# INTEGRATION OF LOW ALTITUDE AERIAL SYSTEMS DATA INTO FIELD OPERATIONS FOR PLANETARY ANALOG SURFACE EXPLORATION

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**Can small Uncrewed Aerial Systems (sUAS) assist astronauts on the Moon and Mars?**

The advantages of sUAS applications for land surveying and Earth science have been clearly demonstrated, and planetary science and operations would surely benefit from this technology capability for space exploration. A multirotor sUAS will be tested in the martian atmosphere and eventually on Titan. Lunar sUAS would need to use gas thrusters (Thangavelautham et al. 2017).

**What are the possible science and exploration activities performed on Earth using sUAS that can benefit astronauts?**

- Topographic surveying using photogrammetry or LiDAR
- Close inspection of the "outdoors" to increase the efficiency of:
  - o sample acquisition planning
  - o infrastructure and equipment assessment and repair
- Extended reconnaissance, scouting and navigation planning
- Sample retrieval
- Equipment and asset delivery
- Spectral and geophysical remote sensing

**What are some of the requirements for a UAS operation to be successful?**

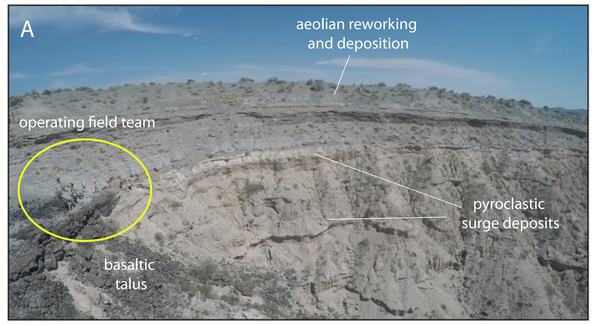
A low altitude UAS operation needs to be simple for a user in a remote location, isolated habitat or spacesuit. Areas of development for sUAS in planetary missions will benefit from:

- Well-defined Con Ops
- Easy to use sUAS control technology
- Familiar human-robotic interfaces with fail-safes
- Autonomous capabilities in GPS-denied environments
- Integration with ground-based assets, such as astronauts and robotics, landers, rovers, orbital instruments and other sUAS

The system needs flexibility to execute different mission goals. Lastly, a UAS cannot have a single point of failure, but has both computer and human "in the loop" for safe operation.

**How is sUAS technology used and integrated in RISE2 field activities?**

- technology assessment
- remote sensing payloads
- Operations scenarios
- Conduct geological investigations using sUAS and evaluate their contribution to scientific advancement
- Possible real-time observation during analog missions
- Documentation of field activities and their efficient dissemination methods
- Integration and fusion of sUAS and ground-based instrument data



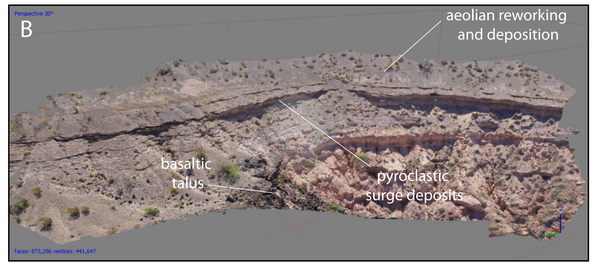




Figure 2. A) Jose Hurtado from the University of Texas El Paso collected oblique image data of the inner walls of Kilbourne Hole. These images serve several functions, such as scouting, reconnaissance and field team observation. These perspective views can be transmitted in real time, or they can be used in combination with georeferencing (such as from GPS or other surveyed reference markers) to create orthoimages, DTMs and other mapping products. B) 3D rendering of data products showing stratigraphy of Kilbourne Hole using oblique image data collected by a DJI Mavic 2 Pro.

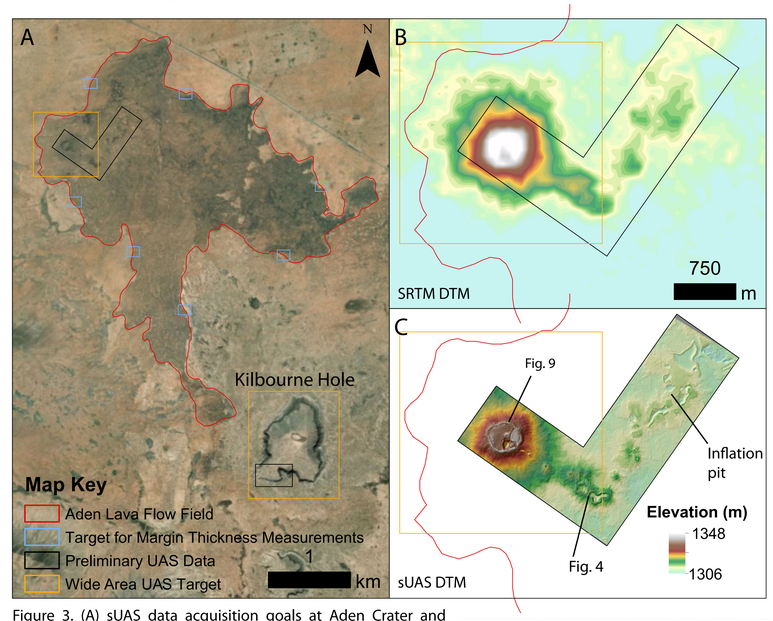



Figure 3. (A) sUAS data acquisition goals at Aden Crater and Kilbourne Hole. Together, they represent a full regional context for the Portrillo Volcanic Field. (B) Inset shows Aden's volcanic edifice; background DTM data is SRTM (30m/pixel). (C) The same inset area shows improvement in spatial resolution of the DTM gained by sUAS data acquisition (10 cm/pixel). Aden's lava flows north of Kilbourne Hole juxtapose pyroclastic deposits to the south, and the data reveal unique lava flow morphologies: inflation pits, plateaus and shatter rings. Basaltic lava is a significant stratigraphic component in several areas around and within Kilbourne Hole. These data were also utilized to support a new NASA SSW proposal. Numbered areas indicate figures below and right.

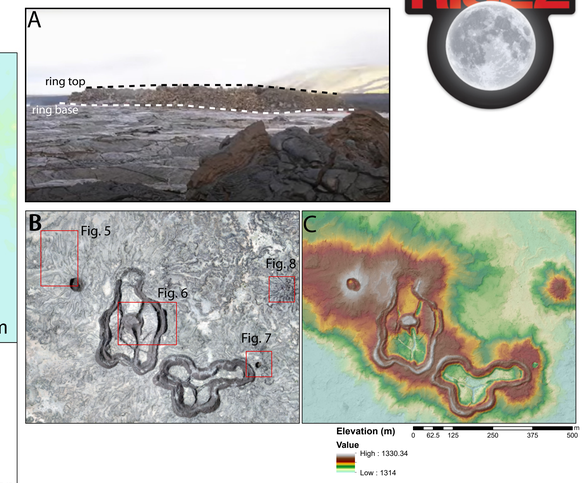



Figure 4. A) A shatter ring, a geomorphic feature observed in Hawaiian eruptions, is a circular rampart of broken rock formed over a lava tube when lava pressure in the tube exceeds the strength of the overlying rock, breaking the roof of the lava tube around the edges as lava extrudes and retracts. Video frame excerpt: U.S. Geological Survey Department of the Interior/USGS, 2006. B) orthoimage and C) DTM of a shatter ring and volcanic pits identified at the Aden volcanic field from sUAS. Detail of insets shown below.

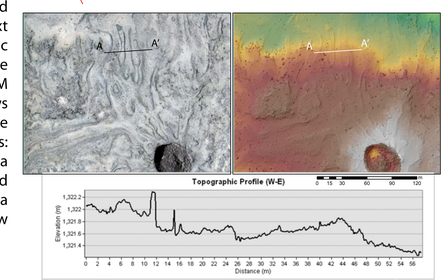



Figure 5. Very shallow levees of lava channels radiate from a collapsed lava tube skylight (~50 m wide). Orthoimage (left) and DTM (right). The topographic profile here shows only ~ 1 meter of relief.

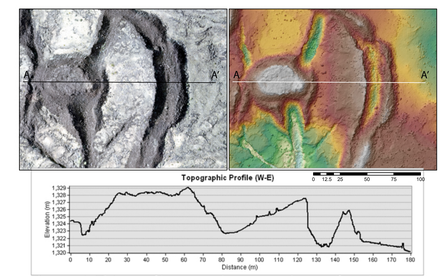



Figure 6. This profile extends across the roof and eastern flank of the shatter ring. Orthoimage (left) and DTM (right). The topographic profile here shows 9 meter of relief.

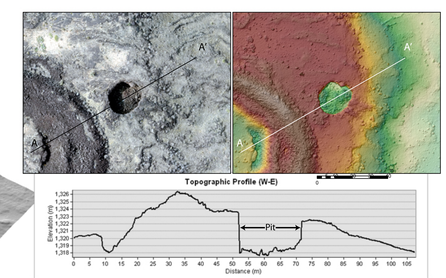



Figure 7. A large 20 m wide skylight from a collapsed lava tube can be found east of the shatter ring. It's large enough for the sUAS to see the floor in sunlight and is 5 meters deep. Orthoimage (left) and DTM (right). The topographic profile here shows only 8 meter of relief.

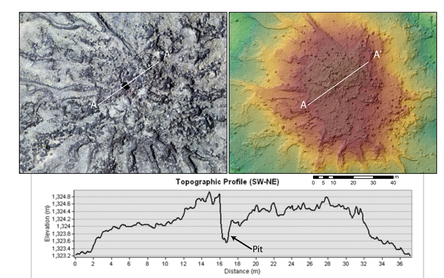



Figure 8. This profile extends across the an open 2 m wide skylight. The floor cannot be seen by the sUAS because it is in shadow, although the DTM gives a minimum depth of ~1 m. Orthoimage (left) and DTM (right). The topographic profile here shows only ~1.7 meter of relief.

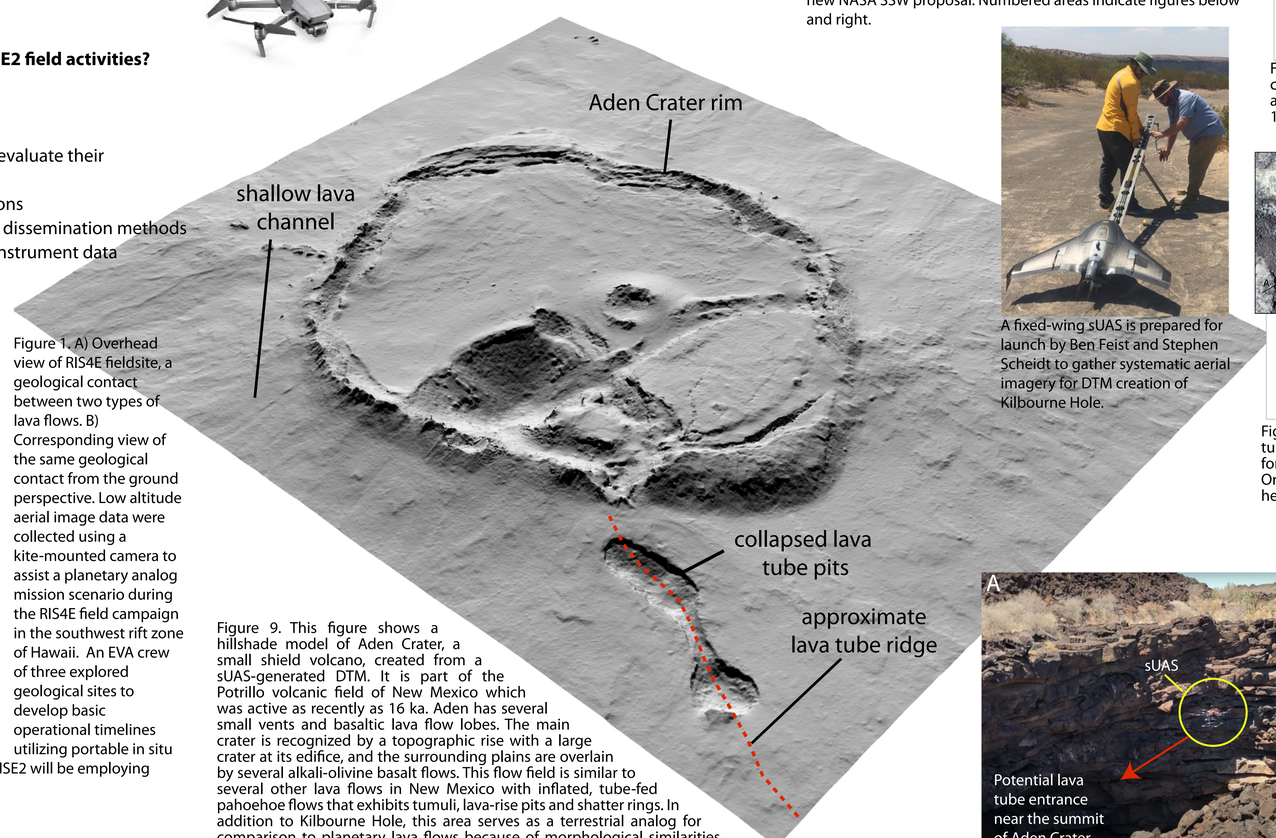



Figure 9. This figure shows a hillshade model of Aden Crater, a small shield volcano, created from a sUAS-generated DTM. It is part of the Potrillo volcanic field of New Mexico which was active as recently as 16 ka. Aden has several small vents and basaltic lava flow lobes. The main crater is recognized by a topographic rise with a large crater at its edifice, and the surrounding plains are overlain by several alkali-olivine basalt flows. This flow field is similar to several other lava flows in New Mexico with inflated, tube-fed pahoehoe flows that exhibits tumuli, lava-rise pits and shatter rings. In addition to Kilbourne Hole, this area serves as a terrestrial analog for comparison to planetary lava flows because of morphological similarities. The lava flow field covers a 150 km$^2$ area extending roughly south of the main edifice. Surrounding piedmont and basin floor deposits consist of silt, loam and clay sediments that are heavily modified by aeolian processes, resulting in a thin mantling deposit over some of the Aden basalts. The area is sparsely vegetated. Several features are pointed out here on the hillshade model, in addition to the highly fractured summit.



A fixed-wing sUAS is prepared for launch by Ben Feist and Stephen Scheidt to gather systematic aerial imagery for DTM creation of Kilbourne Hole.

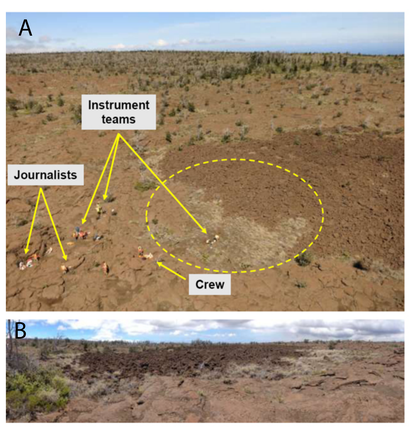
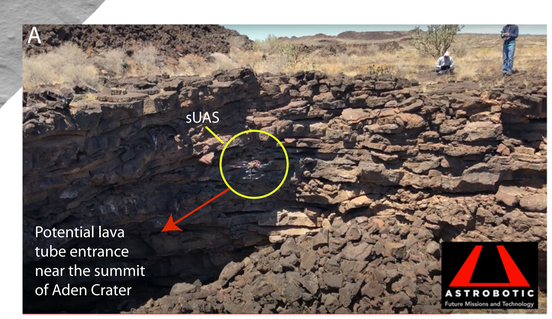



Figure 1. A) Overhead view of RIS4E fieldsite, a geological contact between two types of lava flows. B) Corresponding view of the same geological contact from the ground perspective. Low altitude aerial image data were collected using a kite-mounted camera to assist a planetary analog mission scenario during the RIS4E field campaign in the southwest rift zone of Hawaii. An EVA crew of three explored geological sites to develop basic operational timelines utilizing portable in situ field instruments to characterize chemistry and mineralogy. RISE2 will be employing sUAS to gather image and science data.



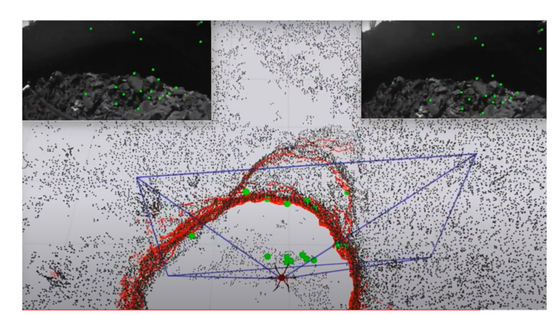



Figure 10. Astrobotic Technology has partnered with the RISE2 SSERVI node, led by Stony Brook University, to demonstrate robotic technologies at Kilbourne Hole and the Aden volcanic field to prepare for Lunar surface exploration. They have developed AstroNav, a custom navigation software product, to provide small free-flying spacecraft the ability to autonomously explore GPS-denied environments, such as lunar lava tubes. This activity dovetails with SSERVI researchers and others that are testing the capabilities of compact and deployable instruments needed to collect and characterize geologic samples in the field. A) Astrobotic tests a sUAS and its ability to navigate using AstroNav. B) A display of the sUAS method of navigation in the mouth of a lava tube entrance through visual simultaneous localization and mapping.

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