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Educating the Space Scientists at Embry-Riddle through Design, Build and Fly Rocketry Experience

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Practical experience for students in rockets and payloads is very valuable in the space industry, and it is something that would give them an advantage over other applicants. Students in Embry-Riddle Aeronautical University's Payload and Integration class were given the opportunity to build a level 1 rocket and gain experience developing, testing, and integrating payloads into a rocket. The students were given the tasks to come up with an idea for a payload, design the payload to fit within the rocket for flight, and assemble and launch the rocket with the payload in the payload bay. The tasks required for this project were split into four different teams - the avionics team was tasked with the data collection electronics that would be in the payload bay, the rocket assembly team was tasked with the preparation of the rocket and the customized payload bay that was added into the rocket, the software team was in charge of calculating flight profiles, and the operations team was tasked with overseeing pre and post launch procedures and documenting the steps during rocket construction and assembly. A Pixhawk flight controller was used as a data collection device along with an Arduino data logger which was custom built by students to collect various flight parameters. The rocket that the students built launched without incident to an apogee height of about 1845 ft, but the descent was faster than anticipated and resulted in the parachute suffering damage. This was found to be the result of the additional payload weight added to the rocket and using a rocket motor that had a longer delay charge that resulted in parachute deployment several seconds past apogee. Data from the rocket was limited due to unexpected data corruption in Pixhawk sensor. The Arduino data logger was the primary source of data from the rocket launch. Weather plays an important role in a rocket launch and the meteorology students involved in this project were able to analyze and record data at the launch site using infrared cameras. One of the objectives of this paper is to compare the recorded field data with the data collected in the payload. Overall, this multidisciplinary project aided students in learning and applying themselves in various new areas such as design, assembly, avionics, programming and meteorology. The data collected in this launch will be used in future payloads projects and the lessons learned will be taught in future courses as case studies to enhance the experience for other students.

I. Introduction

The CSO 390 class at Embry-Riddle Aeronautical University (ERAU) educates students on various aspects of developing, testing and integrating payloads. As part of the CSO 390 coursework in spring 2018, the students in the class built a model rocket to help facilitate an understanding of how to build and launch model rockets and integrate small payloads in the rocket. The experience gained by the students from the Spaceflight operations department will help with future payload projects and in their space related careers.

With the help of the Northeast Florida Association of Rocketry (NEFAR), the students were provided with an understanding of procedures to obtain a license to launch a level 1 rocket and were allowed to fly the rocket at the

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launch site in Bunnell, Florida. The EZI-65 rocket kit¹ was purchased from Apogee Rockets² and the kit was assembled by the students with the help of student assistants and faculty members who are the authors of this paper.

The students were tasked to build a customized payload to launch with the assembled rocket. They came up with the idea to build a data logger to measure and record the telemetry of the rocket along with other environmental data. Students innovatively solved many problems faced during construction and integration of the rocket with guidance from student assistants and the professors. The hands-on experience obtained while building and preparing the rocket to fly, as well as the experience in data extraction and analysis, is invaluable for their future careers in the space industry. Recent model rockets³ have been employed as part of an academic course to enhance student's practical educational experiences and technical skills.

II. Methodology

The tasks required to complete the rocket were split into different teams. The first team was the avionics team which focused on the electronics in the rocket that collected data. One of the first things the team had to do was determine the necessary electronics that they would need to gather the required data, as well as how to best integrate the avionics into the rocket payload area. A data logger was built from scratch using an Arduino Nano⁴ and various sensors that measure environmental parameters, which is displayed in Figure 1a. Data parameters such as, pressure, altitude, temperature, relative humidity, accelerations and gyrations were measured and recorded using the data logger. With the use of the Arduino Nano, the students had to learn the Arduino code^{5,6}, so they could properly program it for their set objective. This included writing the code for the data logger using the Arduino IDE⁷ found on the Arduino website. The team also assembled a Pixhawk⁸ (Figure 1b), which was used in tandem to measure some of the same parameters for redundancy along with GPS data. Before loading the payload into the rocket, the team performed tests of all the instruments and checked the Arduino code for the equipment to ensure functionality.

Figure 1. Payload. (a) Arduino data logger, (b) Pixhawk 2.4.8

Another team was focused on the assembly of the rocket. They prepared the body of the rocket to allow for optimal aerodynamic flight by sanding down the outside of the rocket and ensuring proper placement of the rocket fins. Epoxy was applied by the students to ensure that the motor mount rings and the rocket fins remained secure in flight. A custom payload tube was 3D printed to meet with the requirements of the data collection devices that would be put into the EZI-65 rocket. Having used CATIA v5 software⁹ to design the custom payload tube that was needed, the students then printed the tube in ABS plastic using a Raise3D N2 Plus 3D printer¹⁰. To ensure proper placement of the avionic devices, spray great stuff foam¹¹ was hardened in the shape of the payload tube and grooves were then cut into the foam that the avionics were later placed in. The layout made in the foam was used to properly secure all the components of the Pixhawk and the data logger.

The software team worked on calculating the flight profile of the rocket. This required the use of the RockSim¹² software that was provided by Apogee Rockets. RockSim is an integrated software and has tools to analyze various rocket models sold by Apogee rockets. Shown in Figure 3 is some of the data that was entered into the RockSim software that the students used to analyze the possible flight profile of the EZI-65 rocket.

The operations team was given the task of preparing and overseeing procedures that were to be followed pre and post launch of the rocket. They also documented all the steps followed during the rocket construction and assembly. Another task they had to complete was acquiring information on NEFAR requirements and helping to obtain the level 1 rocket launch certification that was needed to launch the rocket.

Figure 2. Rocket assembly. (a) Epoxying the motor support rings, (b) Sanding the 3D printed payload tube, (c) Applying primer to the assembled rocket body, (d) Assembled payload inside the foam.

Figure 3. RockSim software used to analyze the rocket flight parameters.

Table 1. Rocket dimensional and mass parameters

Item	Mass (g)	Total Length (cm)	Thickness (cm)	Connecting Length (cm)	Lip Circumference (cm)	Below Lip Circumference (cm)	Nose Diameter (below dome) (cm)
Nose cone	240	42.5		10.5	32.8	31.5	2.05
Fins (individual)	38						
Fins Specific measurements				Root chord: 14.3	Tip chord: 9.12	Sweep angle: 10.56°	12.4
Payload tube	94	27		Outer diameter: 10.1	Wall thickness: 0.12		
Body tube	348	87		10.1	0.12		
Motor tube	120	50.5		5.73	0.15		
Launch lug	6	15.2		1.53	0.1		
Parachute	60						
Parachute chord	104						
Spacer (Individual - 3 total)	20		0.55	98.6	2.07		
End spacer	30		0.57	9.58			
Motor stopper	40			6.64			
Hardware	74						
Engine	484			10			
Pixhawk	118						
Dry Payload Rocket	2320						
Loaded Rocket motor	437.5						
Loaded Payload rocket	2757.5						

III. Results & Discussion

On the day of launch the rocket launched without incident. However, the descent was faster than had been anticipated and as a result the parachute suffered damage from the high-tension force that it experienced. From the post-flight assessment of the rocket, it was determined that the use of a motor¹³ which had a longer delay in parachute deployment and exceeding the parachutes weight limit with the additional payload tube were the main factors that caused the fracturing of the parachute. The longer delay meant that the rocket was coming down too fast when the parachutes deployed and the higher speed resulted in higher loads on the parachute chords. It was also found that the Pixhawk data collection device had corrupted data and could not be read. The primary cause of the data corruption is being investigated and the preliminary findings show that it could be due to improper setup before launch. Therefore, most of the data was obtained from the Arduino data logger and used in post flight assessment. Flight preparation launch pad integration and pictures of the rocket launch are shown in Figure 4.

Figure 4. Launch day at the NEFAR launch site in Bunnell, Florida. (a) Pre-launch setup and inspection, (b) Loading the rocket in the launchpad after inspection by the Range Safety Officer (RSO), (c) Launch, (d) Rocket powered climb, (e) Descent with parachute deployed, (f) Landed rocket

The flight profile with the maximum height of apogee at 1845 ft is shown below in Figure 5. It is observed that RockSim over predicted the apogee altitude. This could be due to various factors such as wind conditions on the day of the launch, uneven mass distribution inside the payload (RockSim assumes uniform mass distribution), assembly errors and irregularities in the motor. The greatest altitude shift in the actual flight is shown in Figure 5b. The sharp change is due to the parachute deployment. The parachute deployment should have been right after apogee was reached, and the delay is assumed to be due to the faster descent from the higher mass.

Figure 5. Flight Profile. (a) RockSim prediction for ascent portion of flight. (b) Actual flight

Figure 6. RockSim analysis. (a) Thrust profile, (b) Acceleration profile, (c) Drag force profile, (d) Velocity profile, (e) Mass profile, (f) Pressure profile

The RockSim analysis shown in Figure 6 shows the different aspects predicted for the flight. Figure 6a shows the anticipated thrust profile of the rocket, Figure 6b shows the anticipated acceleration profile of the rocket, Figure 6c shows the anticipated drag force profile, Figure 6d shows the anticipated velocity profile of the rocket flight, Figure

6e shows the anticipated mass profile of the rocket, and Figure 6f shows the anticipated pressure profile of the rocket flight.

Figure 7a illustrates the altitude profile for the rocket. Figure 7b shows the acceleration profile in the x-, y- and z-directions during the 32 seconds flight time. Figure 7c displays the acceleration during the first 2.5 seconds of burn time (MECO). The rocket reached a maximum acceleration in the y-direction (+2.1g) of about during the ascent and before MECO. Figure 7d depicts the acceleration from MECO to apogee. Figure 7e shows the acceleration experienced by the rocket near apogee. During this phase, the rocket experienced microgravity levels of about 2%g to 12%g. During the descent (Figure 7f), the rocket experienced increasing accelerations until parachute deployment. The x- and y-accelerations oscillated between 0.08g to 0.2g, and 0.002g to about 0.09g, respectively. The z-acceleration oscillated between about 0.07g and almost linearly increased to about 0.5g right before parachute deployment. At parachute deployment (Figure 7g), the rocket experienced a maximum acceleration of near 14g. After parachute deployment, these accelerations decreased to maximum levels of 2g, 1.5g and about 1g in the y-, z- and z-directions respectively. At impact, the rocket experienced accelerations of about -12g as recorded per our instruments. Figure 7h shows the temperature of the rocket from the start of flight operations to the end of the flight. The increase in temperature can be correlated to the fast decent of the rocket after apogee was reached. Figure 7i shows the relative humidity of the rocket from the start of flight operations to the end of flight. The decrease in relative humidity can be related to the rocket ascent and the sharp increase can be related to the descent. Figure 7j shows the pressure during flight, which is mirrored in Figure 7a and shows an inverse relationship between the two.

Figure 7. Arduino data analysis for Marea Roja's flight. (a) Altitude. (b) Acceleration of entire flight. (c) Acceleration during burn time. (d) Acceleration coast to apogee. (e) Acceleration near apogee (microgravity). (f) Acceleration during descent to start of parachute deployment. (g) Acceleration during parachute deployment. (h) In-situ temperature measured since the start of flight operations. (i) Relative humidity measured since start of flight operations. (j) Pressure.

Another observation included the thermal output of the rocket after it had landed by using a FLIR C3 IR camera¹⁴. The imaging and optical data device has a thermal sensitivity of less than 0.10°C , and it can take measurements with an accuracy of $\pm 2^{\circ}\text{C}$ at 25°C (77°F). Four measurements within a 45 seconds time span were taken from about 3-9 feet in range as soon as the team arrived to the landing site (~ 300 m south of the launch pad) about 15 minutes after landing. The single point (Sp1) and Sp2 are the measurements taken at a specific point in the rocket. The linear (Li1) and Li2 measurements (average, maximum and minimum) were taken along the depicted line across the payload body tube of the rocket and the motor body tube of the rocket. Note that Sp2 measurement is almost identical to the value of the maximum temperature of Li1 and Li2 (Figure 8).

When using a FLIR C3 infrared camera, it was shown that the main rocket area that housed the payload was an average of 90.4°F . The end of the payload part of the rocket was determined to be 101.5°F where the parachute was connected. These results are shown in Figures 8 to 11 below.

The emissivity of the rocket surface was assumed to be 0.95, which it was expected since the rocket surface had been painted. Usually, oil-based painted surfaces¹⁴ (regardless of color in the visible spectrum) have emissivities over 0.90. For comparison, human skin has emissivity about 0.97-0.98.

The last measurements (Figure 11) obtained was that one of the payload tube coupling. In this case, a cross sectional area was selected (box) for which the average, maximum and minimum values were 88.2°F , 101.5°F , and 81.3°F , respectively. Since the team could not access the landing site until 15 minutes later, we could not collect more precise measurements of the rocket. However, using a linear extrapolation gives a possible temperature at landing. Although hard to establish a prediction, our team estimated the temperature of the rocket to be about 10°F higher at landing.

Measurements		
Sp1		92.8 °F
Sp2		94.5 °F
Li1	Max	94.6 °F
	Min	86.1 °F
	Average	90.5 °F
Li2	Max	94.7 °F
	Min	85.8 °F
	Average	88.3 °F
Parameters		
Emissivity		0.95
Refl. temp.		81.2 °F

Figure 8. Rocket temperature after flight measured by the FLIR C3 infrared camera (3:48:43 PM), at about 9 feet distance.

Measurements		
Li1	Max	94.3 °F
	Min	86.0 °F
	Average	90.2 °F
Li2	Max	93.3 °F
	Min	86.1 °F
	Average	87.7 °F
Parameters		
Emissivity		0.95
Refl. temp.		81.2 °F

Figure 9. Rocket temperature after flight measured by the FLIR C3 infrared camera (3:48: 51 PM).

Measurements		
Sp1		94.5 °F
Li1	Max	92.6 °F
	Min	85.9 °F
	Average	90.4 °F
Parameters		
Emissivity		0.95
Refl. temp.		81.2 °F

Figure 10. Rocket temperature after flight measured by the FLIR C3 infrared camera (3:49:02 PM).

Figure 11. Rocket temperature after flight showing body tube and payload tube coupling (3:49:27 PM), at about 3 feet distance.

IV. Summary and Future Work

Based on the results of the post-flight analysis, it was recommended that a secondary parachute (drogue chute in Figure 13) be employed with all future launches to help reduce the speed of descent and decrease the force of deployment on the primary parachute. It is also recommended that the parachute deployment delay be correctly calculated based on the weight of the rocket and the time taken to reach apogee. With the avionics, it was recommended that trial runs be done beforehand with the equipment and that it run on a test flight to ensure a successful data collection. Overall, the students had a great opportunity to practically understand the various aspects of a rocket and payload assembly, and a level one rocket launch. Although they worked in different teams, every student learnt the techniques involved in design, analysis and integration of a payload and the rocket. This included acquiring skills on CATIA v5, Arduino, basic electronics, aerodynamics, structures and 3D printing.

Because simulations are terminated at apogee¹² and launch angle are restricted to ± 5 degrees from the vertical, we cannot replicate an exact rocket trajectory using the RockSim software. Also, an additional payload of 2.7 kg affected the altitude achieved. In our simulation, the rocket (with no payload) achieved an altitude of about 2,270 ft with a range of 1,030 ft or 314 m (see Figure 14 and Figure 5a for comparison). The actual rocket landed within a 5% error of the simulated range and achieved an altitude of 19% lower than the simulated one due to the extra payload mass added. In our simulations, we assumed other inputs, such as breezy wind conditions (15-25 mph), 50% relative humidity and temperature of 80 °F.

Figure 13. Rocket with parachute chords cut after landing

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The team is currently working on the development of level 2 and level 3 certified rockets to accommodate larger payloads that can fly up to 10,000 ft to 20,000 ft. This will allow us to test various technologies before these payloads can be flown on larger research platforms, such as Blue Origin’s New Shepard, and PLD Space Arion 1 vehicles to suborbital space.

(a)

(b)

Figure 14. Flight parameters simulated with RockSim. (a) Altitude and range values real time. (b) Altitude, range and thrust profiles of rocket at the end of simulation.

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