ASEN 2004
Spring 2021
Water Bottle Rocket Lab
Deliverable 2: Rocket Model Check

Released: Monday, March 28

Deadline: One PDF with each group member's deliverables (downrange distance prediction and error ellipses) and each group members' individual code must be submitted to Canvas by **Wednesday, April 13 prior to your lab section**. **Each team member will also be required to demonstrate your individual model code live during the lab to be checked.**

Working as: Individual (i.e. every person must code their own model and develop their own deliverables)

Submitting as: Full group (i.e. each group needs to submit 1 PDF with every group member's deliverables and code) to Canvas with an in-person check during lab on 13 April.

Grading: 50 points (based on your individual model)

The largest part of the space lab in ASEN 2004 is creating a MATLAB model to predict the performance of a water bottle rocket. You will develop one of these models and validate it against actual launch data from a LA Baseline Rocket. You will then use this model to design a new rocket that gave you the greatest downrange distance, build and test this modified rocket, and then compare the rocket's actual performance to your predictions.

As has been explained in class, there are three ways to model a water bottle rocket's flight. The main difference between these models is how they model the rocket's thrust. The three ways to model thrust are:

1. **Thermodynamic Model (required by 3 of team members)**: Using the thermodynamics of water and air expansion. This model was developed in ASEN 2012.
2. **Rocket Equation Model (required by 3 of team members)**: Using the rocket equation and the specific impulse (I_{sp}) of the water bottle rocket calculated from static test stand data.
3. **Thrust Interpolation Model (optional for 10 bonus points)**: Interpolating one thrust curve of the water bottle rocket calculated from static test stand data.

Details about each thrust model can be found in Appendix A of the Appendices document.

In this deliverable we are asking each student to develop their own model of the rocket. There are a number of reasons to ask for this individual deliverable. First, it ensures that everyone gains more experience with MATLAB, which you will use in pretty much every aerospace course.

Second, having a number of independently-developed models gives your group an excellent opportunity to validate your models.

We are requiring each group to 3 team member individually code the two required models (Thermodynamic and Rocket Equation). This allows for each individual to have two other team members working on the same model to facilitate discussion and group learning/debugging, BUT NOT SHARING OR COPYING of your model code. While you are encouraged to discuss your modeling and your results with your group members, **your MATLAB code must be your own and the Honor Code still applies. Additionally, any member of the team may attempt to also develop a thrust interpolation model using data provided by the lab team for 10 individual bonus points on this lab.**

Each student must create the following two deliverables using their own model:

1. Error ellipses that show the LA Baseline Rocket's landing position with 1, 2, and 3 standard deviations due to uncertainty.
2. A single numerical prediction for the coordinate of the LA Baseline Rocket's landing position (both x- and y-components). This should be the center of your error ellipses.

You should create a 1-page PDF with these two deliverables and your name and thrust model (thermodynamic, rocket equation, or thrust interpolation) clearly written at the top. You should also create a PDF with your full code. Then, to submit these deliverables, your group must package these all together in 1 PDF with all the deliverables followed by all of the code. Submit this PDF to Canvas by the stated due date/time. Additionally, each student will demo their model code during lab on the due date. Each student will be graded on their own deliverables—i.e. students on the same group may receive different scores for this assignment.

Below we'll outline the steps of the model development process.

Develop One Model Individually and Validate Against Group Members' Models and Extreme Parameter Values

Each student should independently develop one of the two models. We are requiring each group to have someone code each model, meaning that 2-3 students on each group will develop each model. While you are expected to develop this model individually, there may be another member of your group developing the same model themselves. This gives you someone with whom you can compare your model outputs. They should be identical, or at least very similar (perhaps the two of you have made different assumptions). This also gives you someone to discuss your code with. The best way to debug is to explain your code to someone else, or even just a rubber duck. The instructors and LAs are also happy to discuss your code in lab and/or office hours. However, as it is very difficult to quickly understand code that someone else wrote, we ask that you **please bring a code flow diagram with you to office hours.** This will greatly help us to help you!

Recall that another good way to test your code individually is to put in extreme values of certain conditions and see if the behavior of the rocket makes sense. For example, if you make the gravity really large the rocket should just plop off the launch stand. If it goes really far with high gravity, something is broken in your model. Some other parameters that you can set to extreme values to test your model include:

- Gravity
- Coefficient of drag
- Fuel mass
- Wind

Compare LA Baseline Data to Your Individual Simulation

You will be provided with data from a rocket built and launched by the LAs this year:

- LA Baseline Rocket – Specifics of the rocket/launch design and the flight performance data will both be released. The purpose of this rocket is to help you validate your models by setting the initial conditions of your model to the LA Baseline Rocket specifications and comparing your model's performance to the actual flight performance.

The data you will receive will include:

- Specifics of the rocket/launch design:
  - Bottle diameter
  - Fin and nose cone geometry
  - Nozzle diameter
  - Coefficient of drag (C_D)
  - Masses:
    - Dry mass
    - Propellent mass (fuel mass)
    - Wet mass (total rocket + fuel)
    - Post-flight mass (which includes some residual water droplets)
  - Launch pad angle
  - Bottle pressure
  - Launch heading angle (degrees *from* North, measured clockwise)
  - Environmental conditions: Winds at ground level, winds aloft, air temperature
- Flight performance data:
  - Time of flight from 1-3 stop watches
  - Downrange landing distance (x-distance)
  - Drift angle left or right (y-direction)
  - Flight altimeter data
  - Flight video data

One part of the data you'll receive about the LA rocket flights is wind data—both winds on the ground and winds aloft (on top of the aerospace building). Wind is measured in mph, which does not match the metric units that you're (hopefully) using in your code. So, you'll have to convert the units. Also, the direction of the wind is reported as the direction FROM which the wind is blowing. So, a "north wind" is blowing *from the north* and traveling *toward the south*. Also, note that our wind measuring setup only allows us to measure wind in the xy plane. We cannot measure any vertical components of wind.

One more note about wind – the magnitude of the wind that we see during launch is between 0-10 mph. Any higher and we can't launch. You can use this range of wind speeds in your uncertainty analyses.

The specifics of the rocket/launch design can just be plugged into your model as initial conditions. However, in order to fully compare your model's output to the flight performance data will need to process and analyze the flight altimeter data and flight video data in order to get the full flight path of the rocket. You should work with your group members to understand how to process this flight data. You will be asked to discuss your model's prediction of your team's rocket design in your final presentation.

Once your group has processed the LA Baseline Rocket flight path data, you can compare the flight performance to the rocket's simulated performance from your individual model. Your goal is to identify and analyze uncertainties in your model, and to mathematically define sources of error in your model and in the experimental data. You should use the opportunity to use engineering critical thinking and compare the predictions of altitude and distance to measured outcomes. Compare and discuss the results from your model, altimeter data and video data and the sources of error for each of these. What assumptions and sources of error are in each of your individual model? What could make the altimeter data incorrect? What could make the video data incorrect?

Conduct an Uncertainty Analysis

To do that you're going to conduct an uncertainty analysis. **You should work with your group members to list every uncertainty you can think of that will affect the flight of a water bottle rocket and provide an estimate for the value of this uncertainty.** In essence, you are accounting for any parameter that you measure or estimate but don't know exactly. Two examples are:

- Launch pad angle: Set to 45° with a normally-distributed error with a mean (μ) of 0° and a standard deviation (σ) of 1°. Mathematically, this error is written as $N(0,1)$ degrees.
- Mass of water: Filled to a certain value with a uniform uncertainty spread from -0.5 to 0.5 grams (presuming the scale rounds to the nearest gram). Mathematically, this error is written as $U(-0.5,0.5)$ grams.

For each uncertainty your group should justify the values you chose. Your group should then hold onto this list of uncertainties and justifications, as you will present it in the Rocket Lab Final Presentation. (To clarify, we expect each member of your group to use the same list and values of parameter uncertainties in their individual uncertainty analysis.)

Lastly, each student should *individually* perform a Monte Carlo simulation in which you run 100 or more simulations with your individual model, each randomly picking the particular value for parameters with uncertainty from their distributions. The exact number of simulations run is up to you. Use the `error_ellipses.m` code provided on Canvas to plot the x and y position of the rocket impact and determine the error ellipses that show the rocket's impact position with 1 standard deviation (1σ), 2 standard deviations (2σ), and 3 standard deviations (3σ). An example is shown in Figure 2.

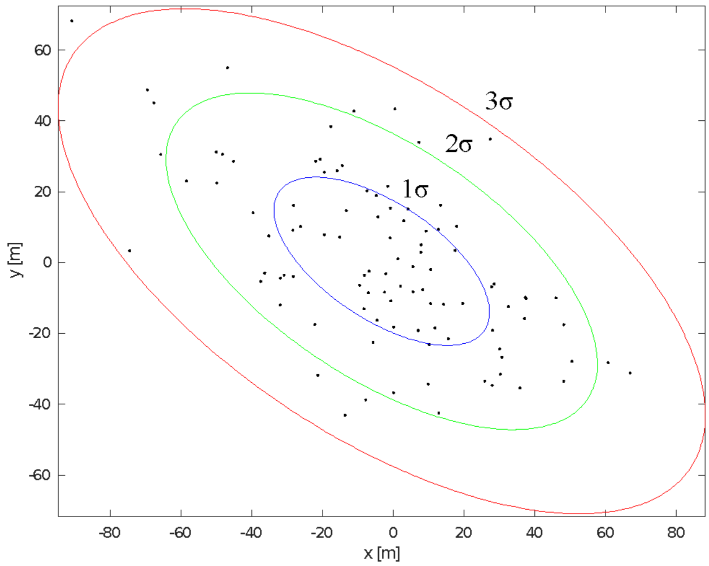

Figure 2. Example plot of rocket impact locations and error ellipses.

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You must also submit a PDF of your code.