Initial Prototype Work on Artemis "Gandalf's Staff" - Science Suite on a Lunar EVA Walking Stick. M. E. Evans[1], M. Leonard[2], J.A. Morgan[3], M.R. Zanetti[4], L. D. Graham[1], J. Bacon[1], B. F. Feist[5], [1]NASA Johnson Space Center (JSC) Astromaterials Research and Exploration Science (ARES), michael.e.evans@nasa.gov, [2]Texas Space Technology Applications and Research (T STAR), [3]Texas A&M University (TAMU), [4]NASA Marshall Space Flight Center (MSFC), [5]Jacobs Technology, Inc. JSC

Introduction: The Apollo program identified a need for a hand-held Extra-Vehicular Activity (EVA) tool to carry a camera, samples, and gnomon with camera calibration bars [1, 2]. Although not implemented, the concept has been proposed using modern technology for the Artemis program. The proposed "Gandalf's Staff" provides many functions [3]. As a walking aid, the staff includes 1) field site and surface detailed illumination, 2) 360° high resolution camera(s), 3) LiDAR and Inertial Measurement Unit (IMU) to create a robust three-dimensional (3D) map of the traverse. It provides a communications and navigation relay to other crewed assets. As a stand-alone device, the staff could be attached to solar arrays as a power generation station and long-duration science platform, or as a navigation buoy. Science instruments are integrated into the legs for geophysical and geochemistry research.

Gandalf's Staff Design: The concept was funded with a $10k JSC Innovative Charge Account (ICA) grant in the summer of 2020 to develop a physical unit (no electronics) that mimics the expected height, weight, and center-of-gravity (c.g.) of a possible field unit. This was reported as a NASA New Technology Report (NTR) MSC-26816. Field tests demonstrated the utility of the device as an EVA tool assisting walking, leaning, bending, kneeling, and standing (Fig. 1).

Next, $100k funding was awarded to develop "proof-of-concept" components for the key electronic assets with a Center Information Fund (CIF) Independent Research and Development (IRAD) award in the fall of 2020 (MSC-26980). As a general design, the navigation/communications array sits atop the staff. Below them is a 360° high-resolution camera (possibly with video), LiDAR, and IMU. LED light boards are attached to the staff below the LiDAR, and focus illumination either outwards or downwards when the staff is upright. A set of upward focused lights can be used in "Wand" mode to illuminate sample details on the surface. All lights will be shielded to prevent damage to crew eyes. Heat rejection is an anticipated issue that will be studied with design options.

The planned total staff weight is 6 kg in the lunar gravity The staff is a 4 cm (~1.5") diameter cylinder standing 2m tall. The staff diameter fits easily in a crew gloved hand, and the height provides elevation necessary for the antenna array and field site illumination. The staff can stand alone, and design options include either folding legs or a mobile stand that can be deployed by the crew. A grab handle is located near the staff c.g. to optimize crew walking motion. Determination of the desired c.g. will be completed with future field tests using a staff with weighed components and EVA-suited crew.

Figure 1: Testing of initial Gandalf Staff physical prototype

Inside the staff are stacked 1.2m of Lithium-Iron-Phosphate battery cells that provide a planned 24v power system to all of the electrical components. The initial prototype power system supports a one-hour traverse. Eventually the staff will be recharged from a hab/rover station, or backup battery-packs (1.2m long) will be available for rapid replacement in the field.

All active data is recorded to terabit memory on the staff, and the operations plan is to download data after each traverse is complete. Live streaming might be possible when sufficient lunar surface bandwidth is available. A computer console (attached to the staff near the grab handle) is intended to provide a minimal set of buttons and display features for crew interaction. Eventually the staff may use voice activated communications via the future xEMU suit informatics system.

"Proof-of-Concept" Development: The FY'21 IRAD grant provides funds for initial design, manufacture, and tests of several key components. The team consists of multiple organizations within NASA JSC and at other NASA centers, as well as collaborations with academic institutions and private companies contributing specific skills to the project. Student teams at Texas A&M University (TAMU), composed of seniors from the engineering college, are developing much of this proof-of-concept for Gandalf Staff. JSC ARES has previously worked with TAMU and the private company T STAR to rapidly (and inexpensively) develop scientific prototypes. In 2013, this successful arrangement created a walking stick prototype including communications relay, 360-camera and GPS system (MSC-25542). Knowledge gained from that prototype aided the creation of this Artemis "Gandalf Staff" concept.

Power/Communications/Navigation: This student team, named "HyperTech" is a partnership between NASA JSC, TAMU, and T STAR. They are designing the battery-driven power system for the staff, and also the physical buttons and computer display connection. Specifically, they are creating the battery power budget and distribution system for planned instruments (working with the other teams). Additionally, they are designing the router, antenna, and UHF radio repeater necessary to implement communications between the crew, staff, and a nearby base station or rover. They are including a Micro-Electro-Mechanical System (MEMS) Inertial Measurement Unit (IMU) for determination of the device attitude. A GPS for navigation on Earth is included as a verification system for future surface-based relative-navigation equipment (to be added in a future prototype).

Illumination and Camera: This student team, named "Aether" is also a JSC/TAMU/T STAR partnership. They are reusing the 360-camera concept from the 2013 project to provide visual light documentation of the traverse. To augment the limited lighting from xEMU helmet lights, the Gandalf Staff adds Programmable Computer Board (PCB) Light Emitting Diode (LED) bulbs attached to the core tube. Design considerations include the placement position and illumination-angle for the LED bulbs in the shadowed region of the lunar South Pole. The heat generated from the LED bulbs must be conducted and radiated away from the staff, so testing of individual hardware components is essential to complete the design. NASA JSC lighting experts are advising the team and conducting experiments with their testing equipment in specialized laboratories (unfortunately this is constrained by the current COVID-19 restrictions for access to JSC).

LiDAR: The LiDAR system on Gandalf Staff provides a unique capability to construct a virtual data field representing the entire physical environment around the crew without requiring any illumination. The choice of laser vendor dictates the field-of-view and resolution of the data field, and several commercial alternatives exist. This team is a partnership between NASA Centers (JSC, MSFC, and GSFC) and a TAMU/T STAR student team named "Lunar Optic Space Techology (LOST)". Specifically, the MSFC project provides funding and skills to purchase and demonstrate rendering from an Ouster OS-0 360-degree LiDAR [4] that operates on a 24v power source. One novel concept (which the team is exploring) is to adapt both the walking stick and a telerobotically-operated sample-return rover to accommodate the same LiDAR. They are building the Graphical User Interface (GUI) for the computer. This team is also supporting research with a graduate student studying the data collection, compression, storage, and display issues associated with the huge point-cloud generated during a walking traverse. The OS-0 provided IMU data will be compared to a precision micro-IMU (implemented by the "HyperTech" team) for resolving the complicated movements of the sensor attached to a walking stick.

Legs/Support: This team consists of NASA personnel at JSC. The Gandalf Staff is intended to function either as a walking stick to assist crew in EVA traverses, or as a stand-alone device. The staff support system must limit pinch points and possible sharp edges that could damage an EVA glove. The ICA concept included light-weight spring-metal aluminum legs that folded against the staff when being used as walking stick. Initial tests of this concept failed to provide sufficient support for the free-standing staff and requires redesign. As the ICA concept evolved, the legs grew in diameter. Eventually, the legs were the same diameter as the central staff (4 cm) to hold auxiliary battery cells. Each leg became an independent science instrument and power system. Preliminary concepts included geochemical sensors (e.g. IR spectrometer), geophysical sensors (e.g. seismometers) or sampling systems (e.g. piston cores or regolith sieves); however, these added much bulk and weight to the overall staff. The IRAD prototype is focused on holding the walking staff upright with either legs or a deployable stand; however, future prototypes for stand-alone science platforms might include larger leg structures.

References: [1] NASA (1965) *Summer Conference on Lunar Exploration and Science*. [2] NASA (1967) *Summer Study of Lunar Science and Exploration* 1] Evans ME et al. (2020) *Lunar Surface Science Conference – Instrument Concepts*, Abstract 5031, [4] Ouster (2020) https://ouster.com/products/os0-lidar-sensor/.