# UC Berkeley Space Technologies and Rocketry
# Flight Readiness Review Addendum
# Project U.R.S.A.[1]

March 27, 2017

[1]Upright Recovery and Sight Acquisition

# Contents

# 1 Project Overview

UC Berkeley Space Technologies and Rocketry (CalSTAR)'s entry to the NASA Student Launch project is URSA Major, which aims to fly a high-powered rocket to 5280 ft. in addition to conducting an engineering payload experiment. Our payload project, SAGITTA-VL, aims to complete the "Target Detection and Upright Landing" task, in which an onboard visual detection system is used to identify and differentiate three colored ground targets during flight, and subsequently land the section housing the cameras in the upright configuration (i.e. orientation on the launch pad). In order to accomplish this, URSA Major contains a Raspberry Pi and camera housed in the upper nose cone, which views the ground through a plastic nose cone tip during descent. At a pre-determined altitude threshold, the nose cone and upper 18" of the vehicle (referred to as the payload section) is ejected from the main vehicle while deploying three parachutes and spring-loaded 'landing legs.' The center of gravity of the payload section is kept low, so as to cause the payload section to rotate and fall upright under the parachutes, eventually landing on the ground with the aid of the landing legs.

On March 4, 2017, URSA Major was flown for the first time, reaching an altitude of 4541 ft. The custom Target Detection algorithm was tested and verified using images obtained from the team's subscale vehicle, URSA Minor. Prior to the full-scale flight, however, various electronic components associated with the Upright Landing system spontaneously failed, and could not be repaired without further analysis. As a result, the Upright Landing system was not activated - no landing legs were deployed, and the payload section was not ejected from the vehicle. In order to verify the full vehicle and payload for flight at the NASA Student Launch event at Huntsville, AL, the vehicle has been modified and updated since the initial full-scale launch to improve the functionality and safety of all systems. The vehicle was re-flown two times since the initial full-scale flight; the results of each flight are described below.

# 2 Updates to Summary of FRR Report

## 2.1 Vehicle Summary

- Updated Mass: 26.4 lbs without motor
- Updated Milestone Review Flysheet: See http://stars.berkeley.edu/sl

# 3 Changes Made Since FRR

## 3.1 Changes Made to Vehicle Criteria

No changes were made to the overall vehicle and airframe after the initial full-scale flight. The vehicle experienced no damage, and the recovery system performed successfully. The second full-scale flight caused non-critical damage to the booster section and avionics bay. Each section was repaired using carbon fiber-reinforced epoxy and fiberglass-reinforced epoxy, respectively, to repair the blue tube airframe. Any deformations in the blue tube were repaired using epoxy and composite materials, resulting in an outer airframe nearly identical to that prior to the second re-flight. The motor mount, fin attachments, and avionics components were undamaged, and as such required no change.

## 3.2 Changes Made to Payload Criteria

The payload, as flown during the initial full-scale flight, used linear solenoid actuators, mounted to the top of the parachute container, to hold the landing legs in “launch configuration” (concealed inside the airframe) and release them to “landing configuration.” However, this system was found to be unreliable due to the issue of the solenoids providing insufficient power to overcome friction against the landing legs when it was time to release. Furthermore, the solenoids required a complex electronics system in order to supply the necessary amount of current. In order to avoid these difficulties, the solenoids were replaced with rotary servomotors, fitted with 3D printed 'arms' and bearings. These arms were used to hold the (modified) landing legs in lieu of the solenoid pins, and were rotated out of the way in order to release the legs. The addition of the bearings resolved any friction against the landing legs, and the servos allowed for the simplification of the electronics system. This system was repeatedly tested on the ground, and was found to be highly reliable. In addition, the parachute spring boards (which pushed the payload parachutes out of their cells when the legs are released) were replaced by the method of attaching string to the landing legs, wrapped around the parachutes to pull them out upon release. This was done in order to reduce the force pushing the legs out of launch configuration, thus improving the flush fit of the legs against the airframe, and was also found to by highly reliable during ground testing.

This system was flown during the first re-flight. Unfortunately, during this flight the rocket crashed, as described below, and the payload experienced critical damage. Various components had to be manufactured again - this presented the opportunity to manufacture certain components to a higher quality and better tolerances than during the initial manufacturing. The first part to be rebuild was the payload bulkhead. This initially consisted of a 1/2” plywood disk, sanded down to 1/8” near the edges to provide clearance for the landing legs, with 1” high wood posts to attach the steel dowel hinge. Additional 1.5” wood posts were added as surfaces against which the hinge torsion springs could push. This bulkhead was rebuilt as a 1/8” plywood disk attached to the base of a 3D printed bulkhead which included most of the bulkhead thickness, as well as hinge posts, spring surfaces, and a mount for the PVC tower. The use of 3D printing allowed us to build with better tolerances, ensuring the three landing legs were at the correct angles to one another. The bulkhead also included space for a 1.25 lbs lead weight, allowing for the convenient inclusion of the necessary ballast to lower the CG of the payload section. The landing legs, which were damaged in the crash, were also rebuilt, with added surfaces to ensure that the blue tube leg shells retained their shape after being cut. Most significantly, the legs were glued to and screwed onto the blue tube before the shells were cut, as opposed to being glued after; this ensured that the leg shells would remain aligned to the tube cut-outs after being cut, such that there would be minimal gap between the airframe and legs in launch configuration. For the second re-flight, the configuration of the payload ejection charges was also modified. They had originally been controlled by the Raspberry Pi through a MOSFET-based switching circuit and an external 9V battery, but this system failed repeatedly (due, we suspect, to a failure of the transistor we used). Ultimately, we chose to use a physical switch built into the payload landing leg, which allowed current to flow while the leg was extended. Keeping in mind that an early leg deployment would thus cause an unsafe payload ejection, we used this circuit to gate a relay that was connected to the output of one of the payload altimeters. Essentially, when the altimeter fired, the ejection charge would separate the payload from the main body if and only if the leg was fully extended and at least one parachute inflated.

### 3.3 Changes Made to Project Plan Criteria

The launch vehicle was re-flown on March 12th with the Livermore Unit of NAR (LUNAR) and on March 25th at Mojave Desert Advanced Rocket Society (MDARS). This was done to attempt to verify compliance with all payload requirements and therefore be able to launch the payload at Huntsville. Details of these re-flights are described below. After these re-flights, the vehicle airframe and recovery system have been demonstrated successfully multiple times. The payload experiment has been demonstrated in ground testing, with several safety features developed and implemented over the course of manufacturing and testing. It has not, however, been demonstrated in a full-scale launch.

## 4 March 12th Reflight

### 4.1 Reflight Results

Prior to the launch, the design changes to payload (i.e. servo arm leg securement and string-based parachute deployment) were repeatedly verified in ground testing. Safety features, including the photoresistor criteria for ejection, were also tested, and the payload was deemed safe to deploy (if all criteria were met) during the launch. In order to mitigate the possibility of air getting into the payload through the small gap between the landing legs and the airframe, a flap of duct tape was placd over the top of the leg in order to keep airflow over the gap.

During takeoff, the rocket spun around on the launch pad, causing excessive vibration, and caused the launch rail to take off with the rocket. The vibrations caused the nose cone to break off the rocket almost immediately after takeoff. This allowed air to rush into the payload section, breaking one landing leg out of its securement and allowing one payload parachute to deploy. This parachute, which blew into the wake of the burning thruster, in combination with the effects of the lost nose cone and attached launch rail, caused the rocket to turn horizontal shortly after takeoff, which induced the deployment of the drogue parachute. The rocket, after dropping the rail and nose cone, landed on the ground shortly after burnout.

Upon inspection, the nose cone was not damaged except for small cracks in the outer layer of fiberglass. The nose cone avionics sled was slightly damaged, but all electronics components were undamaged. The avionics bay was undamaged except for small cracks in the avionics booster, but the outer blue tube was undamaged. The 3D printed avionics sled was irreparably damaged, but the avionics electronics were intact and functional. The drogue and main parachute were also undamaged. The booster section was undamaged except for a large crack in the outer blue tube near the fins. Notably, however, the motor mount, centering rings, and fin attachments were undamaged.

The payload section experienced the most damage. The outer blue tube was largely destroyed, having been torn apart in multiple locations. Each of the 3D printed landing legs had been torn away from the 3D printed servo arms, resulting in the destruction of both the legs and the servo arms. The bottom bulkhead was damaged in some locations. However, the support tower, consisting of the PVC column, aluminum rails, rail carriages, support legs, and parachute box, was completely undamaged (except for having separated from the damaged bottom bulkhead). The servos themselves, on top of the parachute box, were similarly undamaged. Although one payload parachute was burned during the flight, the other two parachutes had not been deployed and were undamaged.

## 4.2 Reflight Analysis

As discussed above, all components and systems on the rocket were deemed safe prior to launch. All safety features were verified through ground testing. The airframe and recovery system had been verified through the initial full-scale launch, and the risks to payload deployment were mitigated to the fullest extent possible.

While loading the rocket onto the launch rail, the rail buttons experienced significant friction against the rail (resulting in a distinct unexpected sound), indicating the possibility that the launch rail was less than optimal. It should be noted that the rail had been used for several high-powered flights (though for less massive vehicles) throughout the day prior to this launch. However, this was not considered to be a signficant problem at the time. Upon inspection of video footage of the takeoff, it was determined that the root cause of the failure was improper securement of the launch rail to the launch pad. It was observed that on the launch pad, the rocket appeared to spin around the center of the launch pad, with the thrust from the motor seemingly firing off the center of the blast plate. It was then observed that the rail took off with the vehicle. After this, the nose cone was observed to vibrate and separate from the payload section. During flight, the nose cone fell off, and only then did the payload parachute deploy - this indicates that the accidental deployment of payload (which caused the damage to the internal components) was not due to a failure in the system design but due to the intense vibrations on the nose cone due to the rail attachment.

It was determined that the cause for the rail failure was that the rail was not properly screwed down to the launch pad. As a result, when the rocket began to take off and applied a torque to the launch rail, the rail unscrewed itself from the launch pad and bound itself to the rail buttons, rising with the rocket as a result. The instability and vibrations due to the attached rail and initial rotation caused the failure of the nose cone-payload coupling.

## 4.3 Impact on Vehicle

The main launch vehicle could be largely repaired. The cracks in the booster section and avionics bay were repaired using fiberglass to reinforce the damaged areas, with carbon fiber used to reinforce the connection between the fins and outer airframe. Thickened epoxy was then added to fill any dents and defects in the airframe, to restore the cylindrical outer shape.

## 4.4 Impact on Payload

In order to restore the payload section, several components were remanufactured. The outer tube and coupler reinforcement were recut from blue tube. The rebuilt payload was built to better tolerances by using 3D printing to create the entire bottom bulkhead, including the hinge posts and spring surfaces. The actual dowel pin and torsion springs were not damaged, and could be reused. This new bottom bulkhead also included a centering feature for the PVC tower, which was not damaged, and included space for a 1.25 lbs lead weight. This allowed us to replace the previous form of ballast, which consisted of individual smaller lead weights arranged throughout the payload, and concentrated the weight in a lower location so as to shift the center of gravity downward. In order to reduce the gap between the landing leg shell and the airframe in launch configuration, the landing leg shell had to be centered correctly with respect to the leg frame; in the first iteration, this was done by cutting the shell first, and then gluing it onto the leg frame. However, this resulted in a poor fit, due to human error in re-aligning the leg. In order to mitigate this, in the rebuilt iteration the leg was glued to the blue tube during initial installation of the internal payload assembly into the tube. This way, when the leg shells were cut, the leg frame would already be attached in the correct orientation. This resulted in a much better fit, and smaller gap. In addition, the new landing leg frames included features to increase the bond surface to the leg shell, ensuring that the shell retains its curvature after being cut. The support tower, parachute box, and servos were directly re-used. New servo arms were printed; the new iterations were made thicker, to resist bending by the spring-loaded leg.

## 4.5 Impact on Safety

Our checklists have been updated to include a step to verify before launch that the launch rail is securely attached to a support or the ground. This way we can ensure that the rod will safely guide the rocket into stable flight. There are no other impacts to safety, since the unforeseen failure of the launch rod attachment was the most significant cause of launch failure.

## 4.6 Impact on Project Plan

The damage sustained from the flight and impact caused a significant shift in the project plan timeline. Considerable time was needed to order and receive necessary replacement materials, and re-manufacture many components. In particular, there were several 3D printed components that took greater than 5 hours to print and were fairly likely to have printing errors. As such, the team deemed that 2 weeks would be necessary to both make all necessary repairs, and design improvements. In addition, the failed launch meant that a second re-launch would be necessary. This second re-launch occurred on March 25th at Mojave Desert Advanced Rocket Society (MDARS) as a result of rainy weather conditions in Northern California.

This launch impacted the team budget considerably as well. Multiple components notably additional blue tube, a replacement Raspberry Pi, a new payload parachute, and another motor needed to be purchased. Nonetheless, this did not cause the budget to be exceeded, and sufficient funds remain to complete the competition.

# 5 March 25th Reflight

## 5.1 Reflight Results

The reflight at the launch site of the Mojave Desert Advanced Rocket Society was a partially qualified success. The rebuilt rocket flew successfully, to an altitude of 3067 ft. The recovery system performed successfully at all stages. Thus, we were able to prove the safety of the refurbished airframe as well as test the payload avionics GPS live monitoring system. However, the Raspberry Pi powering the target detection and leg landing portions of the payload electronics went into a boot loop during final pre-flight checks just prior to launch. As a result, the payload could not be reliably operated, and the decision was made to seal the payload (taping over the legs to ensure they would not be accidentally deployed), and the payload was not activated or ejected during this flight.

## 5.2 Reflight Analysis

The airframe and recovery system, as demonstrated in previous flights, flew with complete success. The low altitude was a result of high winds at the launch location, and are consistent with our altitude predictions under these conditions. The rebuilt payload was verified again in repeated ground testing, confirming the functionality of the servo deployment system, string-based parachute deployment, photoresistor safety criteria for ejection, as well as the introduction of a redundant safety criteria, requiring a pre-deterimined altitude signal in addition to the photoresistor confirmation in order to allow ejection. However, minutes before the flight, the Raspberry Pi computer failed, and the problem could not be resolved with the remaining time and resources available on site. As a result, the payload has not been demonstrated as ejected from altitude.

## 5.3 Impact on Vehicle

The vehicle was moved about a little by wind gusts after touchdown, however a post-flight inspection showed that no parts were damaged during the reflight and only routine maintenance will have to be performed prior to flying again.

## 5.4 Impact on Payload

The payload was not damaged during this reflight. The Raspberry Pi will need to be replaced prior to the next launch.

### 5.5 Impact on Safety

There were no safety issues at the launch, and safety procedures were properly followed. Thus impact to safety is negligible.

### 5.6 Impact on Project Plan

The success and safety of vehicle flight and recovery was further verified by this full-scale launch. The remaining payload requirements - i.e. deploying the payload from altitude during a full-scale flight - were not able to be tested and remain unverified.

Project plan timeline was not altered by the results of this launch, as the team is still scheduled to attend competition and launch in Huntsville, AL.

Project plan budget was not altered by the results of this launch, as no further materials or components are required to be purchased. As such, the team has completed the competition with total expenses (minus travel) amounting to less than our total available funding.

## Appendix A Damage from March 12th Flight

Figure 1: Damaged Payload

Figure 2: Damaged Booster

Figure 3: Damaged Parachute

Figure 4: Damaged Avionic Sled