Post-Flight Performance Report
Team Falcon 1

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By observing the on-board video footage from the dart, good separation was achieved though the altimeter in the booster did not recorded its altitude (it had been activated and displayed the flight "ready" message on the display when it was inserted into the small canister within the upper booster compartment) and the booster deviated somewhat from its initial vertical axial direction shortly after separation. Since this deviation occurred at the moment of its peak velocity, it explains why the booster drifts to a much further extent than the dart. It also appears that a powerful gust of wind potentially swayed the booster further from its path upon descent, increasing the landing distance. The dart parachute had a delayed deployment after apogee which minimized drift prior to landing, but since the predicted altitude was higher than the actual altitude this parachute ended up releasing at only 72 feet above the ground. We also believe the hole drilled in the dart to allow the altimeter to sense the outside atmospheric pressure may have been a bit undersized, inhibiting precise apogee detection. This made it more exciting to watch but no harm was done since the components were relatively light weight and landed safely in fantastic flyable condition.

Propulsion System Assessment

With a burnout time of approximately 1.1 seconds, the Cesaroni I-445 motor functioned within nominal limits. This can be seen at the very beginning in Figure 1 below, an axial acceleration vs. time graph created by data from the Raven3 altimeter using the Featherweight Interface Program.

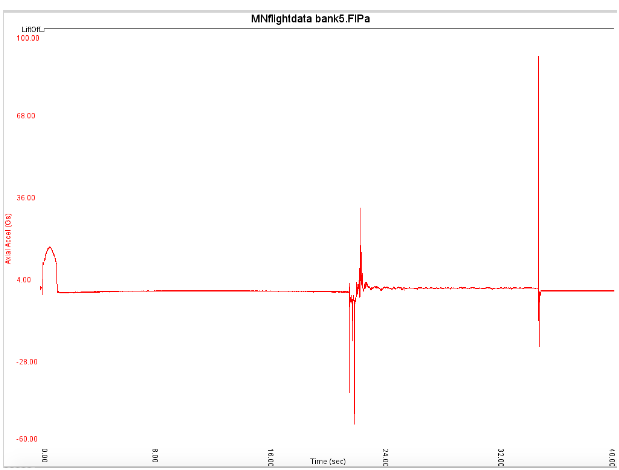


Figure 1: Axial acceleration vs. time showing motor burn, parachute ejection, deployment, and landing

Flight Path Assessment

The flight path during the boosting phase was both straight and steady but with a slight spiral to its motion. Clean separation was seen to occur approximately ¼ sec after motor burnout, with both components flying stably one their own trajectories, following somewhat diverging parabolic flight paths, as seen in figures 2 and 3 below.

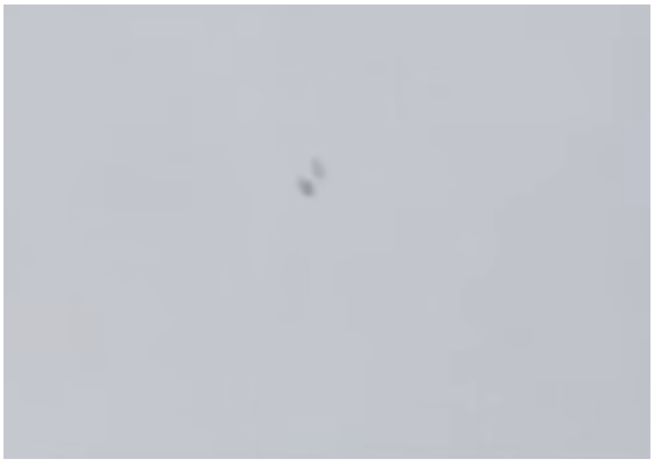


Figure 2: Divergence of the booster (left) and dart (right) shortly after separation.

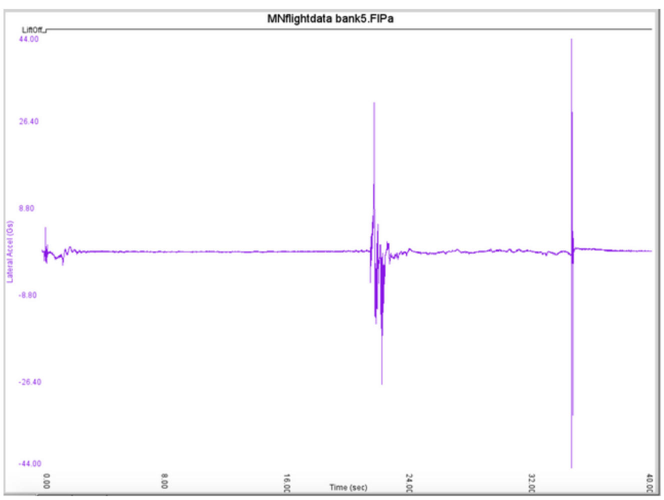


Figure 3: Lateral acceleration vs. time showing divergence shortly after motor burnout.

Recovery System Analysis

The 7 sec delay set for the ejection charge for the booster parachute was chosen to take place just after the booster reached apogee in order to ensure adequate time for opening and slowing the descent. This worked perfectly though it resulted in a fair amount of drift just past a line of trees in the distance, as seen in Figure 4. The dart parachute deployed a bit late, as mentioned, but opened fully far enough above the ground and landed the dart safely in perfect condition nearby since there was little time for any drifting.

Figure 4: Parachuting descent of booster just beyond treeline.

Rocket Location and Recovery Analysis

Both the dart and booster were tracked by eye for the duration of the flight. Because large (24 inch), bright parachutes were used for safe descent, locating the both components of the rocket proved to be a simple procedure. Choosing not to implement equipment such as expensive GPS, radio tracking, beepers, or streamers, the rocket carried less mass (providing a better performance) at a reduced cost. The booster landed fairly close to the launch site, while the dart had traveled further in the opposite direction but at a manageable distance that several team members were walk directly toward the trees where it was last seen and retrieve it easily.

Pre & Post Launch Procedure Assessment

The pre & post launch checklist created by the team was created so that someone unfamiliar with the rocket's actual design would be able repeat our process to ensure a successful launch.

- ❑ chute tethers tied securely, booster____ dart____
- ❑ chute ejection charges wired, booster____ dart____
- ❑ chute packed properly, booster____ dart____
- ❑ electronics bay, arduino & accelerometer batteries voltage 9V (new Duracell preferred)
- ❑ electronics bay, arduino & accelerometer batteries plugged in and secure
- ❑ altimeter battery charged
- ❑ altimeter programmed for proper chute deployment altitude after apogee
- ❑ altimeter wires fed through rocket tube for activation on pad
- ❑ electronics bay secure in dart
- ❑ transition camera charged
- ❑ transition camera activated (push on, light on, push and hold start, light flashes and off to start video recording)
- ❑ transition camera secured, carefully to avoid pushing buttons
- ❑ dart mated to booster with fins aligned
- ❑ outer dart camera charged
- ❑ outer dart camera activated via sequence above
- ❑ outer dart camera secured, carefully to avoid pushing buttons
- ❑ motor delay chosen for ejection just after booster apogee
- ❑ motor secured in booster
- ❑ dedicated observers in place with cameras ready for external video/photography
- ❑ permission given to proceed to launch area
- ❑ rocket threaded on launch tower
- ❑ altimeter wires connected on launch tower once vertical, armed beep-beep-beep-beep sequence verified
- ❑ motor ignition wires inserted as far as possible into motor
- ❑ ignition wiring attached to control wires, continuity verified
- ❑ team members clear of launch area, spread out for different vantage points to triangulate on landing position, if needed
- ❑ recovery of components after landing, booster____ dart____
- ❑ push stop button on camera to save recent file, turn camera off, booster____ dart____
- ❑ celebrate successful launch

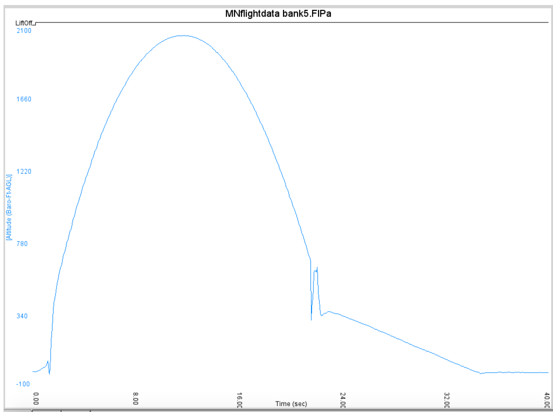
Flight Performance Comparison Sheet

Table of Performance Characteristics (Boosted Dart Version)

Flight Performance Comparison Table	
Operation (determined by RSO or designee)	Yes
Launch	Yes
Separation of Dart from Booster Before Apogee	Yes
Recovery deployment Booster Dart	Yes (both)
Recovered Booster Dart	Yes (both)
Determined to be in flyable condition Booster Dart	Yes (both)
Maximum Altitude (ft)	Predicted: 2375 ft Actual: 2054 ft (AGL) 2520 ft (ASL)
Peak Acceleration (ft/s^2)	Predicted: 798 ft/s^2 Actual: 570 ft/s^2
Peak Velocity (ft/s)	Predicted: 680 ft/s Actual: 425 ft/s

Altitude Comparison

Despite having a steady launch and stable flight of both components, the apogee of the dart according to the Raven AGL altitude estimate was 321 feet (roughly 14%) under the prediction. Figure 5 below shows two altitude vs. time graphs (AGL and ASL, respectively) using data from the Raven3 altimeter. At approximately 1.1 seconds, motor burnout, the parabolic nature of the graph can be seen shifting from concave upward (positive acceleration due to thrust) to concave downward (negative acceleration due to gravity). The Raven3 User Manual states that it uses the International Standard Atmosphere model that assumes a most likely colder atmosphere temperature profile (59°F at sea level) that could result in altitudes that are lower than actual by "10% or more", but the upper graph appears most consistent with the lower acceleration measured (local temperature at launch was 68°F).



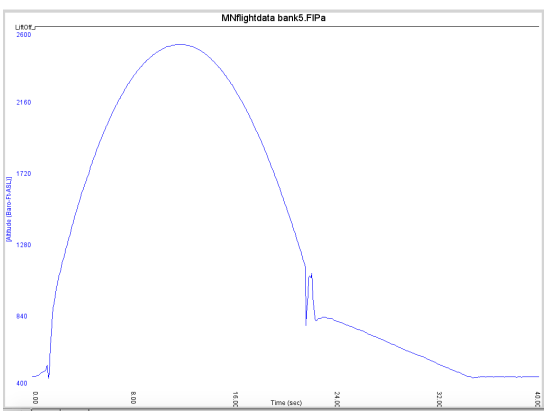


Figure 5: Altitude data reported by Raven3 altimeter vs. time

Acceleration Comparison

Both the predicted and measured maximum acceleration values occur shortly after motor ignition as a result of the short and powerful thrust provided by the engine burn. The actual peak acceleration of the dart was less than the predicted value (about 71% of actual value). A somewhat lower value was expected because not all extra mass was simulated (glue, nose cone foam, dummy camera, screws, wires, charges, etc.), slight spiraling and a trajectory slightly off vertical all result in a less than ideal flight. Copper BB's were glued inside the tip of each nose cone to shift the CG forward for stability, and compressible foam was stuffed to fill in the empty space to keep the mass from detaching from the tip during high accelerations. The mass added to the dart nosecone loosened during pre-flight handling due to the low adherence of the glue to the smooth polyethylene. The overall extra mass was estimated to be around 200g which reduces acceleration roughly 7%, thus reducing speed and altitude (proportional to square of speed). The 526N maximum thrust of the Cesaroni I445 and the total rocket weight of 26N gives an expected acceleration of 19g or 620 ft/s^2 which is within 10% of the actual value.

Velocity Comparison

Both the predicted and measured values for peak velocity occurred at engine burnout because the downward pull of gravity was then the overriding means of acceleration (negative) from that point onward. The velocity vs. time graph (Figure 6) below agrees with both Figure 5 values in pinpointing apogee to be approximately 12 seconds after launch. Similar to the case with acceleration, the measured data for peak velocity turned out to be 27% lower than the predicted velocity, which is consistent with the 29% lower acceleration since these parameters are linearly proportional and the side-mounted cameras added more drag that was not in the simulation.

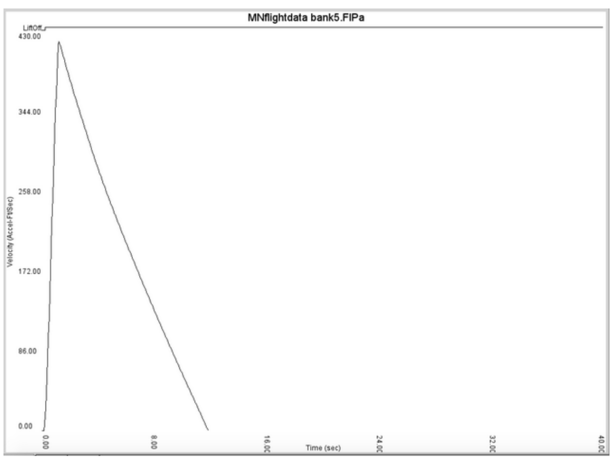


Figure 6: Velocity vs. time

Sensor Data and Performance

Sensor Data Report

The recorded data was provided by a triple-axis ADXL335 accelerometer readout using an Arduino UNO board, two Raven3 altimeters, and two on-board 808 video cameras.

On-board Video

Two 808 keychain cameras were used to record on-board footage in order to capture different perspectives of the flight. One camera was mounted on one side of the rocket, looking downward between two fins with a similarly sized dummy camera mounted on the opposite side. The second camera was mounted looking directly downward in the bottom of the dart transition region and was used as a backup since we've found these cameras to be somewhat unreliable.

Both cameras, requiring a series of two different button pushes to initialize recording, were started manually prior to the flight safety check. A small LED light comes on upon start, then when holding down the button to start recording the light blinks several times and then turns off, so while recording the camera actually looks the same as it does when it's off. In the future we'd choose a different camera. The format of the camera records footage in ten minute intervals per file, immediately opening a new file once the previous reaches that time limit until somebody stops it manually through button pushing, the battery dies, or the microSD card is full. This 10-minute interval actually played a part during the launch, creating a new file shortly after the dart reached its apogee.

The use of multiple cameras proved to be useful since one of the cameras seemed to have stopped recording before proper footage could be recorded. It is believed that the high acceleration of the launch caused the backup camera in the dart transition region to turn off via the means of a single button push.

Figure 7 on the following page shows a snapshot from the dart of the rocket during motor burn, while figure 8, also from the dart, captures the diverging booster shortly after separation. Using figure 7 as a reference, it is apparent that the two stages take on different trajectories following separation. Figure 9 exhibits an image of the dart's footage near apogee, now much further away from the launch site below. The time and date stamp seen on the video footage is incorrect since the TAG.TXT file default found in the 808 keychain was not properly reset to the current date and time.

Watching the video during ascent reveals a spin rate of roughly 9 rotations about the vertical axis in 7 seconds, or 1.3 Hz.

Figure 7: Downward facing video from dart during acceleration

Figure 8: Downward-facing video of separation

Figure 9: Downward facing video as dart nears apogee

Rotation Sensor System

The triple-axis accelerometer data allows for estimating the rotation around each axis, but the deduced rotation rates required precise knowledge of the orientation of the accelerometer chip and its position in relation to the center of mass. For future launches (if rotation is needed), we would use the IDG500/ADXL335 five degrees of freedom setup; this format incorporates two gyroscopes, allowing rotation rates to be measured directly. There was essentially no rotation about either horizontal axis due to the vertical trajectory until near apogee where it was temporarily horizontal as it rolled over, as shown in figure 10. Rotation about the vertical axis was nearly constant, requiring little rotational acceleration to achieve a 1 Hz rotation.

Figure 10: Downward facing video from dart as it crests near apogee

Summary

Learning from the WSGC launch, Falcon One was able to undergo the necessary alterations to perform a successful flight despite the limited time available. While the recorded characteristics of the flight fell short of the initially predicted values, team Falcon One was able to learn many important fundamental aspects about the design of boosted dart rockets and high powered rocketry in general.

Glenn Spiczak 5/28/2015 11:28 PM
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Back row: Jose, Justin, Dr. Spiczak, Farris

Front row: August, Robert