Exploring Low-Cost DIY Rockets with Flight Recording using 3D Printing and Low-Cost Sensors

Design, Launch, Data Analysis, and Lessons Learned

Jannes Kaspar-Müller

2024-10-29

Contents

```
## Warning: Paket 'ggplot2' wurde unter R Version 4.2.3 erstellt

## Warning: Paket 'pracma' wurde unter R Version 4.2.3 erstellt

##
## Attache Paket: 'dplyr'

## Die folgenden Objekte sind maskiert von 'package:stats':
##
##     filter, lag

## Die folgenden Objekte sind maskiert von 'package:base':
##
##     intersect, setdiff, setequal, union

## Warning: Paket 'plotly' wurde unter R Version 4.2.3 erstellt

##
## Attache Paket: 'plotly'

## Das folgende Objekt ist maskiert 'package:ggplot2':
##
##     last_plot

## Das folgende Objekt ist maskiert 'package:stats':
##
##     filter

## Das folgende Objekt ist maskiert 'package:graphics':
##
##     layout

## Warning: Paket 'webshot2' wurde unter R Version 4.2.3 erstellt

## Warning: Paket 'geosphere' wurde unter R Version 4.2.3 erstellt

##
## Attache Paket: 'geosphere'

## Das folgende Objekt ist maskiert 'package:pracma':
##
##     geomean
```

1 Goals

3D printed Fit multiple motors Record as much flight data as possible for “cheap”

2 Design

The design section is divided into three parts. The first covers the rocket's overall design, detailing its structure and components. The second explains the simulations conducted to evaluate the rocket's expected performance and stability. The final part outlines the features of the flight recorder and the key decisions made during its development.

2.1 Rocket Structure

The rocket follows a traditional hobbyist design, featuring a single motor located at the base with no active guidance system (Center, 2024). To ensure stability during flight, fins are positioned at the bottom. Additionally, since the rocket is intended for recovery, the nosecone must be detachable, triggered by the ejection charge from the motor. This requires the ejection blast to travel the full length of the rocket to the nosecone without damaging the on-board electronics responsible for recording flight data. Based on these goals, the following decisions were made regarding the design and manufacturing of the rocket:

2.1.1 The Case for 3D Printing

Due to the goals of affordability and easy of manufacturing the decision to use 3D printing to manufacture as many pieces of the rockets as possible was made. 3D printing allows anybody with access to the 3D model of the rocket to produce it nearly identical. The widespread adoption of 3D printing for hobby projects made printers as well as filament widely available, cheap to obtain and easy use. Therefore the rocket can not only be replicated with low complexity for the builder but also at a minimal cost or effort involved (Pearce & Qian, 2022). Additionally the process of 3D printing allows to easily build geometries that would usually be hard or expensive to machine or produce at small production volumes and scales (Berman, 2012, 2020). Specifically FDM 3D printing was used to build the complete Rocket structure.

2.1.2 Selected Materials

Different 3D printing filaments offer different strength or density properties that might be more beneficial to use on different parts of the rocket (Bambu Lab, 2024). The most used hobbyist Filament, PLA, is an all rounder, offering good toughness, strength, stiffness, layer adhesion and ease of printing for a low price per kilogram. For this reason, PLA was chosen as the default material for most parts of the rocket that aren't subjected to high forces or extreme temperatures.

The option of printing certain components in more expensive, ultra-lightweight filaments like ASA Aero (ASA infused with a temperature-activated foaming agent) was considered. However, this approach was ultimately set aside due to the reduced strength and increased printing complexity, which limits the ability to create intricate designs to some extent.

There are 2 parts on the rocket that required further consideration before selecting the filament:

1. The fins of a rocket are often quite thin and stick out of the rocket body often making contact first when impacting during soft landings or transportation. Therefore the

2. asdf asdfasd fasdfas d.asdf asdfa dafsdfasdfa sdfa.sdf asdfasd fasdfasdfas df.asdf asdfas df adsfasdfasd. adsfasdf asdf asdf asdf asdfa.afsdf asdfas dfasdf asdf asd f.

2.2 Performance & Stability Simulations

2.3 Flight Recording System

3 Launch

3.1 Data Analysis

3.1.1 Pressure Sensor

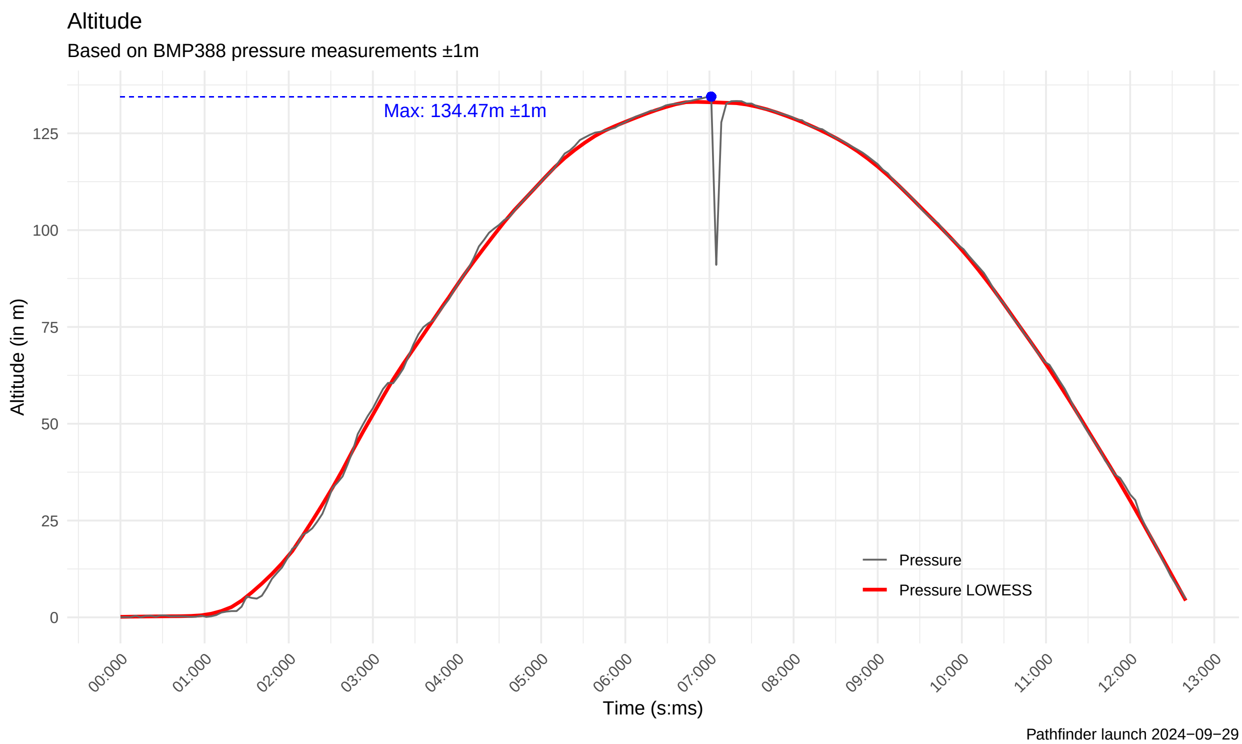

Figure 1: Altitude as measured by the pressure sensor

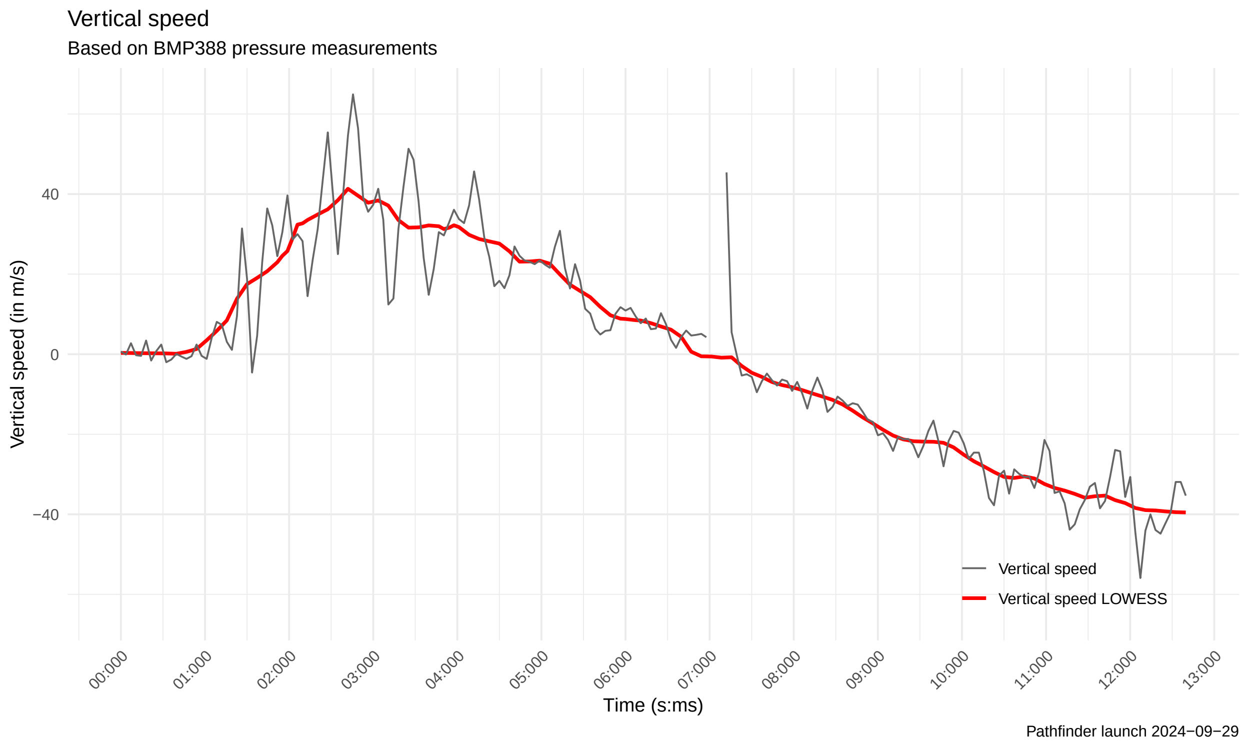

Figure 2: Vertical Speed as measured by the pressure sensor

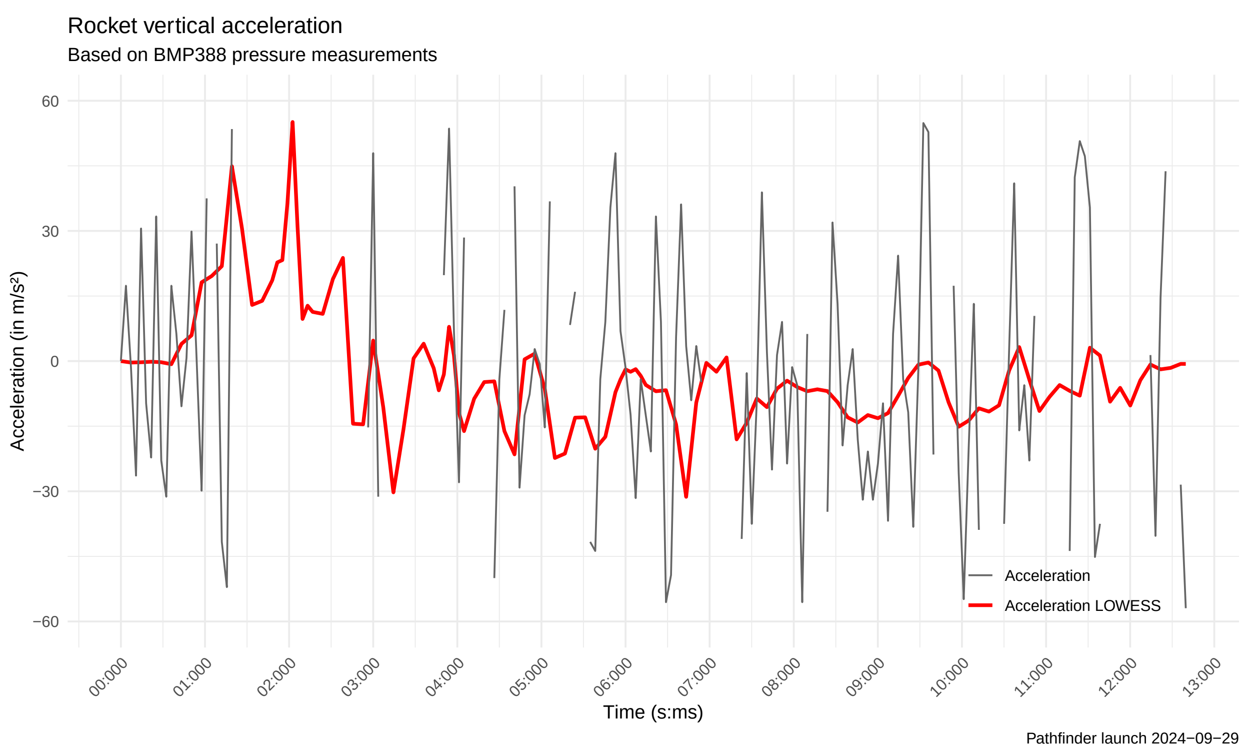

Figure 3: Vertical Acceleration as measured by the pressure sensor

3.1.2 Accelerometer

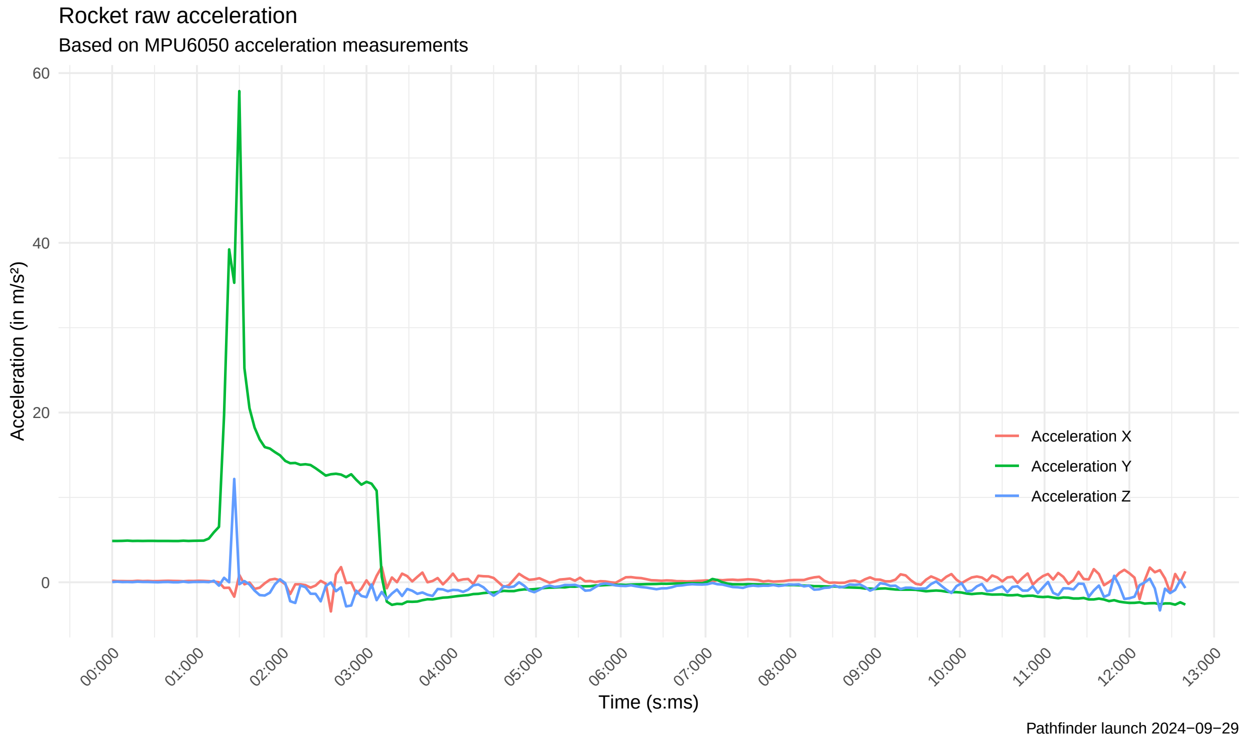

Figure 4: Raw Acceleration as measured by the Accelerometer

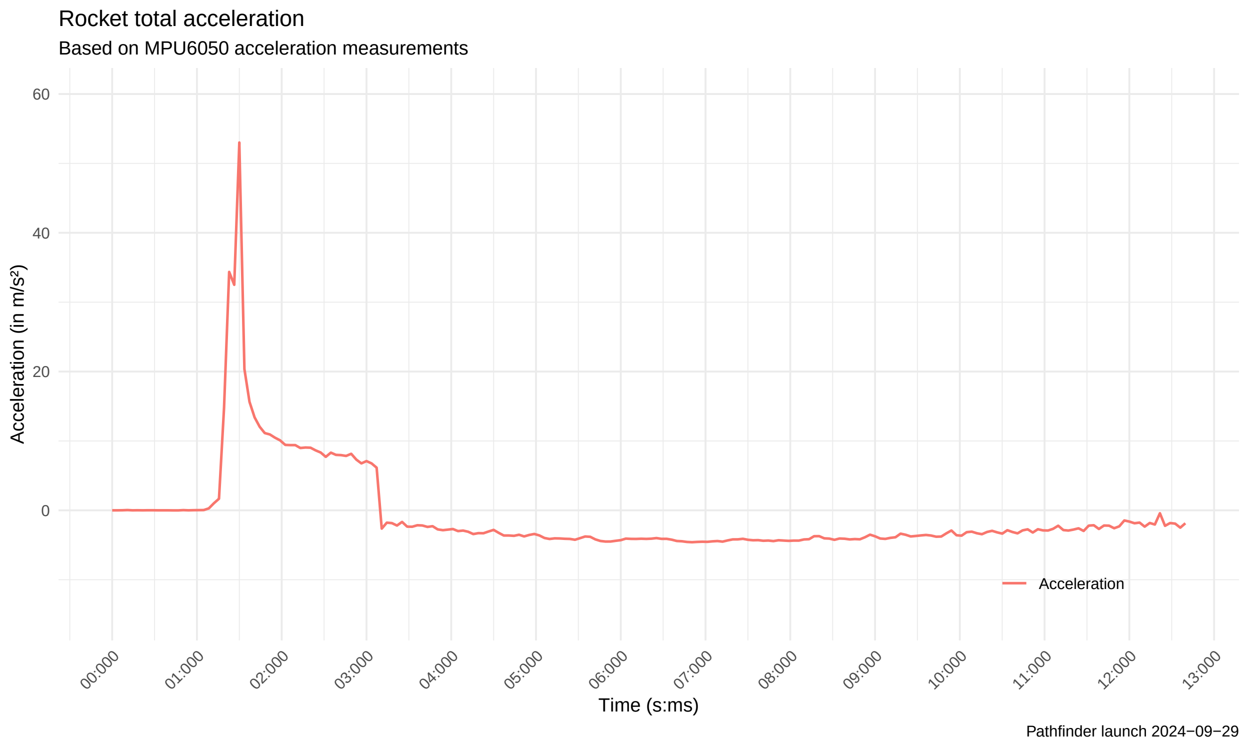

Figure 5: Total Acceleration as measured by the Accelerometer

3.1.3 Gyro

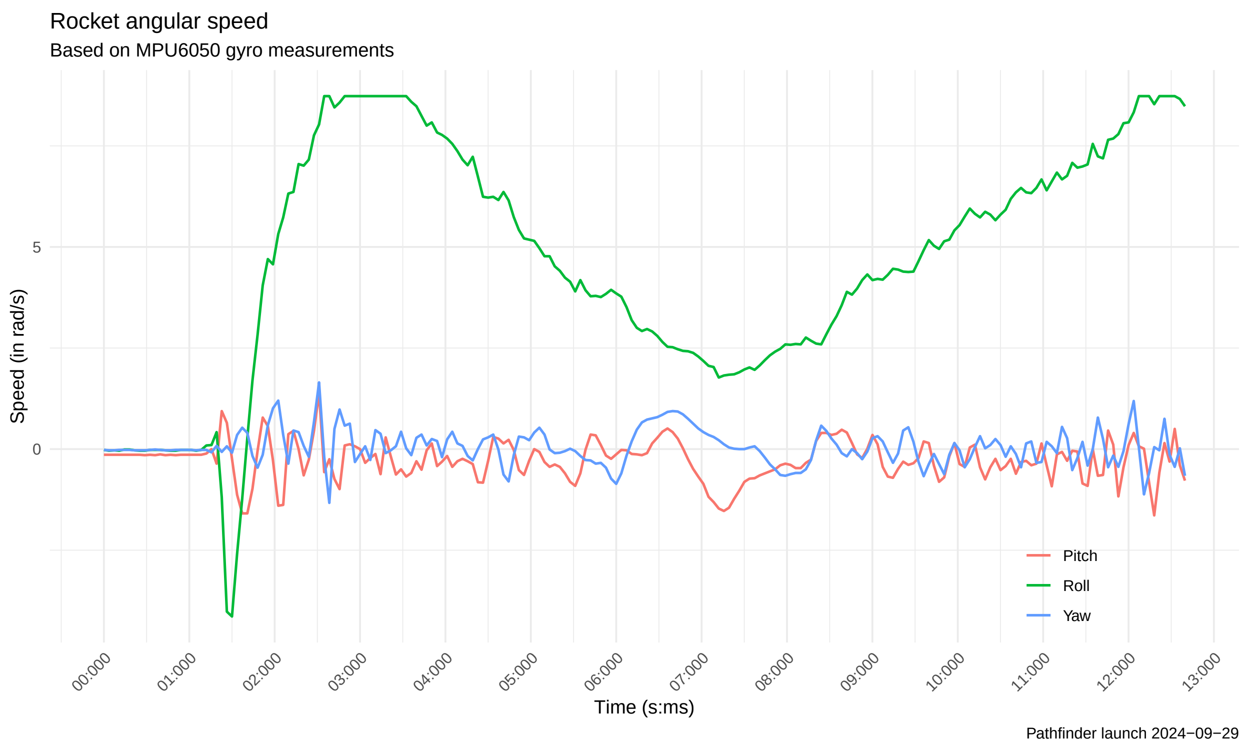

Figure 6: Rocket rotation during flight

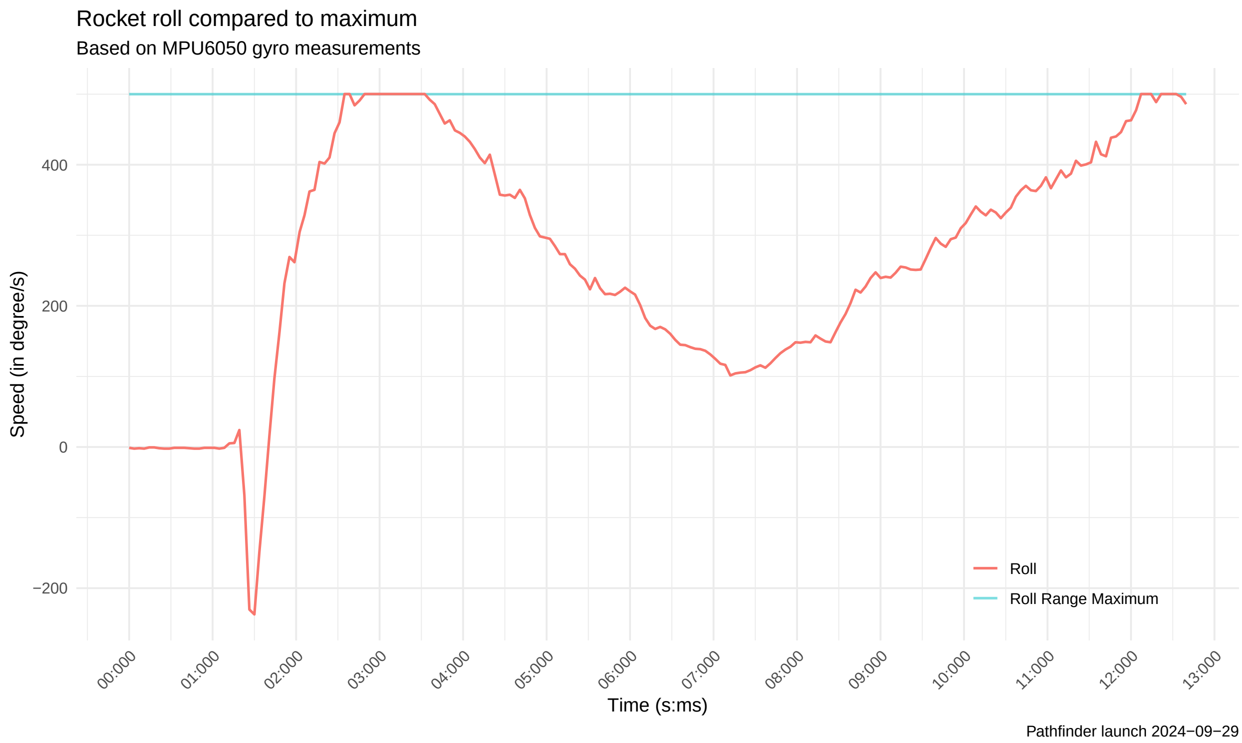

Figure 7: Measured roll compared to maximum range

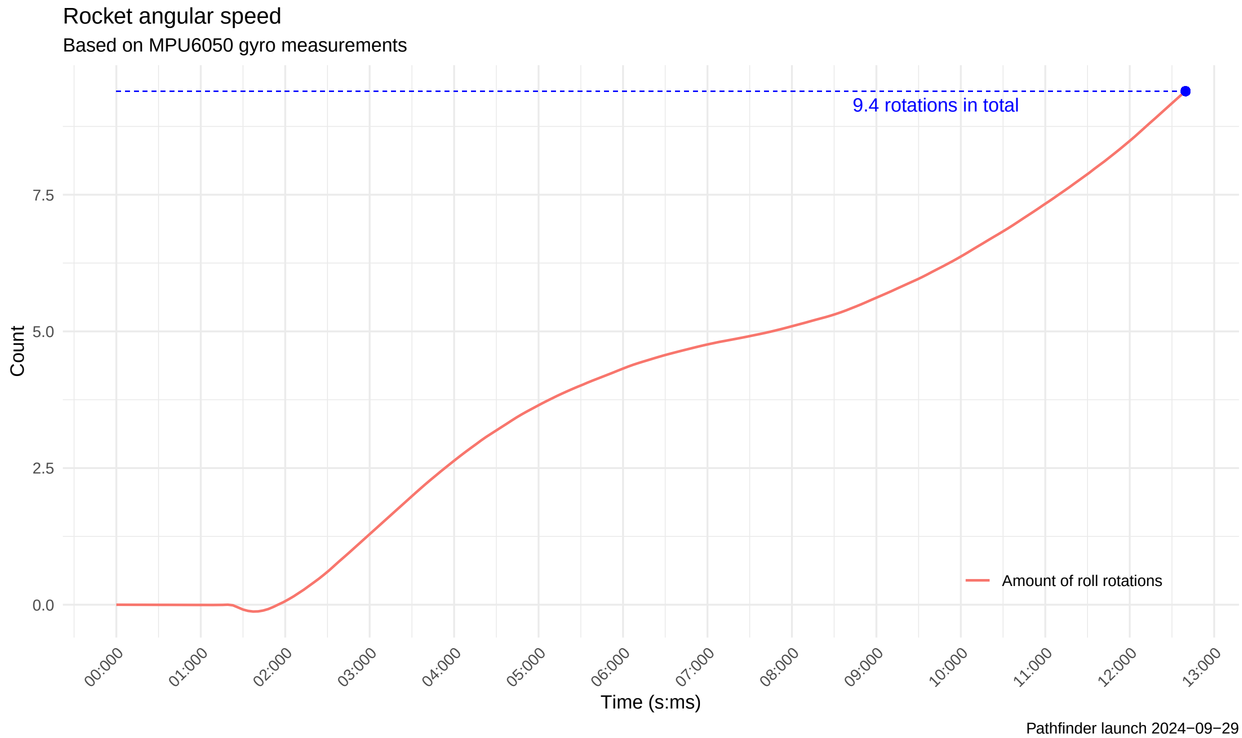

Figure 8: Amount of rotations around roll axis

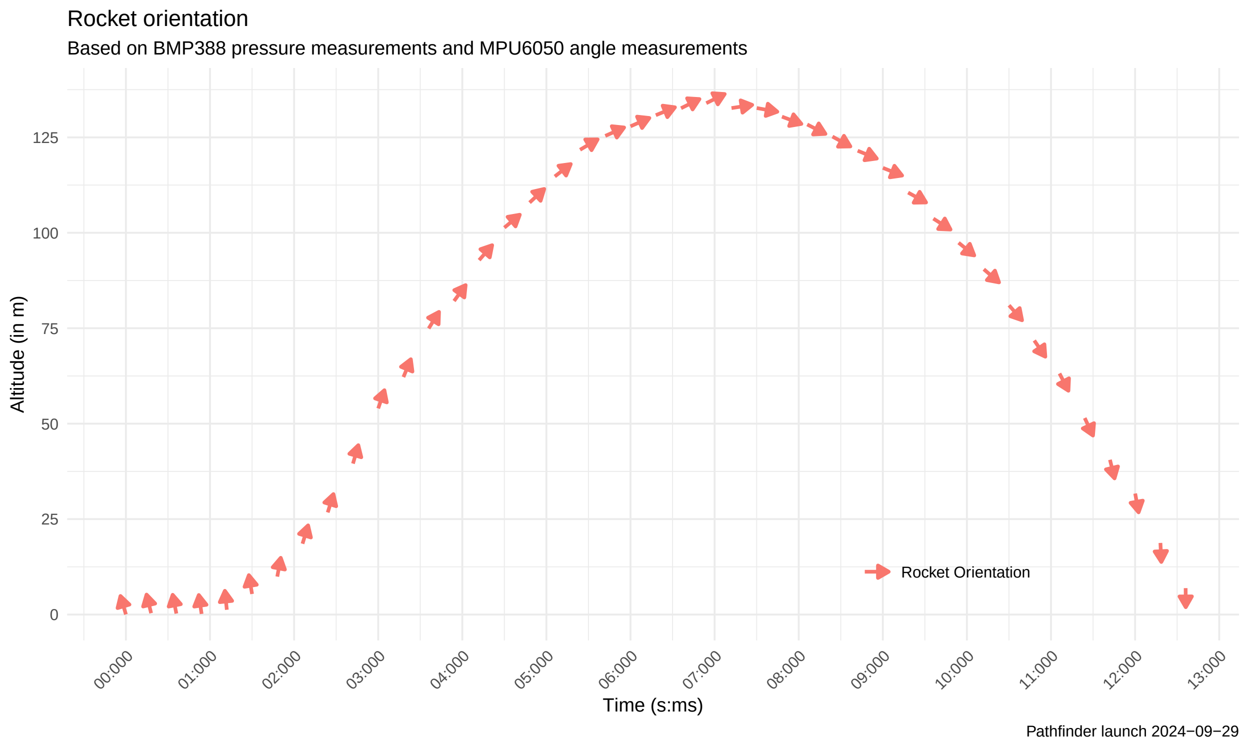

Figure 9: Rocket rotation during flight

3.1.4 GPS

https://github.com/mikalhart/TinyGPSPlus/blob/0a205759da22a1c54c5f5285480fe6132592a4e2/examples/UsingCustomFields/UsingCustomFields.ino#L27 No VDOP, interesting for altitude and most of the speed

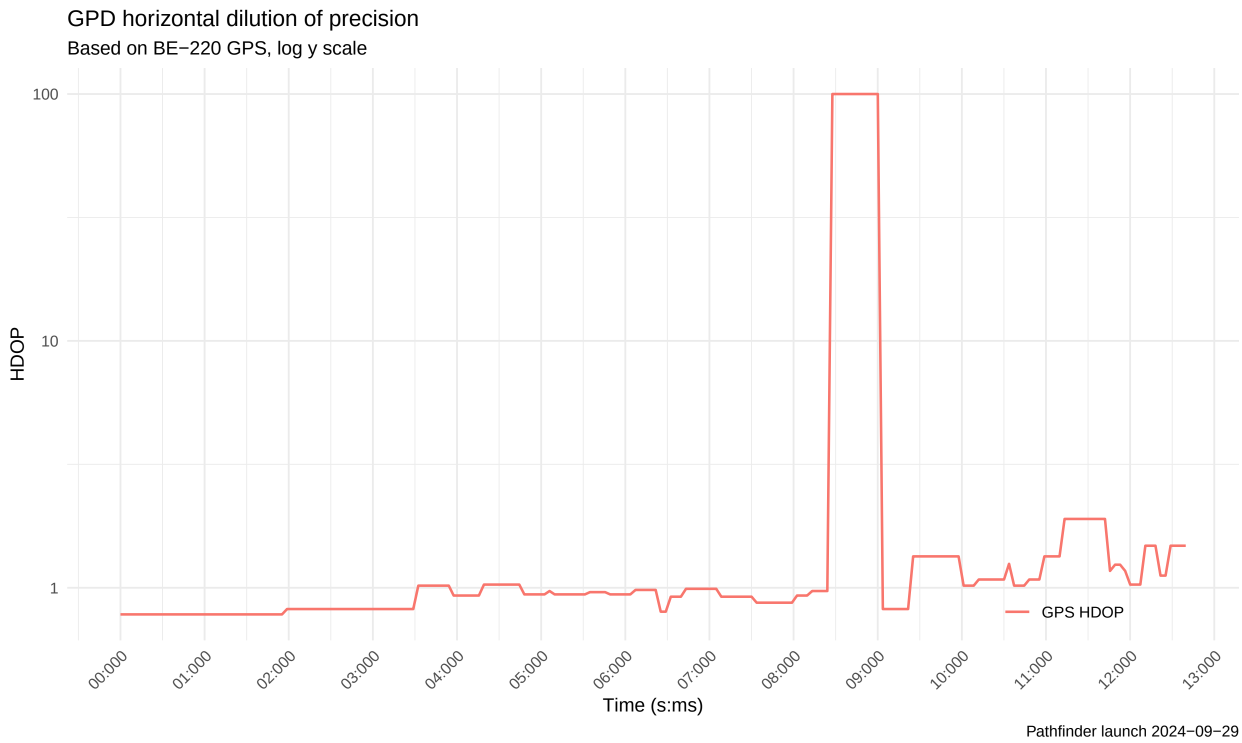

Figure 10: GPD horizontal dilution of precision

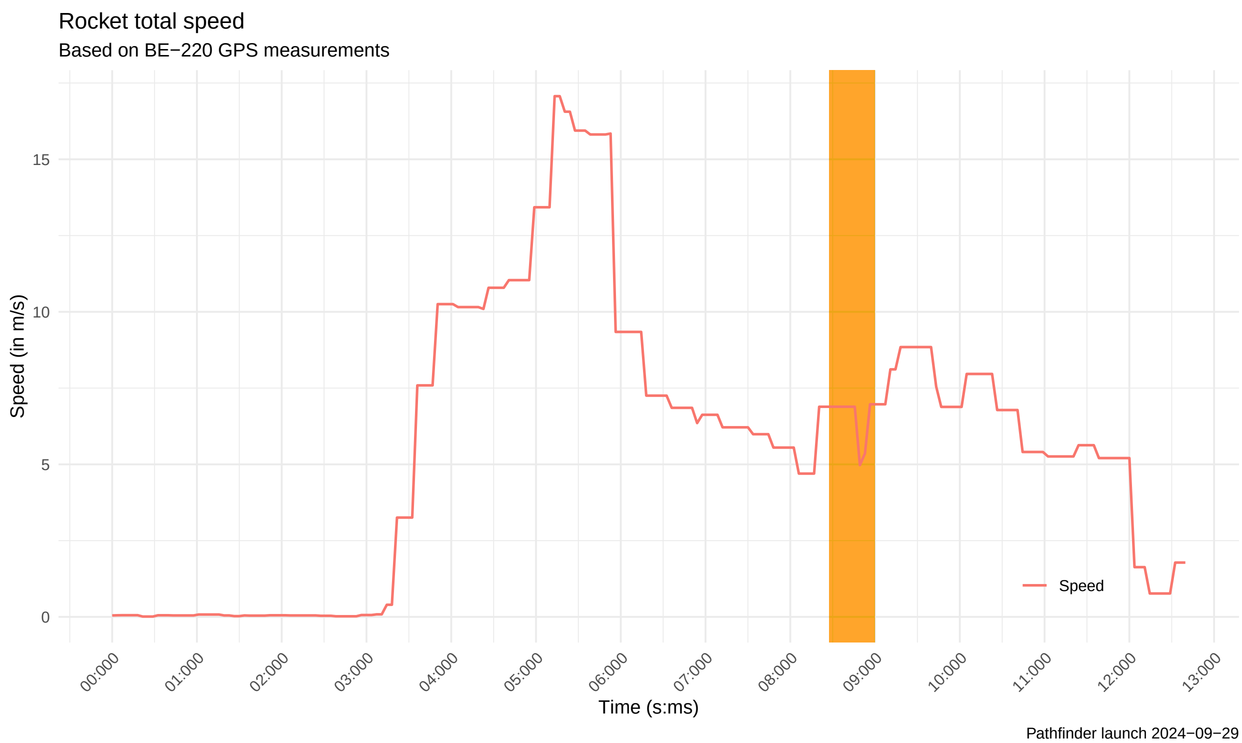

Figure 11: Total speed measured by GPS

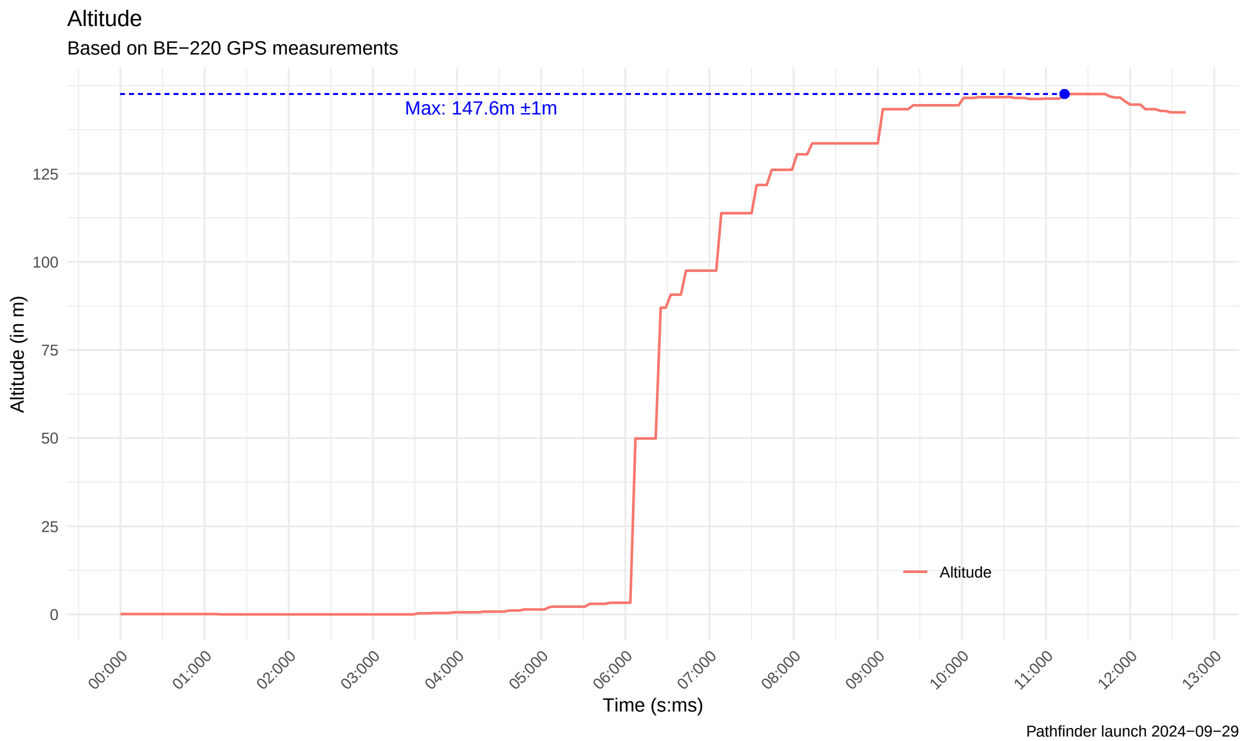

Figure 12: Altitude measured by GPS

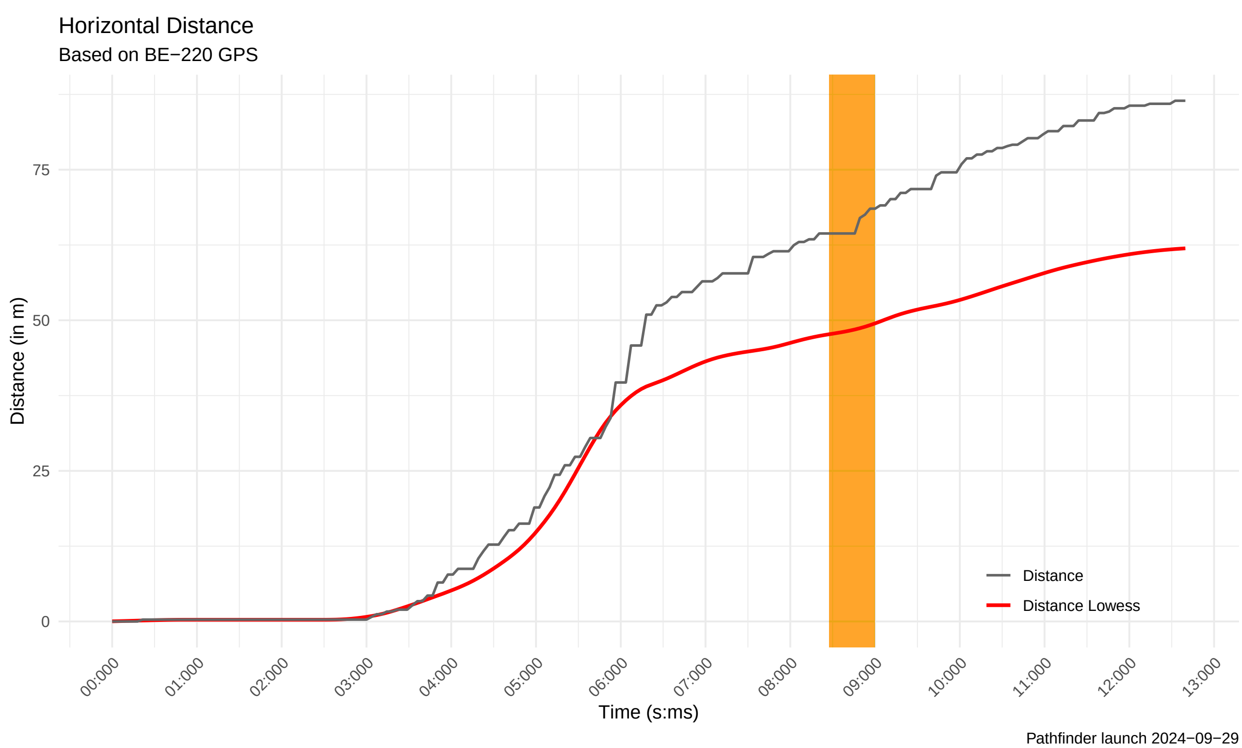

Figure 13: Horizontal distance of rocket based on GPS

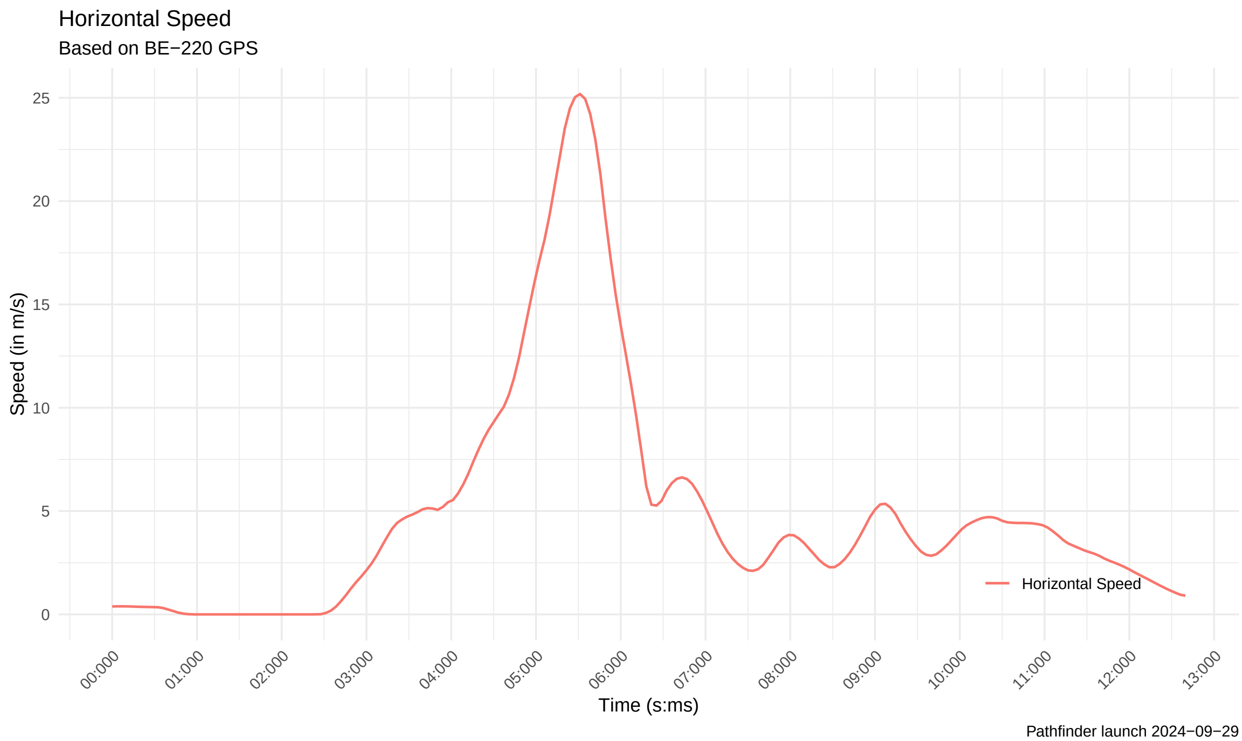

Figure 14: Horizontal speed of rocket based on GPS

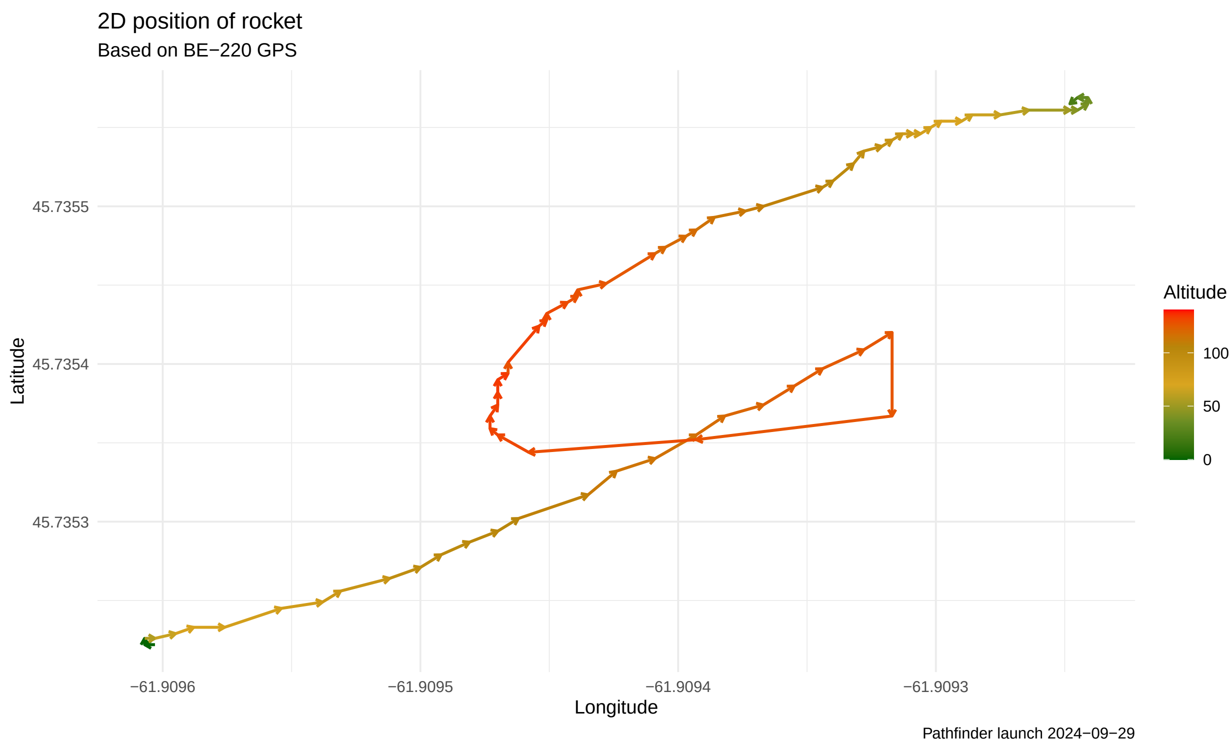

Figure 15: 2D position of rocket based on GPS

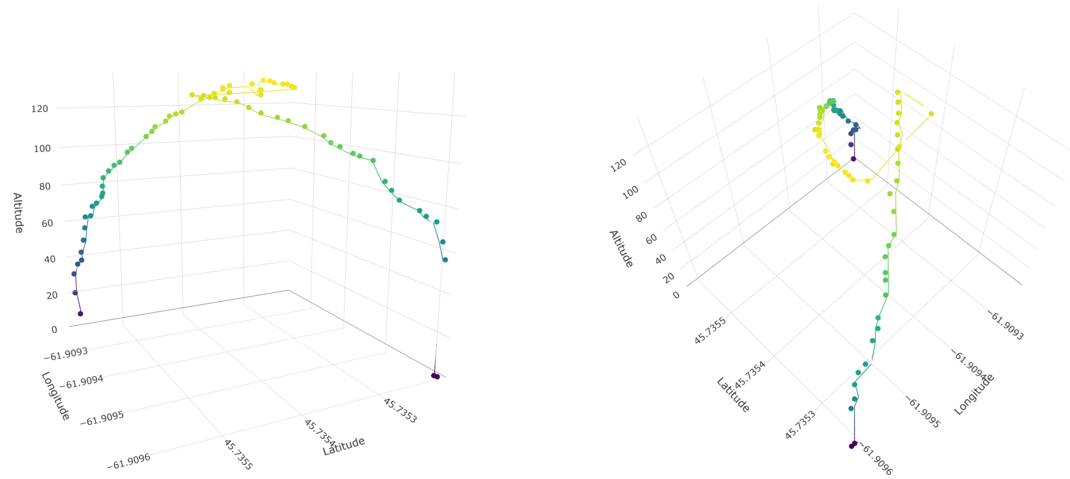

Figure 16: 3D position of rocket based on GPS and Barometer data

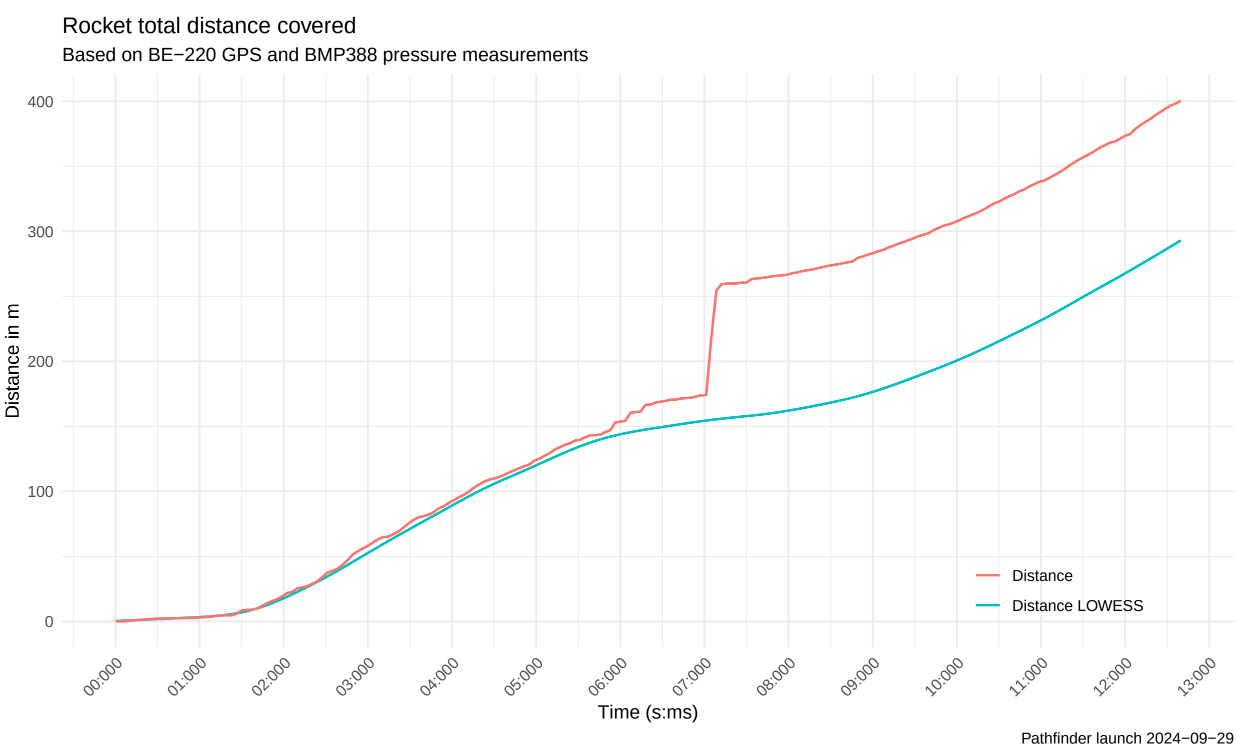

Figure 17: Total distance covered by rocket based on GPS and Barometer

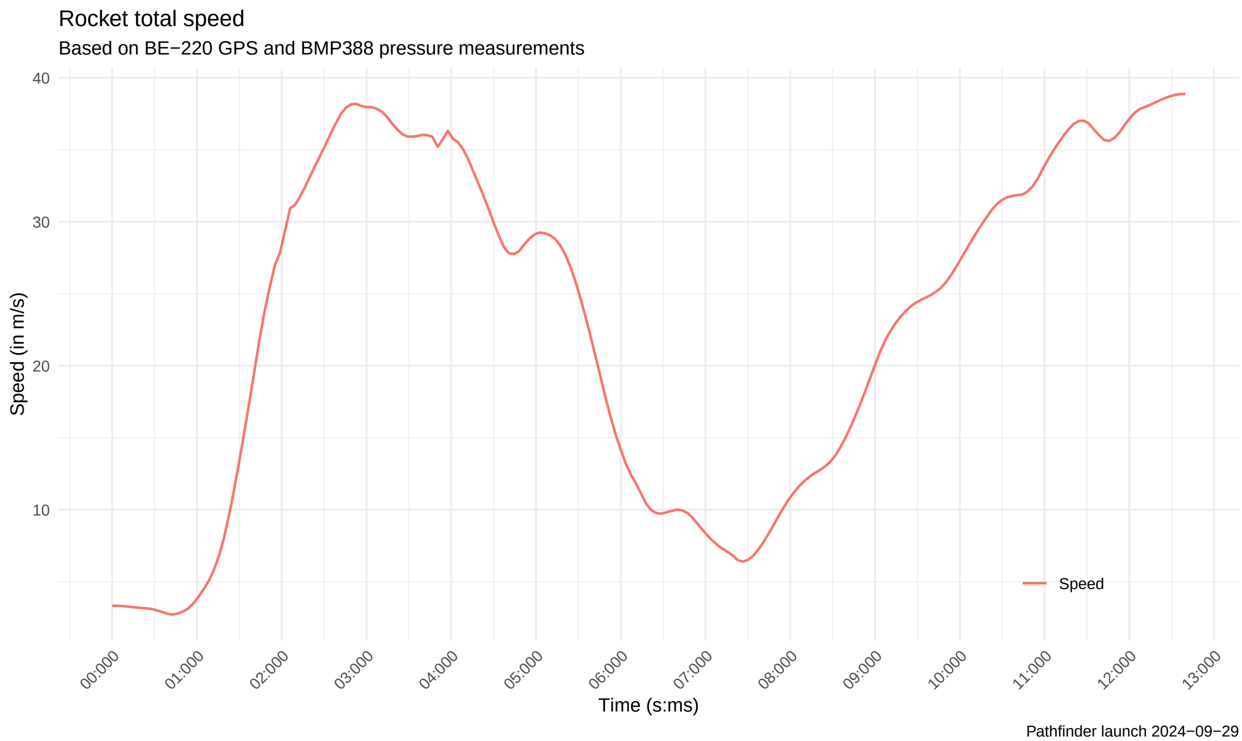

Figure 18: Total speed of rocket based on GPS and Barometer

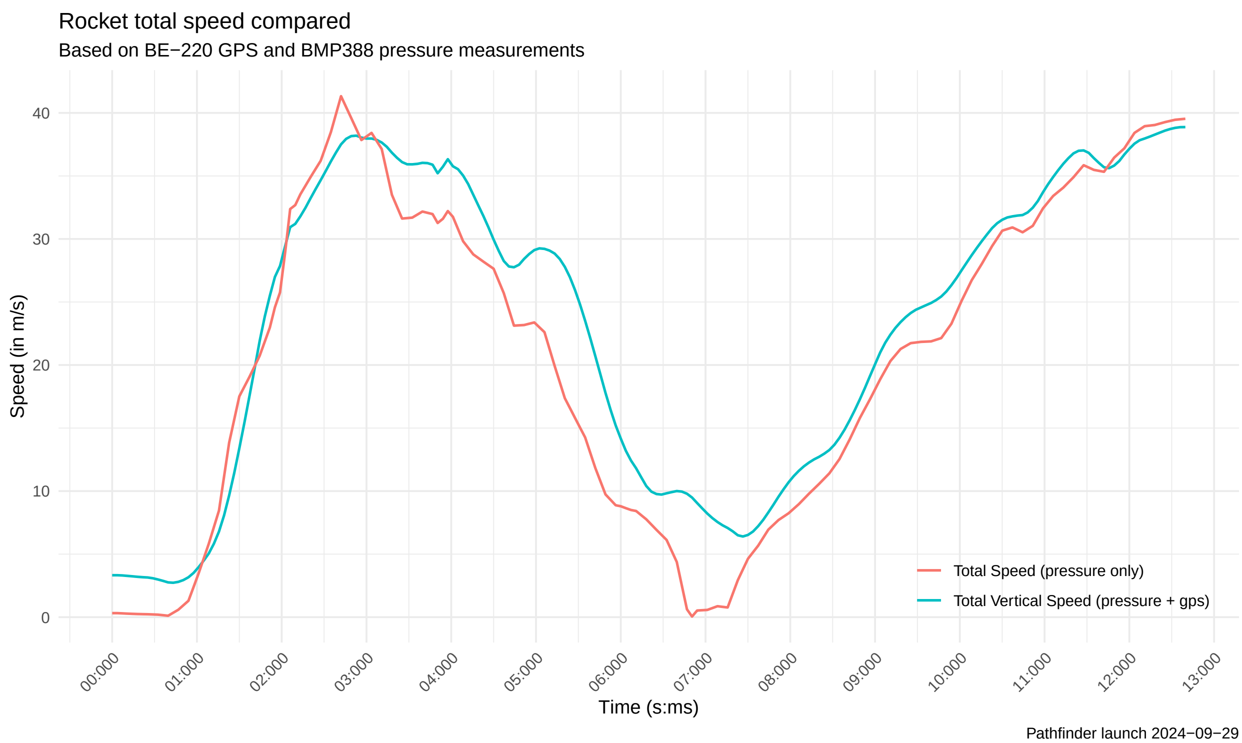

Figure 19: Total speed of rocket compared to vertical speed

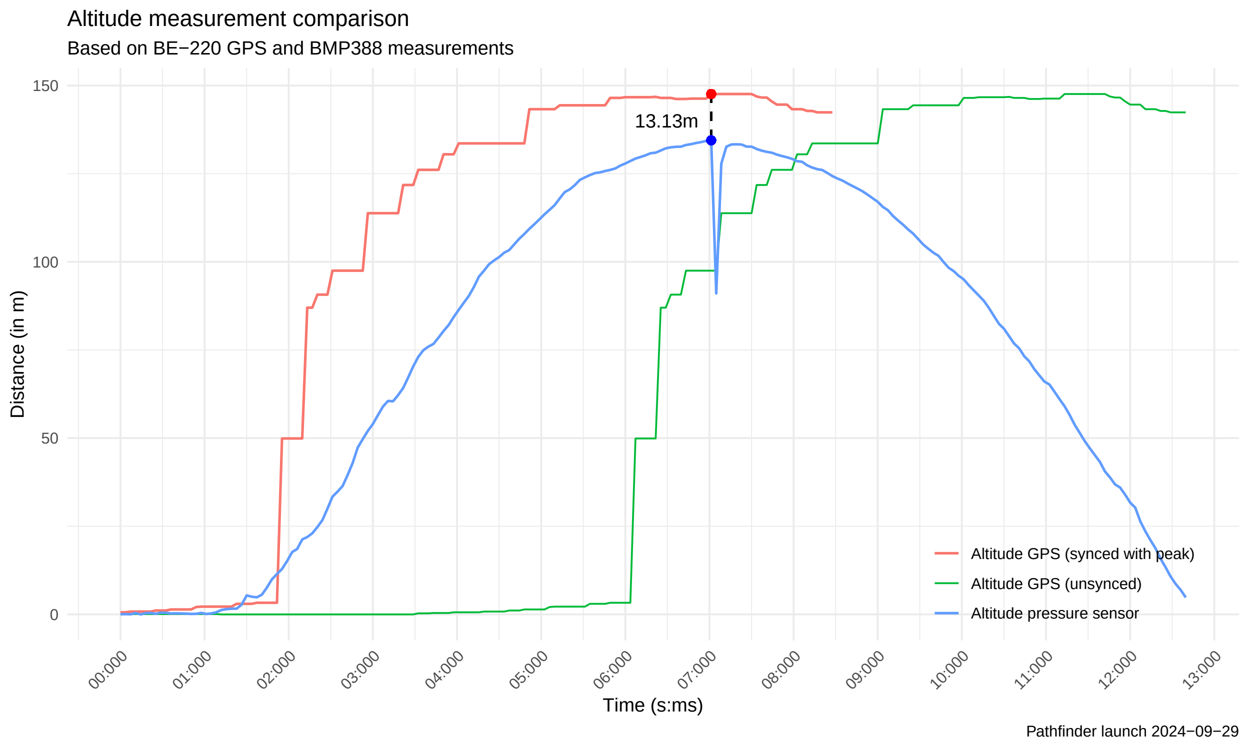

Figure 20: Comparison of GPS and barometer altitude measurements

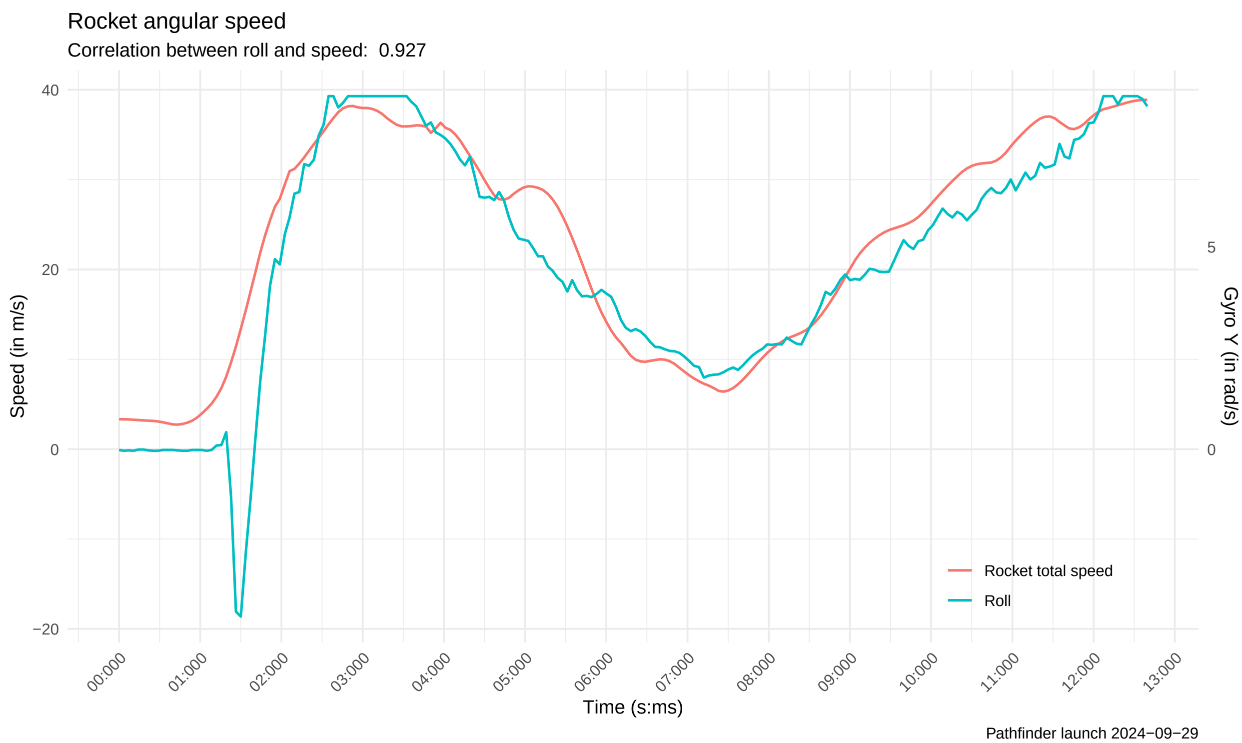

Figure 21: Correlation between speed and roll

3.2 Comparison with simulation

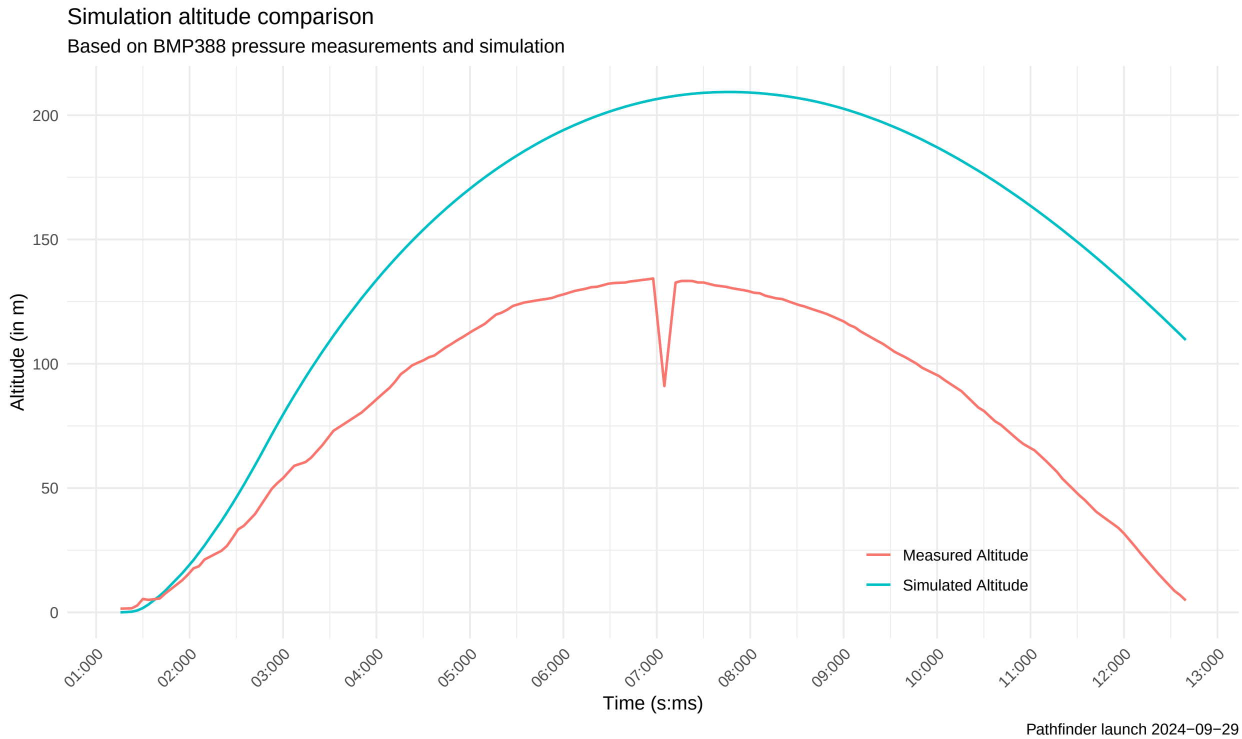

Figure 22: Simulated altitude compared with measured altitude

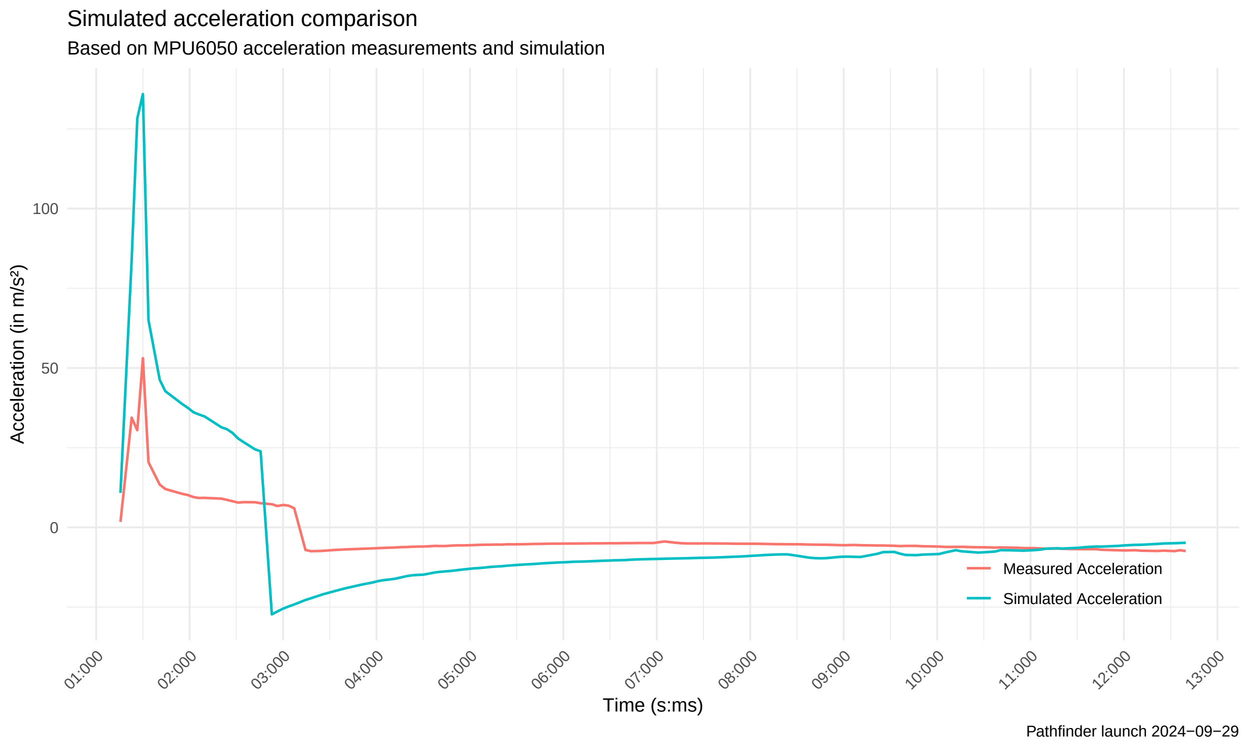

Figure 23: Simulated vertical acceleration compared with measured acceleration

3.3 Failure Analysis - Parachute, SD-Card, GPS VDOP and satellites

4 Conclusion

4.1 Critical Reflection

4.2 Next steps

This is an R Markdown document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. For more details on using R Markdown see http://rmarkdown.rstudio.com.

When you click the **Knit** button a document will be generated that includes both content as well as the output of any embedded R code chunks within the document. You can embed an R code chunk like this:

```
summary(cars)
```

```
##      speed           dist       
##  Min.   : 4.0   Min.   :  2.00  
##  1st Qu.:12.0   1st Qu.: 26.00  
##  Median :15.0   Median : 36.00  
##  Mean   :15.4   Mean   : 42.98  
##  3rd Qu.:19.0   3rd Qu.: 56.00  
##  Max.   :25.0   Max.   :120.00  
```

4.3 Including Plots

You can also embed plots, for example:

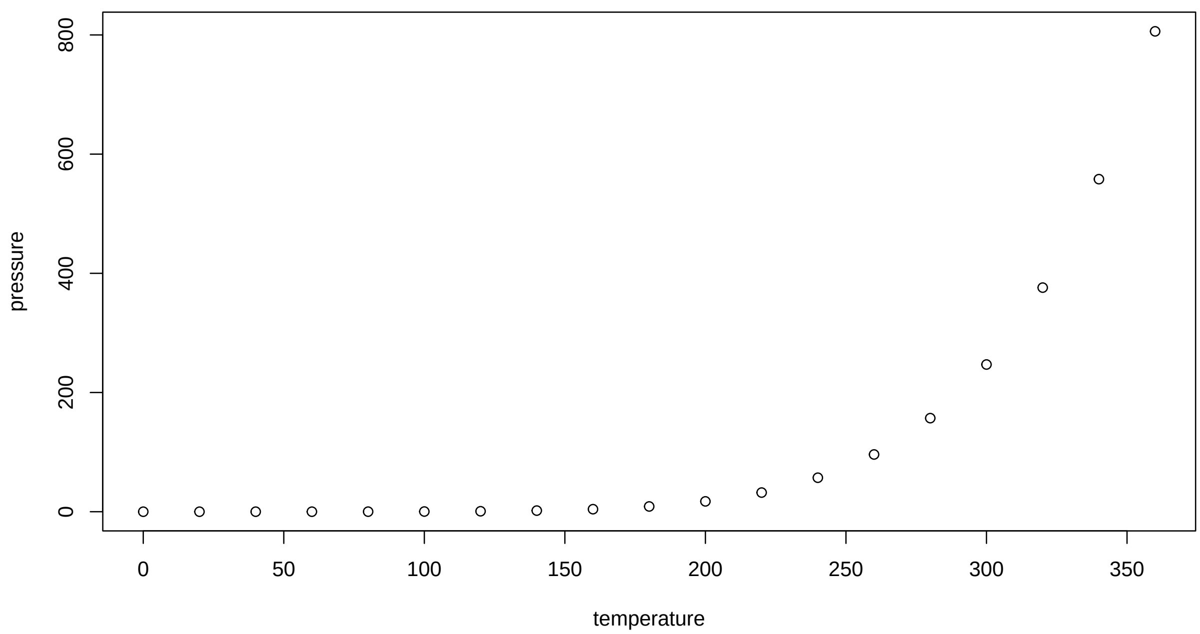

Figure 24: This is my plot

Note that the `echo = FALSE` parameter was added to the code chunk to prevent printing of the R code that generated the plot

References

Bambu Lab. (2024). Choose the right filament - 3d filaments guide for bambu lab printers [Accessed: 2024-10-03]. https://bambulab.com/en/filament-guide

Berman, B. (2012). 3-d printing: The new industrial revolution. *Business horizons*, *55*(2), 155–162.

Berman, B. (2020). Managing the disruptive effects of 3d printing. *Rutgers Business Review*, *5*(3), 294–309.

Center, N. R. (2024). Model rockets [Accessed: 2024-10-04]. https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/model-rockets/

Pearce, J., & Qian, J.-Y. (2022). Economic impact of diy home manufacturing of consumer products with low-cost 3d printing from free and open source designs. *European Journal of Social Impact and Circular Economy*, *3*(2), 1–24.