EVALUATING THE USE OF UNOCCUPIED AIRCRAFT SYSTEMS (UAS) FOR PLANETARY SURFACE EXPLORATION IN ANALOG TERRAIN.

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Introduction: The surface of Mars is highly variable and has been shaped by a range of geologic processes. Current exploration of the surface is limited to surface types accessible to a lander or rover. For rovers, drive distances are also controlled by limitations on ground-based navigation cameras. The Rover–Aerial Vehicle Exploration Network (RAVEN) project aims to develop science operations and exploration strategies for future landed missions to volcanic terrains on Mars, using integrated Unoccupied Aircraft Systems (UAS) and rover technology. The RAVEN framework is being tested at Holuhraun, the site of the largest effusive eruption in Iceland in the past 230 years. Holuhraun is an ideal analog for geologically young volcanic regions on Mars [1].

Mission overview: RAVEN was formulated to test a rover and UAS mission architecture in a Mars analog environment. The key goals of RAVEN are: (1) to develop science operations to fully utilize UAS capability; and (2) to advance UAS technology and demonstrate its uses.

The science operations objectives test three mission architectures (each for at least 10 sols): Rover-only (completed in 2022) [2], UAS-only (completed in 2022), and combined rover and UAS (planned for 2023). This abstract will focus on the UAS-only mission architecture. Mission operations were split into two groups: (1) a science team blind to the field site which created the plan for each sol; and (2) an implementation team at the field site which executed the plan and returned the requested datasets to the science team.

The science operations are guided by a science traceability matrix (STM) developed to meet the science goals of NASA's Mars Exploration Program Analysis Group (MEPAG). Observables that drove science planning and operations include: lava flow morphology, lava–water interactions, hydrothermal alteration features, sediments/rocks with high biosignature preservation potential, geochemistry and mineralogy of active sand, and morphology of aeolian bedforms.

Drone technology and science instrumentation: We designed the capabilities of our simulated Mars UAS based on possible next generation Mars UAS specifications [3]. We restricted the UAS to a flight time of ~6 minutes, a payload capacity of 5 kg, and a range of 1 km. The characteristics of this proposed system match well with the Mars Science Helicopter [4, 5].

Our UAS mission was implemented using multiple drones to accommodate the full suite of science instruments. A DJI Matrice 300 fitted with the Zenmuse P1 camera acquired images in the air and on the ground. The acquired images were degraded to smaller file sizes before downlink. Two DJI Matrice 600s were used for sampling. One of these drones was equipped with a claw/scoop sampler with 4 (interchangeable) designs to test the best instrument configurations for future Mars missions (**Fig. 1**). This is a prototype developed by Honeybee Robotics, called RAVEN Claw. The other DJI Matrice 600 was equipped with a coring drill. In practice, the drill was not yet capable of coring basalt (it was too hard), so a hand coring drill was used instead.

There were two additional hand-held payloads to acquire information about the composition of the terrain. The team initially planned to use a hyperspectral imager (VIS–IR/400–2500 nm) for the first payload. However, due to practical field conditions (variable illumination) and technical challenges (image cubes too large to work within the mission simulation bandwidth), we opted instead to use a point spectrometer. This worked successfully to obtain VIS–IR spectra at landing locations. The remaining payload was a Laser-Induced Breakdown Spectrometer (LIBS) (1064 nm). This is analogous to the SuperCam instrument onboard the Perseverance rover, which is designed to determine the mineralogy of the study site.

The UAS flight plans for each sol were created by the science team and executed by the implementation team at the field site using the Universal Ground Control Station (UgCS) software. All flight plans needed to balance power (333 Wh), data volume (140 MB), and sequencing constraints.

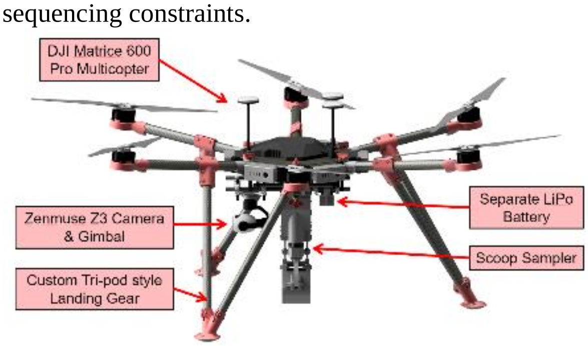

Figure 1: DJI Matrice 600 UAS with custom landing gear and scoop (with swappable jaws).

Science operations: The UAS science operations team consisted of 4 members: Tactical Science Lead, Science Planner, UAS Planner, and Documentarian. We developed and followed a Sol Planning Meeting Protocol (led by the Tactical Science Lead) similar to the Rover Science Operations Team [2]. The procedure consists of the following segments: (1) Downlink Assessment: summary of previous sol and review of data provided by the implementation team; (2) Planning Kickoff: summary of mission to date and review of current UAS location and proximity of science targets; (3) Science Target and Activity Discussion: main planning segment which included discussion of science targets and activities, and flight plans for the next sol; (4) Plan Building: UAS resource calculations to create a final plan and write up the Plan Translation Form (to send to the implementation team). This task also serves as the final process for eliminating science targets and activities that do not fit the technical plan; (5) Look Ahead Planning: brainstorming science targets and activities for N + 1 and N + n sol (where N represents the current sol and n is any positive integer); and (6) Post-Planning Activities: generation of daily sol reports by all team members and plan translation to implementation team.

Mission summary: The UAS team completed a 12-sol mission, of which 9 sols included flights and 3 sols were used for sampling. The UAS flew a total of 10 km (**Fig. 2**), surveyed an area of 70,000 m^2, acquired 86 images, and collected 3 samples, 10 LIBS measurements, and 10 VIS–IR point spectrometer measurements. On flight sols, the average flight distance was 1395 m and the average flight time was 224 s.

Operational results: 1. The UAS conducted high-resolution photogrammetric surveys to scout for landing sites and science targets. The value of these surveys to N + 1 mission planning proved to not be worth their resource allocation. They did not provide additional detail or contrast to identify further targets at selected sites. However, they have been useful for post-mission analysis (e.g., detailed studies of morphology and aeolian bedform mapping). 2. Oblique airborne images had the best resource allocation to usefulness ratio of any data collected. These images were the primary data used for mission planning because they provided a sense of depth and scale of the surface features of interest. Given these lessons learned (early in the mission simulation), we adapted our airborne imaging strategy to include more flight time and airborne images, and fewer mapping surveys. 3. Imaging future landing sites (even from a distance) in a sol prior to going to that site was important for confirming landing hazard analysis based on pre-mission orbital data. This allowed for more precise landings in diverse areas, which otherwise would have been limited to landing on large, flat sandy patches. 4. The UAS was limited to contact science of material on which it can land. Surface types that were too rubbly to land on (i.e., any lava flow surface that was not smooth crust) were not analyzed in detail by the UAS.

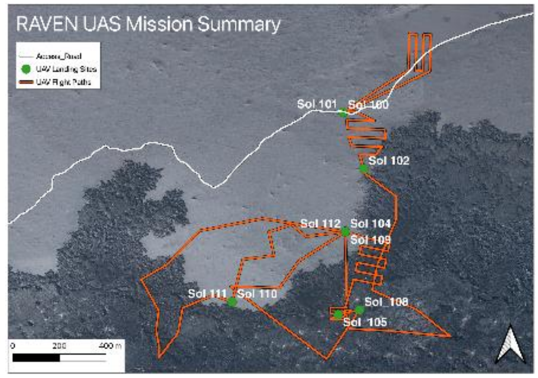

Figure 2: Map showing the UAS landing sites (in green) and flight paths (in orange) with the sol number annotated, overlain the 20 cm/pixel UltraCam-Xp basemap.

Future work: We are developing a combined rover and UAS mission architecture for the 2023 field campaign. We will test if the science improvements justify the complexities of a combined architecture. The lessons learned from RAVEN science operations will have applications not only for future Mars exploration, but also for NASA's Dragonfly Mission to Titan [6]. Dragonfly is a rotorcraft lander mission that will explore the surface of Titan and investigate the prebiotic chemistry there. Much like RAVEN, Dragonfly will have in-flight and landed operations. How in-flight and landed data is used for science target selection during the RAVEN mission will be of particular interest to both Dragonfly and future Mars UAS.

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