How to Win the Team America Rocketry Challenge

Trip Barber

National Association of Rocketry

TARC Manager and Co-Founder

What is Team America Rocketry Challenge?

- An annual nationwide outreach program sponsored by NAR and the Aerospace Industries Association
- The world’s largest rocket design and launch contest
  - Created here in 2003, now operating overseas in UK, Japan, France, and Australia
- Designed to encourage students in grades 7 through 12 to pursue careers in aerospace
- Funded by aerospace companies
  - Supported by NASA, DoD, and teacher organizations
  - 750-800 teams with ~5000 students enter each year

TARC Prizes

- $100,000 in cash and scholarships for top 10 teams at Finals
- Raytheon Company sponsors the 1st place team's trip to Paris or London air show to compete vs national winners from the UK, France, and Japan

What is the Problem?

- Current U.S. aerospace workforce is aging and retiring rapidly and U.S. leadership is at risk
  - 60% of the current workforce is age 45 or older
  - Same statistics apply to the NAR’s membership
- Not enough young U.S. citizens are choosing to enter aerospace careers or study technical fields in college – or join the NAR
- Technical fields are not perceived by students as offering exciting and rewarding futures and craftsmanship hobbies are not popular

What Has TARC Done?

- Enrolled 11,359 teams of students in its 16 years
  - Over 65,000 student participants, from all 50 states
- Ignited interest in aerospace among students
  - 66% say it increased their interest in technical fields
  - 54% say they plan on technical majors in college
  - 46% say it increased their interest in aero careers
  - And about 1/4 of the participants are girls

How Does TARC Work?

- Teams of 3 to 10 students register by early December
- Students develop their own designs using computer design/flight simulation programs
- Students build what they designed then flight test it
  - Video training program provided on how to build and fly
  - Local adult NAR “mentors” provide safety advice
- By the end of March teams must do two local “qualification flights” in front of an NAR observer and send in flight scores
- Top 100 teams nationally then invited to attend National Finals in mid-May near DC for a head-to-head fly-off

For Students and by Students

- All rockets must be entirely designed, built, and flown by student members of the team
- Help can come from outside in learning how to build and fly, use of altimeters, launch safety procedures, etc.
- Teams practice-fly with local clubs or with experienced adult members of the NAR

What Does TARC Teach?

- How to work as a team with measurable results that require skill and persistence to achieve
- Physics
- Electronics
- Aerodynamics
- Weather
- Craftsmanship
- Experimental technique

How Does it Teach?

- Students progress through design, simulation, building, and flight test phases, teaching them in sequence:
  - Flight stability to determine fin size and body length needed
  - Flight physics & mathematics to determine relationship between rocket motor power, rocket mass, and flight altitude
  - Mechanical skills to fabricate the rocket and launcher
  - Electrical skills to design & build an electrical launch controller
  - System engineering to learn how to position, connect, and protect all the key components of the rocket for flight
  - Experimental technique to determine what variables to measure during flight test, how to measure them, how they affect flight
  - Aerodynamics to determine why the rocket’s real aerodynamic drag is different from the ideal value in the simulation software

The TARC 2018 Challenge

- Work as a team to design, build and fly a model rocket with specific dimension constraints that carries two raw eggs on a mission to:
  - Achieve a precise flight duration of 41-43 seconds
  - Reach a precise flight altitude of 800 feet measured by an altimeter
  - Return the eggs safely and uncracked

- Each year the challenge changes a little so teams can't reuse the same rocket

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

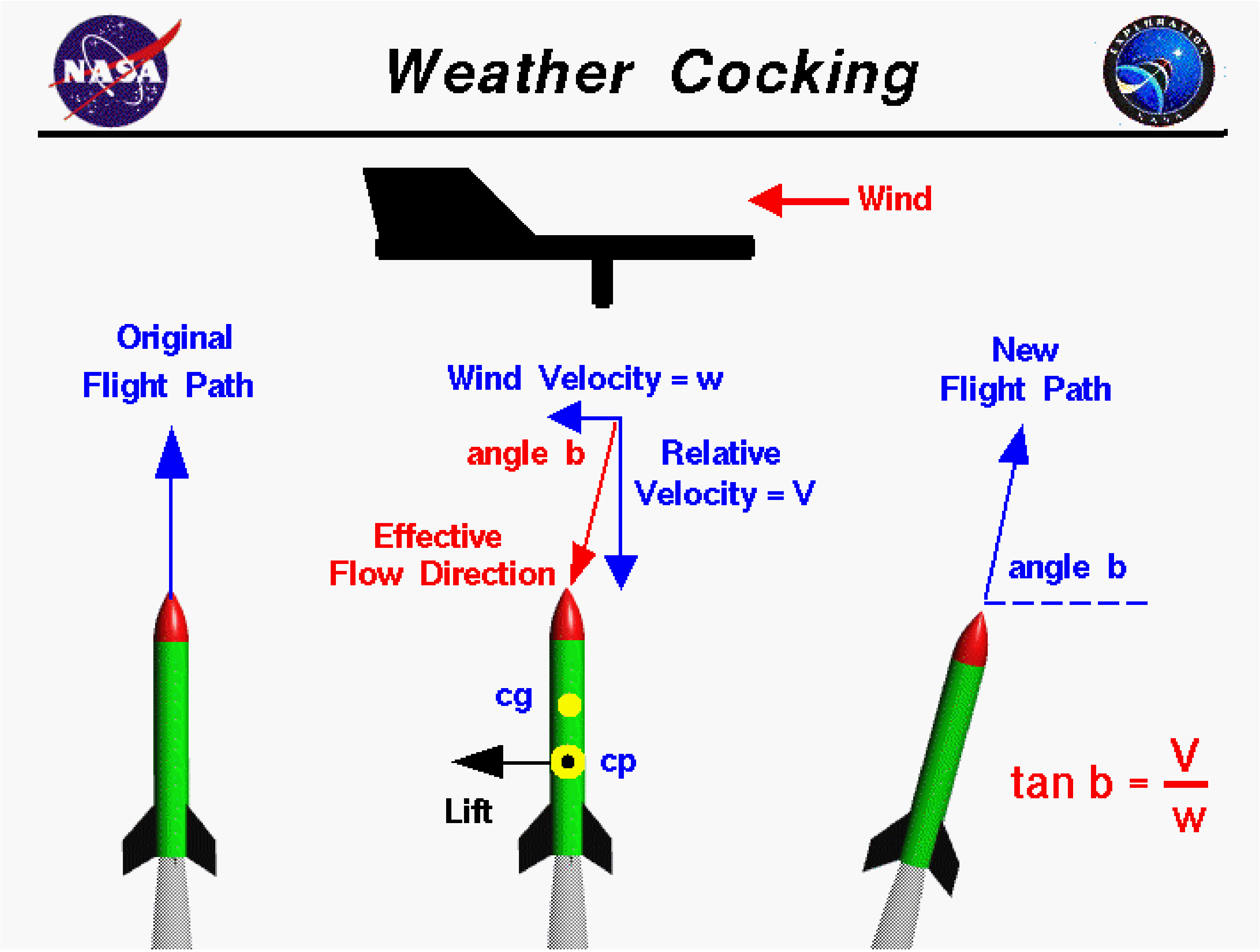
Common TARC Rocket Failure Modes

- 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, between eggs, or between egg and altimeter
- Broken rocket part on landing
  - Landing speed too high or part materials not strong enough

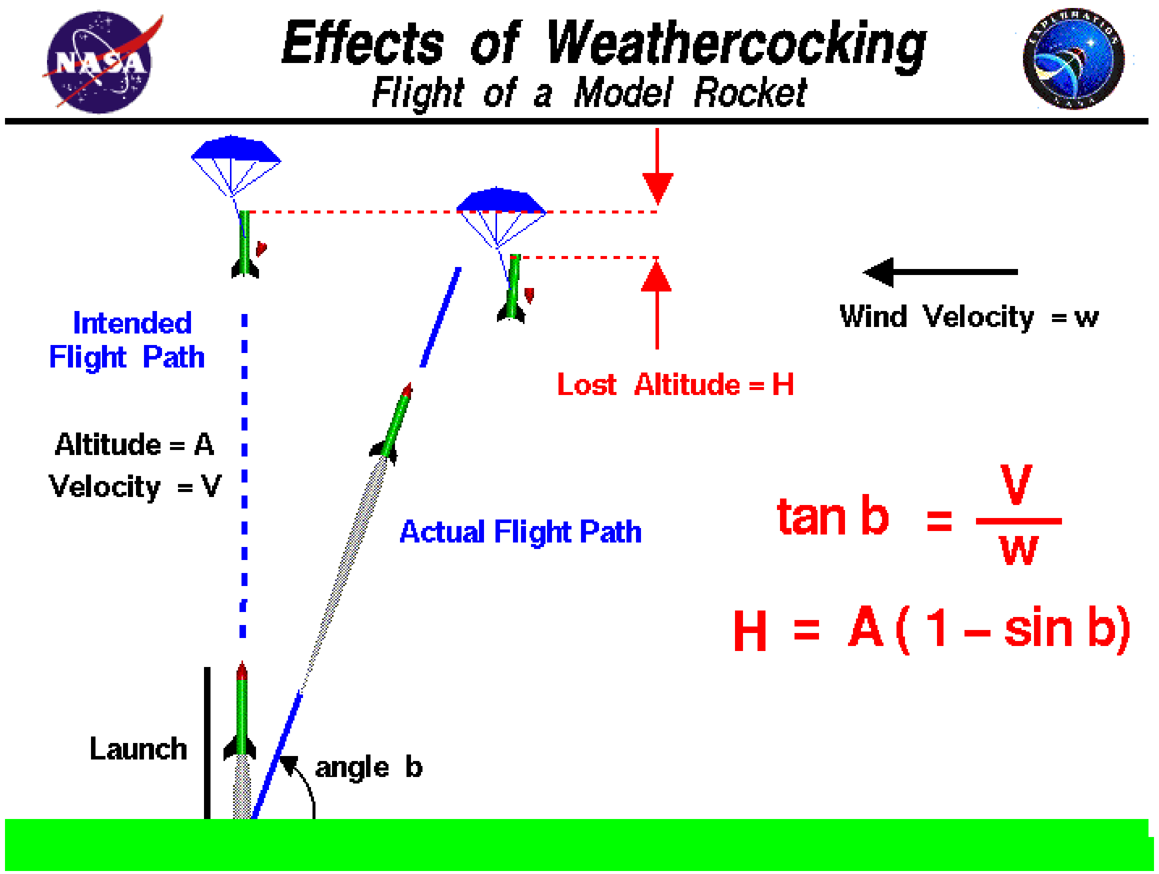
Use of checklists is a good way to help avoid making (or repeating) mistakes in flight testing

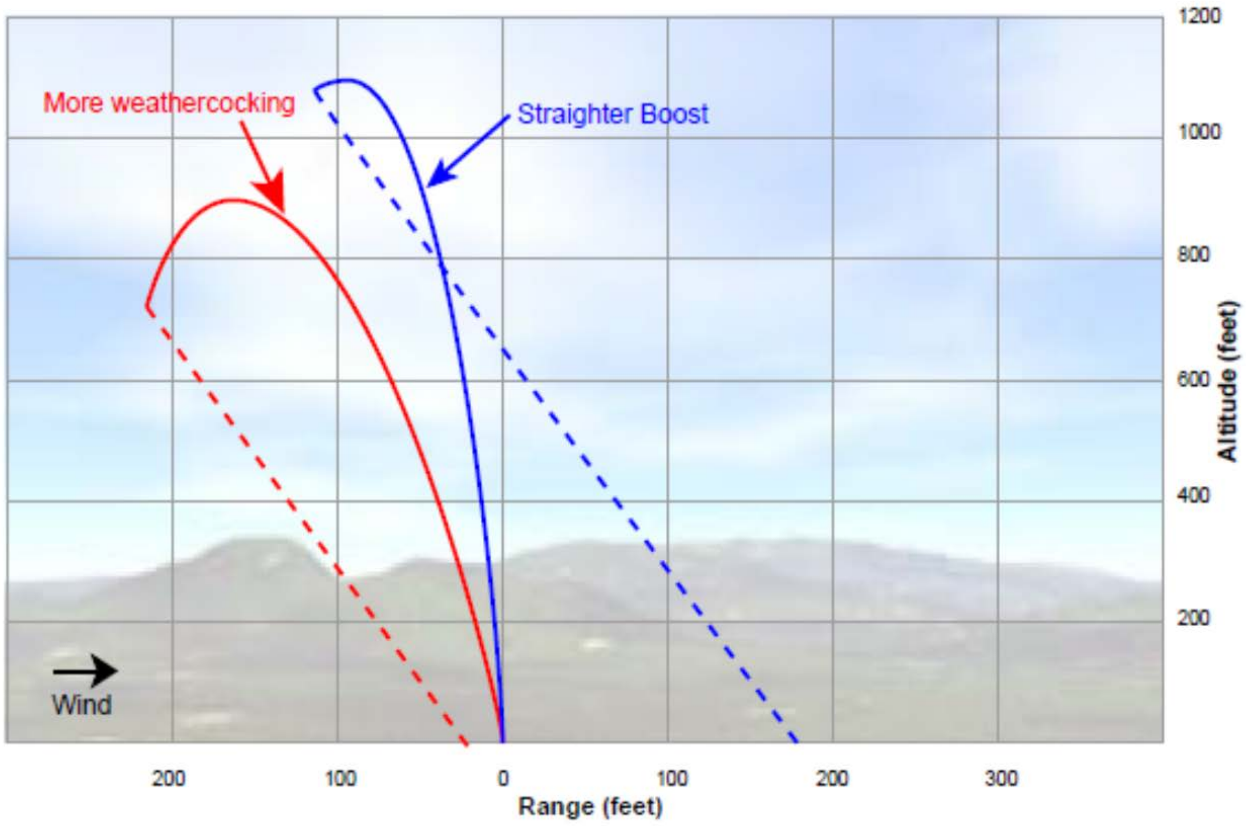
Computer vs Reality

- 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

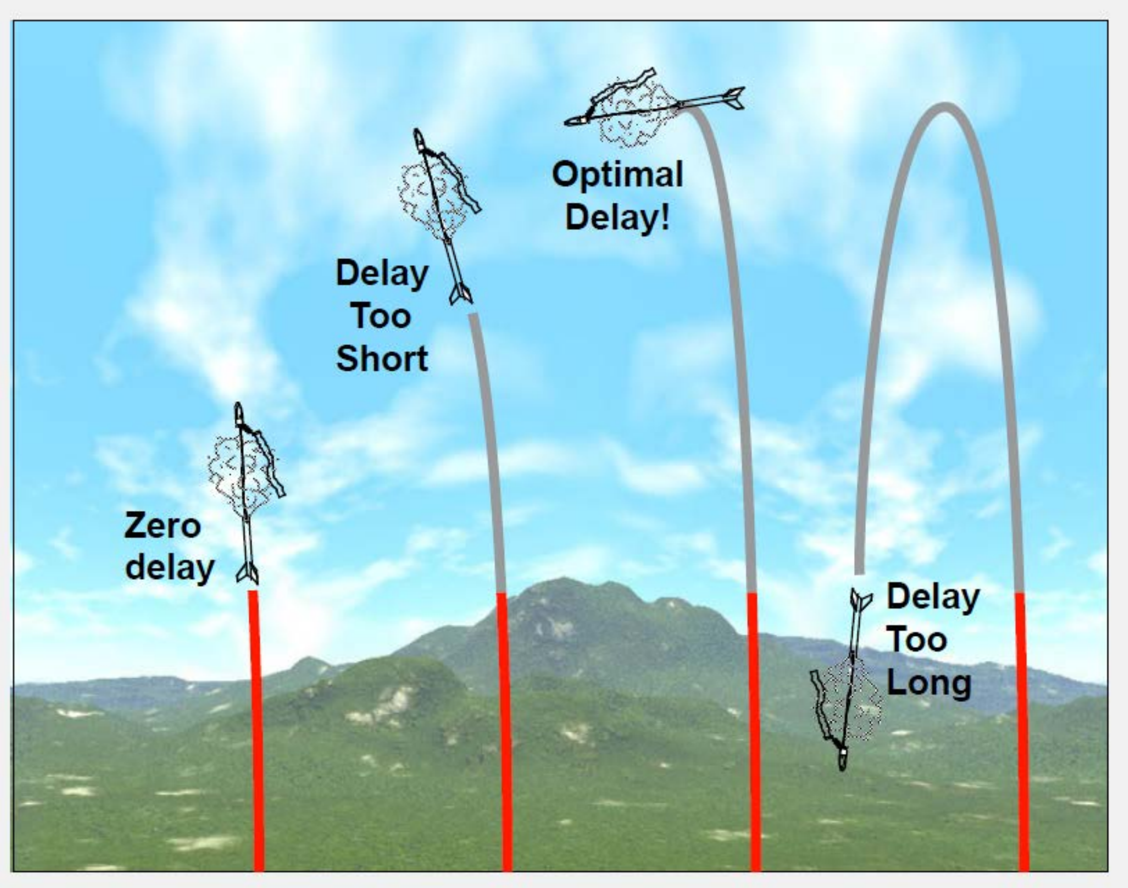
67% of motors will be within 1% of the average

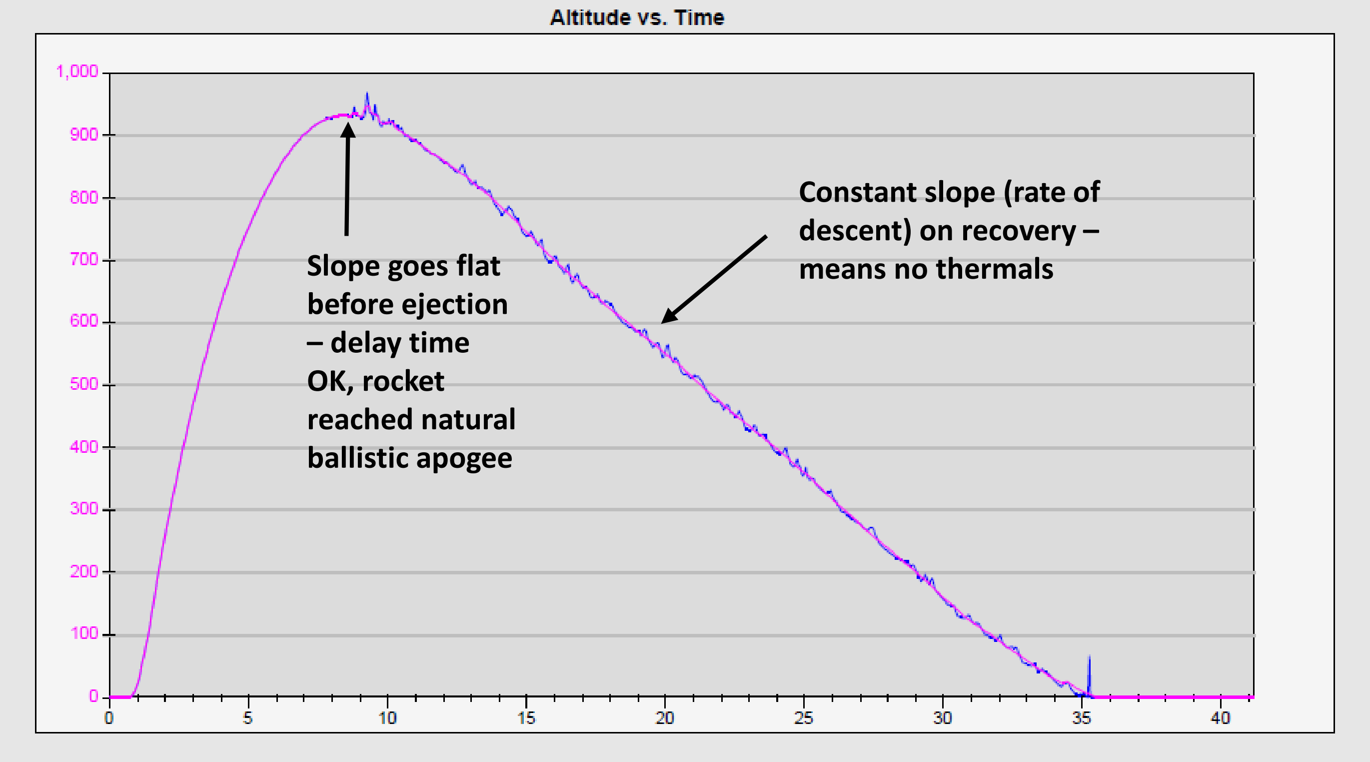
Total Impulse: 49.66 newton-seconds (σ 0.49)
Peak Thrust: 59.47 newtons (σ 5.29)
Burn Time: 1.33 seconds (σ 0.05)
Average Thrust: 37.34 newtons

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

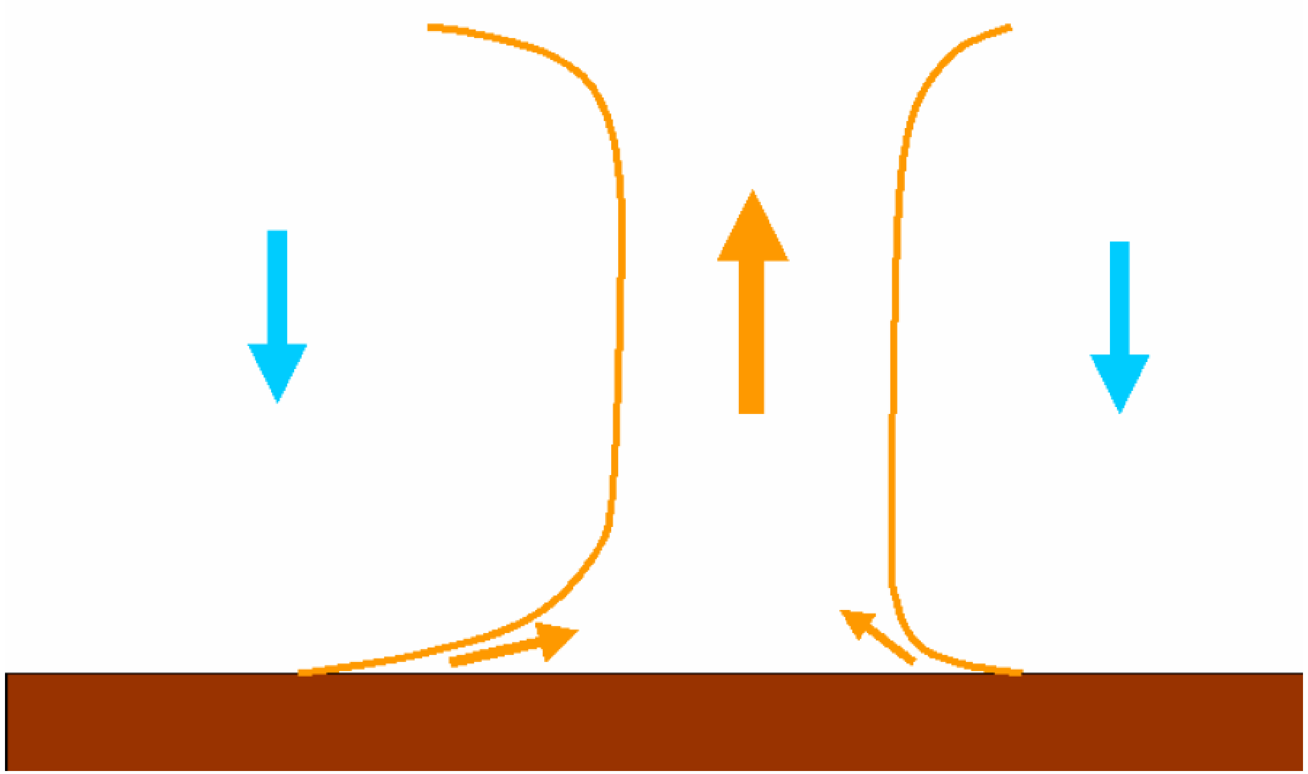


Figure 4: Side view of a thermal. Rising air is inside the orange outline.

- 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!