NASA RASC-AL

2021 Moon to Mars Ice and Prospecting Challenge, Mid-Project Review

Sub-lunar Tap Yielding eXplorer (STYX) & Surface Telemetry Operations and Next-generation Excavation System (STONES)

Team Members

All student members are undergraduates studying mechanical engineering at the California Polytechnic State University, San Luis Obispo. This team is composed of two sub teams and was formed on 9/14/2020.

Mechanical Team

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Mechatronics Team

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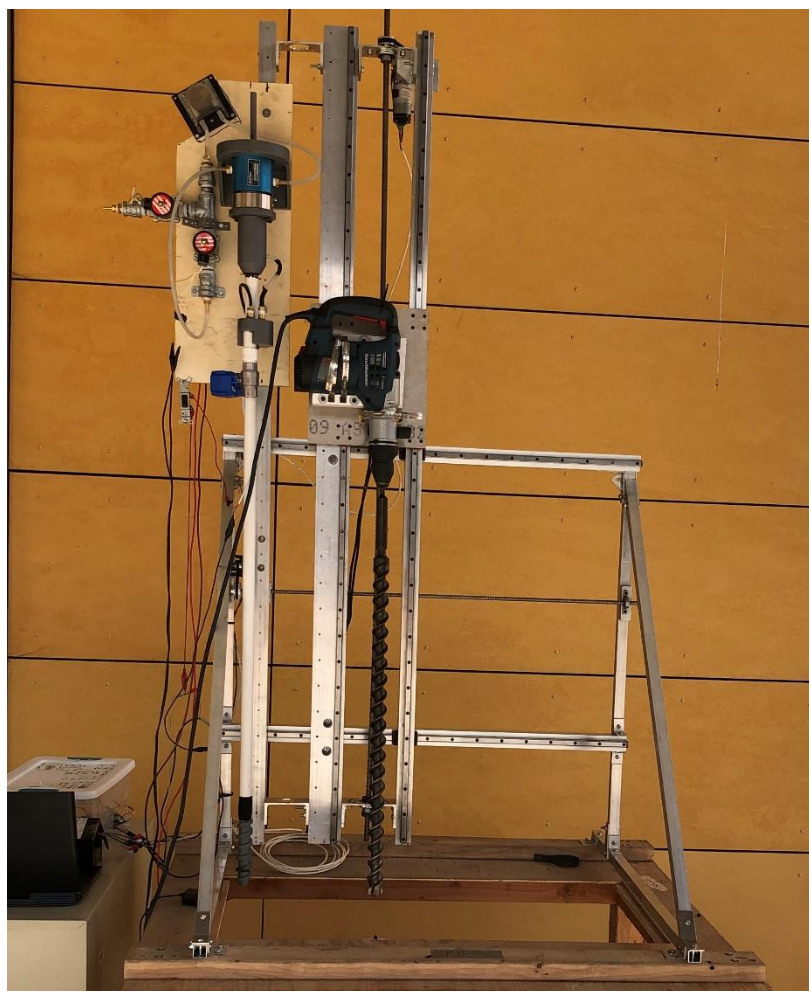

Introduction

This Mid-Project Review (MPR) report and accompanying video are intended to provide the NASA RASC-AL competition with evidence that the Cal Poly team has made significant design, build, and testing progress since the Project Plan submitted in November 2020. This report first addresses all build progress by subsystem, focusing on the requested subsystems, then addressing others. Challenges encountered by the team thus far, and major design changes since the last submittal are also included. The next section lays out all future testing plans for STYX & STONES subsystems. The final section covers the team's tactical plan for contingencies and redundancies, an updated timeline for future progress, and a safety plan for operation and use of the equipment. The STYX & STONES Team is confident that we will have a fully functional prototype in time for the competition.

Build Progress by Subsystem

Per the MPR guidelines, this section will focus on current build progress by subsystem: mounting, system control, telemetry, excavation, heated auger, and pumping and filtration. A summary of current build progress is included in Attachment 1.

A. Mounting: Frame and Lid Interface

Most of the components of the frame have been manufactured and assembled, apart from the Z-axis components supporting the heated auger tool. Completed parts include the linear rail and lead screw assemblies for both X- and Z-axis motion. The frame is mounted to a temporary plywood testbed intended to simulate the one provided at the competition using 3 ¼" lag bolts at each corner. Alternative mounting holes have been added into the design of the frame footing to account for the uncertainty in the 2"x4" positioning provided by NASA.

B. System Control and Telemetry

To verify that all components after the 9A fuse remain under the current limit, the team has simulated the system using Simulink. The wiring diagram for completed components is shown in Attachment 2. This includes the wiring the Z-axis gear motor, the X-axis stepper motor, and the operation of the load cells. In addition, motion control of the X- and Z-axis motors has been completed and tested. Preliminary code for turning on and off the motors has been developed and linked to limit switches. This allows the lead screw movement to stop automatically when the tool carriage or drilling unit meets its limit switch on the X- or Z-axis, respectively. Similarly, code for the servo motor used to reverse the direction of the drill has been successfully tested on the servo motor. Load cells interfacing with the Z-axis lead screw have been calibrated and have been integrated with the Z-axis tool plate. Real-time weight-on-bit (WOB) data was successfully recorded during drilling, and the recorded data will later be analyzed with a different program to create a digital core.

C. System Programming and Software

All software used to read motor encoders and set motor power distribution has been written in C. In addition, a finite state machine has been created to encapsulate the controls of the overall system. A task scheduler is currently being developed for task sequencing and interrupt handling to enable tasks to run autonomously with no need for user input. This is planned to be completed and tested by May 1st, 2021.

D. Excavation: Drilling Operations

As mentioned in the system control section above, movement of the drilling unit along the X- and Z-axes has been completed. The RH432VCQ Bosch rotary hammer and 1.5" diameter masonry drill bit proved successful in cutting through concrete and ice. The team recorded the complete X- and Z-axis motions to occur at rates of ~30in/min and ~18 in/min, respectively. During drilling, it was observed that the drill bit could not cut through the concrete as quickly as it was being lowered into the material. To address this, the drill was lowered into the material, the program was paused allowing time to cleanly cut through ~2in of concrete, then the program was resumed to plunge further into the concrete. A plunge rate of ~10 in/min was found using this method. Considering the team's design focuses on drilling a small number of holes and maximizing water collection from each, these times are acceptable.

E. *Water Collection: Heated Auger*

The team has successfully created and tested a 1" diameter copper prototype of the heated auger. The 250W cartridge heater was verified to produce a sufficient vertical melt rate of 0.38 in/min in the ice. Combined with the 11.5 in/min linear melt rate of a 120°F waterjet, the team expects to extract about 15 quarts of water per 5" diameter well created with the waterjet. Plans are in place to continue testing with and without debris in the hole using the final prototype. The team has purchased and drilled the waterjet nozzle, acquired the internal tubing and supporting components, and assembled the parts in a 3D-printed auger to rehearse assembly and demonstrate the desired actuating motion of the auger. The team has used the 3D-printed prototype for testing with debris removal, clogging, and waterjet capability. Final heated auger tool manufacturing is scheduled to be completed by April 20th , 2021.

F. *Water Collection: Pumping and Filtration*

Thorough fluid system analysis has accounted for all head losses and predicts that the peristaltic pump can pull a vacuum of 0.5 bar(vac) and draw water 2m up from the auger tip. The 12V BLDC peristaltic pump was successful at pulling vacuum and drawing water during a physical test using the 40-micron prefilter, 3D-printed heater probe, and the rotary union. The team has also acquired and installed the 5-micron filter which is only used when the valves route the water to the collection bucket instead of the waterjet.

Build Challenges

The STYX & STONES team has had to work with limited access to machine shop facilities due to Cal Poly's COVID-19 restrictions. Approximately 25 hours have been spent waiting for machines because only 12 students are allowed in the Mustang '60 Machine Shop at once. Shop time can only be reserved in 2-hour blocks, so the team's ~50 hours of active machining had to be strategically separated to accommodate this. Luckily, the team's project schedule was designed to leave a margin between completion of full system testing and the competition's full integration deadline, so delays in manufacturing should not significantly impact final system performance. Aside from these delays, we are pleased to say we have had very few issues so far.

Major Design Changes Since Project Plan Submission

The design is very similar to that proposed in the project plan, though some changes have been made to the heated auger tool design and drilling unit.

A. *Sealed Tank Assembly*

The sealed tank assembly has been replaced with a rotary union (RU). This change was driven by doubts about the tanks keeping a clean seal and sediment building up in the lower tank. The RU manufacturer specified limited performance if the water has debris in it, so the team will test the RU with various debris sizes. The team also designed a prefilter that rotates with the shaft to limit any debris that could enter the RU to be no larger than 40-microns.

B. *Heated Auger Actuation*

Another minor design change was the shift from using a Ryobi D43K hand drill to a 12V DC gear motor to drive the heated auger's rotation. This change was motivated by the weight requirement, as the original drill weighed ~ 5lbs while the gear motor weighs ~ 0.5lbs.

C. *Drill Spacer*

The drill assembly now includes a 2"x6" aluminum spacer to ensure alignment between the heater probe and the hole created by the rotary hammer. As shown in the video, the centerline of the drill bit lies 4.5" off the front of the mounting plate. The team ensured that this design change would only incur minimal deflection by performing finite element and vibrational analysis. During physical testing, the spacer did not experience any deflection that could generate complications during drilling.

Integration and Operation Test Plan

Planned testing for the drilling unit, frame, control system, water collection system and telemetry will occur throughout April 2021. After full system assembly, repeated full system tests will be done to simulate the competition.

A. *Mounting: Frame and Lid Interface*

The aluminum frame will be mounted on two 2"x4" wood boards to mimic competition testing, and the resulting stability of the frame and platform interface will be inspected during operation. Any visible, detrimental deflection across the top X-axis member will require modifications to the frame and lid interface. The strength and the stability of the frame will be verified with repeated testing.

B. *System Control*

To assess the motion control of the system, testing has been done to ensure that the stepper motors respond appropriately to the engaged limit switches. Testing to ensure power consumption of critical components remains within safe operating conditions, and that the system is responsive to real-time user input is underway with anticipated completion in May. The X- and Z-axis motors and servo motors run at 12VDC, while the TI MSP432 microcontroller and current, thermal, and pressure sensors run at 5VDC. On-board DC power supplies will be used to convert the 120VAC power source to the correct voltage required for each component, and voltmeters will be used to monitor component power consumption. Brushed DC motor drivers will be used for the operation of each motor with logic control from the microcontroller. All electronics will be housed in a central containment unit at the base of the platform within which a common grounding bond will be made with every component to avoid shorting.

C. *Excavation: Drilling Operations*

The STYX & STONES team has already verified the rotary hammer's ability to penetrate through concrete and ice. However, further testing to determine the optimal cutting speed and Z-axis velocity is planned to avoid using the pause/resume method described in the Build Progress section above. The 3D-printed auger geometry has also been proven sufficient at removing overburden from a 1.5" drilled hole. Further testing will be done on the heated auger upon completion of the tool in April.

D. *Water Collection: Heated Auger*

After using a CNC mill to manufacture the copper auger, the auger will be further tested to fully simulate the competition environment. Using thermocouples placed in critical locations such as the wiring interface, the team will test the temperature control system (simple on/off based on if-else logic) to develop the most efficient method for melting ice quickly.

E. *Pump/Filtration System*

The team will focus on testing waterjet/collection operations and transitions between operations while verifying reliable contingency plans for clogging or exceeding temperature limits. To avoid cavitation, the team is actively testing the fluid system with thermocouples to ensure the water temperature at the pump suction does not exceed 175°F during operation. To maintain the effective water jet melt rate, the team is conducting tests with an additional 250W heater located at the discharge tube that enters the RU in the recirculation path down to the waterjet. Testing the 5-micron filter will tell us if a finer prefilter is required to avoid unnecessary clogging of the secondary filter. Both the inlet and outlet of the pump will be fitted with pressure transducers that will allow us to determine which filter is fouled first. Calibration and testing of the pressure sensors will take place in April. Endurance testing for the final fluid system prototype will occur after the copper auger has been manufactured in April.

F. Telemetry System

The basic functionality of the load cells and successful collection of real-time WOB data has been verified. The next step is to continue real-time data collection during hammer drilling and test the ability of the telemetry program to make an accurate digital core.

Tactical Plan for Contingencies and Redundancies

For all mechanical components and electrical hardware, the STYX & STONES team's plan for contingencies consists of purchasing and acquiring backup equipment in the case of failure. The team budget will allow for the purchase of backup electronics, drilling hardware, and pump/filtration systems. A team member's personal 3D printer will also be brought along to aid in any other unforeseen issues. There are two load cells in the platform in case one fails, and most other subsystems have been designed to be serviced on-site. In addition, the system software includes a digital logic system with backup analog overrides available for telemetry, drilling, and the water extraction system. These will allow for manual operation using switches and dials integrated into the system's electrical box if the program malfunctions. Finally, an emergency stop state is included in the software for if the machine is at risk of damaging itself or encounters unexpected problems. The stop state will have a protocol to attempt to overcome the error and continue, or in the worst case, start the operation over.

Updated Timeline of Deliverables

A condensed timeline including all major project deliverables and registration dates is in Table 1 below. An extended timeline including STYX & STONES testing and building dates has been included in Attachment 3.

Table 1. Key Dates and Deadlines

Date	Description
3/15/2021	Mid-Project Review Video and Report deadline
4/2/2021	Part procurement complete
4/16/2021	Heated auger tool manufacturing and assembly complete
4/20/2021	Anticipated date for completed full integration.
4/21/2021	Begin all-up testing and endurance tests.
5/1/2021	Complete software and electrical testing
5/18/2021	Technical Paper and Integration Document submission deadline
TBD	Onsite Competition at NASA Langley Research Center

Safety Plan

As the team entered the build phase of the project, a set of hazards specific to STYX & STONES operations were compiled into a safety plan. The hazards and their relative severities were assessed using several methods including FMEA and DesignSafe risk assessment software. The resulting safety plan is shown in Table 2 below. PPE requirements include safety glasses, face masks, and hearing protection.

Table 2. Design Hazards Corrective Actions

Description of Hazard	Planned Corrective Action
Rotating Drill Bit	- Do not stand within 3 feet of drill during operation. - Stand behind protective casing during operation. - Tie loose hair and do not wear loose clothing. - Allow drill bit to cool before handling.
High Temperature Water Jet	- Have access to emergency power shutoff. - Operate only under the surface at the excavation site.
High Temperature Heater Auger	- Allow heated auger to cool before handling. - Prevent contact with neighboring components.
Electrocution	- Keep the electrical box closed during operation. - Do not make changes to circuit while it is powered. - Do not handle live wires. - Connect a common ground to all components.
System Misuse	- Only members with the appropriate training may run the system in the presence of an accompanying group member.
Pinch Points	- A protective clear acrylic case will surround the device to protect members from moving components during operation.
Hazardous Noise Levels and Air Particulate	- Earplugs, masks, and eye protection can be distributed to anyone at risk.

Attachments

[1] Build Progress Summary

[2] Electrical Wiring

[3] Spring 2021 Gantt Chart