TEAM 501: LANDING SYSTEM FOR UNCERTAIN TERRAIN VALIDATION

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ABSTRACT

Team 501 has designed a spacecraft landing system capable of landing on the hypothesized surfaces of the Psyche asteroid, an M-Type asteroid likely largely made of metal. Scientists believe that Psyche may be remnant core material from a planetesimal. Launching in 2022 and arriving in 2026, an orbiter will get a closer look at Psyche and gather information. Scientists are hopeful that this asteroid could provide useful information about the formation of the solar system and the cores of rocky planets like Earth. Potential motivation from the findings could result in future mission teams proposing to land a spacecraft on Psyche. Currently, the surface of the asteroid is unknown but thought to be uneven, with a mix of rock and metal, unlike other solar system bodies visited before. The proposed landing attachment will be able to land a spacecraft on the asteroid's different hypothesized surfaces. The selected design uses three legs to support the spacecraft. Each leg features a shock absorber to take the impact force of landing. The shock absorber is a piston-like assembly with an aluminium honeycomb-filled cylinder that deforms on impact. To stabilize the spacecraft, each leg adjusts its height independently for a levelled position. At the bottom of the leg is a pin screen foot, modelled after the popular children's toy. The pin screen toy is known for being able to form to the shape of any three-dimensional relief it is placed on. Displayed on the pin screen is the relief's shape with pins. Consisting of closely packed metal pins that slide back and forth in slots, the pin screen feet form to the uneven terrain of Psyche. The pins prevent the feet from slipping on the terrain as well. Team 501's design achieves the goal to create a landing system that can successfully land a spacecraft on Psyche's range of hypothesized surfaces.

PROJECT BACKGROUND

The purpose of this project is to design a landing system capable of safely landing on the range of hypothesized surfaces and terrains of asteroid 16 Psyche. Team 501 has designed a landing system to handle the assumed range of surfaces on Psyche and have validated the project targets.

Psyche is believed to be possible remnant core material from a planetesimal. This is what makes Psyche so unique, in addition to its terrain as well. Psyche's terrain is hypothesized to be uneven, with a mixture of metal and rock. With this different range of terrains, the landing system that Team 501 has designed will handle the potential uneven terrains, rocky/metallic terrain, and the impact energy that the spacecraft would experience.

THE LANDING SYSTEM DESIGN

The landing system designed includes a double A-arm suspension with gas shock absorbers diagonally placed in between the A-arms. The suspension is commonly seen in vehicles and ATVs. The gas shock absorber used is purely for the purpose of repeated testing of the earth prototype. For the Psyche prototype, crushable honeycomb core dampers will be used. Attached to the end of the A-arms is a knuckle clamp to hold the linear actuator, connecting it to the A-arms. The linear actuators are used for the legs of the system. They can adjust each leg height individually with 16 inches of adjustable length. Attached to the bottom of the linear actuator is a U-joint attached to a pin screen foot. The U-joint allows the foot to tilt in two directions while limiting the tilt so that the foot will not fold underneath the lander. The pin screen foot is modelled after the popular child's toy that forms to the shape of any 3D relief it is placed on, such as someone's hand. The pin screen is used to conform to the shape of rocks or any evenness that the lander may face. The pins also act as a gripping mechanism to eliminate slipping on the surface of Psyche. Fig. 1 shows the CAD model of the landing system design with the components identified.

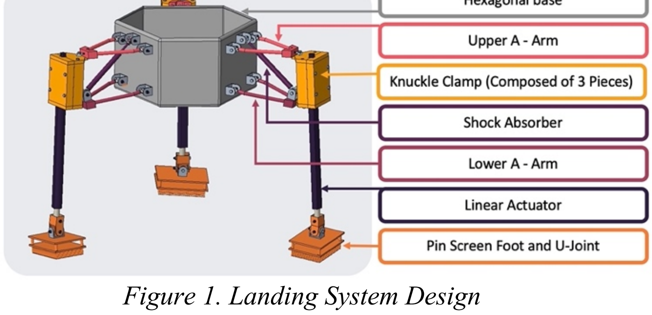

Figure 1. Landing System Design

Fig. 2 shows a detailed view of the pin screen foot. It is shown conforming to the rocks used on the test bed.

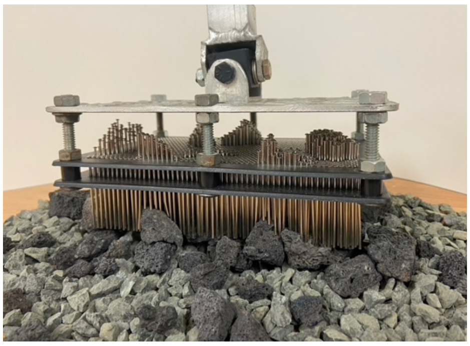

Figure 2. Pin Screen Foot Close-Up

PROJECT GOALS AND CRITICAL TARGETS

The goals of our project are reflected in our critical targets that our lander must hit. The lander needs to be stable on Psyche's surface, supporting the weight of the spacecraft and ensuring the components inside of lander are undamaged. It also needs to secure its position on the landing surface. The landing system itself is not reusable but the components inside of the lander where a payload would be needs to remain safe during impact. The list of critical targets and the numbers associated with them are shown in table 1 below. This table shows values for both the Psyche prototype and the Earth prototype that has been tested.

Table 1. Critical Targets

Target	Psyche	Earth
Mass of System	150 kg	23 kg
Weight to Support	21.6 N	225.63 N
Impact Velocity	6 m/s	0.92 m/s
Final Angle of Lander	~0° in any direction	~0° in any direction

The mass of the system for the Psyche prototype is estimated by research on previous landers to smaller planetesimals. The mass of the landing space craft for Earth testing is gathered by weighing the prototype. The weight that the landing system needs to support is determined by multiplying the respective gravity by the respective mass. The formula is shown in equation 1.

$$Weight = mass * gravity \quad (1)$$

The gravity on Psyche is 0.144 m/s^2 whereas on Earth it is 9.81 m/s^2. The impact velocity with which the lander would need to be able to withstand on Psyche is assumed from research done on past landing missions on small planetesimals. The impact velocity for the Earth prototype is calculated by a fraction comparison between the masses of the Psyche and Earth prototype. From the lander mass (m) and the impact velocity (v) the impact energy with which the dampers need to dissipate can be calculated by equation 2.

$$Impact\ Energy = \frac{1}{2}mv^2 \quad (2)$$

TESTING

A testing rig was created using structural Aluminium beams and a double pulley to lift the prototype over a test bed. The test bed was constructed to resemble Psyche's surface with rocky and uneven terrain. A counterweight of 20.77 kg was attached to the free end of the pulley to consistently control the speed in descent and height it was lifted. The testing rig can bring the prototype up 1.5 m. The test rig is shown below in fig. 3.

Figure 3. Testing Rig

With the prototype on the testing rig attached to the pulley with a counterweight on the other end, testing was done to verify a successful landing on the test bed. The legs on the prototype were extended to half of their full length, 20.32 cm. The TOF laser sensors read the distance between themselves and the surface below it and calculated the amount of time to run the linear actuators, either retracting or extending. Then a flap obstructs the view of the sensors to measure the length of the legs and verified that they were the correct lengths for a level landing position. The counterweight was released, and the prototype was allowed to descend and secure its position on the test bed. The same adjustment and impact test was repeated for a total of 5 test runs. Fig. 4 shows the landing system prototype on the test bed after testing.

Figure 4. Landing System Prototype Landed on Surface

RESULTS

From these tests, the following parameters were collected; legs extended 20.32 cm, prevented tipping, undamaged hardware, impact velocity, legs accommodated surface, and that the lander secured its position on the surface.

Table 2. Leg Starting Length Validation

Validate the Legs Extended 20.32 cm			
Test Run #	Leg 1 Length (cm)	Leg 2 Length (cm)	Leg 3 Length (cm)
1	19.65	21.55	21.40
2	19.21	20.86	21.51
3	19.45	21.16	21.87
4	19.10	21.18	21.77
5	19.33	21.40	21.99
Desired Length	20.32	20.32	20.32
% Error	4.8%	4.5%	6.8%

The first step for the mechatronics is to extend the linear actuators halfway out, 20.32 cm. The linear actuators do not have encoders, motion in the linear actuators is dictated by the amount of time power is supplied to them in a certain direction, distance travelled in given by stroke rate, so errors are expected. The highest rate of error was seen on leg 3, at 6.8%. This is shown in Table 2. The different errors are attributed to the varying stroke rate on each leg from wear and the power supplied to them.

Table 3. Validation of Tipping Prevented

Validate Tipping Prevented		
Test Run #	Pitch (deg)	Roll (deg)
1	-4	-5
2	-3	-5
3	-6	-4
4	-5	-3
5	-4	-5
Maximum Angle (deg)	-5	-5
% Failure	20%	0%

After landing on the uneven testbed, the pitch and roll were collected to check the intensity of tipping, this is shown in table 3. A successful landing was characterised by orientation angles of less than 5°. Out of 5 tests, only one test resulted in one angular offset greater than 5°.

Table 4. Condition of Damping System Components

Condition of Damping System and Components			
Test Run #	Wiring Inside	Dampers	Legs
1	2	2	2
2	2	2	2
3	2	2	2
4	2	2	2
5	2	2	2
Ranking: 2 = Good 1 = Acceptable 0 = Unacceptable			

After testing, the damage to the lander was assessed. The impact test has the risk of causing electronics to come out of place and deforming the dampers and legs. These components were visually inspected to ensure all were in proper condition. Test scripts were also run to check the mechatronic connections. After each test the prototype was in satisfactory condition to run the test again. The results of the condition after each test are shown in Table 4.

Table 5. Validation of Impact Velocity

Validate Impact Velocity			
Test Run #	Distance (m)	Time (s)	Velocity (m/s)
1	0.0701	0.067	1.05
2	0.0809	0.067	1.21
3	0.0775	0.067	1.16
4	0.0627	0.067	0.935
5	0.0732	0.067	1.09
Desired Velocity (m/s)		0.92	
% Error		18%	

The prototype was created to withstand a 0.92 m/s impact velocity for the earth prototype. Table 5 shows the impact velocities the prototype approached the surface with for each run. Every impact velocity tested was above the desired velocity 0.92 m/s. Our model successfully landed and withstood the impact energy at the goal impact velocity.

Table 6. Validation of Leg Length Extension.

Validate the Legs Accommodate Surface			
Test Run #	Leg 1 Length (cm)	Leg 2 Length (cm)	Leg 3 Length (cm)
1	7.60	16.51	33.10
2	6.35	15.26	33.08
3	5.06	13.97	34.22
4	5.12	16.55	35.48
5	6.42	16.48	35.66
Desired Length	5.08	15.24	35.56
% Error	20%	3.4%	3.5%

From our testing bed, the length of the legs is known for a levelled orientation. After landing and running checks on the leg lengths the leg lengths were measured. The measurements are shown in table 6. There was a 20% error on leg 1 which could be explained by an inconsistent stroke rate from the amount of current supplied under the load of carrying the prototype's weight.

Fig. 5 shows the pin screen foot after impact on the testing rig. The pins formed to the shape of the terrain and gripped in place, ensuring no slipping, or sliding on the surface. This verifies that the position of the lander on the asteroid was secured.

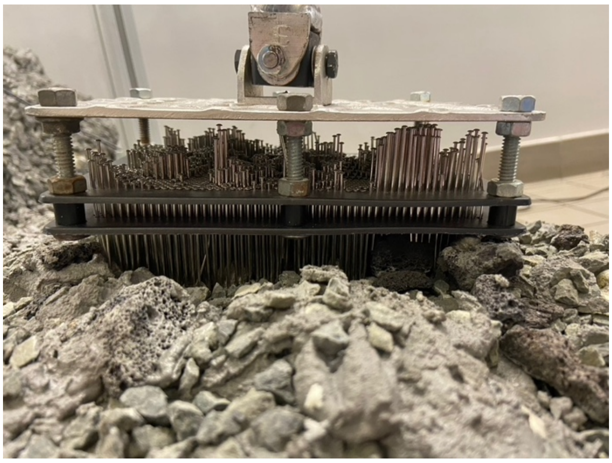

Figure 5. Validated Position on Surface is Secured by Pin Screen Foot

CONCLUSION

The uneven, unknown surface of Psyche presents a design challenge to create a landing system based on what is currently known about the asteroid. From our testing and results, a successful design was created to land on an asteroid with uneven terrain over a hypothesized range of surfaces. Our feet were able to adapt to the rocky terrain of the test bed and provide ample grip to secure the position of the lander. The legs were able to achieve a nearly levelled orientation without any feedback control, as well as successfully transfer impact energy to the suspension without breaking. The damping systems on board were able to support the base without causing any damage to the system. The model created poses solutions to securely landing on the range of hypothesized surfaces on asteroid 16 Psyche.

PROJECT DISCLAIMER

This work was created in partial fulfillment of FAMU-FSU College of Engineering Capstone Course "EML4551-4552C." The work is a result of the Psyche Student Collaborations component of NASA's Psyche Mission (https://psyche.asu.edu). "Psyche: A Journey to a Metal World" [Contract number NNM16AA09C] is part of the NASA Discovery Program mission to solar system targets. Trade names and trademarks of ASU and NASA are used in this work for identification only. Their usage does not constitute an official endorsement, either expressed or implied, by Arizona State University or National Aeronautics and Space Administration. The content is solely the responsibility of the authors and does not necessarily represent the official views of ASU or NASA.

REFERENCES

There are no works referenced in this document.