TYCHO – A MODERN ASTRONAUT TRAINING VEHICLE. C. J. Skiba[1], S. Booth[1], J. M. Crowell[1], A. Deran[1], N. M. Estes[1], J. Hicks[1], K. Lanjewar[1], J. R. Leland[1], P. Mahanti[1], C. E. Miconi[1], M. S. Robinson, S. Saripalli[2], and R. V. Wagner[1]. [1]School of Earth and Space Exploration, Arizona State University, jleland@ser.asu.edu, [2]Texas A&M University.

Introduction: Tycho (**Fig. 1**) is a modern training vehicle designed and built to meet the needs of 21st century human exploration of the Moon and Mars. Tycho was built by a team of staff and students at Arizona State University using primarily off-the-shelf consumer and industrial components.

Fig. 1: Tycho driving down stairs during testing after the steering upgrade.

The Need for this Technology: The Apollo era Geologic Rover (Grover, **Fig. 2**), built by the USGS in the mid-1960's [**1**], supported astronaut training for lunar EVAs and was borrowed by NASA Centers for modern training exercises. Since the USGS declared Grover a historic object, it has been retired to museum status.

Tycho is a rugged, more technically advanced successor to Grover, intended to serve as a flexible and robust training test bed. In the future, Arizona State University students and faculty will use Tycho to test exploration concepts. It could also be made available for loan to relevant institutions.

Goals and Objectives: The primary goal of the Tycho project is to build an advanced successor to the Apollo era Grover that can be used for astronaut training and lunar surface operation simulation. The design and construction of Tycho employs a three-phase strategy. Phase I features at least one on-board human operator. Phase II will see Tycho remotely operated by a human. Ultimately, phase III will add autonomous driving capability.

Requirements: Tycho is battery powered and capable of carrying two crew members across terrain with slopes and at speeds equal to, or greater than, those achievable by the historic USGS Grover. A minimal requirements set was established for Tycho:

- Attain a speed of 15km/hr on +/- 2º slopes.
- Negotiate a 15º terrain slope from rest.
- Operate continuously for two hours on +/- 2º slopes.
- Drive sideways and turn around in place

Vehicle Description: Tycho consists of a central aluminum frame to which various components are attached. Each wheel is independently driven and features a 180º range of motion.

Tycho is controlled by a single joystick with additional driving modes accessible via multiple selection buttons. Rover status information is shown to the driver on a direct-Sun-viewable monitor, console mounted between the seats.

Frame. The frame was constructed from 2" X 3" aluminum square tubing with a 1/8" wall thickness. The frame is welded and has appropriate bracing to provide adequate stiffness for the current design as well as future suspension options. After welding, the frame was shot peened to relieve stress points (and it looks cool!).

Fig. 2: Original Grover on display at the USGS Astrogeology center in Flagstaff, AZ.

Each end of the frame has welded a vertical 1/2" aluminum mounting plate that is drilled to accept the drive and steering component mounting structure and allow for replacement or upgrade of the drive system without affecting the rover electronics or electrical system. As necessary on the top of the frame, T-slotted extruded aluminum building system components (80/20, Inc.) are mounted using steel hardware. These provide attachment points for other components such as seats, batteries, electrical components, etc.

Drive and steering component structure. Bolted to each end of the aluminum frame, using grade 8 bolts and nuts, is a structure designed to hold both the steering and drive apparatus. The structure is composed of welded sections of 1" square steel tubing with appropriate 3/16" plate steel bracing.

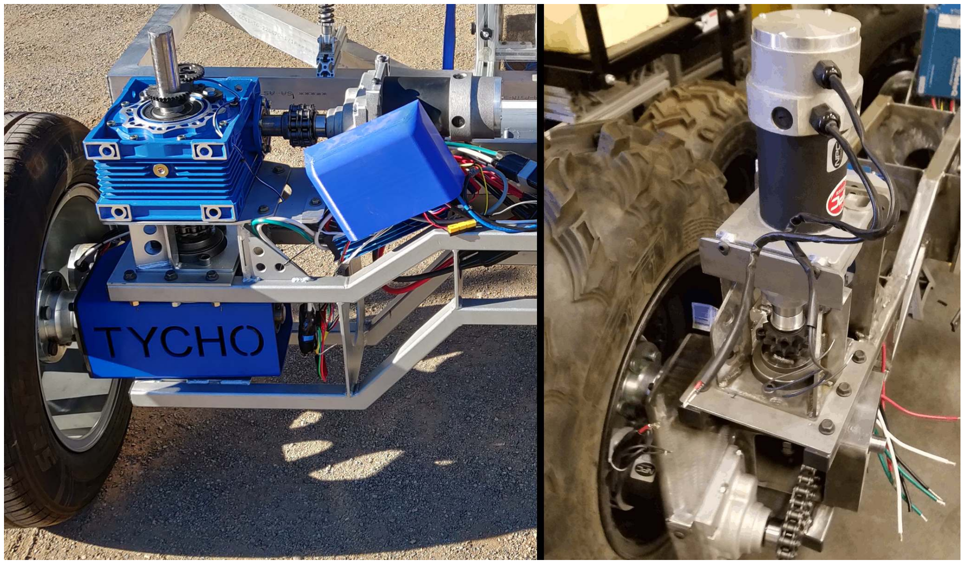

Fig. 3: Comparison of the new steering configuration (left) designed after testing with the original steering ocnfiguration (right).

Drive components. The drive components are the same for each corner of the vehicle and consist of a motor, a chain drive assembly, axle shaft, wheel flange, locking hub, chain and gear set to connect the motor to the axle shaft, and a wheel and tire. The components in each wheel assembly are readily available off the shelf, though some required modification.

Steering components. The steering components are also the same for each corner of the vehicle and consist of a motor, gear box, steering shaft, and thrust bearings. The steering motors are the same as the drive motors and are attached to the steering shaft and thrust bearing assembly that supports the drive component.

Motor controller. A single motor controller controls both the drive motor and the steering motor on each corner of the vehicle, synchronizing the drive and steering motors to accurately control wheel position.

Power: The power for the eight motors as well as computers, controllers and other electronic components is supplied by four 6-Volt deep-cycle flooded/wet lead-acid batteries connected in series providing 24 volts. Tycho, like most automobiles, uses the frame as ground (the negative side of the battery group is connected directly to the frame). Various components receive power through appropriately sized wiring/cabling some as large as 4/0 and the circuitry is protected with appropriately sized fuses and circuit breakers.

High-level control: A Raspberry Pi 3b+ running the Raspbian operating system with ROS (Robot Operating System [**2**]) and two Arduinos (**Fig.4**) controls the rover. ROS facilitates communication with the Arduinos and ultimately the various sensors, controllers, relays, etc. ROS also has the ability to monitor the status of various sensors which can then be displayed to Tycho operators.

Summer 2019 Testing: Tycho was taken to Flagstaff, AZ for the summer for testing at the Cinder Lake area (same site where the Apollo astronauts trained with Grover). Testing consisted of operating Tycho in various depths of cinders on different degrees of slope. The results of the testing showed that Tycho has sufficient battery power to achieve its two hour operating goal; however, weaknesses in the steering system were found. The two primary issues with the steering system were a lack of sufficient torque and angle adjustments were too fast for the amount of mass rotating. Fortunately, both of these problems were resolved with the same fix. A heavy duty worm gear reduction box was installed on each wheel (**Fig. 3**). This gear box has a reduction of 20:1 which results in a total of 400:1 reduction of the steering motor. The time to turn the wheel from one extreme to the other is more in keeping with what people expect from driving other consumer vehicles, and the increased steering torque has made all driving modes of Tycho more responsive and reliable in the post-upgrade tests. The Tycho team will take the rover back to the Flagstaff area, including Cinder Lake, and test all requirements.

References: [**1**] Schaber (2005), USGS Open-File Report 2005-1190 http://pubs.usgs.gov/of/2005/1190 [**2**] http://www.ros.org