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THE OPEN UNIVERSITY HYPERVELOCITY IMPACT LABORATORY: AN ALL-AXIS AEROBALLISTIC RANGE FACILITY

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ABSTRACT

Introduction

Hypervelocity impact (HVI) was a pivotal process in the origin of the Solar System and continues to drive its evolution. The significant effect of HVIs on astrobiology, and growing awareness of the risk to planetary defence, drives new research into HVIs. Numerical hydrocode modelling can provide high resolution insight into the dynamics and conditions experienced during an HVI. However, ground truth, provided by laboratory impacts, is crucial to validate numerical results. This paper introduces the Hypervelocity Impact Laboratory (HVI Lab) at The Open University [1], presents studies that have used its facilities, and introduces aims to improve *in situ* instrumentation and expand on the distinctive capabilities of the lab.

The Open University Hypervelocity Laboratory

The Open University's Hypervelocity Impact Laboratory was established in 2000 [1]. It is uniquely equipped with an All-Axis Two-stage Light Gas Gun (AALGG) and a 2 MV Van de Graaff accelerator to focus on space exploration and utilisation (materials, protection and detector calibration), as well as planetary impact research.

The powder driven, 5.7 m long AALGG at The Open University (Fig. 1 & 2), is equipped with a 0.5″ diameter pump tube (27″ in length) and 4.5 mm (0.177" calibre) bore rifled launch tube. It has the distinctive ability to rotate between horizontal and vertical firing, facilitated by a purpose-built retractable floor and hand driven gearbox. This enables impact angles of 0°, 30°, 45°, 60°, 75°, and 90° from vertical to suit the needs of the experiment. A small (200 mm diameter) downrange target chamber is used for most experiments because it facilitates a fast pump down time, can achieve any impact angle, and is easily accessible for target re-loading through three 0.18 m diameter circular portholes. The AALGG can also connect to a large cylindrical chamber (0.9 m tall, 0.9 m wide and 2.0 m long) in the vertical configuration to accommodate larger targets, as well as fluid or loosely consolidated granular targets (Fig. 1 & 2).

Currently, the AALGG can accelerate spherical, cylindrical, ogive and cube projectiles of 1.0-4.5 mm diameter up to 6 km s^{-1}. If the projectile is the same size as the bore, they can be fired alone, or if smaller, they are held within an Isoplast sabot. The sabot is caught by a stop plate at the end of the blast tank. Loose particles can also be loaded into the sabot for "buckshot" launch capability, which has enabled the investigation of ices, dust and salts [2]. In addition, a pseudo-buckshot design was developed at the facility to enable vertical buckshot launch capability [3] (discussed below).

Instrumentation & velocity determination

To determine the velocity of the projectile, two laser light curtains, situated beyond the stop plate, detect particles that travel past (Fig. 1 & 2). An intervalometer measures the first particle large enough to trigger the signal. However, the minimum particle size to trigger the signal is not known, so this technique cannot be relied upon for projectiles smaller than 2 mm in diameter at high velocities, especially buckshot.

Recently, an additional method to measure velocity has been used in conjunction with the light curtains to improve reliability. A Photron FASTCAM SA-Z type 2100K-M-16GB High-Speed Camera (HSC), triggered by the firing mechanism, records a shadowgraphic video (>1M frames per second) of the flight of the projectile and sabot segments in the blast tank before reaching the stop plate. Calibration of the movement between frames and the known distance within the field of view, gives an estimate for the launch velocity of the projectile(s). The HSC is particularly useful for buckshot, as the beginning and the end of the particle cloud can be identified and an average and range of launch velocities determined. The longitudinal dispersion of projectile particles in a buckshot has been suggested as <2% [4-5], although shots conducted recently exhibited 6-21% dispersion with sabot and particle velocities that can vary up to 1.32 km s^{-1} [3]. A limitation of the HSC is that it might not capture the sabot segments, owing to poor lighting, focus, alignment, or being obscured by the bright gas flash that precedes the projectile by a few frames. Shading calibration is conducted before each shot, although sometimes this is insufficient to counteract the change in lighting conditions after the flash passes. Improving the time-of-flight capabilities, reliability and accuracy for smaller projectiles at higher velocities are top priorities for development of the AALGG.

The primary purpose of the HSC, combined with high-intensity illumination, is for shadowgraphic and high-resolution filming of the impact process at the target. Images are processed in-house using PFV4 and used where required for particle ejection tracking.

Further *in situ* assessments include analysing the outgassed volatile headspace from impacts into ice representing the surface of Enceladus using a quadrupole mass spectrometer during [2] and measuring the thermal profile of an impact flash from solid targets using a high-speed pyrometer.

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

Research Projects

The AALGG has a long history of noteworthy projects, including: EU "Near-Earth Objects Shield", a Planetary Defence project [6]; ESA "Sterilization limits for sample return planetary protection measures", a Planetary Protection study [7]; and "Survival of Ejected Martian Biosignatures" (SEMB) PhD project [3]. The AALGG is in high demand for projects, including: Comet Interceptor DISC dust shield performance studies [8]; Martian regolith simulant impact modification PhD project [9]; and Analysing volatile profiles from fresh plume material from Enceladus analogue ices PhD project [2].

A significant outcome from the SEMB project was the innovative design of pseudo-buckshot projectiles with bespoke composition [3]. A mixture of Mars-like rock powder and biosignature molecules were cemented together with a geopolymer binding (Fig. 3 & 4). Developed originally as a sustainable alternative to ordinary Portland cement [10], this binding method combined a dry powder mixture of solid alkali activator or liquid alkali activator and a solid aluminosilicate precursor with water to initiate the polymerisation reaction. The low strength of the 2.9 × 5.8 mm cylindrical pellets resulted in disintegration upon launch acceleration, generating a buckshot cloud. These pseudo-buckshot projectiles could offer a solution to the challenge of conducting buckshot impacts into granular or liquid targets, because a vertical impact orientation would be required that would otherwise result in projectile fragments falling down the launch tube before firing.

Conclusion

In summary, the AALGG in the Open University HVI lab is in demand to conducts research for space instrumentation and astrobiology, as well as innovating solutions for aeroballistic challenges, including generating bespoke pseudo-buckshot projectiles. However, the laboratory is looking to develop better time of flight capabilities, broaden its *in situ* analysis instrumentation and improve internal cleanliness for future high-sensitivity chemistry investigations.

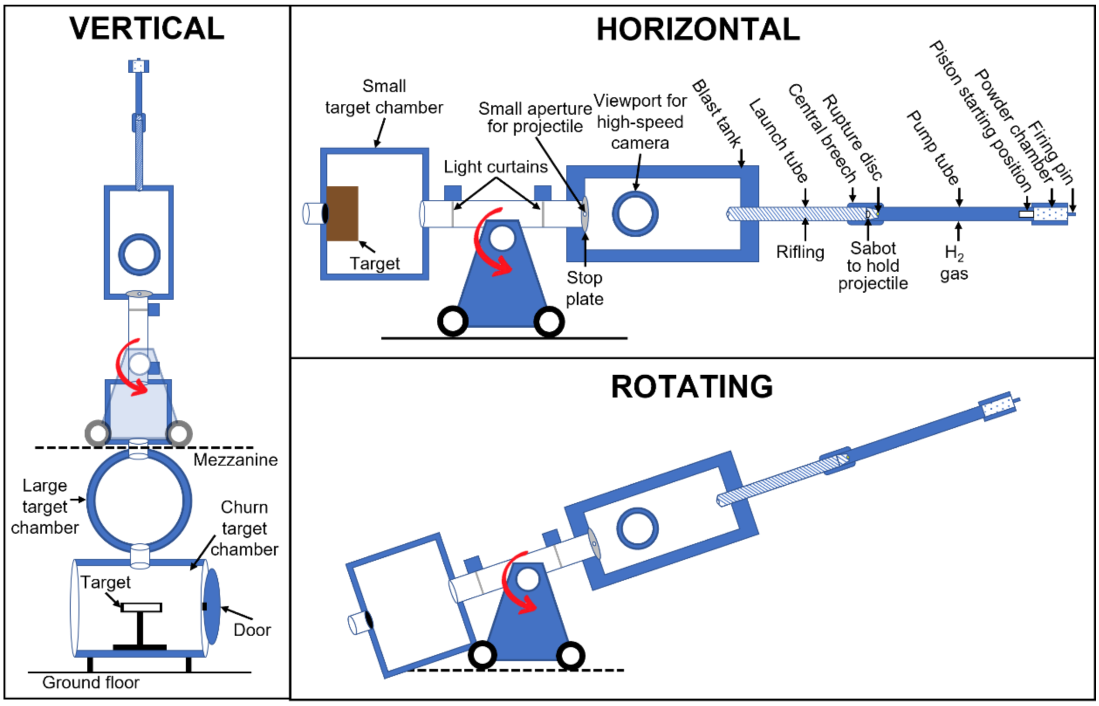

Figure 1: illustrative diagram of the AALGG at the Open University rotating between horizontal and vertical orientation.

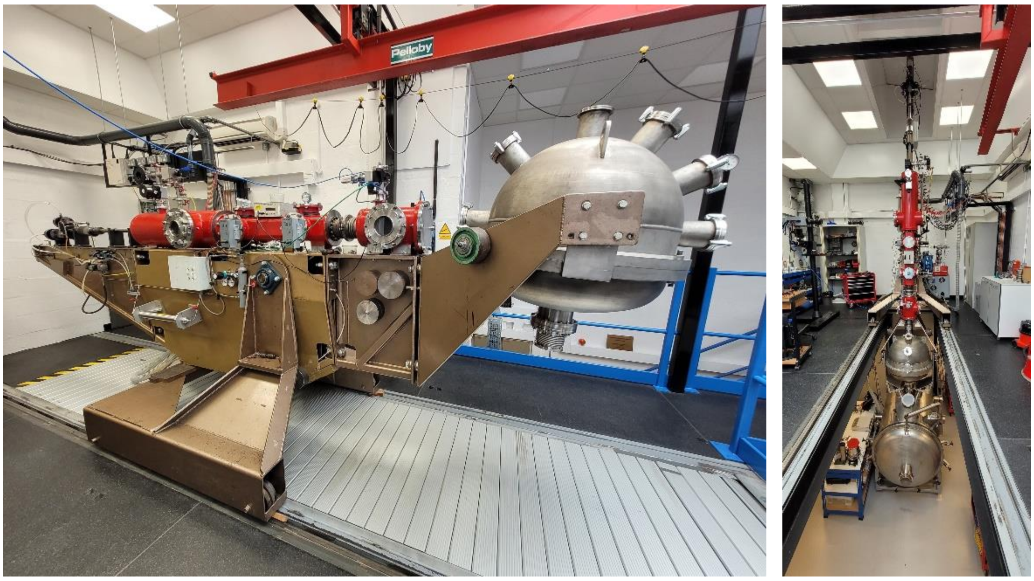

Figure 2: The AALGG at the Open University in horizontal (left) and vertical (right) orientation.

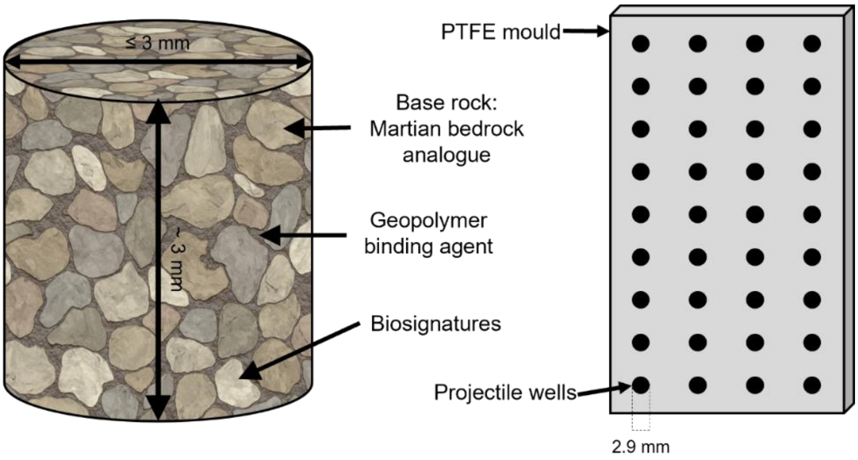

Figure 3: Left: illustrative diagram of the bespoke aggregate cylindrical projectiles, grain size not to scale. Right: mould to achieve cylindrical shape of pellets.

Figure 4: Strongest glycine-doped projectiles after optimising binding process - 2.9 × 5.8 mm.

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