THE SMART 1 IMPACT EVENT: FROM THE LABORATORY TO THE MOON. M. J. Burchell[1], R. Robin Williams[1], B.H. Foing[2], and the Smart 1 Impact Campaign Team. [1]School of Physical Sciences, Ingram Building, Univ. of Kent, Canterbury, Kent CT2 7NH, UK. M.J.Burchell@kent.ac.uk. [2]Space Science Dept., ESA – ESTEC, Postbus 229, 2200 AG Noordwijk, The Netherlands.

Introduction: Although the lunar surface is heavily cratered, there has been no well understood, well observed lunar impact event. This ignores the folk law "impacts" such as the Canterbury event of 1178AD, a lunar light flash recorded in contemporary literature and more recently suggested as the possible origin of lunar crater Giordano Bruno [1, 2]. It also ignores the somewhat better founded reports of lunar light flashes of more recent years and the seismic impact data from the Apollo era in-situ lunar seismometers (e.g. [3]). The problem in these latter cases is the lack of knowledge either of the impactor or the resulting crater.

However, the recent demise of the ESA spacecraft Smart 1 in a deliberate impact upon the moon provides a more definite impact event for study. The Smart 1 mission [4 – 6] was deliberately ended by a controlled impact of the 285 kg spacecraft onto the Moon's surface. The impact was at 2 km s^{-1} and at a shallow angle of 1° from the horizontal. The resulting light flash was observed from the Earth [7, 8]. This event offers the opportunity to attempt to explain a well constrained impact event on a rocky body. The crater is as yet still unobserved, but should be within the capability of future lunar orbiters to image. The analysis is thus a blind test of the ability of laboratory experimentation and/or modeling to explain a geological impact event.

Method: The speed of the Smart 1 impact event is within the range of laboratory impacts using guns, but the mass of the spacecraft exceeds the ability of any gun. Therefore laboratory experimentation alone cannot recreate the event (even neglecting the difference in lunar and terrestrial gravity). However, laboratory experiments can be used to gain insight into the processes involved in the impact. Combined with appropriate scaling models, predictions can then be made for the shape and size of the actual (as yet unseen) resulting lunar crater. In addition, there is data on the light flash and associated plume from the impact which were observed from Earth. This should also be included in any detailed explanation of the impact event.

The laboratory experiments were made using a two stage light gas gun at the Univ. of Kent [9]. The target was fine grained sand. This flows under impact into the classic bowl shaped impact crater with a raised rim. Since the Smart 1 impact was at a very shallow angle of incidence, the sand target was adjustable over a range of impact angles (here 1° to 10°). The projectiles were 2.03 mm dia. aluminium spheres. 14 shots were made at a mean speed of (2.08±0.08) km s^{-1}. Four shots were at 1°, four at 2°, four at 5° and two at 10°. The resulting craters were measured and the evolution of crater shape with impact angle was obtained as well as the overall crater sizes. By in-filling the craters after each impact the excavated crater volume was also measured. This has two components, material which flowed into the raised rim walls and that which was ejected by flight. In some impacts the rim walls were pushed back into the crater before in-filling occurred, permitting an estimate of the relative magnitudes of these two effects.

The crater shape (as seen from above) was found to remain circular until angles of incidence of 5° or less were obtained. Then increasing non-circularity was apparent. From 2° and downwards the non-circularity was increasingly due to the emergence from the main crater of secondary craters along the line of flight. Such behaviour had also been previously reported in laboratory experiments [10]. A typical crater at 1° incidence is shown in Fig. 1.

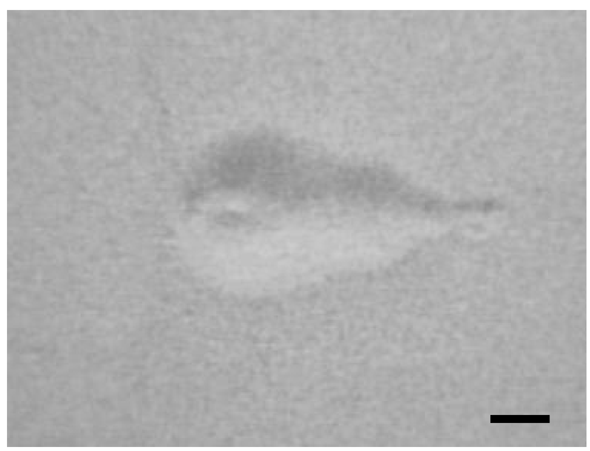

Figure 1. Impact crater in sand in the laboratory at 2 km s^{-1} and 1° incidence (from left). A 1 cm scale bar is shown (bottom right).

The craters were very shallow, with rim wall height approximately 50% of the crater depth (as measured from the original undisturbed surface plane). In these shallow angle impacts the projectile ricocheted from the surface at a very shallow angle. In general this angle was not equal to the angle of incidence; for impacts at 1° the ricochet angle was almost 1°, rising slowly to 2.5° as the impact angle was increased to 10°. Taken at face value this suggests the Smart 1 spacecraft may have bounced off the lunar surface at the initial impact site.

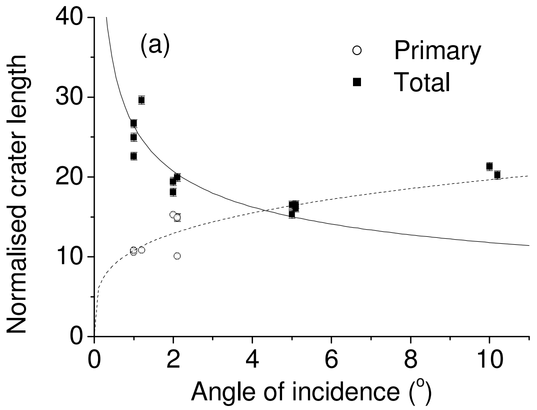

Figure 2. Evolution of crater length with impact angle. Length is shown normalized to projectile diameter.

The behaviour of the crater size and shape vs. impact angle was recorded from the laboratory data. An example is crater length (Fig. 2). In Fig. 2 the primary crater length is estimate at small angles from its general shape and total length is that of the overall impact feature. That total length is controlled at shallow angles by the emergence of other craters attached to the main crater (Fig. 1) is evident. By contrast, crater width is controlled solely by the primary crater (which is always the widest) and continues to decrease even at the shallowest angles.

However, what is of main interest here is the prediction of what the corresponding lunar impact crater will look like. When using scaling relations, there is no single, definite prescription for how to handle highly oblique impacts. Suggestions include replacing the impact speed with its perpendicular component and do not allow for the emergence of multiple impact craters. However, here we have the same angle in the lab and the impact. As a simple approximation we consider this is fixed in the two cases (lab and on the moon) and apply pi scaling to the average laboratory dimensions of the craters at 1° incidence (using total length for the length). Pi scaling (e.g. [11]) adjusts the scaled value for parameters such as crater diameter and excavation volume according to relations linked by power laws. The powers in these relations have to be defined. Here we use the mean values for sand of $\gamma = 0.5$ and β – 0.165 suggested by [11]. The scaling laws also allow for the local gravity aiding extrapolation between the laboratory (Earth) and the Moon. The results suggest that the Smart 1 impact crater on the Moon should be 5.5 m long and 1.9 m wide and depth 0.23 m. The volume of ejected material (after correction for that which flowed into the rim walls) is approximately 2200 kg.

The prediction for the impact light flash and ejecta plume observed on Earth require on-going work. Groups are still producing their estimates of the energy of the flash and the volume of material in the observed plumes.

Conclusions: The Smart 1 impact event has-been simulated in laboratory experiments. Accompanying hydrodynamical computational simulations are awaited. The event was also observed as a light flash and plume of ejecta witnessed from the Earth. Work is underway to tie all these observations into a single account of the impact event. This will necessarily be incomplete, as the crater itself has not yet been observed. However, there is the reasonable expectation that this will be observed in the future. The crater will thus act as a blind test of impact modeling (experimental and computational) and covers both the impact crater and the associated plume of ejecta. To the extent that the lunar regolith is held to be understood based on Apollo era observations, the reasonably well constrained impact represents a good test of our ability to understand impact events. The size scale is still less than the large impacts normally associated with planetary impacts and the spacecraft was an irregular shape not expected to occur naturally, but nevertheless it is one of the few well constrained Solar System impact cratering events known. When finally imaged the results may be similar to the known lunar crater Messier, long held to represent a highly oblique impact e.g. [12].

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