University of South Florida

NASA STUDENT LAUNCH 2019

POST LAUNCH ASSESMENT REVIEW

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SOCIETY OF AERONAUTICS AND ROCKETRY

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1.1 TEAM INFORMATION

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1.2 VEHICLE AND PAYLOAD SUMMARY

1.2.1 LAUNCH VEHICLE SUMMARY

For the 2019 NASA Student Launch Initiative, SOAR designed and built *Apis III*, a 6" diameter, 138" long fiberglass rocket with carbon fiber fins. The unloaded launch vehicle (without the 10 lb. motor or payload) weighs 39.3 lb. and features two separate altimeter bays, each with fully redundant avionics, to recover the two sections.

1.2.2 PAYLOAD SUMMARY

The launch vehicle was designed to carry the *Nautilus* payload, a soil-collecting rover intended to simulate the type of payload that may be used on a real-world exploration mission. The 3D printed rover sits inside the vehicle airframe until the rocket lands, at which point it is designed to deploy from the rocket via a remote signal before driving 10 ft from the rocket. At this point, the rover collects a 10 mL soil sample using a custom vacuum soil-collection system.

1.3 LAUNCH SUMMARY

Under launch day conditions, the loaded rocket, flying on an AeroTech L2200 Mojave Green rocket motor, was simulated to reach an altitude of 4,992 ft, just 8 ft. short of the team's selected target altitude of 5,000 ft. After a successful and stable flight and recovery, altimeter data showed an actual apogee of 4,780 ft – a difference of 220 ft.

2 VEHICLE REVIEW

2.1 VEHICLE SUMMARY

Apis III is a 138″ (11.5′) long rocket with a nominal outer diameter of 6″ and an unloaded mass of 39.3 lb. The rocket is fully reusable and consists of two sections that separate during flight and are recovered separately.

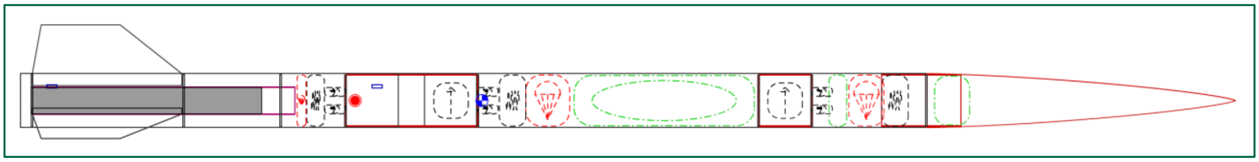


Figure 1: Layout schematic of the launch vehicle.

Figure 2: Render of assembled launch vehicle design.

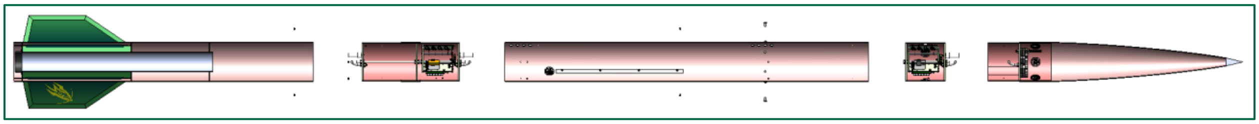


Figure 3: Cutaway view of launch vehicle sections, with avionics and ABS visible.

2.1.1 UPPER SECTION

The upper section of the rocket features a 35″ long fiberglass Von Karman-profile nose cone, which contains the adjustable ballast subsystem (ABS). The nose cone fits onto the 57″ long upper section airframe, which houses the upper section recovery subsystem components, the upper section avionics bay, the payload descent leveling subsystem (PDLS), and the *Nautilus* payload.

2.1.1.1 ADJUSTABLE BALLAST SUBSYSTEM

To allow for fine-tuned ballast adjustments up to the point of final rocket assembly (thus accounting for launch-day conditions as accurately as possible), the rocket contains a modular adjustable ballast subsystem. This system consists of stacking individually-removable ballast plates made from CNC-milled acrylic, each of which can hold several standard 1 oz. iron automotive wheel weights. The system mass can range from 0 to 43 oz, with a resolution of 1 oz.

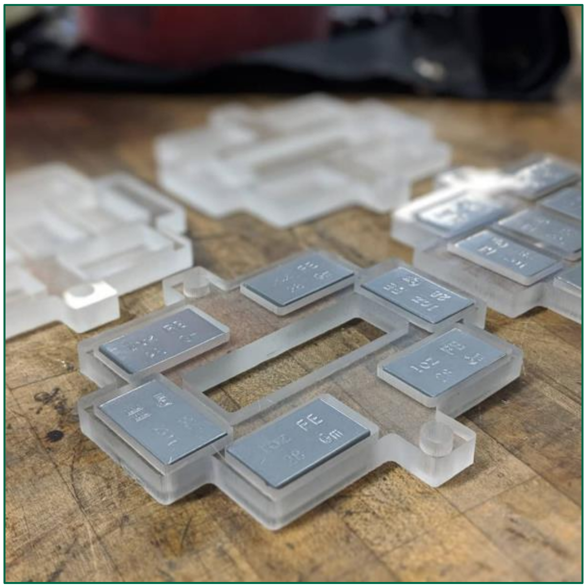


Figure 4: Constructed ABS plate with weights installed.

2.1.1.2 PAYLOAD DESCENT LEVELING SUBSYSTEM

A common issue with payload deployment is foreign debris entering the payload-exit end of the upper section airframe, due to the parachute attachment point being at the opposite end of the airframe. To prevent this, a leveling system was developed that would cause the upper airframe to land sideways, rather than vertically. This system consists of a stainless-steel wire that is installed on the exterior of the rocket and attaches to the payload-exit end of the airframe and to the upper section main parachute shock cord. Upon deployment of the system through a signal from a Missile Works RRC2 altimeter, the wire and shock cord form a triangular harness that holds the airframe horizontally.

Figure 5: PDLS system after deployment during vehicle test flight.

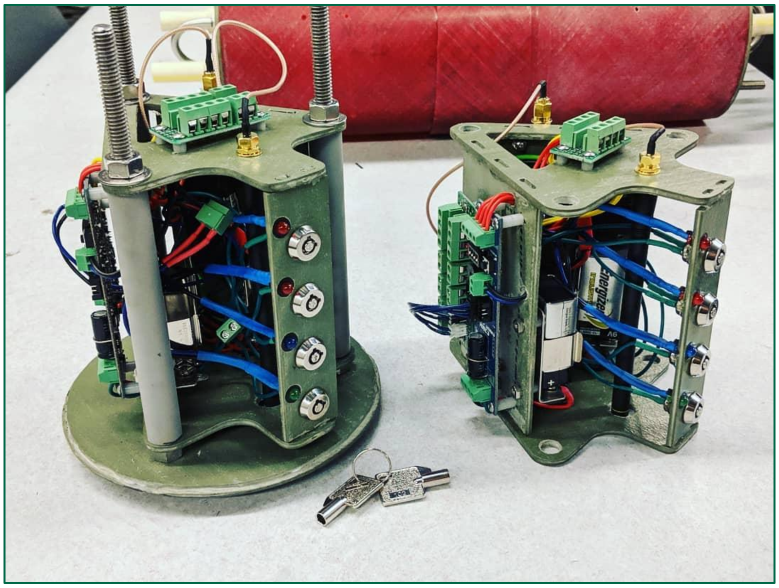
2.1.2 LOWER SECTION

The lower section of the launch vehicle consists of the lower section avionics bay (which is also the coupler that joins the upper and lower sections) and the lower airframe. The 43" long lower airframe is also constructed from G10 fiberglass, into which three CNC-milled carbon fiber fins are through-mounted to the fiberglass motor mount tube, which is centered and secured using three CNC-milled fiberglass-reinforced plastic (FRP) centering rings. The motor itself is secured in the motor mount tube using a standard AeroPack 75mm flange-mount motor retainer and Cesaroni Pro75 motor casing hardware.

2.1.3 RECOVERY SUBSYSTEM

Recovery of the launch vehicle is performed using a single SkyAngle Classic 20" drogue parachute, a FruityChutes Iris Ultra Standard 96" main parachute for the upper section, and a FruityChutes Iris Ultra Standard 84" main parachute for the lower section. The drogue parachute is deployed using a black powder separation charge in the lower airframe at apogee, while the main parachutes are deployed simultaneously at 700' AGL with two more separation charges (which also separate the upper and lower sections).

All deployment charges are controlled by the onboard altimeters, which also record flight data. Each deployment charge has a full backup charge controlled by an identical altimeter with its own battery and switch. All altimeters are MissileWorks RRC3 flight computers. Each section also transmits its GPS coordinates during flight using a MissileWorks RTx device. All flight electronics are efficiently mounted in the avionics bays with CNC-milled FRP electronics sleds.



Assembled upper (left) and lower (right) section avionics sleds.

2.2 FLIGHT RESULTS AND ANALYSIS

After three test flights throughout the spring 2019 season, *Apis III* completed a successful competition flight in Huntsville, AL on April 6, 2019, using a mock payload (as the competition payload was not approved to fly in Huntsville due to safety concerns). After an extended pad stay time, the rocket performed a completely stable ascent before reaching an apogee of 4,780 ft. All parachutes and sections separated as expected and the rocket was recovered with minimal damage and wear.

Two weeks later, on April 20, 2019, *Apis III* completed a section flight to demonstrate reusability and perform a test of the *Nautilus* competition payload. Once again, the rocket completed a stable flight and was successfully recovered.

The flight analysis in this section focuses on the April 6 competition flight.

2.2.1 FLIGHT CHARACTERISTICS

2.2.1.1 ALTITUDE DATA

Immediately prior to final assembly, flight simulations were performed with measured launch conditions to accurately determine required ballast. Based on the conditions in Table 1, no ballast was installed in the rocket. Simulated flight characteristics are presented alongside actual flight data in Table 2 and Figure 6. Uncertainty for actual data was calculated using the Student's t-value method, where the number of collected data points is four (or two, after separation): one for each altimeter.

Table 1: Launch conditions values used for launch day simulations.

Launch Condition	**Value Used**
Average Windspeed (mph)	6
Wind Direction (°)	90
Temperature (°F)	70
Ground Pressure (mbar)	1022
Latitude (°, N)	34.9
Longitude (°, E)	-86.6
Ground Altitude (ft)	740
Launch Rod Angle (°, into wind)	5

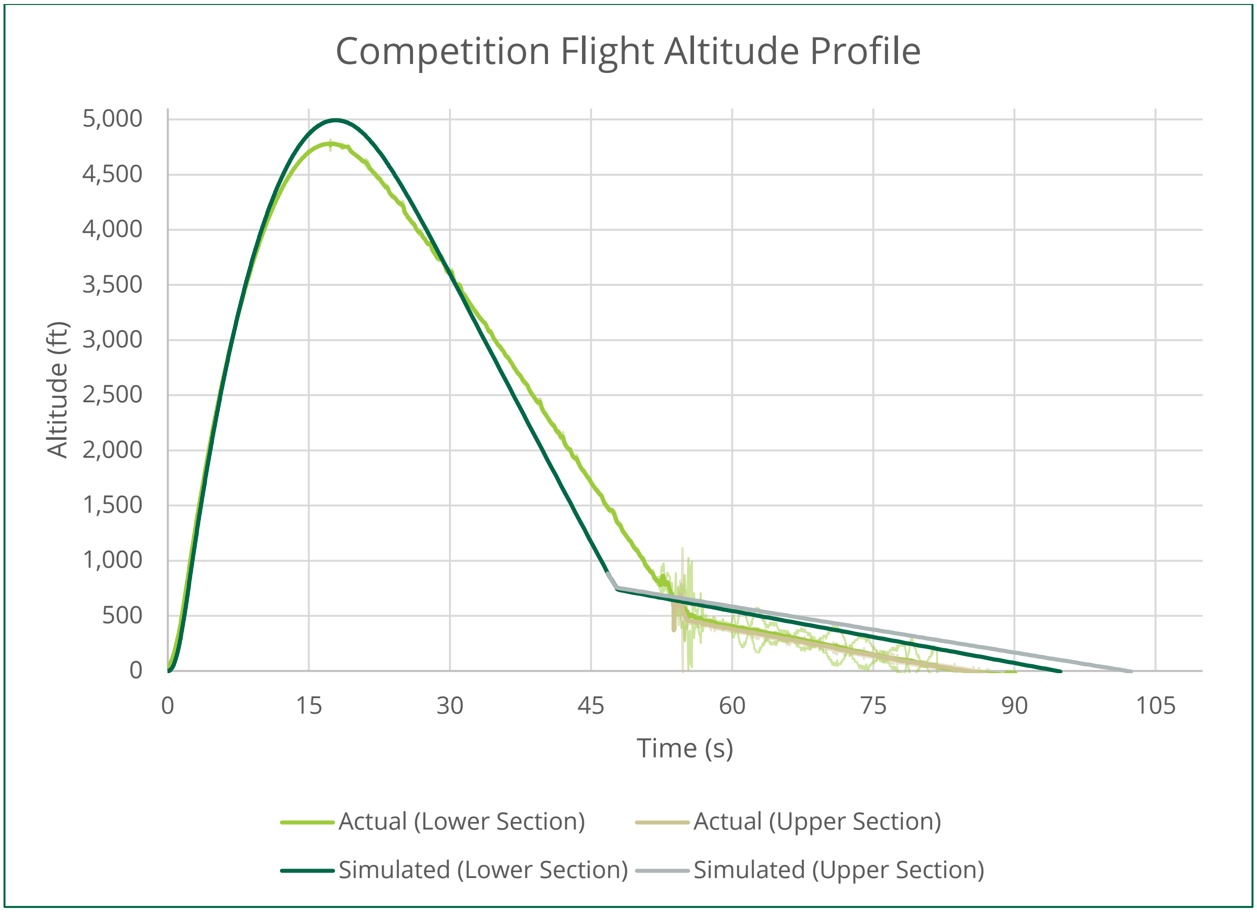


Figure 6: Altitude data from simulated and actual competition flight, with uncertainty shown.

Table 2: Apogee above ground level (AGL) of primary flight events.

Event	**Target** (ft)	**Predicted** (ft)	**Actual** (ft)
Apogee	5,000	4,994	4,780.1 ± 9.28
Drogue Parachute Deployment	4,980	4,978	4,780.1 ± 9.28
Main Parachute Deployment	700	700	637.2 ± 48.1

2.2.1.2 DISCUSSION

Actual flight altitude was significantly lower than the simulated and target altitudes. After considering all flight properties and reviewing data, there are three most likely reasons for this deviation:

1. The launch rail angle may have been higher than the predicted 5° from vertical.
2. As there was significant pad stay time prior to launch, wind speeds had increased somewhat from simulations. Higher wind speeds typically result in decreased apogee and farther drift.
3. While solid rocket motors have nominal reported thrust values, some error is present when compared to actual values. The motor used may have not reached those values.

2.2.2 SUBSYSTEMS PERFORMANCE

2.2.2.1 RECOVERY SUBSYSTEM

The recovery subsystem performed primarily as expected, however the flight was not perfect. The lengthy pad stay time caused the GPS system batteries to fail just before flight, preventing GPS tracking. This did not cause any actual issues; however, it could have theoretically prevented location of the rocket if the main parachute had deployed early and caused significant drift. Also, the main parachute deployed somewhat late, interfering with the PDLS. It is not clear why this occurred, except that the rocket may have been falling too fast for the altimeter to fire in time.

2.2.2.2 PAYLOAD DESCENT LEVELLING SUBSYSTEM

The only issue that occurred during flight was the failure of the PDLS. The system was set to deploy at 500 ft AGL, which is 200 ft lower than the main parachute deployment altitude. The intent was for the PDLS to deploy after the parachutes had fully deployed, preventing shock forces from applying directly to the PDLS wire. However, the system apparently deployed too early, impacting significant forces to the wire. This caused the PDLS wire to snap and forced the upper section main parachute shock cord into the upper section airframe at high speed, causing structural damage to the airframe itself. The damage was made more significant due to the presence of previous repairs in this area. This damage was repaired quickly using carbon fiber and AeroPoxy, and the PDLS wire replaced in time for the next launch, so no significant costs or time delays were incurred due to the failure.

Figure 7: Damage to airframe due to PDLS failure, prior to repairs.

3 PAYLOAD REVIEW

3.1 PAYLOAD SUMMARY

The payload design was intentionally kept simple and minimal, therefore, just three motors run the drive and soil collection systems. *Nautilus'* structure was fully 3D printed from PLA with varying infills. This design was also simplified as much as possible and was printed in as few pieces as possible. The vacuum system inside was taken from a portable hand vacuum, and the design was built around these parts specifically.

Nautilus was fully operational for the April 20th relaunch, complete with changes made since the last flight to improve retention support. These changes included strengthening the set screw holding the upper wheel to the motor shaft, and the new hook connected to two threaded rods instead of one on the deployment system. It was believed that such changes would fix previous payload retention issues.

3.2 DATA ANALYSIS & RESULTS OF THE PAYLOAD

Upon main parachute deployment, *Nautilus* separated along one of its epoxied joints, leading to a retention failure for a decent part of the payload itself. Upon the upper airframe landing on the ground, the approximately 15 mph winds dragged the body about 100 yards from the landing site, including through a small pond. Upon inspection, this water encounter destroyed all electronics on board the deployment system, making a deployment of the remaining rover impossible.

3.3 VISUAL DATA OBSERVED

It was observed that the forces acting on the payload upon main parachute deployment are significantly more than previously calculated. The payload design was based upon several simulations, which appear to have not been conservative enough. Before the launch itself, both the deployment system and the rover were working according to plan, so it is believed that a successful recovery would have led to a fully operational payload and deployment.

3.4 LESSONS LEARNED

Estimates as to the force on the payload were inaccurate, and a better understanding of specifically how much force the payload needs to withstand is needed. Potential future payloads for non-competition launches may include a sensor capable of collecting this specific data. Beyond that point, more realistic testing procedures need to be developed to allow payload testing without full launches.

4 EXPERIENCE REVIEW

Overall, this was a largely positive experience. Despite some setbacks, the launch vehicle performed as expected and was able to launch a total of five times in as many months - a new record for SOAR. This extensive testing brought with it many lessons that will vastly improve future designs. Unfortunately, payload design is always the more challenging aspect of the project, as it requires new designs and knowledge to come from practically nothing every year (rather than building on prior rocketry experience). With regards to the competition administration and management, very few, if any, negative things could be said.

5 STEM ENGAGEMENT REVIEW

SOAR completed seventeen STEM engagement events this year, reaching over 2,500 participants. These events included the USF Engineering Expo, training events, and Girl Scout Trip visits.

Table 3: Summary of STEM engagement participants.

Participant Type	**Education**		**Outreach**	
	Direct Interactions	**Indirect Interactions**	**Direct Interactions**	**Indirect Interactions**
Preschool – 4th Grade	164	-	50	50
5th – 9th Grade	528	-	45	710

Participant Type	**Education**		**Outreach**	
	Direct Interactions	**Indirect Interactions**	**Direct Interactions**	**Indirect Interactions**
10th – 12th Grade	100	-	30	485
University Students	10	-	-	80
Educators	11	-	-	30
Adult Non-Students	20	50	75	260
Total	833	50	200	1,615
Grand Total	***2,698***			

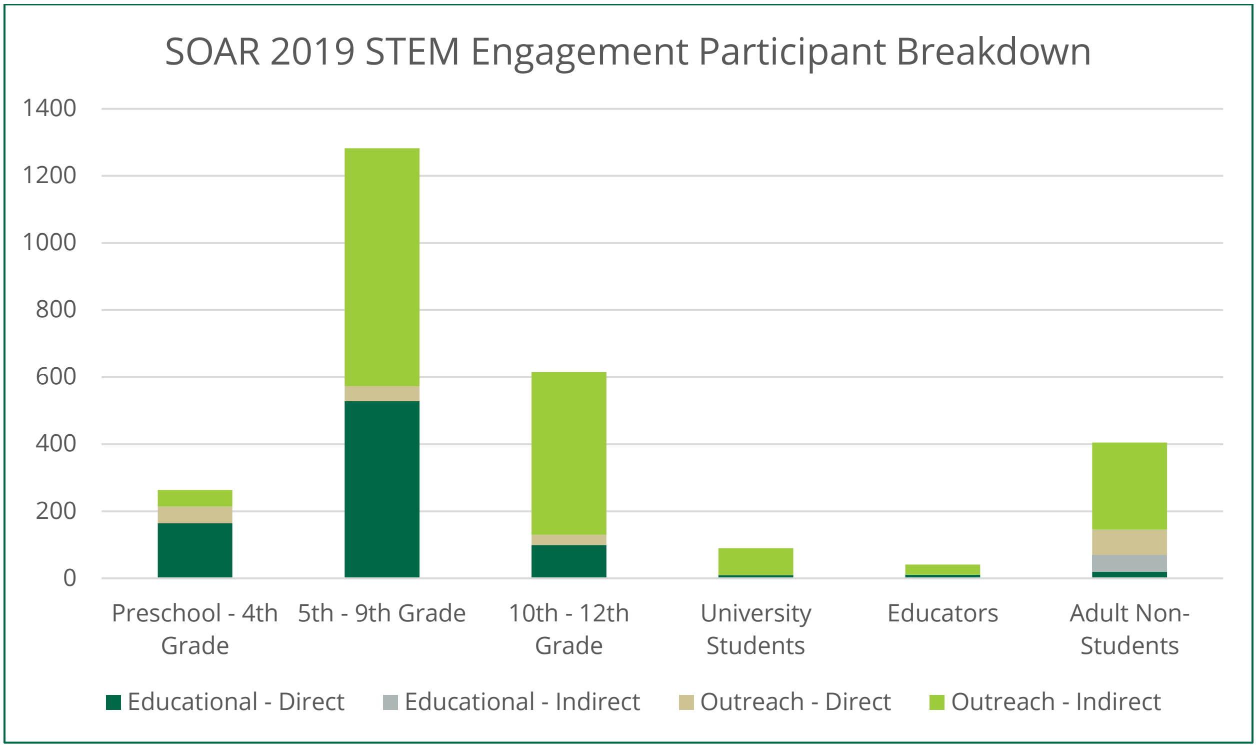


Figure 8: Plot of STEM engagement breakdown.

6 FINAL BUDGET REVIEW

The total amount spent by SOAR on the NASA Student Launch project this year was $14,374.82, which is $3,974.82 more than the original proposed budget of $10,400. The increased costs were primarily caused by the upper section landing in a body of water during the first test launch, necessitating full replacement of all upper section and payload electronics, at significant cost. Also, more launches were required than expected, requiring more motors to be purchased than originally planned.

This funding came from several sources, including USF Student Government, the NASA Florida Space Grant Consortium educational grants program, a sponsorship from CAE Inc, and SOAR's cash reserves (which includes individual donations and money raised through traditional fundraising methods).

Table 4: Final budget breakdown, as spent.

Budget Category	**Amount Spent** ($)
Full-Scale Vehicle Materials	4,921.57
Vehicle Tools	440.90
Payload Materials	2,348.13
Payload Tools	96.30
General / Shared	1,864.43
Subscale Vehicle Materials	1,356.04
Travel	1,091.00
Full-Scale Launch Supplies	1,542.23
Subscale Launch Supplies	166.99
Rocket Fair	547.23
Total	**14,374.82**

Table 5: Budget funding breakdown.

Funding Source	**Amount** ($)
USF Student Government	9,387.91
SOAR Cash Reserves / Fundraising	1.448.41
CAE Sponsorship	2,500.00
NASA FSGC Grant	1,038.49