ATHLETE: Double Auger Anchoring Mechanism

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The All-Terrain Hex-Legged Extra –Terrestrial Explorer (ATHLETE) is a six-limbed robot designed to support surface explorations on Near Earth Objects, the Moon and Mars. ATHLETE can carry large payloads on its top deck and can carry a fully equipped pressurized habitat in low gravity. The robot has wheels on each of its six articulated limbs, allowing it to actively conform to terrain while driving and to walk when driving is impractical. With the use of a tool adapter, ATHLETE limbs can be equipped with end effectors to support various mission objectives. For work on Near Earth Objects and other microgravity environments, an anchoring mechanism is needed to keep the ATHLETE from floating off the surface. My goal for this spring session at JPL was to design and build a counter rotating, double auger, anchoring mechanism. The mechanism mates to the tool adapter and is driven off the wheel motor. The double auger anchoring mechanism will be tested in a regolith simulant that will determine the uplift capacity of the anchoring mechanism.

I. Introduction

JPL is developing ATHLETE as part of the Human-Robot Systems (HRS) Project, managed by NASA Johnson Space Center. HRS is one of several projects funded by NASA to develop innovative technology to support human exploration.

II. Background

ATHLETE is a six-limbed robot designed with a wheel on the end of each limb. The wheel-on-limb design gives ATHLETE sufficient degrees-of-freedom for the limbs to be used as manipulators. The Tri-ATHLETE, the second generation of ATHLETE, is constructed as two independent three-limbed robot that can join together to become a six-limbed robot. ATHLETE has a quick-disconnect end adapter on the limb which allows a wide variety of tools to be attached. The tools will attach to the tool clamp at the end of the limb, and the rotation of the wheel will activate the tool and the actuated limbs can maneuver the tool.

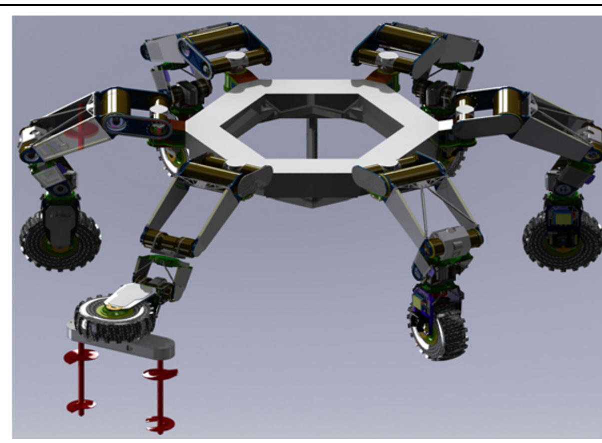

Figure 1. Second generation ATHLETE with Double Auger Anchoring Mechanism.

It is currently proposed to send ATHLETE to an asteroid to explore its surface. My goal for this internship was to design an anchoring mechanism, which will allow ATHLETE to be securely anchored to the asteroid for surface exploration.

III. Asteroids

The first portion of my project was to research about the surface properties of asteroids, in order to get a better idea of the required capabilities of the anchoring mechanism. Since little is known about asteroids, data about

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comets were used to get a better understanding about the environment of asteroids, since asteroids are similar to dead comets.

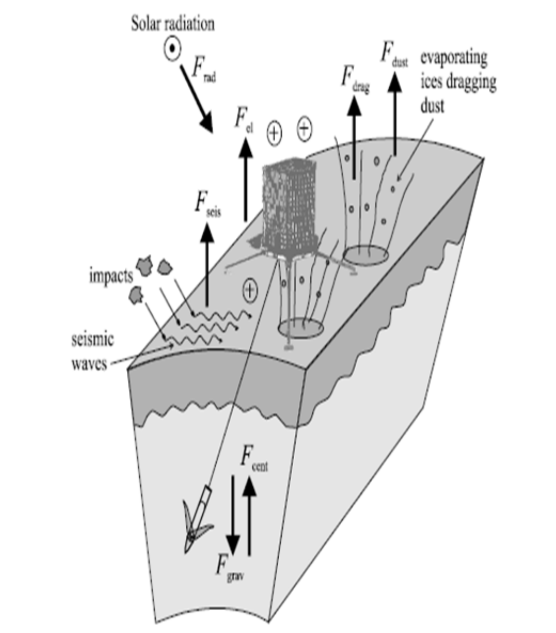

Figure 2. Forces acting on a Lander[2]

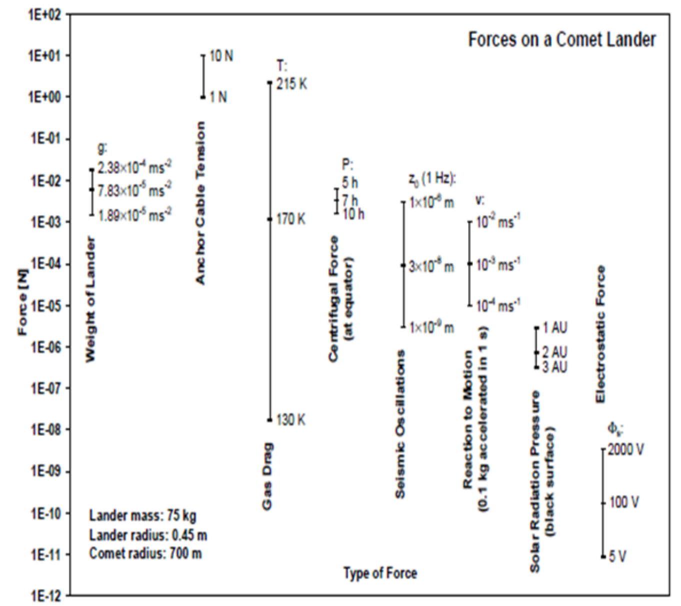

Figure 3. Magnitude of Forces. The graph shows the magnitude of the forces acting on a 75 kg Lander[2].

Figure 2 shows the free body diagram of the Lander. From the figure, we can see that most of the forces are trying to push the Lander off the surface. The only forces that are keeping the Lander on the surface are the tension in the anchor, gravity, and solar radiation, but figure 3 shows that most of the forces acting on the Lander are negligible. The force from gas drag, which occurs when gas pockets are created from eruption, causing gas to escape and push the Lander off upward, is an upward force large enough to push the Lander off the surface. From figure 3, 10N of force is needed to keep a 75kg Lander on the surface of a comet with radius of 700 m.[2] If we assume that there is a linear correlation between weight of Lander and force needed to keep the Lander onto the surface, the anchoring mechanism needs to have a uplift capacity of at least 200N to anchor the 1500 kg ATHLETE onto the surface of the asteroid.

IV. Anchoring Mechanism Design

The main portion of my project was to use Solidworks to create 3D CAD model of the anchoring mechanism. There are many ways to design an anchoring mechanism, such as inflatable anchor, harpoon or tension rope, but the ATHLETE mechanical team and I decided to use augers to anchoring ATHLETE since augers are easy to unanchor if needed to drive on the surface of the asteroid.

Requirements for the anchoring mechanism were defined to give a better idea of the features of the anchoring mechanism. The first requirement was that the mechanism must fit on the tool clamp. This was so that ATHLETE can change between tools quickly, without decreasing the maneuverability of the limbs. The second requirement was that the auger must counter rotate. Two augers must counter rotate in order to negate the torque created when one of the augers is drilling into the surface, or the robot will start spinning due to the torque created by the auger.

[2] Figure 2 and 3 from : "Measuring Physical Properties at the Surface of a Comet Nucleus" Andrew J Ball, Ph.D thesis 1997, University of Kent, Canterbury, UK. Web. Accessed 04/20/11

A. Anchoring Mechanism using Worm Gears

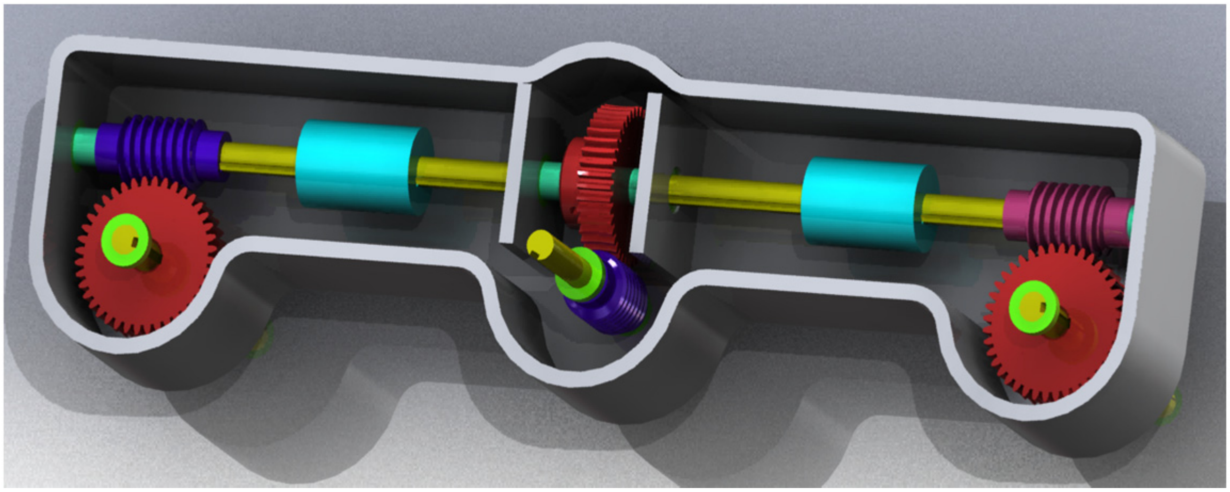

Figure 4. Anchoring Mechanism using Worm Gears

The first prototype anchoring mechanism uses worm gears. The middle worm gear is driven by the motor on the wheel, which will rotate the middle red gear and middle shaft. The purple and violet colored worm gears are left and right handed, respectively, causing the red gears at the ends to counter rotate. If the middle shaft was one single shaft, there is a chance of misalignment, which may cause the shaft to bend and break. For that reason, three shafts with shaft couplers are used to prevent damages due to misalignment of the shaft. The shaft couplers will allow the two shafts to be misaligned, and still rotate, allowing the mechanism to still function.

The reason for not using this design was due to the torque on the gears. Since worm gears have an extremely high gear ratio, the torque would be extremely high, since the torque on the output gear is equal to the gear ratio times input torque. After looking at different vendors, such as Quality Transmission Components and Stock Drive Product/Sterling Instrument, I decided to not use this design, since it is quite difficult to find worm gears that can handle a lot of torque.

B. Anchoring Mechanism using Bevel/Miter Gears

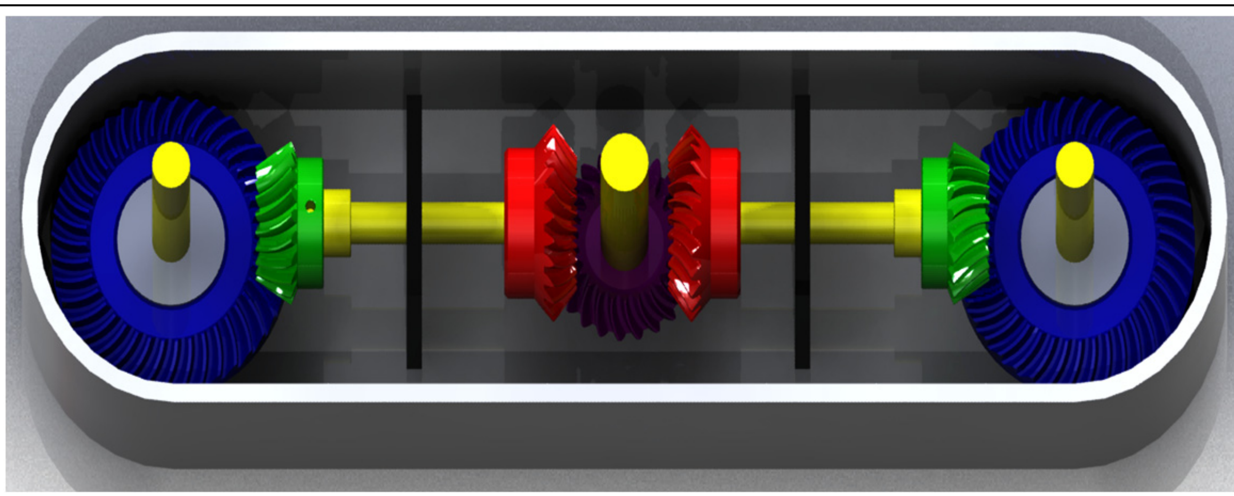

Figure 5. Anchoring Mechanism using Bevel/Miter Gears

The second prototype of the anchoring mechanism uses bevel and miter gears. The shaft will drive the purple gear, causing the two red gears to counter rotate. Each red gear will drive the green gear, which will rotate the blue gears, turning the augers that are attached to the shaft. Again, the torque on the gears is the main problem with this design. The bevel gears are better at handling the torque, compared to the worm gears, but the bevel/miter gears will have to be large and heavy in order to handle the torque outputted of the motor. It is possible to current limit the motor, which will decrease the torque, but that is a route that the ATHLETE Mechanical team would like to avoid, unless it is necessary.

C. Anchoring Mechanism using Pulleys and Spur Gears

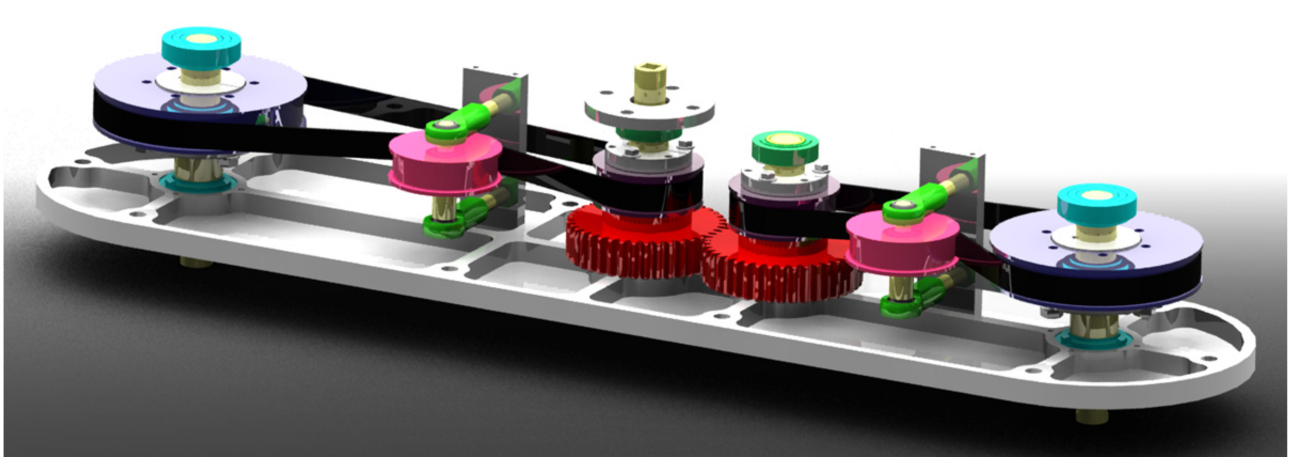

Figure 6. Anchoring Mechanism using Pulleys and Spur Gears

The final version of the anchoring mechanism uses a combination of timing pulleys and spur gears. From the figure above, the left red spur gear will be driven by the motor on the wheel and drive the right spur gear, causing the purple pulley to counter rotate, since the red spur gears are counter rotating. The belt will drive the large violet pulley, which will rotate the augers. The pink pulleys are tensioner pulleys which will cause tension to the belt in order to prevent the belt from slipping due to centrifugal force. The tensioner pulley can increase or decrease the tension on the belt by extending the shaft with rod ends attached, with the use of a wrench and turning hex nuts behind the face plate. Torque was not an issue since it is quite easy to find spur gears and belts that can handle the torque outputted by the motor of the wheel.

Since the environment on an asteroid will be dusty, dust seals are used to prevent dust particles from entering the mechanism and damaging the components. The shafts that attach to the augers and motor will have spring load seals which will prevent dust particles from entering through the openings of the shaft holes. The side panel, which is not shown in the figure above, will have grooves on top and bottom of the panel, where o-ring cord stock will be placed to prevent dust from entering through the cracks of the sides. There will also be labyrinths, within the side panel, where dust particles will need to go through many obstacles before entering the mechanism.

V. Auger Design

A critical part of the double auger anchoring mechanism is the auger themselves, since they keep the ATHLETE on the surface of the asteroid. After researching on asteroids and the forces needed to keep a Lander on the surface of the asteroid, we can assume that about 200N is necessary to keep ATHLETE on the asteroid with a radius of 700m. In a microgravity environment, the auger must rely only on the cohesion of the regolith to create an uplift capacity of at least 200 N.

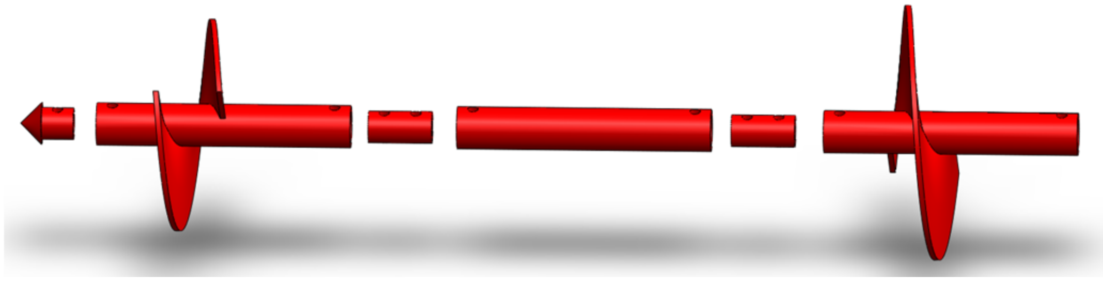

Figure 7. Design of the Auger

The auger is designed so that it can be broken down into separate parts. This design allows ATHLETE team to replace parts if necessary without rebuilding the whole auger. For example, if the bottom helical plate breaks, the team would disassemble the tip and connector and replace with a new helical plate, and then lock them into place using fasteners. The middle rod can be replaced so that the distance between the helical plates can increase or decrease. The ability to adjust the diameter of the helical plates and the length of the middle rod is important since adjusting the size also adjusts the uplift capacity of the auger.

The size of the helical plate and middle rod determines the uplift capacity of the auger since the cohesion force depends on the cylindrical surface area between the two helical plates. The uplift capacity comes from the frictional strength between the regolith captured between the helical plates and the surrounding regolith. [3] The figure on the right shows the cylinder where the cohesion force will act on.

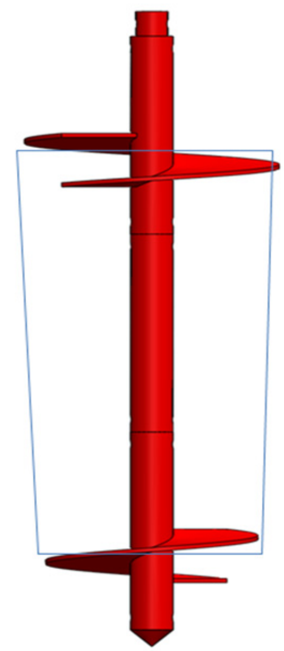

Figure 8. Outline of Cylinder on Auger

$$\text{Uplift Capacity} = \text{Surface Area} * (9 * \text{Cohesion}) \quad (1)$$

Eq. 1 tells us that the uplift capacity of the auger depends on the surface area of the cylinder and cohesion of the regolith on the asteroid. The cohesion of the regolith on an asteroid can range from ~40 Pa to 10kPa. In order to increase the uplift capacity, we need to increase the surface area of the cylinder, either by increasing the diameter of the top and bottom helical plates or increasing the length of the middle rod. Commercial helical anchors are designed so that the distance between the helical plates is 3 times the diameter of the bottom helical plate. The current design of the auger uses 10 and 12 inch helical plates with 30 inches between the helical plates, which equals to about 190 N of uplift capacity, where the cohesion of the loosely packed regolith is 70 Pa. Since there are two augers, the anchoring mechanism will have an uplift capacity of 380 N.

VI. Building and Testing

After finalizing the design of the anchoring mechanism, the next step was to start assembling and testing. The components for the pulley system, bearings and fasteners were bought from McMaster-Carr, the gears were bought from Quality Transmission Components, and the shafts, top and bottom plates were machined from raw materials. The augers could not be manufactured because the manufacturing team did not have the proper equipment to make the helical plate on the augers. They found it very difficult to weld the flat pattern of the helicoid to the shaft. The following figure below shows the partially done assembly of the double auger anchoring mechanism.

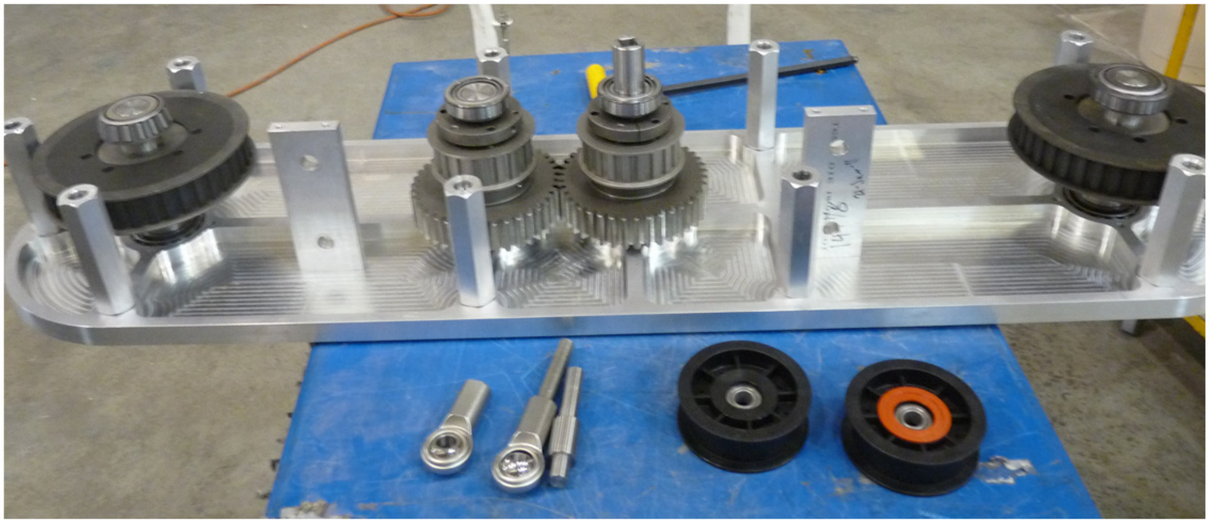

Figure 9. Components of the Mechanism

During my internship at JPL, testing the anchoring mechanism was not possible because of the lack of augers and a bin to test the mechanism in. During my internship, the anchoring mechanism will be clamped to the tool adapter on ATHLETE and will run the motor to test if the pulley system or gears break. When the augers and bin are built, the ATHLETE team can test the anchoring mechanism. There are number of ways to simulate regolith on asteroid surface. One way to simulate regolith is to use a fine powder like talc powder. A second way is to use glass beads stuck together to simulate irregular particles and water as the gluing agent.[4] For testing the uplift capacity of the augers, ATHLETE will lower the mechanism into a large bin of regolith simulant and, with the use of its sensors, determine the uplift capacity of the augers to see if the uplift capacity is sufficient to keep ATHLETE anchored on the surface of an asteroid.

VII. Conclusion

Over the course of the internship, I had an opportunity to work with ATHLETE team to design a double auger anchoring mechanism that will allow ATHLETE to securely anchor onto an asteroid. During the first portion of my internship, I researched asteroids and its environment to determine the necessary uplift capacity of the auger mechanism. The second portion of my internship was creating 3D CAD modeling, building, and testing the double auger anchoring mechanism.

While working on this project, I have furthered developed my experience in computer -aided design, finite element stress analysis and engineering drawings. I also got to experience presenting my design to ATHLETE mechanical team by doing design reviews. It was also a great experience being part of other design reviews to see how the engineers work together to design other mechanical parts. I have also got a great understanding about tolerances and how important to understand that no part will be manufactured with exact dimensions, and there needs to be space for parts to fit in. For example, I put a tolerance for bearing housing and shaft since I know that if I made the dimensions of the hole and shaft as the same as the bearing outer diameter and hole, respectively, then the parts will not fit. During my internship at JPL, I have learned a lot from great engineers, and they have made interning at JPL the best experience of my engineering career.

Acknowledgements

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Reference

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