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2018 NASA SL Team

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Flight Readiness Review Addendum

March 27, 2018

1 Full Scale Flight Summary

The second full scale flight was not fully successful. The fore section parachute was unable to fully open as three of the shroud lines slid over the main parachute. This caused the landing velocity to be significantly higher than expected and the landing kinetic energy was higher than the requirement of 75 ft.-lb. The launch off the pad is shown in Figure 1.

All other NASA and team derived requirements were met. The other concern from the flight is that the motor appeared to be underpowered. The rocket reached an altitude of 3855 ft. which was 1173 ft. lower than expected. In addition, the maximum velocity was 89 ft./s, which was lower than expected. Given the success of the sub scale and previous full scale flight, the poor performance is attributed to the motor underperforming. This idea was corroborated by the team mentors who attended the launch.

Integrating the rocket at the launch site took longer than expected since there were two mistakes made prior to launch that had to be fixed. One e-match was wired to the incorrect altimeter port. This oversight was discovered when checking the beep sequence after installing the ejection sled. The e-match was rewired to the proper port and reinstalled. After sealing the rocket and placing in the shear pins, it was realized that after replacing the altimeter sled, one of the bulkheads did not have putty put back on it to create a full pressure seal. The nose cone was removed, and putty placed on the bulkhead before proceeding.

Figure 1: Full Scale Launch – March 18th, 2018

The tracking system performed perfectly, and there was communication with the on board GPS until both sections landed behind a small hill. The changes to the retention of the ATU system performed well and there were no parts that broke from their socket or vibrated loose when recovered. The rocket landed 1500 ft. away from the launch pad. The drift distance was primarily due to wind cocking towards the apogee of the rocket.

The rocket was stable off the launch pad with a small amount of wind cocking while coasting to apogee. At apogee there was a successful separation of the two recovery sections. Both sections came down under drogue and had the Jolly Logic Chute Releases open to deploy the main chutes at 1000 ft.

The main chute on the aft section opened as expected and descended with no issues. The fore section main had three shroud lines slip over the top of the parachute, which kept it from fully opening and sped up the descent. The packing method used has been used on two flights and the opening of the packing method has been ground tested with this beng the first instance of this issue encountered. The tangled main parachute on the fore section can be seen in flight in Figure 2 and upon landing in Figure 4.

Figure 2: Descent of Rocket Sections Under Mains, Left to Right: Fore Section, Aft Section

Figure 3: Fore Section Landing

The fore section landed 1790 ft. away from the launch site. Besides the issues with the parachute deployment, the drogue parachute was also significantly tangled in the un broken sacrifice folds. There is no data on the fore section tumbling/drogue since the main deployed at apogee on the first launch, so it is not clear whether this affected the descent rates.

Figure 4: Left to Right: Fore Section Main Landing, Fore Section Drogue Landing

Figure 5: Aft Section Landing

The aft section landed 1913 ft. away and had routine recovery. The drogue parachute was also twisted like on the fore section, but this was expected after our first full scale launch. Although it did not interfere with anything, the lower Nomex blanket slid up the harness as far is it could go to below the drogue. The Kevlar cord on the main parachute blanket was successful in retaining the blanket on both main parachutes.

Figure 6: Left to Right: Aft Section Main Landing, Aft Section Drogue Landing

1.1 Issues and Mitigations

To mitigate any issues like those that occurred during preparation, the team has updated all checklists and procedures with additional steps and inspections. Each task has been assigned to a team member, and they are responsible for performing the checklist operations. Each task has an additional team member assigned whose role is to watch the person performing the task, read the checklist, and ensure are steps are properly followed. An integration test was performed on 3/24/2018 with the new checklists and procedures.

The issue with the shrouds slipping over the main parachute is believed to have been caused by several factors. A vacuum was created when pulling off the nosecone to re-putty the bulkhead, with an audible “pop” once the nosecone was off. The decrease in pressure in the vacuum followed by the increase in pressure caused the Chute Releases to activate and open the main parachute, which rolled out slightly on the table. The Nomex blanket was placed back over the parachute and Chute Releases secured, but the parachute was not thoroughly inspected or re-rolled after opening on the ground. It is thought that when the main rolled out, the shroud line rolled around it lost tension, allowing three shrouds to slip over the bundle during deployment or inflation.

After the Chute Releases opened the parachutes should have been fully re-inspected, and clear steps for troubleshooting have been added to all procedures to avoid similar problems in the future.

The packing method for the main parachutes was also slightly changed. Instead of wrapping the full length of the shrouds around the parachute bundle, half of the shrouds are tucked into the parachute fold, and only the remaining half rolled around the parachute. This keeps the shrouds to the center of the bundle and away from the edges, making it more difficult for a shroud line to slip over the top of the bundle. Both packing methods are shown in Figure 7.

Figure 7: Left to Right: Old Main Packing Method, New Main Packing Method

Each set of sacrifice folds on the main section will have one less loop, making it more likely that all the folds break during recovery.

The lower Nomex blankets will be retained using Kevlar cord in the same way that parachute blankets are retained.

1.2 Launch Day Conditions

The temperature upon arriving at the launch site in Brothers, Oregon at 8:00 A.M. was 16° Fahrenheit. The launch site had about 2 in. of snow when the team arrived. When the rocket was launched at 12:30 P.M. the temperature was 37° Fahrenheit with a wind speed of 5 mph. The sky was clear with high visibility.

1.3 Launch Day Conditions Simulation

An OpenRocket simulation using the launch day conditions was used to model the flight. The apogee was predicted to be 5028 ft. with a maximum velocity of 549 ft./s. The time to reach apogee was predicted to be 18.7 seconds. An 8 ft. launch rail was used for the launch, as a 12 ft. rail was not available. The predicted velocity of the rocket off the 8 ft .rod was 52.7 ft./s.

The OpenRocket simulation provided a drogue descent velocity of 102 ft./s with a landing velocity of 13 ft./s. The total descent time of the rocket was simulated to be 95.3 seconds.

1.4 Full Scale Flight Analysis

The data logging module, which contained an additional barometric sensor, IMU sensor, and high g 3-axis accelerometer, was not functional by the time of the second full scale launch. Analysis data is thus based solely off the four barometric altimeters used for recovery. A summary of the ascent, descent, and landing kinetic energies are provided in Tables 1, 2, and 3, respectively.

Table 1: Full Scale Ascent Summary

	Fore		**Aft**		
	RRC3	**Stratologger**	**RRC3**	**Stratologger**	**Average**
Apogee Altitude (ft.)	3852.0	3916.0	3760.0	3893.0	**3855.3**
Apogee Time (s)	16.7	16.8	16.8	17.0	**16.8**
Max Velocity (ft./s)	472.4	453.2	452.0	463.1	**460.2**
Motor Burn Time (s)	4.6	4.5	4.1	4.1	**4.3**
Rail Exit Velocity (ft./s)	no data	52.6	no data	70.7	**61.6**

Table 2: Full Scale Descent Summary

	Fore Section			**Aft Section**		
	RRC3	**StratoLogger**	**Average**	**RRC3**	**StratoLogger**	**Average**
Drogue Velocity (ft./s)	79.6	78.7	**79.2**	91.1	89.9	**90.5**
Landing Velocity (ft./s)	26.7	26.6	**26.7**	12.1	12.1	**12.1**
Descent Time (s)	67.4	68.3	**67.9**	94.0	95.4	**94.7**
Drift Distance (ft.)	1790			1913		

Table 3: Full Scale Landing Kinetic Energies Summary

	Mass (lb.)	Velocity (ft./s)	KE (ft.-lbf)
Motor Section	16.01	12.2	**36.3**
Payload Section	14.40	26.7	**171.3**
Nosecone	4.41	26.7	**47.6**

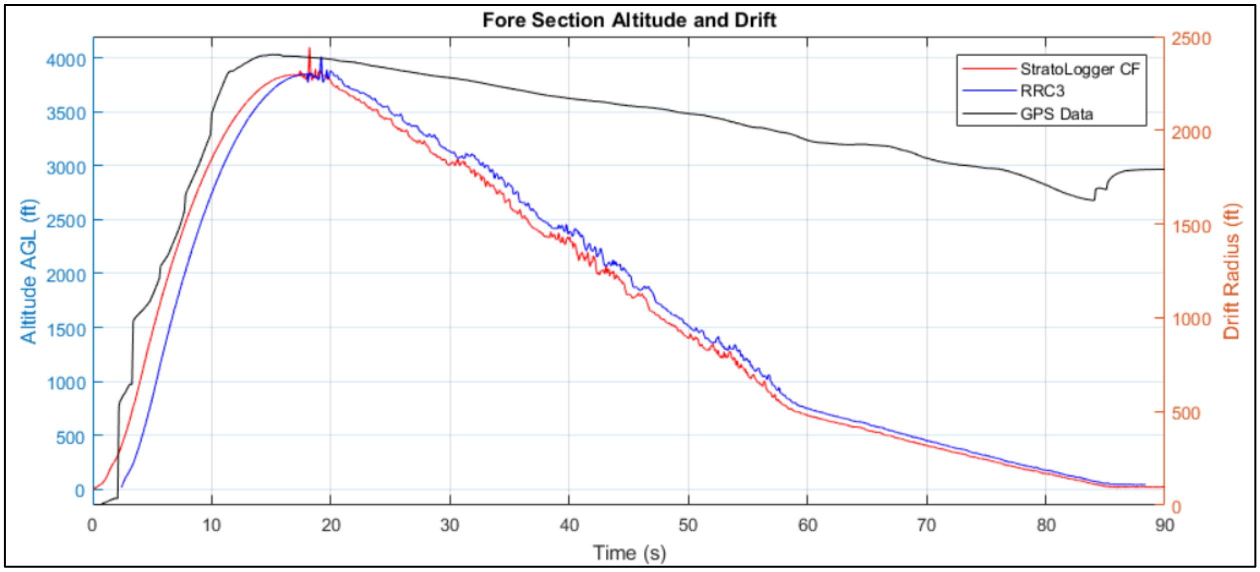

Figure 8: Fore Section Altitude and Drift Profiles

The fore section altitude and drift are shown in Figure 8. and the fore velocity profiles for the ascent, drogue descent, and main descent are shown Figure 9.

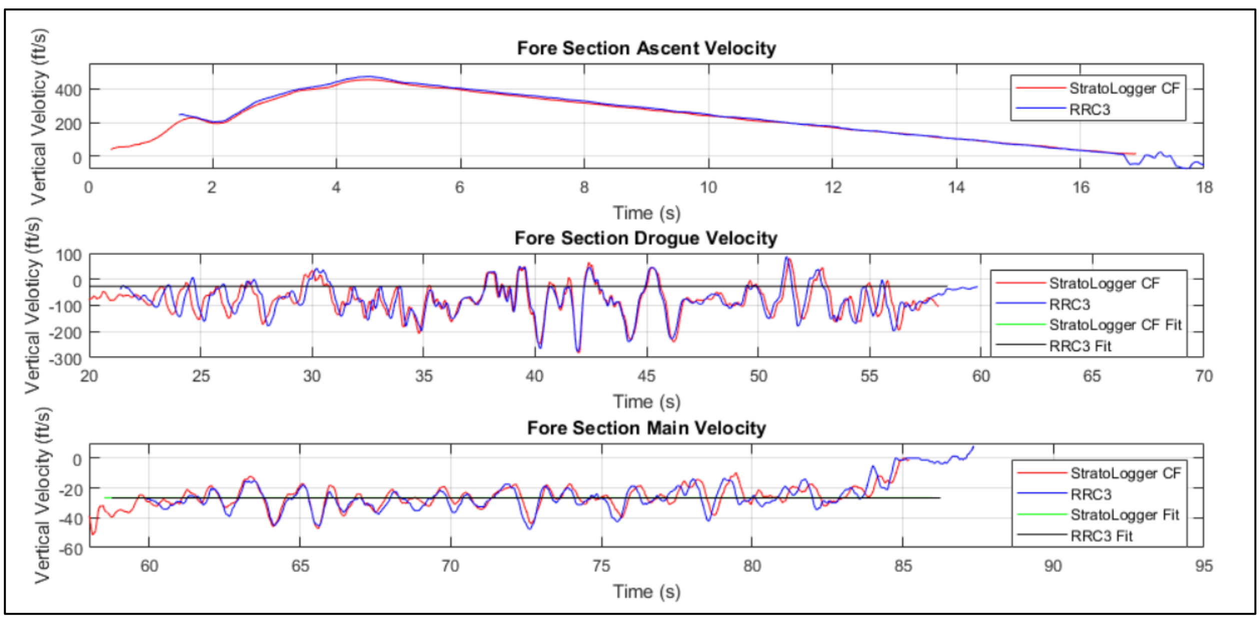

Figure 9: Fore Section Velocity Profiles

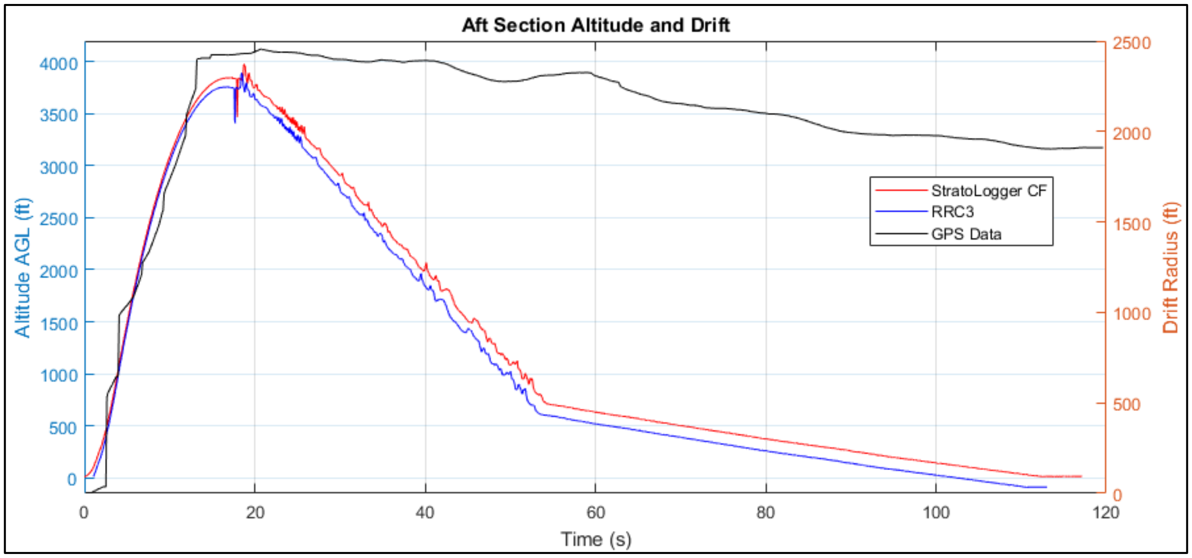

Figure 10: Aft Section Altitude and Drift Profiles

The aft section altitude and drift are shown in Figure 10, and the aft velocity profiles for the ascent, drogue descent, and main descent are shown in Figure 11.

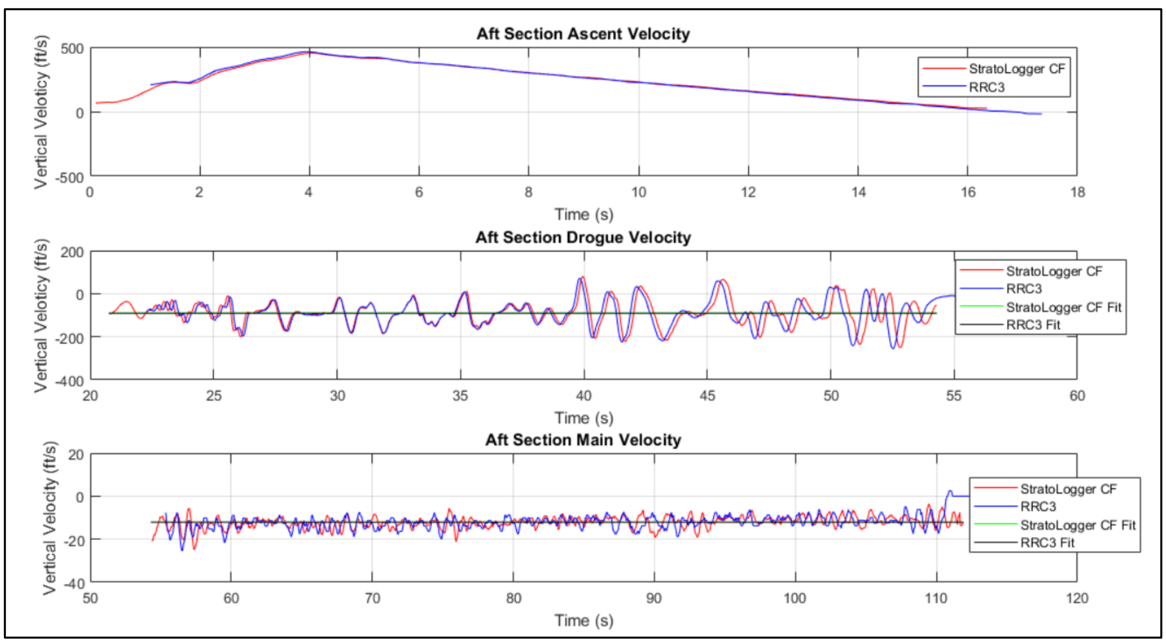

Figure 11: Aft Section Velocity Profiles

1.5 Comparison of Predicted and Actual Flight

A summary of simulated flight characteristics from OpenRocket and a custom MATLAB script, as well as the actual recorded values are reported in Table 4.

Table 4: Summary of Simulated Flights and Recorded Flight Data

		Open Rocket	MATLAB	Average Recorded from Flight
Ascent	**Apogee Altitude (ft.)**	5028	-	3855
	Apogee Time (s)	18.7	-	16.78
	Max Velocity (ft./s)	549	-	460.2
	Motor Burn Time (s)	4.4	-	4.3
	Rail Exit Velocity (ft./s)	52.7	-	61.62
Fore Descent	**Drogue Velocity (ft./s)**	102.0	77.0	79.2
	Landing Velocity (ft./s)	13.0	14.1	26.7
	Descent Time (s)	95.3	116.3	67.9
	Drift Distance (ft.)	698.7	852.9	1790
Aft Descent	**Drogue Velocity (ft./s)**	102.0	84.2	90.5
	Landing Velocity (ft./s)	13.0	15.2	12.1
	Descent Time (s)	95.30	107.59	94.70
	Drift Distance (ft.)	698.7	789.0	1913

The recorded apogee altitude was 1173 ft. lower than expected and occurred 1.9 s earlier than predicted. The maximum velocity was 89 ft./s slower than predicted. All of these are attributed to a faulty and underpowered motor. Recorded rail exit velocity was slightly higher than simulated for an 8 ft. rail.

The recorded drogue descent velocities were lower than those from OpenRocket by about 22 ft./s, and were higher than the values from MATLAB by 3-5 ft./s. This agrees with our sub-scale flight and first full-scale flight, where it was found that OpenRocket typically reports higher values for drogue and tumbling velocities, while MATLAB was more accurate.

The recorded aft main velocities was higher than predicted from OpenRocket and MATLAB. The recorded fore main velocity was higher than both predictions, but this is due to the shroud lines slipping over the parachute.

With predicted hit velocities, all sections were calculated to land under maximum KE limitations. The payload section, which fell with the fore section, was recorded to have exceeded the KE limitations in our most recent launch. However, the first fullscale launch, the fore section landed within the requirements, and this was with the parachute being reefed by the Nomex blankets. Providing the parachutes deploy as expected, the first fullscale launch shows that all parachutes are sized properly to land all sections under the maximum allowable KE.