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The Hypervelocity Impact Facility at the University of Kent: Recent Upgrades and Specialized Capabilities.

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Abstract

Impact events are ubiquitous across the entire Solar System; craters are observed from Mercury to distant Pluto. This process has been occurring since the Solar System formed and is still occurring today. During such events, which typically occur at speeds measured in kilometers per second, extreme pressures and elevated temperatures are created. In order to understand the physical processes that occur under such conditions, we have been using a two-stage light gas gun to recreate hypervelocity impacts on a range of targets that are representative (in both composition and physical condition) of the surfaces of all objects within the Solar System.

Within this paper we describe the advances we have made in light-gas gun technology, specifically focusing on the University of Kent's light gas-gun, over the past 30 years which have led to significant advancements in Planetary Science and the general field of shock physics.

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1. Introduction

The University of Kent's two-stage Light Gas Gun (LGG) has been in operation for over 25 years. It was originally purchased from Physics Applications Inc. and the first shot occurred in August of 1989 [1]. Since the facility first came online, the LGG has undergone a number of upgrades and modifications which has diversified the impact research that scientists can perform.

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Fig. 1. The light gas gun at the University of Kent (circa 2008). The left image shows the gun before any major modifications. The right image shows the gun as of April 2017 with the most obvious addition being the grey framework that is the support structure for the vertical firing axis.

Within this paper we describe the enhancement and upgrades that have been made to the Kent facility since the 1990's and briefly summarize the research that has driven these upgrades.

These alterations can be broken down into the following broad categories: expanded range of target conditions, projectile materials (and conditions) and gun upgrades.

2. Projectiles

Originally, the Kent light gas gun (see Fig. 1) was only capable of firing 0.170" diameter nylon cylinders with a length of approx. 4 mm and diameter of 4.5 mm. The simplest modification made to the projectile set-up was the addition of rifled launch tubes. The rifling of the launch tubes produces one full rotation of the projectile for every 0.7 m the projectile travels, thus giving the projectile a rotational speed.

The addition of rifled launch tubes has added the ability to use split-sabots (Fig. 2), which are comprised of four interlocking segments that are capable of housing a projectile within them. The rifled launch tube imparts a rotational component to the velocity of the sabot during acceleration; once the sabot is no longer confined by the launch tube the four segments begin to spin away from the gun axis while leaving the projectile to continue down the gun range. The split sabot system is described in greater detail in [1].

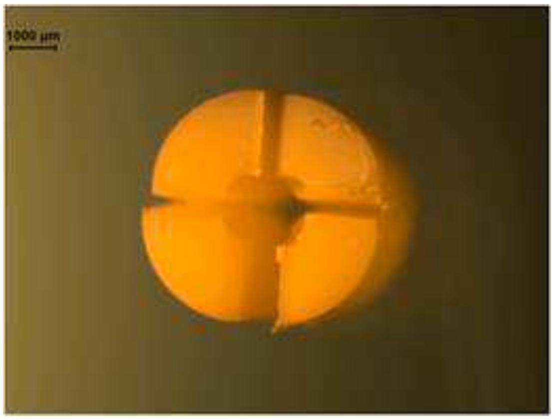

Fig. 2. A split sabot demonstrating the four interlocking segments and the central hole which houses the projectile(s).

The encased projectile can take a variety of forms. Single projectiles ranging in size from 0.1 to 3.0 mm can be used, provided that the material is capable of withstanding the extreme acceleration and "jerk" (acceleration/time) of order $10^9 – 10^{10}$ m s^{-3} they experience during launch. Using rifled launch tubes and split-sabot technology it is also possible to fire a buckshot of material consisting of many small particles (buckshot as small as 100 nm silica spheres has been successfully fired). These small particles can be used as analogues for dust particles found throughout the solar system, such as cometary or interplanetary dust.

Since their introduction in 1993, split sabots have been used extensively in the impact research undertaken at Kent. One example of work that relied heavily on the use of split sabots is the experimental simulations of dust particle impacts onto aluminium foils carried out by Kearsley et al (2006) [2]. These experiments were used to support the NASA Stardust mission to comet 81P/Wild-2 [3, 4]. They enabled us to better understand the impact craters found on the *Stardust* aluminium foils (used to secure the aerogel captures cells within the sample return capsule), and aided in the creation of a calibration for the size of the dust particles that had impacted the foils [5]. They also provided a calibration for the pre-impact size of the particles capture in the aerogel itself [6]. This helped provide insight into the structure of comet Wild-2, as well as a serendipitous discovery that led to a much greater understanding of the cratering mechanisms of very small particles at high speeds when strain rate dependent strengths become significant [7].

Another example to demonstrate the flexibility of using split-sabots is the firing of live bacteria onto a variety of target materials in order to test their survivability in the context of the theory of Panspermia [8]. This shot program impacted bacteria infused into porous ceramic projectiles directly onto plates of nutrient material at speeds of 5.0 – 5.3 km s^{-1}. The target plates were then incubated and examined for colony growth. Growth was discovered on several target plates demonstrating that it is possible for bacteria to survive hypervelocity impacts. This was one of the first demonstrations that living organisms could survive such extreme pressures.

In addition, the Kent light gas gun has the capability to fire frozen projectiles in the form of solid ice (plus any constituents) frozen into a hollowed-out cylinder. This is then fired as a single projectile, as there is (currently) no way to strip the encasing cylinder from its frozen contents. These ice filled cylinders are often used for research related to the field of astrobiology, such as investigating the survivability of yeast spores and fossils in hypervelocity impact events. Yeast spores were shown to be able to survive impacts up to 7.4 km s^{-1}, albeit with an extremely low survival rate. The survival probabilities were calculated to be ~50% for 1 km s^{-1} impacts, but fell to ~10^{-3}% for 7.4 km s^{-1} impacts [9].

These hollowed out sabots were also used to fire fossilized diatoms either frozen in ice or suspended in liquid water (when a cap was placed to seal the hollowed out sabot). This latter technique permits us to fire liquid samples doped with whatever we wish at targets. The diatom fossils were found to be capable of surviving intact when subjected to impacts up to 5 km s^{-1} (19 GPa). While the larger fossils broke up during the impact events, intact fossils up to 30 μm were found at 5 km s^{-1}, implying that larger structures are broken first at lower shock pressures [10, 11].

3. Targets

As well as being able to fire onto standard bulk material targets, we have also developed a variety of target holders that allows the investigation of targets at a range of temperature (from 100 K to 1000 K). These target holders are used to simulate impacts on different bodies throughout the solar system, where there is a large temperature variation ranging from Pluto at 33 K to Venus at 735 K. For example, a hot target holder capable of heating cylindrical targets up to 1000 K using a heating coil and maintaining the desired temperature until just prior to impact (Fig. 3a). The hot target holder has been used to study the cratering efficiency of metal targets as a function of temperature and the mixing of molten target and projectile material.

Craters in metal targets were shown to increase in size as the target material approaches its melting point. This is due to the thermal softening of the material and therefore a loss in yield strength [12]. While the mixing of molten target and projectile material, has so far been found to be difficult to achieve in the laboratory [13], other studies that have relied extensively on the hot target holder include investigations into the cratering formation process on rocky bodies [14, 15].

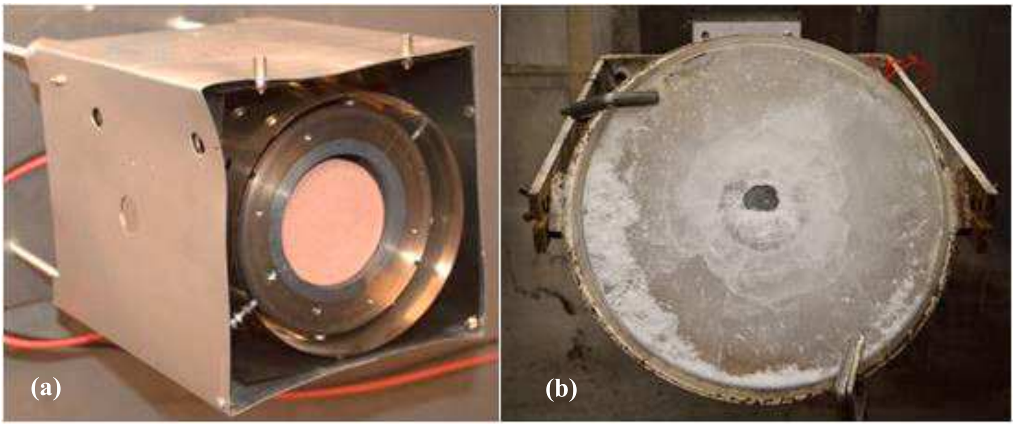

Fig. 3. (a) The hot target holder with a 60 mm diameter cylinder of sandstone housed in the centre ready for heating. (b) A water ice layer over a solid basalt target at an impact angle of 45˚ (target diameter 40 cm).

To complement the hot target holder, it is also possible to impact onto frozen targets. This method utilises standard freezers in the lab to cool a frozen target before a shot. This target is then transferred to the target chamber of the light gas gun whilst the gun is prepared for firing (Fig. 3b). This has allows us to construct large targets made of ices that can be used to simulate icy bodies in the outer solar system. This facility has been used to determine how changes in velocity [16], impact angle [17] and ice temperature [18] influence crater morphology in water ice targets. Investigations have also been conducted to determine the effect of ice layers over other target materials such as water, sand and basalt. This study indicated that the density of the subsurface material does result in differing crater morphology [19].

Additionally, a rotating target holder capable of rotating spherical targets up to 150 mm diameter at speeds of up to 3.5 Hz has been constructed (Fig. 4). This allows investigation into whether a rotating target has a lower catastrophic disruption energy than a stationary target and, if so, how this energy changes as a function of target rotational velocity. This is particularly important for understanding the dynamics of asteroid fragmentation as an aid to determining the origin of the large crater on asteroid (2867) Steins [20].

As the Kent light gas gun is a horizontal gun it can be problematic to simulate impacts onto bodies of water. The water-target holder was developed to address this problem. It consists of an aluminium container with a 30 mm circular opening on one side to allow the passage of a projectile. Inside the container is a frame holding a very thin (approx. 10 microns thick) plastic bag filled with liquid to simulate a body of water (Fig. 5). After the impact this water can be collected and filtered to examine the remnants of the projectile. This target holder has been used to investigate the theory of Panspermia by simulating oceanic impacts. This was achieved by measuring the survival rates of simple organisms after impact events, such as the experiment involving the survivability of yeast spores mentioned earlier [9], and by testing if sufficient volumes of material with the potential to house such organisms survive the impact process. It has been used to show that large fragments (~10% of the original mass) from millimetre sized projectiles are capable of surviving a 5 km s^{-1} impact into water, demonstrating that large asteroids may deliver significant volumes of solid material to Earth; thus providing a possible mechanism for panspermia [21].

The ocean target holder has also been used to determine the influence on the crater formation for a solid rock target with a layer of water above the target. It was found that an overlying water layer resulted in a reduction of crater dimensions when compared to a corresponding impact without a water layer. The study showed that a layer of water approximately 12 times the projectile diameter was required to stop crater formation in the rock target [22].

Finally, it is also possible to pressurise the target chamber up to 100 mbar with any inert gas/air. This can be used to determine if the presence of certain atmospheric constituents alters the physical or chemical interactions between the projectile and the target during impact. The method was used to investigate the possible sources of methane in the Martian atmosphere. These impact experiments showed that the atmospheric methane on Mars is likely not due to release from impacts onto methane bearing basalt, They also demonstrated that the impact pressures achievable with the light gas gun were not sufficient to induce rapid serpentinization, which is another suggested theory for the presence of methane on Mars [23].

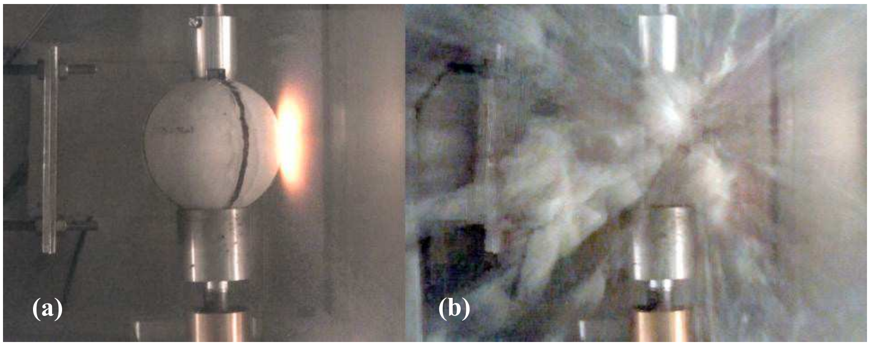

Fig. 4. A spherical target in the rotating target holder at (a) the moment of impact and (b) during complete disruption of the target.

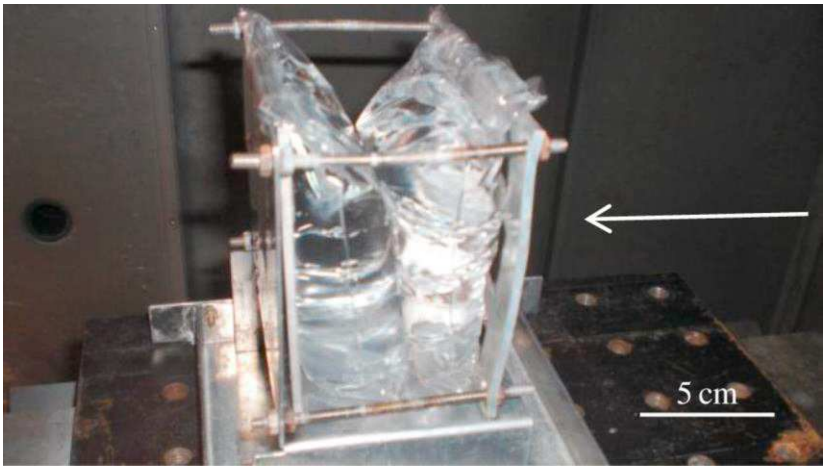

Fig. 5. The ocean target holder showing the frame holding two bags of water. The arrow indicates the path of the incoming projectile.

4. Gun Upgrades

The original light gas gun had a speed range of 1.2 to 4.5 km s^{-1} and much work has been done to extend this range in order to give a greater choice in the shock pressures that can be created. To increase the upper speed limit, a longer pump tube was added to allow for a greater volume of gas to be compressed in the first stage. This modification has increased the maximum (reliable) speed of the gun to 7.7 km s^{-1}.

On-going development is underway to allow the light gas gun to be converted to a single stage configuration to achieve speeds less than 1.2 km s^{-1} (the lowest speed achieved so far is ~100 m s^{-1}). We have found that is it sometimes desirable to impact materials without entering the hypervelocity impact regime and the associated shock phenomena, which can occur at higher impact speeds. This has been particularly useful when investigating the structural deformation of targets made of crystalline materials [24].

This low-speed implementation involves the replacement of the standard aluminium rupture disk (situated between the pump and launch tubes), with a system that is capable of releasing the pressurised gas in the pump tube without having to first compress it. The replacement rupture disk uses the principle of an electric fuse. This replacement disk (Fig. 6) is connected to an external power source (in this case a standard 12V car battery). Upon ignition, the external power source is activated by passing a current through the disk. The disk heats up almost instantaneously and melts like a fuse, the material that was once holding back the gas has now been removed and the gas is free to expand into the launch tube and accelerate the projectile.

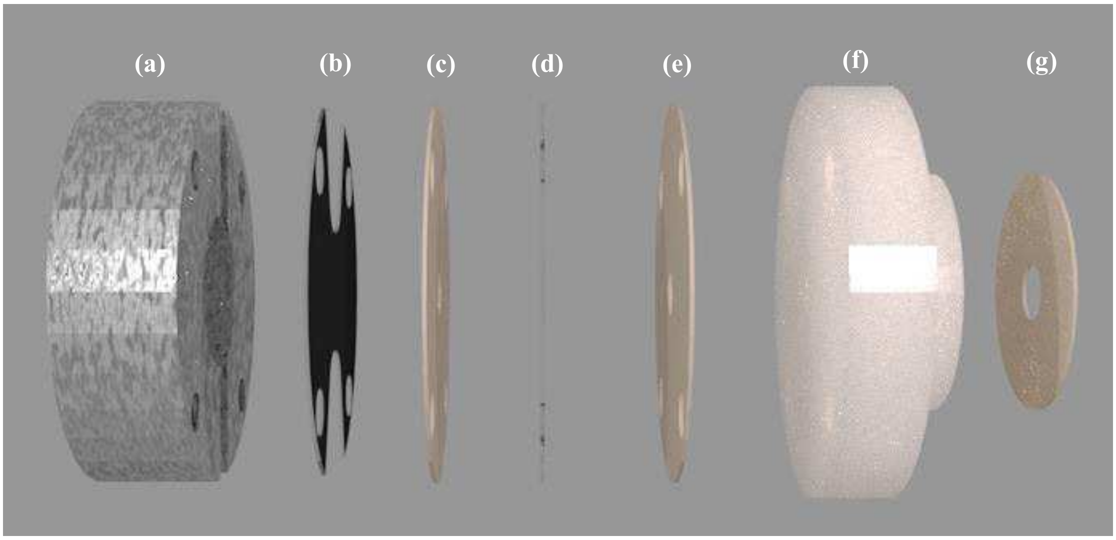

Fig. 6. The layers involved in the Electronic Burst Disk (ECB). From left to right: (a) Steel electrodes, (b) 100 micron aluminium foil, (c) adhesive tape, (d) acetate backing, (e) adhesive tape, (f) nylon holder and (g) adhesive tape.

The layers shown in Fig. 6 are as follows (from left to right):

- Electrodes
- 100 micron thick aluminium foil
- Adhesive tape
- Acetate backing
- Adhesive tape
- Nylon holder
- Adhesive tape

One of the electrodes is insulated from the rest of the system making the aluminium foil the only means of completing the circuit, guaranteeing that the current will pass through the foil causing it to fuse. The acetate backing was not initially part of the design but was added once it became apparent that the fusing process was damaging the nylon holder. This acetate backing has proved effective as acting as an insulator between the aluminium foil and the nylon holder, thereby extending the life of the holder. The adhesive tape layers are simply used to keep the entire system in alignment, with the final tape layer having the secondary function of creating a seal between the burst disk and the launch tube of the light gas gun. All layers except for the aluminium foil have a central hole that allows the flow of gas once the foil has been fused.

This method, referred to as the Electronic Burst Disk (ECB), is capable of reliably extending the lower speed limit of the gun down to 200 m s^{-1}(and as low as 100 m s^{-1} at times). We also hope to further develop this method to allow for finer temporal and velocity control in other light gas gun configurations. Development of this system is still ongoing and further details will be made available in a later publication.

5. Conclusions

The Kent light gas gun has been an invaluable tool in the investigation of many branches of science, and not just in the field of Planetary Science. Through constant innovation and collaboration the Kent impact facility remains at the forefront of hypervelocity impact research. The latest modification is a vertical firing section which is nearing completion and, once commissioning has been completed, will be reported in a follow-up publication.

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