P2 Final

Presented to: Carlie Trimble

APSC 200-293

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Sunday, April 5th, 2020

Statement of Originality

Our signatures below attest that this submission is our original work. Following professional engineering practice, we bear the burden of proof for original work. We have read the Policy on Academic Integrity posted on the Faculty of Engineering and Applied Science web site: https://engineering.queensu.ca/policy/academic-integrity and confirm that this work is in accordance with the Policy.

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1. Introduction

The client, MECHmania Rocketry, is looking to modify and improve their current parachute deployment system for an indoor model rocket. The rocket must not surpass a maximum height of 12 m and must be fully deployed in no less than 4 m in height. To deem the design successful, the deployment system must be operated passively, the payload and capsule must not sustain signifcant damage, and the rocket must perform 3 successful launches within 10 minutes. Additional criteria that need to be considered are the payload weight, the cost-effectiveness of the design, the fewest number of test launches and the shortest time in between successful launches.

This report goes in depth on the following components.

1. A description of the preliminary processes used to come up with ideas and how other similar concepts were used as inspiration.
2. The full description of the final design and how it works.
3. Why the design solution is a good fit for MECHmania rocketry.

Additionally, this report includes technical data located in the appendices to further solidify claims made in the report.

2. Background

2.1 Comparable Systems

The capsule deployment and parachute system are similar to many different systems currently used. One such system is drone recovery, as seen in Figure 1 [1]. This system uses a drogue chute to pull the main chute out and recover the drone. This is similar to the design used in the indoor tests however, with a drogue chute.

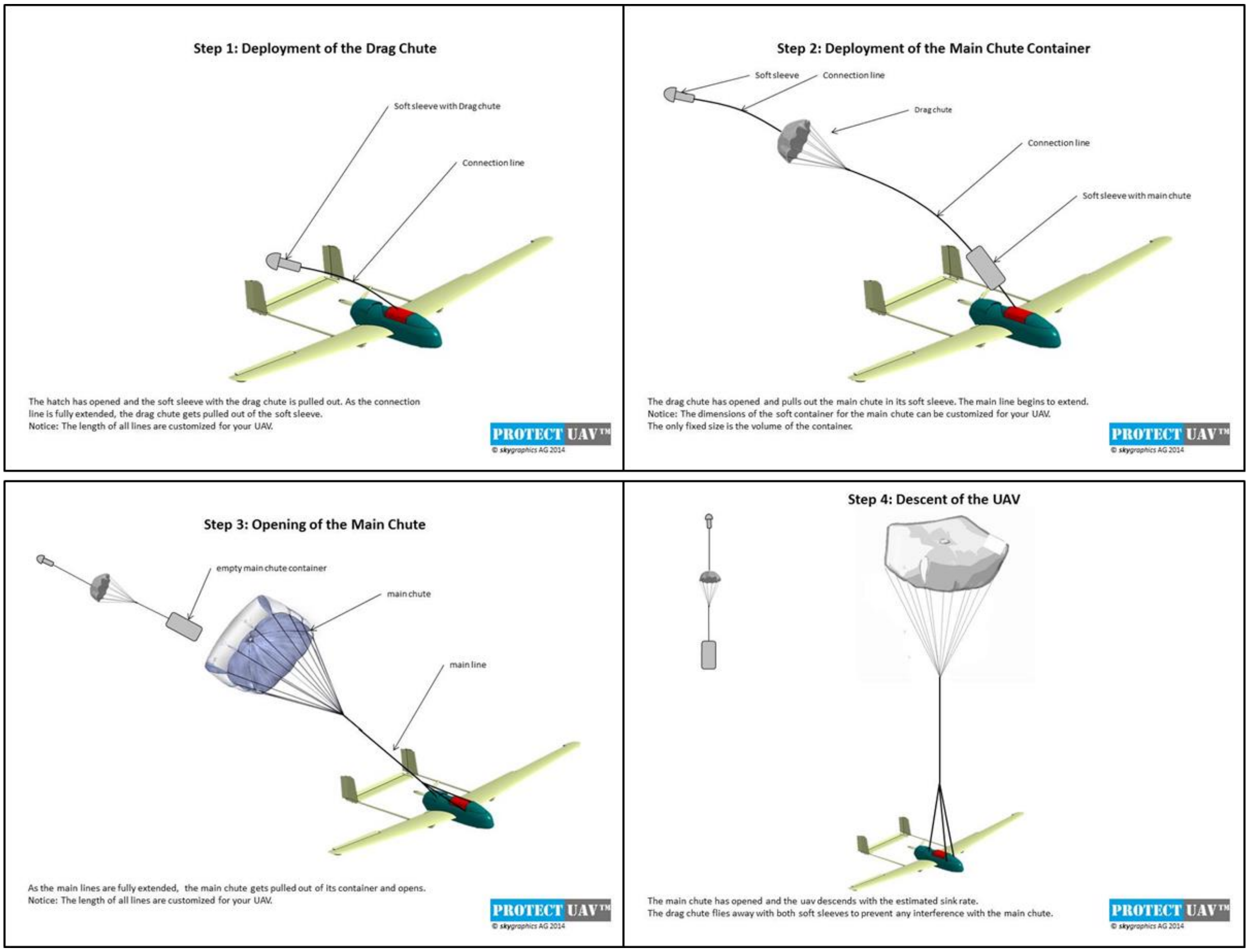

Figure 1: Deployment sequence of drone recovery system.

The parachute needs to be able to exit the capsule quickly to increase the chance of a safe landing. This can be done by tightening the parachute, or increasing the force pulling the chute out. In the final design, this is done by orienting the capsule with the cap facing downwards. This allows the air flowing past the capsule to pull the cap and therefore, pull the parachute out. This is similar to the drone recovery above as the cap is facing opposite to the direction of motion.

Another comparable system is an outdoor model rocket. After a model rocket has used up all its fuel, it behaves nearly identical to the capsule system. A typical model rocket is like the one seen in Figure 2 [2]. The nose cone is removable, and the parachute deploys during the descent to prevent damage to the rocket.

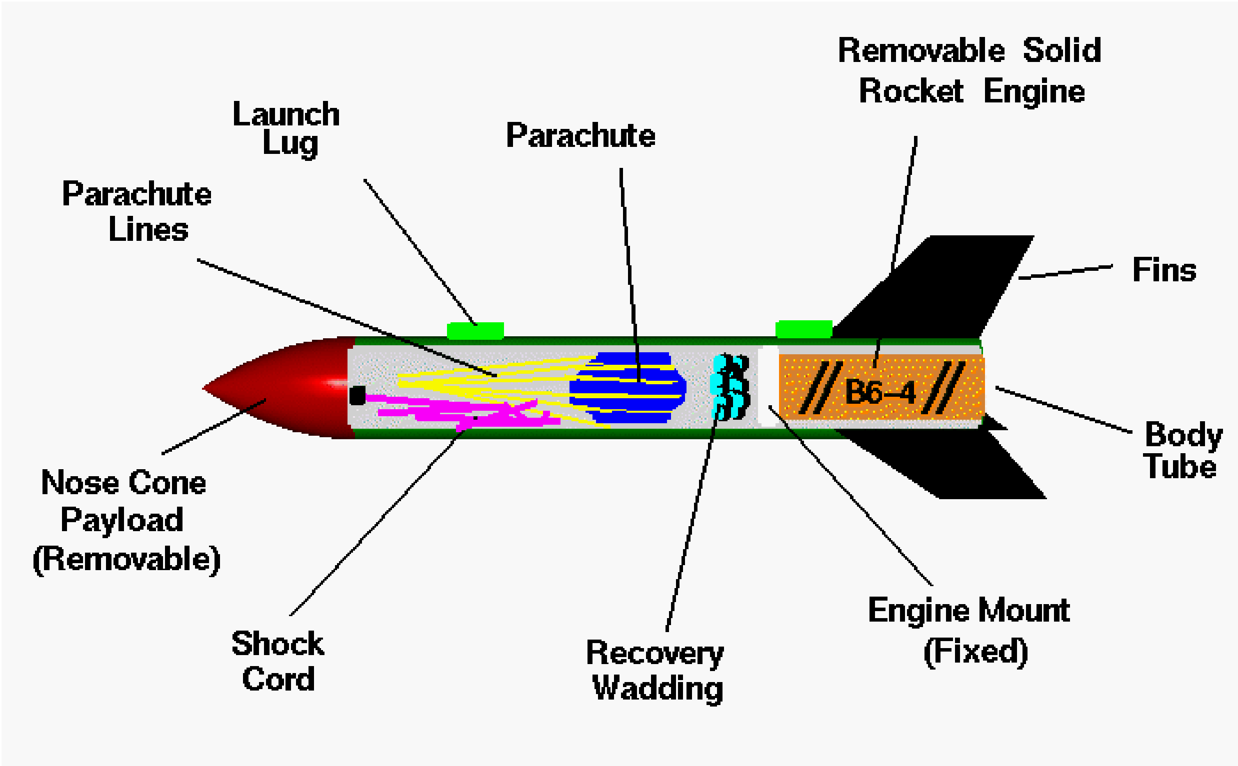

Figure 2: Model rocket cross section sketch

Due to the aerodynamic properties of the rocket, the parachute cannot passively deploy. Instead some kind of active deployment is used to jettison the nose cone and the parachute, allowing for proper deployment.

2.1.1 Parachute types

The parachute needs to be able to provide enough drag to slow the payload to a safe descent rate before landing. This is done by increasing the coefficient of drag to the point where the terminal velocity is so low that it is slow enough for safe landing. There are different types of parachutes, all with their own advantages and drawbacks. Three main parachute types were researched and are, round, cross-form, and ram air. These parachutes are used in many applications including military, skydiving, and model rocketry. Their specifics are explored in the Table 1.

Table 1: Parachute types, advantages and disadvantages

Parachute Type and Photo	Advantages	Disadvantages
Round Parachute [3] 	• Simple Design • High drag • Easy to pack	• Unstable at high speeds • Low max lateral speed (this may be an advantage depending on the context)
X (cross) form parachute [4] 	• Stable during descent • Good option for drogue • Tightly packed	• Lower drag • Square packing may present a challenge for circular capsule
Ram air Parachutes [5] 	• High max lateral speed • Ability to steer • Easily controllable	• Difficult to pack • Impractical • Naturally moves laterally

After analyzing the advantages and disadvantages of these three different types of comparable systems, it was determined that a circular parachute would be the most practical for the project. Calculations were made using Fruity Chutes to determine the descent rate.

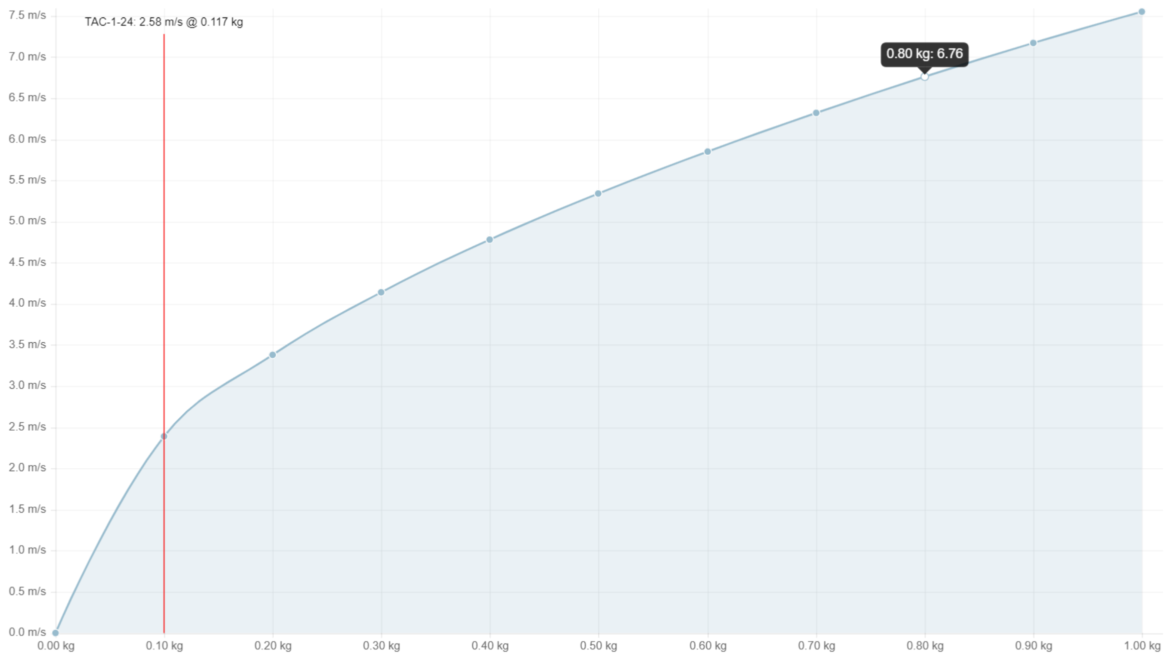

Figure 3: Fruity Chutes descent rate calculator

As seen in Figure 3**Error! Reference source not found.**, it was determined that the descent rate of the p ayload would be 2.58 m/s. This is assuming a circular parachute of 24 inches and a payload of 20 gm [6].

2.2 Design Process

The first step of the design process was to create a firm foundation to build our future iteration on. For this project, the existing design of the parachute was first experimented on. Drop and live tests of the system were carried out. Next, considerations were made regarding the weak points of the design. Elements of the client's provided design such as the packing method of the parachute were improved upon. Solutions were proposed for these issues and implemented into a prototype.

Next, testing ensued. This process not only focused on applying the prototype, and thusly the proposed solution to the problem, in actual conditions, but also mandated organized and thorough documentation. This included videos and photographs of the capsule during its flight of each tests. Certain tests also included an altimeter and damage records. Careful measurements of launch parameters, such as the mass, the launch pressure, and the center of mass, were conducted and a clear description of the launch procedure was recorded. Only with clear documenting of such details can the effects of the specific modifications on the capsule be isolated and iterated upon.

Next, analysis of these effects was performed. For each test, the apogee was visually inspected to determine how the changes in mass, launch pressure, and capsule shape affected the height. Slow-motion analysis of the videos could be used to determine how the behavior of the capsule was altered from previous tests to determine the effectiveness of the modifications.

The findings would then be used to determine the next steps. In certain cases, the measures may have worked but introduced additional issues. In other cases, the failure of the proposed measures gave insight into alternative solutions to the specific problem. Regardless of the outcome, testing and iteration of the design was performed until a solid, reliable solution was devised and proven. This whole design process is summarized in Figure 4.

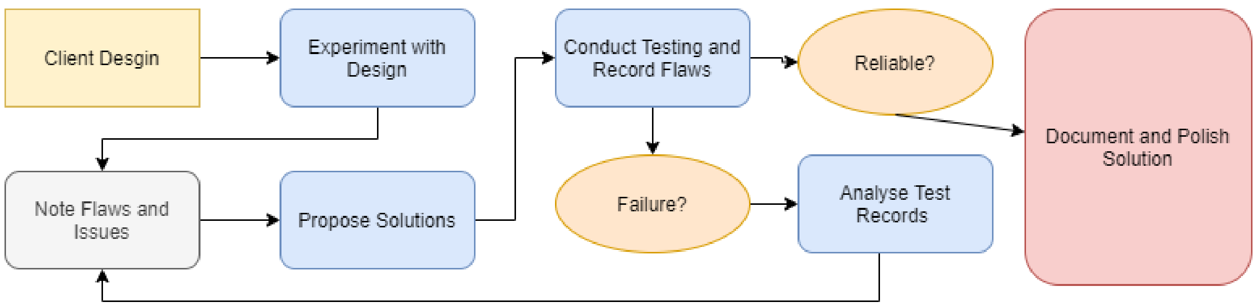

Figure 4 - A flowchart of the summarized design process

Using this design process, multiple iterations and prototypes were created. The design was initially launched with the cap facing forwards and a moderately tightened parachute. This did not function as the parachute would not separate from the capsule. There was significant concern that the parachute would not be able to deploy quickly if it was tightened; this was the main justification for not tying it tighter. Despite this concern, the parachute was tightened for the next launch session. It was able to deploy. However, it deployed below the minimum deployment altitude. During the analysis it was discovered that the parachute was deploying immediately after being tied. This meant that the concern about parachute deployment was not an issue however, the parachute was still deploying too low. In the third launch session a new design was tested which involved cutting significant portions of a capsule. It was hoped that this would allow for the parachute to separate more easily as the capsule would widen due to the cuts. During the launch the parachute got stuck in the jagged edges of the cuts and was unable to deploy. It was determined that using the old method with a tightened parachute and launching it with the cap facing downwards would allow for consistent deployment. This is summarized in Figure 5.

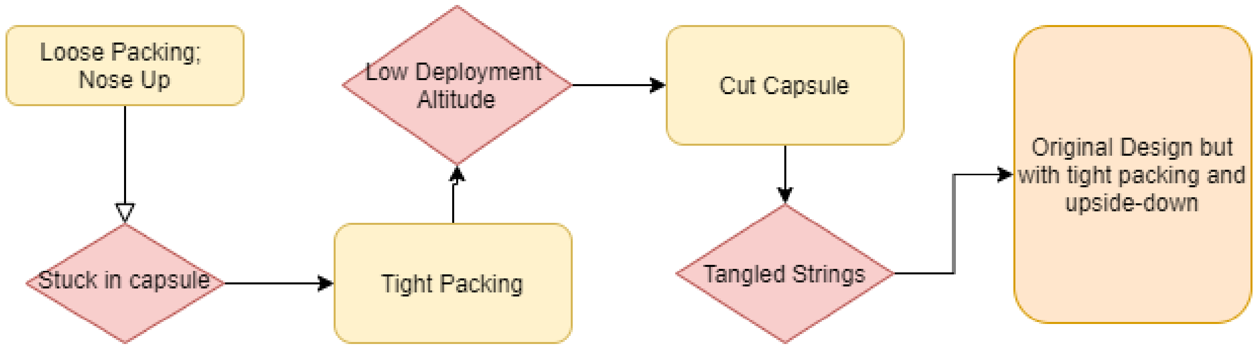

Figure 5 - A flowchart of the simplified choices that arose from the design process

3. Design and Analysis

3.1 Description of Design

The final design is similar to the original design as it does not use additional components. It was determined that new components were not needed for the design to function. The main difference is that the parachute is packed significantly tighter. This allows for the parachute to easily exit the capsule with minimal friction. Having the parachute exit as soon as possible will give it the highest chance of a successful deployment. The parachute immediately deploys once it exits the capsule, therefore there is no concern of it failing to deploy once it has left the capsule. The launch orientation was chosen to be 'cap-down', meaning that the detachable cap is facing downwards at launch. This is to allow the cap to separate earlier as the air resistance will pull the cap off more consistently than if it were facing upwards.

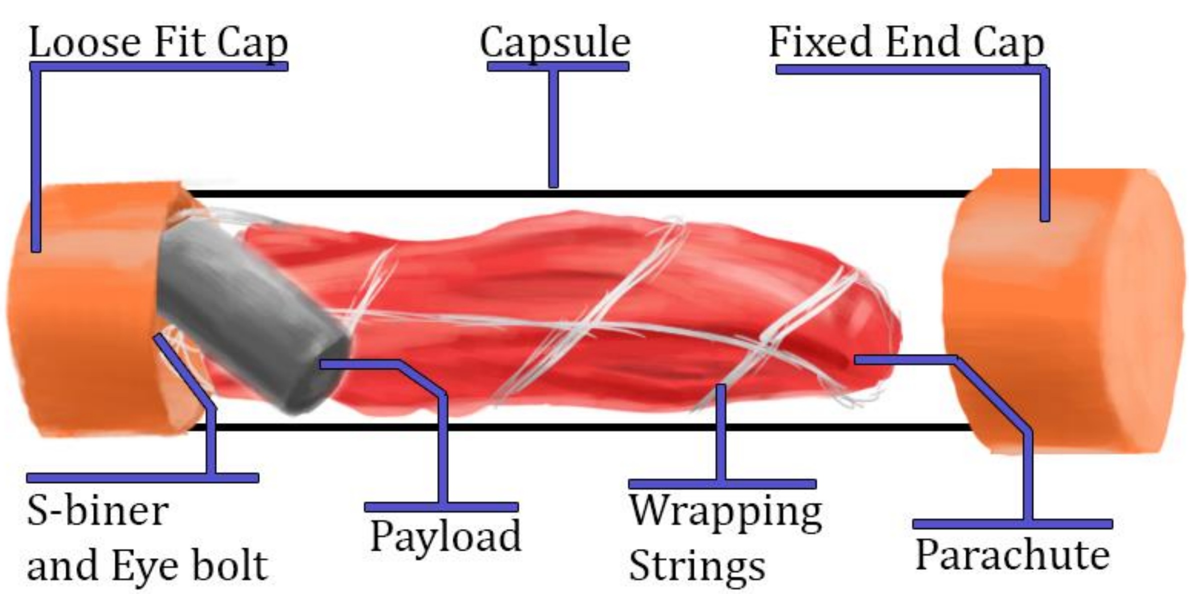

Figure 6 - A sketch of the assembled capsule. Tape not shown. S-biner and eye bolt not visible.

Figure 7 - A perspective warped image of the capsule. The wrapping method seen is an old iteration.

3.1.1 Predicted Sequence of Events

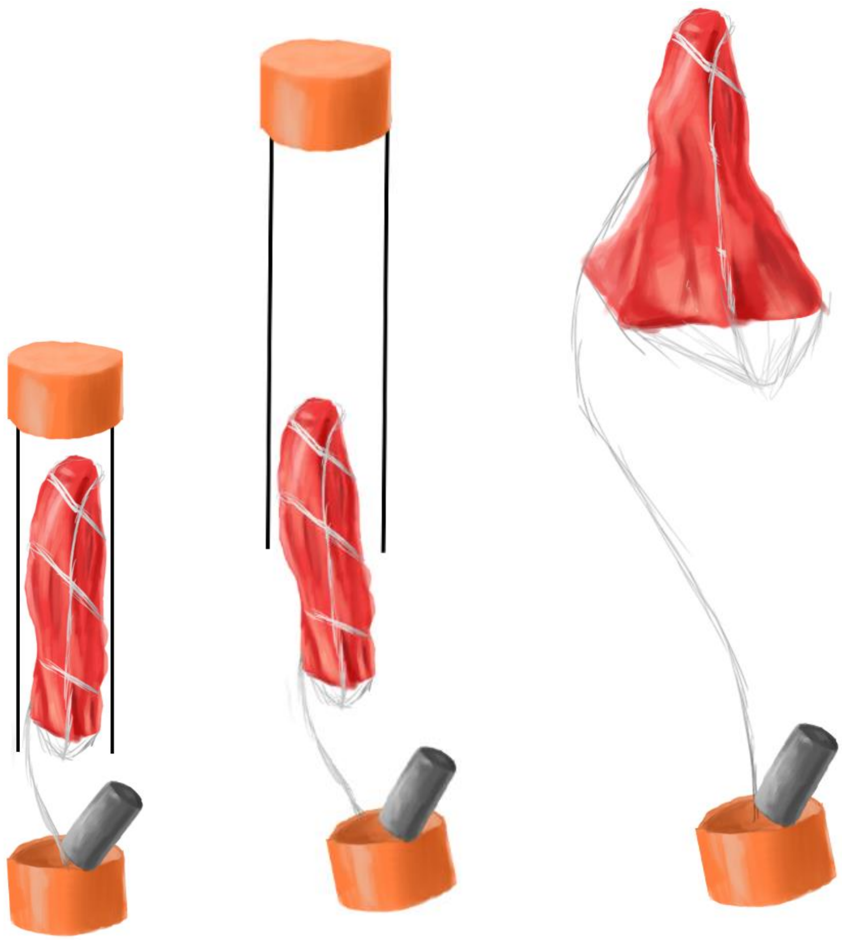

Figure 8 – The first three stages of the parachute's deployment.

Table 2 – A table describing the events of figure 7.

Picture	Location during launch	Description
Left	Immediately following launch	System exits the launch tube. Air that does not impact the bottom cap travels around, adding to the speed of the capsule. Difference in velocity creates initial separation.
Middle	Later than halfway of ascent; prior to apogee	Higher drag on the cap and difference in initial velocity pulls the parachute out of the capsule.
Right	A bit before or after apogee	Parachute and cap separate entirely from the capsule. Wrappings on the parachute start undoing due to turbulent conditions. Bottom of the parachute catches air and starts opening.

Figure 9 - Fully deployed parachute

Table 3 – A continuation of Table 2, describing figure 8.

Picture	Location	Description
Final	Below 10 meters and above 4 meters in the descent.	Parachute complete separates from the bindings and deploys.

3.2 Analysis of Design

The launch used a pressure of 2.4 bar, reaching a height of 11.85 m as seen in Figure 10. This was 3.4% higher than the NASA projected apogee of 11.46 m [2] as seen in Figure 11. In the first launch the parachute was able to deploy and there was no damage. It was not a complete success as the parachute deployed at approximately 3.5 meters, which is below the 4-meter requirement, shown in Figure 17.

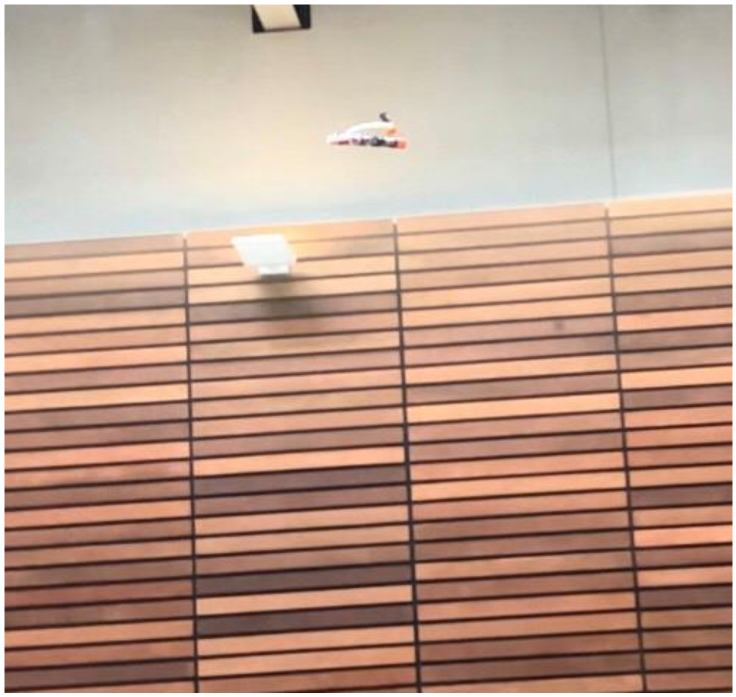

Figure 10 - A picture of the apogee of the launch

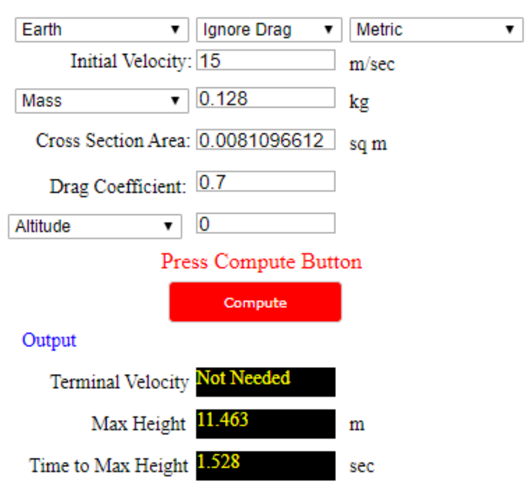

Figure 11 - A calculation of the max height of the launch

3.2.2 Video Analysis of Launch

Though no videos were taken of this proposed design as world events prevented any more testing, analyses of similar designs were taken and can be shown along with the proposed design. The format of the image analysis can be found in Appendix E.

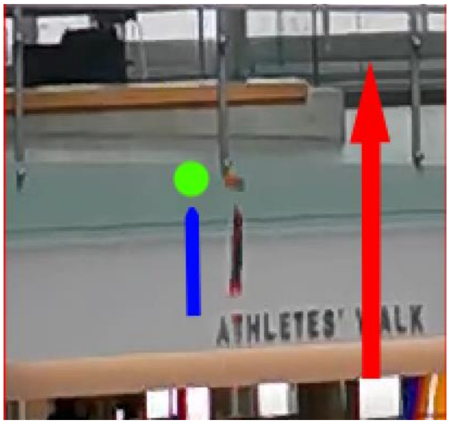

Figure 12 - Photo at t = 0.207s

Capsule exits from the launch tube. Immediate seperation of cap from capsule.

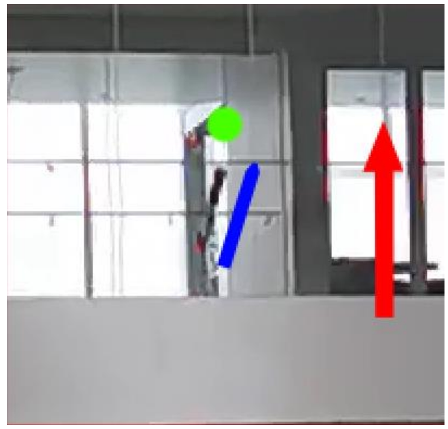

Figure 13 – Photo at t = 0.467s

Cap continues straight. Minor rotation develops in capsule.

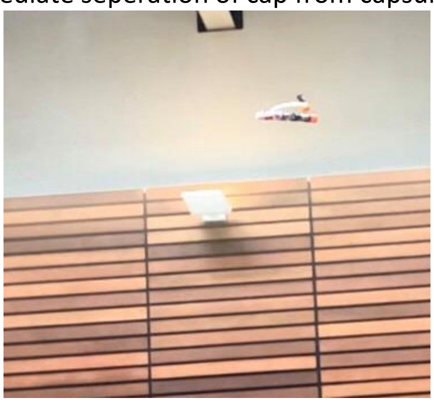

Figure 14 - Capsule at Apogee (Out of frame on main slow-motion analysis) (High enough resolution for no markers)

Rotatation in capsule worsen to the point of being horizontal. Major seperation of cap.

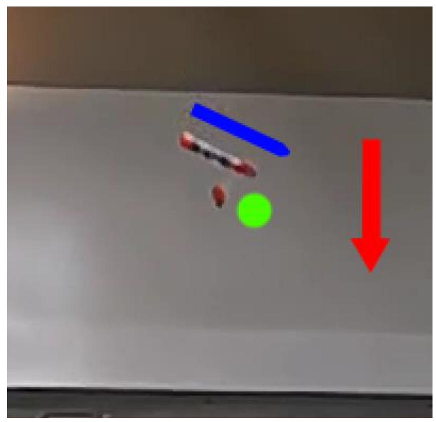

Figure 15 - Photo at t = 2.147s

Capsule tilts to start pointing downwards. Seperation pulls on chute.

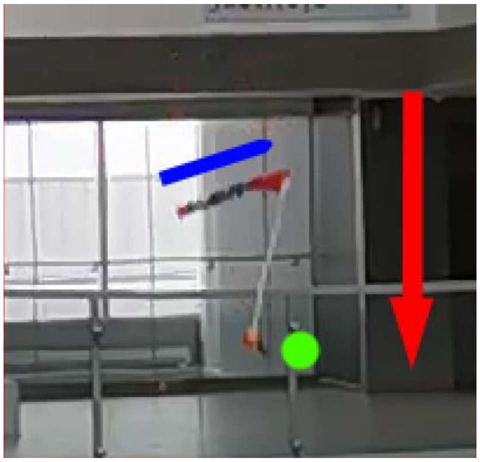

Figure 16 - Photo at t = 2.599s

Chute seperates. Capsule rotates right-side-up as cap stops pulling on it.

Figure 17 - Photo at t = 2.841s

Near immediate full deployment of chute at less than four meter target.

From the video analysis, it can be seen that once the system turns over and there is sufficient seperation of the of the cap from the capsule, the system will deploy. Turning the capsule around should not have a significant effect on the seperation, but by having the capsule upside down, the capsule will meet the other criteria directly. Thus, the design should have all the advantages of the previous design, but likely be significantly more reilable and deploy at a higher point.

3.2.2 Altimeter Data Analysis

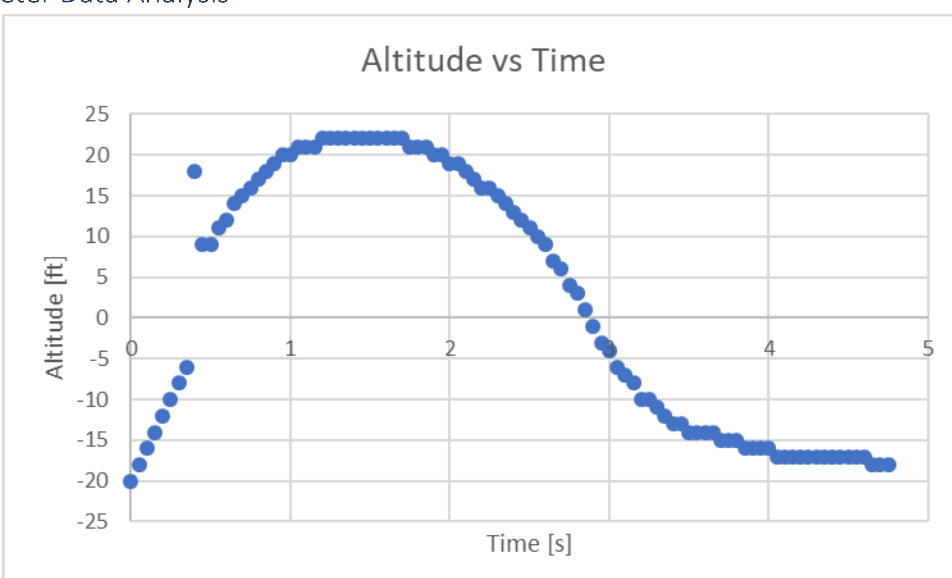

Figure 18: Launch profile

Once the parachute had deployed the data registered a descent rate of 2.7 ± 0.3 m/s. This is slightly faster than the prediction found on Fruity Chutes, however the prediction is still within the standard error.

4. Conclusion

In conclusion, the final design is reliable, has minimal cost, and is simple to understand and use.

Although it is difficult to provide hard proof of reliability due to the lack of opportunities to test, by logically propagating the previous design, and barring any outstanding failure of the new design, it is fair to conclude that this final solution would have a greater success rate than the previous design. As the old designs had a success rate of around 50%, a likely success rate for the new design, which would solve the key flaws of the old design, would be 80+ %.

The system would remain competitive for cost. No additional parts were purchased since the last report, resulting in a total expenditure of 3 CAD. With reference to last year's minimum spent cost, it is likely that we can compete for the grade boost of 0.5%. Moreover, due to the simplicity of the system, it will remain competitive for the timed launches. There are no substantial modifications to the original system, meaning that the launch and packing procedure is quick and well-established from the previous tests. However, coordination and practice will be required to bring the most out of this strength and aim for the 1% grade boost. It may be difficult to compete in the weight category because there is only one chute. However, by carefully choosing masses and considering the variability in each launch, it is possible that the design fares decently, but not competitively in the 1% weight grade boost contest.

These properties are also desirable for the client and not only the competition. The projected reliability of the system is sufficient for these low-altitude indoor rocketry applications, while the low cost is beneficial for both the manufacturers of the product and the users. Simplicity helps expand the audience that the system can cater to while also reducing costs.

In conclusion, in its innovative simplicity, the system prioritizes the needs of the client to provide a versatile and applicable product while striving for a strong competitive edge.

References:

[1] "Drone Parachute Recovery System - Drone HD Wallpaper Regimage.Org." http://www.regimage.org/drone-parachute-recovery-system/ (accessed Apr. 02, 2020).

[2] "Model Rockets." https://www.grc.nasa.gov/WWW/K-12/rocket/rktparts.html (accessed Apr. 05, 2020).

[3] "Amazon.com: Relationshipware StratoChute 24" Red Rip-Stop Nylon Parachute for Water or Model Rocket: Toys & Games." https://www.amazon.com/Relationshipware-Rip-Stop-Nylon-Parachute-Rocket/dp/B004091ZIS (accessed Apr. 05, 2020).

[4] "Dino Chutes 30" X-Form Parachute." https://www.apogeerockets.com/Building-Supplies/Parachutes/X-Form-Parachutes/Dino-Chutes-30in-X-Form-Parachute (accessed Apr. 05, 2020).

[5] "Parachute Types," *Long Island Skydiving Center*. https://www.longislandskydiving.com/about-skydiving-long-island/articles/what-parachute-types-are-there/ (accessed Apr. 05, 2020).

[6] "Parachute Descent Rate Calculator | Fruity Chutes!" https://fruitychutes.com/help_for_parachutes/parachute-descent-rate-calculator.htm (accessed Apr. 05, 2020).

Appendix A: Individual Contributions

Table 4 - Individual contributions

Names:	Content	Write-up	Editing
Ohm Patel	1. C, 4., 3.11, 2.1	C, 4., 3.11, 2.1	General editing
Richard Meng	2.2, 3.1, 3.1.1, 3.2, 3.2.2, E, 4.	2.2, 3.1, 3.1.1, 3.2, 3.2.2, E, 4.	General editing
Bradley Litster	A, B, D, 1., 2.11	A, B, D, 1., 2.11	General editing
Jeremy Walsh	2.1, 3.1,3 .2, 4	2.1,3.1,4, App B, App F	General editing

Appendix B: Cost Break-down

- Note: All the additional costs were from the now defunct cut-capsule method. The final design has no extra components. If the cut-capsule method was not tested, the total cost would be $0.

Table 5: Cost of additional components

Component – Code – Qty	Cost for Components, cost*quantity
Broken Capsule – BRK12, QTY=2	1x2=$2
Cap – ECO, QTY=1	1x1=$1
Total Cost:	$3

Table 6: Cost of base components

Component – Code – Qty	Cost for components
Parachute 24" – P24R, QTY=1	1x24=$24
12" tube with end cap – TUBE, QTY=1	1x9=$9
End cap with eyebolt – ECE, QTY=1	1x2=$2
Total cost:	$35

Appendix C: Design Constraints

There are some design constraints that the team must consider when iterating our design to develop the rocket. It must always launch with a film cannister that contains a dummy payload or an altimeter of the same mass. Any additional mass added must be in the form of 40-gram cars. The film canister and cars must be detachable from the rocket, using a carabiner. The cars cannot be altered in any way and must remain detached from other cars. If any parachute is altered, it must be purchased by the team. There must not be any protruding components that could be deemed unsafe, and lastly, there can be no form of lubrication used in the design.

Appendix D: Parameters

Table 7: Parameters of chosen design

Dimensions	12” length, 2.5” width
Mass	128.3 grams
Launch Orientation	Cap facing downwards
CoM	11cm from the cap
Total Cost	$3 (see Appendix B: Cost Break-down for more details)

Appendix E: Image Formatting

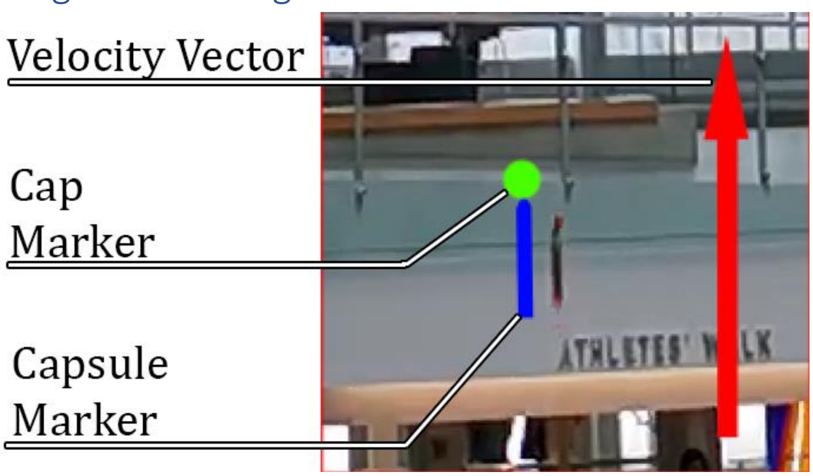

Figure 19 - A Photo at t = xxx s (Examplar)

Moments of interest and snapshots scattered throughout the trajectory have been outlined in the format above. The red arrows indicate the approximate direction and magnitude of the capsule’s velocity at the time elapsed since launch denoted in the caption. This is rough and should be mainly used to determine the approximate position during the capsule’s parabolic path. The timestamp can be used for this purpose as well: the predicted duration without the parachute is around a bit less than 3 seconds, with 1.5 seconds being the predicted apogee time. The timestamp can be used for this purpose as well: the predicted launch duration without parachute deployment is around 3 seconds, with 1.5 seconds being the predicted apogee time.

Due to the poor resolution of the footage, a pointed blue rectangle has been placed near the capsule pointing towards the open end. Additionally, a green circle has been drawn near the cap to, in conjunction with the rectangle, provide the approximate orientation of the system. Kept at constant size, the markers can also be used to recognize the effect of parallax on the analysis.

Appendix F: Raw launch data and Regression

Table 8 - Regression analysis of the post-deployment descent

SUMMARY OUTPUT							
Regression Statistics							
Multiple R	0.89844						
R Square	0.807194						
Adjusted R Square	0.798013						
Standard Error	0.466						
Observations	23						
ANOVA							
	df	*SS*	*MS*	*F*	*Significance F*		
Regression	1	19.0919	19.0919	87.91788	5.91E-09		
Residual	21	4.560277	0.217156				
Total	22	23.65217					
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 68.0%*	*Upper 68.0%*
Intercept	-5.02767	1.234312	-4.07326	0.000545	-7.59456	-2.46078	-6.2849	-3.77044
X Variable 1	-2.74704	0.292972	-9.37645	5.91E-09	-3.3563	-2.13777	-3.04545	-2.44862

Table 9 - raw launch data

Time (s)	Pressure (Pa)	Altitude (ft)	Xacc (Gs)	Yacc (Gs)	Zacc(Gs)	TotalAcc (Gs)
0.00	101173.00	-20.00	-0.05	-0.97	0.00	0.97
0.05	102219.00	-18.00	-4.20	-5.69	1.41	7.21
0.10	100582.00	-16.00	0.70	0.37	1.02	1.29
0.15	101068.00	-14.00	-0.29	-0.36	0.43	0.63

0.20	101097.00	-12.00	-0.15	0.60	0.00	0.62
0.25	101118.00	-10.00	-0.28	0.73	-0.54	0.95
0.30	101107.00	-8.00	-0.16	0.49	-0.08	0.52
0.35	101093.00	-6.00	-0.25	0.45	-0.12	0.53
0.40	101090.00	18.00	-0.22	0.38	-0.13	0.46
0.45	101080.00	9.00	-0.20	0.28	-0.05	0.35
0.50	101078.00	9.00	-0.15	0.20	-0.09	0.27
0.55	101076.00	11.00	0.08	0.11	0.32	0.35
0.60	101075.00	12.00	-3.36	0.38	-0.14	3.38
0.65	101058.00	14.00	-0.09	0.01	-0.29	0.30
0.70	101047.00	15.00	0.26	-0.15	-0.81	0.86
0.75	101042.00	16.00	-0.07	-0.07	-0.27	0.28
0.80	101040.00	17.00	-0.15	-0.04	-0.33	0.36
0.85	101039.00	18.00	-0.04	-0.16	-0.26	0.30
0.90	101037.00	19.00	-0.06	-0.05	-0.18	0.20
0.95	101036.00	20.00	-0.09	-0.07	-0.13	0.17
1.00	101037.00	20.00	-0.08	-0.05	-0.13	0.16
1.05	101039.00	21.00	-0.05	-0.06	-0.12	0.14
1.10	101037.00	21.00	-0.06	-0.04	-0.07	0.10
1.15	101032.00	21.00	-0.03	-0.06	-0.06	0.09
1.20	101034.00	22.00	-0.02	-0.04	-0.07	0.08

1.25	101030.00	22.00	-0.02	-0.01	-0.04	0.05
1.30	101030.00	22.00	0.01	-0.01	-0.07	0.07
1.35	101030.00	22.00	0.02	-0.02	-0.07	0.07
1.40	101029.00	22.00	0.02	0.00	-0.06	0.06
1.45	101031.00	22.00	0.01	-0.01	-0.07	0.08
1.50	101030.00	22.00	0.01	-0.03	-0.05	0.05
1.55	101025.00	22.00	0.00	0.00	-0.07	0.07
1.60	101031.00	22.00	0.00	-0.01	-0.05	0.06
1.65	101031.00	22.00	0.01	-0.01	-0.04	0.04
1.70	101034.00	22.00	-0.03	-0.05	-0.05	0.07
1.75	101032.00	21.00	-0.01	-0.04	-0.07	0.08
1.80	101035.00	21.00	-0.05	-0.07	-0.12	0.15
1.85	101037.00	21.00	-0.04	-0.06	-0.13	0.15
1.90	101037.00	20.00	-0.07	-0.07	-0.16	0.19
1.95	101027.00	20.00	-0.06	-0.07	-0.18	0.21
2.00	101044.00	19.00	-0.03	-0.07	-0.18	0.20
2.05	101044.00	19.00	-0.04	-0.07	-0.16	0.18
2.10	101041.00	18.00	-0.05	-0.11	-0.24	0.27
2.15	101050.00	17.00	0.00	-0.11	-0.30	0.32
2.20	101053.00	16.00	-0.03	-0.14	-0.30	0.33
2.25	101051.00	16.00	0.04	-0.11	-0.37	0.39

2.30	101054.00	15.00	0.06	-0.06	-0.32	0.33
2.35	101062.00	14.00	0.07	-0.06	-0.38	0.39
2.40	101065.00	13.00	0.08	-0.07	-0.40	0.42
2.45	101070.00	12.00	0.07	-0.05	-0.35	0.36
2.50	101073.00	11.00	0.17	-0.04	-0.44	0.47
2.55	101073.00	10.00	0.24	-0.08	-0.41	0.48
2.60	101071.00	9.00	0.31	-0.12	-0.39	0.51
2.65	101074.00	7.00	0.28	-0.18	-0.33	0.47
2.70	101083.00	6.00	0.32	-0.26	-0.38	0.56
2.75	101097.00	4.00	0.23	-0.32	-0.45	0.60
2.80	101094.00	3.00	0.29	-0.32	-0.60	0.74
2.85	101105.00	1.00	-0.66	-1.03	-1.94	2.29
2.90	101115.00	-1.00	1.07	-1.01	-0.63	1.60
2.95	101123.00	-3.00	0.38	-1.54	-0.97	1.86
3.00	101131.00	-4.00	-1.77	-2.31	0.05	2.91
3.05	101135.00	-6.00	-1.40	-4.33	-1.15	4.70
3.10	101143.00	-7.00	-1.98	-2.58	-1.76	3.70
3.15	101153.00	-8.00	-1.72	-2.14	-1.72	3.23
3.20	101153.00	-10.00	-0.78	-1.99	0.11	2.14
3.25	101162.00	-10.00	-0.59	-1.74	-0.41	1.88
3.30	101156.00	-11.00	-0.33	-1.18	-0.28	1.26

3.35	101155.00	-12.00	-0.35	-1.03	-0.13	1.10
3.40	101159.00	-13.00	-0.38	-0.81	-0.29	0.94
3.45	101156.00	-13.00	-0.44	-0.50	-0.45	0.80
3.50	101158.00	-14.00	-0.53	-0.49	-0.45	0.85
3.55	101160.00	-14.00	-0.63	-0.70	-0.34	1.00
3.60	101161.00	-14.00	-0.51	-0.93	-0.20	1.08
3.65	101169.00	-14.00	-0.43	-1.13	-0.10	1.21
3.70	101177.00	-15.00	-0.46	-1.27	-0.11	1.36
3.75	101168.00	-15.00	-0.43	-1.29	-0.14	1.36
3.80	101174.00	-15.00	-1.98	-2.53	-5.59	6.45
3.85	101172.00	-16.00	3.01	-0.80	0.47	3.15
3.90	101168.00	-16.00	-0.01	-0.48	0.43	0.64
3.95	101167.00	-16.00	0.25	-0.58	-0.05	0.63
4.00	101176.00	-16.00	0.18	-0.51	-0.06	0.54
4.05	101170.00	-17.00	0.17	-0.60	-0.04	0.63
4.10	101171.00	-17.00	0.15	-0.77	0.01	0.79
4.15	101172.00	-17.00	0.08	-0.63	0.04	0.64
4.20	101172.00	-17.00	-1.38	1.33	-4.91	5.27
4.25	101174.00	-17.00	-0.20	-0.31	-0.37	0.52
4.30	101172.00	-17.00	-0.71	-1.39	0.73	1.72
4.35	101179.00	-17.00	0.89	0.64	-0.50	1.20

4.40	101174.00	-17.00	0.57	-0.60	-0.65	1.05
4.45	101174.00	-17.00	0.27	0.41	0.52	0.71
4.50	101175.00	-17.00	-1.63	-0.49	-0.88	1.92
4.55	101175.00	-17.00	-0.42	0.92	0.76	1.26
4.60	101174.00	-17.00	-0.54	-0.23	0.04	0.59
4.65	101172.00	-18.00	-0.76	-0.02	-0.01	0.76
4.70	101177.00	-18.00	-0.97	0.13	-0.13	0.99
4.75	101177.00	-18.00	-1.05	0.01	-0.21	1.07