How to Do Flight Testing for TARC

Trip Barber
NAR TARC Manager
February 2017

The TARC Cycle

- Learn the rules and basic rocketry
- Design and “fly” your rocket on the computer
- Build your rocket to your design with real hardware
- Test-fly your rocket
- Qualify for the TARC Finals

Why Test Fly?

- Your rocket may not work perfectly the first time, or every time
  - Failure modes that happen occasionally are not likely to be discovered in just one or two test flights

- The computer software does not always accurately estimate your real rocket's flight performance even if the rocket works perfectly

- Weather conditions affect a rocket's flight performance and you need to figure out how to recognize and compensate for them

Teams that qualify for the TARC Finals typically have done at least 15 test flights

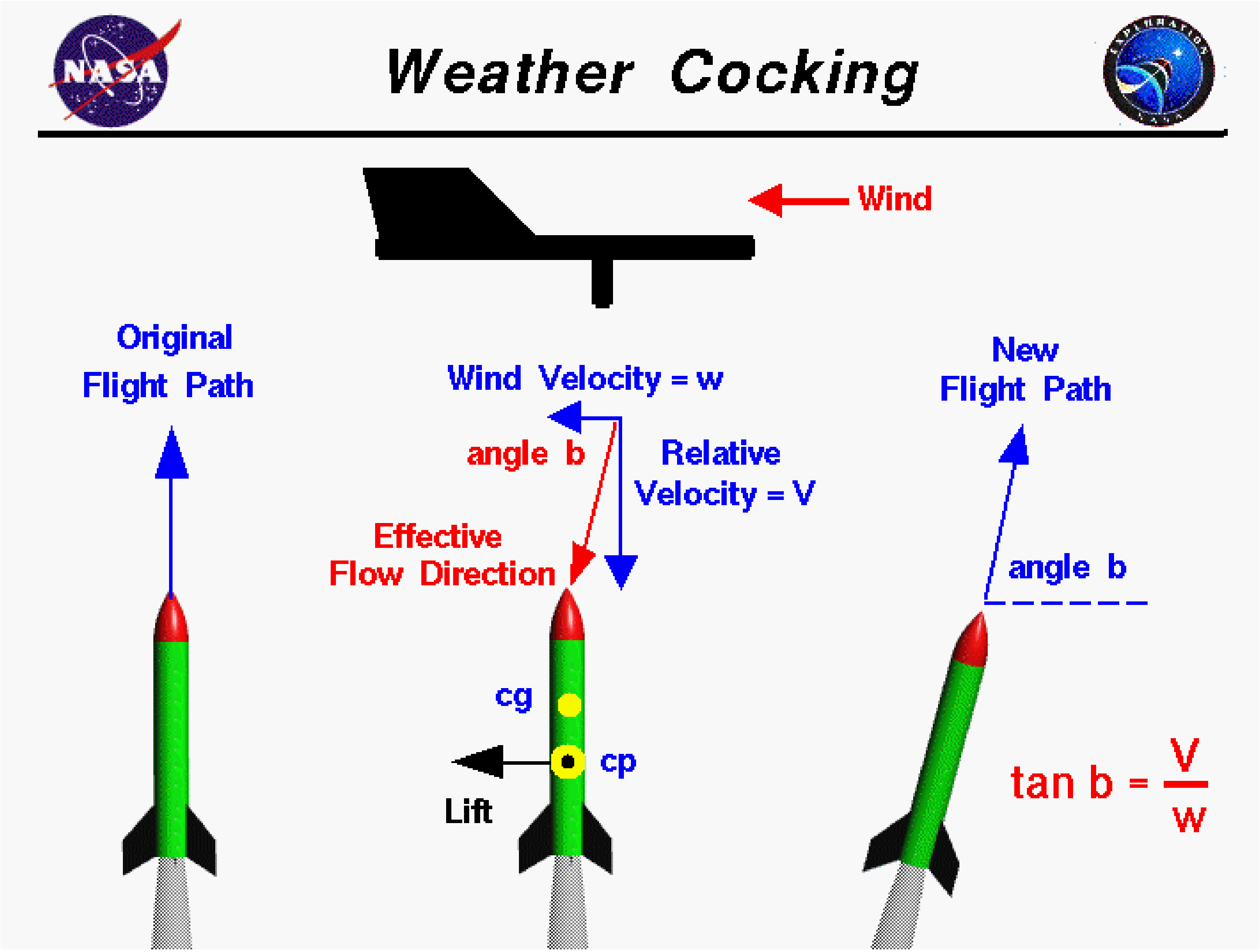
Common TARC Rocket Failure Modes

- Non-vertical flight
  - Insufficient thrust-to-weight, or launcher was angled wrong or wobbled
- Recovery device deployment incomplete
  - Not sufficiently systematic and careful about how it was packed
- Separated part
  - Connection or mount not strong enough or worn from previous flights
- Broken egg
  - Insufficient padding, particularly on the sides or between eggs
- Broken rocket part on landing
  - Landing speed too high or part materials not strong enough

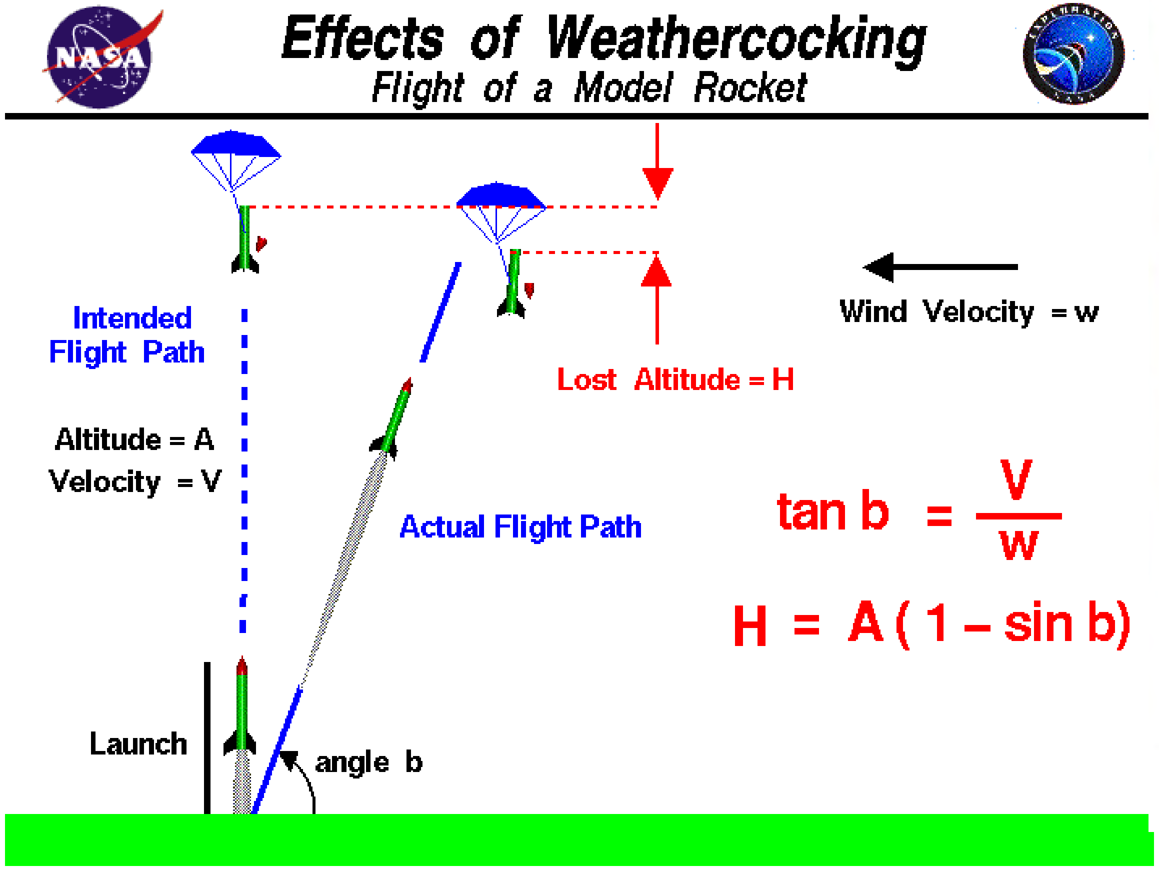
Use of checklists is a good way to help avoid making (or repeating) mistakes in flight testing

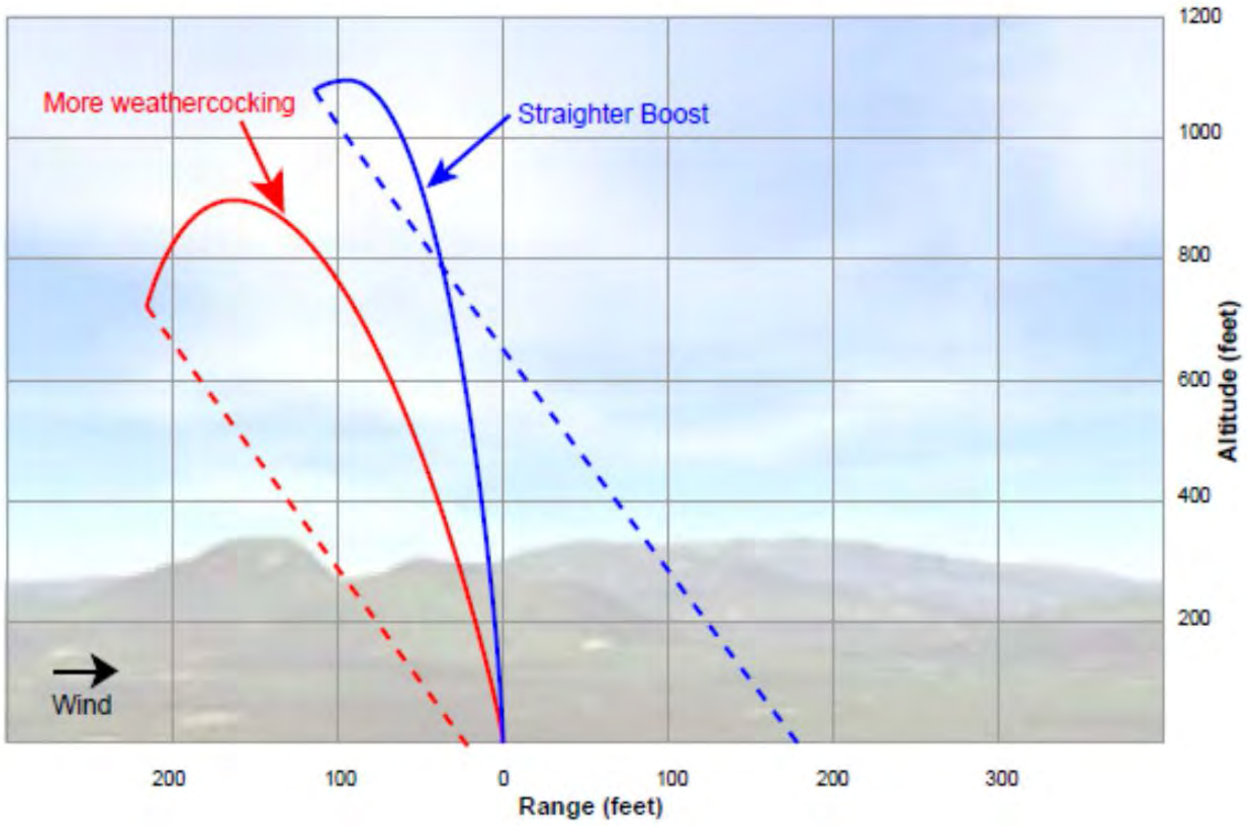
Computer vs Reality

- Computer altitude prediction may not match (and is usually higher than) actual flight altitude due to one or more of five factors:
  - Non-vertical flight - due to weathercocking in wind or launch device angle or movement
  - Rocket motor performance – may not exactly match values in computer
  - Rocket weight – may not match weight in computer
  - Atmospheric conditions – temperature, launch site elevation, humidity
  - Rocket drag – highly variable based on your personal construction techniques and flight damage
- Motor performance effects and non-vertical flights can be minimized
- Actual rocket weight and launch atmospheric conditions can be entered into the computer and will be corrected for <u>if you measure them</u> when flying
- After you've flown a few times you can make the computer simulation match measured actual altitude <u>from your flight data</u> by manually adjusting drag coefficient in the computer, once these other factors are controlled



Rockets with higher thrust motors get off the pad faster and have a higher V = velocity when they clear the launch device, so they are less vulnerable to weathercocking in wind. Using long (6-foot) and rigid launch devices (rails) gives the rocket more time to build up velocity.





Rockets that weathercock into the wind lose altitude because they do not fly exactly vertically. Angle the launch device in the opposite direction from the wind (away from it) to compensate and get a vertical flight. Figure out the amount of angle needed vs wind speed for your rocket in your test flights by taking data.

Rocket Motor Variability

AEROTECH F39

Total Impulse: 50 newton-seconds
Delays: 3, 6, 9 seconds

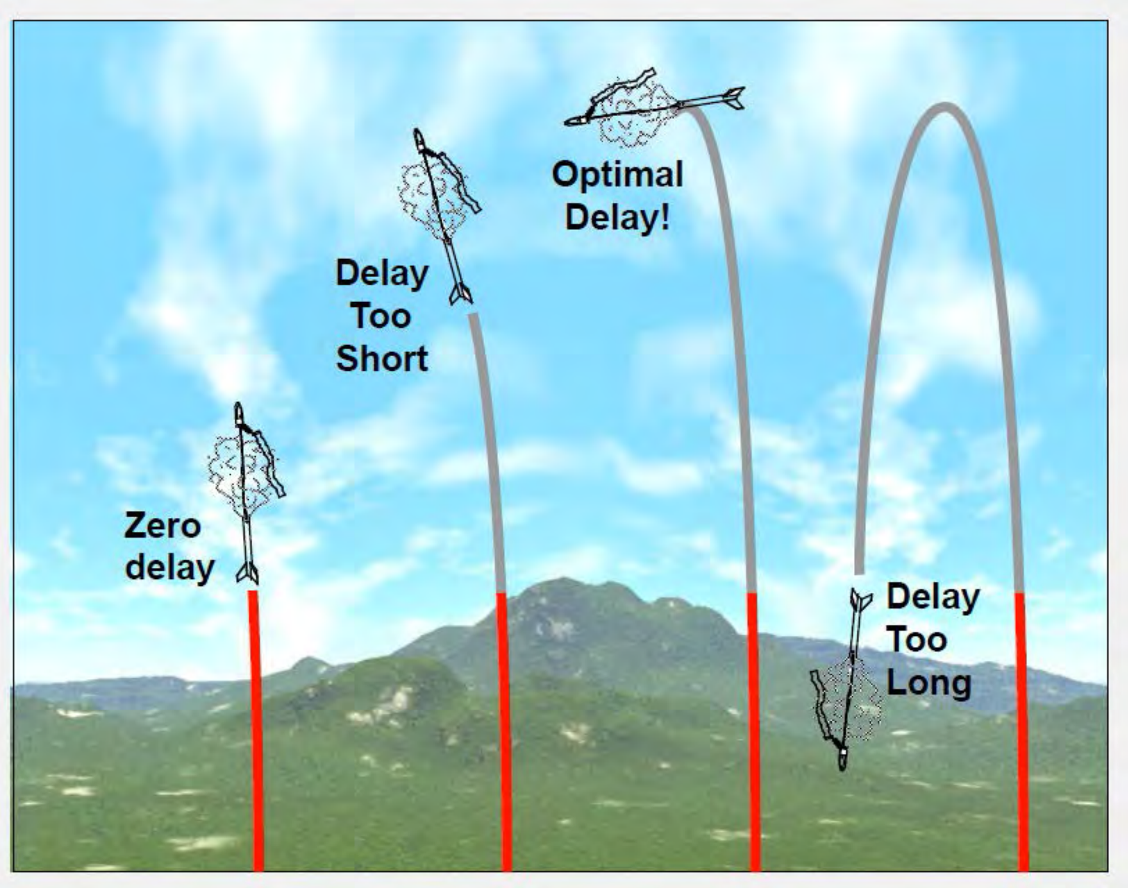
67% of motors will be within 1% of the average

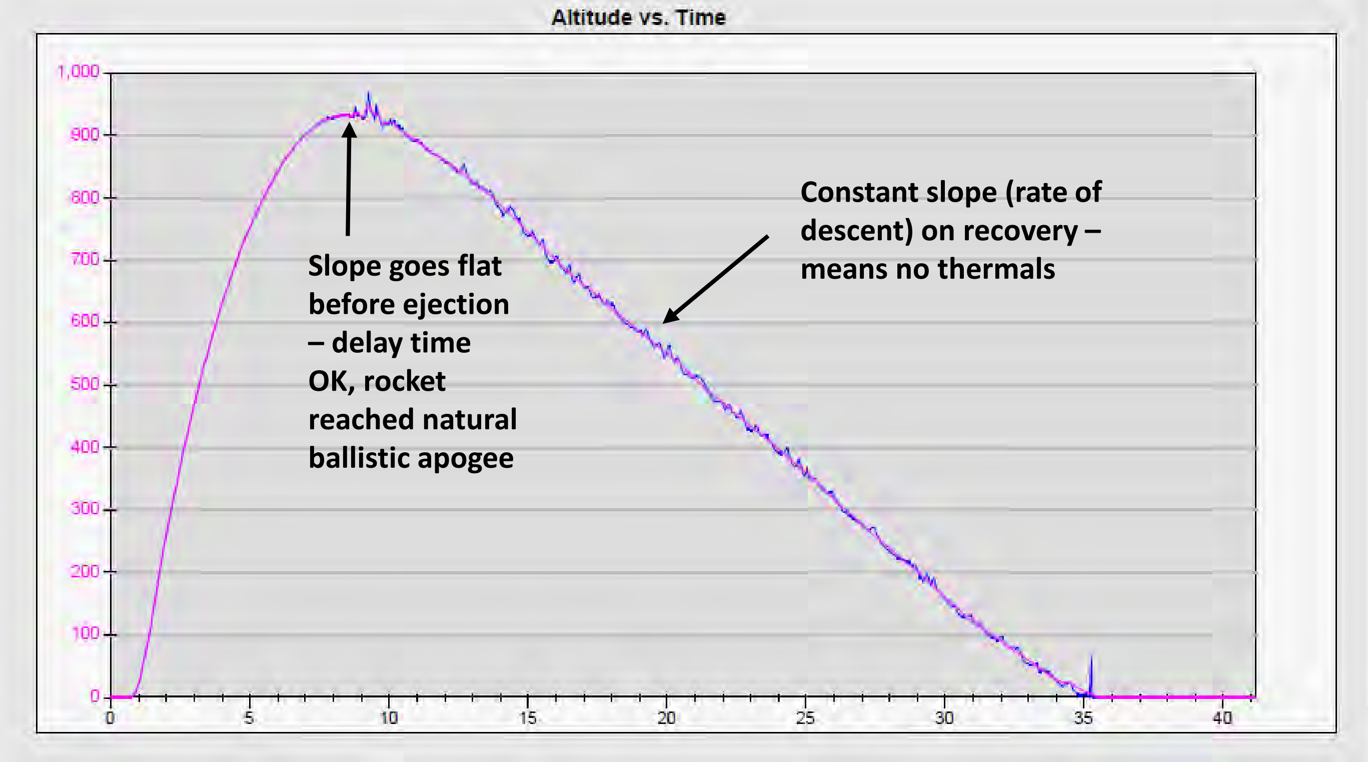
Total Impulse: 49.66 newton-seconds (σ 0.49)
Peak Thrust: 59.47 newtons (σ 5.29)
Burn Time: 1.33 seconds (σ 0.05)
Average Thrust: 37.34 newtons

Mass After Firing: 30.3 grams

Delay Time	Average Measured Delay	Initial Mass	Mfg Recommended Max Liftoff Weight
3	3.17	59.3 g	511 g
6	6.27	60.0 g	397 g
9	9.56	60.6 g	255 g

- Computer programs use average test data from NAR Standards and Testing for rocket motor performance.
- Key factors affecting altitude are total impulse (power) and delay time.
- Altitude is proportional to total impulse, and it can vary ~1% motor to motor for composite motors (more for black powder).
- Use composite motors all from the same production batch (date code) in test-flying program to minimize error.
- Use delay times that are long enough to ensure your rocket flies up through its ballistic apogee before ejection.





- If your delay is too short, the rocket will still have upward velocity at ejection that would have yielded more altitude – you will see this <u>from a recording altimeter's data </u>in your flight testing
- Because delay times are not very accurate, this early ejection will change peak altitude unpredictably
- It's better to go a little (not too much) past natural ballistic apogee before ejection; effect on duration will be small compared to the TARC score penalty from missing the altitude target.

Atmospheric Density

- Drag is the force the atmosphere exerts resisting the movement of the rocket through the air and it effects (reduces) rocket altitude.
  - Drag is proportional to the density of the atmosphere
- Atmospheric density (drag) decreases as the air gets hotter or more humid, or as launch site elevation above sea level increases
  - The same rocket will go higher on a warm or humid day, or at higher elevations, than it would on a cold or dry day, or at sea level
  - Effect of temperature on density (not altitude) is about 2% per 10 degrees F
  - Effect of site elevation is 3.4% per 1000 ft
  - Effect of humidity is comparatively negligible
- Taking weather data when you fly is critical to making adjustments to hit the TARC altitude target

Atmospheric Motion

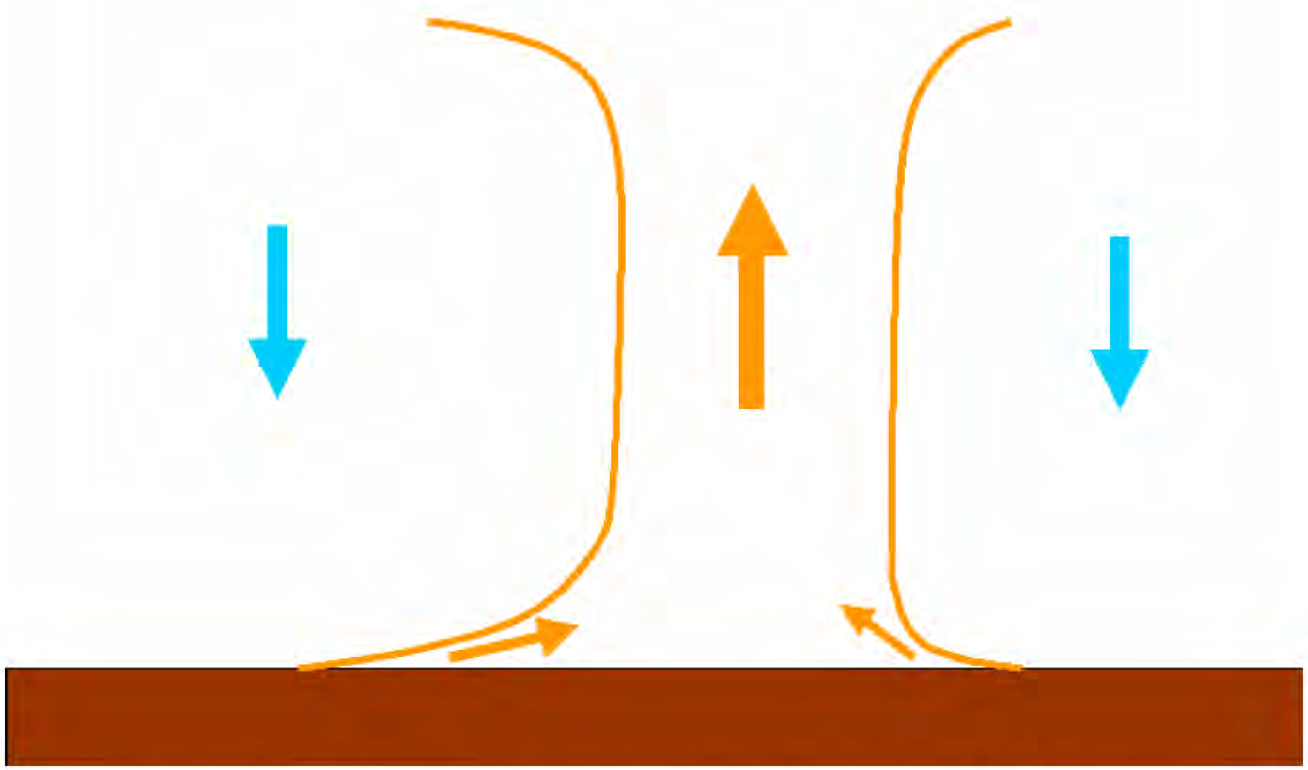


Figure 4: Side view of a thermal. Rising air is inside the orange outline.

- Wind alone does not affect rate of descent (duration) much, only how far a rocket drifts during that time
- A rocket's rate of descent through the air during recovery is generally constant, but the air itself can be rising or falling with respect to ground
- A body of rising air called a "thermal", caused by the sun heating the ground (especially plowed ground or pavement) or the accompanying falling air, will make a rocket's duration unpredictable
- Thermals increase in number and strength as the day goes on
- **Fly early in the day to minimize effect**

Successful Flight Testing

- Flight testing needs to be systematic – take data, understand what it tells you, and use it to make purposeful adjustments
- Record everything about each flight in a consistent format – rocket weight, flight characteristics, launch device angle, weather; not just altitude and duration
- Use a data-logging altimeter and evaluate the trace after each flight
- Use computer simulations adjusted with the rocket's actual weight and drag coefficient to determine how much weight change will be required to change the altitude the number of feet needed to hit the altitude target
- Adjust your rocket to hit the altitude target, then adjust the recovery device to hit the duration target – and do your qualification flights early in the day
- Figure out based on your data how to adjust your rocket's launch angle for different wind speeds to get a vertical flight and its weight for different temperature conditions to get the right altitude

Test-fly early, often, and systematically!