Team True Fire
SUNCOAST SCIENCE CENTER
Faulhaber Fab Lab

Post-Flight Report: Vanguard Mission Analysis

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for

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I. Introduction

On July 15, 2023, The Suncoast Science Center's Team True Fire, launched Vanguard from Spaceport Rocketry Association in Palm Bay, Florida. The mission aimed to break the sound barrier while exploring the performance and behavior of the rocket under real-world conditions, providing valuable insights into various aspects of the flight. This paper details the post-flight analysis of the data collected by Vanguard's avionics, with the goal of reconstructing the vehicle's flight path and determining its apogee. The findings presented herein contribute to our understanding of the complex dynamics and aerodynamic characteristics encountered during the mission, providing a foundation for future improvements and advancements in experimental rocketry.

II. Data Collection Systems

The avionics system consists of multiple independent data acquisition systems, enumerated below.

1. The Altus Metrum Easy Mini is a self-contained data acquisition system often used in amateur rocketry. The Easy Mini features a two-axis accelerometer and a barometric altimeter with a sampling rate of 100 per second. It also offers high-current outputs to fire the recovery system after apogee.
2. The Missile Works RRC2+ is a self-contained barometric altimeter used as a backup in case the Easy Mini experiences malfunction during the flight. It also provides additional data to confirm primary altimeter's results.
3. The Eggtimer TX is a self-contained unit that records GPS packets to non-volatile memory and transmits those GPS packets over the 925MHz RF band. For this flight, the TX was configured to send a data packet every 2 seconds.

III. Flight Sequence of the Vanguard Rocket

The Vanguard rocket's flight sequence commenced after a delay caused by an ignition system malfunction at the launchpad. Following the replacement of the firing controller, the launch finally took place at 4:35 PM.

During the ascent phase, the rocket experienced a total duration of 18.3 seconds. Within this period, 3.7 seconds were dedicated to the motor's boosted operation, providing thrust for the rocket, while the remaining 14.6 seconds constituted the coasting phase after the engine's burnout.

At an altitude of 6397 feet, the Easy Mini altimeter detected the apogee and successfully initiated the ignition of a 2.5g black powder charge, facilitating the deployment of the drogue parachute. Subsequently, the RRC2+ altimeter fired a backup charge, although it was ultimately unnecessary for recovery purposes.

The rocket then entered a stable descent phase, descending at a consistent rate of 42 feet per second for an additional 127 seconds. Upon reaching an altitude of 900 feet, the altimeters fired black powder charges once again, leading to the deployment of the main parachute. It took approximately 40 feet for the main parachute to fully open, gradually slowing the rocket down to a descent rate of 20 feet per second.

During the final 43 seconds of the flight, the rocket steadily approached the ground, ultimately completing the entire flight sequence after a total duration of 188.8 seconds.

IV. GPS Data and Rocket's Recovery

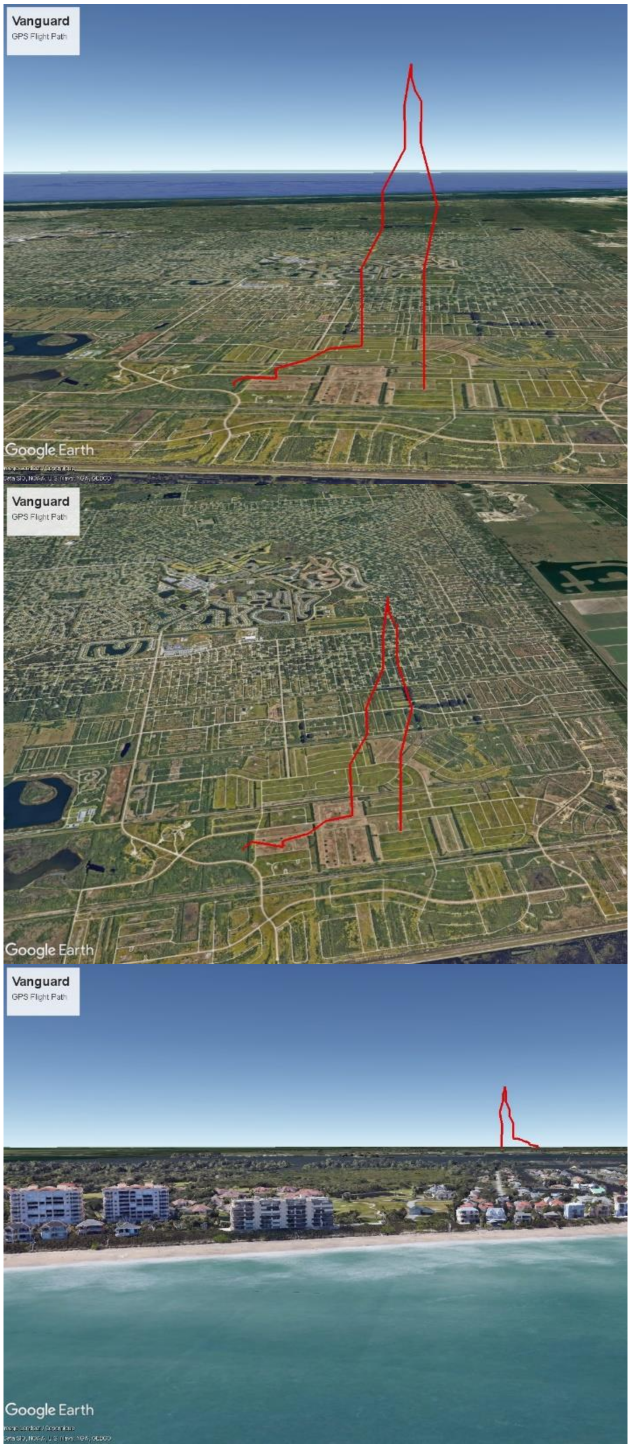
The GPS handheld receiver collected data from the Vanguard rocket at 2-second intervals during its flight. The recorded data provided precise coordinates throughout the rocket's descent. Upon reaching the end of the descent, indicated by stationary coordinates, the recovery team initiated the search in the direction of the last recorded position.

The GPS coordinates directed the team towards a densely forested area, indicating that the rocket had landed within the tree line. A drone was deployed to aid in the search, successfully locating the parachute due to its contrasting color against the tree backdrop.

Upon entering the forest, the team encountered challenges. The drogue parachute sustained damage during recovery, resulting in tears. Additionally, one of the shock cords became entangled in the trees, requiring it to be cut for safe retrieval.

After 30 minutes of dedicated efforts, the team successfully recovered the rocket from the trees. The final landing location was determined to be approximately 4000 feet north of the launchpad.

After successfully recovering the GPS unit from the Vanguard rocket, the team proceeded to import and convert the flight data using GPS Visualizer software. This software converted the GPS data into a format compatible with Google Earth, enabling the team to visualize the flight path from various perspectives. By plotting the data in Google Earth, the team gained valuable insights into the trajectory and overall path followed by the rocket during its flight. The results of these Google Earth plots are depicted below, providing a comprehensive visualization of the Vanguard rocket's journey through the skies.



Figures 1-3

GPS Data of the flight

Notes: The last visualization shows how the flight of the rocket would look like from the east coast of Florida (approximately 10 miles away from the launchpad)

V. Atmospheric Conditions vs. GPS Data

The atmospheric conditions encountered during the Vanguard rocket's flight played a crucial role in shaping its trajectory and eventual landing site. As the launch took place, NOAA's National Blend of Models data indicated the approach of a thunderstorm in the area. This resulted in a notable increase in wind speed from 6mph to 14mph, blowing from the west direction.

The intensified wind speed had a pronounced effect on the rocket's behavior as it descended closer to the ground. The force exerted by the wind on the rocket's fins caused it to pitch towards the west direction. This maneuver is called weather cocking and is visually presented below on an infographic from NASA Glenn Research Center. This deviation from its intended path was a direct consequence of the wind pushing against the rocket's surface area.

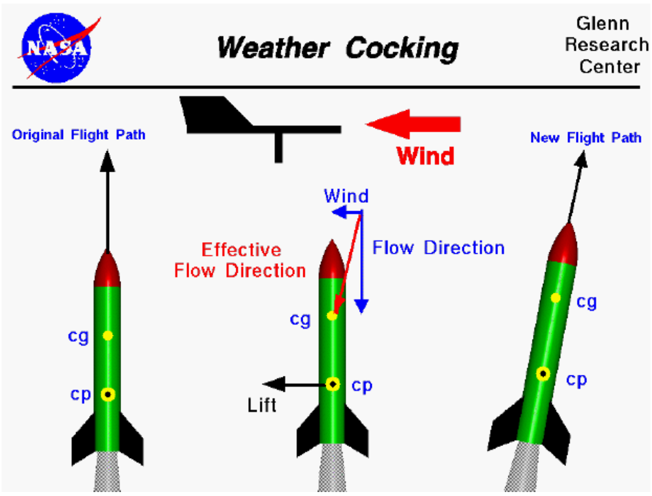


Figure 4

Weather Cocking visual explanation.

Further analysis of atmospheric data revealed a shift in wind direction at higher altitudes. At approximately 3000ft and 9000ft, the wind changed its course to originate from the south-west, with an approximate velocity of 12ft/s. This change in wind direction had a significant impact on the rocket's movement, causing it to be propelled towards the north.

As the drogue parachute deployed, the rocket continued its descent in a north-east direction for approximately two minutes. This continued movement towards the north reduced any substantial east-west displacement that may have occurred during the ascent phase. Consequently, the overall direction of the rocket's fall throughout the flight became predominantly northward.

The GPS data obtained from the rocket's onboard transmitter supports these observations, with the landing site of the rocket aligning closely with the northward trajectory. The atmospheric conditions, characterized by increased wind speed and changing wind directions, explain the flight's path and subsequent landing site.

VI. Altimeter Data

This section will delve into the analysis of the altimeter data obtained from the Vanguard rocket's flight. The data collected by the Altus Metrum Easy Mini altimeter provides crucial information about the rocket's altitude, ascent and descent phases, parachute deployments, and overall flight dynamics. By examining the altimeter data in detail, we gain valuable insights into the rocket's performance, behavior, and adherence to predicted flight parameters. This analysis allows for a comprehensive evaluation of the altimeter's effectiveness in accurately measuring and recording critical flight data, contributing to the enhancement of future rocket designs and missions.

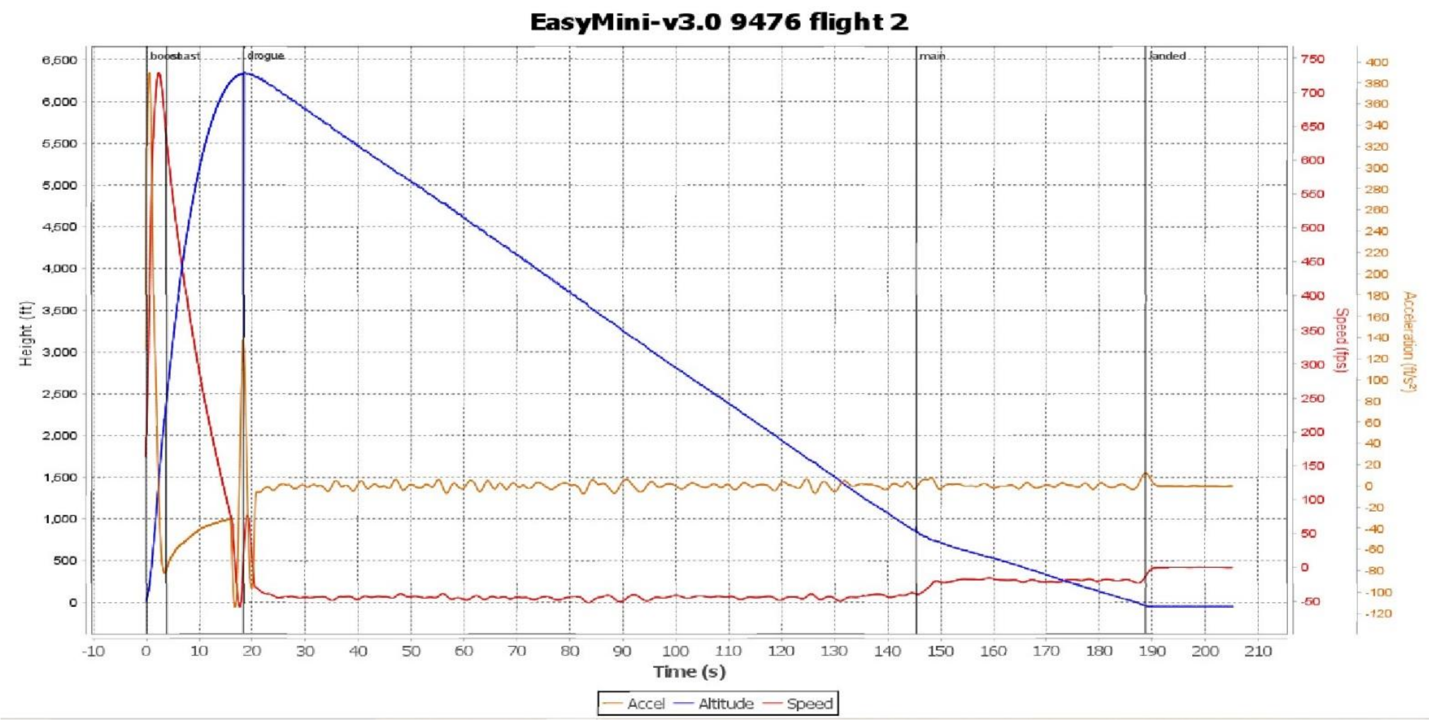


Figure 5 – *Altus Metrum Easy Mini Full Flight Altimeter Data*

The analysis of the altimeter data collected from the Vanguard rocket's flight provides key quantitative information about various aspects of the mission. The maximum altitude recorded by the altimeter was determined to be 6397 feet, representing the peak vertical position achieved by the rocket during the flight. The maximum speed attained during the mission was measured at 729 feet per second (fps), equivalent to 497 miles per hour (mph) or Mach 0.65. Additionally, the altimeter data revealed a maximum boost acceleration of 12.11 Gs or 390 feet per second squared (ft/s^2). This data aids in understanding the dynamics of the rocket's ascent and provides insights into its performance capabilities. Furthermore, the altimeter data enables the assessment of parachute deployments, descent rates, and overall flight time, contributing to a comprehensive evaluation of the rocket's behavior and informing future design optimizations.

VII. Flight Simulations vs. Onboard Data

OpenRocket is a powerful and widely used rocket simulation software that plays a fundamental role in the field of experimental rocketry. Developed as an open-source platform, it allows enthusiasts and professionals alike to design, simulate, and analyze rockets with remarkable precision. As a critical tool in the pre-flight planning and design phase, OpenRocket employs advanced physics models to simulate a rocket's performance, considering various parameters such as rocket dimensions, materials, engine specifications, and atmospheric conditions. In this section, we compare the simulation results obtained from OpenRocket with the actual data collected during the flight of the Vanguard rocket. By examining the accuracy and alignment between the simulated and actual performance, we gain valuable insights into the effectiveness of OpenRocket as a predictive tool and its implications for enhancing future rocket designs and missions.

Figure 6 – *OpenRocket model of the Vanguard Rocket*

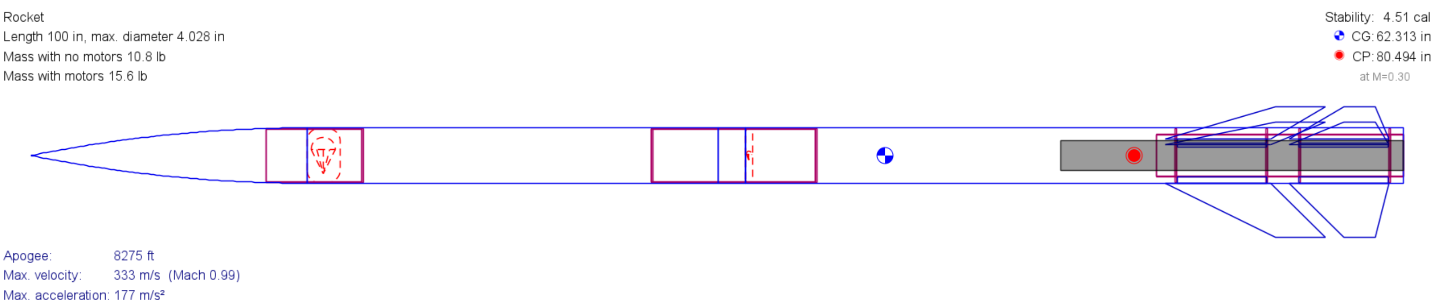
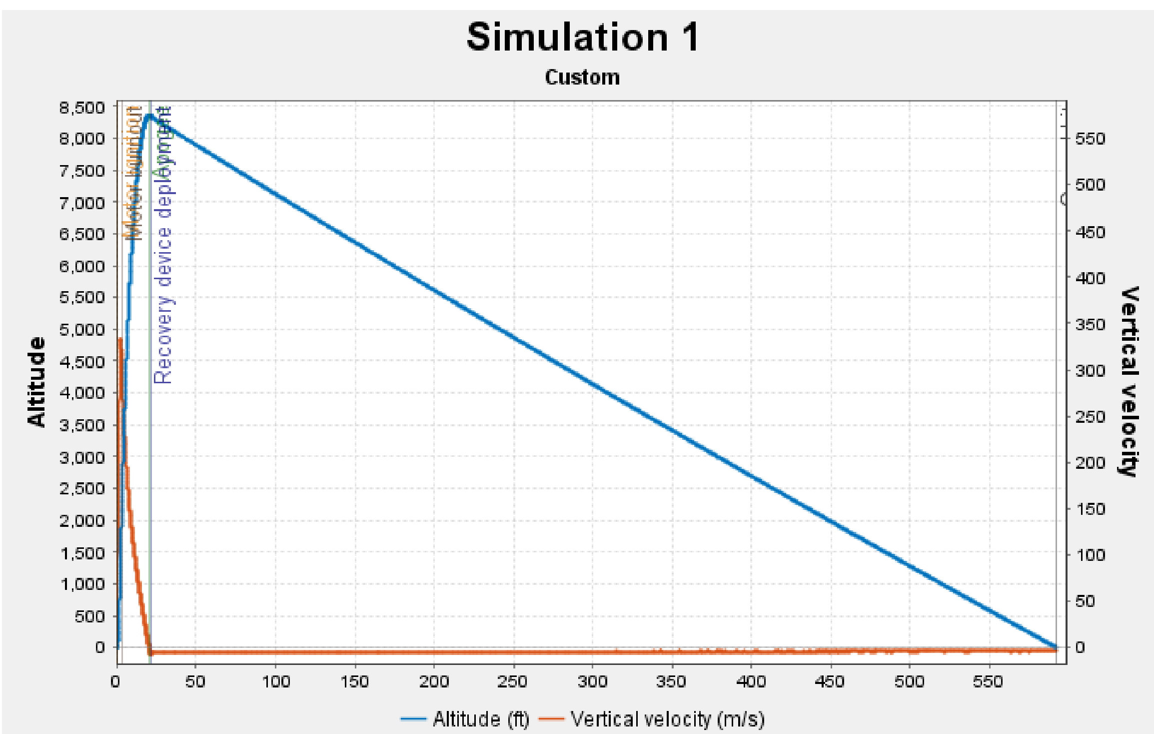


Figure 7 – *OpenRocket Flight Simulation of the Vaguard Rocket*



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The simulation data obtained from OpenRocket unveils impressive performance characteristics of the Vanguard rocket. With supersonic capabilities, the simulation predicts a peak speed of Mach 0.99 (1095ft/s). Notably, the simulation was conducted with a wind speed of 16ft/s, representing a worst-case scenario with higher wind gusts factored in. The simulation also indicates a peak acceleration of 18.05G and a maximum altitude of 8275ft. This data-drive analysis provides valuable insights into the rocket's flight dynamics.

Upon a thorough comparison of the simulation data generated by OpenRocket with the actual onboard data from the Vanguard rocket's flight, significant discrepancies were observed in both speed and maximum altitude estimations. The simulation predicted a speed of Mach 0.99 and a maximum altitude of approximately 8275ft, while the actual onboard data revealed a lower speed of Mach 0.65 and a maximum altitude of around 6397ft. These disparities highlight the complexities and uncertainties associated with real-world rocket flights and emphasize the importance of understanding the underlying factors contributing to these variations.

To gain deeper insights into the altitude and speed differences, the simulation files and data were shared with the University of Colorado Boulder, where students of Aerospace Engineering will lend their expertise to aid in the analysis. Collaborating with CU SRL (Sounding Rocket Lab) offers a unique opportunity to leverage high-end aerospace software and advanced analytical tools. Their expertise will be invaluable in identifying potential sources of error in the simulation model and explaining the discrepancies between the simulated and actual flight data. The collaboration aims to refine the simulation model, optimize rocket design parameters, and enhance the accuracy of future predictions for improved performance and mission success.

We would like to express our sincere gratitude to all our sponsors and supporters who have been essential in contributing to the success of the Vanguard rocket mission. Your generous support and encouragement have been invaluable in helping Team True Fire pursue our passion for experimental rocketry. Your belief in our capabilities has motivated us to achieve our goals and push the boundaries of scientific exploration. We are deeply thankful for the opportunities you have provided, and we look forward to continuing our journey with your continued support. Thank you for being a crucial part of our achievements and for making our mission possible.

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