ISRU Explorations with WINE (the World is Not Enough). Z. Fitzgerald[1], K. Zacny[1], P. Metzger[2], P. Morrison[1], V. Vendiola[1], N. Traeden[1], S. Lam[1], Jim Mantovani[3], Rob Mueller[3]. [1]Honeybee Robotics, 398 W. Washington Blvd Suite 200, Pasadena, CA 91103, KAZacny@honeybeerobotics.com. [2]Florida Space Institute, University of Central Florida. [3]NASA KSC.

Introduction: Honeybee Robotics has developed the **WINE** system (**the World is Not Enough**) to demonstrate the possibility of using **In-Situ Resource Utilization** (**ISRU**) technologies in CubeSat spacecraft. An ISRU capability would provide the opportunity to extend mission operations by using captured water as fuel for further exploration. A demonstration of the WINE concept was performed at Honeybee Robotics to explore the viability of this mission concept. During this testing, the WINE captured water from a Ceres regolith simulant and used the water to propel itself off the surface (Figure 1).

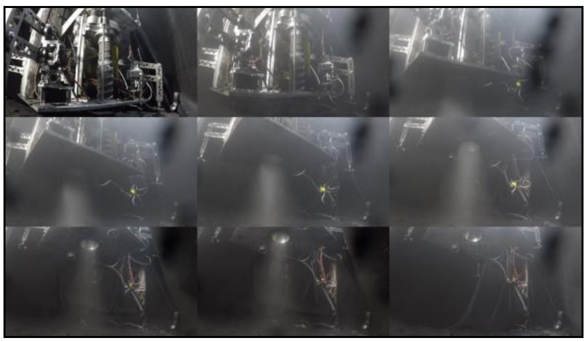

Figure 1. WINE thrusts off the simulant surface using collected water.

Background: The paradigm of exploration is changing. Smaller, smarter, and more efficient systems are being developed that can do as well as larger, more expensive, and heavier systems from the past. The science fiction becomes reality fueled by advances in computing, materials, and nanotechnology. These new technologies found their way into CubeSats – a booming industry in the 21st century. CubeSats are no longer restricted to aerospace companies. Universities and even high schools can and do develop them. To take advantage of CubeSat capabilities NASA has a CubeSat Launch Initiative (CSLI) which offers opportunities for small satellite payloads to fly on rockets planned for upcoming launches.

Honeybee Robotics has further pushed the evolution of CubeSat systems with the development of WINE. WINE reflects the new generation of CubeSats by taking advantage of maturing 3D printing techniques and ISRU technologies. These technologies open the possibility of missions with an indefinite timeline and greatly increases the data yield of a CubeSat.

Methodology: The WINE spacecraft includes many of the systems critical to the development of an actual ISRU CubeSat system. These systems include: heated coring drills, a water collection system, propulsion components, and locomotion capability. Also included in this demo-craft is all valving and sensing components necessary for the system demonstration. Electrical and power systems were tethered to the WINE through vacuum chamber pass-throughs.

Mining Devices. The WINE uses two ~33mm dia. x 200mm water extraction augers. They consist of a heated copper sleeve enveloped by a machined Garolite auger, which acts as an insulator to the surrounding regolith. The copper sleeve is supplied with up to 60W through a slip ring at the top of the drill. A stationary tube, passed through a trombone-seal in the center of the drill provides a flow path for volatiles to reach the cold trap.

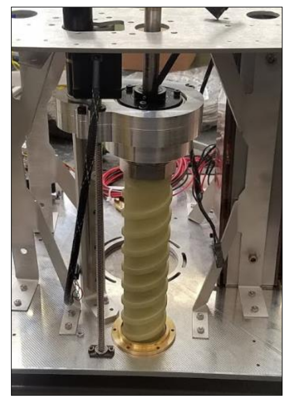

Figure 2. Water extraction drill.

Volatile Capture. The WINE is equipped with a large water collection system to drive volatiles from the coring drills to a propellant tank. The water capture system consists of two cold traps (one for each drill) separated by a large heat sink filled with phase change material. Thermo-electric coolers (Peltiers) sit between these components to cool and heat the condensing chambers, rejecting their heat to the phase change material. Water vapor from the drills freezes on heat-sink surfaces in the condensing chambers. After collection, solenoid valves redirect plumbing. The Peltiers reverse polarity, re-vaporize the captured water, and push it into the propulsion tank.

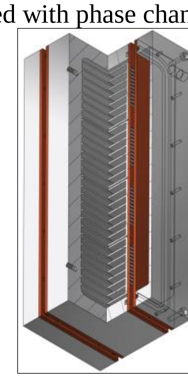

Figure 3. Water collection system CAD.

Propulsion. The propulsion system consists of a small static tank, steam-pressure valve, and nozzle. Steam is generated by a resistive heater ribbon which is wrapped around the tank. A steam-rated solenoid valve controls the flow. The propulsion was characterized prior to integration with a custom thrust stand. Thrust values as high as 10 lbf were captured when thrusting into vacuum.

Figure 4. Propulsion system, unintegrated.

Locomotion. The WINE is equipped with four legs to allow for movement across the surface and to reorient the spacecraft for efficient drilling, setting of an initial launch azimuth, and absorbing the impact of landing.

Demonstration Setup: The WINE demonstration was performed in Honeybee Robotics' Mars-analog vacuum chamber. This chamber is over three meters tall and can withstand the particulate and water generated by these demonstrations. Electrical feed-throughs built into the chamber provided a simple method of interfacing with the spacecraft.

Figure 5. Wine within the vacuum chamber.

Simulant. The WINE demonstration used a Ceres simulant provided by Phil Metzger's team at UCF. This simulant is a mixture of epsomite and magnetite which is believed to replicate the expected low albedo carbonaceous chondrite surface of Ceres.

Mass Offload. The WINE spacecraft was mass offloaded significantly to simulate the approximate 1/36th Earth gravity of Ceres. The mass offload was accomplished through a pulley mass rigging. This is a simple setup which effectively reduces the mass of the spacecraft but does significantly increase the inertia of the system.

Demonstration Overview: Each component of the mission operation was performed separately for time and complexity constraints. These operations included:

1. Landing - The spacecraft touches down on the surface, performing a landing burn and relying on the compliance of the legs to cushion its impact.
2. Orientation and Drilling - After using the legs to orient the craft normal to the surface, WINE uses a heated coring drill to penetrate the surface and release frozen or bound water.
3. Water Extraction - The freed water flows up through the drill and into a cold trap, where it deposits as ice.
4. Reorientation - Using the legs, WINE continues to move around the surface, drilling more holes and collecting more ice.
5. Tank Filling - When an appropriate quantity of ice has been collected, the water is pushed from the cold trap into the propellant tank.
6. Launch Orientation - While the propellant is being heated, the legs of the spacecraft are used to set an initial azimuth and elevation for launch.
7. Launch - Once the water in the tank is at a sufficiently high temperature and pressure, the thrust valve is opened and release of steam into vacuum propels the spacecraft to its next site of operations.

Results: The WINE completed all of its project objectives during the demonstration. A short video was produced to provide a digestible overview of the demonstration. (https://www.youtube.com/watch?v=-BhnL1GqhxM&).

In the weeks following the demonstration, WINE received much public attention through various news and internet outlets.

Future Developments: Future development of the WINE would see additional efforts devoted to the packaging of CubeSat components into the spacecraft envelope. Power generation, electrical systems, communication, GN&C, thermal, and sensing equipment would be integrated. In addition, current subsystems would be matured to provide more robust, reliable systems capable of many operation cycles. These developments would serve to further validate this mission concept.

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References: [1] Zacny K., P. Metzger, K. Luczek, J. Mantovani, R. Mueller, The World is Not Enough (WINE): Harvesting Local Resources for Eternal Exploration of Space, AIAA Space. [2] Metzger P., K. Zacny, K. Luczek, M. Hedlund., Analysis of Thermal/Water Propulsion for CubeSats that Refuel in Space, ASCE Earth and Space Conference, April 11-15, 2016, Orlando, FL.