How to Win Precision Eggloft Events: U.S. TARC and International S2P

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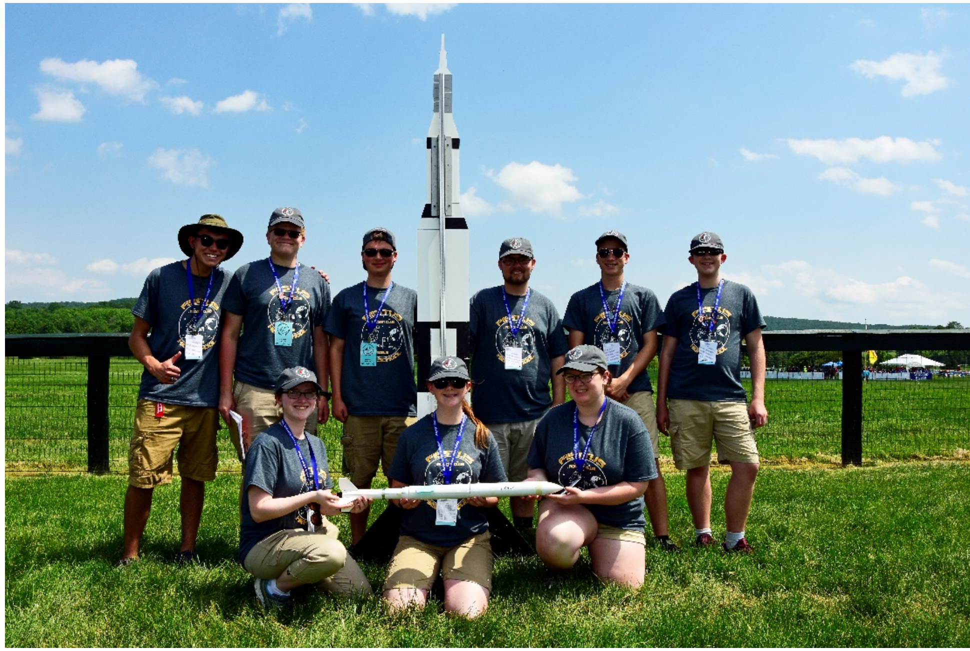
What is The American Rocketry Challenge?

- TARC is an annual nationwide STEM program for 6th-12th grade students sponsored by NAR and the Aerospace Industries Association
- The world's largest rocket design-build-fly contest
  - Created here in 2003, now operating in UK, Japan, Ukraine, France, and Australia
- Designed to encourage students to pursue careers in aerospace
- Funded by aerospace companies
  - Supported by NASA, DoD, and teacher organizations
- Flown by teams of 3 to 10 students
  - 700-900 teams with ~4-5,000 students enter each year
- $100,000 in cash prizes at national Finals
  - Top 100 teams based on pre-Finals qualification scores are invited to come compete each May



What is International S2P?

- "Precision Fragile Payload" (S2P) is an event flown in World Space Model Championships (WSMC) and other rocket competitions sponsored by the Federation Aeronautique Internationale (FAI)
  - 20 nations typically compete at a WSMC
  - Next WSMC is in Austin, TX in July 2023
  - US Team for 2023 selected at NARAM in July 2022
- Developed from TARC and very similar in requirements
  - Except it is flown by individuals, not teams, and is flown in age divisions: Junior (18 and under) and Senior
  - 3-4 fliers per nation in each age division
  - Prizes are FAI World Champion medals

Event Differences

- Some of the TARC requirements change a little each year
  - TARC 2022 objective is to lift two eggs to 835 feet and recover them in 41-44 seconds
  - TARC 2022 requires that the airframe use two different diameter body tubes
- Other TARC requirements stay the same every year
  - Maximum liftoff mass 650 grams, minimum length 650 mm, 80 N-sec motor power limit
  - Winner is based on the sum of two flight scores
- All S2P requirements stay the same every year
  - Flight objective is 300 meters (984 feet) and exactly 60 seconds, with one egg
  - Winner is based on the sum of three flight scores
  - Motors must be single-use, not reloadable
  - For the 2023 WSMC (only), motors limited to 30 grams of propellant (~60 N-sec)

A TARC 2022 rocket, flown with only one egg, could work well for S2P

The Success 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 event

The path to success in either TARC or S2P is the same: rigorous flight testing

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

Those that are successful typically have done at least 15 test flights

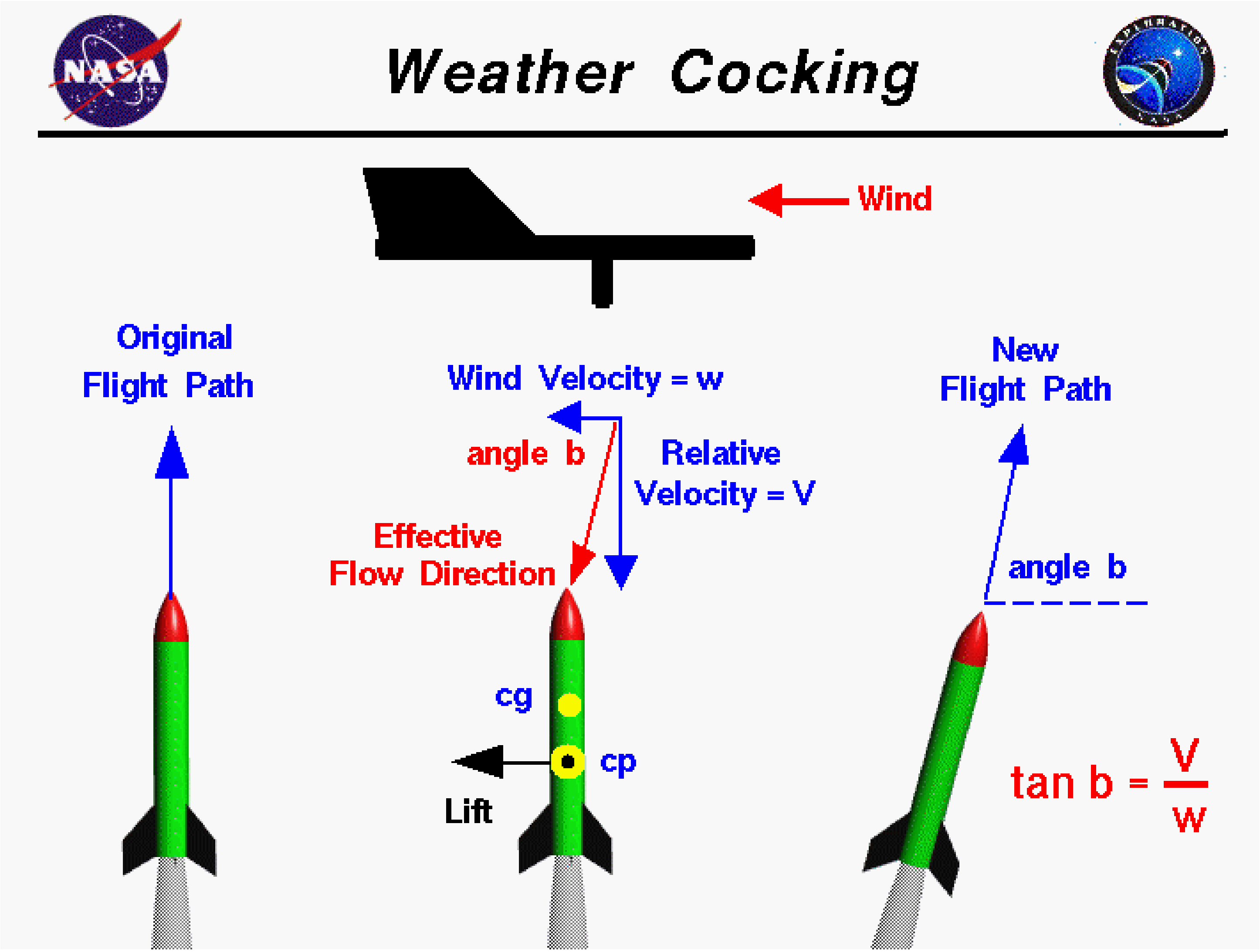
Common Rocket Failure Modes

- 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

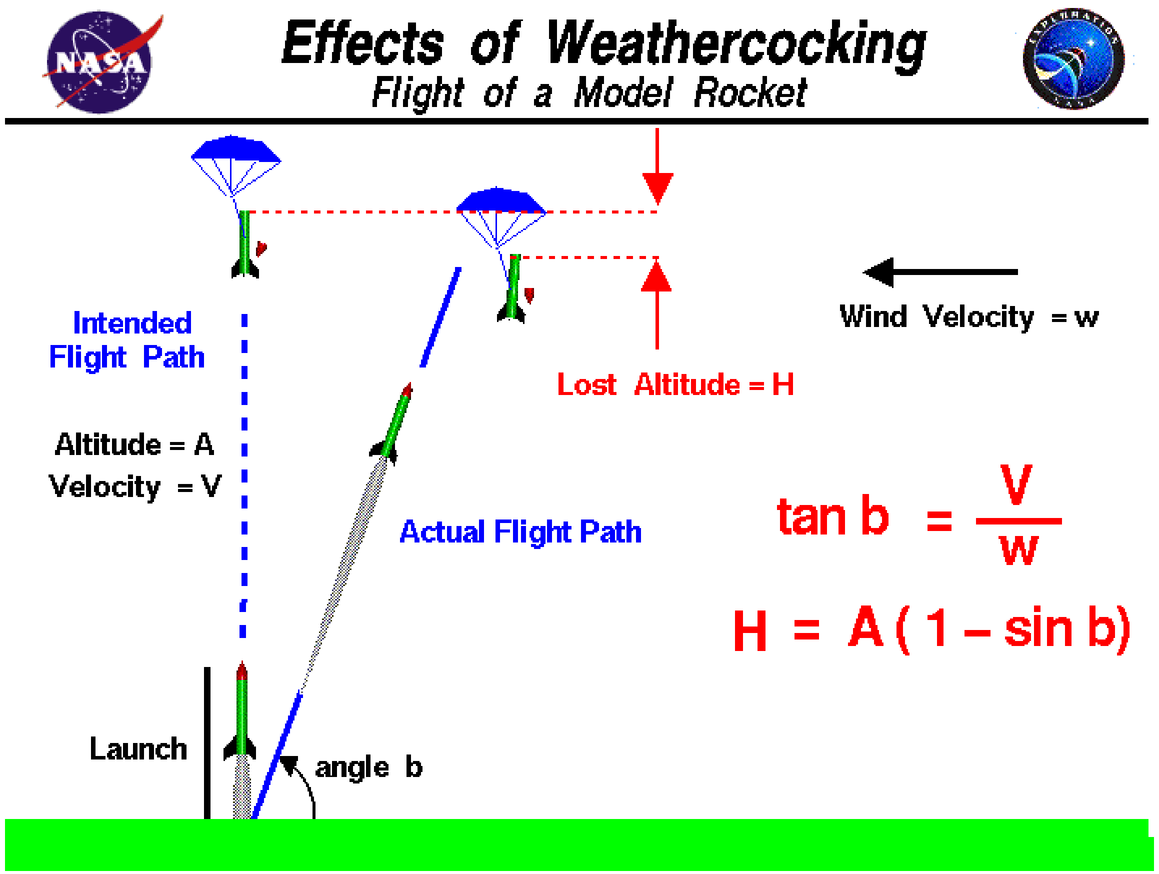
Use of checklists is a good way to help avoid making (or repeating) mistakes in flight testing

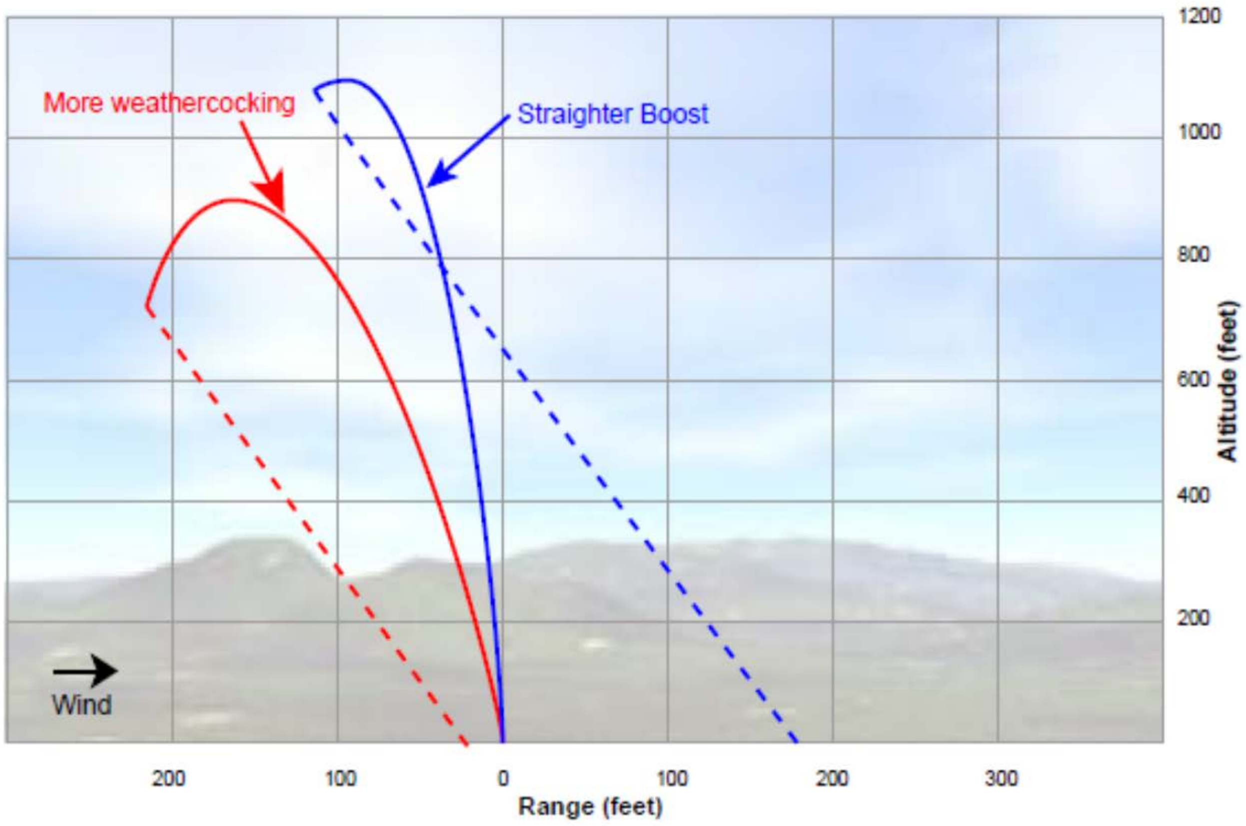
Computer vs Reality

- 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 <u>by taking data</u>.

Rocket Motor Variability

AEROTECH F39

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

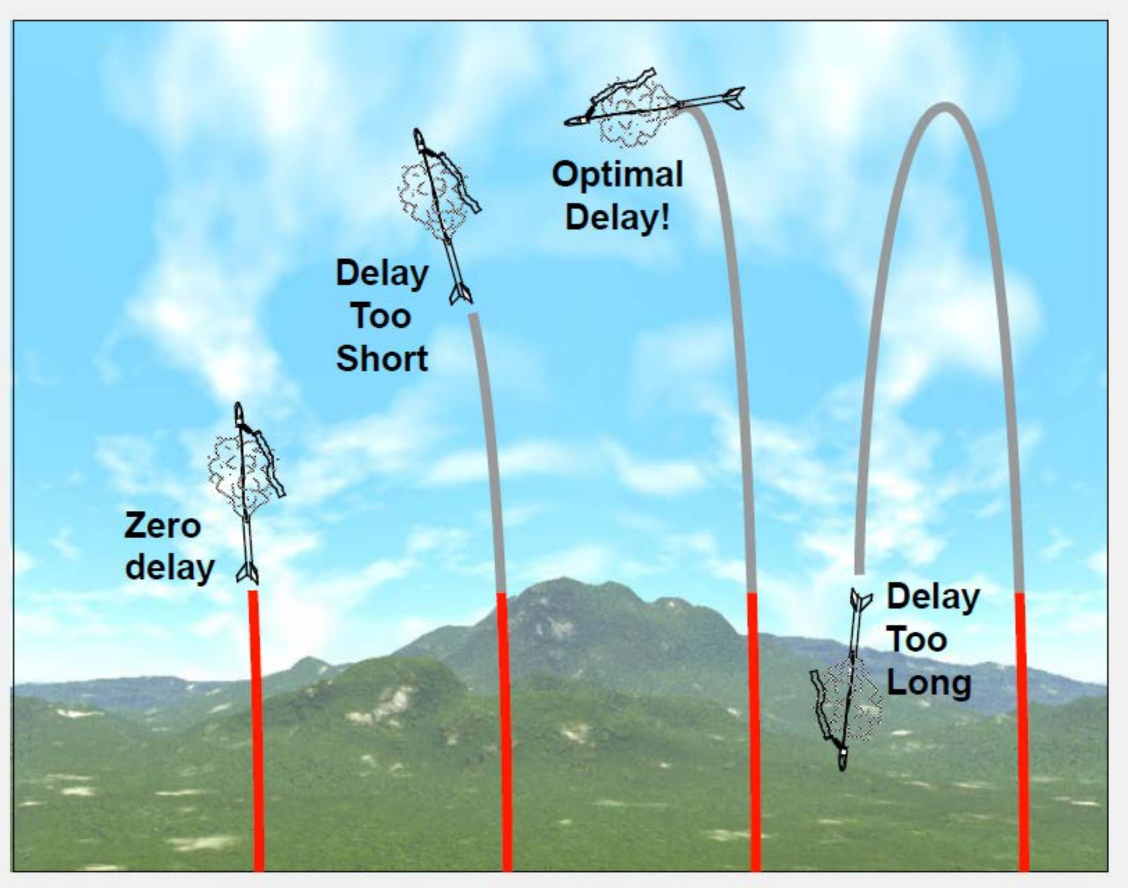
67% of motors will be within 1% of the average

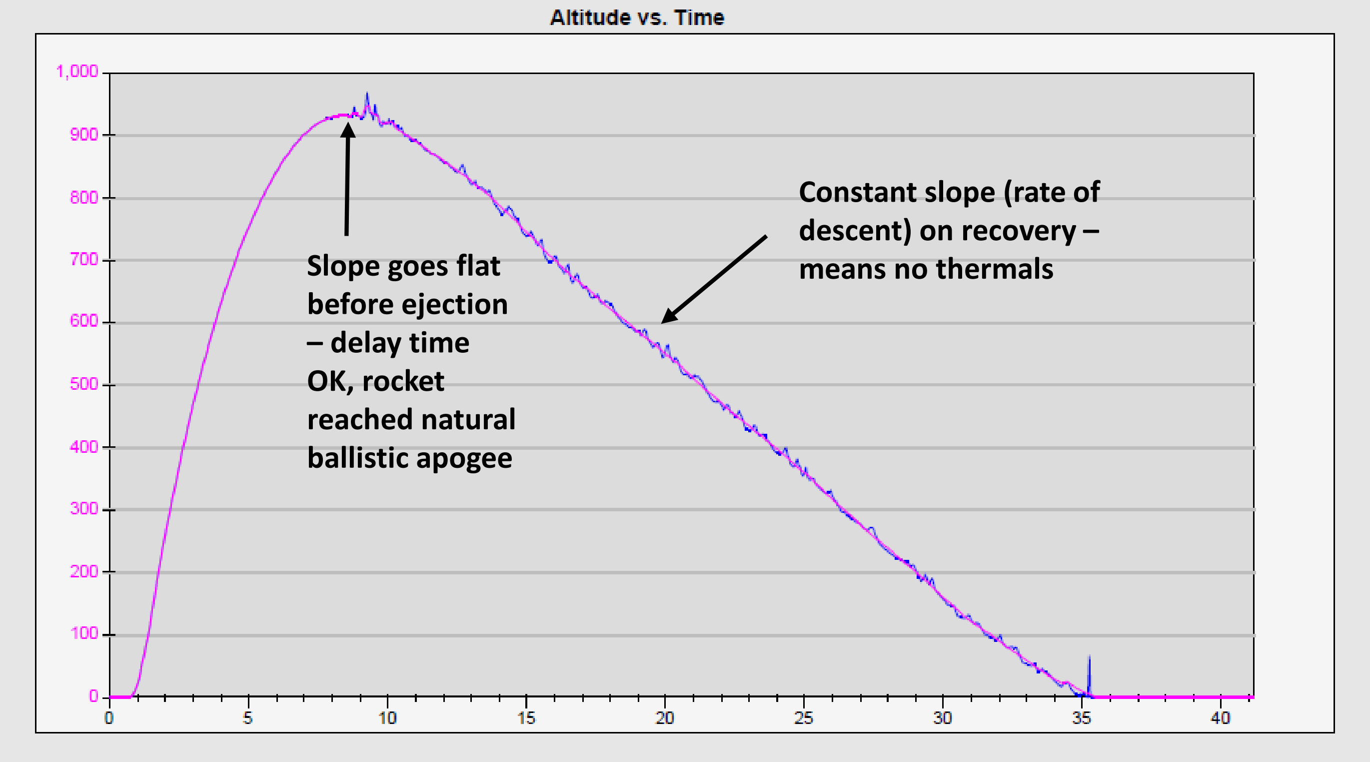
Total Impulse:	49.66 newton-seconds	(σ 0.49)
Peak Thrust:	59.47 newtons	(σ 5.29)
Burn Time:	1.33 seconds	(σ 0.05)
Average Thrust:	37.34 newtons	

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

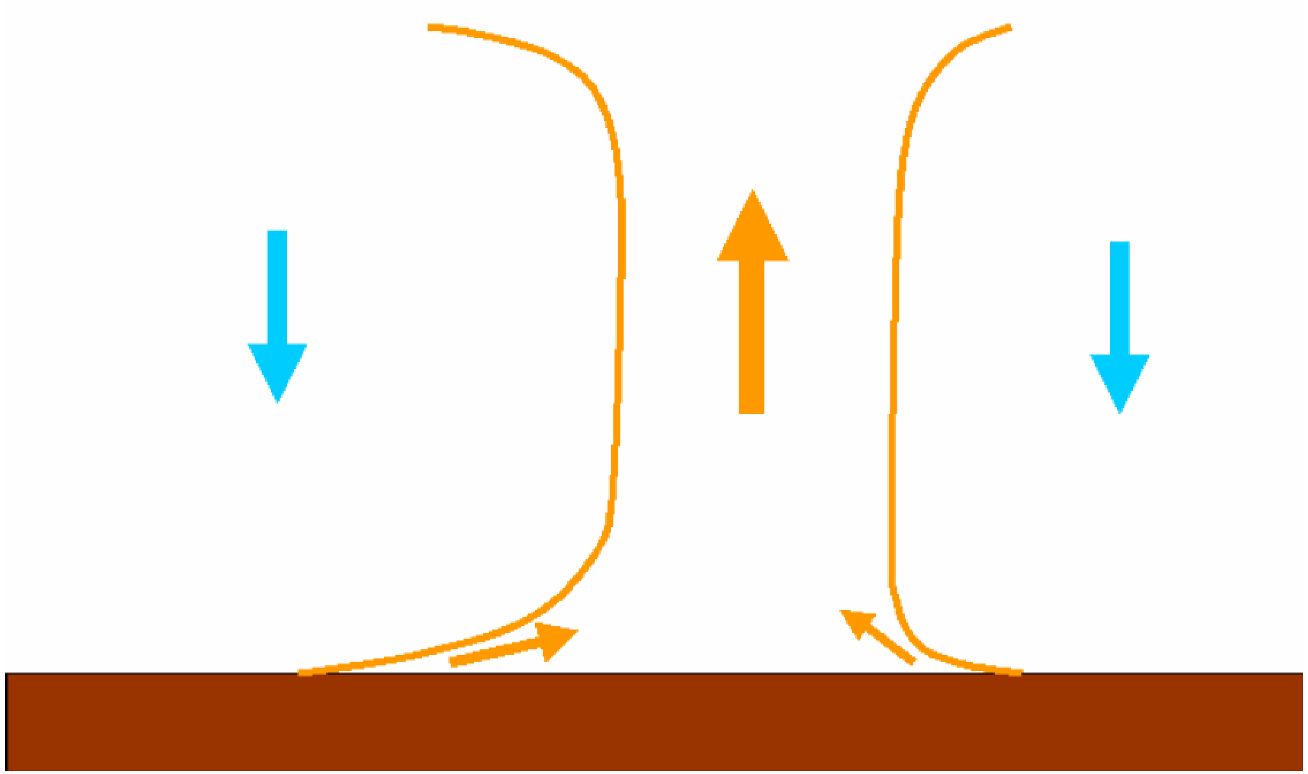
- Computer programs use average test data from NAR Standards and Testing for rocket motor performance.
- Key factors affecting altitude are total impulse (power) and delay time.
- Altitude is proportional to total impulse, and it can vary ~1% motor to motor for composite motors (more for black powder).
- 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 from a recording altimeter's data 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 score penalty from missing the altitude target.

Atmospheric Motion



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**

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 day, or at higher elevations, than it would on a cold 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 negligible
- Taking weather data when you fly is critical to making adjustments to hit the altitude target

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 amount 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!