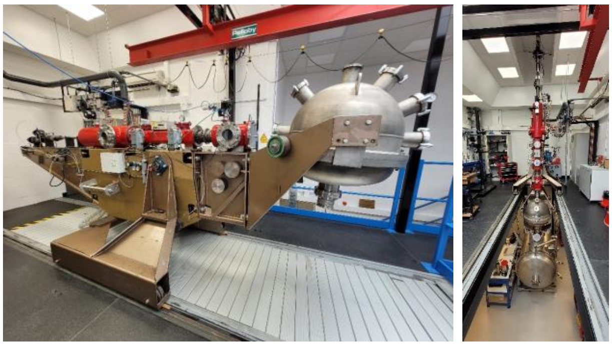

Figure 1. The AALGG at the Open University in horizontal (left) and vertical (right) orientation.

2 AALGG FUNCTIONAL AND DIAGNOSTIC CAPABILITIES

The AALGG has the distinctive ability to rotate between horizontal and (downwards) vertical firing, facilitated by a purpose-built retractable floor and hand driven gearbox, which enables a range of impact angles and the use of loosely consolidated targets.

Two target chamber sizes are available for use: a smaller 200 mm diameter chamber (horizontal & vertical orientations); and a larger 0.9 m diameter and 2.0 m long cylindrical chamber (vertical orientation only) to accommodate larger targets, each equipped with viewports, and electrical feedthroughs for in-situ diagnostics. High-speed cameras, including a Photron FASTCAM SA-Z record high-resolution (>1M frames per second) videos of impacts. Further in situ assessments include analysing the outgassed volatile headspace from impacts using a quadrupole mass spectrometer; developing debris cloud tracking using shadow laser photography; and measuring the thermal profile of an impact flash using a high-speed pyrometer. Crucially for space debris applications we aim to collect ejected material in aerogel or foam witness plates to characterise the fragmentation of spacecraft materials into ejected debris clouds.

The AALGG can accelerate spherical/cylindrical projectiles of up to 4.5 mm diameter up to 6 km/s, with aims to reach faster velocities with current developments.

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Loose particles can also be fired as “buckshots”, enabling the investigation of micrometeoroids, dust and fragmented spacecraft materials.

Pre- and post-impact characterisation of impact materials are conducted on-site, including physical properties (density and compressive strength) and microscopic textural and compositional modifications (scanning electron microscopy, electron backscatter diffraction, electron microprobe x-ray diffraction, Raman analysis).

3 RECENT PROJECTS

The AALGG at the Open University has conducted numerous tests over the past two and a half decades into the vulnerability of spacecraft structures to penetration from hypervelocity impact of small particles (Fig. 2).

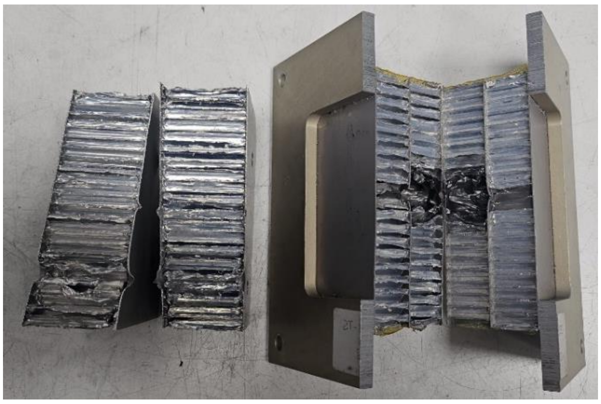

Figure 2. Impact of two representative spacecraft Whipple shields showing the penetration of a 3 mm stainless steel projectile at ~4 km/s through a single layer of aluminium honeycomb sandwich (left), but no penetration through the multi-layer alternative.

From 2021 to present the AALGG has been crucial in testing the functionality and survival of the Comet Interceptor’s Dust Impact and Sensor Counter’s light aerogel-stuffed dust shield [8-9]. A HVI test campaign firing nylon and aluminium projectiles 0.5-3.0 mm in diameter up to 6 km/s, was combined with numerical modelling to verify that the shield design would likely protect DISC from the most hazardous impact conditions experienced during the mission.

ODIN Space Ltd (www.odin.space) are developing the next generation of space debris impact detectors designed to be placed on spacecraft for space-based data collection in LEO and beyond. In 2024, as part of ongoing research and development they conducted hypervelocity impact tests for their new prototype next generation acoustic impact sensor system (Fig. 3). Data from these experiments have fed back into the design of the system, with plans for the next iteration to be ready for spaceflight testing in 2025/26.

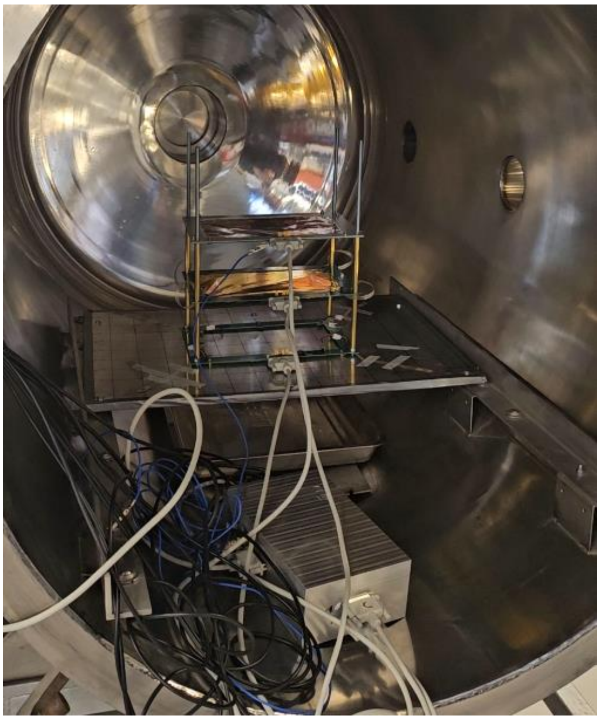

Figure 3. ODIN Space Ltd sensor protype in the large target chamber for hypervelocity impact testing.

In 2025, First Light Fusion announced a partnership with The Open University and NASA to develop its Velocity Amplifier (VIPER) technology for higher velocity impact testing with single and two-stage light gas guns (https://firstlightfusion.com/media/first-light-fusion-announces-strategic-update/). Designed to enhance the performance of existing single and two-stage light gas guns, VIPER is strategically positioned to support research into space debris that require velocities in the region of 10-20 km/s. Currently, First Light Fusion are developing two prototype designs that act as a 3rd stage in a gas gun to launch solid single and buckshot projectiles.

Prototype I: Gas filled ‘drum’ design (Fig. 4 top) uses the impact from a simple solid projectile from the 2nd stage of the gas gun to compress a high-pressure gas-filled cavity. Momentum is transferred through a buffer material into a final projectile.

Prototype II: Alternating heavy-light layer pairs (Fig. 4 bottom) uses alternating layers of heavy and light materials impacted from a simple solid projectile from the 2nd stage of the gas gun to transfer momentum into the final projectile.

Initial prototype testing using First Light Fusion’s “small” two-stage light gas gun encouragingly revealed a ~40% increase in velocity between the simple projectile leaving the 2nd stage of the gas gun and the final projectile leaving the 3rd stage. However, it was predicted the velocity could increase by up to ~70%, therefore further development with additional tests are planned for mid-2025.

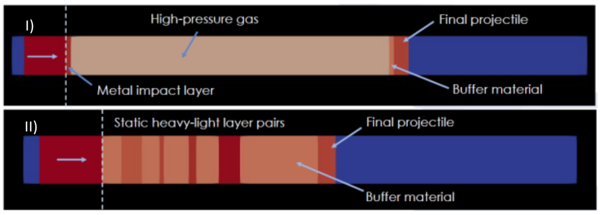

Figure 4. First Light Fusion one-dimensional schematic designs of its VIPER prototypes I (top) and II (bottom).

Continued and future collaborations are being established for experiments to investigate the impact dynamics and fragmentation behaviours of spacecraft CCDs, the vulnerability of spacecraft through impact focusing of x-ray gratings and Whipple shield spallation, and atmospheric impacts from space debris ablation.

4 CONCLUSIONS

The Open University's HVI Lab facility aims to partake in more collaborative projects to address significant knowledge gaps that remain to understand the impact dynamics, debris fragmentation, material behaviours and long-term debris evolution and atmospheric degradation in the near-Earth environment. Furthermore, the facility is taking steps to improve its functional and diagnostic capabilities to address known experimental limitations.

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