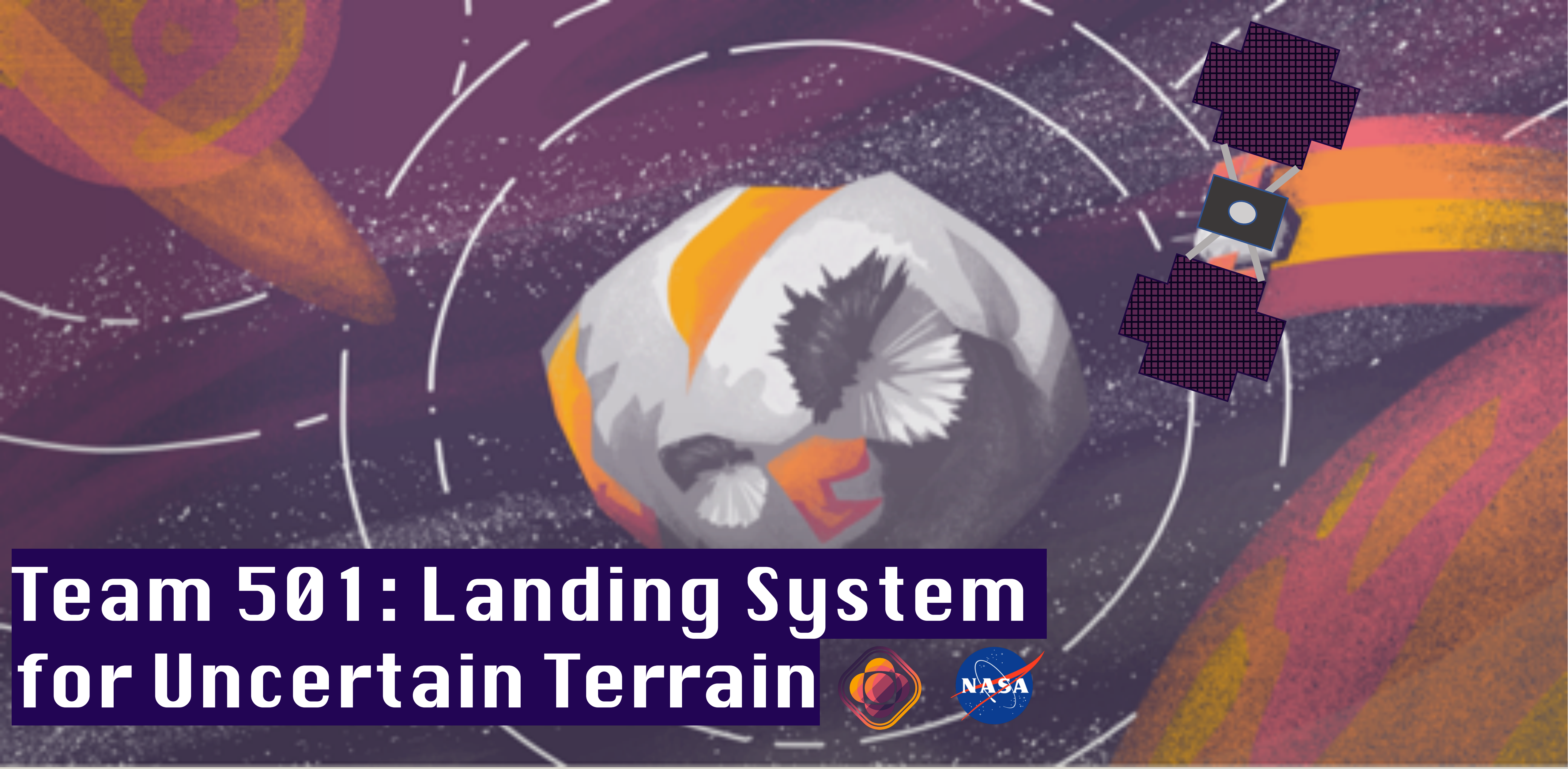


Team 501: Landing System for Uncertain Terrain

Department of Mechanical Engineering

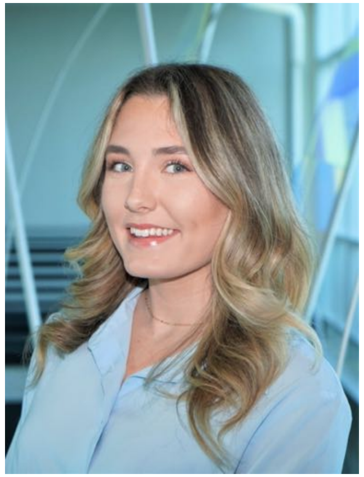
FAMU-FSU Engineering

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.

Elzbieta Krekora

Team Introductions



Saralyn Jenkins
Mechanical Systems Engineer

Elzbieta Krekora
Materials Engineer

Andrew Sak
Mechatronics Engineer

Julio Velasquez
Mechanical Engineer

Elzbieta Krekora

Sponsor and Advisor

<u>Engineering Mentor</u>
Cassie Bowman, Ed.D.
Associate Research Professor, ASU

<u>Academic Advisor</u>
Camilo Ordóñez, Ph.D.
ME Teaching Faculty

Elzbieta Krekora

Objective

The objective of this project is to design a landing system capable of safely landing on the range of hypothesized surfaces and terrains of 16 Psyche.

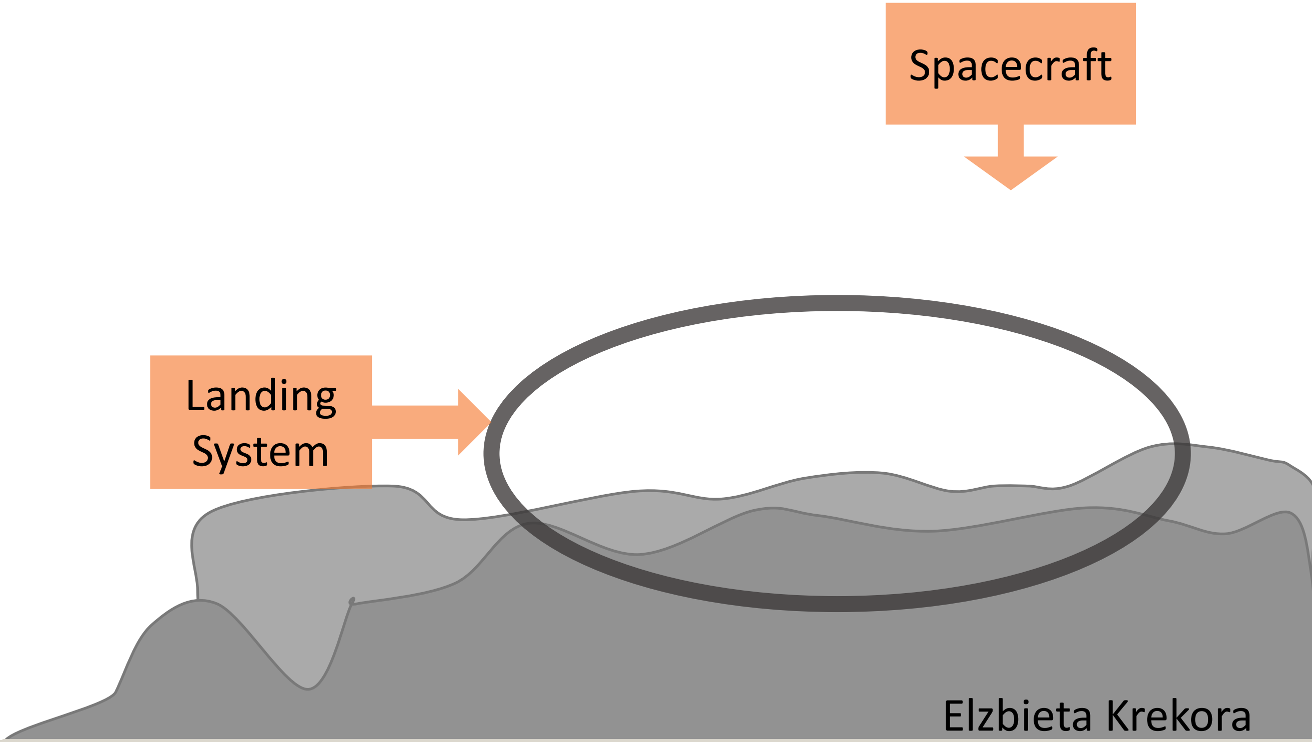
Elzbieta Krekora

Project Overview

Psyche: Believed to be an exposed core of an early planetesimal that lost its rocky outer layers due to violent collisions billions of years ago

Our Mission:
To design a possible future landing system (i.e. what lands/supports the spacecraft)

Terrain:
Scientists hypothesize that Psyche may have a range of terrain types (i.e. rocky, uneven and metallic)



Elzbieta Krekora

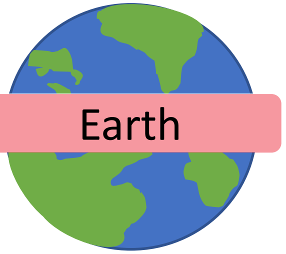
Assumptions

Psyche

- Attaches to future spacecraft without issue
- Operated in minimal gravity, space like temperatures and conditions
- Perform a soft landing on Psyche

Both

- Spacecraft approaches perpendicular to surface
- Controlled Autonomously
- Power supplied by spacecraft



Earth

- Test model and forces are analogous to Psyche mission variables
- Testing terrain resembles assumed surface of Psyche

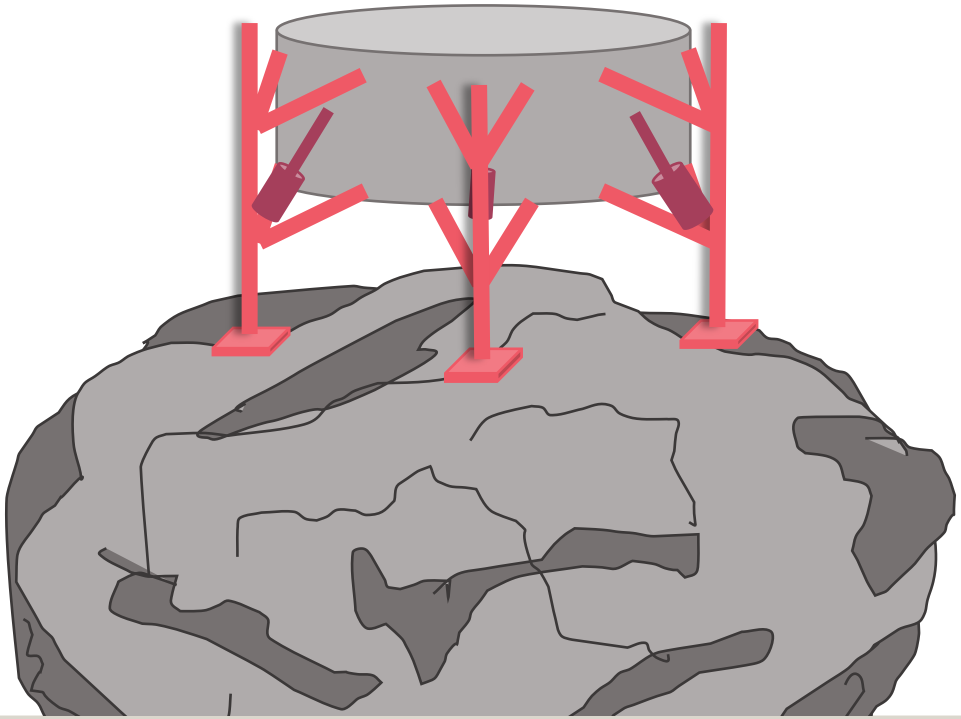
Saralyn Jenkins

Critical Targets

Dampens impact energy

Prevent lander from tipping

The system can support the weight of the lander

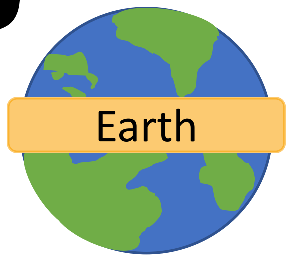


Lander can accommodate for any of the hypothesized surfaces

The lander is stable on Psyche's surface

Saralyn Jenkins

Validation of Targets



Constraints: Mass of Lander and Gravity	Psyche: 150 kg $0.144\ \frac{m}{s^2}$	Earth: 23 kg $9.81\ \frac{m}{s^2}$	Measure mass with appropriate scale to ensure following values are valid
Max Impact Velocity	Psyche: 6 m/s	Earth: 0.92 m/s	Read from sensors
Supports Weight	Psyche: 21.6 N	Earth: 225.63 N	All components in prototype specked to support weight based on this value

Saralyn Jenkins

Concept Generation

Brainstorming

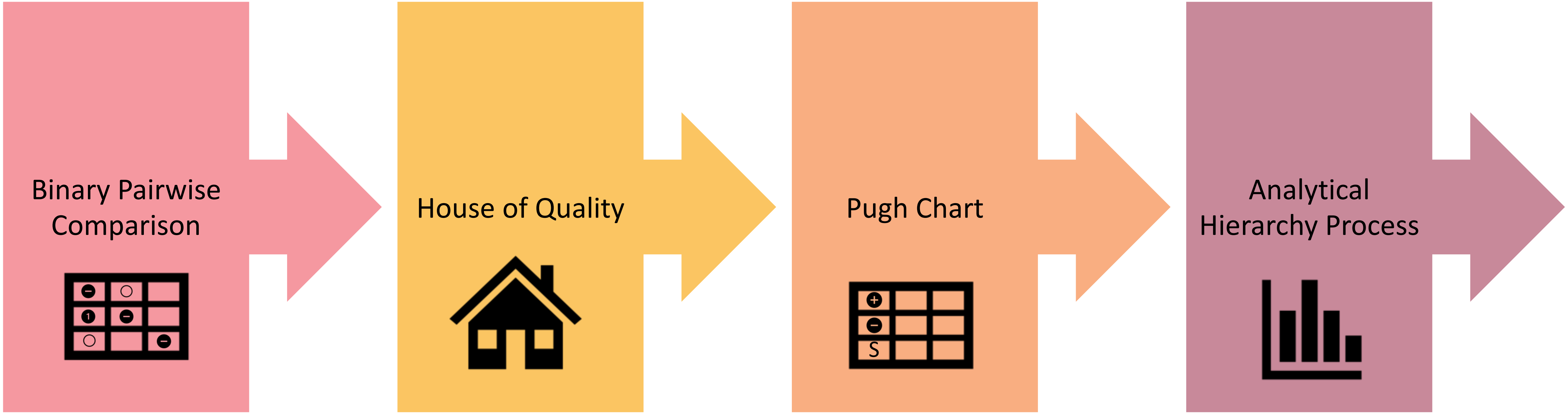
Biomimicry

Crapshoot

Forced Analogy

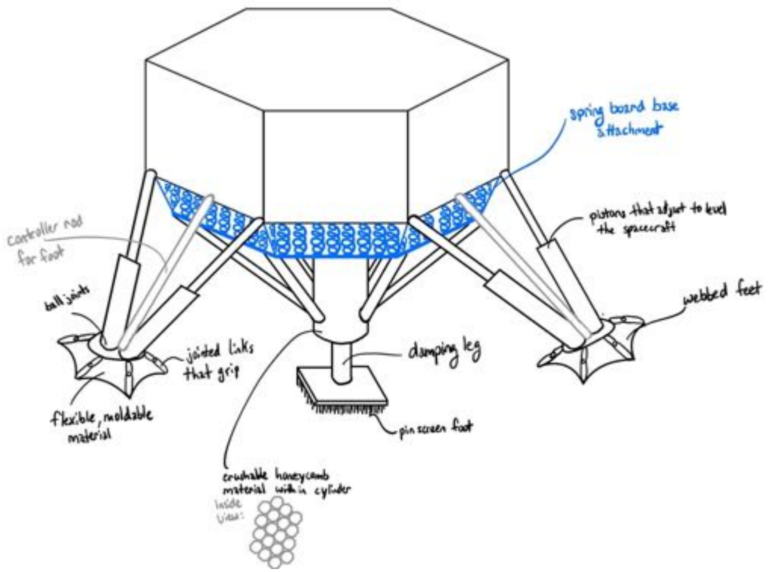
Saralyn Jenkins

Concept Selection Process

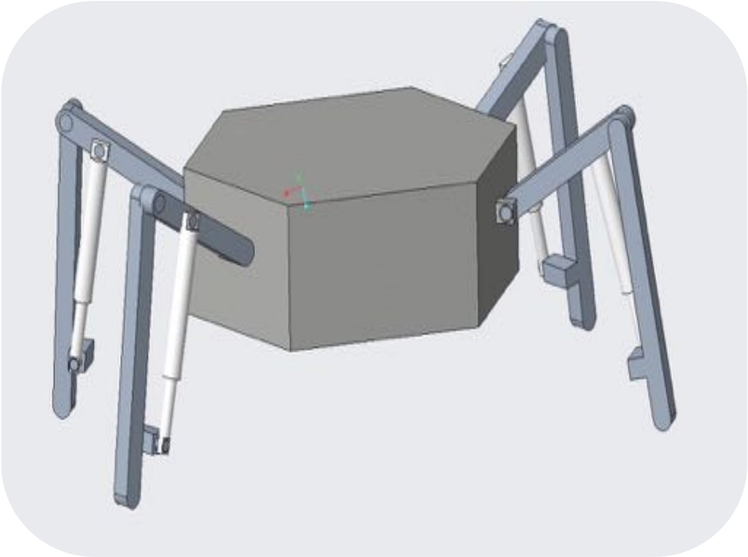


Saralyn Jenkins

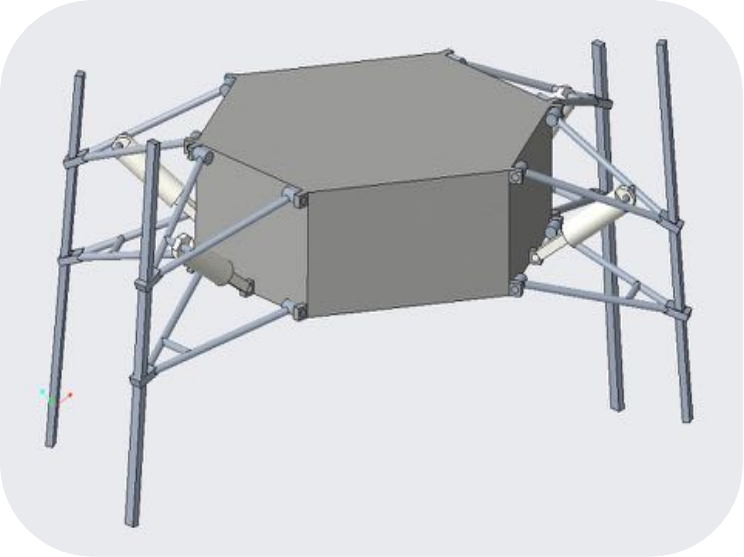
Top 3 Concepts



Single Impact Leg, Springboard Base, 3 Stability Legs



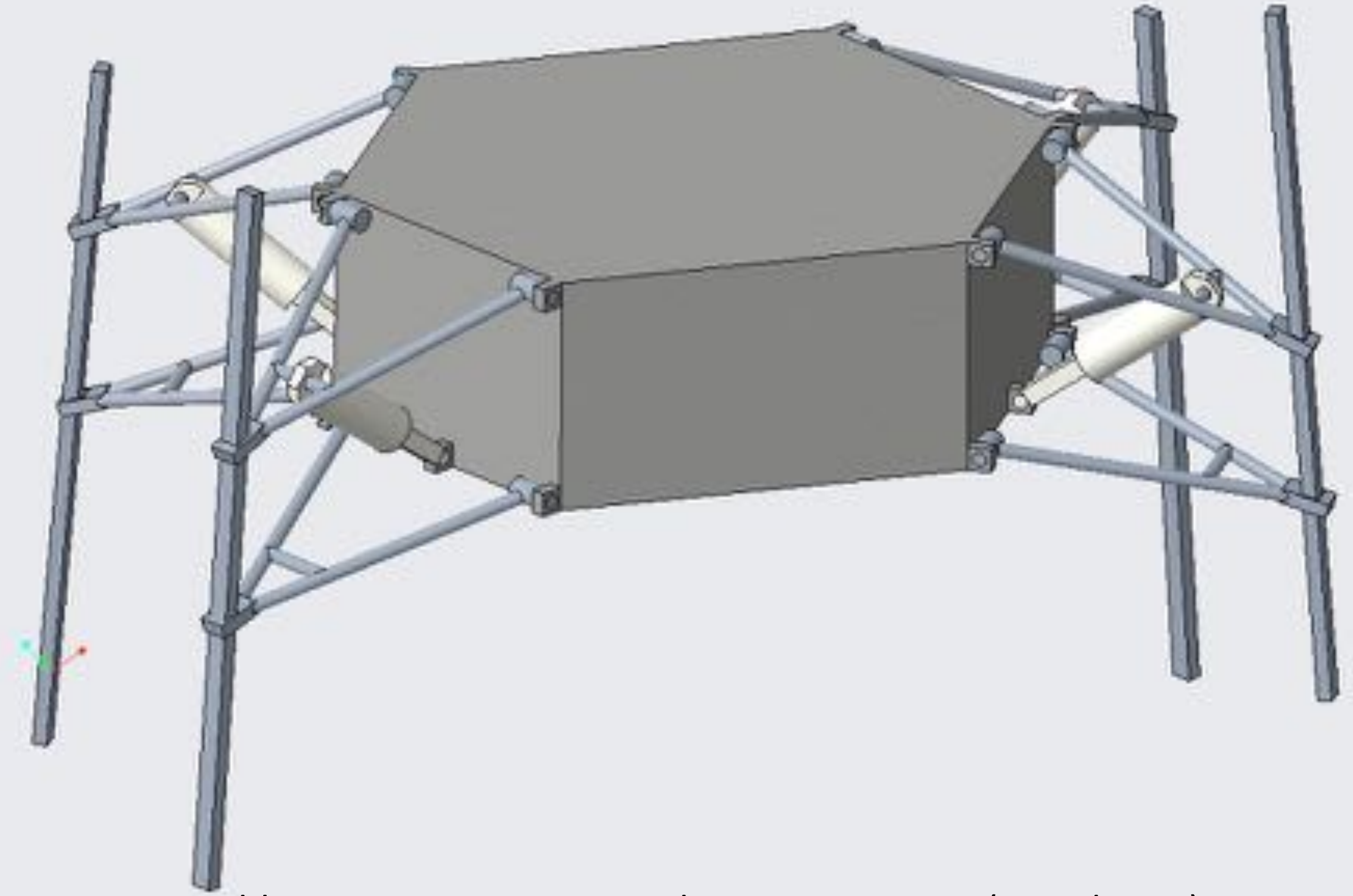
Grasshopper Suspension



Double A-arm Suspension

Saralyn Jenkins

Selected Concept



Double A-Arm Suspension with Pin Screen Feet (Not Shown)

Saralyn Jenkins

Original Landing Feet Design

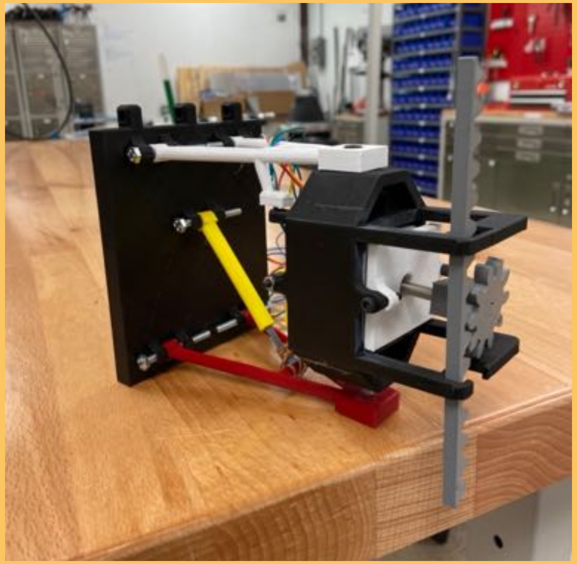
Pin screen with closely packed pins that conform to shape of surface it is placed on

Uneven terrain made of paper

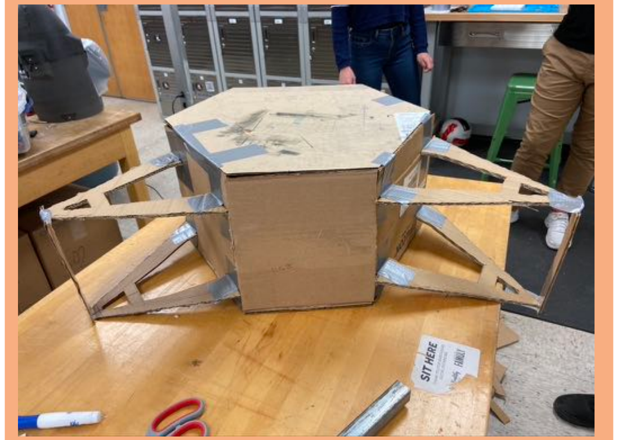
Saralyn Jenkins

Prototyping Process

3D Printing

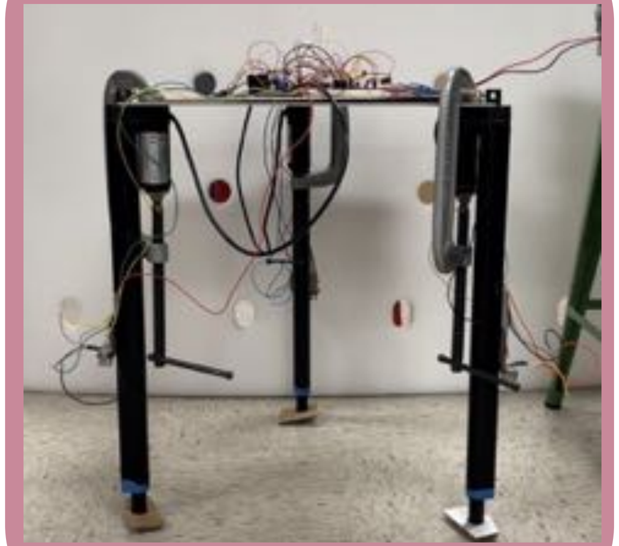


Sizing of Prototype



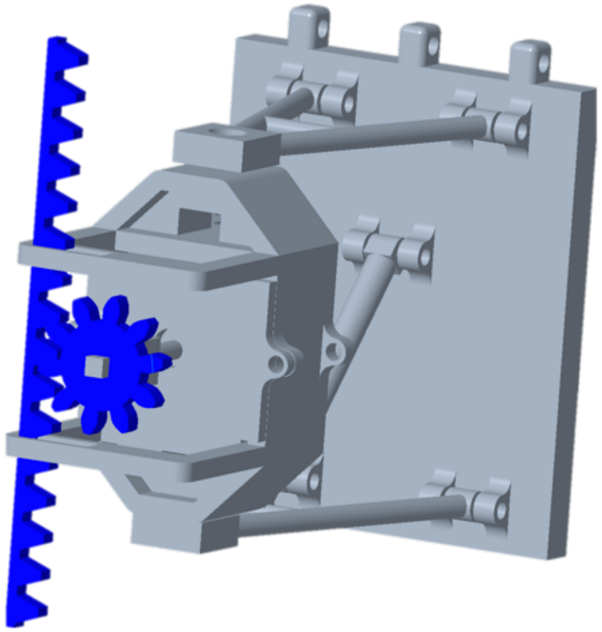
Testing and Reinforcement of Feet

Experimentation of Sensors and Legs

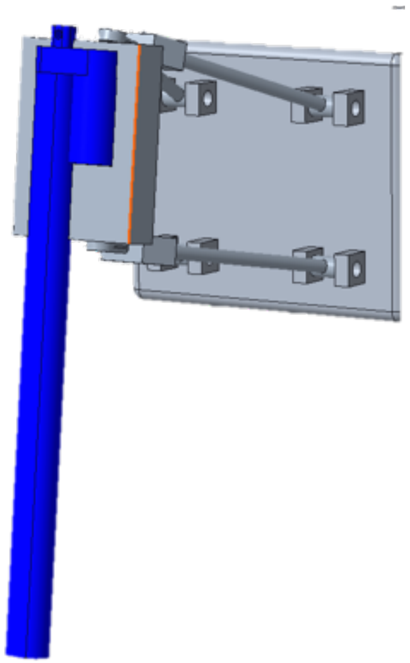


Elzbieta Krekora

Adjustment of Design: Legs



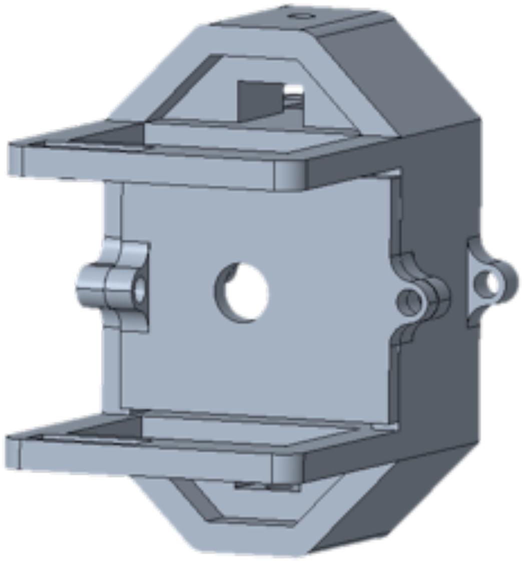
Rack and Pinion



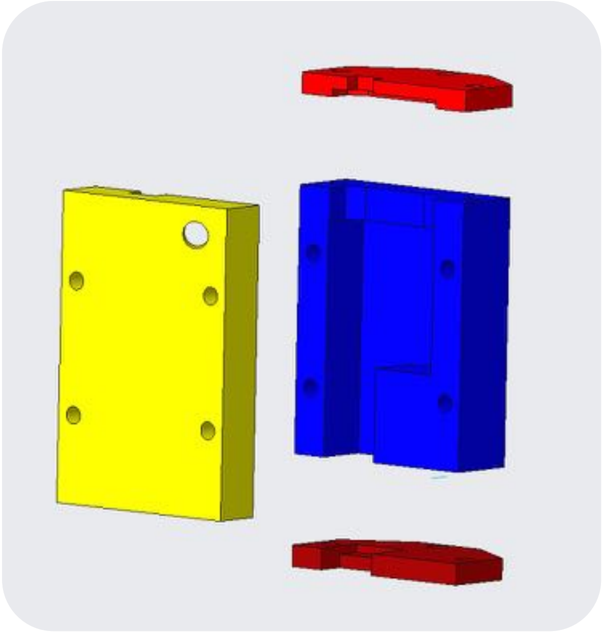
Linear Actuator

Julio Velasquez

Adjustment of Design: Knuckle



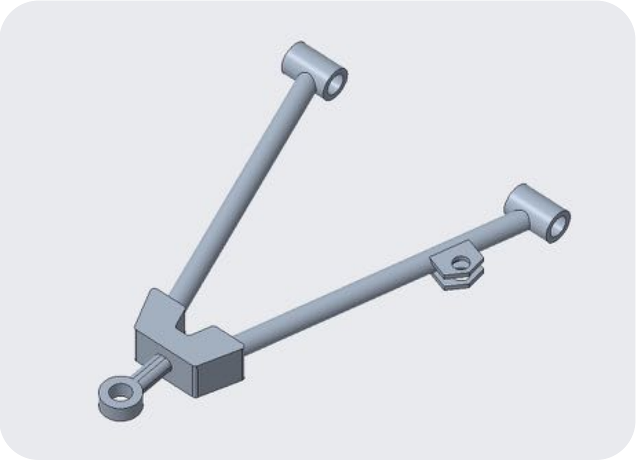
Knuckle



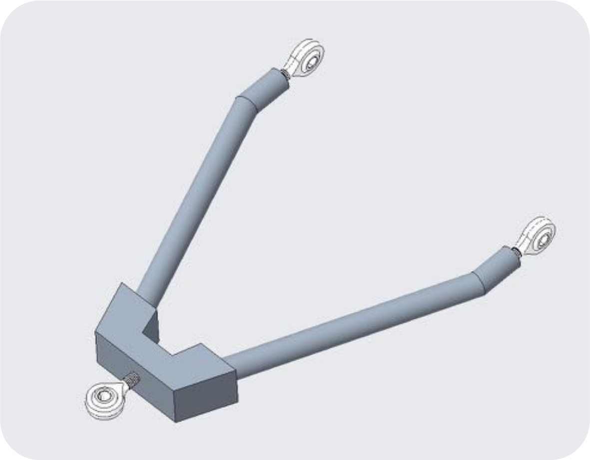
Knuckle Clamp

Julio Velasquez

Adjustment of Design: A-Arms



A-Arm with Revolute Joints

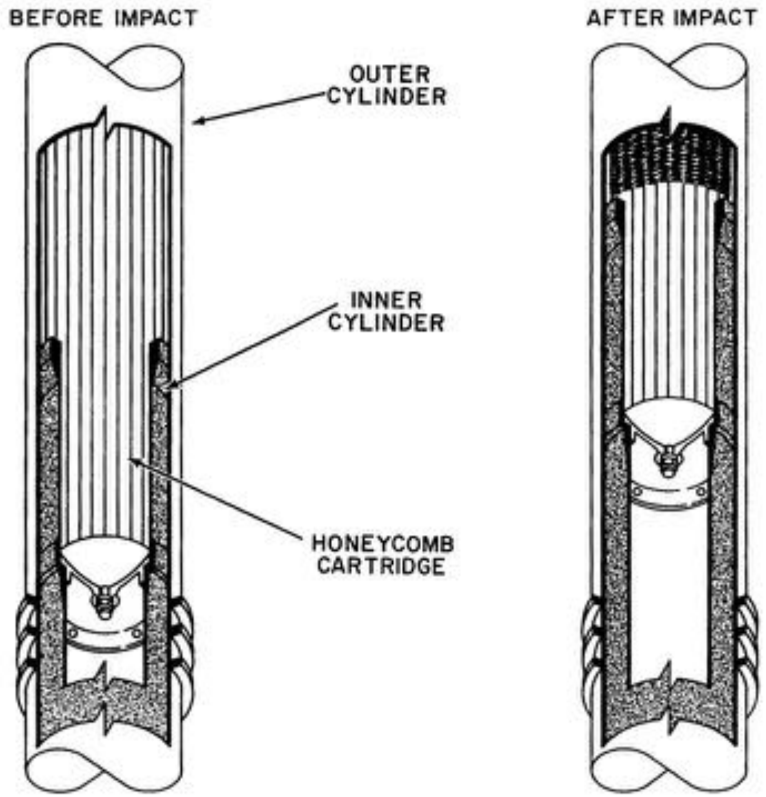


A-Arm with Hem Joints

Julio Velasquez

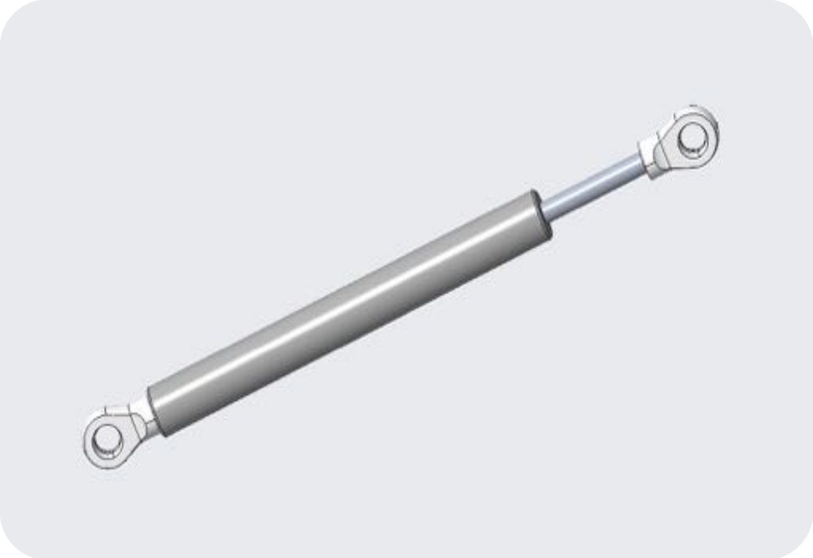
Adjustment of Design: Damping

Psyche Model



Crushable Honeycomb Damper

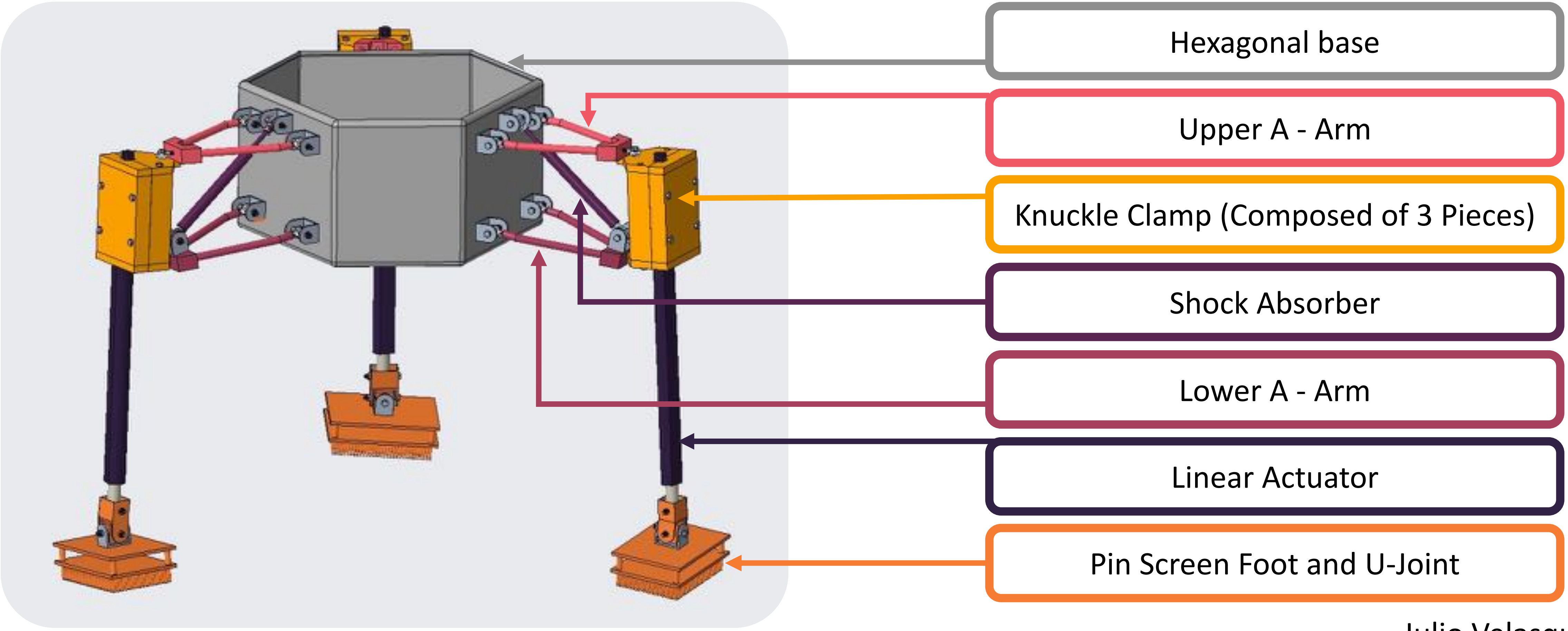
Earth Prototype



Gas Shock Absorber

Julio Velasquez

Prototype Model: Final

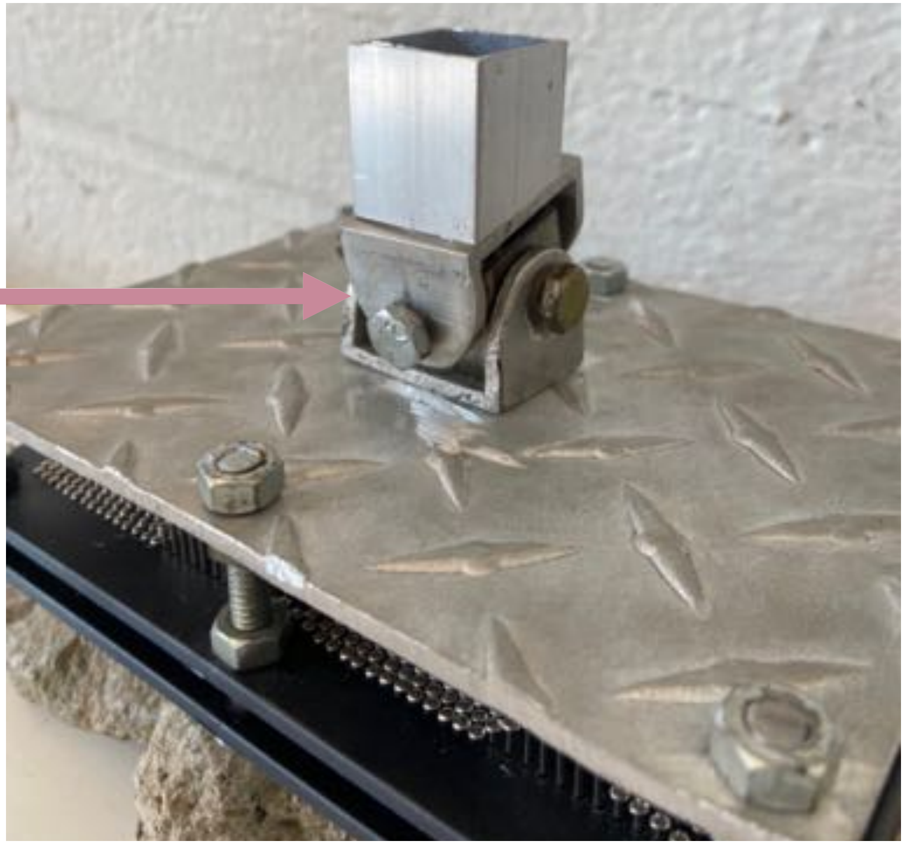


Julio Velasquez

Landing Feet: Detailed View

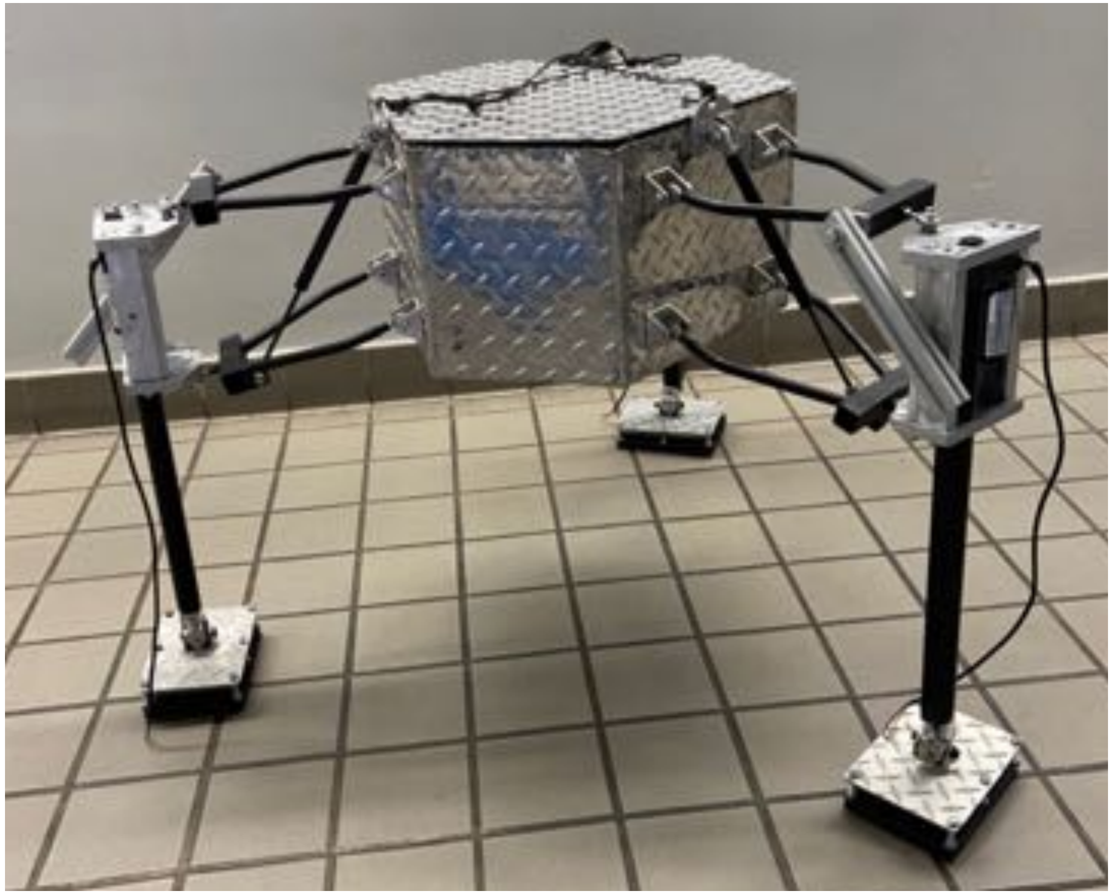
U-Joint that attaches to leg and allows tilting of foot

Reinforced with metal screws and metal plate to support up to ~880 N



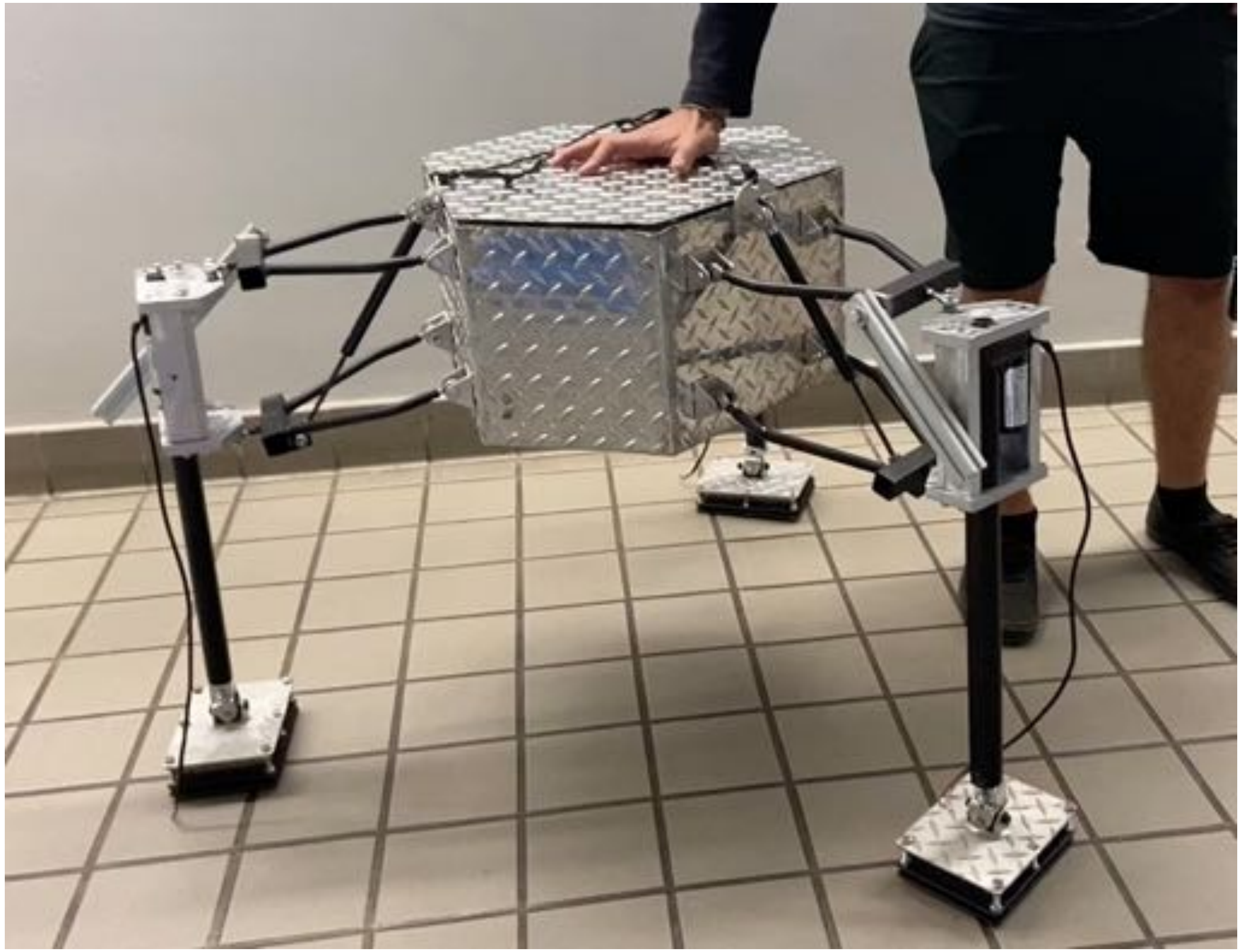
Saralyn Jenkins

Physical Prototype Assembled



Saralyn Jenkins

Motion of the Prototype



Saralyn Jenkins

Test Rig

Pulley to Lift Lander

Uneven Terrain

Andrew Sak

How It Works

Distance Sensed by Sensors	Distance sensors read the distance from the lander to the ground.
Midplane of Terrain Calculated	Midplane of the terrain is calculated by taking in the furthest distance and the closest distance to the ground.
Legs Adjusted Before Impact	Legs are adjusted up or down depending on the distance between the lander and the landing area of each foot.
Orientation Adjusted After Impact	After landing, the IMU reads in the orientation of the lander and makes orientation adjustments.

Andrew Sak

Lander Algorithm

Extend Legs Halfway → Calculate Adjustment Lengths from Distance Sensors

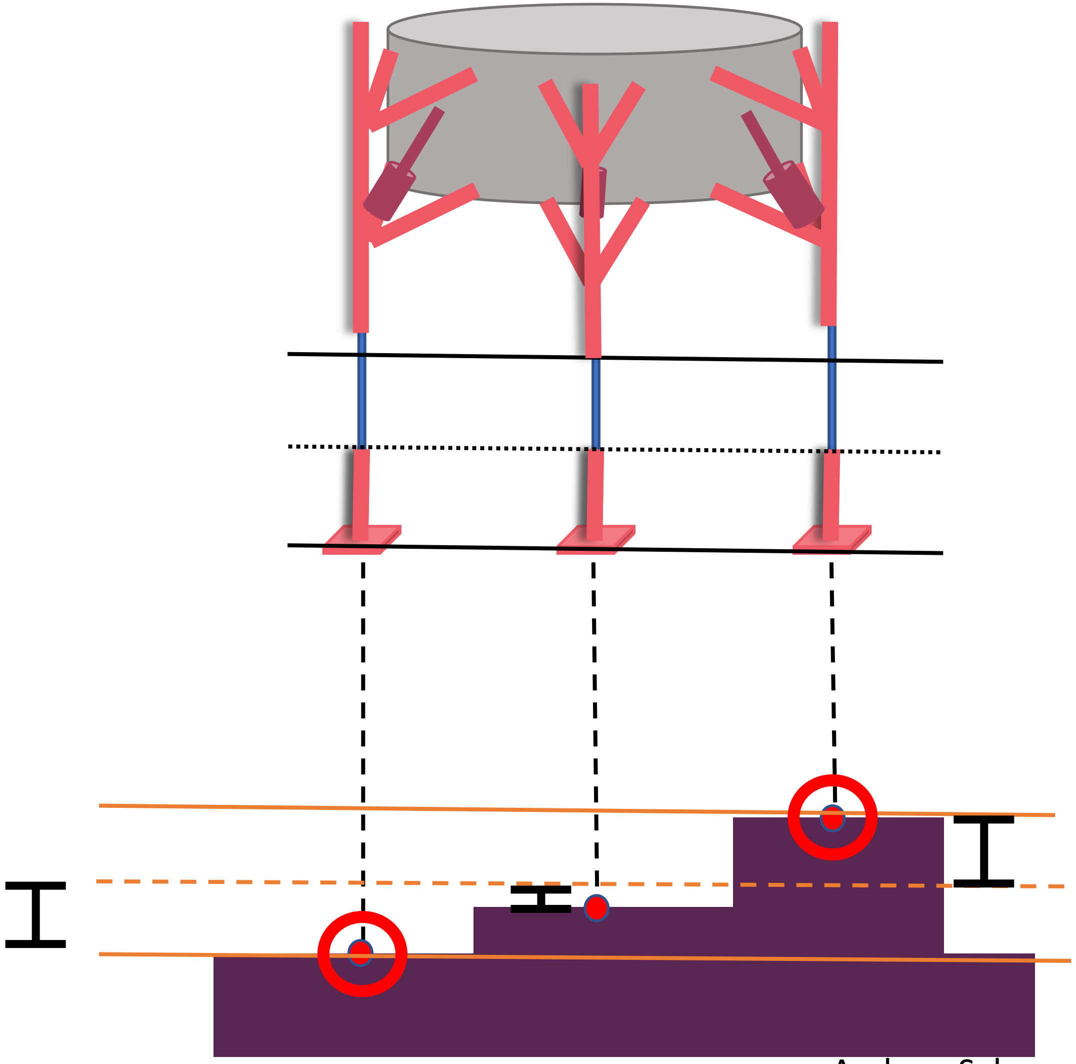
1. Read distance from sensor to terrain below

2. Find the closest point and farthest point on surface

3. Find midplane between closest and farthest point

4. Find distance from midplane to each point on surface

5. Overlay distances on lander leg frame



Andrew Sak

Lander Algorithm

Extend Legs Halfway → Calculate Adjustment Lengths from Distance Sensors → Adjust Legs

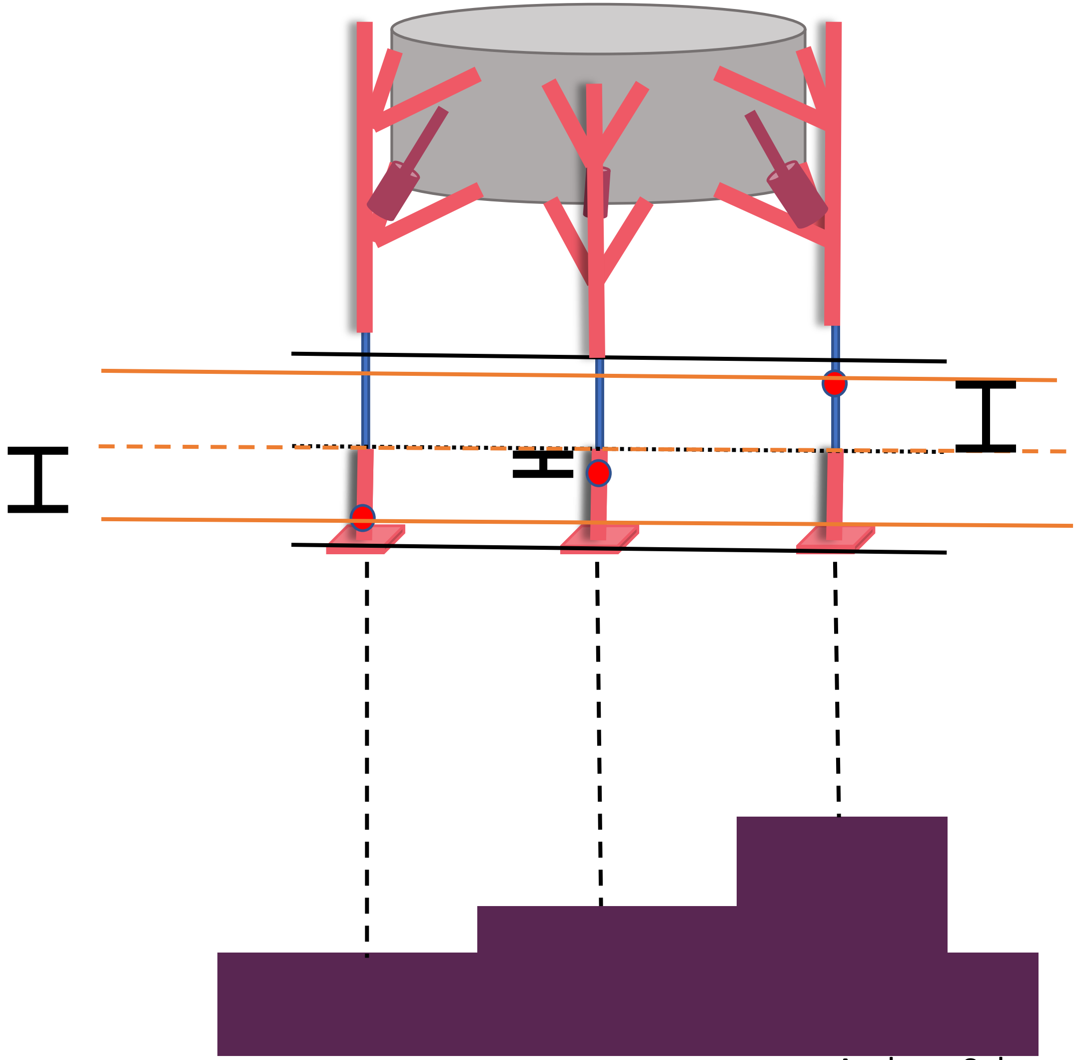
1. Read distance from sensor to terrain below

2. Find the closest point and farthest point on surface

3. Find midplane between closest and farthest point

4. Find distance from midplane to each point on surface

5. Overlay distances on lander leg frame



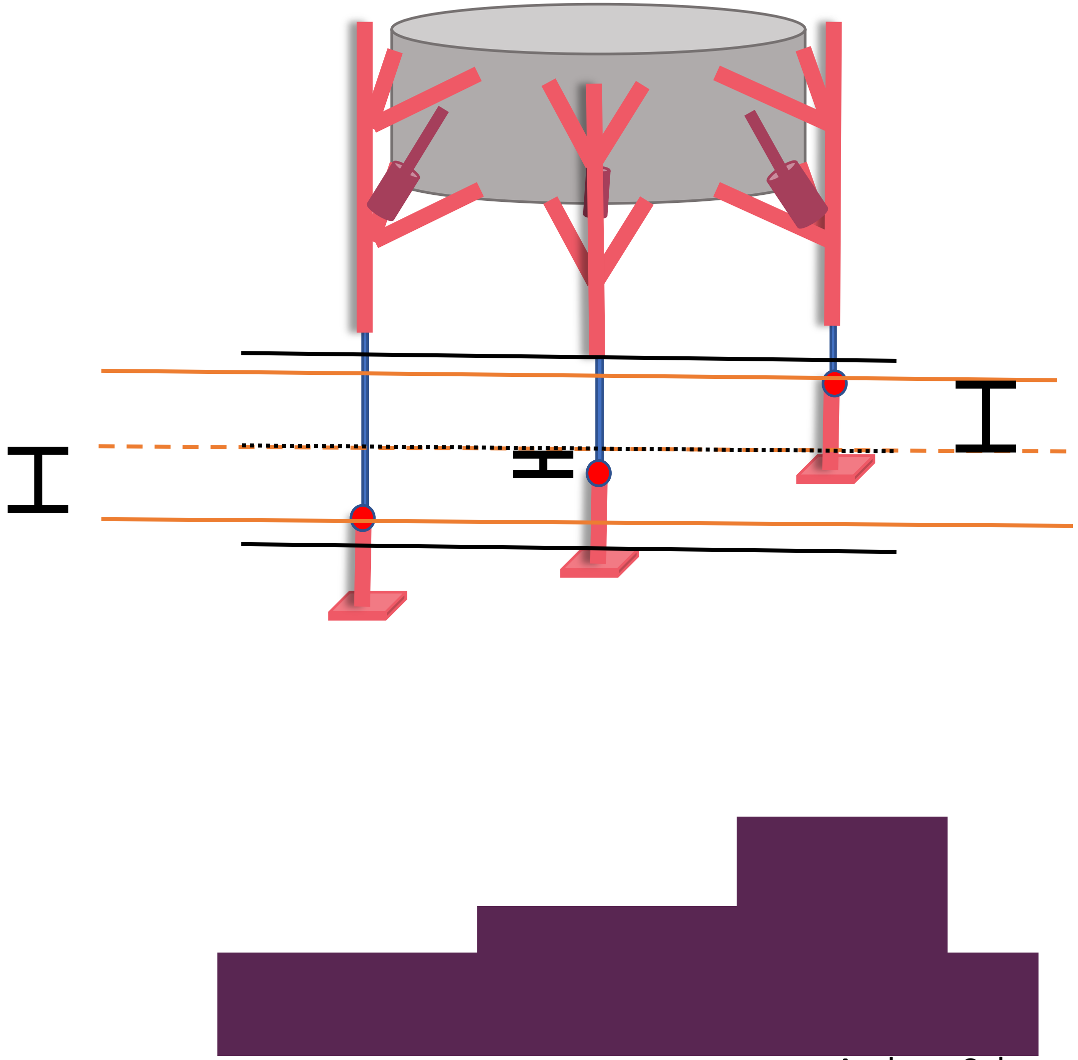
Andrew Sak

Lander Algorithm

Calculate Adjustment Lengths from Distance Sensors → **Adjust Legs** → Wait for Impact

Points below the midplane cause actuators to extend

Points above the midplane cause actuators to retract



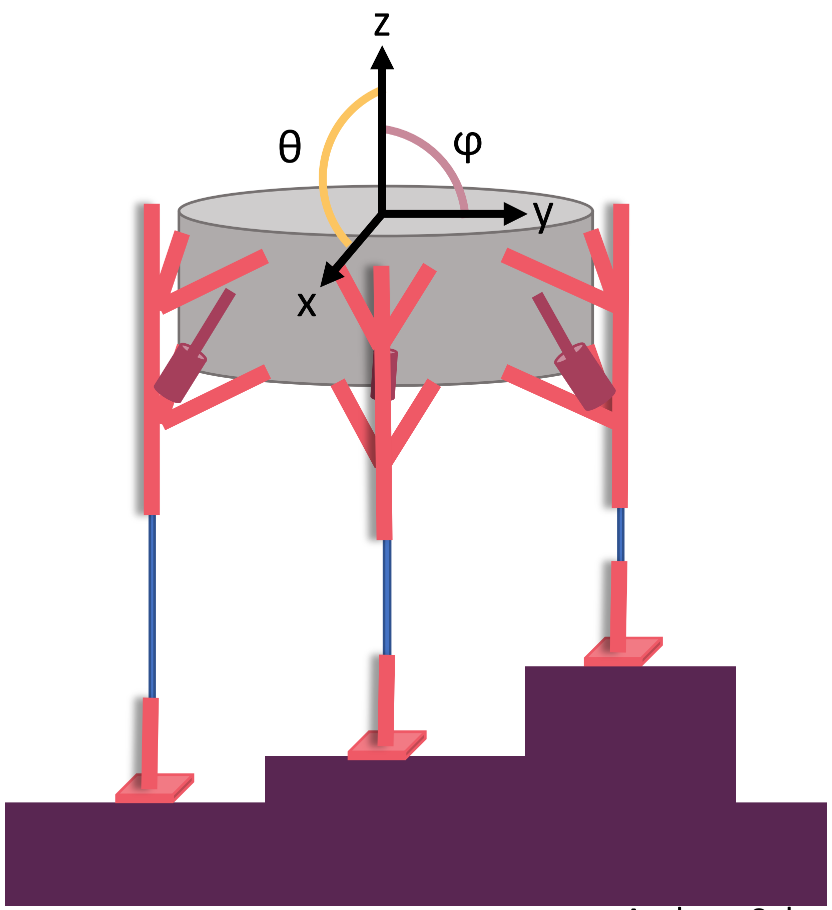
Andrew Sak

Lander Algorithm

Adjust Legs → Wait for Impact → Calculate Adjustment Lengths from IMU Orientation

The actuators can control roll, φ, and pitch, θ

Finds linear adjustment lengths to minimize angles



Andrew Sak

Prototype Testing

Andrew Sak

Prototype After Impact

Landed prototype with all landing components undamaged

Pin screen feet gripped onto terrain

Andrew Sak

Outputs

Confirming Impact Velocity

- Distance sensors used to find velocity and displayed on LCD
- Camera outside test rig to measure frames to find velocity

Confirming Orientation

- Final orientation of IMU displayed onto LCD screen

Confirming Secured Position

- Landing base inspected for any damage to parts inside
- Any bounce or slide of prototype will be measured via a camera during testing

Elzbieta Krekora

Future Work

Optimization of Sensors

Test Changing Height Terrain

Test Crushable Honeycomb Damping

Transfer Design to Psyche Prototype

Elzbieta Krekora

Lessons Learned

- Create Bill of Materials Early for Multiple Budgets
- Plan Machining Before Materials Arrive
- Create CAD Model of Testing Rig
- Test physical pieces along the way before finalizing CREO models

Elzbieta Krekora

Summary

Psyche is an asteroid with an uneven profile and uncertain terrains.

Our design was created to overcome a range of hypothesized surfaces with sufficient damping, adjustable legs, and gripping/adjustable feet.

Our design choices have been validated through computer modeling/simulation and from physical testing.

Elzbieta Krekora

Contact Information

Saralyn Jenkins
Email: srj18@my.fsu.edu
Connect on LinkedIn:

Elzbieta Krekora
Email: ek18d@my.fsu.edu
Connect on LinkedIn:

Andrew Sak
Email: avs15b@my.fsu.edu
Connect on LinkedIn:

Julio Velasquez
Email: jav19e@my.fsu.edu
Connect on LinkedIn:

Materials Used for Prototype

Base:
- Aluminum diamond plate
- 1-inch aluminum square tubing

A-Arms:
- ½ inch steel tubing
- ¾ inch steel square tubing
- M6-01 nuts
- M6-01 spherical rod ball joints
- 1 ½ inch aluminum U-channel
- Plastic spacers

Knuckle:
- Aluminum blocks
- M6-01 screws
- M6-01 nuts

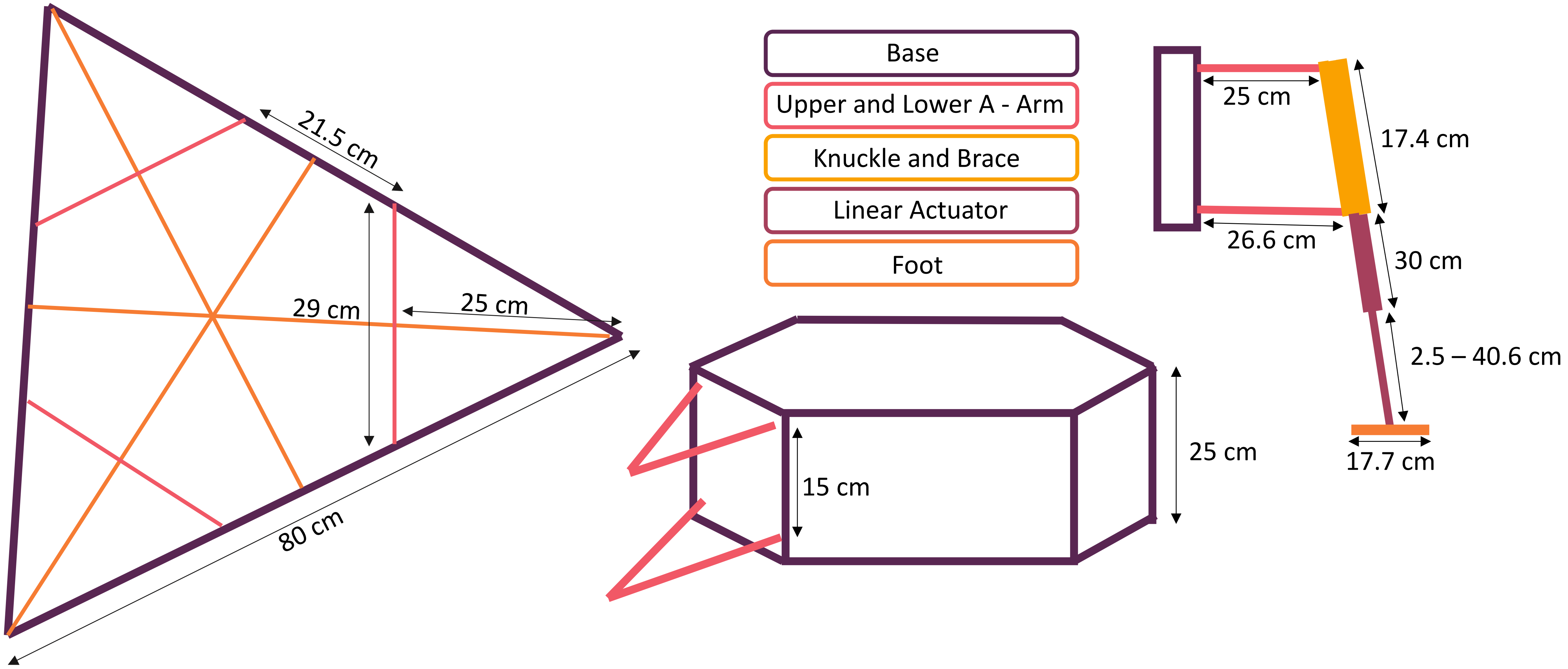
Legs and Feet:
- Linear actuators
- 1 ½ inch U-channel
- 1 inch aluminum square tubing
- ¾ inch steel square tubing
- M6-01 nuts
- M6-01 screws
- Pin screens
- Aluminum diamond plate

Electronics:
- TOF laser sensor
- 9-DOF IMU
- Linear actuators
- Servo motors
- LCD

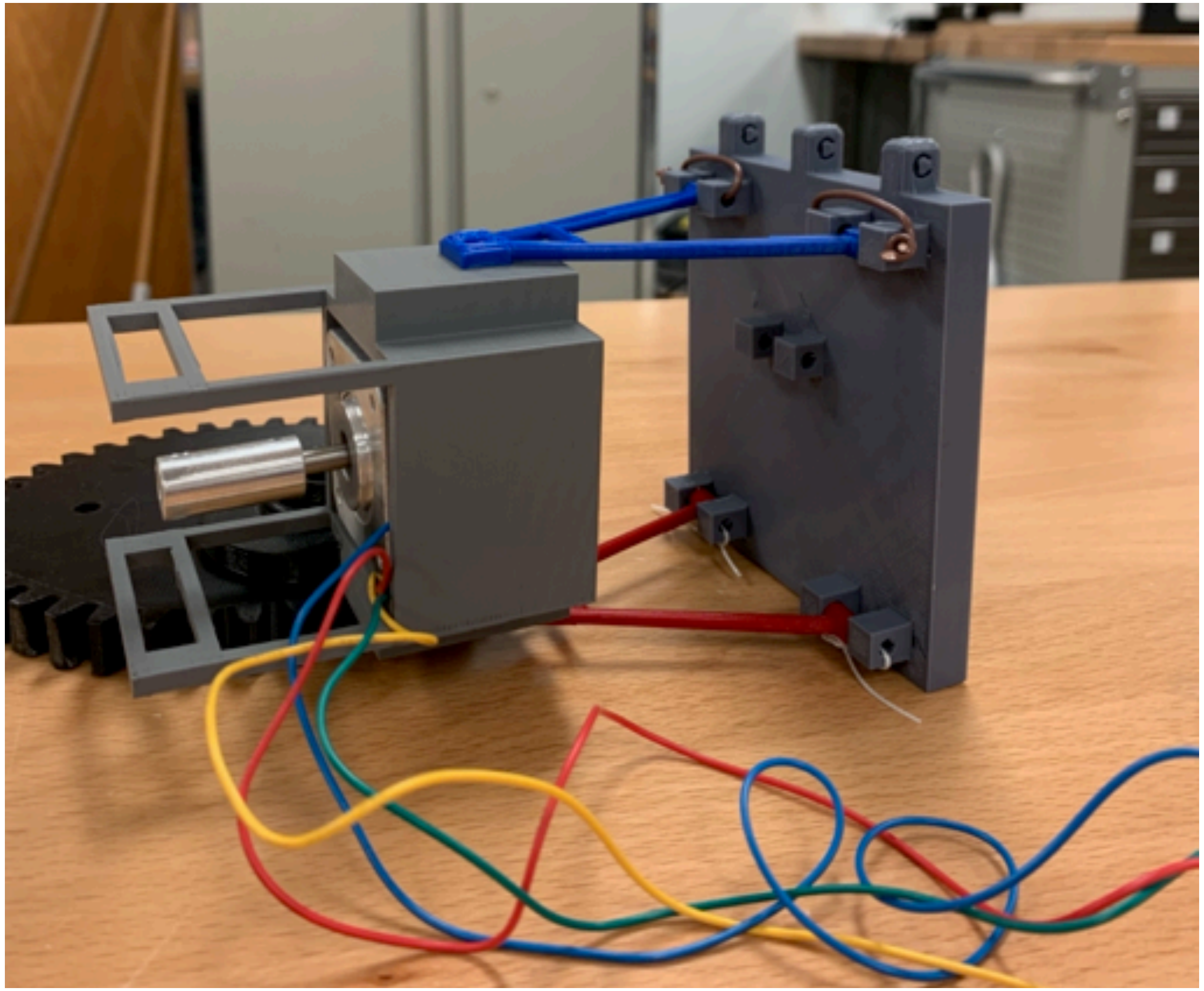
Testing Assembly:
- 2-inch square structure bars
- 90-degree mount brackets
- Floor mounts
- Pulleys
- 25-foot rope
- Counterweight
- ¾ inch plywood
- Sandbags
- Canvas drop cloth
- Polyurethane glue
- Black washed gravel
- Lava rocks
- Basalt gravel

****NOTE: None of these materials are meant for use in space-like conditions and are for prototyping purposes only****

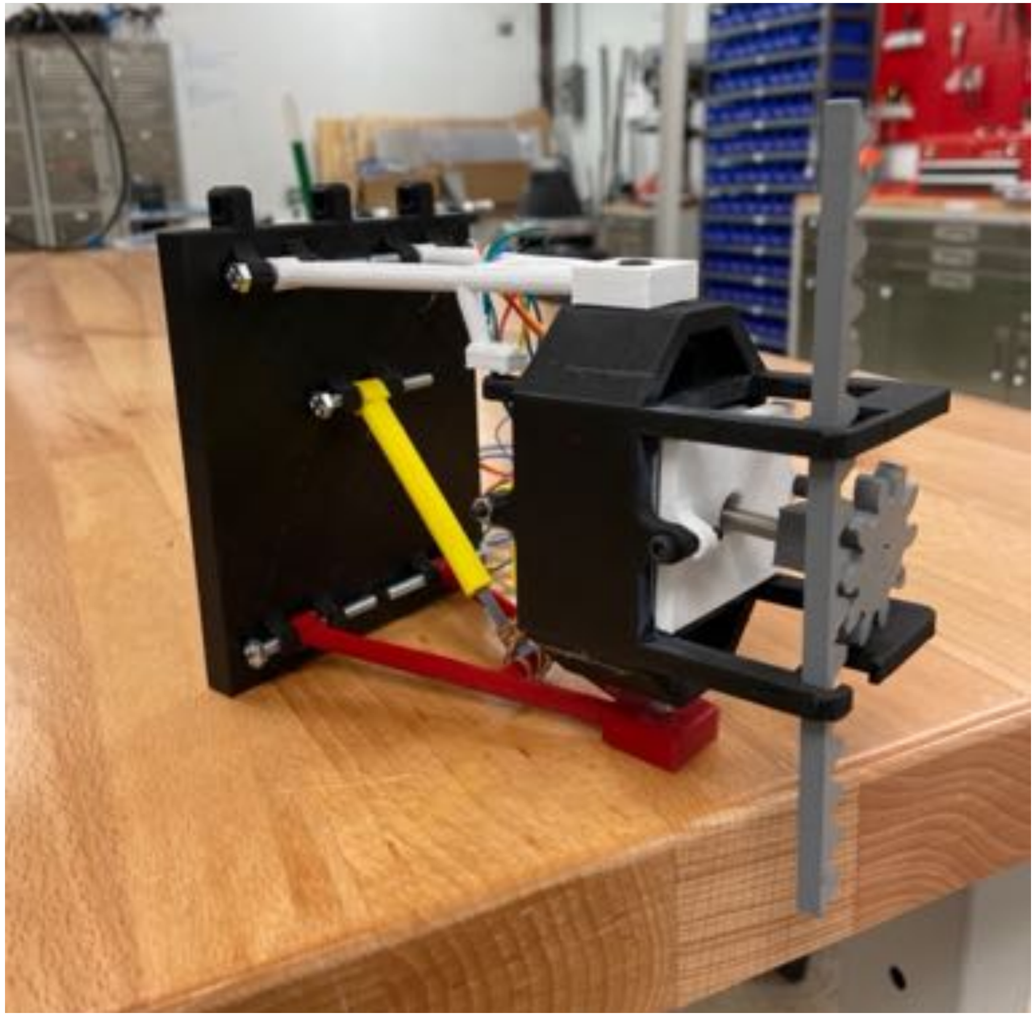
Sizing of Prototype



3D Print of Model

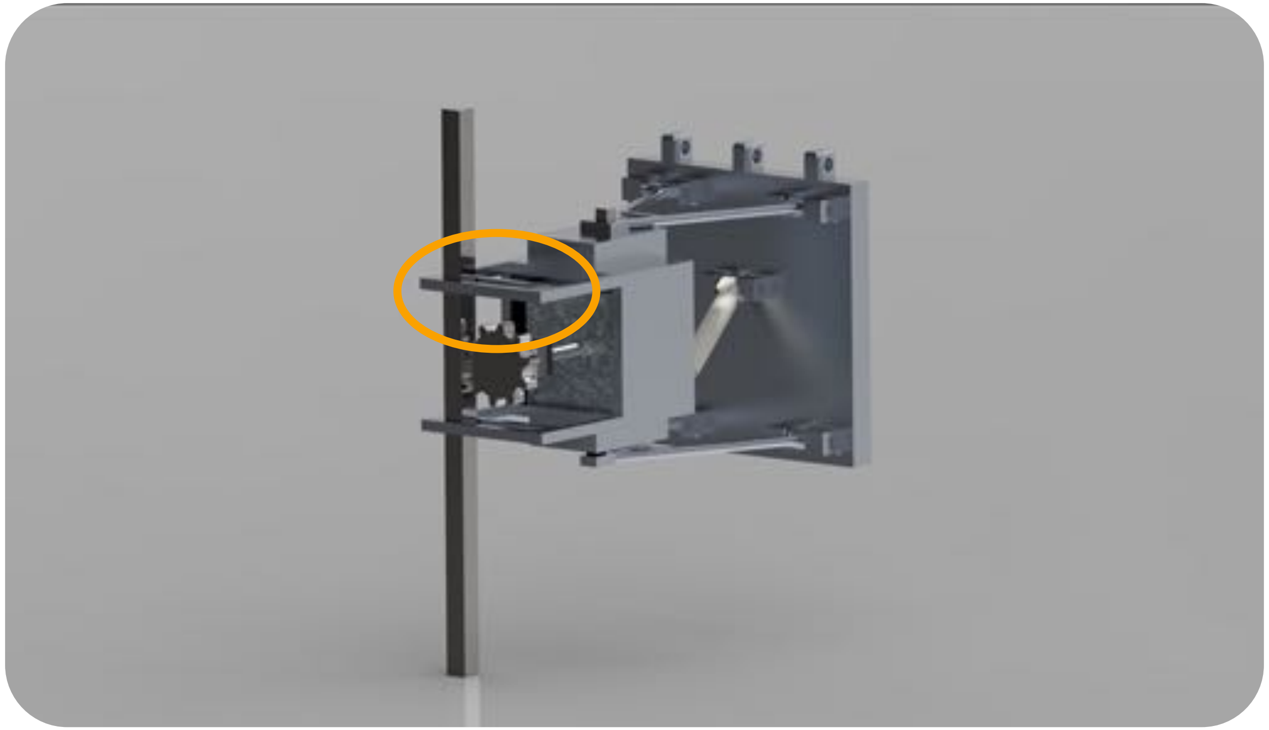


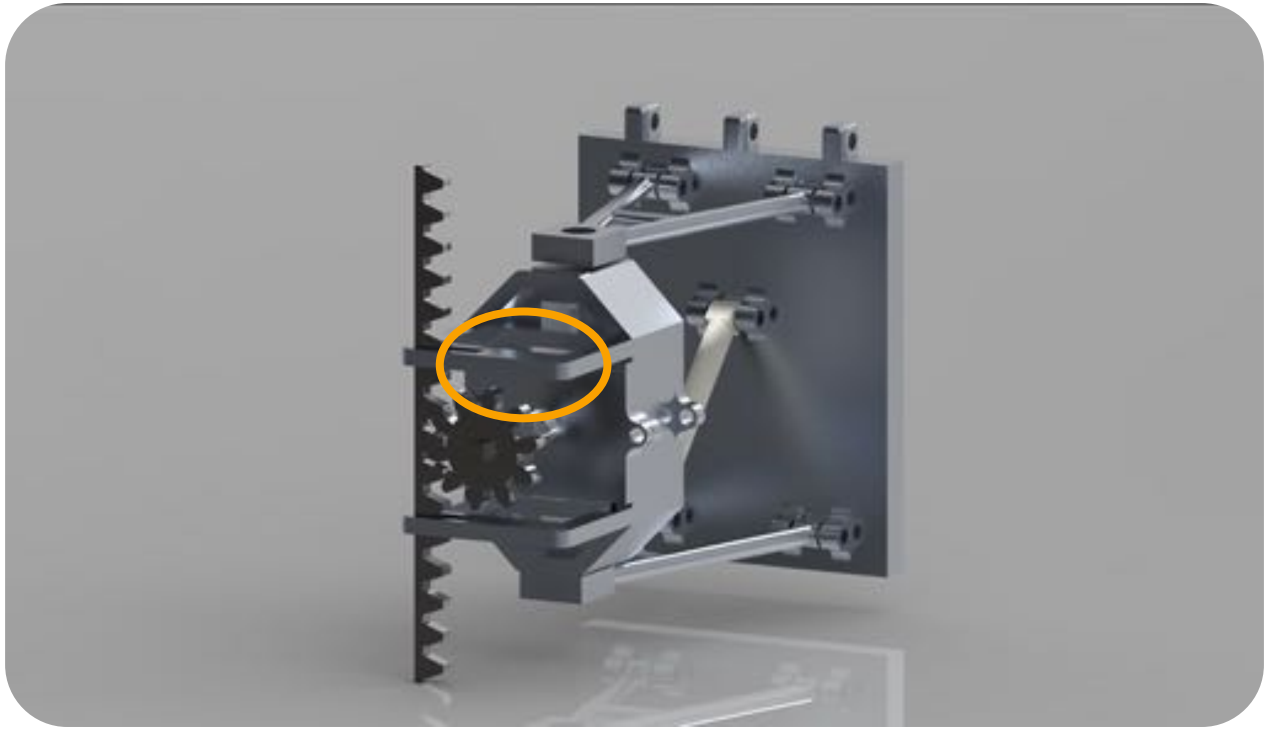
First Print



Second Print

Adjustment of Design: Knuckle



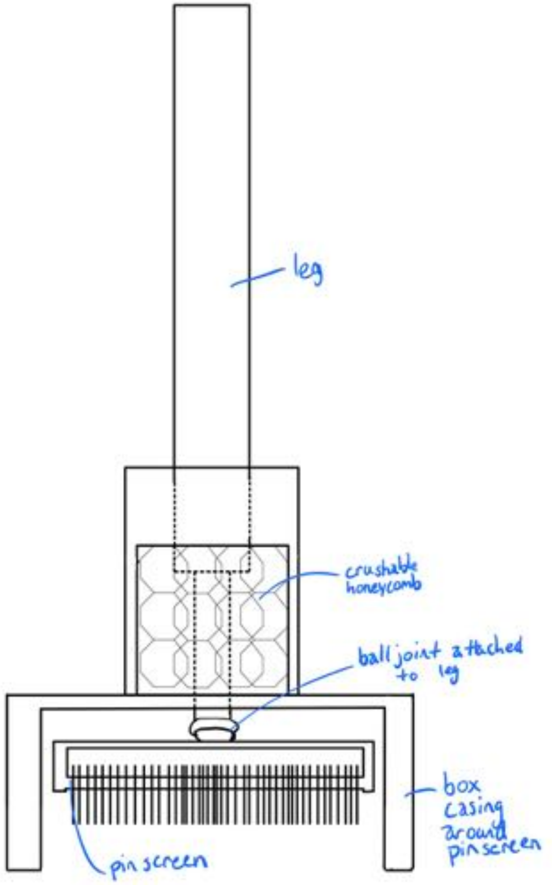


Original Design of Knuckle

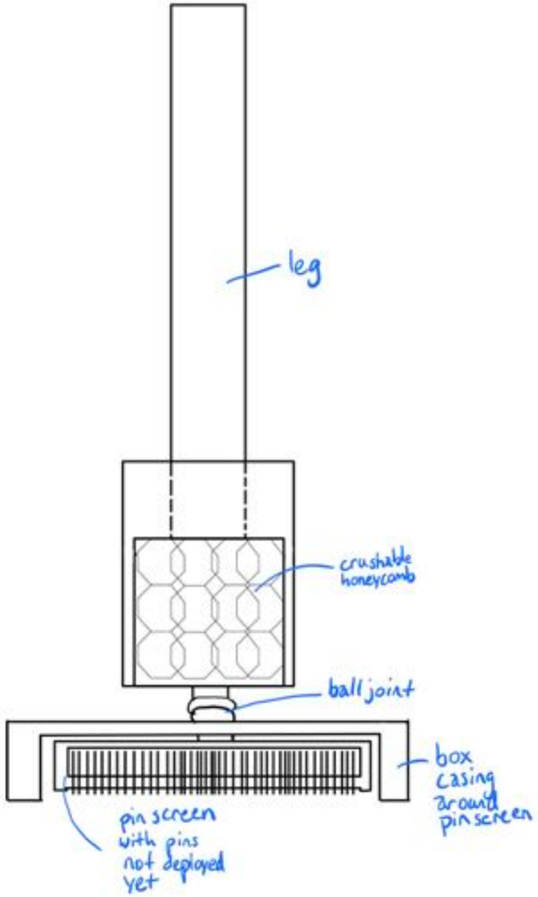
Modified Design of Knuckle

Elzbieta Krekora

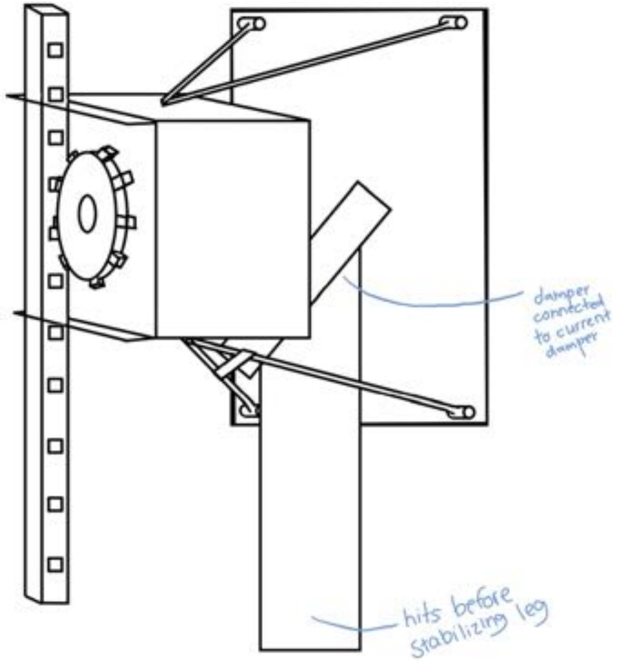
Adjustment of Design: Additional Damping



Design 1: Damping Attached to Foot (Attachment 1)



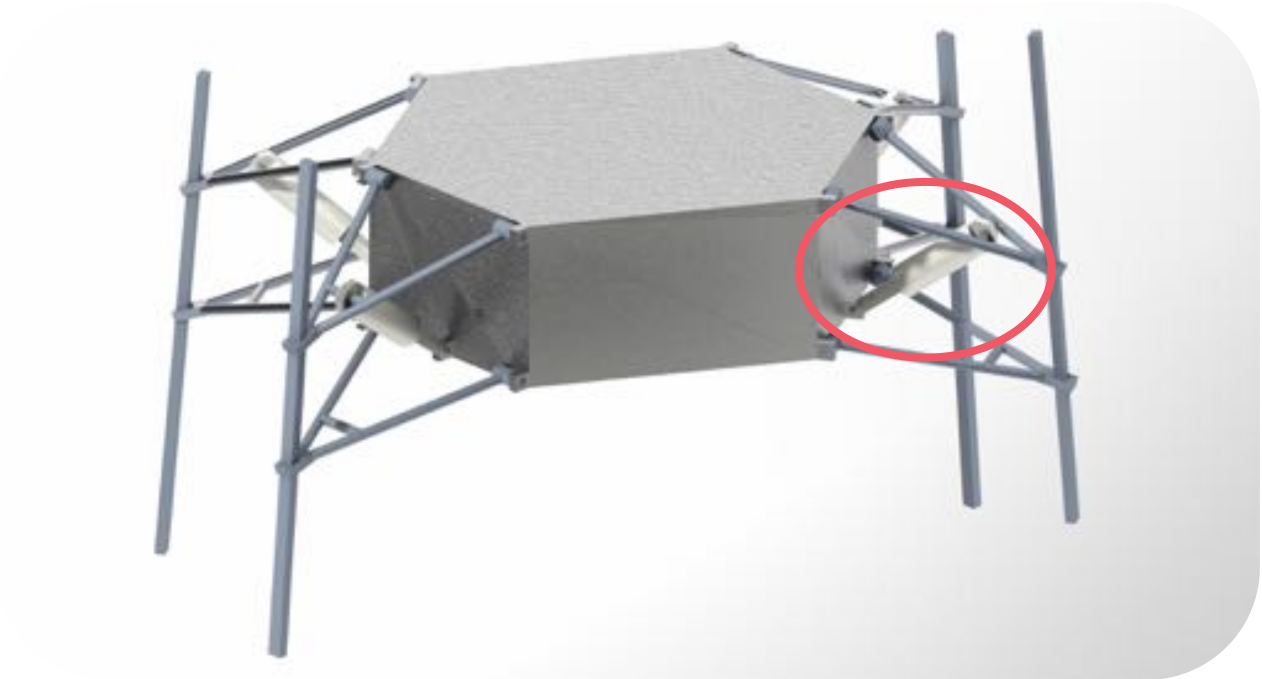
Design 2: Damping Attached to Foot (Attachment 2)



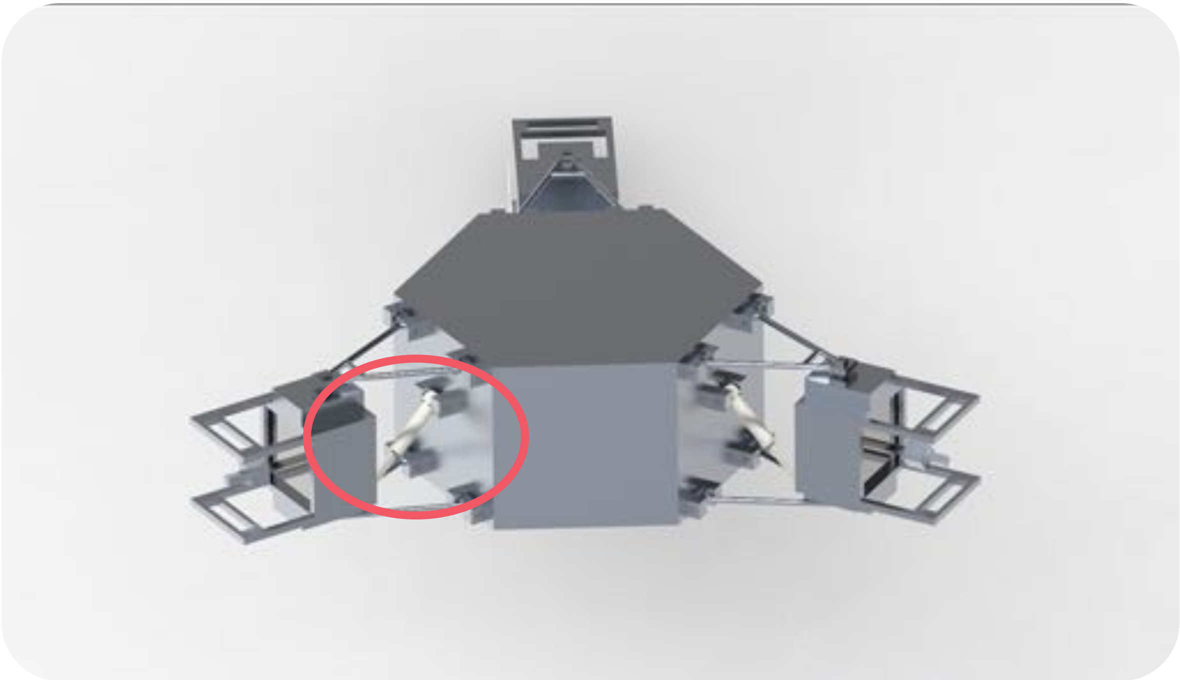
Design 3: Damping Attached to Separate Component

Saralyn Jenkins

Adjustment of Design: Suspension



Original Design (Feet Not Shown)



Modified Design (Legs and Feet Not Shown)

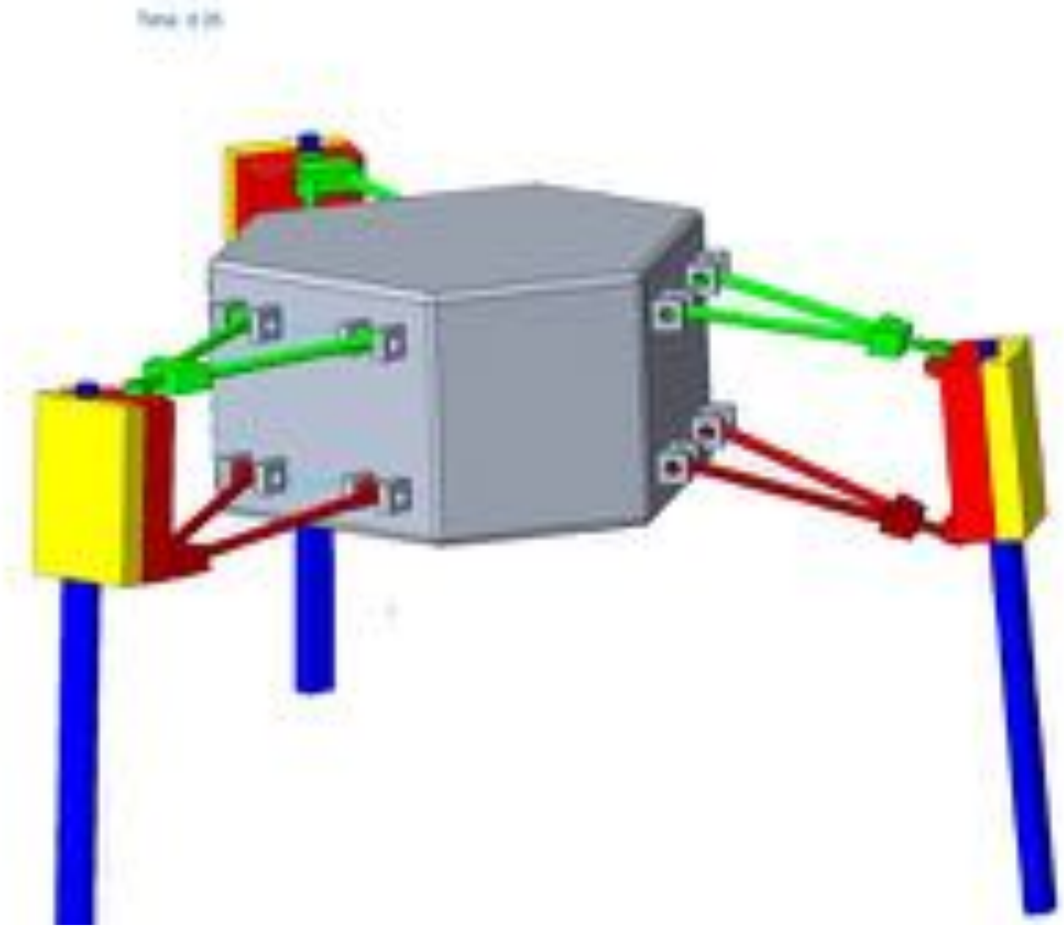
Elzbieta Krekora

Landing Feet Reinforcement and Testing

Reinforced with metal screws and metal plate to support up to ~880 N

Julio Velasquez

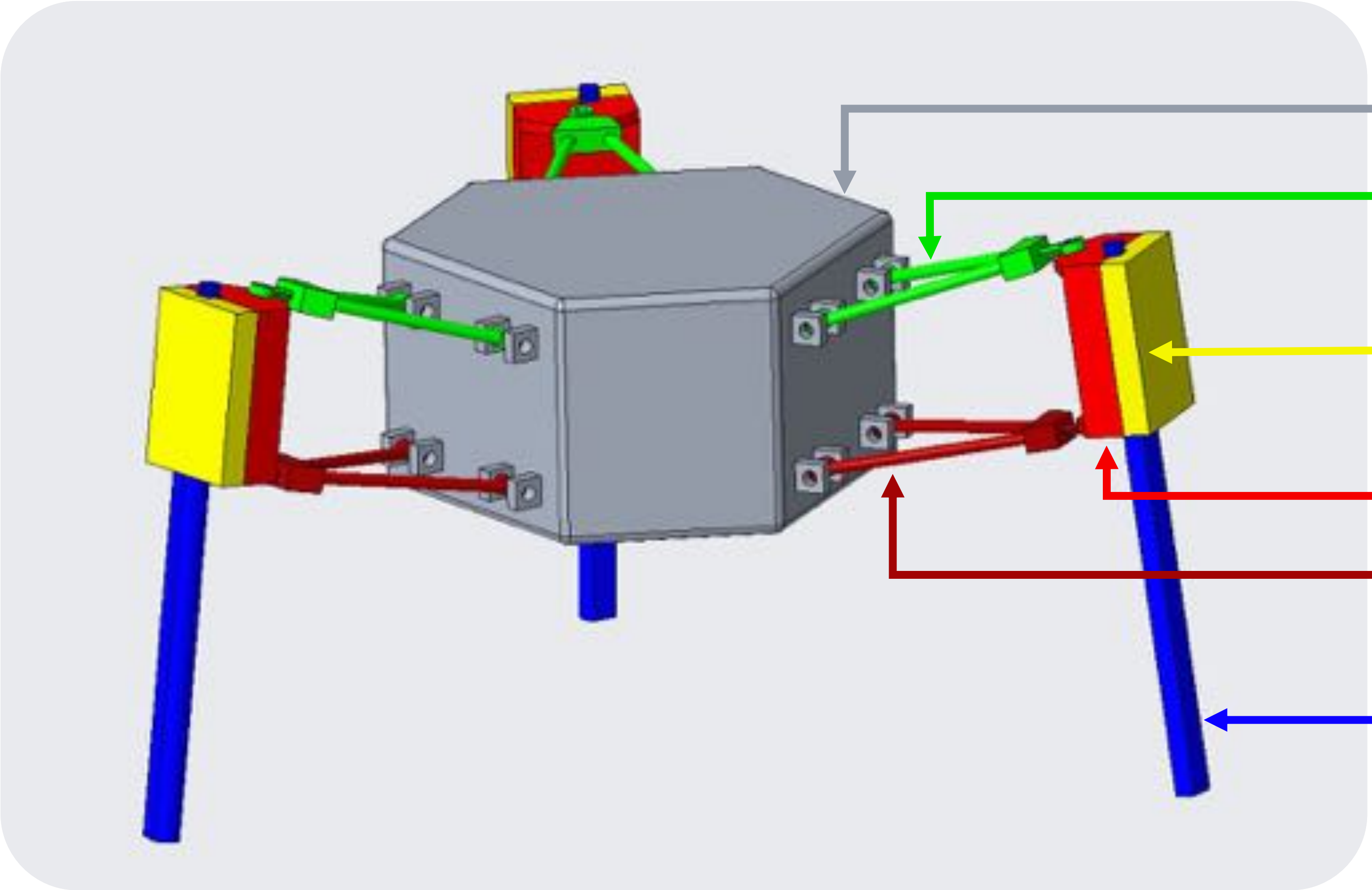
Prototype Model: Motion



NEED UPDATED ONE

Julio Velasquez

Prototype Model: Before Final Changes



Note: Shock absorber/damper and pin screen feet not shown

Hexagonal base

Upper A - Arm

Knuckle Clamp

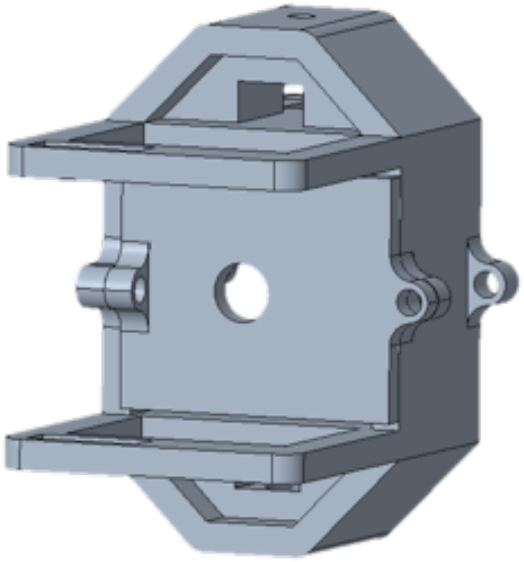
Knuckle

Lower A - Arm

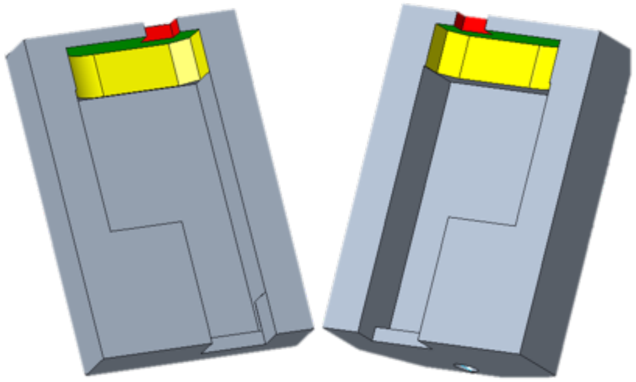
Linear Actuator

Julio Velasquez

Adjustment of Design: Knuckle



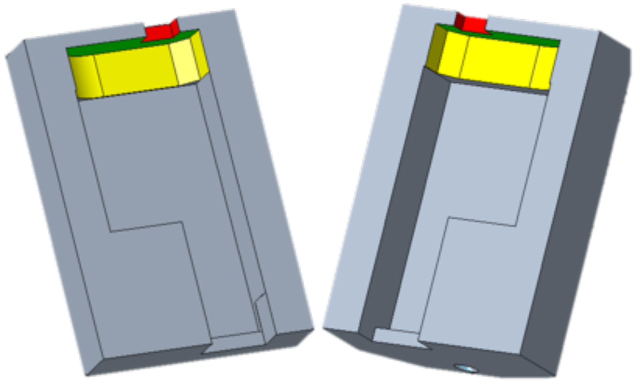
Knuckle



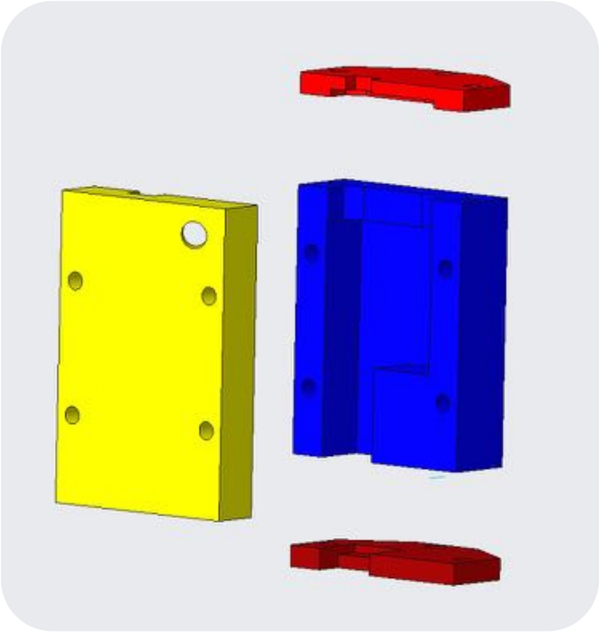
Knuckle Clamp

Julio Velasquez

Adjustment of Design: Knuckle



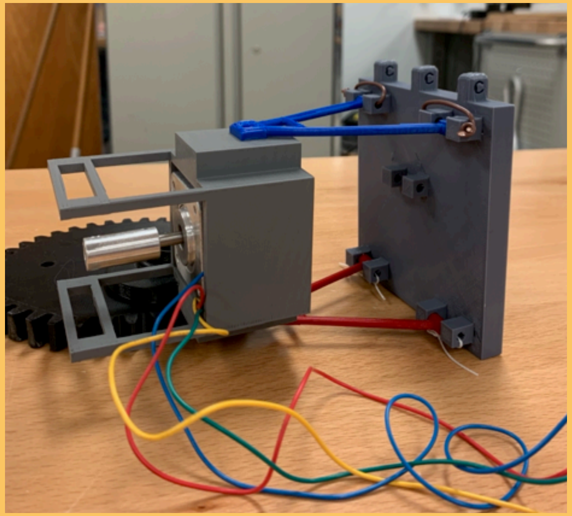
Knuckle Clamp



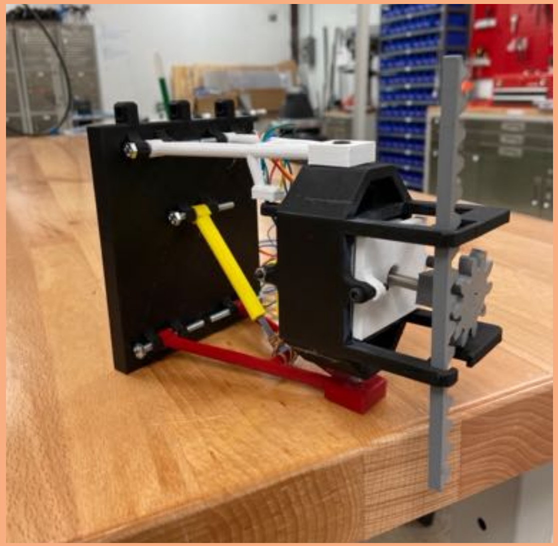
Knuckle Clamp Version 2

Julio Velasquez

Evolution of Prototype



First 3D Print of Original Design



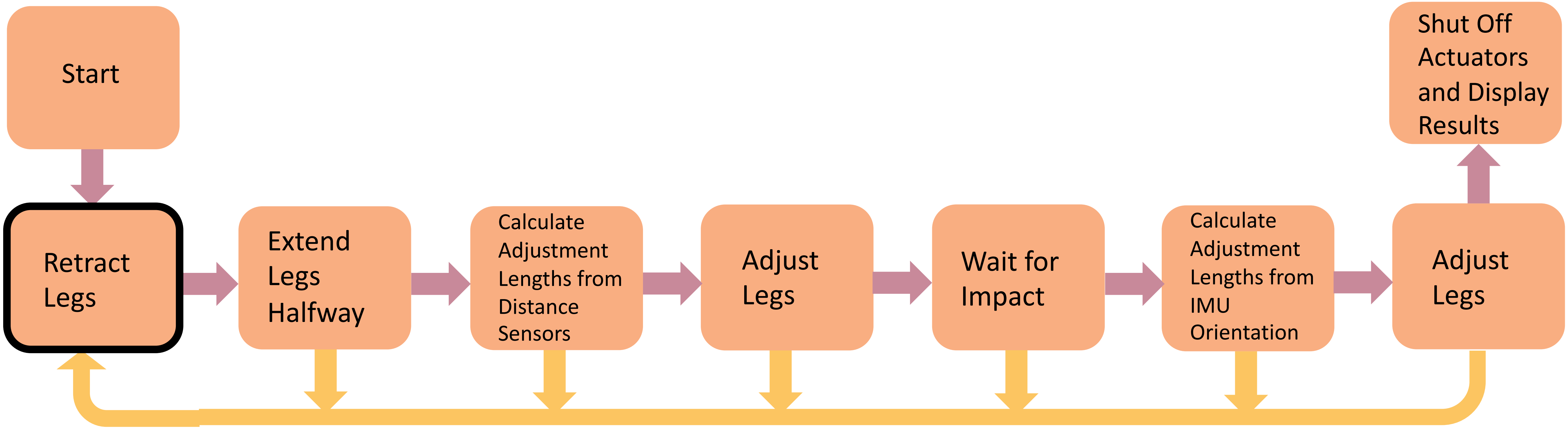
Second 3D Print of Adjusted Design

Landing Legs Changed to Linear Actuators

Final Prototype in the Process of Being Assembled

Elzbieta Krekora

Lander Algorithm



Andrew Sak

Lander Algorithm

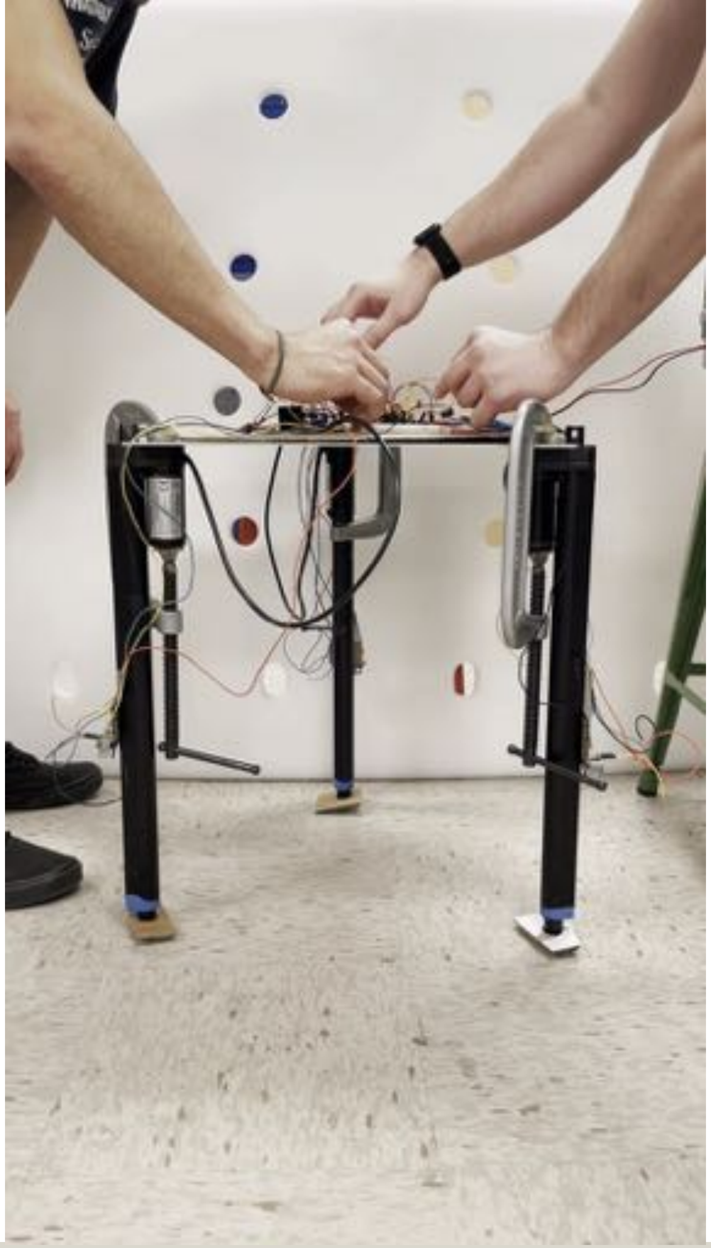
Start

Retract Legs

Andrew Sak

Lander Algorithm

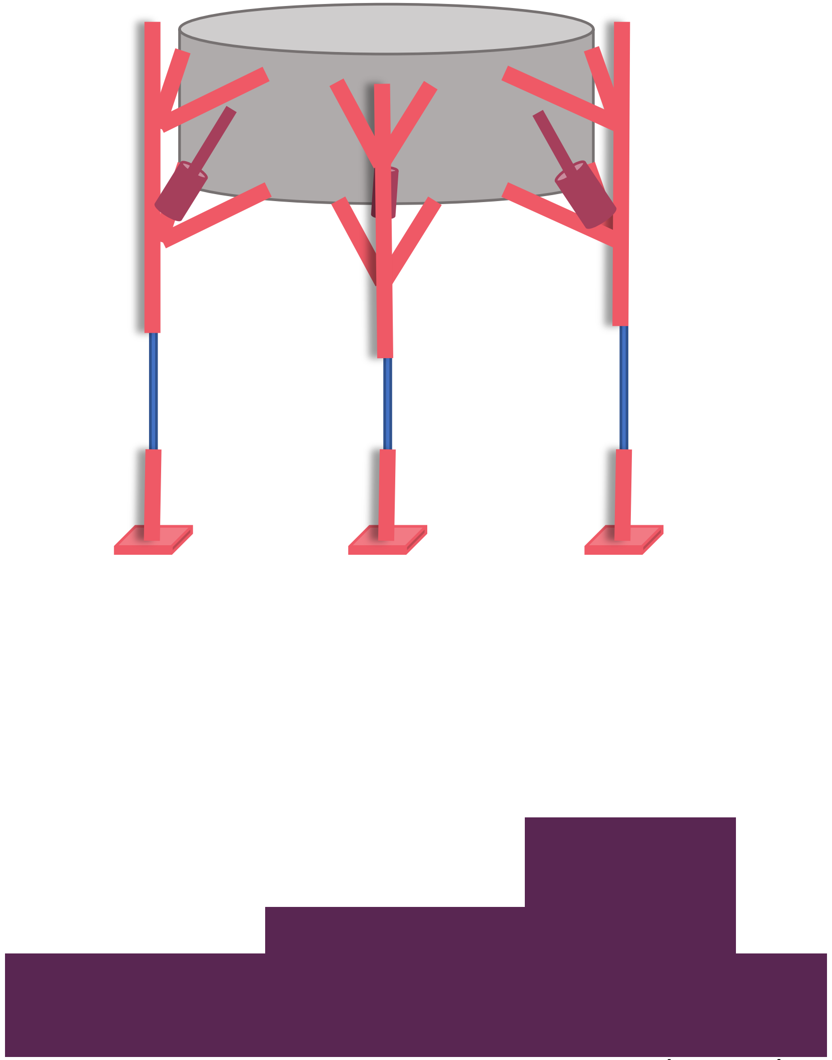
Start → Retract Legs → Extend Legs Halfway



Andrew Sak

Lander Algorithm

Retract Legs → Extend Legs Halfway → Calculate Adjustment Lengths from Distance Sensors



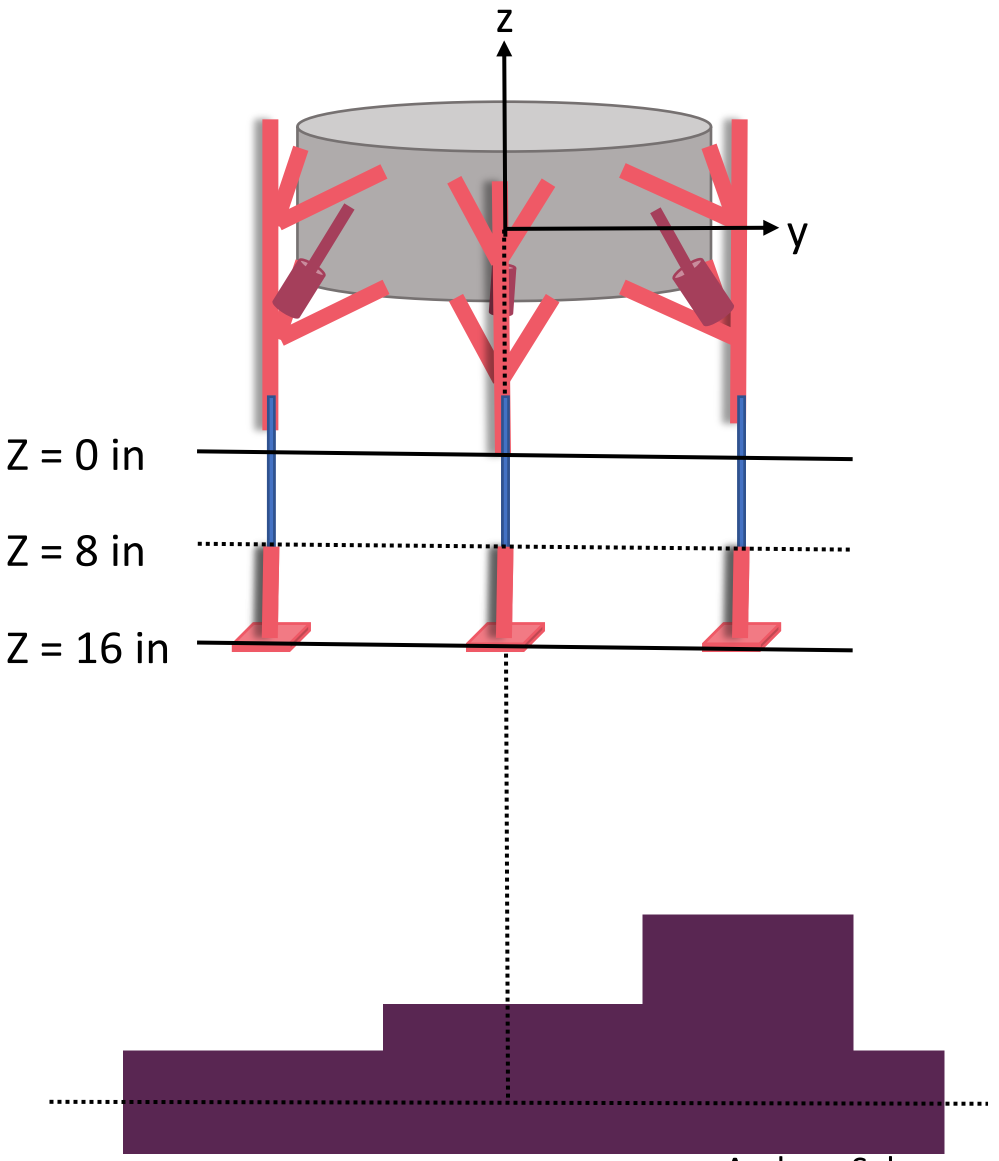
Andrew Sak

Lander Algorithm

Extend Legs Halfway → Calculate Adjustment Lengths from Distance Sensors

Lander approach is perpendicular to a predetermined plane

Linear actuators are extended halfway



Andrew Sak

Lander Algorithm

Extend Legs Halfway → Calculate Adjustment Lengths from Distance Sensors → Adjust Legs

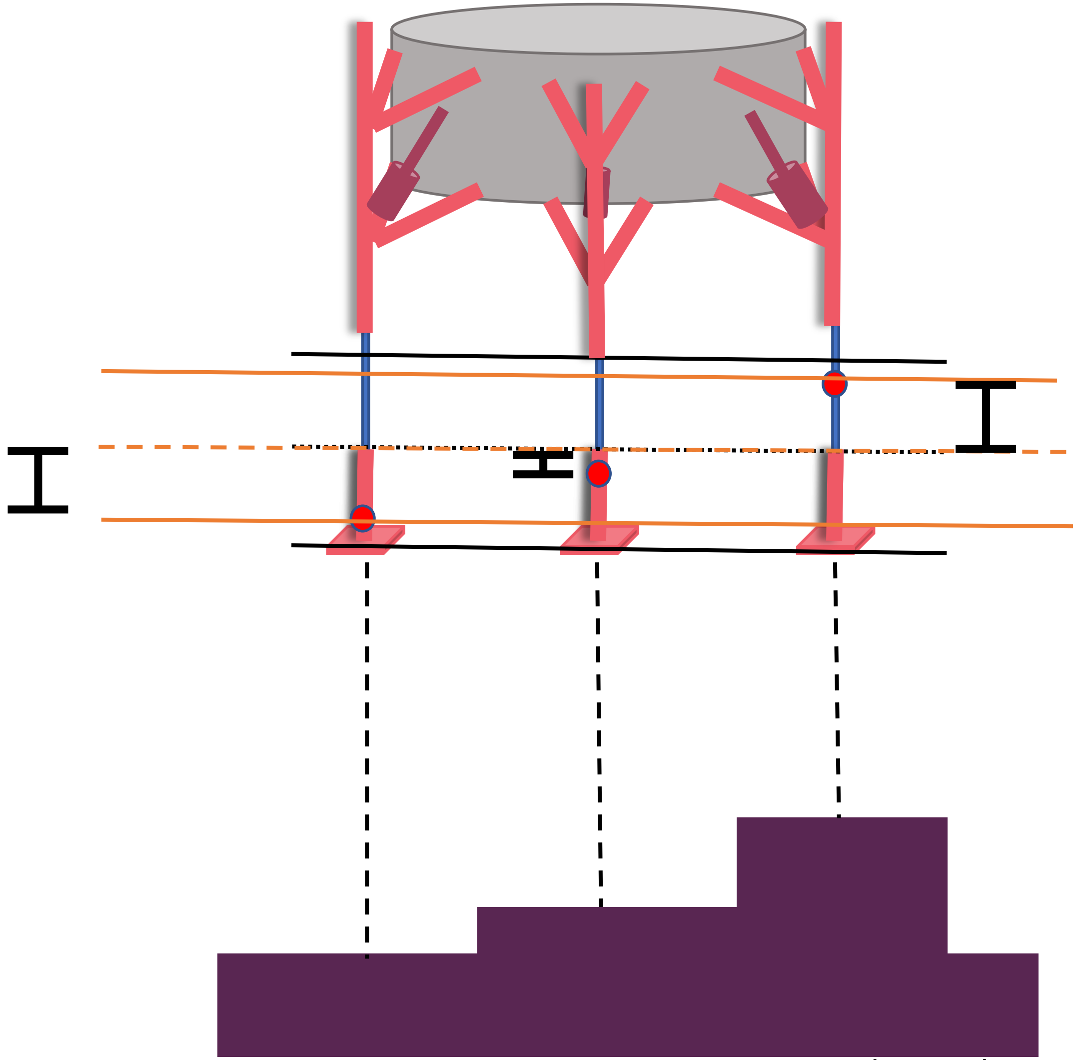
1. Read distance from sensor to terrain below

2. Find the closest point and farthest point on surface

3. Find midplane between closest and farthest point

4. Find distance from midplane to each point on surface

5. Overlay distances on lander leg frame



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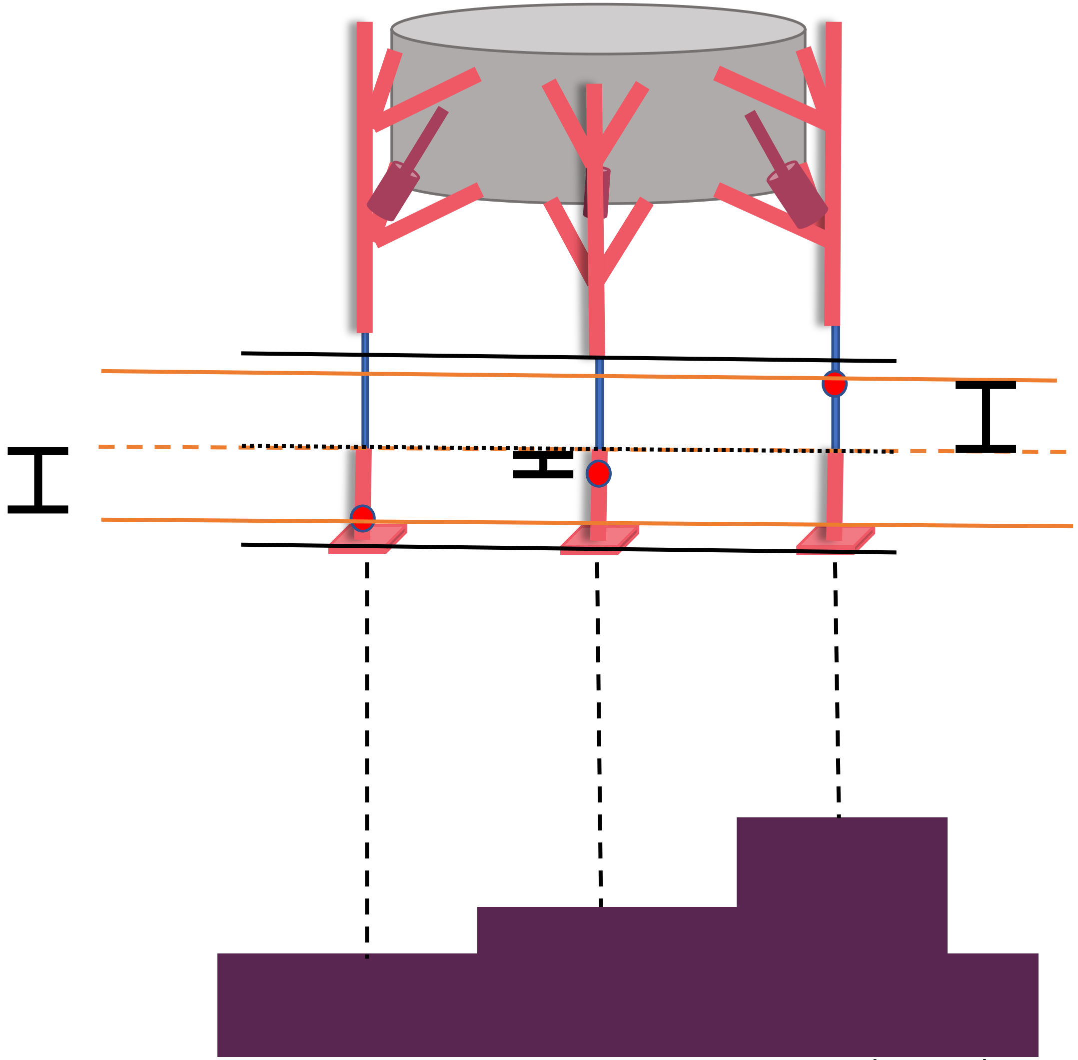
Lander Algorithm

Calculate Adjustment Lengths from Distance Sensors → Adjust Legs

Points below the midplane cause actuators to extend

Points above the midplane cause actuators to retract



Andrew Sak

Lander Algorithm

Calculate Adjustment Lengths from Distance Sensors → Adjust Legs

Points below the midplane cause actuators to extend

Points above the midplane cause actuators to retract

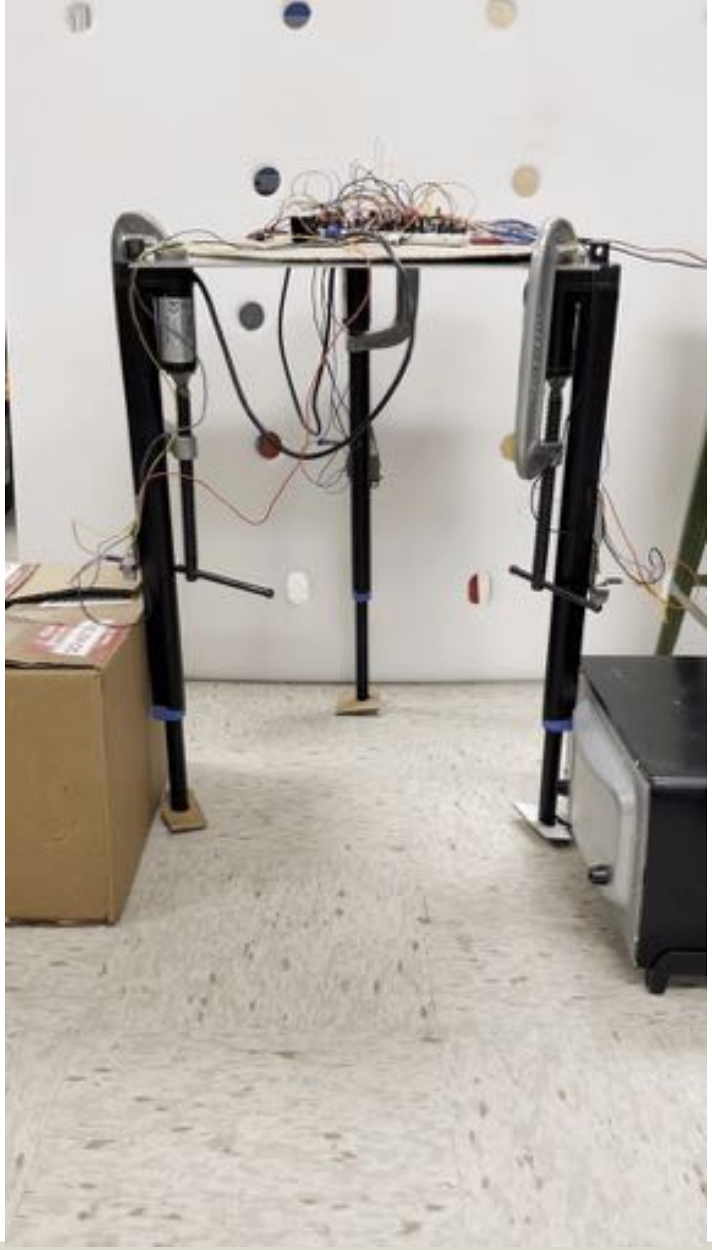
Andrew Sak

Lander Algorithm

Calculate Adjustment Lengths from Distance Sensors → Adjust Legs

Points below the midplane cause actuators to extend

Points above the midplane cause actuators to retract



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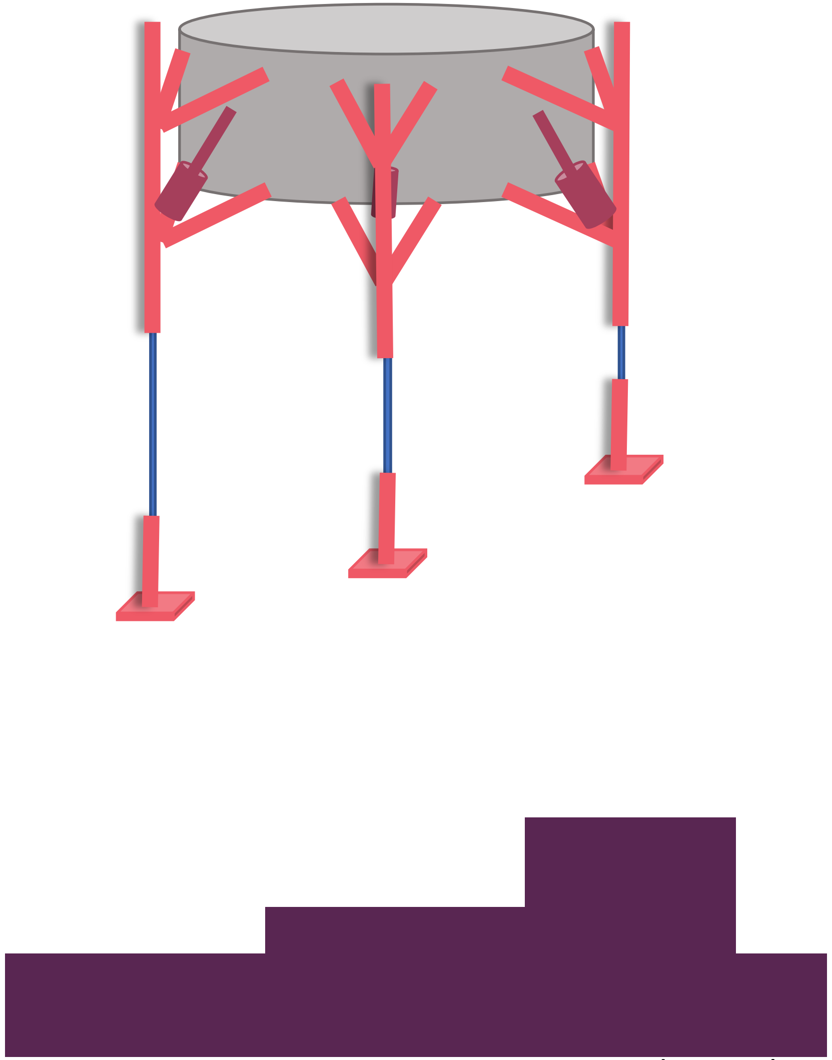
Lander Algorithm

Calculate Adjustment Lengths from Distance Sensors → Adjust Legs → Wait for Impact

Points below the midplane cause actuators to extend

Points above the midplane cause actuators to retract



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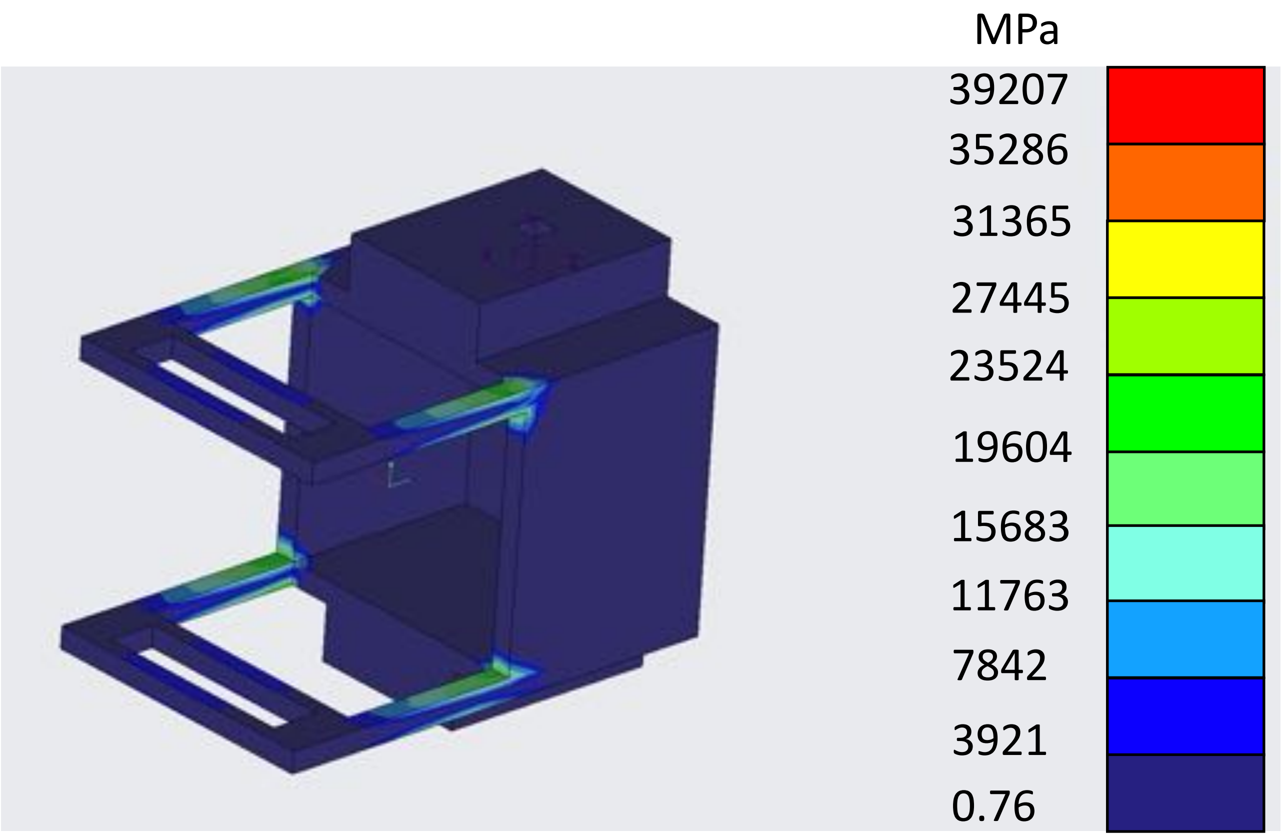
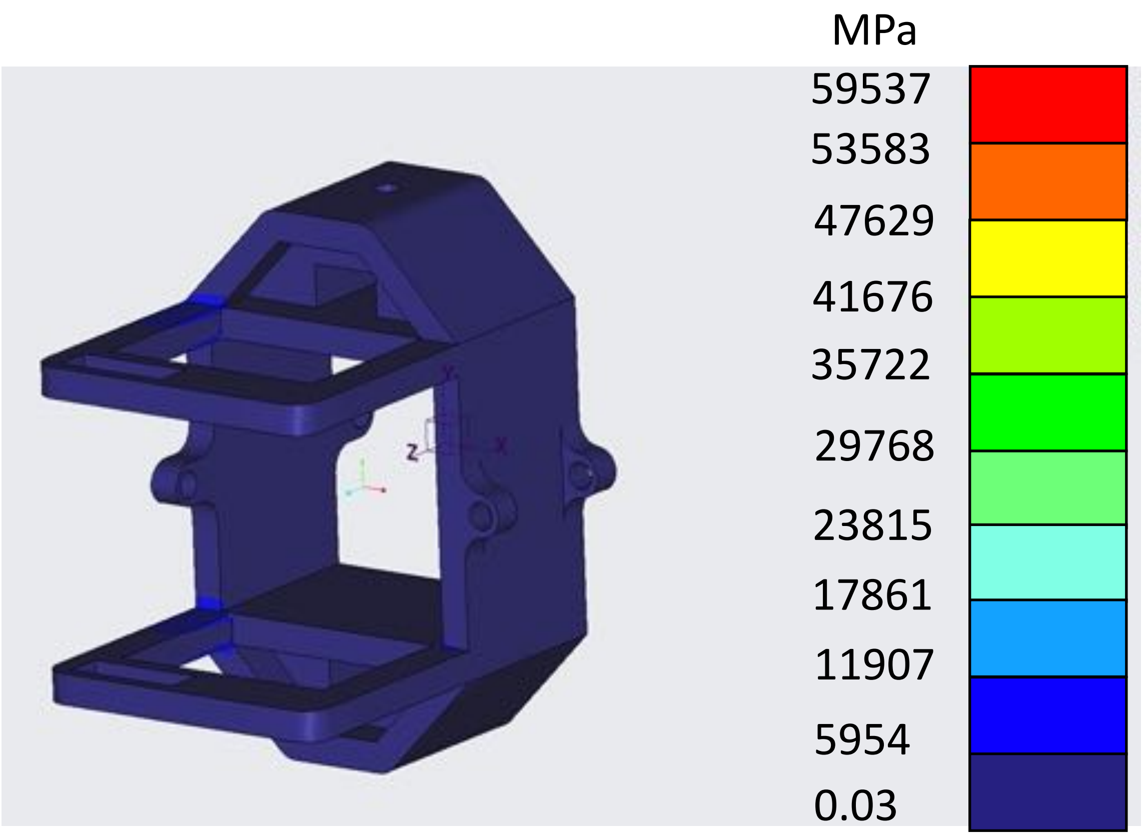
Creo Simulation: Knuckle



Original Design of Connector



Modified Design of Connector

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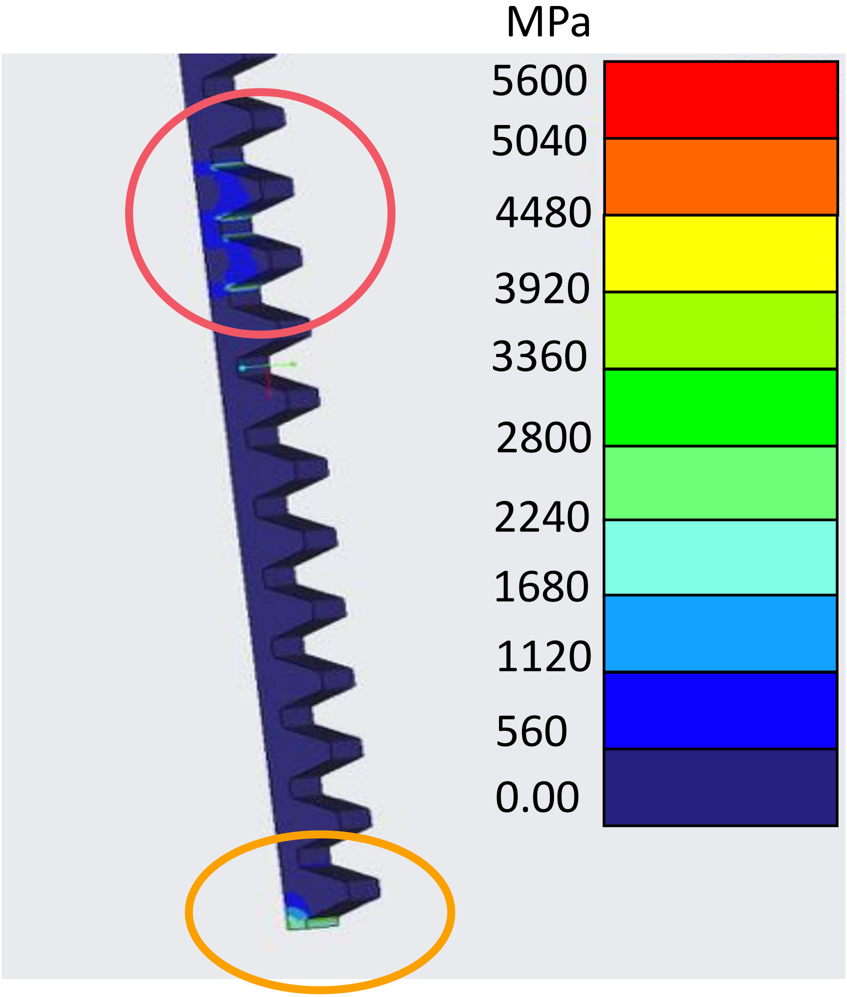
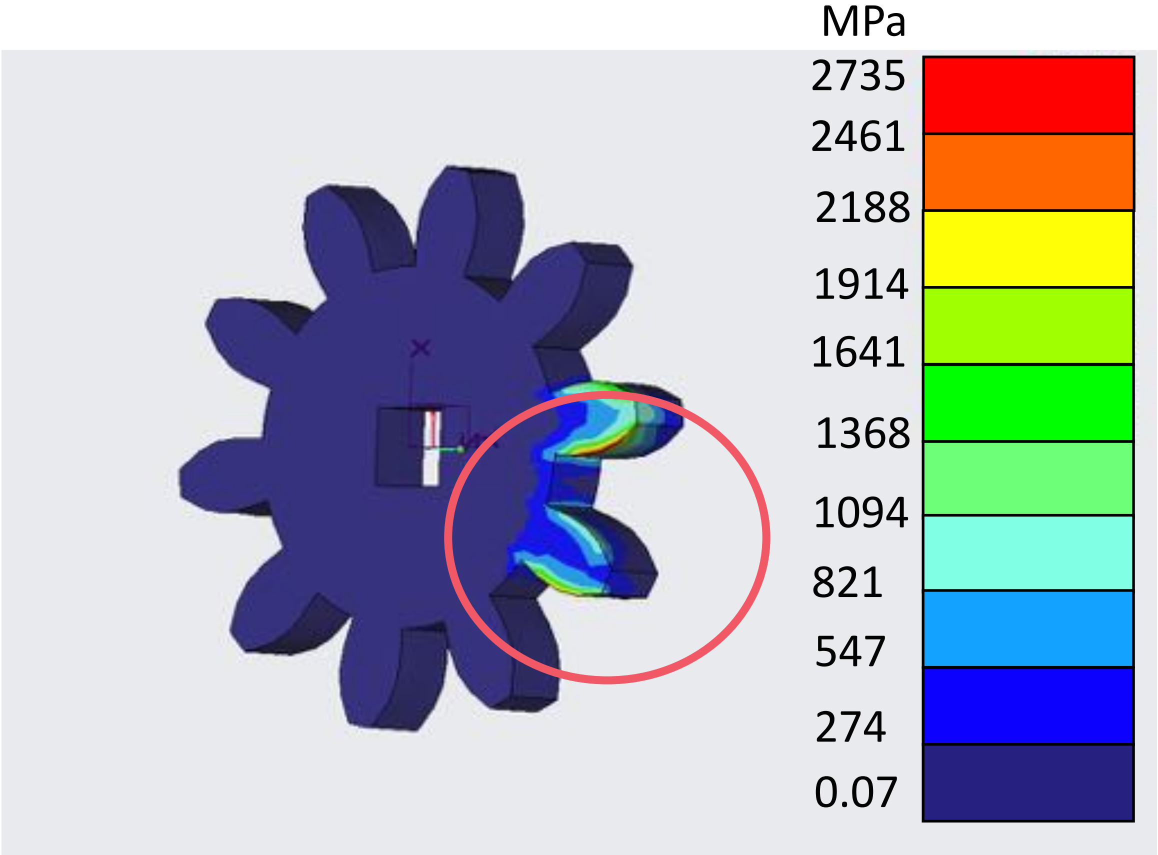
Creo Simulation: Rack and Pinion



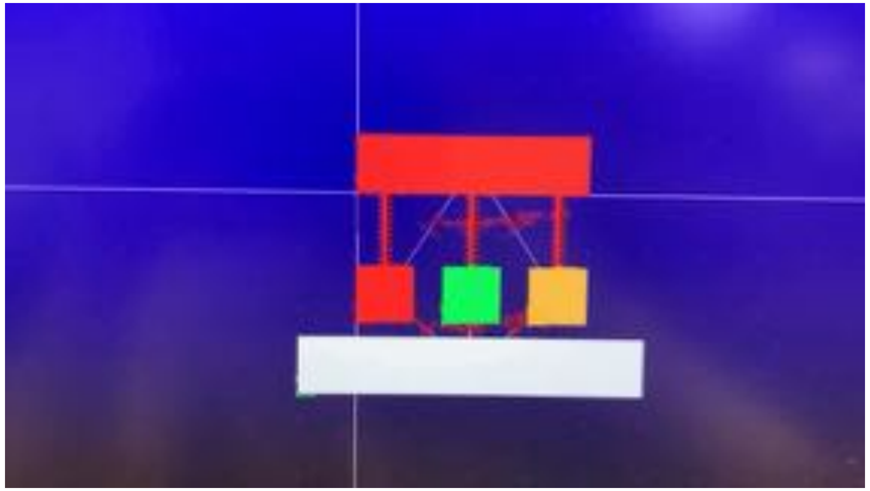


Contact Point with Ground

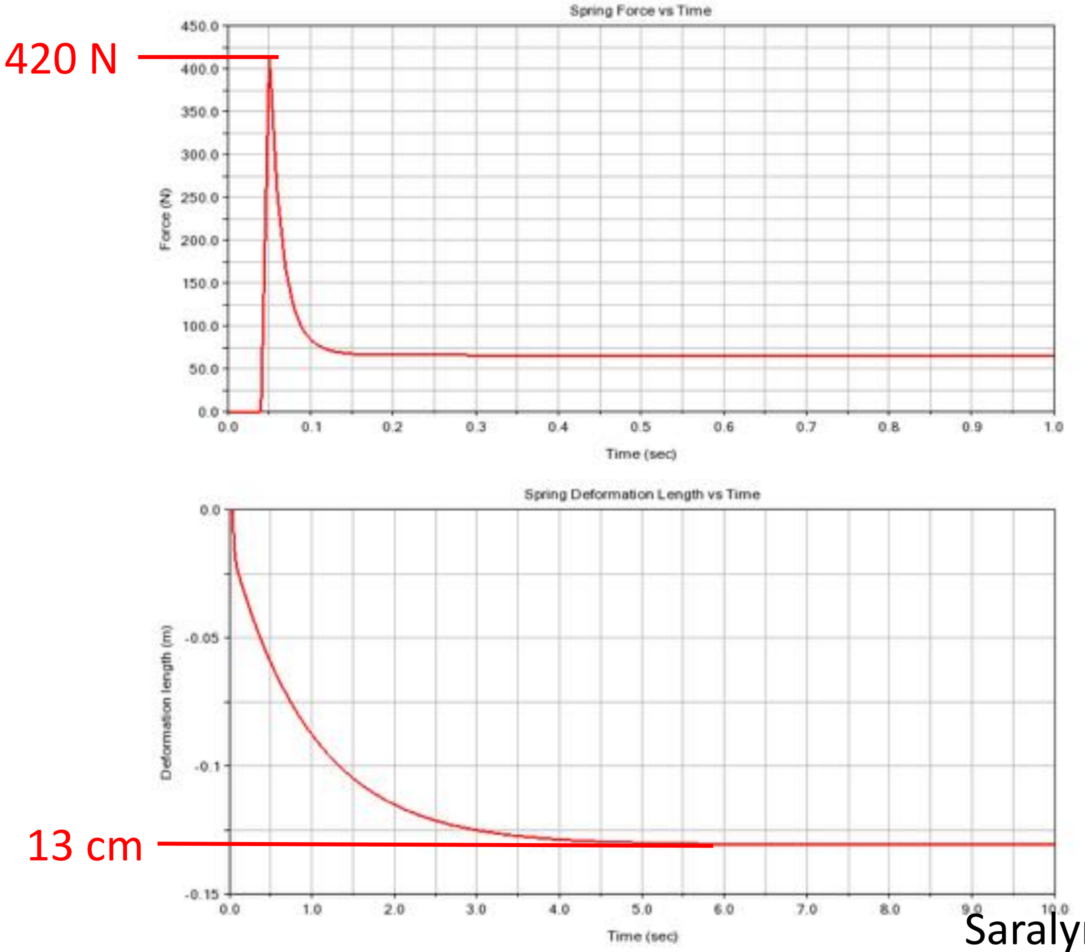
Contact Point Between Gears

Saralyn Jenkins

Simple Adams Simulation



Successful Dampers



Saralyn Jenkins

Binary Pairwise

Binary Pairwise Matrix						
	The system is autonomous	Supports the spacecraft and associated components	Withstands or dissipates the potential energy from the fall and impact velocity	Adjusts to the hypothesize d terrains of Psyche	The system does not have to be reusable	Total
The system is autonomous	-	0	0	0	1	1
Supports the spacecraft and associated components	1	-	0	1	1	2
Withstands or dissipates the potential energy from the fall and impact velocity	1	1	-	1	1	3
Adjusts to the hypothesized terrains of Psyche	1	0	0	-	1	1
The system does not have to be reusable	0	0	0	0	-	0

- Customer needs are listed in rows and the same customer needs listed in columns
- Compared against each other to determine ranking of customer needs
- 1 is assigned if row customer need is more important than the column customer need; 0 for vice versa

House of Quality

		Engineering Characteristics							
Improvement Direction		↓	↑	↑	↑	↑	↑	↓	↓
Units		m^2	kg	m; m/s; m/s^2;deg	deg to tip	N	m	deg	m
Customer Requirements	Importance Weight Factor	Houses Components/Hardware	Supports Weight	Reads Lander Data	Prevents Tipping	Dampens Impact Energy	Senses Sourrounding Topography	Adjusts Orientation	Secures Position on Asteroid
The system is autonomous	1	1		9	9		9	9	9
Supports the spacecraft and associated components	2	3	9		3	3		3	3
Withstands or dissipates the potential energy from the fall and impact velocity	3		9	3		9			1
Adjusts to the hypothesized terrains of Psyche	1			9	9	1	9	9	9
The system does not have to be reusable	0	1				3			3
Raw Score	206	7	45	27	24	34	18	24	27
Relative Weight %		3.40	21.84	13.11	11.65	16.50	8.74	11.65	13.11
Rank Order		8	1	3	5	2	7	5	3

- Gives a ranking of the engineering characteristics governing our project from most important (1) to least important (8)
- Importantance weight factor chosen from Binary Pairwise
- Determined if engineering characteristic contributed to fulfilling customer need
    - Values of 0,1,3, or 9 assigned; 0 being no contribution and 9 being the highest level of contribution

Pugh Chart

Engineering Characteristics	Concept 7	Concept 2	Concept 6	Concept 8
Houses Components\Hardware	- DATUM -	S	S	S
Supports Weight		-	+	+
Reads Lander Data		S	S	S
Prevents Tipping		+	+	+
Dampens Impact Energy		+	S	S
Senses Sourrounding Topography		S	S	S
Adjusts Orientation		+	+	+
Secures Position on Asteroid		-	S	S
Total Pluses		3	3	3
Total Minuses		2	0	0

- Four Pugh Charts were used in total; this is the last one of the series
- Started by choosing a datum to compare the concepts too; Mars Phoenix Lander
- Every chart after the first had a new datum which was a concept similar to the last datum
- (+) assigned if that concept fulfills that engineering characteristic better than the datum; vice versa for (-); (S) if it's the same

Analytical Hierarchy Process

	Supports Weight	Dampens Impact Energy	Prevents Tipping	Secures Position on Asteroid	Reads Lander Data
Supports Weight	1.00	3.00	1.00	1.00	0.33
Dampens Impact Energy	0.33	1.00	1.00	0.33	0.11
Prevents Tipping	1.00	1.00	1.00	1.00	3.00
Secures Position on Asteroid	1.00	3.00	1.00	1.00	9.00
Reads Lander Data	3.00	9.00	0.33	0.11	1.00
Sum	6.33	17.00	4.33	3.44	13.44

- Engineering characteristics are ranked against each other with 1 denoting equal weight and 9 denoting a strong preference to one over the other
- The first one gets a weight factor for each characteristic
- This same process was done for each individual characteristic against the three final concepts

Prototyping Process

1. 3D Printing
2. Sizing of Prototype
3. Testing and Reinforcing of Feet
4. Experimentation of Sensors and Legs

Elzbieta Krekora

Elzbieta Krekora

Prototype/Testing

Saralyn Jenkins

Results

Confirming Impact Velocity

- Distance sensors used to find velocity and displayed on LCD
- Camera outside test rig to measure frames to find velocity

Confirming Orientation

- Final orientation of IMU displayed onto LCD screen

Confirming Secured Position

- Landing base will be inspected for any damage to parts inside
- Any bounce or slide of prototype will be measured via a camera during testing

Andrew Sak

Assumptions

Test model and forces are analogous to Psyche mission variables

Attaches to future spacecraft without issue

Controlled Autonomously

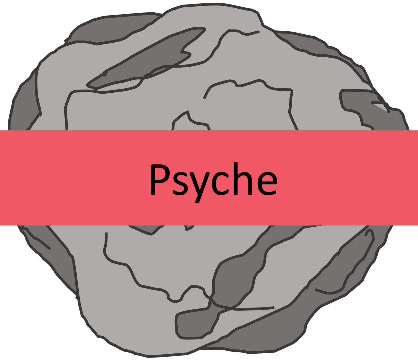
Operated in minimal gravity, space like temperatures and conditions

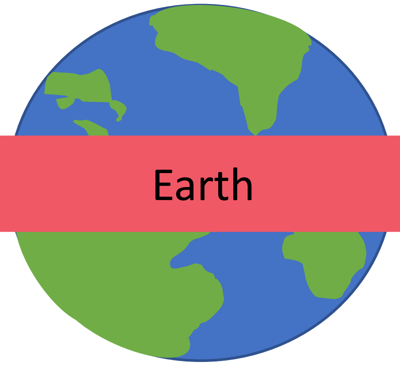
Perform a soft landing on Psyche

Power supplied by spacecraft

Elzbieta Krekora

Transfer of Design





Idk if we need this,
But I made it just in case we
Want to clarify

Honey comb -→ shock absorber
Spacegrade materials --> aluminum and plastic