Accelerometer Measurements of Water Rocket Motion

Junbin Cao
Faculty Mentors: Dr. George Stecher, Dr. Kim Pierson
Physics and Astronomy Department, University of Wisconsin-Eau Claire

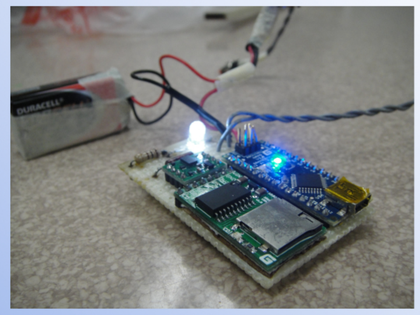
Introduction

The prices of accelerometers and micro-controllers have dropped dramatically in recent years. They can now be used in experiments that were previously too expensive to conduct. We have used these devices to measure the acceleration of water rockets, and have compared our results to a theoretical model developed by Peter Nielsen of the University of Queensland.

Procedure

1. Assembling a circuit board

We designed and built a data acquisition circuit using an Arduino Nano micro-controller, an MMA7455 3-axis accelerometer, and a 4GB micro-SD card.



Data acquisition circuit

2. Programming the micro-controller

We programmed the Arduino to read accelerometer data every 3 milliseconds during flight and to retain this data in the the Arduino's memory. The data were then written to the micro-SD card every second to ensure that no data were lost if the the micro-controller lost power or if the card was ejected on impact. (Both power losses and the ejection of cards occurred during early test flights.)

3. Building the rockets

We made each water bottle rocket from a 2-liter plastic soda bottle, a smaller bottle to hold the circuitry, cardboard for fins, a tennis ball to act as a shock-absorbent nose, and duct tape. The circuit board itself was protected by a small plastic can and layers of plastic foam. An external switch allowed the circuit to be powered on and off easily.

Typical rocket before launch

4. Launching

We used a pneumatic rocket launcher built by Dr. Kim Pierson. Initial runs yielded accelerations well above 8g, the maximum value our accelerometer can measure. As a result, later runs were made with larger masses of water and lower air pressures to keep the acceleration within our measureable range. Multiple rockets were built because many were destroyed on impact.

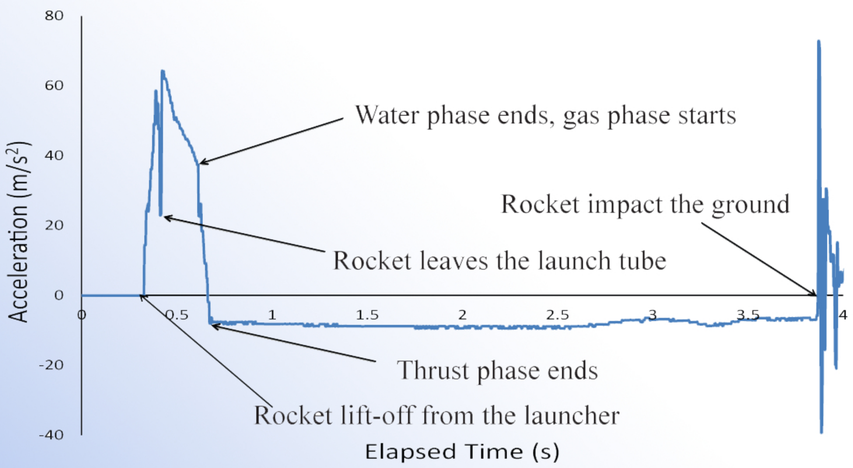
Rockets sitting on the launcher

Rocket crushed after impact

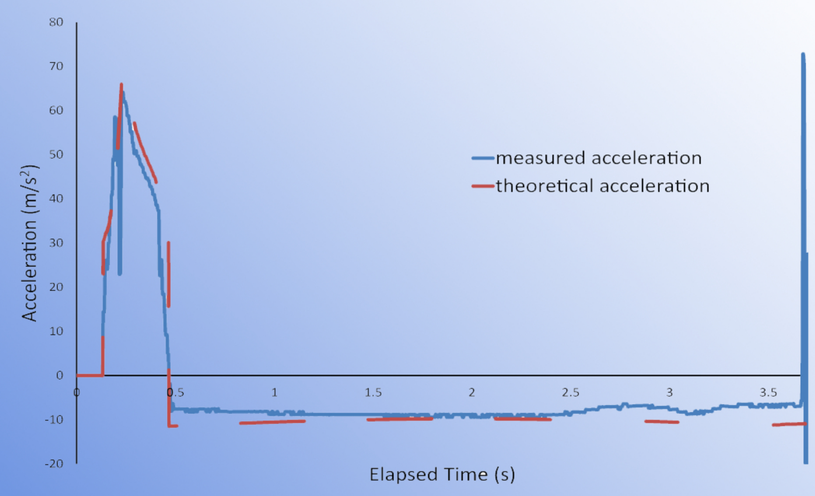
Results and Analysis

Accelerometers do not measure true acceleration directly, but rather a combination of the true acceleration and the graviational field g. Measurements made while the rocket sat vertically on the launcher were used to determine g and the orientation of the accelerometer compared to the rocket's longitudinal axis. The value of the gravitational field was subtracted from our data. (We had to take into account the rocket's change of direction at the apex of its flight to do this.)

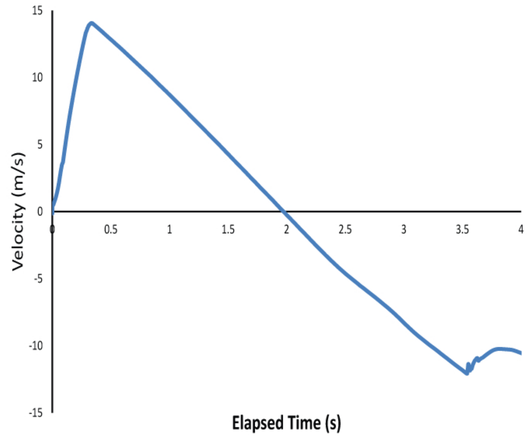
The following graph shows our acceleration data throughout the flight with important phases of the flight marked.

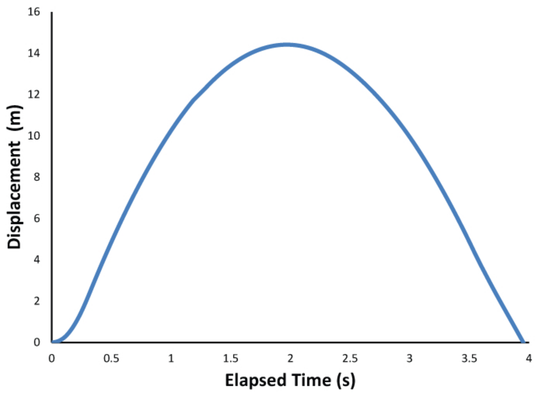


The next graph shows our data with the theoretical model of Nielson superimposed. We had only crude measurements of the air pressure in our rockets, and chose the pressure in Nielsen's model to give the best fit to our data. There are no other free parameters in the model.



We then numerically integrated the acceleration data to find the velocity and altitude of the rocket as functions of time.





Conclusions and Future Work

- Inexpensive micro-controllers and accelerometers can be used to make acceleration measurements of rockets in flight.
- Our data confirm Nielsen's theoretical model for water rocket flight.
- Water rocket flights routinely exceed 8g of acceleration.
- For future work, we suggest developing a more precise method for measuring the air pressure in the rocket. We also suggest using an accelerometer capable of reading a larger range of accelerations.

References

Details of Nielsen's theoretical model can be found at:

http://www.ohio.edu/mechanical/programming/rocket/Nielsen_Rocket.pdf

http://www.uq.edu.au/~webfluid/downloads/rocket.pdf

Acknowledgements

Special thanks to Xunyang Zhang and Tianran Gao for help with rocket launches.