Development of a Doppler Radar System to Determine Plume-Surface Interaction Ejecta Velocities. J. G. Mantovani[1], A. G. Langton[2], B. W. Kemmerer[3], A. R. Atkins[4], and D. P. Batcheldor[5], [1]NASA (Kennedy Space Center, FL 32899, james.g.mantovani@nasa.gov), [2]NASA (KSC, FL 32899, austin.g.langton@nasa.gov), [3]NASA (KSC, FL 32899, beverly.kemmerer@nasa.gov), [4]Amentum (KSC, FL 32899, austin.r.atkins@nasa.gov), [5]SURA (KSC, FL 32899, dan.batcheldor@nasa.gov).

Introduction: A sustained human presence on the moon entails multiple landings and launches in relative proximity to the surface assets required to support a crew and their lunar exploration activities, e.g., investigations of permanently shadowed regions (PSRs). However, observed damage to Surveyor III from regolith ejected by the Apollo 12 lunar module plume-surface interaction (PSI) highlights the need to understand the risks posed by high velocity regolith particles to equipment [1], and the potential contamination of PSRs and surface regolith to be utilized for ISRU and lunar science studies. It is therefore necessary to determine what velocities PSI ejecta can reach so that mitigation measures can be put in place.

Analysis of Apollo landing videos indicate that descent engine plume interactions may accelerate regolith to significant velocities [2]. Other analyses using unfied flow solvers [3] and lagrangian simulations [4,5] have also demonstrated PSI ejecta could reach high velocities. However, while there is broad variation in these results, there is the potential for PSI ejecta to be accelerated above 2 km/s. Therefore additional velocity constraints on PSI ejecta velocities are necessary to establish confidence in the risk they pose.

In-situ velocity measurements from lunar landers during upcoming missions shall provide the most accurate data on PSI induced ejecta dynamics. The development of the Dust Ejecta Radar Technology (DERT) instrument is therefore underway at NASA's Kennedy Space Center (KSC). Here we report on the developmental progress of DERT to date, and discuss the further tests required for a future lunar lander mission.

Dust Ejecta Radar Technology: DERT is a millimeter wave Doppler radar system designed to measure the velocity of particles the size of lunar regolith. Figure 1 shows a prototype DERT supplied by SpaceK Labs (www.spaceklabs.com). This unit is vacuum rated and currently undergoing extensive lab-based testing at KSC to raise the technology readiness level of DERT. It operates at 94 GHz and returns time resolved Doppler shifted frequencies as a function of signal strength. These data cubes can be controlled and output via a spectrum analyzer or oscilloscope. The Doppler shifted frequency spectra are converted to velocities, and neighborhood comparisons are used to find local maxima in each spectrum for each timestep. A high-speed camera is used to independently confirm the velocities derived from DERT.

Figure 1: DERT Prototype currently being tested.

DERT development at KSC has been conducted to test the accuracy and precision of the radar system at a range of velocities and distances, and to determine the nature of the radar field pattern. BP-1 lunar regolith simulant has been used in each case. At distances of less than 2 m from the DERT prototype velocities below 2 m/s have been tested with a pendulum, velocities below 10 m/s with a specifically designed Lunar Regolith Ejecta Simulator (LuRES), and velocities of 20 – 80 m/s at Johns Hopkins Whiting School of Engineering. LuRES is a belt system that enables the radar field pattern to be probed. Distances over 2 m have been tested at KSC's weapons training area using NATO 5.56 mm rounds and BP-1 packed shotgun shells (Figure 2). The deceleration of BP-1 in atmosphere significantly limits the distances at which particle detection can be successful, and highlights the need for large-scale vacuum testing of DERT.

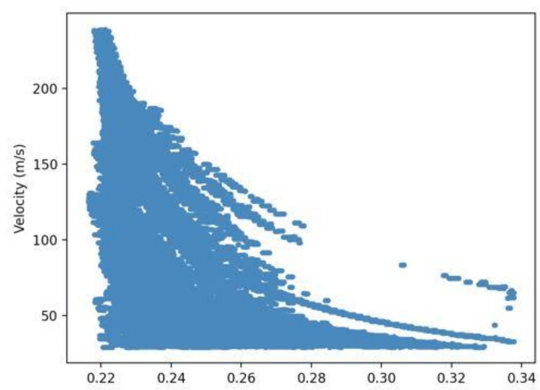

Figure 2: Deceleration of BP-1 in atmosphere.

References: [1] Immer, C. et al. (2011) *Icarus, 211*, 1089. [2] Immer, C. et al. (2014) *Icarus, 214, 46*. [3] Tosh, A. et al. (2011), *JSR, 48, 93*. [4] Lane, J. et al. (2015), *Acta Geophysica, 63, 568.* [5] Lane, J. et al. (2010), *E&S 2010, ASCE.*