MOMENTUM ENHANCEMENT EXPERIMENTS AND CALCULATIONS OF BASALT-BASED RUBBLE PILE SIMULANTS, 2 AND 5.5 KM/S, MOTIVATED BY DART. J. D. Walker¹, S. Chocron¹, D. J. Grosch¹, D. D. Durda², S. Marchi², M. V. Grimm¹. ¹Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas, 78238. james.walker@swri.org, ²Southwest Research Institute, 1050 Walnut Street Suite 300, Boulder, Colorado.

Background: Impact experiments were performed into targets made of basalt, sand, and grout. These targets were based on the observations of Dimorphos by the DART spacecraft impact as well as what targets could be hung from a pendulum. The momentum enhancement caused by the ejecta from the impact was measured for experiments performed with aluminum spheres of radii 3.0 cm and 4.45 cm and impacts at speeds of 2.0 km/s and 5.5 km/s. Computations were performed with the EPIC impact code to examine the effect of the rock size in the target on $\beta$. These impacts followed work measuring momentum enhancement of impacts into other arrangements of rock, which data was collected in the context of the DART impact [1,2].

Technical Approach: Targets of crushed basalt rock of three sizes were fabricated (a photograph is in [3]). Original work with the crushed basalt, described in [3], used grout mixed with water and sand to hold the material in place. For some targets in this experimental series, the same procedure was employed. However, for some targets, water was not added, and it was found that packing the crushed basalt, sand, and grout was sufficient to hold the target material in place (Fig. 1).

A series of 11 impact experiments were performed at 2 km/s where a 50-mm diameter bore powder gun was used to launch aluminum spheres. Spheres launched were of two diameters, 3.0 cm and 4.45 cm. The swing of the pendulum allowed a measurement of the post-impact momentum of the pendulum assembly, and hence a determination of the momentum enhancement $\beta$ (Fig. 2). These experiments were performed in open air which facilitated the high-speed video photography of the impact, the debris formation, and the subsequent debris motion (Fig. 3).

Figure 1. Crushed basalt rock target, where the basalt is mixed with sand and grout, though no water is added. The target is attached to the pendulum by chains. (2 km/s impact experiment #4.)

Figure 2. Post impact image showing the debris from the crushed basalt target, after the swings of the pendulum had come to rest. The target is $57 \times 57 \times 29$ cm in size with a mass of 218 kg. The impact speed was 2.02 km/s. (2 km/s impact experiment #4.)
Experiments were also performed at 5.5 km/s using a large two-stage light gas gun. For these experiments, the large pendulum was placed in an evacuated impact chamber. Six experiments were performed into crushed basalt targets. Combined with the five experiments that were previously performed and reported at the last LPSC [3], these now give 11 data points at the higher impact speed. In these experiments, there are variations in crushed-basalt rock size and in whether water was used in the fabrication. The pendulum swing was also measured in these experiments for a determination of the momentum enhancement $\beta$.

Along with the physical experimentation at relatively large scale, computational modeling of impacts was also performed. These computations were performed with EPIC, which is an impact physics finite-element code where, upon large deformations, the finite elements transform into interacting particles (similar to SPH). These computations are being used to explore the influence of the crushed basalt rock sizes and on the numerical schemes that are being used to model the impacts.

Here, computations were performed with EPIC to compute the momentum enhancement of a solid block of rock impacted by an aluminum sphere at 5.5 km/s. They will be compared with the impact on a “rubble pile” which is ideally simulated as a collection of small blocks (Fig. 4). The material model accounts for crush-up of porosity, strength dependence with pressure and strain rate, and bulking of material upon failure. For the simulations, both hollow and solid spheres were used as impactors to compare their effectiveness at producing ejecta. Plots of momentum enhancement vs. time show that, as expected, the solid block impacted by a hollow sphere is the configuration producing the smallest momentum enhancement, while the highest is produced by the solid sphere impacting the rubble pile.

Ultimately, these experiments and computations will be compared to the DART impact results [4] as well as being used to extrapolate to other impact scenarios.