Delta VT

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Executive Summary

On May 16, 2016, Delta VT launched a high power rocket with an active drag system twice, once with the drag system retracted and once more with the drag system deployed for the 2016 Space Grant Midwest High-Power Rocket Competition. The goal of this competition was to design and construct a rocket with an active drag system with the ability to reach an apogee of at least 3000 ft (914.4 meters) above the ground and be recovered safely in a flyable condition. Additionally, flight performance needed to be predicted with and without the drag system active, and a non-commercial on-board data collection package was constructed that would characterize the rocket's coefficient of drag over time. The final rocket had a overall height 8.5ft (2.6 meters) of and weight of 17lb (7.7 kilograms) reaching a maximum altitude of 3222 ft (982 meters) without the drag deployment and a height 2283 ft (696 meters) with deployment. Two cameras both inside and strapped outside the rocket were placed to document the state of the drag system, however both failed to record any footage during both flights.

Rocket Operation

Rocket was launched twice during competition. For the first launch without the drag system activated, the rocket was recovered in flyable condition. However, upon closer inspection, a small crack on one of the epoxy fillets was discovered. The team opted to reinforce this connection by sanding down the spray paint to expose raw G10 and Blue Tube. The fillet was repaired with JB Weld to prevent any further damage to the six points of contact. For the second launch with drag system deployment, 70.9% of the previous flight max altitude was achieved, and the rocket was recovered in flyable condition. Flight data analysis confirms nominal deployment of the drag system after motor burn out and retraction before apogee.

	Drag Retracted	**Drag Deployed**
Launch (Pass/Fail)	Pass	Pass
Drag System Deployment(Retracted/Deployment)	Retracted	Deployment
Parachute Deployment (Drogue/Main/Both)	Both	Both
Recovery in Flyable Conditions (Pass/Fail)	Pass	Pass
Performance	**Drag Retracted**	**Drag Deployed**
Predicted Apogee	4747 ft (1447 m)	3543 ft (1080 m)
Target Apogee After First Flight	N/A	2416 ft (737 m)
Achieved Apogee	3222 ft (982m)	2283 ft (696 m)

Table 1: Characteristics of Flight

Active Drag System Operation

The drag system was designed to use a high pressure air system to actuate a set of drag flaps. An off-the-shelf high-pressure paintball air tank was used to provide pressure to the system. The natural operating pressure of this tank was 3000 PSI. In order to safely utilize the pressure tank in the drag system, a paintball regulator that steps the native pressure down to 300 PSI was used. A double stroke piston was used in a normally open configuration to ensure secure opening and closing of the flaps. Once the valve on the air tank was opened, the system automatically pressurized. A five port, 2-way solenoid was used to switch the flow to the piston. Due to the default position of the solenoid, once the air tank valve was opened, the cylinder was automatically pressurized, holding it in the closed position. This ensured that the drag system only opened when the solenoid was actuated by the arduino. OpenRocket simulations indicated that the rocket would experience a maximum deceleration upon motor burnout on the order of 328 ft/s^2 (100m/s^2) - a force of about 157 lb-f (700N). Assuming the entire aerodynamic decelerative force is incident upon the airbrakes, each flap was required to withstand 100 lbs force (450 N) to achieve a safety factor greater than two. Using a MEAD USA pneumatics handbook it was determined that 100 PSI of pressure was needed. A second, non-adjustable regulator was then used to step down from 300 to 100 PSI. Most connections were ¼ inch NPT push button connectors. Some brass right angle connectors were used to handle space issues in the rocket.

In order to control the pneumatics, a system was needed to activate the 12V minimum solenoid with a 5V signal from the arduino microcontroller, which was accomplished via a relay. When the relay is sent a 5V signal from the arduino, it passes an 18V current from two 9 V batteries in series to the solenoid valve, causing it to actuate.

Propulsion System Performance

As demonstrated by Table 2, both flights with the reloadable Cesaroni P5-4G had a different performance than what was expected, however this could be due the last minute repairs after transportation that caused an increase in weight.

	Expected	**Actual**
Burn time (sec.)	4.08s	4.08s
Max. Acceleration(G)	~ 100 m/s = 10.2 g	~ 80 m/s^2 = 8.16 g
Max. Velocity (meters/sec.)	160 m/s	140 m/s

Table 2: Propulsion System Performance

Flight Path Assessment

	Expected	Actual
Drag Retracted Apogee	4747 ft (1447 m)	3222 ft (982 m)
Drag Deployed Max Apogee(m)	3543 ft (1080 m)	2283 ft (696 m)
Drag Retracted Time to Apogee(s)	16.89 seconds	15.8 seconds
Drag Deployed Time to Apogee(s)	13.7 seconds	12.4 seconds

Table 3: Flight Path Assessment

Although our drag system did perform as expected in response to the first launch, our initial trajectory predictions did not match our results. Our initial predictions had our apogee with the drag system retracted at 4747 ft (1447m), well above the 3000 ft minimum. However, our first flight yielded an apogee of only 3222 ft (982m), only 67.9% of our predicted value. The second flight was expected to reach an altitude of 3543 ft (1080m), but only reached 2283 ft (696m), or 64.4% of our expected apogee. As both flights differed from the predicted values by roughly the same percentage, this suggests that the same error was present in both flights. This strongly suggests an error in the simulation. Despite this difference from our expected flight parameters, we did come very close to the target altitude of 75% of our initial flight apogee. From our first flight, the target altitude for the second flight was 2416 ft (737m). Our actual apogee was only 133m below this target, a difference of only 5.5%.

Recovery System Assessment

	Expected	Actual
Time to Drogue Parachute Deployment(s)	Flight 1: 16.89 seconds Flight 2: 13.7 seconds	Flight 1: 15.8 seconds Flight 2: 12.4 seconds
Time to Main Parachute Deployment	Flight 1: N/A Flight 2: N/A	Flight 1: 47.6 seconds Flight 2: 35.0 seconds
Descent Rate(m/s)	Both flights:5.2m/s	Both flights: 5.18m/s

Table 4: Recovery System Assessment

The rocket was recovered in a safely and flyable condition for both launches, as seen in Figure 1 and Figure 2. After launch one the rocket was recovered 20 meters from the launch pad and recovered 85 meters for the second flight. The motor ejection was not set for parachute deployment. Instead, redundant black powder charges were ignited by e-matches, deploying both the drogue and main parachutes. A 1 gram charge was used to deploy the drogue parachute at apogee, followed by a 3 gram charge that deployed the main parachute at 213.36 meter of altitude. In order to avoid overpressurization of either parachute compartment, the redundant charges were set to ignite after the primary charges. The redundant drogue event was set to +1 seconds after apogee, and the redundant main event was set to 152.4 meters of altitude. The pre and post launch procedures can be found in the appendix section below, these procedures facilitated and ensured the safe handling and preparation for both launches of the rocket. The pre-flight checklist includes the folding procedures for both parachutes and contains the correct sequence for the altimeters. The post-flight checklist enables the team to collect data after each launch.

Figure 1: Drag System Retracted

Figure 2: Drag System Deployment

Data Collection and Flight Performance Analysis

Two Stratologgers, which also engaged the drogue and main parachutes, simultaneously measured the vehicle's altitude with respect to time during both flights. They each took altitude readings with a frequency of 20 Hz, producing the following altitude plots.

Note: the Stratologgers measured altitude in feet, but all other calculations and measurements will be made using metric units.

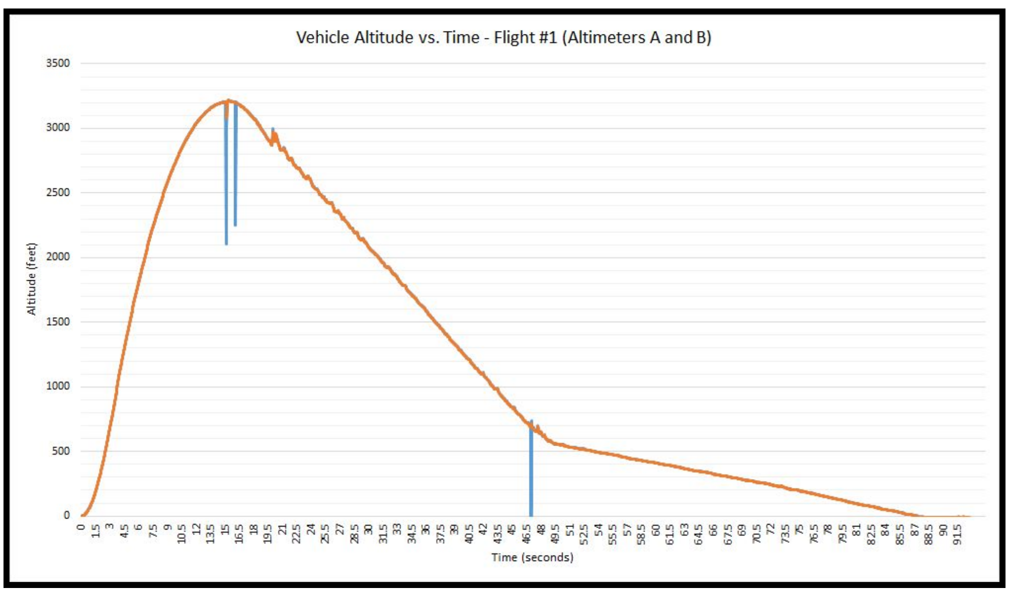

Figure 3: Flight #1 Almineters A&B

This plot of altitude vs. time for Flight #1 demonstrates that the vehicle reached a maximum altitude of 3,222 feet at about t+15 seconds. The spike in the blue curve is due to the voltage drop in voltage of Stratologger A when it fired its drogue chute e-match. The primary chute was fired at 700 feet above the ground, as indicated by another voltage drop at that altitude. The slope of this plot indicates touchdown velocity was about 17 ft/s.

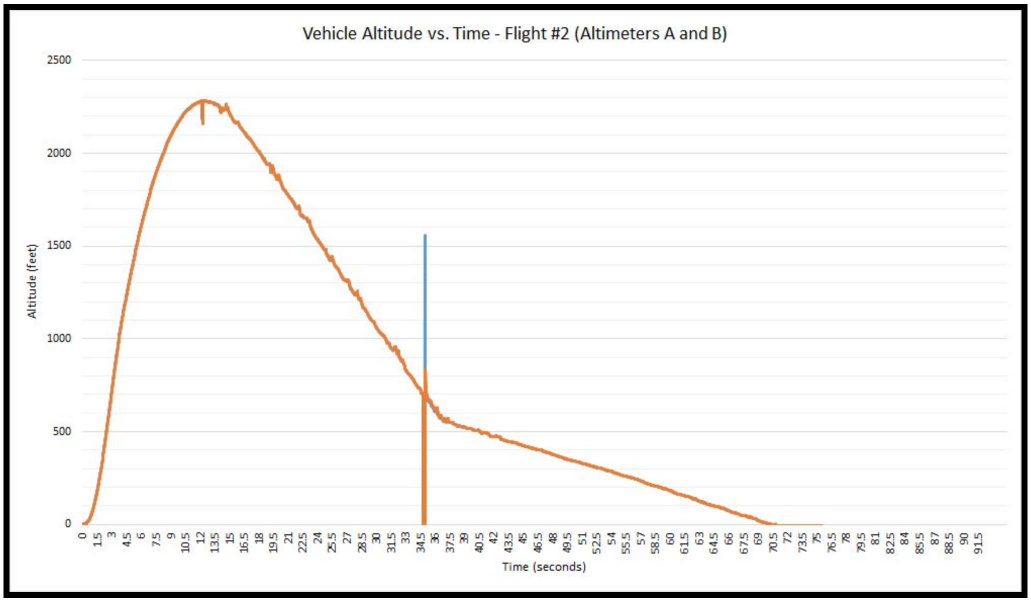

Figure 4: Flight #2 Altimeters A and B

The plot of Flight #2 indicates similar results. The vehicle reached an apogee of 2,283 feet above the ground, immediately deployed its drogue chute, and deployed the main chute at 700 feet. The flight was notably shorter, as expected, with apogee about 12 seconds after launch and chute deployment about 35 seconds in. This plot also indicates a touchdown velocity of 17 ft/s.

Velocity calculation and prediction was important to the vehicle's performance as well - higher velocities would yield longer airbrake deployment, and vice versa - velocity curves were generated from the altimeter data. They're extremely sporadic with time, but follow the trends we were expecting, within a margin of error.

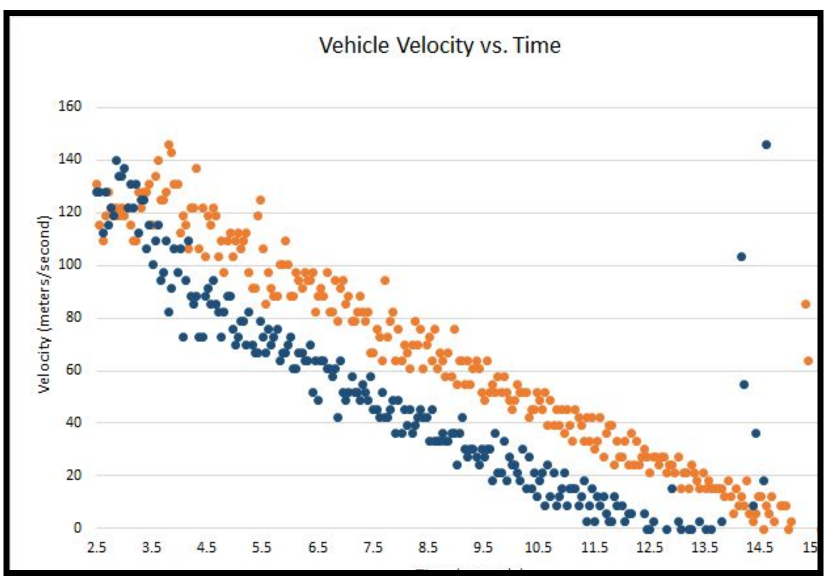

Figure 4: Vehicle Velocity vs Time

The scatterplot above displays the velocity of the rocket (in meters per second) with respect to time (in seconds after ignition) as calculated from the Stratologger altitude measurements. Flight #1 is orange; Flight #2 is blue. Data before burnout and after apogee was considered irrelevant to this particular analysis, as our programming didn't operate in either regime.

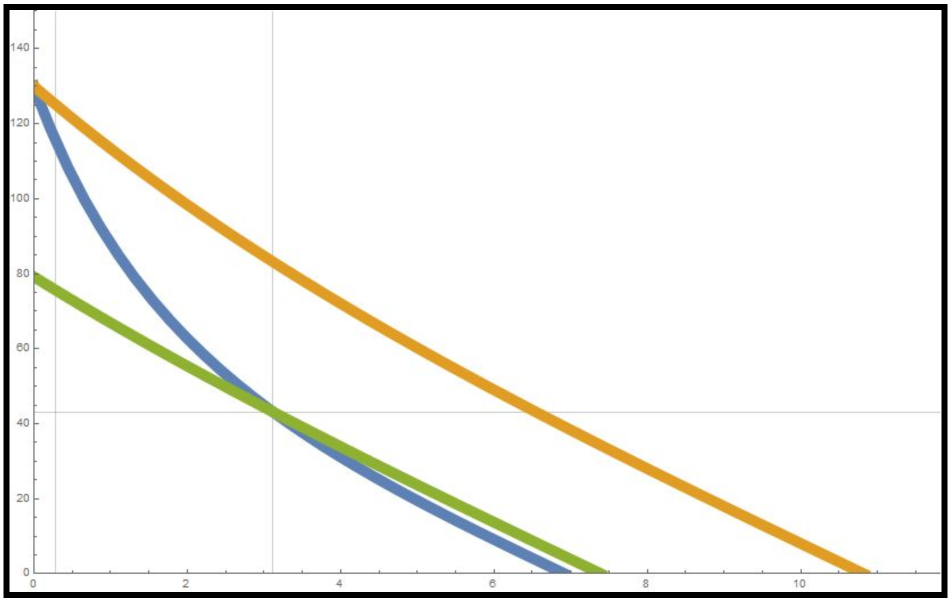

Figure 5: Predicted Velocity of Vehicle

The plot above depicts the predicted velocity of the vehicle during both flights in meters per second. The orange curve is the first flight, and the blue and green curves are the second. The intersection of the blue and green curves represents the point at which the airbrakes are retracted, and the velocity should transition from the blue to the green curve.

Our interpretation is that, during Flight #2, the vehicle opened its air-brakes for about two and a half seconds following engine burnout at t+4 seconds. Its velocity, indicated by the blue scatter plot above, follows remarkably close to the prediction plot. Something of note: with the initial conditions the vehicle was experiencing at burnout, it was expected that the flaps should open for 3 seconds, though the data seems to indicate they only opened for 2.5. This is most likely due to the fact that the arduino's data collection, particularly the measurements of its velocity, are subject to random noise and other imperfections. The vehicle likely believed it was going slower than it was, and accordingly opened the flaps for less time than expected.

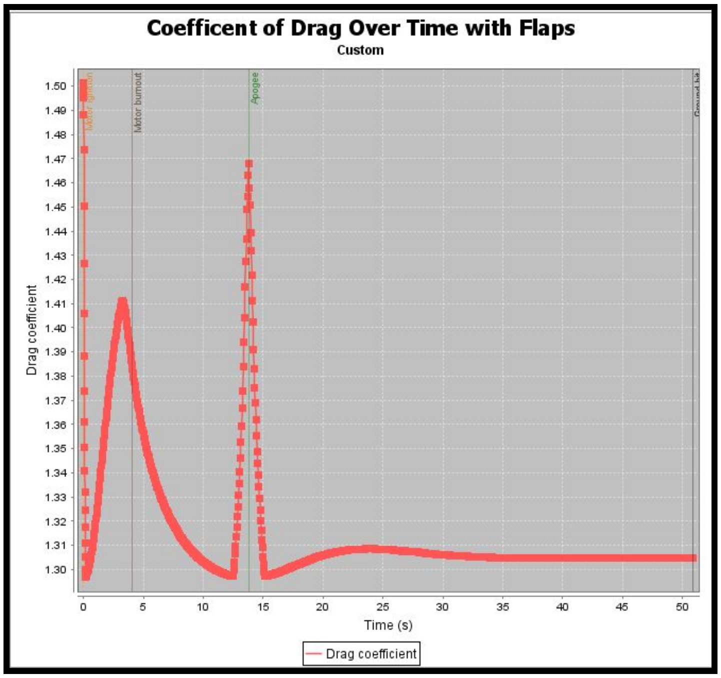

Figure 6: Coefficient of Drag Over Time with Flaps

Above is the predicted drag coefficient over time for the drag flaps being open for the entire flight. This number was generated in openrocket and since the flaps were unable to be deployed in simulation the flaps were left open the entire time then the coefficient of drag produced after burn out was put into a program to determine the resulting time the flaps needed to be open to reach the target altitude.

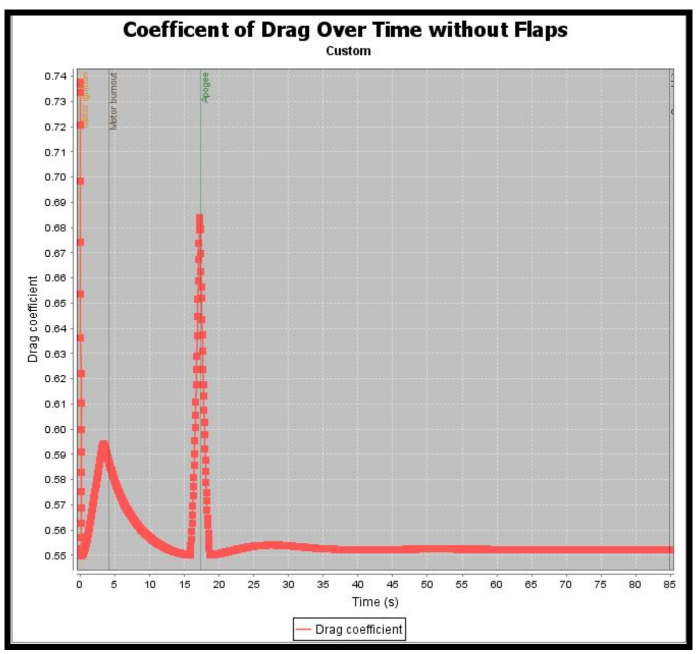

Figure 7: Coefficient of Drag Over Time without Flaps

The graph above shows the coefficient of drag over time without the flaps being open, simulating the first flight to an accurate degree. This number was also calculated in openrocket and directly used to determine the predicted altitude for the first flight in both openrocket and the program created by the team.

Appendix

Pre Flight Checklist

Before Launchpad

Electronics
1. Ensure Rocket_OS.ino is running on the Arduino e-bay #1
2. Turn on Drag e-bay
    a. Ensure lights are blinking from the outside
3. Mount coupler tube on the drag e-bay
4. Check that altimeters are on. DO NOT LOAD BLACK POWDER
    a. Star them on properly, pay close attention the beeping signals
        i. A one digit number corresponding to the currently-selected program present
        ii. Two second pause, then a three or four digit number corresponding to the main deploy , expect the backup altimeter to beep for 5 seconds, If not heard. DO NOT LAUNCH!
        iii. Two second pause, then 3 - 6 digit number representing the apogee and altitude of the last flight,
        iv. Two second pause, a 2- 3 digit number representing the voltage of battery, should read 9 volts
        v. Two second pause, and then a continuity beeps repeated every 0.8 . A single beep means drogue e-match continuity is OK, two beeps means main e-match continuity is OK, three beeps means both drogue & main have good continuity.
5. Turn on camera

Mechanical
1. Put the air tubing from the air cylinder through the holes in the air tank centering rings
2. Begin to slide air tank with centering rings into the body tube
3. Connect air tubing from air tank and air cylinder, a total of 3 tubes, to the solenoid.
4. Connect control wires from the power converter to the bottom of the drag e-bay
5. Attach batteries to battery clips, attached to the power converter unit
6. Turn air tank to the open position
7. Velcro power converter unit to the top of the air tank valve
8. Slide air tank all the way into the body tubing
9. Slide batteries and solenoid into the body tubing, leaving 4 in. clearance from top of tube

Aero
1. Check that the nuts on the threaded rod are tightly secured
2. Remove any leftover shear pins from previous flights
3. Prepare four black powder charges by running an e-matches through each prospective powder well
    a. Drag chute 1 gram, repeat for redundant charge

    b. Main chute 3 grams, repeat for redundant charge
4. Afix e-match leads to corresponding electrical terminals on the ends of recovery ebay
5. Seal any holes leading into the e-bay with chromate tape
6. Assembly of Main and Drogue Parachutes
    a. Attach all recovery hardness to respective ebay locations.
    b. Fold Parachutes

        i. Main Parachute
            1. Fold parachute into eighths radially, fold into thirds longitudinally, and roll halves to the center
            2. Align parachute cord through parachute and fold tightly
            3. Wrap the parachute in the nomas chute protector, completely covering the chute. Further protect any exposed patches with and edges with insulation(dog barf)
            4. Load the main parachute with shock cords into the tube.
        ii. Drogue Parachute
            1. Fold parachute into eighths radially , fold into thirds longitudinally, and roll into halves
            2. Aligns parachute cord through parachute and fold tightly
            3. Wrap the parachute in the parachute protector, completely covering the parachute and covering any exposed patches with insulation.
            4. Connect the link to the e- bay and fold the two shock cords into hand-lengths up to the folded parachute. Clip the second shock cord to the nose cone.
            5. Load the drogue parachute with shock cords into the tube and re-insert the nose cone.
7. Align shock cord along gove in couple and slide payload section into the appropriate depth
8. Attached the chutes to the shock cord with a quick link
9. Run the nose cone shock cord to the the top of the recovery system ebay
10. Secure the nose cone, making sure that it fits snugly. Use shear pins

Ribits in before parachute

Remove non essential personnel

<u>At Lunchpad</u>

Electronics
1. Switch on both altimeters
2. Repeat Step #4 in electronics selection, making sure altimeters are on and beeping
3. Proceed to a safe distance away

Mechanical

1. Check rail buttons and load rocket onto guide rails
2. Assemble motor and load into the rocket
3. Insert and secure igniter

Post Flight

!!!!!Do not touch engine mount!!!!

Electronics

1. Sequence of altimeter
    a. First a 3-6 digit number representing the peak altitude in feet
    b. Followed by a long separation, next a 2-5 digit representing the max velocity in miles per hour
    c. A loud siren will go off to notify of location
2. If rocket makes it to the ground, but only one black charge detonated: TURN OFF IMMEDIATELY
3. Download data from altimeters to computer
4. Download video from camera

Mechanical

1. Open drag compartment
2. Slide air tank up and out of tube
3. Remove the power converter from the tank valve
4. Close the air tank valve

Aero

11. Parachutes
    a. Untangle parachute and shock cords and evaluate the condition of the parachute cords
        i. If the cords are deemed to be too tangled, undo the knot and retie the parachute cords. Fold the parachutes.
        ii. If the cords are adequately untangled, proceed to fold the parachutes.