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Rocket Trajectory Prediction using OpenRocket Simulator and Featherweight GPS Tracker of a Solid Propellant Rocket

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Abstract: Morgan State University aims to launch a Liquid Propellant Rocket (LPR) that could reach an apogee of 50,000 feet in March 2022. However, all systems must be carefully integrated and tested on a Solid Propellant Rocket (SPR) first to have a successful flight mission. The design of an SPR becomes a crucial task, especially when a wide variety of factors need to be considered, such as the placement of each system in the avionics bay area. One of the central systems of Morgan State's SPR is the GPS. The MSU Rocketry Team has decided to use the Featherweight GPS System to track the rocket's position. During Morgan State's previous rocket launching, an unexpected error occurred in which the Featherweight GPS recorded incorrect data. One of the leading hypotheses of this error is the location of the tracking device inside the rocket that causes system interference with other devices. A reliable GPS is needed to accurately record the apogee and location of the liquid propellant rocket. This research investigates the effects of geometrical areas of the GPS placement inside the rocket to prevent interference with the other systems. A series of simulations were made using OpenRocket Software to have theoretical data of the rocket's altitude and lateral distance when launch. To conduct an experimental analysis of the reliability of the Featherweight GPS system, the MSU Rocketry Team isolated the tracking device and placed it inside the nose cone rather than in the avionics bay. During the rocket launched on the second day of July 2021, the data collected from the Featherweight GPS system was 98.74%, similar to the result of the theoretical data. Furthermore, results indicated that both theoretical and experimental data were the same in terms of the lateral distance of the rocket traveled, which is 840 feet. Since the placement of the GPS made a significant impact in terms of the accuracy of the data, the MSU Rocketry Team has decided to continue using the Featherweight GPS system on their liquid-propellant rocket, as long as it will be placed in the rocket's nose cone. In this event, students' exposure and engagement were heightened using the different software to compare theoretical and experimental data. Every essential system of the SPR, such as the motors, electronics systems, the interior and exterior structures, and recovery, was individually analyzed, assessed, and considered during the simulation process to get accurate data. The findings of this report will provide a basis for future innovations within Morgan State University's Rocketry curriculum.

Keywords: Solid Propellant Rocket (SPR), OpenRocket Simulation, Featherweight GPS Tracker, Lateral Distance, Apogee, Rocket Trajectory Prediction (RTP)

1. Introduction

Morgan State University (MSU) has been awarded a grant from BASE 11 for building a rocketry program where MSU students have an opportunity to participate in the design and fabrication of rockets (Alamu et al., 2019). Last year, October 20202, the rocketry team in MSU was able to launch their first Solid Propellant Rocket (SPR) in Maryland and Delaware Rocketry Association at Sullnick, Gaithersburg. Figure 1 shows the MSU Rocket team members, both faculties and students, during the launching event. By using the SPR as the main testing rocket, the MSU Rocketry team was able to find out the best devices and systems to be used on their Liquid Propellant Rocket (LPR). MSU chose to launch using an SPR because of its design simplicity and application of its propulsion. It has a few moving components, but at the same time, it does not require filling up the tanks before launch since it can be ignited at a moment's notice. Furthermore, the SRM's propellant contains only the fuel and oxidizer. Thus, once it is launch, it can operate in the vacuum of space. However, the downside of using SPR is that it has a lower specific impulse compared to LPR and cannot be throttled more than it is supposed to be. Once the SPR is ignited, its motor will continuously burn until it runs out, unless a system terminates its thrust during launch (Nowakowski et al., 2017).

Figure 1. Morgan State University Rocketry Team

Figure 2 illustrates a generic model of the SPR components where each of them plays a vital role in the success during the launch. The components include but are not limited to the nose cone, parachute lines, shock cord, parachute, body tube, rocket engine, and engine mount. Furthermore, Morgan's SPR comprises three primary systems, and of them is the GPS System. The rocketry team decided to use the Featherweight GPS Tracker during the launch based on its availability, ease of use, price, and re-usage. Additionally, it was also due to its weight and reliability (Flaten et al., 2019). The Featherweight GPS Tracker also is the rocketry's longest-range tracking system and the only system designed to work with iPhone devices. Afterward, the students placed the Featherweight GPS in the altimeter bay located in the rocket's airframe. However, the data collected had a slight difference from the simulation results. The problem with Morgan's SPR is that even though it has the proper systems to collect the necessary data – apogee and lateral distance, it is not sure whether the placement of the sensors is correct. Thus, a study is needed to show the most efficient and optimal location. A proper location of these systems should be thought out to gather appropriate data for the LPR launching.

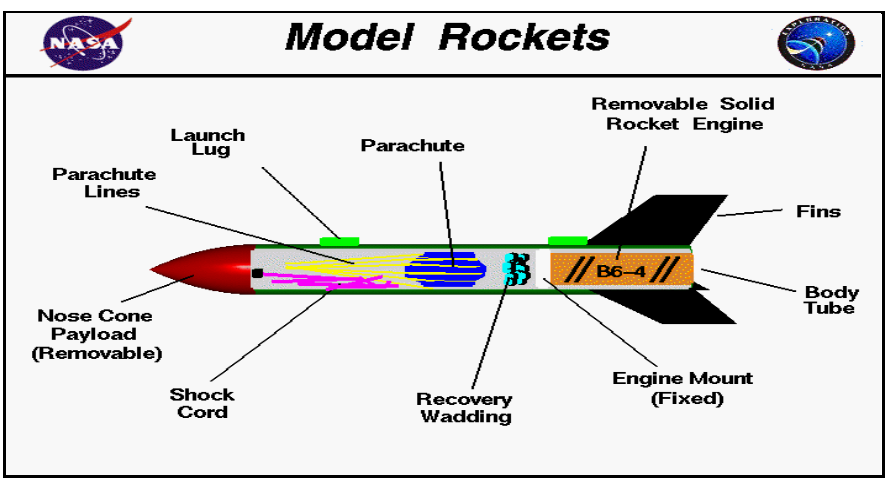

Figure 2. NASAs Solid Rocket Preplant Design

1.1 GPS System User Integration (UI)

The research of Malanowski et al. implies that different rockets use various tracking systems. However, the choice of usage is solely on its range, price, and reliability (2018). MSU Rocketry use the GPS Featherweight Tracker. The total length is approximately 4.1 inches without the antenna installed. To receive the GPS signals properly, it needs to be clear of metallic obstructions between the device and the sky. The Featherweight tracking app provides information about GPS signal strength that validates for installation. The antenna connector is an SMA (not reversed polarity). The antenna provides the best signal strength in the direction radiating from the antenna's side and the worst signal strength in the direction pointing down the long end of the antenna. Thus, to achieve a better result when tracking, the ground station antenna must be placed horizontally rather than pointed in the direction of the rocket (Nilsen et al., 2019). The radio in the Featherweight GPS Tracker has equipped with the Long Range (LoRa) spread-spectrum technology, which is responsible for the most extended range available in GPS trackers. One of the main reasons the MSU students chose the GPS Featherweight is that it has a track record to be fully functional even though it has been tested and proven several times in model rocketry. The GPS has a record-breaking of tracking a rocket with over 137,000 feet altitude with 145,900 feet full range last September 2017 located above the Black Rock Desert. Using the iPhone's screen recording capability, MSU students can easily record the display on the screen during its launch in real-time. The MSU's SPR and is composed of the nose cone, airframes, and fins. The modeled rocket kit is 4 inches in diameter and 52.5 inches long. Based on the simulation results using OpenRocket software, the rocket's altitude range could reach between 1000 to 3000 feet. The rocket's payload bay will be 4 inches diameter System where the Data Acquisition System (DAQ), GPS Tracking, and the Recovery System will be located. The motor mount will be 2.15 inches in diameter, using an AeroTech engine, model number I 11FJ-14A.

1.2 Pre-Launch Integration and Results

The MSU's SPR consists of three different independent sensors that track the rocket's performance during launch. The DAQ and recovery system records the data performance of the rocket and is only accessible during the rocket's recovery. However, the Featherweight GPS device is independent of the two systems since it is consist of a tracker that fly with the rocket and a ground station that communicates with the iPhone and records immediately as soon as it is connected. Thus, the GPS can both collect and transmit data in real-time without any delays.

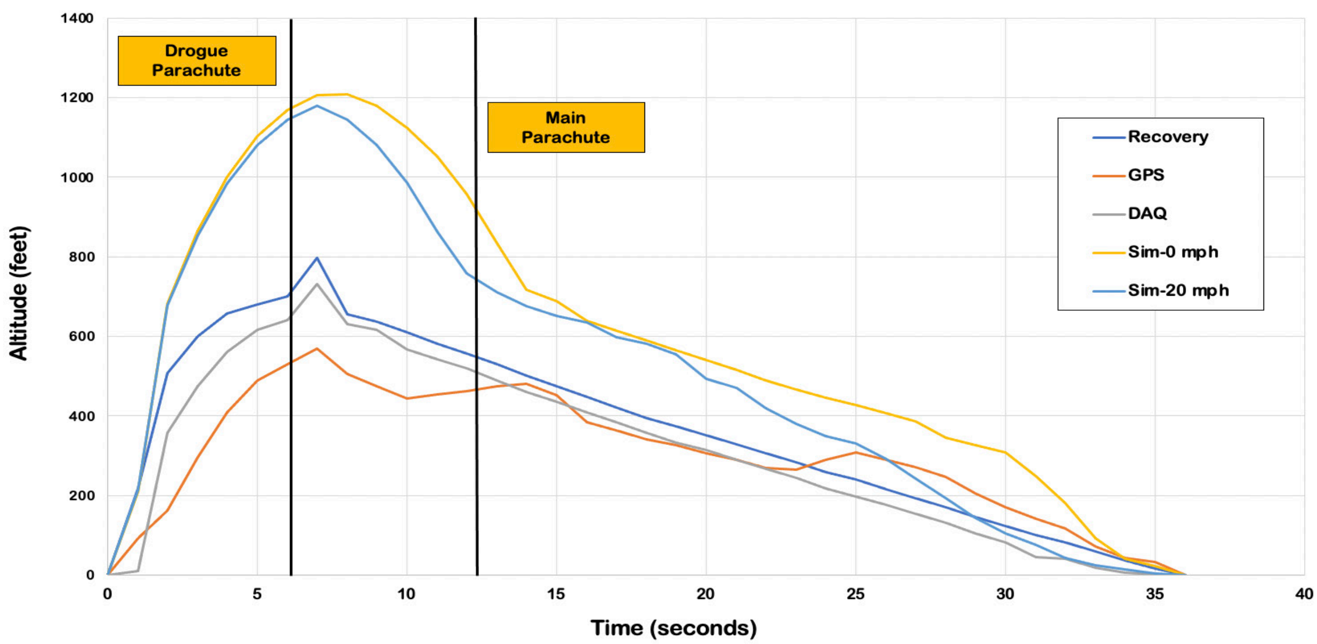

Figure 3. Time vs Altitude of SR of All Systems in both Theoretical and Experimental Data

Figure 3 shows the graph of the collected results of all the systems and simulations: the recovery, GPS, DAQ, 0 mph wind speed simulation, and the 20-mph wind speed simulation in terms of altitude per second. The given simulation results indicate that if the wind speed is 0 mph, the apogee that the rocket reaches is 1208 feet, while on the other hand, if the wind speed is around 20 mph, then the highest apogee reach is 1180 feet. The rocket launch data showed that all three sensors – recovery, GPS, and DAQ gave the highest altitude of only 798, 539, and 732 ft, respectively. The observations by the students and the people from the rocket club estimated that the rocket reached at least 1000 ft. Hence, indicating that the data collected is wrong. In addition, sudden spikes in the graph imply that the pressure-based altitude measurements (recovery and DAQ) increased just after the drogue deployment (Rodi et al., 2019). Therefore, indicating that the pressure inside the altimeter bay was released from the nose cone and captured. Overall, there is a high chance the rocket flew higher than the sensors measured. Due to these errors, a hypothesis implied by the students that each system might cause interference with each other since they are closely placed in a tight space of the altimeter bay area. In addition, the MSU students picked the GPS to be isolated from the other systems since it has a better result in capturing the altitude due to its functionalities and capabilities. The objective of this research is to conduct a comparison between theoretical data through the usage of OpenRocket and the experimental data from the actual launch. However, since it gave an error during the first launch, the MSU rocket team will place the Featherweight GPS on the nose cone and check if there is still a considerable difference between data. All data and findings will be recorded and submitted to the MSU Rocketry Association archives collection.

2. Methodology

2.1 SPR Nose Cone Modification and GPS Integration

The configuration of the MSU's SPR is a must to produce a more accurate outcome that closely resembles the simulation results. Figure 4 shows the 3D model of the nose cone. As observed, there is now a hole in the nose cone together with the GPS. The current design of the GPS includes a support board to secure and protect the system. Furthermore, a small hole was made for the wire to go through and switch for the GPS.

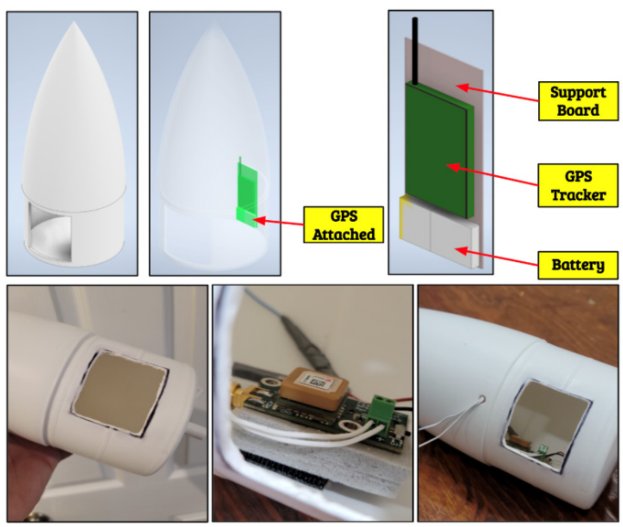

Figure 4. SPR Nose Cone Modification with Featherweight GPS Tracker

2.2 OpenRocket Software

MSU students utilized OpenRocket software to design a constant generic rocket design in the airframe, motor, and fins to predict the estimated altitude and lateral distance. Figures 5 and 6 illustrate the design modeled using the OpenRocket Simulation Software, which has a total weight of 7.2 pounds and 52.5 inches in length. Both upper and lower airframes are model using a spiral component material density of 0.491 oz/in3. The motor used in this model simulation was Aerotech's 11FJ-14A with a total impulse of 313 Ns, an average thrust of 553 N, a maximum thrust of 643 N, and a burn time of 0.567 seconds.

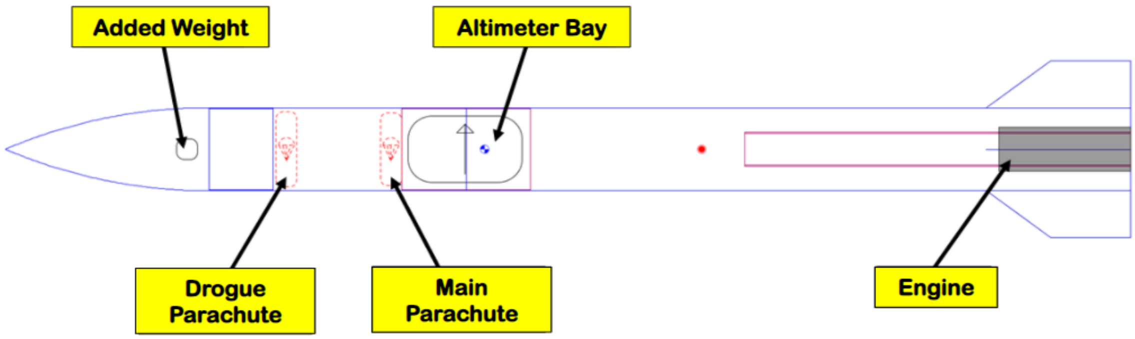

Figure 5. OpenRocket Rocket Simulation Components

The OpenRocket simulator allows MSU students to design every part of the rocket before the actual launch. Additionally, students can conduct several scenarios such as wind speed, environment, and weather conditions. Thus, theoretical values can be collected to predict and model. Furthermore, figure 5 displays the exterior part of the SPR via OpenRocket, showing the location of each component of the rocket. It also shows other valuable and relevant information, including the rocket's dimensions, mass, and material type. The design window also displays apogee, maximum velocity, acceleration, stability, the center of gravity (CG), and the center of pressure (CP).

Figure 6 shows the part detail of the SPR. It has all the information on the components used in the SPR. As observed, it has the type of parts, overall mass, length, diameter, and density of the material. This overview is beneficial since the students can easily access the information needed. As observed, most of the materials used were cardboard with a density of 0.393 oz/in^3. One of the main reasons the students chose cardboard is that it is light, and the modification is easy.

Parts Detail

Sustainer

Nose cone	Cardboard (0.393 oz/in³)	Ogive	Len: 9.5 in	Mass: 0.348 lb
Addded Weight		Dia$_{out}$ 0.984 in		Mass: 2.94 lb
Upper Airframe	Cardboard (0.393 oz/in³)	Dia$_{in}$ 3.9 in Dia$_{out}$ 4 in	Len: 12 in	Mass: 0.183 lb
Tube coupler/Altimeter Bay	Cardboard (0.393 oz/in³)	Dia$_{in}$ 3.83 in Dia$_{out}$ 3.9 in	Len: 6 in	Mass: 2 lb
Main Parachute	Ripstop nylon (0.22 oz/ft²)	Dia$_{out}$ 48 in	Len: 0.984 in	Mass: 0.194 lb
Shroud Lines	Braided nylon (2 mm, 1/16 in) (0.011 oz/ft)	Lines: 10	Len: 38 in	
Drogue Parachute	Ripstop nylon (0.22 oz/ft²)	Dia$_{out}$ 35 in	Len: 0.984 in	Mass: 0.095 lb
Shroud Lines	Braided nylon (2 mm, 1/16 in) (0.011 oz/ft)	Lines: 6	Len: 9 in	
Lower Airframe	Cardboard (0.393 oz/in³)	Dia$_{in}$ 3.9 in Dia$_{out}$ 4 in	Len: 31 in	Mass: 0.473 lb
Inner Tube	Cardboard (0.393 oz/in³)	Dia$_{in}$ 1.52 in Dia$_{out}$ 1.64 in	Len: 18 in	Mass: 0.132 lb
Fins (4)	Cardboard (0.393 oz/in³)	Thick: 0.118 in		Mass: 0.137 lb

Figure 6. OpenRocket Design of Morgan's Panda

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3. Results and Discussions

3.1 Post Launch Result

The MSU Rocketry team did their second launching of their SPR's in July 2021 at the Delaware-Maryland Association Rocket Site. The rocket's GPS was functioning well, which resulted in the rocket's recovery at ease. The rocket often loses contact during the retrieval because of ridges and signal disruption and affects the other systems. Fortunately, one of the advantages of using the Featherweight GPS Tracker is its capability of finding a lost rocket without interference. Furthermore, aside from the GPS's essential addons, over-the-horizon relay, and estimated landing point, several advanced features were also implemented during the launch, such as the spoken telemetry and automatic data logging. Figure 7 illustrates the user interface (UI) of the GPS in the user's handheld device. The data collected indicates that the initial coordinates before the rocket launch were 38.99980 and -76.10458 in latitude and longitude, respectively. Furthermore, the final coordinates indicated that the rocket landed at 38.59533 and -76.06146. Also, the lateral distance that the rocket traveled from point A to B was approximately 840 feet. The rocket traveled higher than expected because of the wind speed during the day, which was 9.2 mph. It is a fact that weather conditions are a launch requisite and play a huge factor in the rocket's performance during flight. Even though clear skies and still winds are the most suitable conditions when launching a rocket, these factors are not always the case. There are still several conditions to meet in order not to risk the safety during launch. The SPR exhausted and burned the fuel resulting in the deactivation of the engine and stoppage of thrust. Afterward, the SPR coasted upward until its velocity went zero, and the maximum altitude was 1022 feet. The weight is still acting on the rocket; it immediately begins to fall back to land.

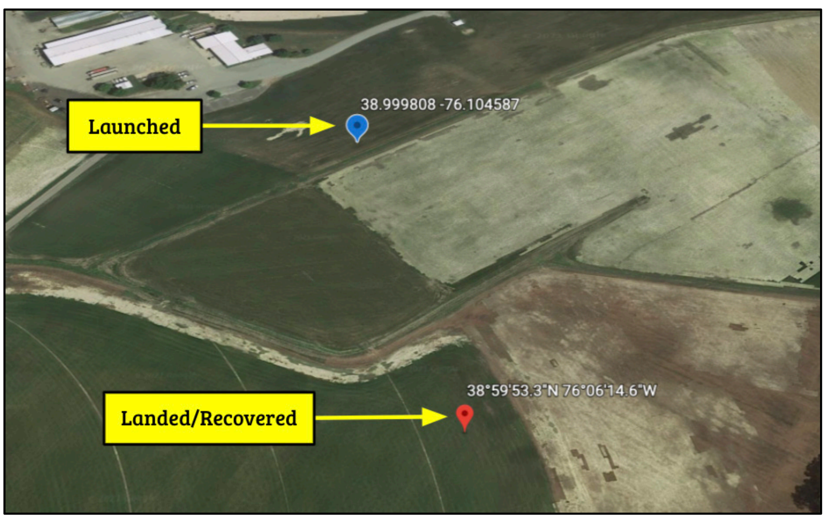

Figure 7. GPS System User Interface (UI)

3.2 Theoretical and Experimental Data Comparison

Based on the collected data, the apogee was 1022 feet. On the other hand, its lateral distance was 840 feet away from the original launching ground. Table 1 shows the comparison data between the theoretical and experimental. As observed, the theoretical data is composed of two different scenarios, when the wind speed is 5 and 10 mph. During the launch day, the measured wind speed was 9.2 mph, thus, making it in between the simulated scenarios. Students used interpolation to conduct the ideal apogee in the simulation when the wind speed was 9.2 mph. Based on the results, the data collected shows that when the Featherweight GPS Tracker is on the nose cone, it had a 98.74% similarity to the simulated result. Thus, this observation implies that the placement of the Feather GPS Tracker directly affects the rocket's performance. Furthermore, the MSU students also attached the Jolly Logic Altimeter One (JLAO) in the rocket to provide more comparison to the GPS based on the apogee result. The JLAO is a digital altimeter that is barometric, where it measures the altitude by assessing the location's air pressure – since the air pressure is inversely proportional to the altitude.

Table 1. Comparison Between the Theoretical and Experimental Data

Theoretical Data from Simulation				
Conditions	5 mph Wind Speed		10 mph Wind Speed	
	Apogee (ft.)	Lateral Distance (ft.)	Apogee (ft.)	Lateral Distance (ft.)
Mass Added (7.05 lbs.)	1098	701	994	961
Experimental Data				
	Featherweight GPS Tracker		Jolly Logic Altimeter One	
Conditions	9.2 mph Wind Speed		9.2 mph Wind Speed	
	Apogee (ft.)	Lateral Distance (ft.)	Apogee (ft.)	Lateral Distance (ft.)
Mass Added (7.05 lbs.)	1022	840	1014	N/A

4. Conclusion

In conclusion, the data collected from different systems, the Featherweight GPS Tracker and Jolly Roger Altimeter One, were compared and analyzed. During the first launch, there were discrepancies in the data collected. Thus, resulting in unreliable data. As a result, the MSU students integrated the GPS into the nose cone, which resulted in a 98.74% similarity to the simulated result on the second launch. Therefore, it implies that the Featherweight GPS Tracker is suitable to be isolated from the other devices to avoid system interference.

Furthermore, the students in the MSU Rocketry concluded to have a design modification on the next SPR launch. The current design altimeter bay and board are very tight, and the space is not distributed correctly, as shown in figure 8. Thus, it ended up having uneven and unutilized areas to maximize the placement of each sensor – including the batteries and proper wiring. Furthermore, due to the limited space available, the students used duct tape and epoxy glue to fit everything all together, especially when they considered the placement of the CO_2 cartridge.

Figure 8. Current SPR Altimeter Bay Design

5. References

Alamu, S. O., Caballes, M. J. L., Yang, Y., Mballa, O., & Chen, G. (2019, October). 3D Design and Manufacturing Analysis of Liquid Propellant Rocket Engine (LPRE) Nozzle. In *Proceedings of the Future Technologies Conference* (pp. 968-980). Springer, Cham.

Flaten, J., Bartlett, J., Krieg, E., Lenz, E., & Bowers, R. (2020, April). Flying "Mock CubeSats" on Stratospheric Balloon Missions. In *Academic High-Altitude Conference* (Vol. 2019, No. 1). Iowa State University Digital Press.

Malanowski, M., Borowiec, K., Rzewuski, S., & Kulpa, K. (2018). Detection of supersonic rockets using passive bistatic radar. *IEEE Aerospace and Electronic Systems Magazine*, *33*(1), 24-33.

Nilsen, C., Meyer, S., & Meriam, S. (2019). Purdue liquid oxygen-liquid methane sounding rocket. In *AIAA Scitech 2019 Forum* (p. 0614).

Nowakowski, P., Okninski, A., Pakosz, M., Cieslinski, D., Bartkowiak, B., & Wolanski, P. (2017). Development of small solid rocket boosters for the ILR-33 sounding rocket. *Acta Astronautica, 138*, 374-383.

Rodi, P. E., Stoldt, H., Hill, C., & Johansen, C. T. (2019). Design of a Sounding Rocket Flight Experiment to Validate Transonic Drag Minimized Waveriders. In *AIAA Aviation 2019 Forum* (p. 2812).