Final Report Summarizing the Design and Build for the Titan Spacecraft Project

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Submitted on:
April 13th, 2023

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DISCLAIMER

This report was prepared by engineering students for MECH 223 at the University of British Columbia. The contents of this report are meant to fulfill the requirements of MECH 223 and not for any other purpose. Please note that the readers are accepting full liability for applications of any kind involving the methods discussed.

SUMMARY

In the final report we have included a description of team 10's full design process for the Titan project including our:

- Project Strategy
- Concept Generation
- Concept Evaluation
- Concept Iteration and Testing
- Final Design Solution.

The final solution for the design challenge includes a dual spring mechanism, where an extension spring is used to launch the orbiter and a compression spring is used to launch the lander. The design uses a photogate to sense the rotations in the wheel axle and converts the readings into distance measurements. To vary the velocities of the orbiter, the extension spring is latched onto a sheet metal comb with many teeth; this enables us to change the spring extension to attain varying velocities.

The majority of the orbiter and launcher weight comes from wood or repurposed plywood, making our design quite sustainable. The launcher stand, v-ramp and a few small components have been 3D printed, but these components take up less than 50% of the net weight of the system. Other remaining components were made of metal which are considered infinitely recyclable, but these do not have a major effect on the sustainability score.

Finally the overall aesthetic of the orbiter and launcher were inspired by race cars and tracks and the system has been painted and designed to match this theme.

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1.0 INTRODUCTION

The Titan launcher is a student-designed mobile launcher developed as part of the Mech 223 course at the University of British Columbia. The project aims to simulate a probe landing on one of Jupiter's moons, Titan. To achieve this, students must build a "launcher" that can transport an "orbiter" across a platform and launch a "probe" into a gravity well located at the center of the table.

In addition to the core objective, the project includes several score multipliers that can improve a team's score in the competition. These multipliers can be earned by achieving a high aesthetic score from other teams and using sustainable materials.

Team 10 took a multidisciplinary approach to the challenge, dividing into three sub-teams. Conor and Michael developed the software and used simulations to optimize launches, while Aidan, Julie, and Horace were responsible for designing and building the orbiter and its accompanying probe launching system. Finally, Grayson and Oscar designed and manufactured the orbiter Launcher.

To maximize the learning experience for all, each team member made small contributions to each sub team. The project provided an opportunity to apply engineering principles to a real-world problem, with a focus on collaboration and problem-solving.

2.0 PROJECT STRATEGY/GOALS

At the beginning of the project, we held a discussion on all the factors affecting the final score of our solution. These factors were categorized as "Multipliers", "Performance Scores", "Base Scores", and "Property Scores". Examples of the scoring categories, their criterion and score ranges are displayed in the table below.

Table 2.1 - *Scoring Breakdown*

Scoring Categories	**Scoring Criterion**	**Score Range**
Multipliers	Aesthetic	1x - 1.16x
	Sustainability	0.8x - 1.2x
Performance Scores	Orbit Time	0.5 - 1
	Orbiter Target Speed	0.5 - 1
	Delay time	1 - 0 (decreases with delay)
Base Scores	Various	Various (Base scores depend on conditions of performance scores, and are included as lower bound score values for these criterion)
Property Scores	Cost	0 - 0.5
	Weight	0 - 0.25
	Volume	0 - 0.25

Our general strategy for the project was to prioritize multipliers and performance and base scores. The multipliers were given high priority because they change the entire final score by multiplying by a factor. Performance and Base scores were also given high priority because they offered a large number of points, and were already in line with the end goals of the project. The property scores were given the lowest priority, since they did not offer many points in total, and did not closely align with the tasks set out in the design challenge.

3.0 FUNCTION DECOMPOSITION

To begin our concept generation stage, we took the design problem and divided it into sub-problems that could more easily be addressed. The top-level problems identified are as follows:

1. Launching the orbiter by stored potential energy
2. Launching the lander
3. Translating the orbiter across the competition surface
4. Releasing the lander

It was important that we considered these four main top-level functions because they had the most effect on the design and build of the project. The most determinative function is “1” and the least determinative is “4”, as the first concept has a large impact on the final build. For instance, once an orbiter launching mechanism is chosen, we become constrained to that launching mechanism, which could affect the type of concept fragments we can use for other functions due to size constraints, weight constraints, or other reasons. Additionally, having chosen whether we use wheels with an axle or skis to slide on, we limit the type of sensors that we can use to time/position the lander release.

For each of the listed top-level functions we developed sub-functions and listed more specific solutions. The solutions were partially inspired by concepts found during an external search. The full function decomposition chart can be found in Appendix A.

4.0 CONCEPT GENERATION

After subdividing the complex problem with our function decomposition chart and researching potential solutions from external resources, we conducted internal research and held brainstorming and brain sketching sessions.

From our first brain sketching session, we came up with potential solutions to the lander and orbiter launching mechanism and the sensor/lander aiming device. Refer to the following document that contains the sketches from that concept generation meeting in Appendix B: Concept Generation 2 - Sketching

The concepts generated from the brain sketching session have been summarized in the chart below.

Table 4.1 - *Concept Fragments Generated*

Function						
Orbiter Launcher which Stores Potential Energy	Ramp	Elastic Band	Spring	Magnet Cannon	Pendulum	Slingshot
Lander Launch which Stores Potential Energy	Curved Ramp	V-ramp	Spring	Treadmill	Pendulum	Flywheel
Sensors	Time From Release	Accelerometer	Magnetic Field	Wheel Rotation to Distance	Vibration sensor	Laser

Following the first brain sketching session we held a whole concept generation meeting where we combined concepts fragments that were previously developed. The sketches integrate the orbiter and lander launch systems and the sensors for determining the lander release. Refer to the document linked below that contains the full concept sketches in Appendix B:

Concept Generation 3 - Sketching (Full Concept)

These full concepts are summarized in a morphological chart in Appendix C.

5.0 CONCEPT EVALUATION

Before winnowing our generated concepts, we discussed the parameters to reach consensus on the importance of each aspect of our concepts. Everyone had different experiences to share and brought up concerns regarding designing for manufacturing, cost of materials, and coding challenges. Additionally, we considered the bonus multipliers and which designs would be possible to pursue with sustainable materials. Refer to Appendix D for the list of evaluation criteria used, and Appendix E for the winnowing chart.

After winnowing, we selected three concepts for further analysis, these three concepts are shown below in Figure 5.1. Since there were only three concepts that passed, we did not conduct ranking, but used a WDM and did some thorough analysis of the concepts. The WDM can be found in the engineering files (Appendix B) under the section titled "Concept Development and Selection".

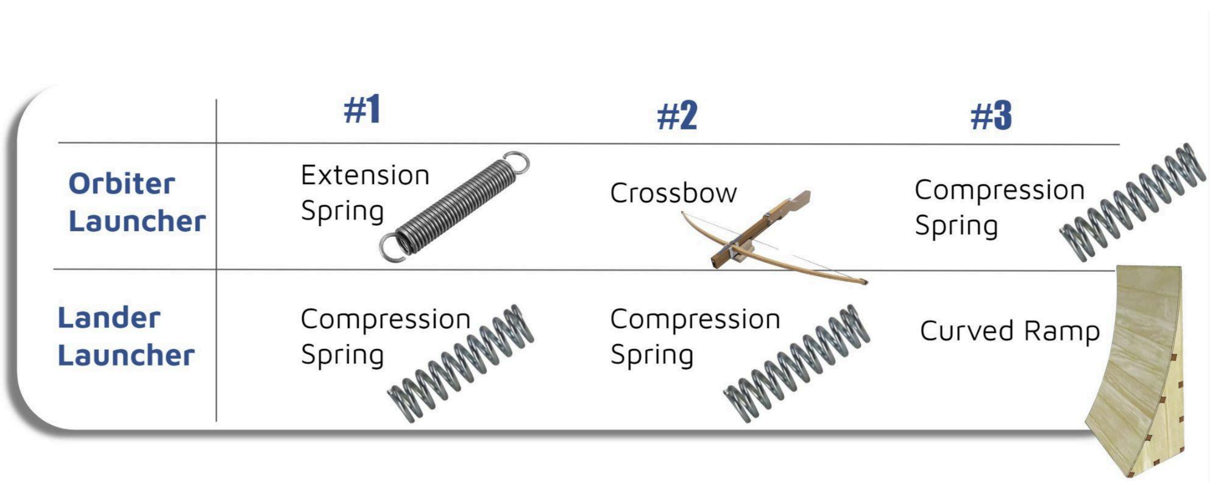

Figure 5.1 - *Top 3 Selected Solutions*

- Design #3 used a compression spring to launch the orbiter and a curved ramp to deploy the lander. We decided not to use this design as we believed it would be challenging to prevent the orbiter from tipping over or lifting its wheels due to its high center of gravity.
- Design #2 used a crossbow to launch the orbiter and a compression spring to launch the lander. While it performed well in winnowing, we had concerns about how large the crossbow would be, and its potential to interfere with the lander launcher.
- Ultimately, we chose Design #1, which uses tension springs to launch the orbiter and a compression spring to launch the lander. This design will be discussed in detail in section 6.0 of our report: Overview of Selected Concept.

6.0 OVERVIEW OF SELECTED CONCEPT

As stated above, our selected concept used the following concept fragments: Tension Spring to launch the orbiter, and Compression spring to launch the lander.

6.1 Orbiter Launcher Function

The final form of the design takes inspiration from handheld slingshots. Extension springs are attached to two vertical braces on either side of the device and an acrylic "push plate". This push plate applies the spring force to the orbiter and is guided by the two horizontal guide rods. The push plate is held back by the curved pegs on either arm of the trigger lever. The extension of the springs can be varied by adjusting which peg the push plate is engaged with. The pegs are spaced 1 cm apart, allowing for 1cm adjustments to the spring deflection. Refer to figure 6.1 below for breakdown of important parts.

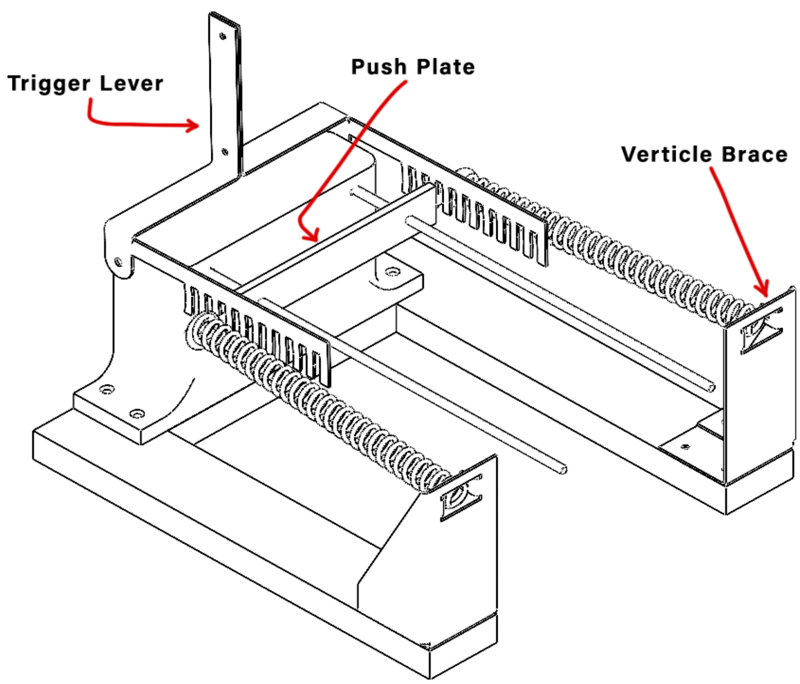

Figure 6.1 - *Orbiter Launcher*

6.2 Orbiter & Lander Launcher Function

The orbiter is a four-wheeled cart with an onboard microprocessor for controlling electronics. The lander launcher is powered by a single compression spring, which pushes directly on the lander sphere. The spring is held in the compressed position by a servo-actuated release mechanism. Attached to the wheel axle there is a photogate-encoder system (see Figure 6.2a) which the microprocessor uses to calculate the velocity and distance traveled by the orbiter. The processor then uses this information to properly time the release of the lander (see Figure 6.2b).

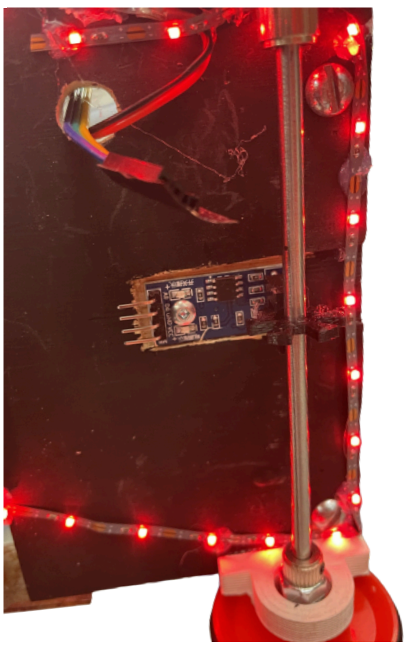

Figure 6.2a - *Bottom of Orbiter Showcasing the Photogate Sensor*

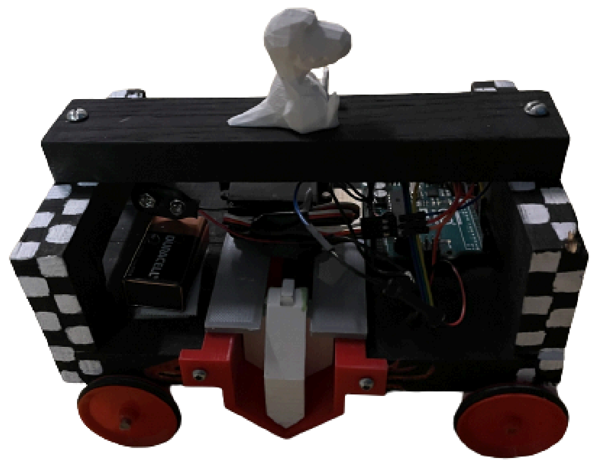

Figure 6.2b - *Orbiter with Integrated Lander Launcher*

6.3 Satisfaction of Competition Requirements

Below are the competition requirements outlined in the project description, along with how our selected concept satisfies each requirement (note that Appendix D contains the detailed target specifications analysis).

1. Orbiter must be able to launch landers of up to 40mm diameter, made of steel, aluminum, wood and plastic.

   The lander launcher mechanism uses a compression spring in a V-shaped channel with a 40mm interior width to launch landers.

2. The launcher and orbiter may only use kinetic, elastic, or gravitational potential. You can combine these forms of energy but may not use other forms.

   Both the orbiter and orbiter launcher utilize springs to store and deliver energy to their respective projectiles.

3. The orbiter and launcher must stay together respectively, you cannot detach parts from the crafts or leave parts on the playing surface.

   No parts are removed or ejected at any point during operation, apart from the orbiter and Lander which are propelled towards their respective targets.

4. Any energy used to launch the lander must be stored on the orbiter, this could take many different forms like a battery or a spring. But it must be stored and triggered on the orbiter.

   The energy used to launch the lander is stored completely within a compression spring onboard the orbiter. Electronics are powered by a single 9V battery.

5. Device is non-hazardous

   The device has no compressed gasses or hazardous materials.

6. Device must be durable enough to run multiple times

   The device has proven to withstand repeat uses, to at least 20 cycles.

7. The orbiter and launcher systems should use environmentally friendly materials whenever possible.

The orbiter and launcher systems make use of recyclable or biodegradable material when possible, and when not possible, upcycled/reclaimed materials are used. With an exception of a few 3D printed PLA, or Acrylic Parts.

7.0 PROTOTYPE TESTING

One of the concepts generated used elastic bands as the source of energy for propelling the orbiter. With elastic bands being lighter and cheaper than metal extension springs, they would be a better design choice. To test the feasibility of using elastics, we devised a prototype test.

The goals of the test were as follows:

- Determine whether elastic bands could reach the target velocity of 4m/s at the midpoint
- Determine the relationship between velocity at the midpoint and pullback distance
- Determine the relationship between total distance and pullback distance
- Determine the feasibility of elastics in the launcher mechanism.

The full prototype testing document is provided in Appendix F. The main conclusions from the test are:

- Reaching 4m/s using rubber bands is possible, but fitting enough rubber bands on our launching mechanism may become an issue with more rubber bands
- The relationships between pullback distance and velocity and total distance appear to be linear. This matches with expectations based on the kinetic and potential energy equations.
- The elastic force applied by the elastics changed after every launch trial. This inconsistency made it infeasible to use in our launcher.

Several observations were made during testing that were considered in our final build. The most important of these observations is:

- The 3D-printed PLA base was noticeably bending during testing, indicating that reinforcement was needed for the final build to have consistent launches and minimize the potential for damage.

8.0 COMPETITION CONCEPT

The final design differs from previous versions in several ways. Through testing we have been able to observe problems and further iterate our design, see Figure 8.1 below for the finalized design and refer to Appendix G for the design's engineering. Described below are some changes we have made between experiment testing and the competition.

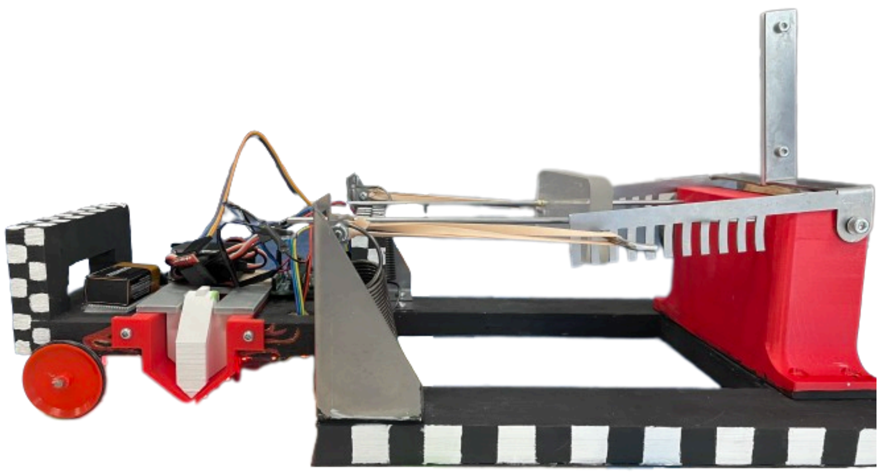

Figure 8.1 **-** *Final Design Preview*

1. Installing Rubber Under the Launcher

During the orbiter launches we conducted, we noticed that when the launcher was not held down, it had a tendency to recoil. This recoil sometimes made the launcher jump out of earth's bounds, or turn, causing the orbiter to travel at an angle. This was a significant problem as we needed to control orbiter trajectory to perform well in the competition, and the launcher leaving earth's bounds is against the rules. As a solution to these problems, we added a rubber sheet below the launcher to increase friction between the launcher and MDF surface. The rubber shown in Figure 8.2a was attached to the launcher as shown in Figure 8.2b.

Figure 8.2a - *Rubber Sheet*

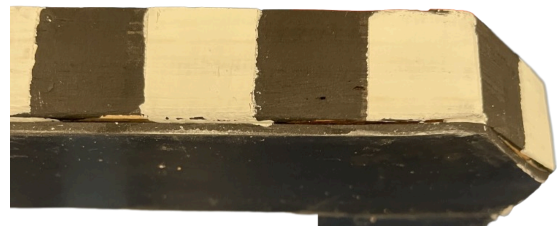

Figure 8.2b - *Rubber Sheet Adhered to the Launcher Base*

2. Decreasing Orbiter Mass

Prior to the competition, we removed material from the orbiter to reduce mass and reach higher orbiter velocities. Most material was removed from the top plate, front plate and back plate of the orbiter without compromising structural integrity (see Figure 8.3a and b). With the orbiter being lighter, we expect a higher speed and less recoil in the launcher from each launch.

Figure 8.3a - *Slimmed Down Top Plate*

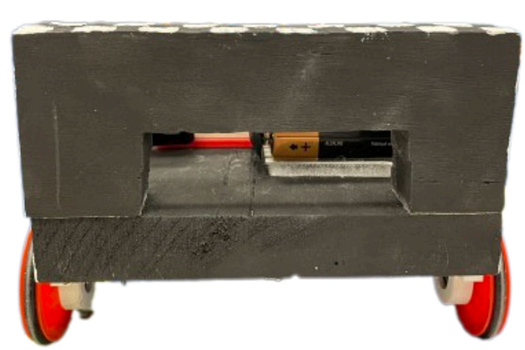

Figure 8.3b - *Cut Out Section Of Front/Back Plate*

3. Orbiter Aesthetic Improvements

To improve our aesthetic score, we painted all wood pieces black with white stripes, added flames onto the orbiter, and attached red LED lights on the bottom (see Figure 8.4).

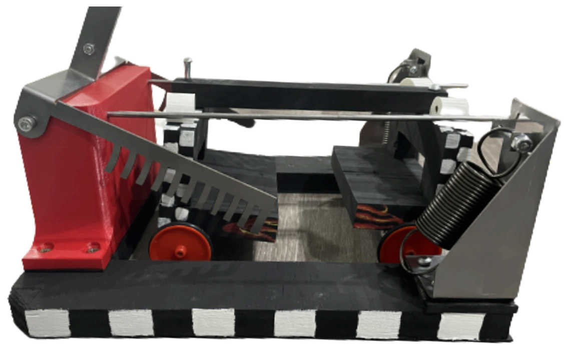

Figure 8.4 - *Painted Orbiter and Launcher*

4. Changes to the Lander Launching Mechanism

    a. Changing the Lander Release Mechanism

To ensure that the servo used was able to easily activate the launch without being damaged we eliminated any designs that involved the servo arm being directly pulled on or being torqued off of its axis. A set of gears were used to double the torque delivered by the servo and to ensure that no torque is directly applied to the motor. The gear mechanism can be seen in Figure 8.5 below.

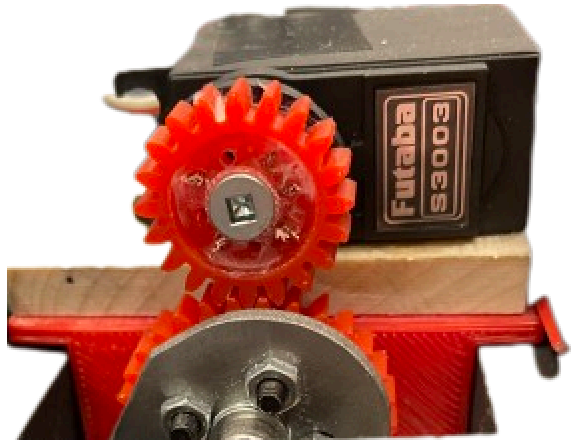

Figure 8.5 - *Servo Gear Mechanism*

b. Increasing Battery Capacity

Between our first lander launch test and our competition design, we changed our power source from 4 AA batteries to a single 9V battery, as it was lighter and took up less space.

c. Improving the Lander Gate

The lander spring plate went through multiple design iterations, going from a single wood plate with an aluminum rod to a 3D printed plate with an aluminum rod. Changing the plate material from manufactured wood to printed PLA allowed us to better form the plate according to the V-ramp's dimensions, and made it easier for us to add the lander holder described in the next section (see Figure 8.6 a and b). Fitting the plate within the ramp was crucial for providing the landers with a consistent push force. To vertically constrain the plate, a U-shaped piece was 3D printed to fit on top of the spring plate (see Figure 8.6b).

Figure 8.6a - *3d Printed Spring Gate*

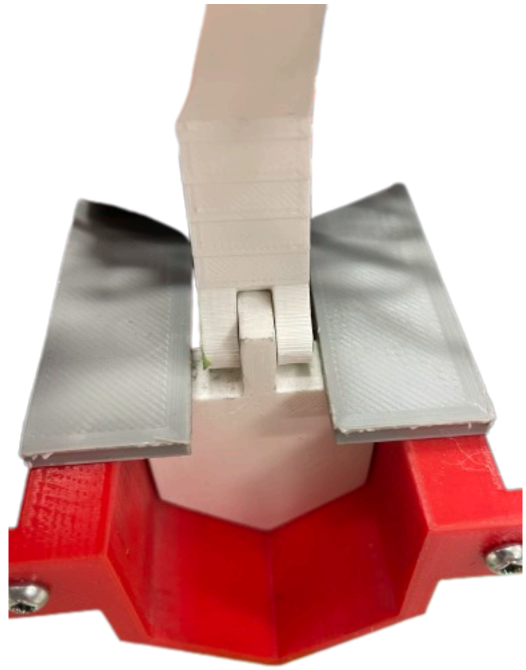

Figure 8.6b - *U-shaped Plate and Spring Gate in the V-Ramp*

d. Improving the Lander Holder

A critical part of the lander launch mechanism is the device that retains the lander during the orbiter launch. We noticed that while the orbiter was in motion the lander would sometimes leave the V-ramp. To solve this issue, we designed a curved flap which attaches to the spring gate and holds the lander back (see Figures 8.7a and b).

Figure 8.7a - *3d Printed Lander Holder*

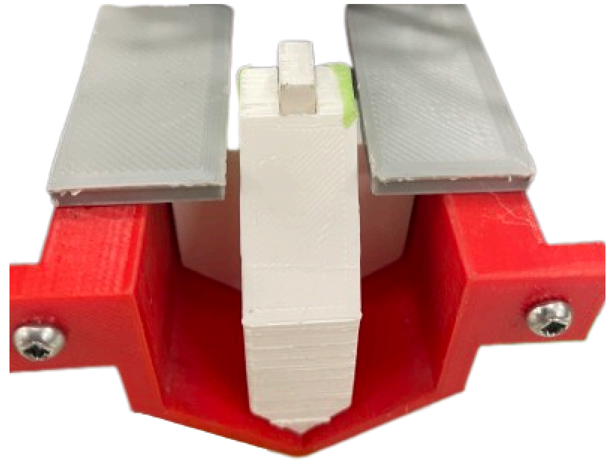

Figure 8.7b - *Lander Holder Laying in Front of Gate within V-Ramp*

Overall, after incorporating all of the aforementioned design changes, we have developed a bill of materials for the full concept. The total cost of the design is $209.49, but a more detailed cost breakdown can be found in Appendix H.

5. Improving Orbiter Directional Consistency

Throughout testing, we noticed that the orbiter struggled to move in a perfectly straight line and consistently curved towards the left. Due to manufacturing imperfections, the left and right sides of the bodies were different lengths, resulting in the axles not being perfectly parallel with each other. This caused the orbiter to regularly curve towards one. To make the two sides of equal length, we used a metal bar to tighten one side, shortening it and eliminating any curving.

9.0 SIMULATIONS

To achieve a high aesthetic score, we wanted to use lightstrips to appeal to the audience; however, the combination of lightstrips and the photogate encoder would take up a significant portion of the arduino's system resources. To reduce the load on the arduino, we ran most calculations in a MATLAB simulator on a laptop. The output of this simulator was an image of the theoretical lander trajectory. The inputs to the simulator are: Earth's position, lander launch position, and lander and orbiter velocities. Combined with calibration data, the lander launch position can be estimated and refined.

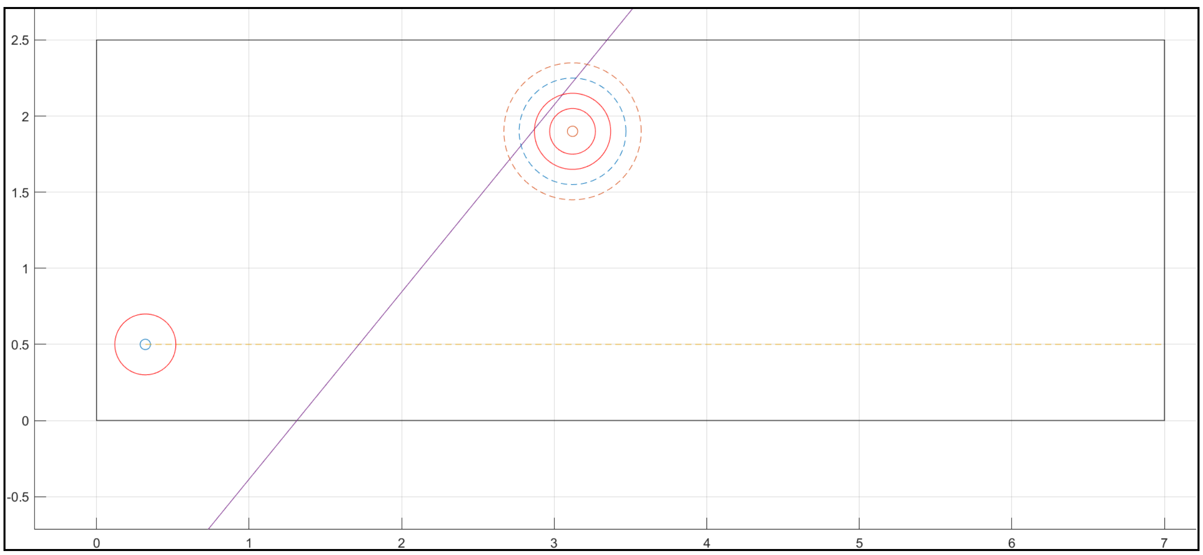

Figure 9.1 - *Round 4 Simulated Guess*

A copy of the simulation used can be found in Appendix I.

10.0 CONCLUSION

Following our prototype testing, we carried out many iterations and improved the orbiter and launcher systems, optimizing them for the competition. The final design considered the competition evaluation criteria and has been developed to maximize some of the major score contributors. The table below summarizes a few of the determinative design changes that were made and the benefits they had in our prioritized scoring categories.

Table 10.1 - *Summary of Major Design Changes*

<table>
<tr><th>Scoring Category</th><th>Orbiter Improvements</th><th>Launcher Improvements</th></tr>
<tr><td>Aesthetic</td><td>Painting Race Car Tracks and Flames</td><td>Painting black and white stripes</td></tr>
<tr><td>Sustainability</td><td>Using primarily wood and metal materials to meet category 2 standards</td><td>Using repurposed plywood and sheet metal to meet category 2 standards</td></tr>
<tr><td rowspan="2">Orbiter Target Speed</td><td rowspan="2">Keeping the orbiter lightweight</td><td>Opting for extension springs over rubber bands</td></tr>
<tr><td>Using pegs to vary spring extension</td></tr>
</table>

APPENDICES

Appendix A - Function Structure Diagram

A detailed function structure diagram can be found following the hyperlink above. The diagram includes the most determinative functions with decreasing influence from the top down. The top level functions are listed on the left column. Branching off the top level functions are the sub-functions on the right hand side. Additional sub-functions of the sub-functions can also be found right of its respective category.

Appendix B - Engineering Files

An instruction document for the location of all documents related to the design process can be found following the hyperlink above. Documents in the Engineering Files can be accessed by their associated hyperlinks. Alternatively, the complete Engineering Files folder can be accessed with a hyperlink at the top of the instruction document.

Appendix C - Morphological Chart

A detailed list of complete concepts with the mechanisms for the orbiter launcher and lander launcher and the type of sensor can be found following the hyperlink above. The list includes 20 complete concepts with different combinations of the concept fragments, which are provided below the table.

Appendix D - Target Specifications

A detailed spreadsheet with the stakeholders, needs, requirements, and evaluation criteria can be found following the hyperlink above. The leftmost side of the spreadsheet includes the groups of stakeholders along with their influence on the project. Following the stakeholders table is a list of the need statements grouped by their need categories. A list of the requirements is provided after the list of need statements. The list of requirements includes the specific entity to be measured with its dimension followed by the acceptable threshold (maximum and minimum) for the entity. Lastly, a list of evaluation criteria is included at the right most of the spreadsheet. The list of evaluation criteria includes the weightings and justifications for the weightings for each of the evaluation criterias for the design.

Appendix E - Evaluations

A detailed spreadsheet for winnowing 20 different complete designs can be found following the hyperlink above. The spreadsheet checks the feasibility, 10 different requirements of the project, and the technical readiness of each of the designs. At the top of the spreadsheet is a color-coding scheme that was implemented for readability.

Appendix F - Prototyping Analysis

A detailed prototype testing report can be found following the hyperlink above. The report includes the main objective of the testing, the assumptions we made for ease of testing, description of the setup and materials used, and the procedure of the testing. A table of the data collected and observations during testing followed by a detailed analysis of the data can also be found in the report. At the end of the report, a list of recommended changes based on the result from the testing is provided.

Appendix G - Engineering Drawing

A detailed list of engineering drawings of the final design can be found following the hyperlink above. The document includes one overall assembly with the orbiter and launcher in orthographic view with relevant dimensions and subassemblies. The document also includes an exploded view of the orbiter and launcher sub-assemblies. One detailed specification drawing (*not to scale*) of the single most complex custom design is attached in the document as well.

Appendix H - BOM

A detailed spreadsheet for the bill of materials can be found following the hyperlink above. The spreadsheet provides the manufacturer, part number, quantity used and cost for each individual part used in the final design. Additional description for the use of the purchased parts in the design is also provided. The total cost for all material used is located at the top of the spreadsheet.

Appendix I - Simulation Code

A detailed simulation code for the launching location for the lander can be found following the hyperlink above. Information regarding the simulation code is found in section 9.0 Simulations.