Model Rocketry in Education

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A Brief History of Rockets

History of Rocketry

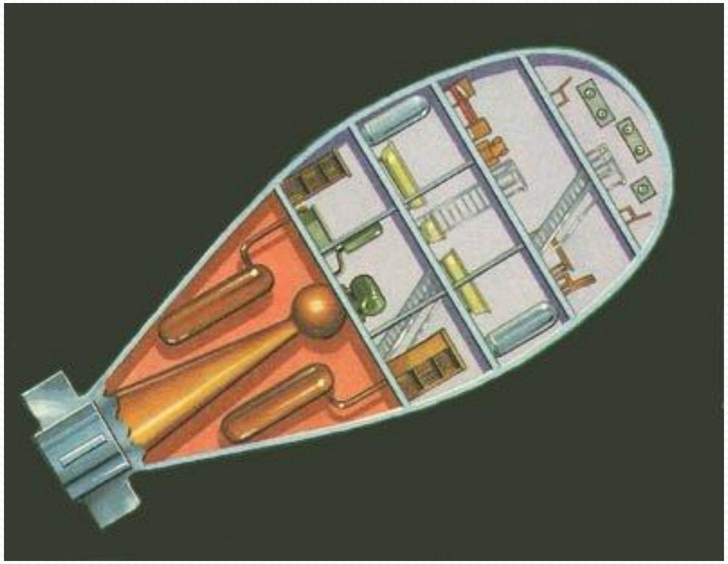
Historians believe that armies began hurling combustible weapons toward one another as early as 1,000 B.C.

By about 200 B.C. it is believed that the Chinese mastered the mixing and use of gunpowder. Known as black powder until the invention of guns, gunpowder would prove to be the primary ingredient of the first true ballistic rockets.

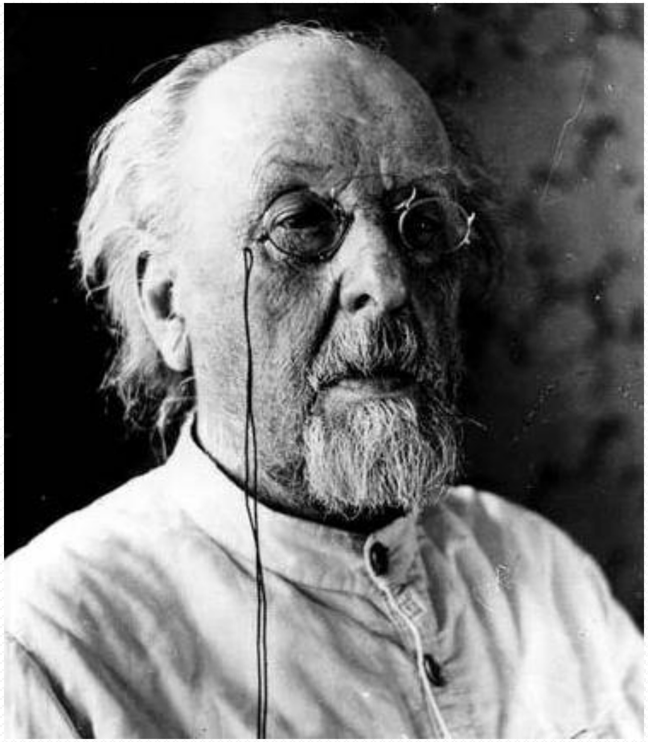
- 1,000 years later, during the War of 1812, rockets were more curiosities of war rather than a deadly weapon.

The **Congreve Rocket** was a British military weapon designe d and developed by Sir William Congreve in 1804.

- Three men are considered the early pioneers of rocketry during the early 1900’s: Konstantin Tsiokovsky (Russian), Robert H. Goddard (American) and Hermann Oberth (German)



Konstantin E. Tsiolkovsky

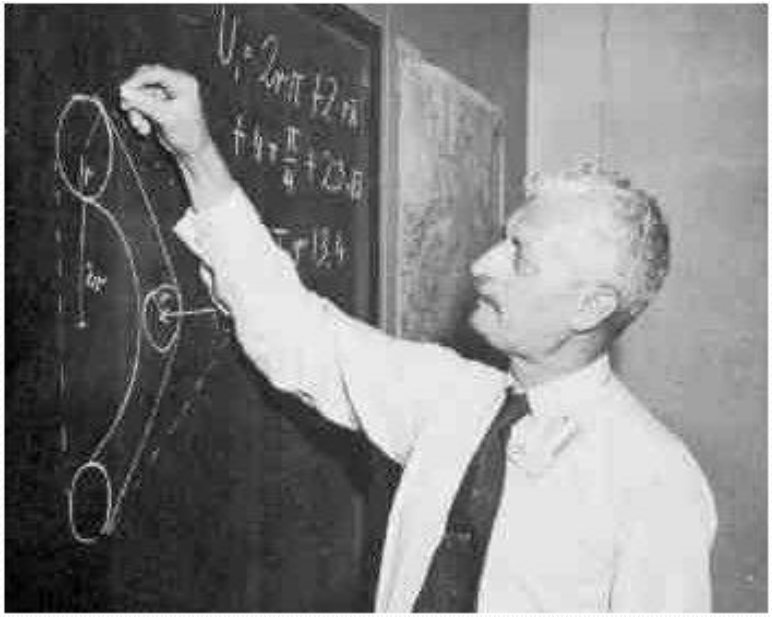


- Tsiokovsky was inspired by the writings of Jules Verne and became e theoretical engineer.
- He knew that thrust would work on a vacuum and that liquid propellant would work better than gunpowder.

Robert H. Goddard

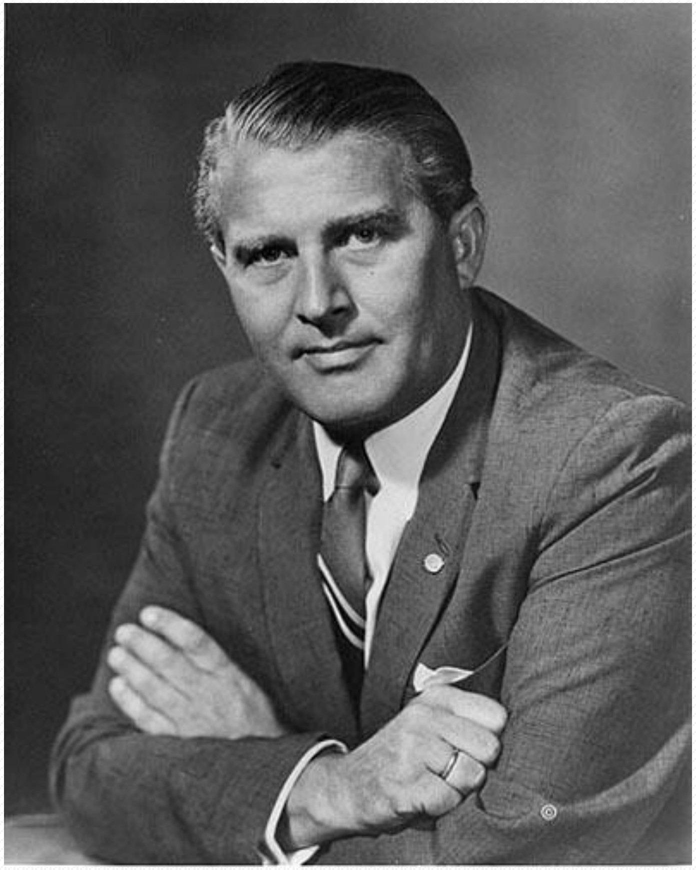
- On March 16, 1926 Goddard launched a 10-foot long rocket from a 7-foot long frame. The rocket reached a maximum altitude of 41 feet at an average velocity of 60 m.p.h. The rocket remained in the air for 2.5 seconds and flew a distance of 184 feet.
- This was the first successful launch of a liquid fueled rocket.

Hermann Oberth



- Oberth advanced the idea of using liquid propellants.
- Aided by a young and eager scientist named Wernher von Braun, Oberth was able to construct and static test a small rocket engine on July 23, 1930.

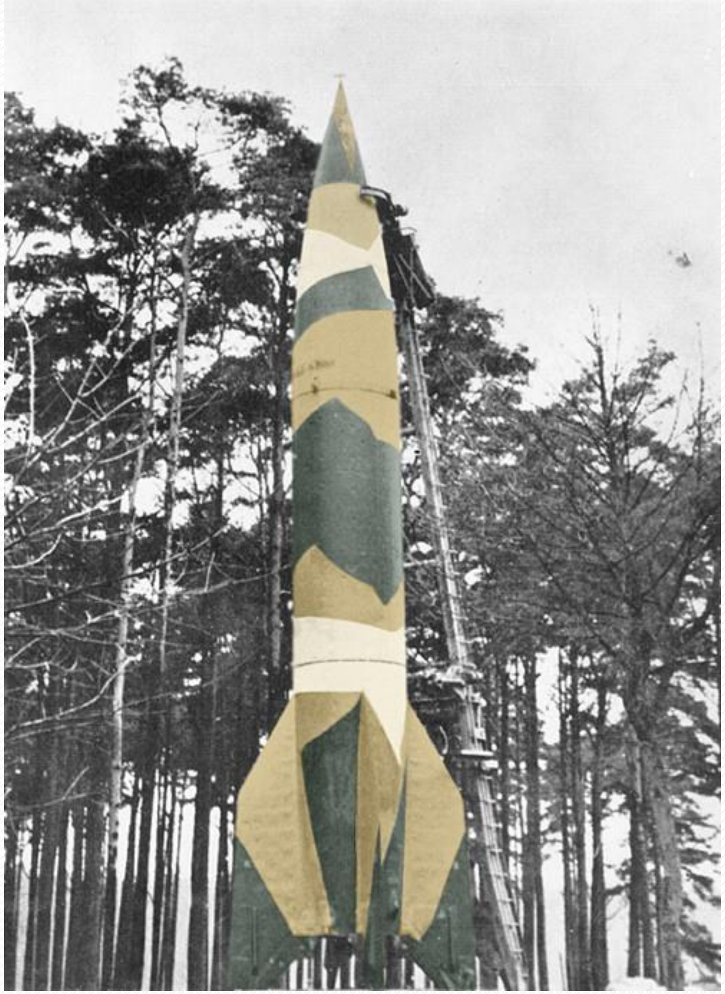
Wernher von Braun



- Werner von Braun (1912-1977) is credited as the inventor of the first successful long-range liquid propelled ballistic missile.

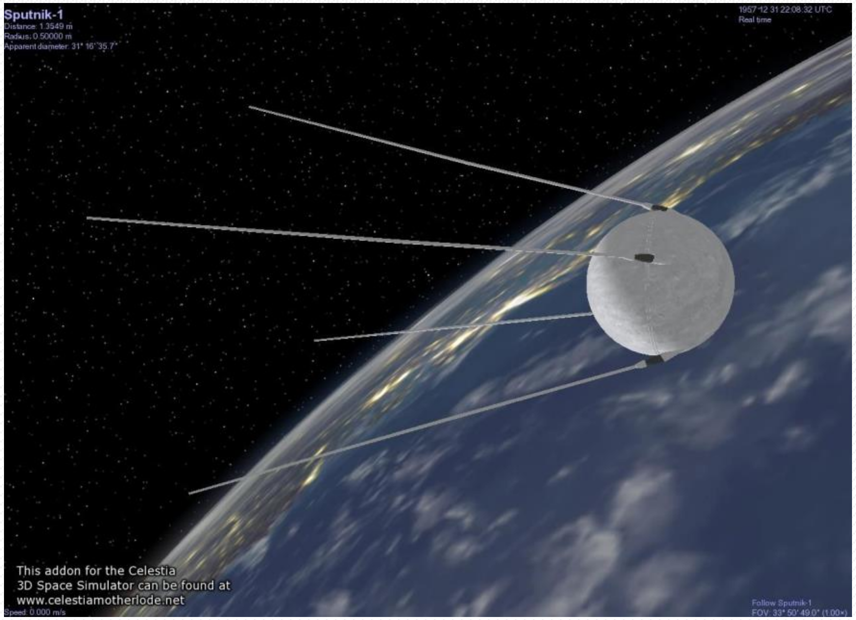
Vergeltungswaffe 2 (V2)

- Over 3,000 V-2s were launched as military rockets by the German Army against Allied targets in World War II.
- When Germany surrendered, von Braun came to the United States to continue his work on rocket development.



The Space Race

- The race to the Moon began on October 4, 1957 when the Soviet Union launched Sputnik I



Explorer 1

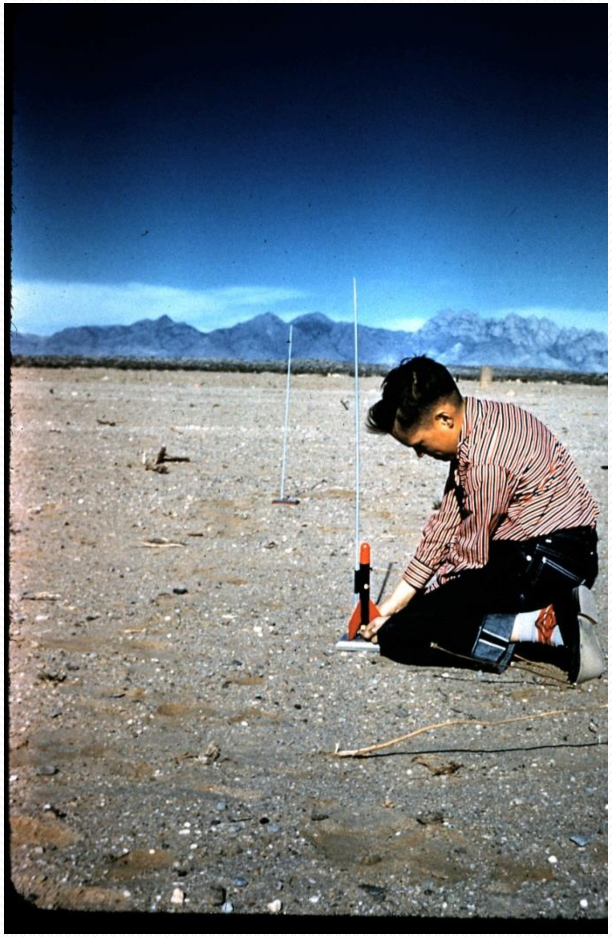
- The United States joined the Space Race when Explorer 1 was launched on February 1, 1958

Rocket Boys

- The beginning of the Space Race inspired many young Americans to build their own rockets, including Homer Hickam, who recorded his early attempts at rocketry in his book *The Rocket Boys*.
- All over the United States, young and old alike were inspired by the earliest space flight.

Rocket Boys

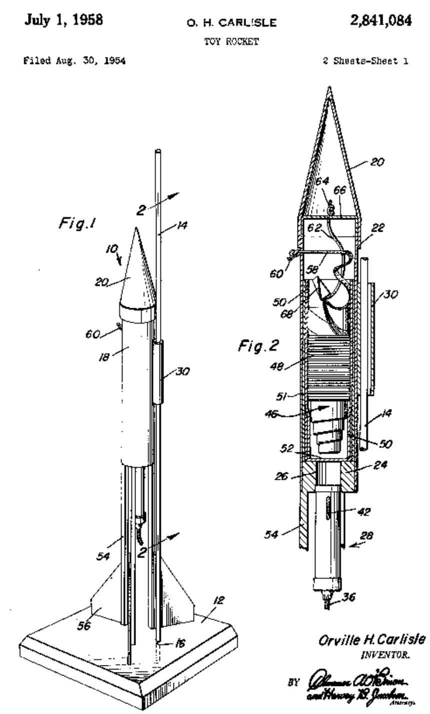
- They made their own propellant mixtures and dried them under the furnace in Homer’s home.
- In the early days of amateur rocketry, one out of seven non-professional rocketeers were killed or hurt while engaged in amateur rocketry.



Overview of Model Rocketry

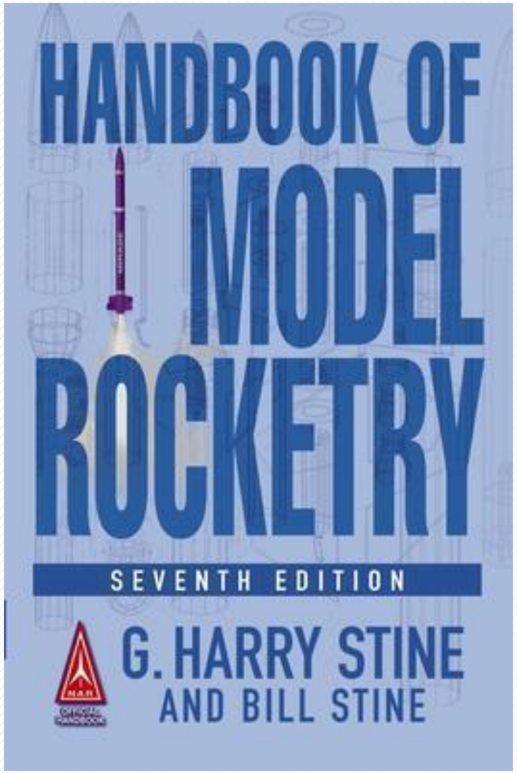
Birth of Model Rocketry

- Several events transformed amateur rocketry, a dangerous activity banned in most states, into the safer hobby of model rocketry.
- Orville H. Carlisle, an amateur pyro technician, and his brother Robert, a model airplane enthusiast, combined their skills to build the first model rockets in 1954.



Birth of Model Rocketry

- G. Harry Stine, a range safety officer at White Sands Missile Range used his missile range experience to write the *Handbook of Model Rocketry* to be used as a safety handbook.



Birth of Model Rocketry

- In 1957, the National Association of Rocketry (NAR) was founded to further promote the safety of model rocketry.
- It was established by Orville Carlisle and G. Harry Stine and is currently headed by Ted Cochran.

Model Rocket Safety Code

1. **Materials.** I will use only lightweight, non-metal parts for the nose, body, and fins of my rocket.
2. **Motors.** I will use only certified, commercially-made model rocket motors, and will not tamper with these motors or use them for any purposes except those recommended by the manufacturer.
3. **Ignition System.** I will launch my rockets with an electrical launch system and electrical motor igniters. My launch system will have a safety interlock in series with the launch switch, and will use a launch switch that returns to the "off" position when released.

Model Rocket Safety Code

4. **Misfires.** If my rocket does not launch when I press the button of my electrical launch system, I will remove the launcher's safety interlock or disconnect its battery, and will wait 60 seconds after the last launch attempt before allowing anyone to approach the rocket.

Model Rocket Safety Code

5. **Launch Safety.** I will use a countdown before launch, and will ensure that everyone is paying attention and is a safe distance of at least 15 feet away when I launch rockets with D motors or smaller, and 30 feet when I launch larger rockets. If I am uncertain about the safety or stability of an untested rocket, I will check the stability before flight and will fly it only after warning spectators and clearing them away to a safe distance. When conducting a simultaneous launch of more than ten rockets I will observe a safe distance of 1.5 times the maximum expected altitude of any launched rocket.

Model Rocket Safety Code

6. Launcher. I will launch my rocket from a launch rod, tower, or rail that is pointed to within 30 degrees of the vertical to ensure that the rocket flies nearly straight up, and I will use a blast deflector to prevent the motor's exhaust from hitting the ground. To prevent accidental eye injury, I will place launchers so that the end of the launch rod is above eye level or will cap the end of the rod when it is not in use.

7. Size. My model rocket will not weigh more than 1,500 grams (53 ounces) at liftoff and will not contain more than 125 grams (4.4 ounces) of propellant or 320 N-sec (71.9 pound-seconds) of total impulse.

Model Rocket Safety Code

8. **Flight Safety.** I will not launch my rocket at targets, into clouds, or near airplanes, and will not put any flammable or explosive payload in my rocket.

9. **Launch Site.** I will launch my rocket outdoors, in an open area at least as large as shown in the accompanying table, and in safe weather conditions with wind speeds no greater than 20 miles per hour. I will ensure that there is no dry grass close to the launch pad, and that the launch site does not present risk of grass fires.

10. **Recovery System.** I will use a recovery system such as a streamer or parachute in my rocket so that it returns safely and undamaged and can be flown again, and I will use only flame-resistant or fireproof recovery system wadding in my rocket.

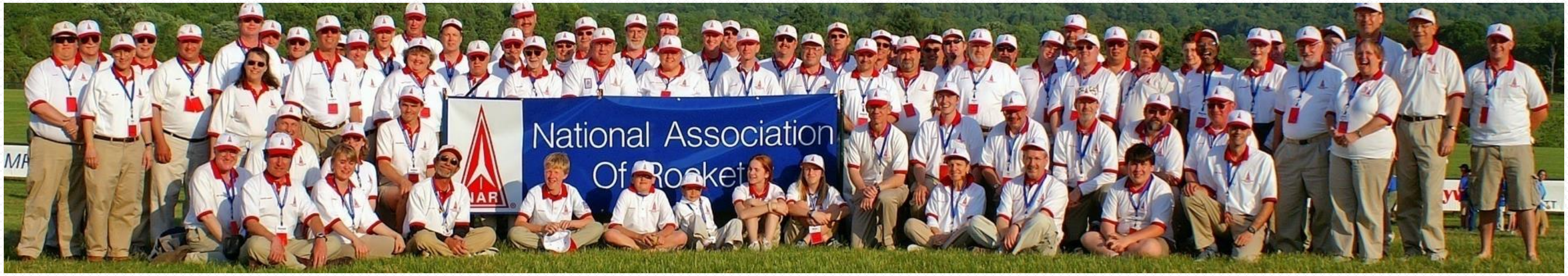
Model Rocket Safety Code

10. Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places.

Installed Total Impulse (N-sec)	Equivalent Motor Type	Minimum Site Dimensions (ft.)
0.00--1.25	1/4A, 1/2A	50
1.26--2.50	A	100
2.51--5.00	B	200
5.01--10.00	C	400
10.01--20.00	D	500
20.01--40.00	E	1,000
40.01--80.00	F	1,000
80.01--160.00	G	1,000
160.01--320.00	Two Gs	1,500

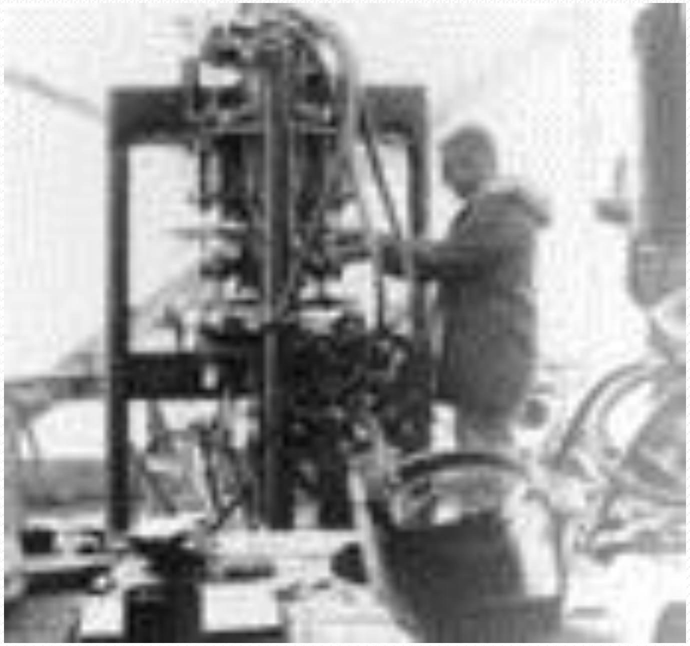
National Association of Rocketry

- The oldest and largest national non-profit consumer organization for rocket fliers
  - 5835 members and 120 clubs, providing services to tens of thousands of non-member youth fliers
- Writes the hobby's Safety Codes and does the national safety certification testing on rocket engines
- Represents the hobby's interests to national agencies and organizations such as FAA and NFPA



Birth of Model Rocketry

- In May of 1958, G. Harry Stine was looking for a reliable supplier for his fledging model rocket company called Model Missiles. He contacted Verne Estes and ordered the manufacture of 5,000 rocket motors a day.
- Estes went to work to create such a machine and the end result was christened Mabel.



Birth of Model Rocketry

- When Stine cut back the order, Verne and his wife Gleda decided to create their own model rocket company and named it Estes Industries.
- By 2003, nearly 600 million model rockets had been flown safely and successfully in the United States alone. The hobby is far safer than swimming, boating, baseball, football, and cycling (Stine, 2004).

A Scientific Age Hobby

NAR®

Applications in Science and Math

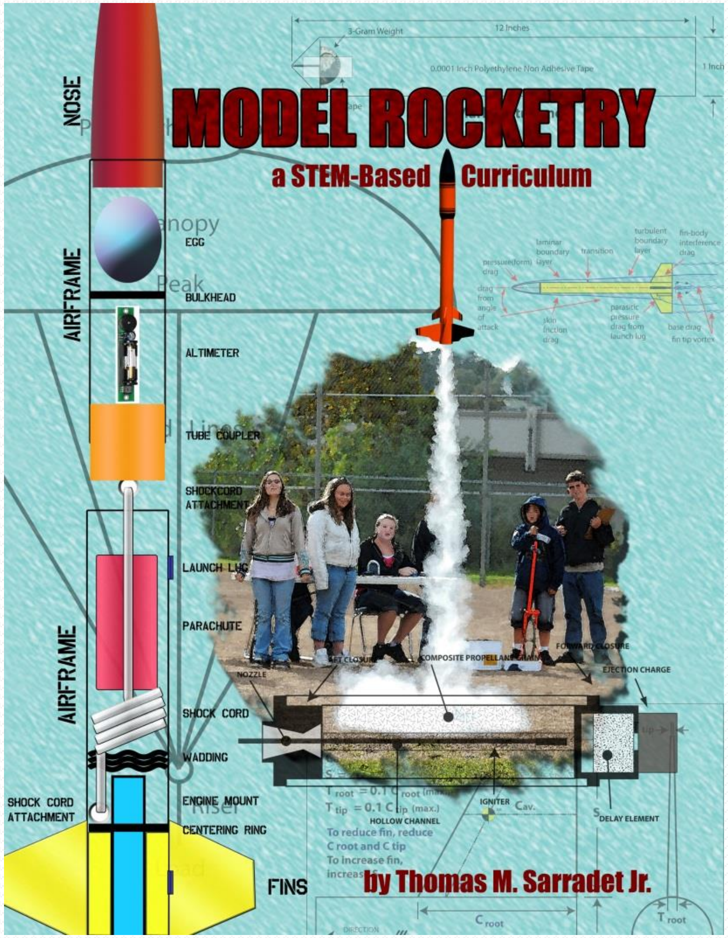
- From its earliest beginnings, model rocketry was recognized as a powerful learning tool for the hands-on teaching of math and science.
- Estes began publishing *Model Rocketry News* in 1961.
- The company also published technical reports and notes. The technical notes covered topics such as rocket stability, altitude tracking, and building a wind tunnel.
- TN-5 is a collection of articles written by Robert L. Cannon that originally appeared in *Model Rocket News* from 1969 to 1970.

Rocketry Library

- ***Handbook of Model Rocketry*** by G. Harry Stine
- ***Model Rocket Design & Construction*** by Tim van Milligan (Apogee Rockets)
- ***Topics in Advanced Model Rocketry*** by Mandell, Caporaso, and Bengen

STEM-Based Curriculum

- The Team America Rocketry Challenge was analyzed and 28 skill sets were identified.
- Lessons were developed to meet these skills
- The skills and lessons were matched up to STEM standards



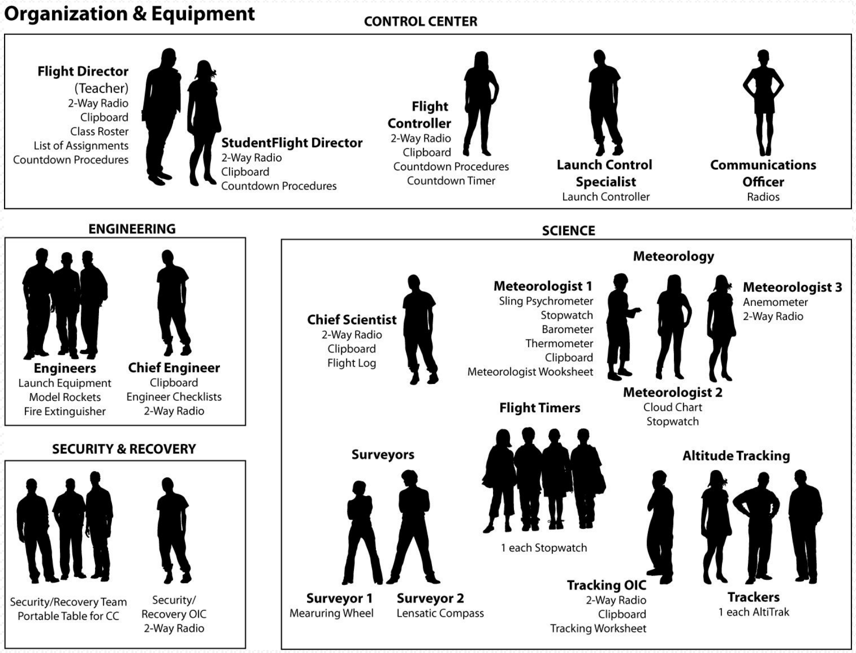
Curriculum Uses

- An elective class.
- Part of a math/science class
- A model rocketry club
- A summer camp

Class Phases

- Lecture and Demonstration
- Design & Engineering
- Construction
- Investigation and Discovery

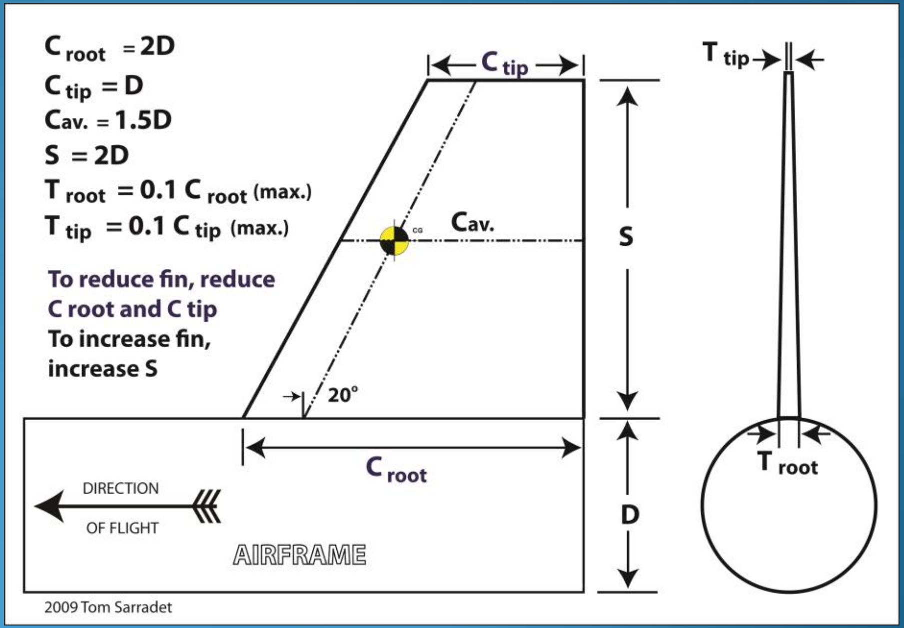
All Hands on Deck!



- All students are involved in the launch:
  - Control Center
  - Engineers
  - Science
    - Data Collection
    - Meteorology

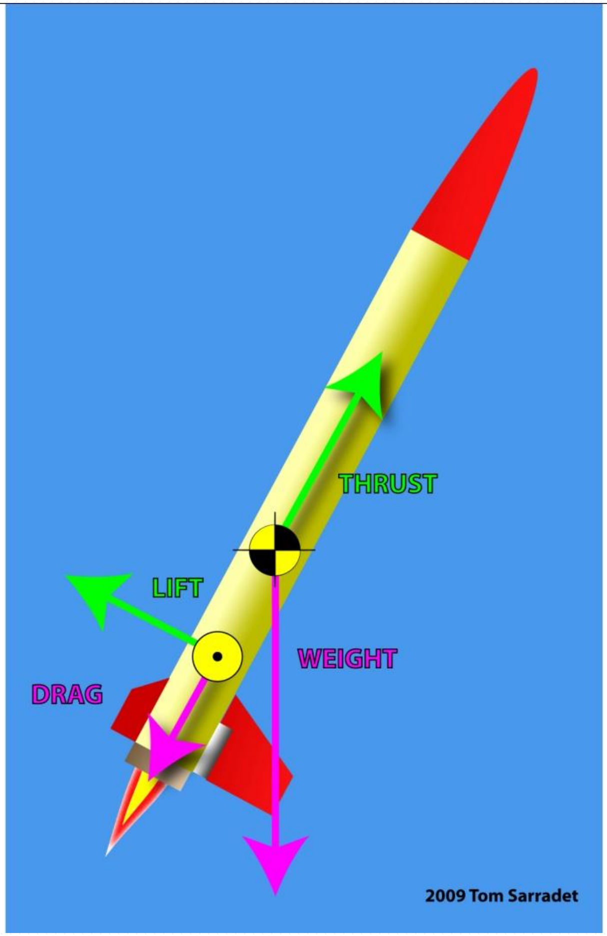
Lecture & Demonstration

Class Phase 1



Lecture and Demonstration

- PowerPoint presentations on:
  - The Model Rocket
  - Newton's Laws of Motion
  - Aerodynamics
  - Rocket Stability



Lecture and Demonstration

- Demonstrative flights using teacher-built models that reinforce the lecture material.
- Demonstrations can also be conducted on Rocksim.

Design & Engineering

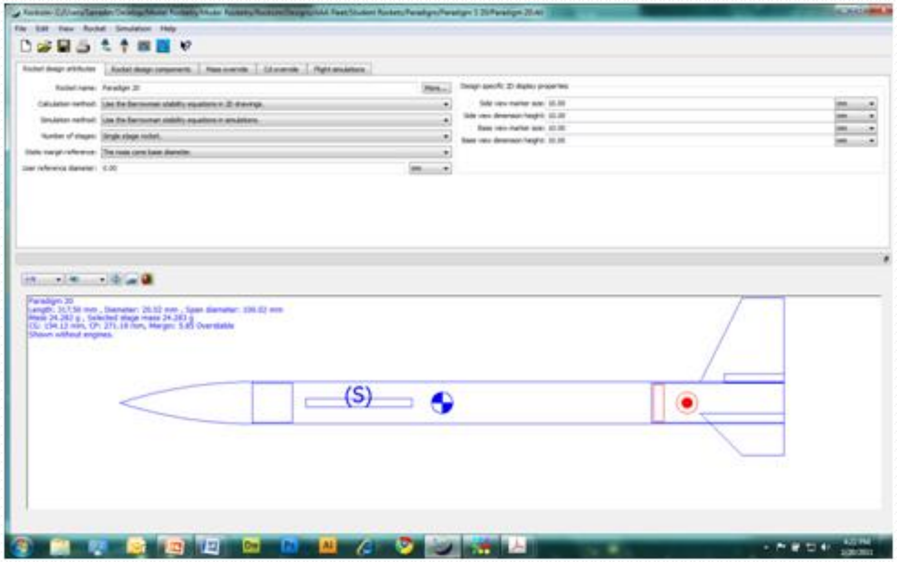
Class Phase 2

Design & Engineering

- Students design model rockets using computer software.

Design & Engineering

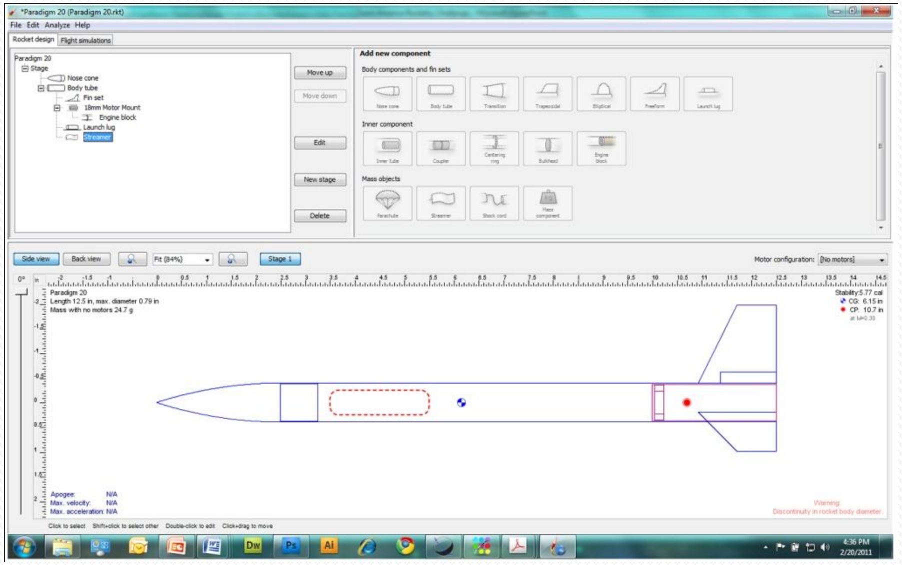
- **Rocksim**
  - Most used program
  - Has an animated flight profile
  - Educational pricing available for multiple copies.



http://www.apogeerockets.com/

Design & Engineering

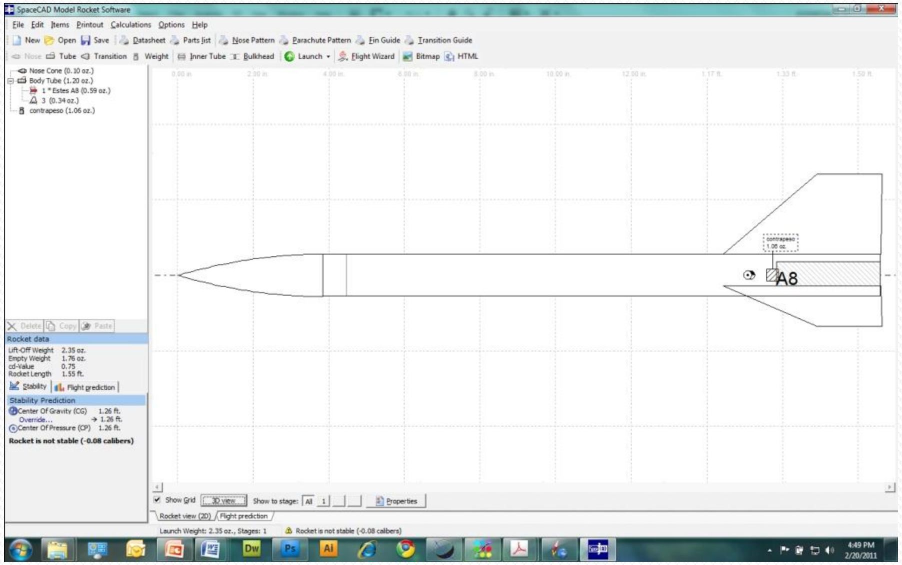
- **Open Rocket**
  - Free
  - No animation
  - Can import Rocksim files



http://openrocket.sourceforge.net/

Design & Engineering

- **Space CAD**
  - No flight animation
  - Expensive but offers TARC discount



Model Rocket Construction

NAR®

Construction

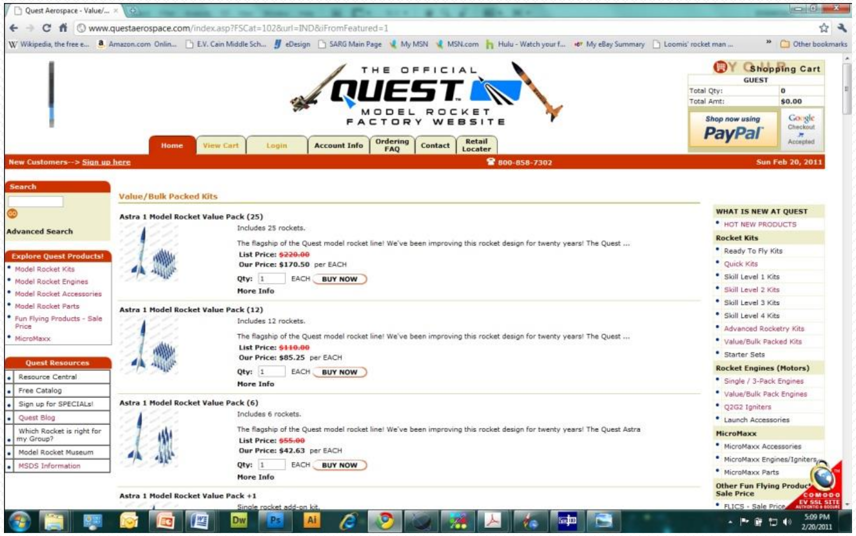
- Students build the model rockets that they will use during the investigation and discovery phase.

Model Rocket Selection

Class Phase 3

Selecting a Model Rocket

- Value packs are available for groups of 6 – 25 students.
- Several online vendors offer value packs.

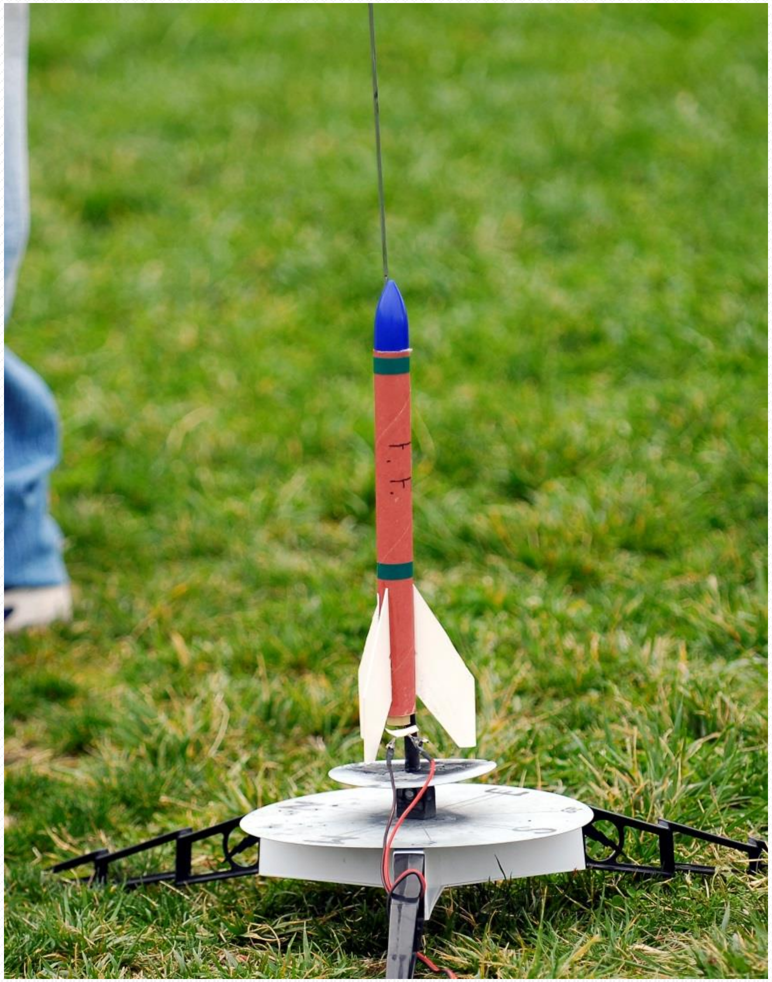


Pitsco Value Pack

- Motors and building supplies for 50 rockets
- Current Price $215
- http://www.pitsco.com/Aerospace/Rockets/Solid_Fuel/Economy_Rocket_Packs

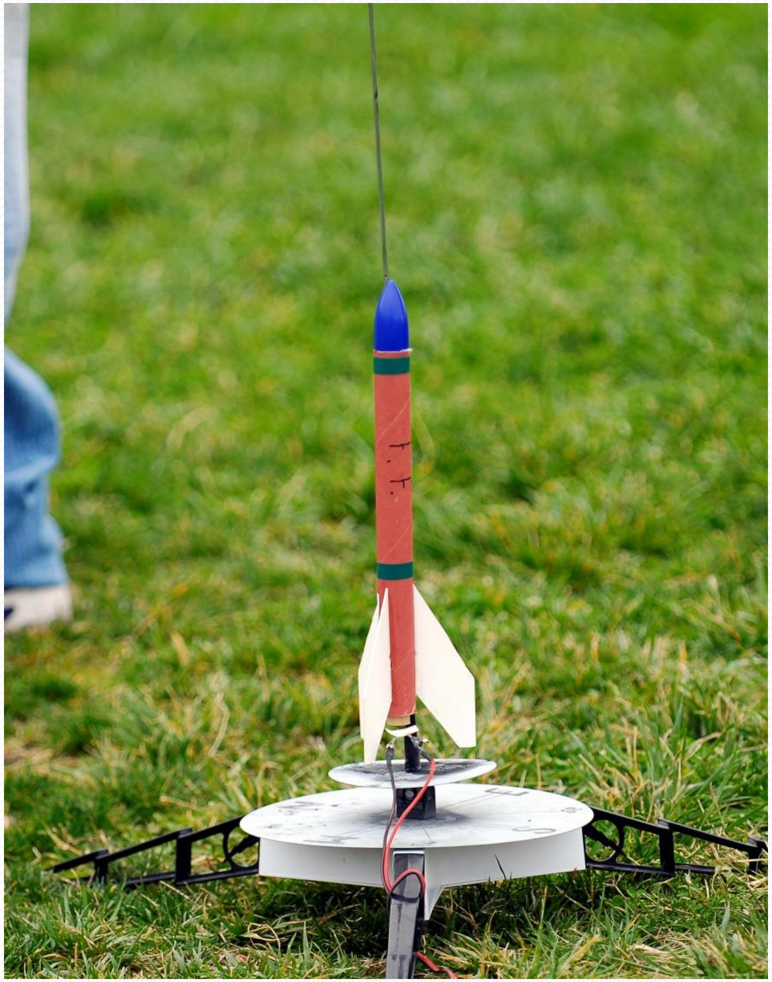
Pitsco Value Pack

- Pros
  - Slow, easy to see flights
  - Most affordable option among kits
  - Compressed cardboard fins cut with scissors
  - Easy to repair on launch site.



Pitsco Value Pack

- Cons
  - Gummed paper airframe construction difficult for some students.
  - Unusual diameter (1”)
  - Not very durable

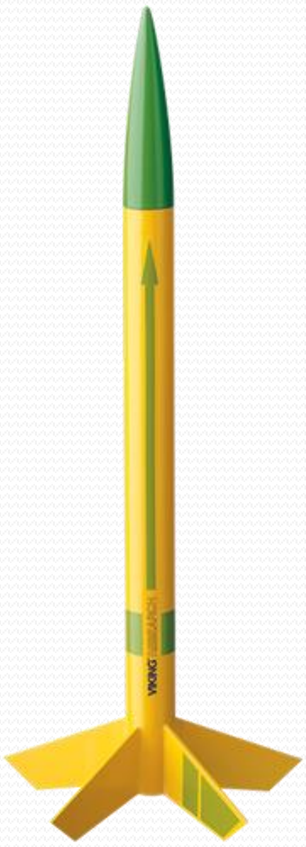


Estes Viking Bulk Pack

12 pack - $40 @ AC Supply Company

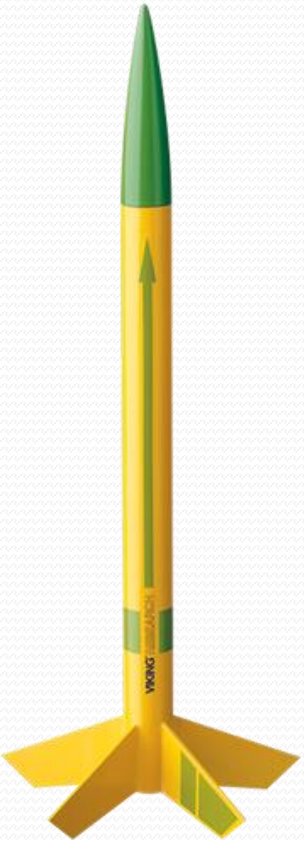
A8-3 x 24 bulk pack - $43.19

http://www.acsupplyco.com/estes/bulk.htm



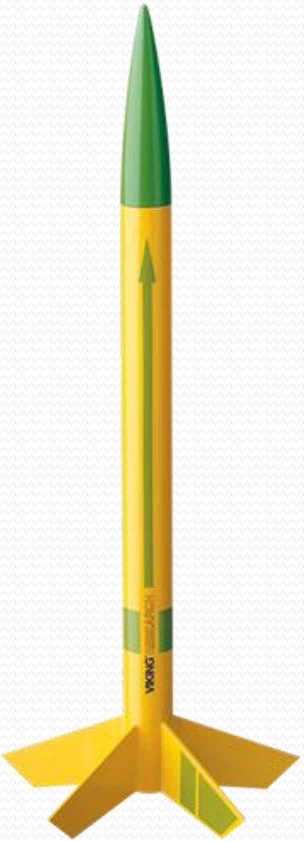
Estes Viking Bulk Pack

- Pros
  - Pre-cut compressed cardboard fins can be arraigned in 48 different configurations.
  - Easy to build
  - Uses streamer



Estes Viking Bulk Pack

- Cons
  - Small and fast rocket is hard to track.
  - Easily lost
  - Fins not durable



Quest Starhawk

- 12 pack - $60
- 25 pack - $147.25

- No Engines included

Quest Starhawk

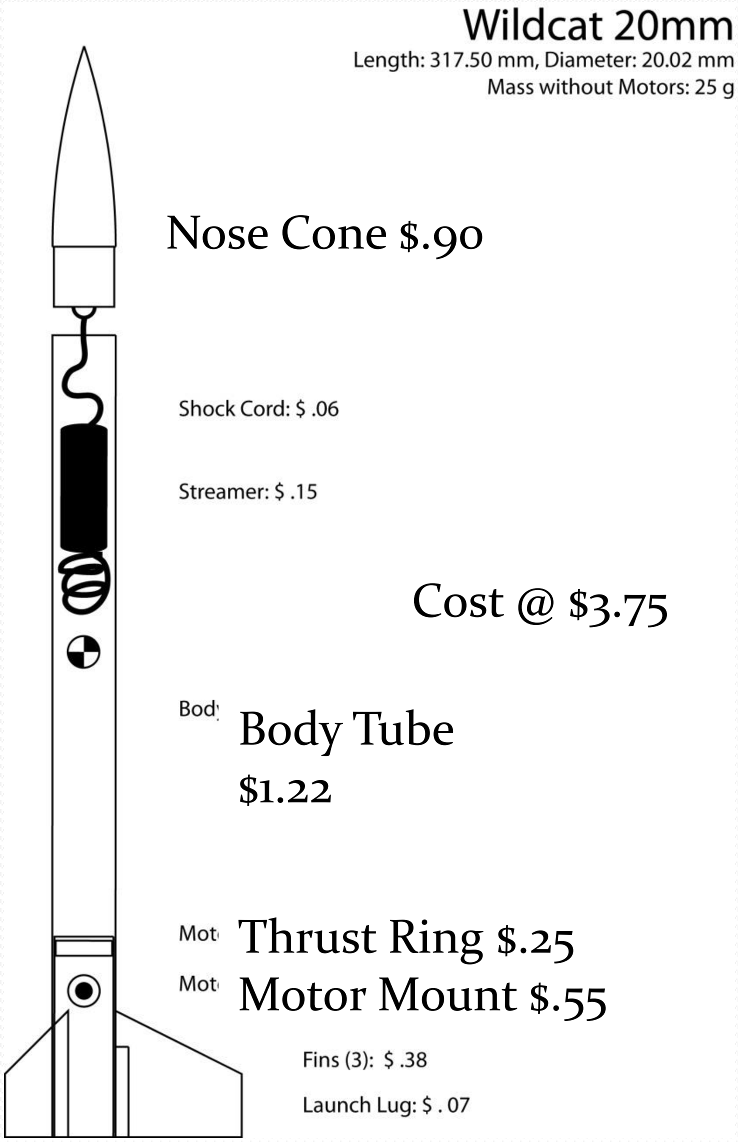
- Pros
  - Easy and quick to build
  - Fin can give consistent flight
  - 18mm motor mount fits inside 20mm airframe without centering rings

Quest Starhawk

- Cons
  - Expensive for large groups

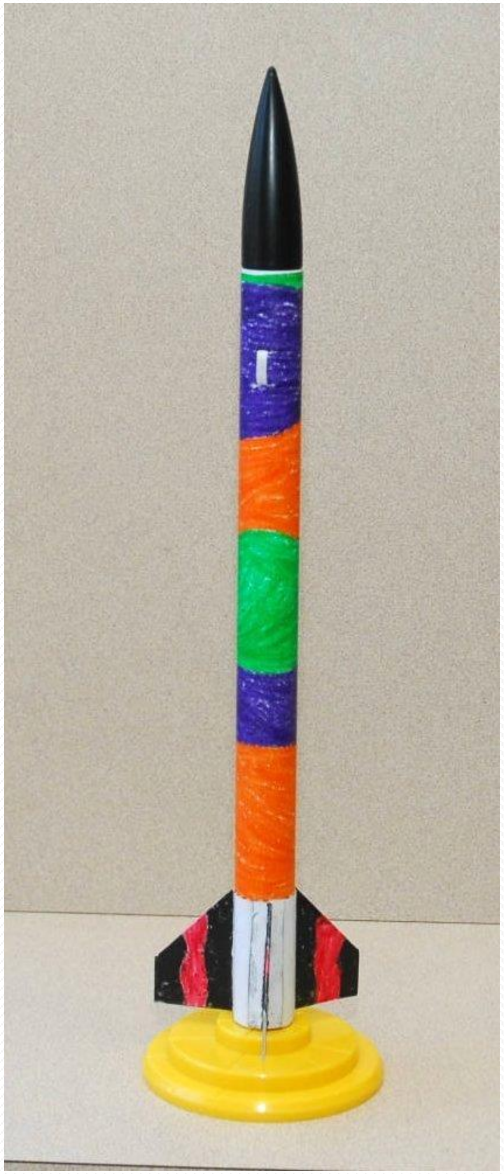
Scratch Built Kit

- 20 mm nosecone airframe and motor block from Quest
- Bulk shock cord, fin material, and launch lug from Pitsco
- 18mm motor mount from Uncle Mike's Rocket Shack.
- Fins made from compressed cardboard or card stock
- Streamer is crepe paper from Dollar Tree.



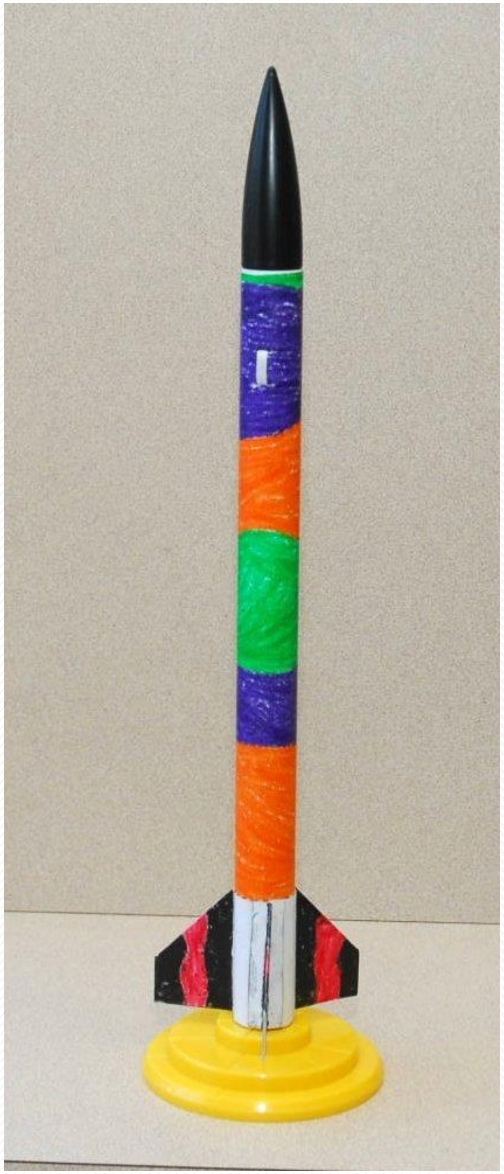
Scratch Built Kit

- Pros
  - Easy to build.
  - Fins can be cut with scissors
  - Takes 1-3 days to build
  - Affordable alternative for large groups



Scratch Built Kit

- Cons
  - More preparation time for teacher
  - Limited number of flights



Water Rockets

- Water rockets can fly in excess of 300 feet
- Recovery systems can be used
- Less expensive that solid propellant rockets
- Require hot glue guns and a launcher for water rockets

Air Rockets

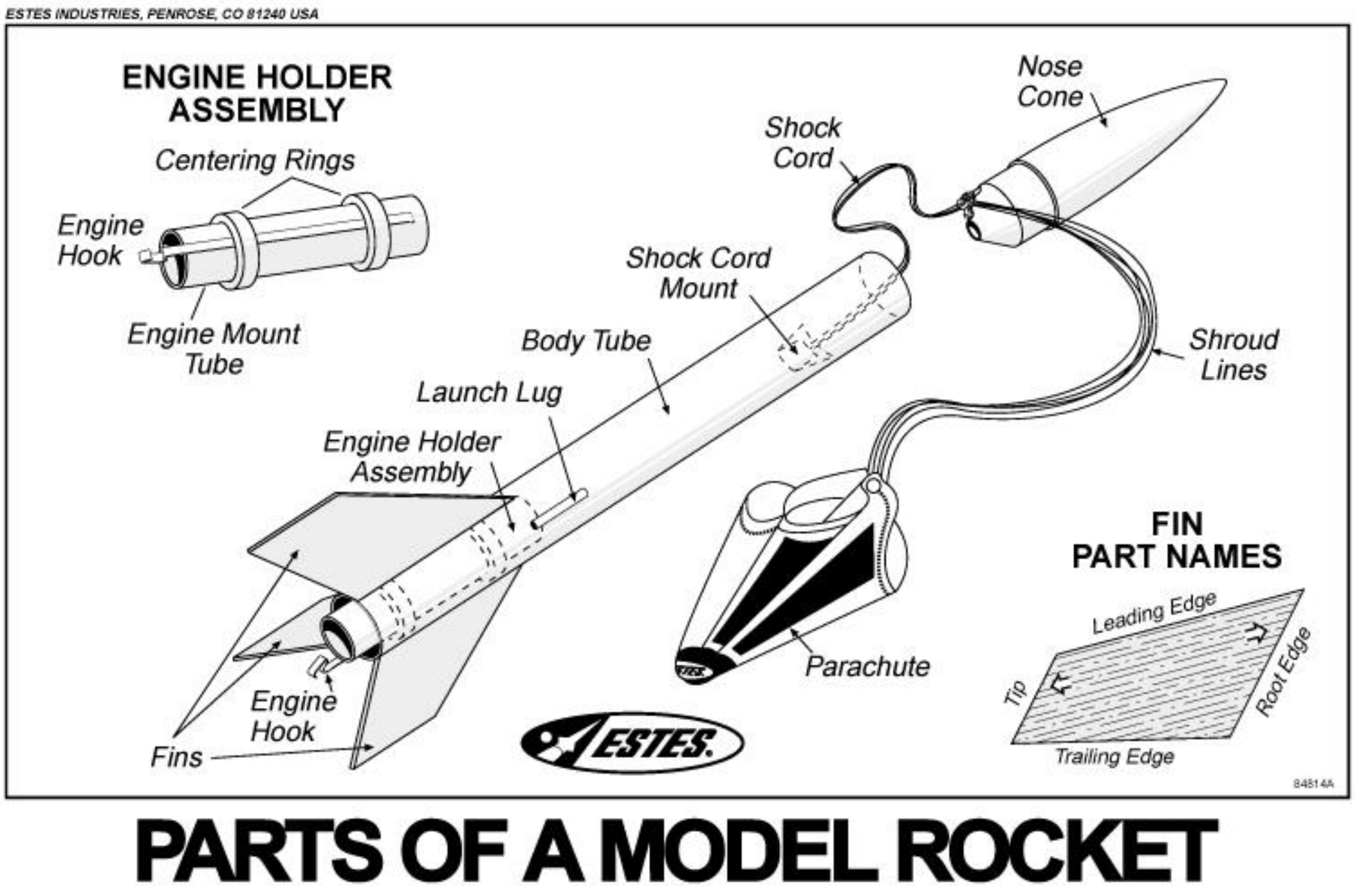
- Least expensive
- Built with glue sticks and scissors
- Very portable
- Design similar to solid propellant rockets
- Possible to install recovery system

10 MINUTE BREAK

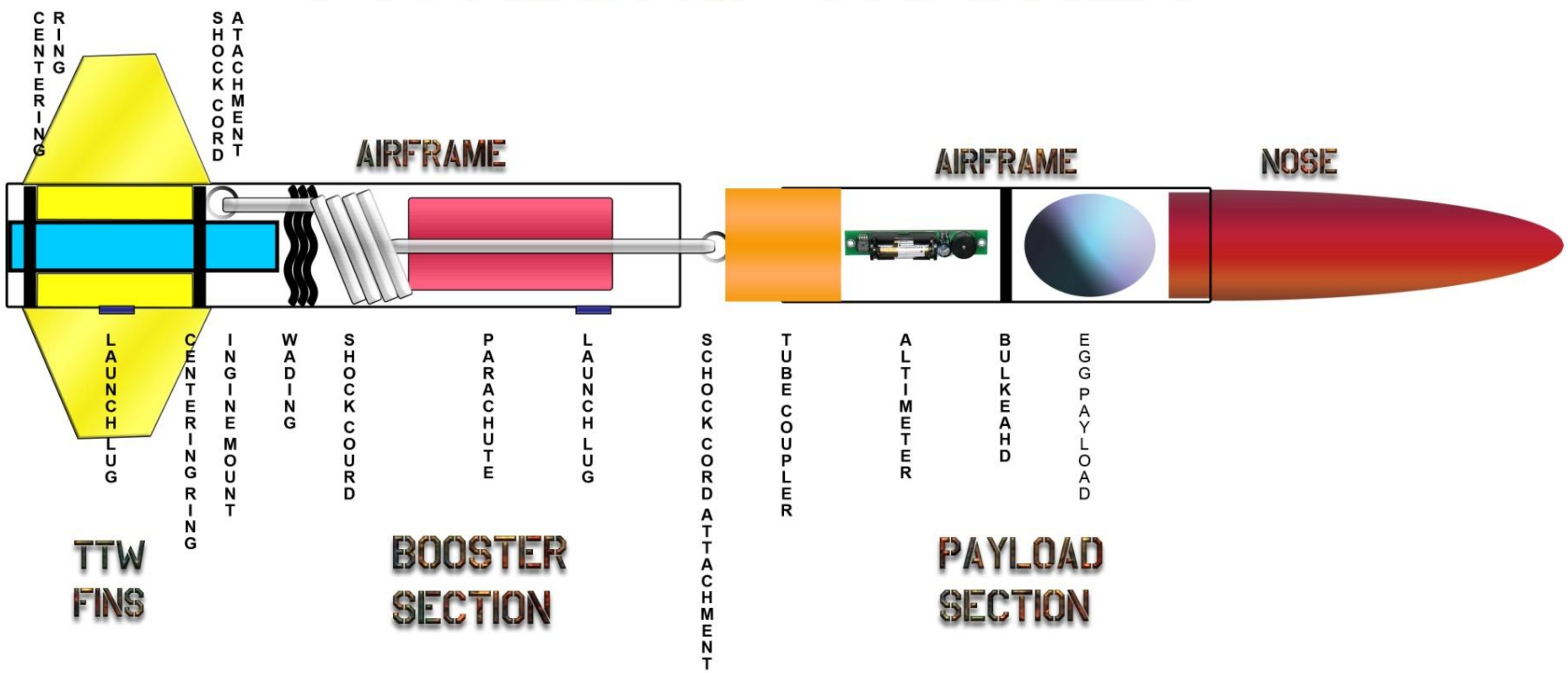
The Model Rocket

Model Rocket Construction

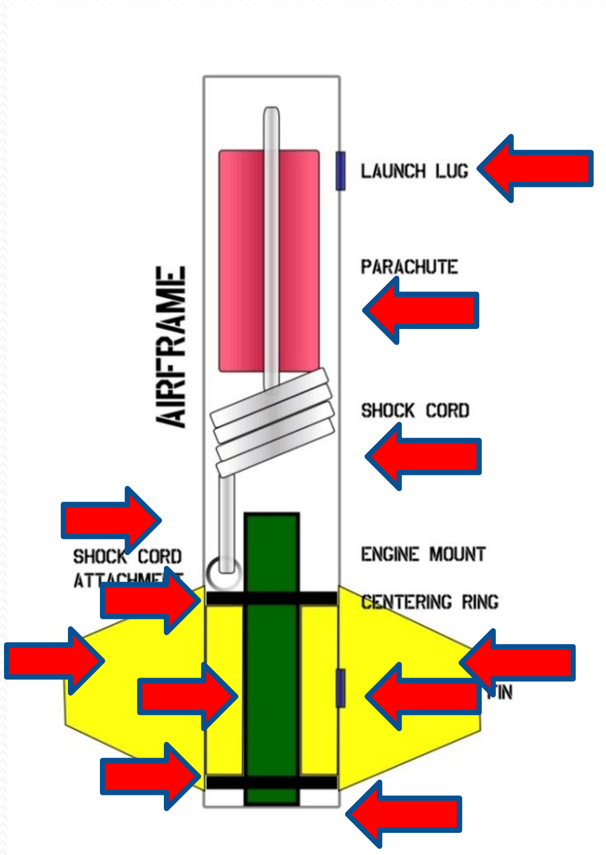
Sport Rocket



PAYLOAD ROCKET

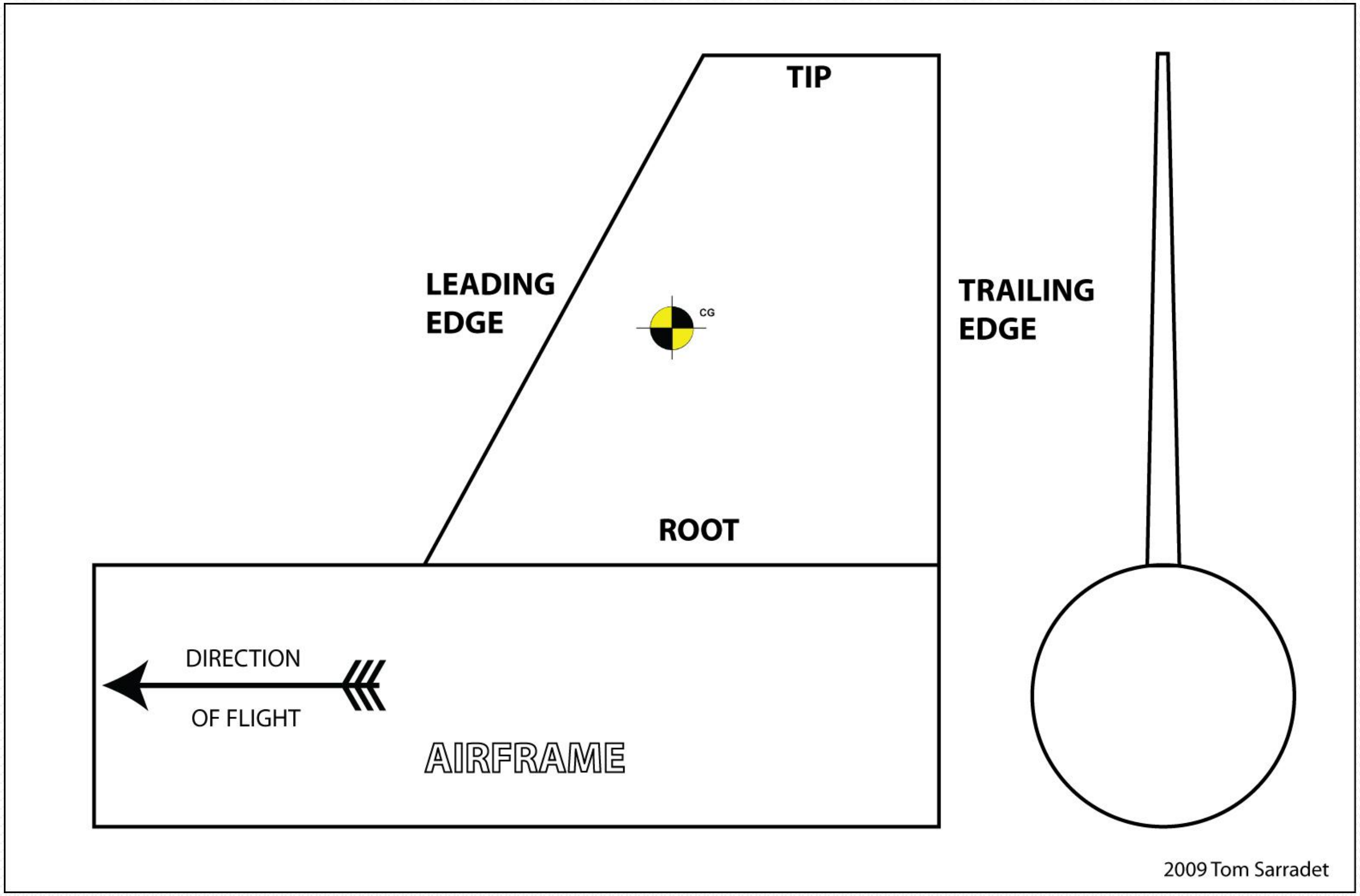


Booster Section



- **Launch Lug** – helps to guide the rocket upward until it reaches enough velocity for the fins to engage.
- **Parachute** – assists in the safe recovery of the rocket.
- **Shock Cord** – connects the parachute and nosecone to the booster. It absorbs the shock of ejection charge.
- **Shock Cord Attachment** – attaches the shock cord to the booster section.
- **Centering Rings** – attach the engine mount (and sometimes the fins) to the airframe.
- **Engine Mount** – holds the rocket engine inside the rocket.
- **Engine Retainer** – prevents the engine from being ejected by the ejection charge.
- **Fins** – guides the rocket in a straight path.

The Fin

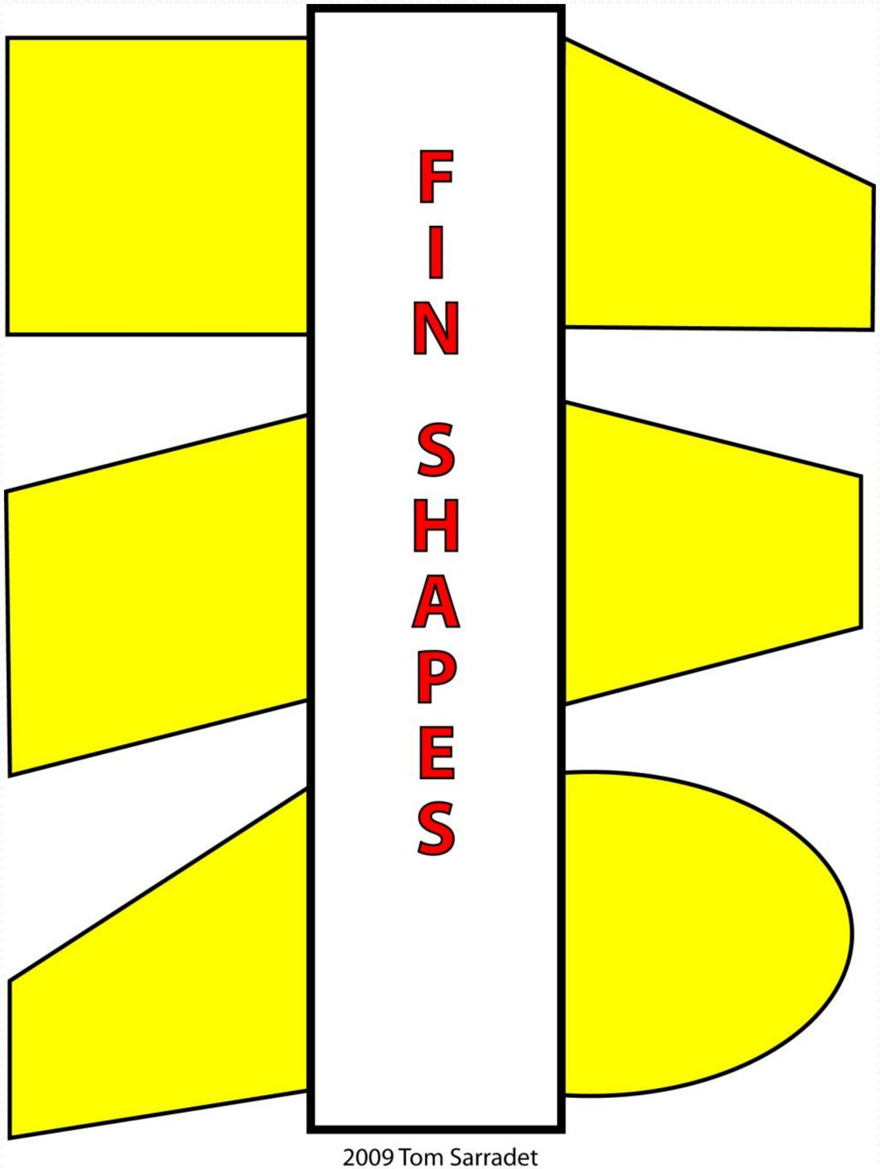


TIP
LEADING
EDGE
CG
TRAILING
EDGE
ROOT
DIRECTION
OF FLIGHT
AIRFRAME
2009 Tom Sarradet

RECTANGULAR
Simple to make, least aerodynamic

SWEPT
Simple to make, slightly better aerodynamics

TAPERED SWEPT
Moves Center of Pressure back, good design for fast moving rockets.

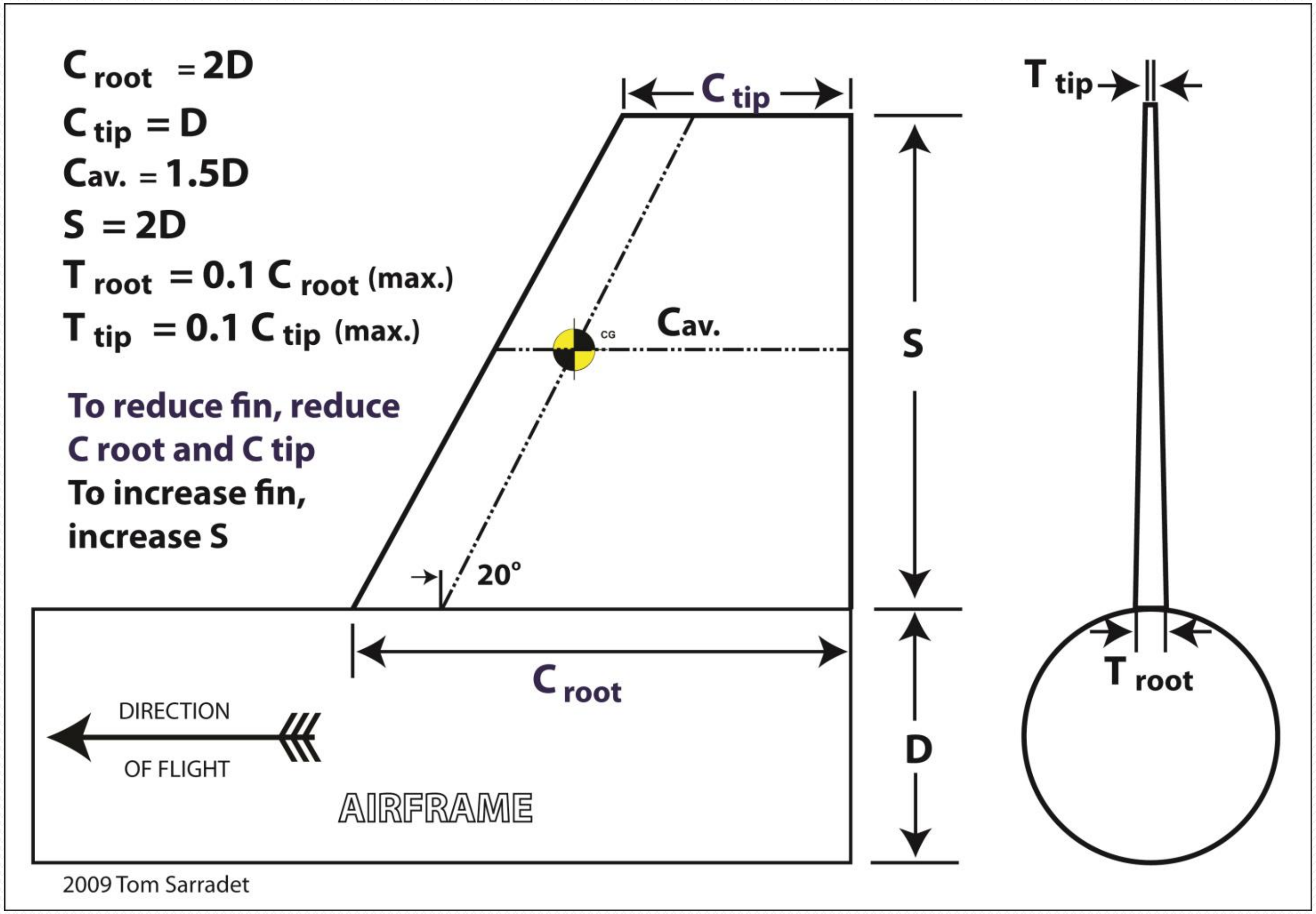


CLIPPED DELTA
Good aerodynamic fin, used on low-drag, high-performance rockets

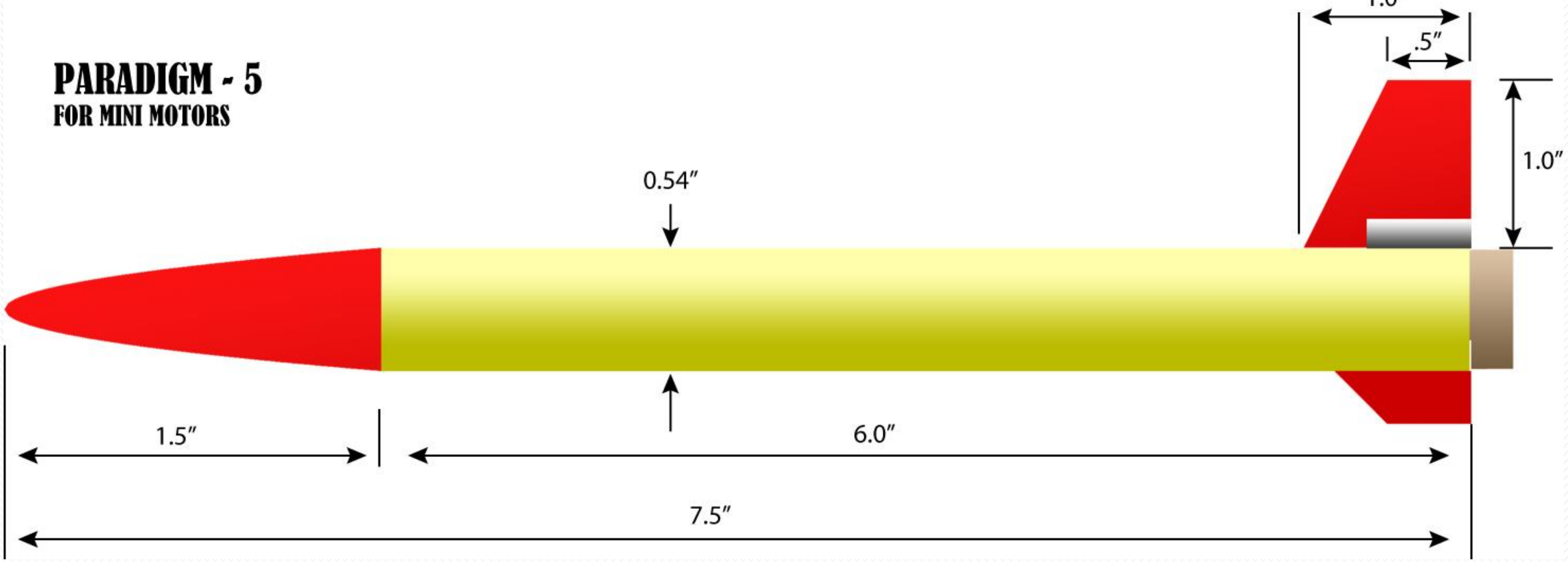
TRAPEZOIDAL
Good aerodynamic fin for payload rockets, moves the Center of Pressure forward.

ELLIPTICAL
Best aerodynamic fin, difficult to construct.

The Fin: Low Drag Design

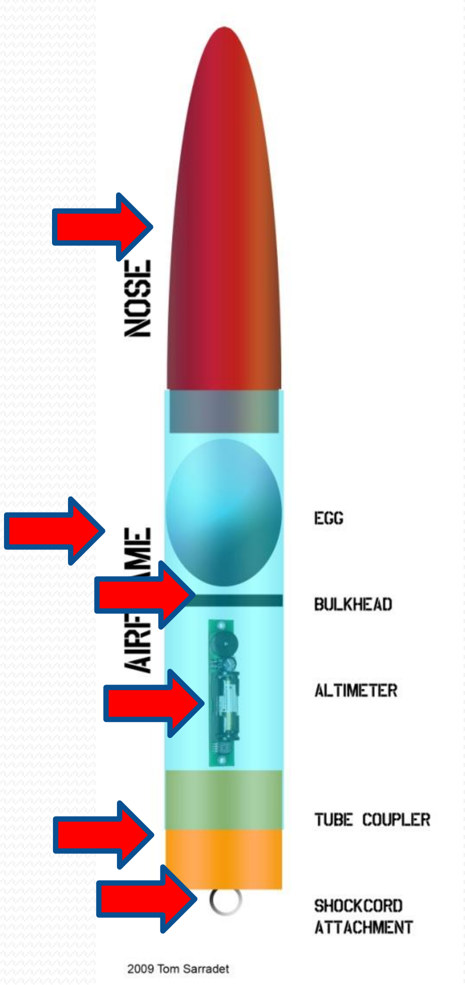


Low Drag, High Performance Rocket



The Paradigm–5 is an example of a **low-drag**, **high performance** model rocket design that uses a low-drag clipped delta fin.

Payload Section

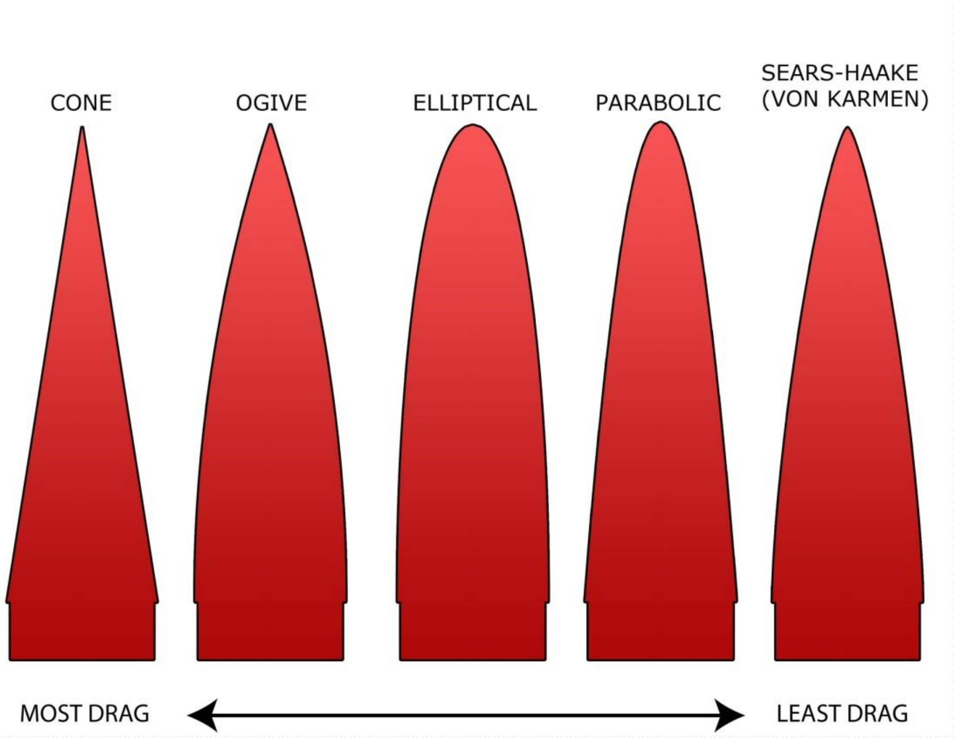


- **Nose** – creates an aerodynamic shape. May also hold a payload.
- **Airframe** – holds the payloads in place.
- **Bulkhead** – separates the egg section from the electronics section, preventing vortex effect and causing a false altimeter reading.
- **Altimeter** – measures the changing air pressure to calculate apogee. Must have vent holes in airframe in order to operate properly.
- **Tube Coupler** – connects the payload section to the booster section by means of the shock cord. Also protects the payload from the ejection gases.
- **Shock Cord Attachment** – a metal eye for the secure attachment of the shock cord.

The Egg

- Eggs have an '**arch structure**' at each end that transfers pressure to the sides.
- About **35 Newtons** of force is required to break an egg on its end and about **25N** to break it on its side.

Nose Shape



- Rocket noses are **balsa, plastic, or fiberglass**.
- For aircraft and rockets, below Mach .8, the nose pressure drag is essentially zero for all shapes and the major significant factor is friction drag.
- Having a smooth finish on the nose is more important than nose shape for rockets flying under the speed of sound.

Rocket Motors

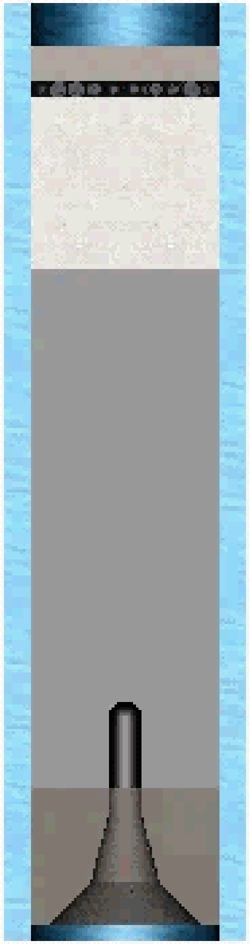
Model Rocket Construction

Rocket Motors

Engine or Motor?

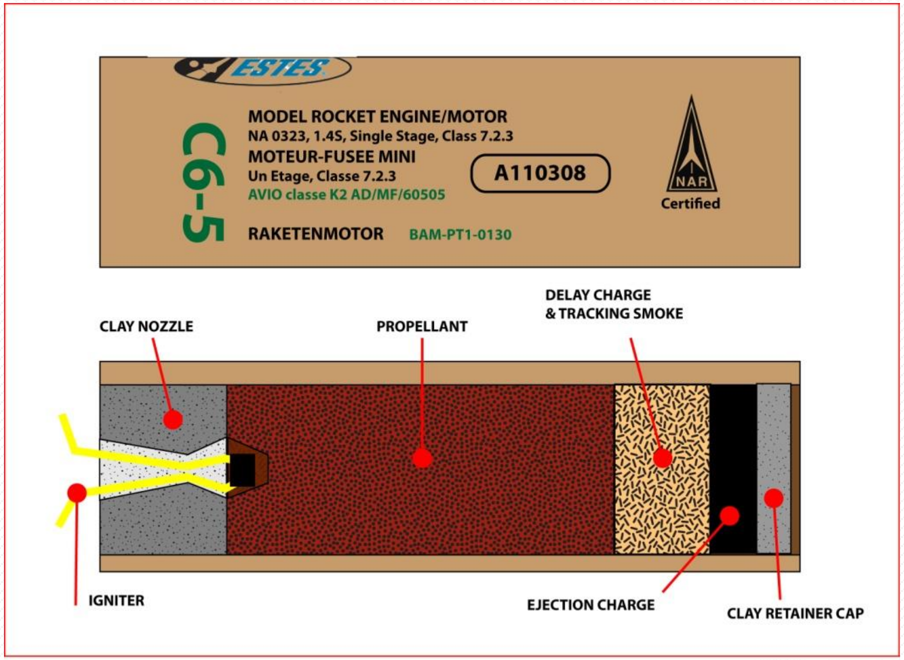
- Something that **imparts** motion is called a **motor**.
- An **engine** is a machine that **converts energy** into mechanical motion.
- While referring to the propulsion system of a model rocket as a **motor is more accurate**, the use of the term engine is common.

Black Powder Motor Burn



- Black powder motors burn from the **rear forward**.
- When the propellant is spent, it ignites the **delay charge**.
- The delay charge burns forward and ignites the **ejection charge**.
- The clay nozzle forces the pressure **forward**, expelling the nose cone and recovery system.

Black Powder Motor



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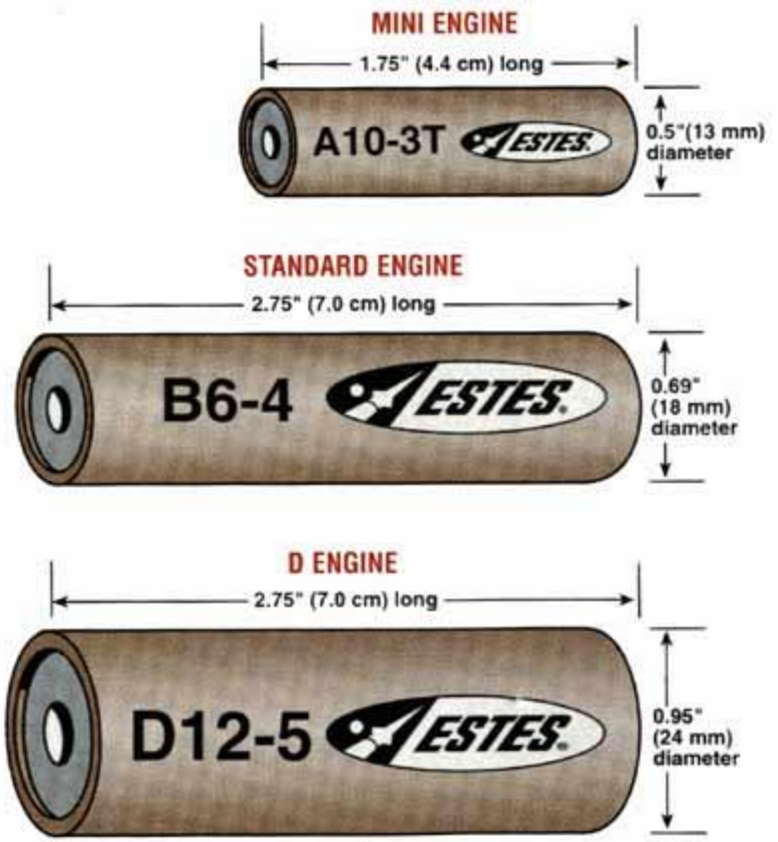
- **B** – The letter indicates the total **impulse power** produced by the motor in Newton-seconds. Each letter doubles the power.
- **6** – The first number gives the **average thrust** of the motor in Newtons.
- **4** – The last number indicates the **delay seconds** between the end of thrust and the ejection charge.

Motor nomenclature

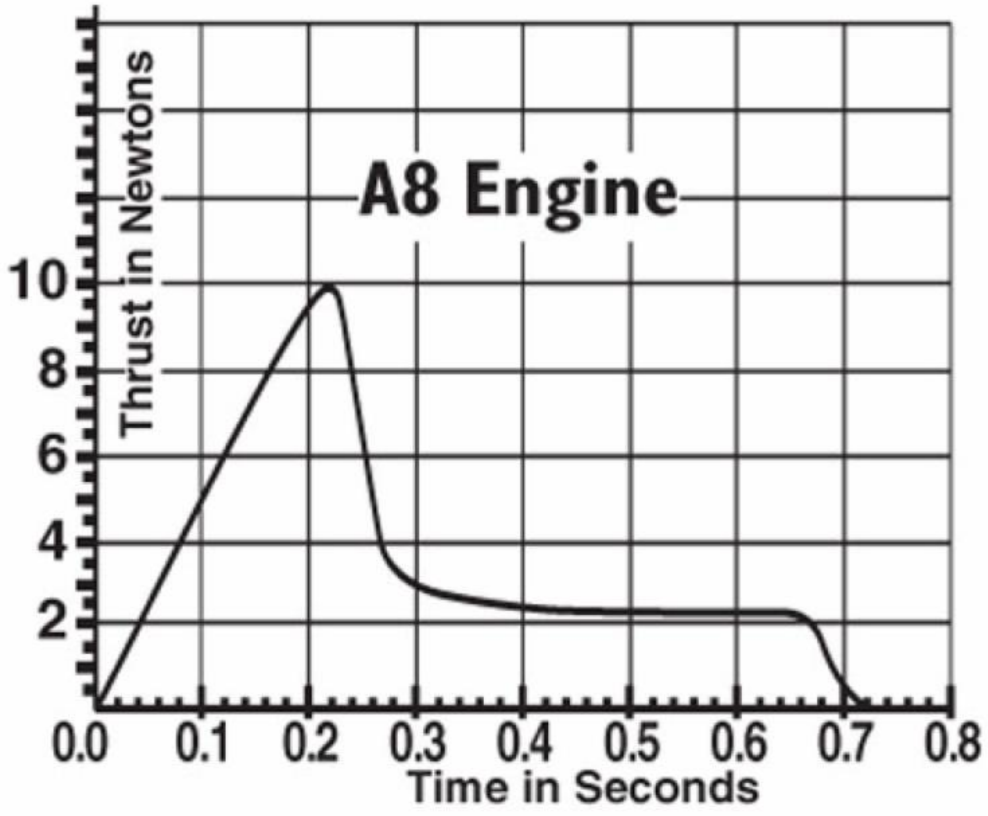
CLASS	Total Impulse Newtons-sec
1/4A	.000 - .625
1/2A	.626 – 1.25
A	1.260 – 2.50
B	2.510 – 5.00
C	5.010 – 10.0
D	10.01 – 20.0
E	20.01 – 40.0
F	40.01 – 80.0
G	80.01 – 160.0
H	160.01 – 320.0

Motor Sizes

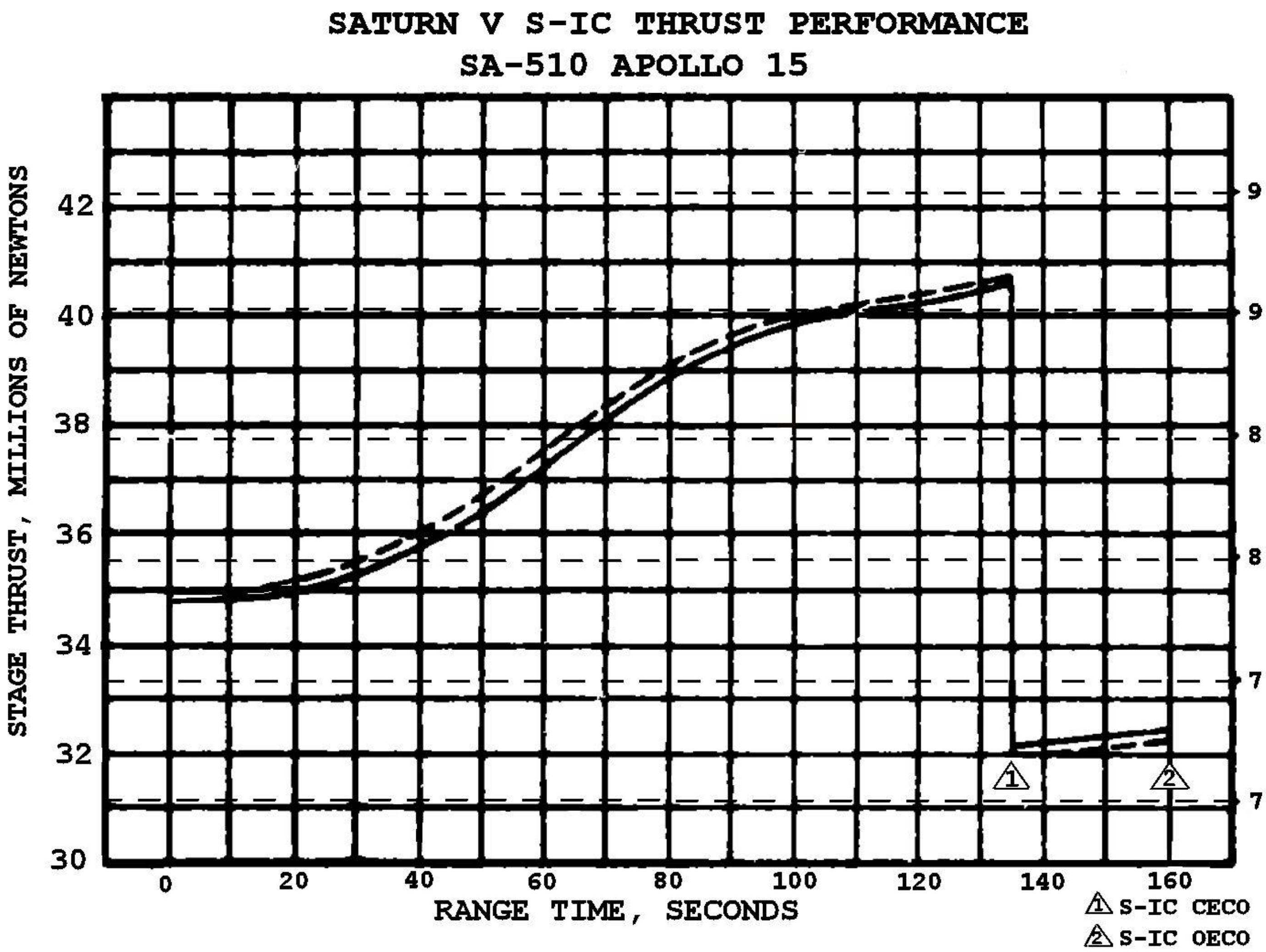


- Motor diameter is measured in **millimeters**.
- Sizes for low to mid-power rockets are **13mm, 18mm, 24mm, and 29mm**.

A8-3 Engine Thrust Curve



Saturn V Thrust Curve



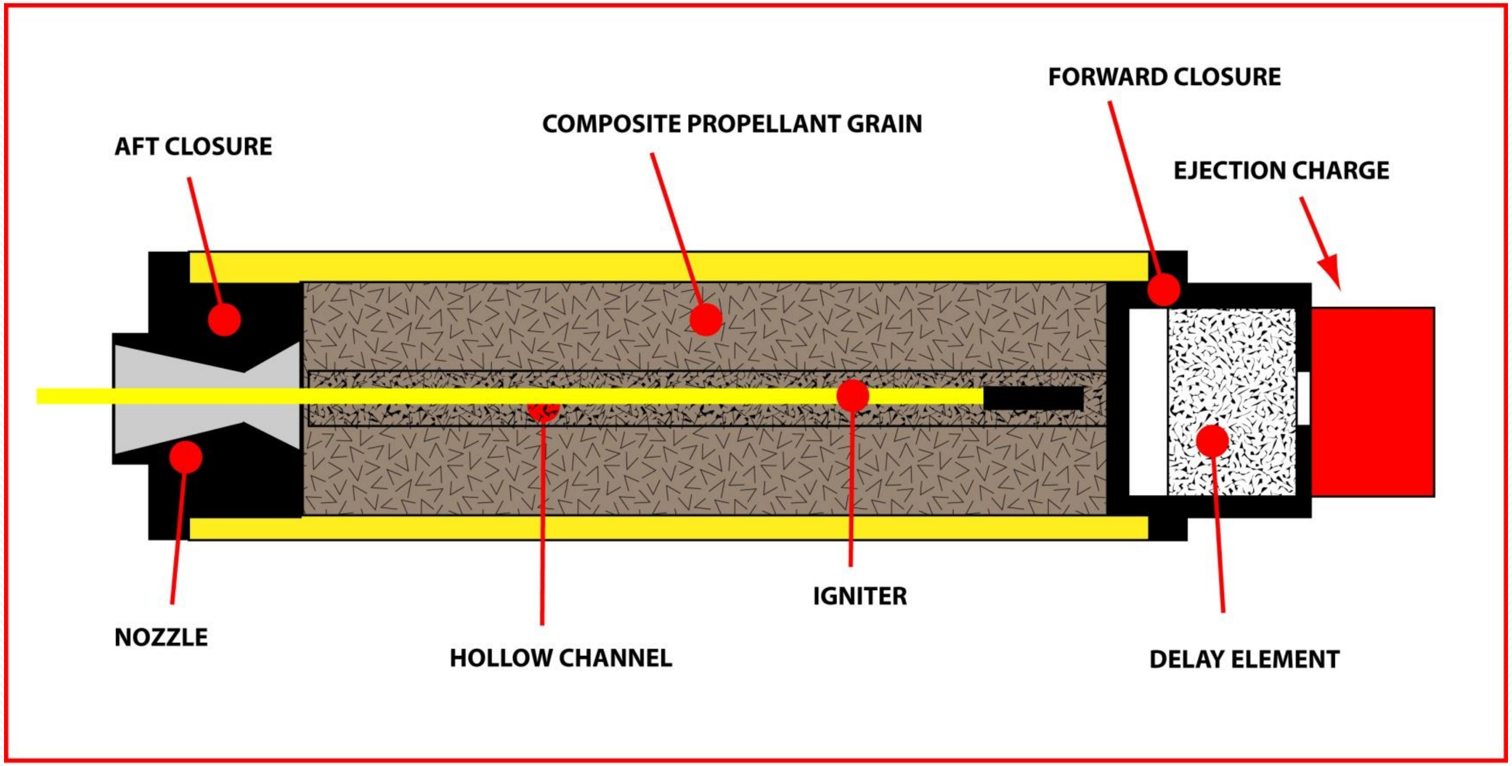
Ammonium Perchlorate Composite Propellant

- Composite motors burn from the inner core out.
- The delay element is ignited with the propellant and burns forward. Because of this, tracking smoke is produced immediately.
- The delay element ignites the ejection charge.

Reloadable Motors

- Motor casings can be reloaded multiple times.
- Wide range of motors are available
- Used in mid and high power rocketry

Reloadable Motors



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Building a Model Rocket

Class Phase 3

Quest Starhawk

Tools, Supplies, and Resources

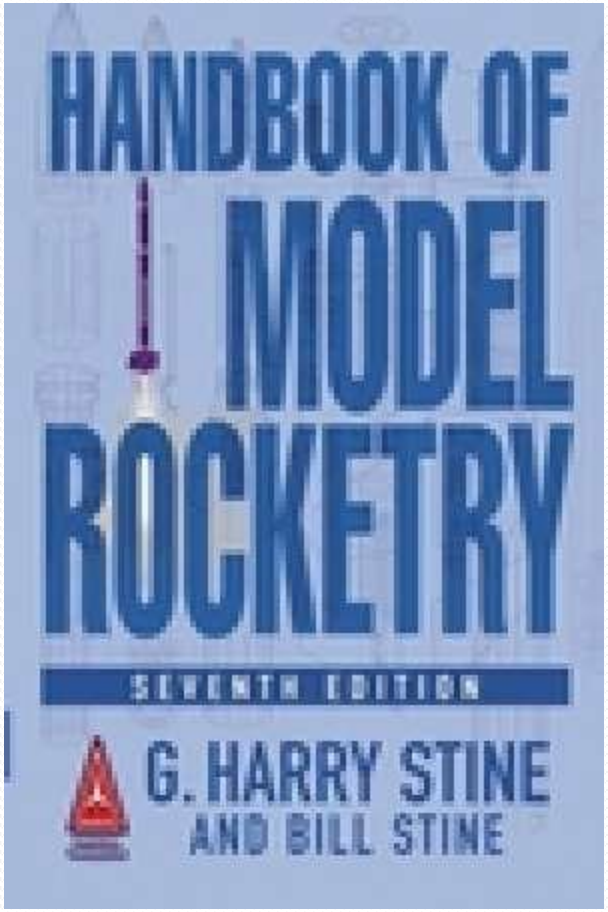
A list of vendors can be found at **http://www.sargrocket.org/Vendors.html**

Funding of Program

- Local education foundation
- Air Force Association Grants (National & Local)
- 4H County Offices (partnered with NAR)
- NAR Cannon Award

Resources

- Area Rocketry Groups
- Parents with rocketry experience
- Local scout units
- Online Resources
- Model Rocketry Publications



Curriculum Resources

www.sargrocket.org

www.nar.org

http://www.rocketcontest.org/

Local Support

Washington Aerospace Group

http://www.washingtonaerospace.org

Tom Sarradet

tsarradet@auburn.k12.ca.us

30 MINUTE LUNCH

Topics in Education

Investigation & Discovery

Class Phase 4

Investigation & Discovery

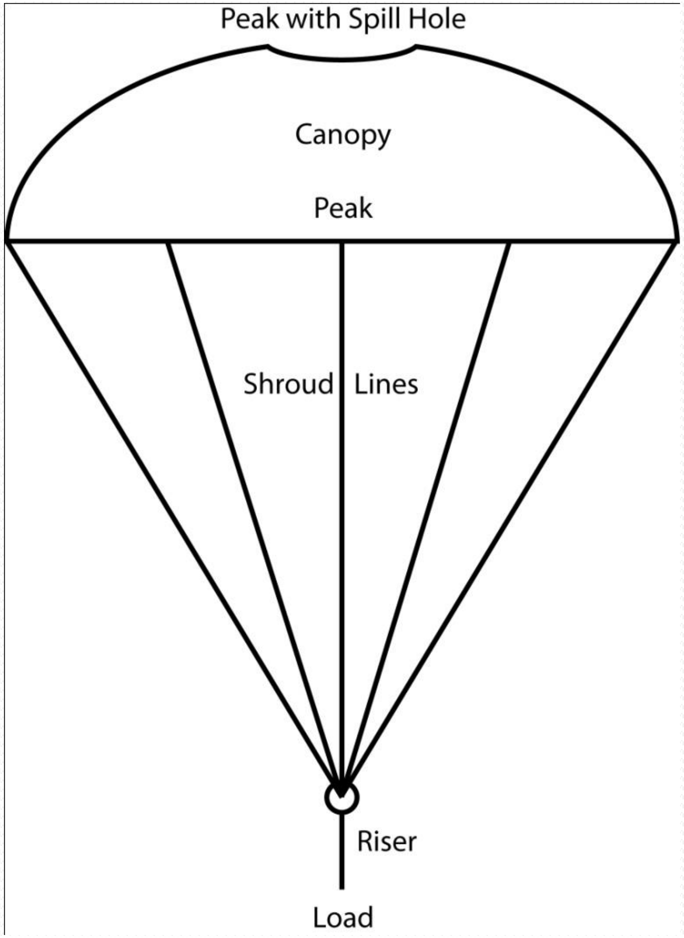
- Students are formed into teams and conduct scientific missions.
- Many STEM content standards are taught during this phase.

Preparation for Launch

- Prepare rockets the day prior to the launch
- Pack the parachutes the day of launch
- For the first time using the equipment, conduct a practice launch with one rocket.
- Ensure students know their assignments

Investigation & Discovery

- Team Missions:
  - Altitude & Velocity
  - Fin Design
  - Fin Drag
  - Investigating Energy
  - Nose Cone Design
  - Streamer Recovery
  - Parachute Recovery

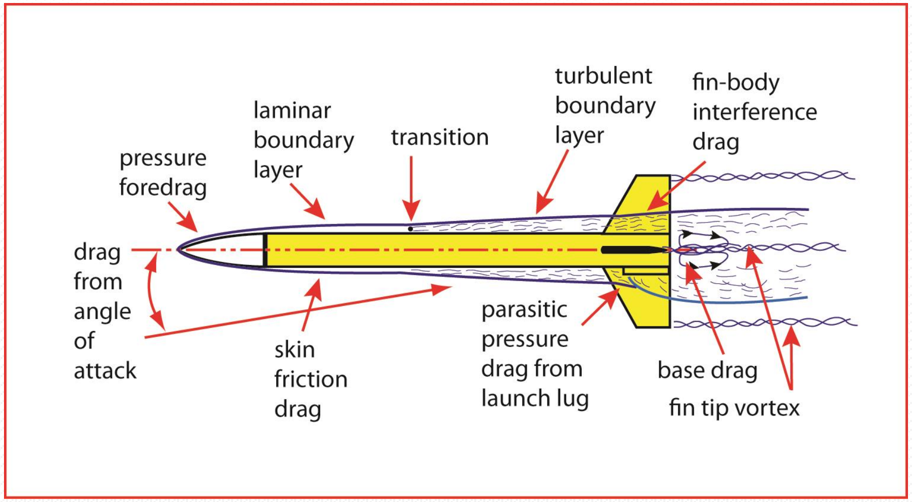


LESSON LD04

AERODYNAMICS

Definition

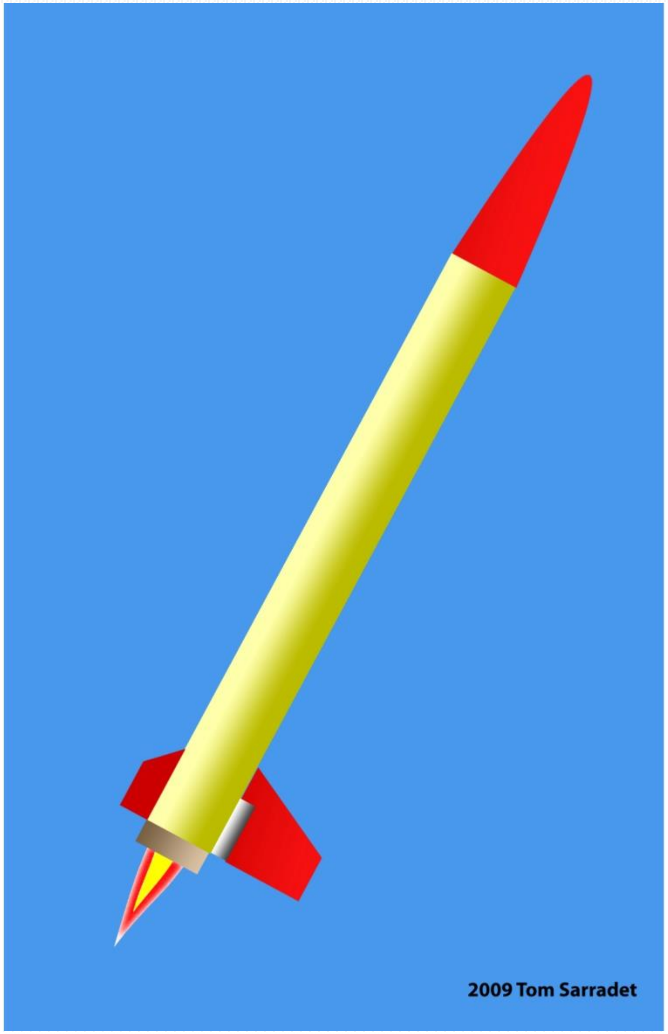
- **Aerodynamics** is the study of the motion of air, particularly when it interacts with a moving object.
- In physics the term **dynamics** customarily refers to the time evolution of physical processes.



Factors that Affect Aerodynamics

The Object:
Shape & Size

The Motion:
Velocity & Inclination to Flow



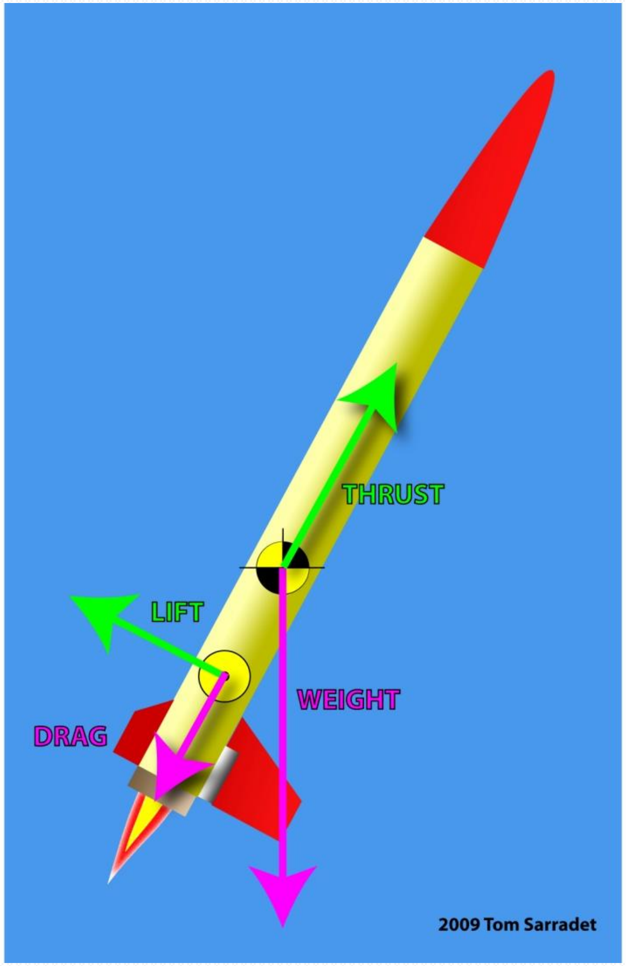
The Air:
Mass, Viscosity, Compressibility

Four Forces of Flight

- **Lift** is a force used to **stabilize** and **control** the direction of flight.
- **Drag** is the **aerodynamic force** parallel to the relative wind.
- **Weight** is the force generated by **gravity** on the rocket.
- **Thrust** is the **force** which moves the rocket **forward**.

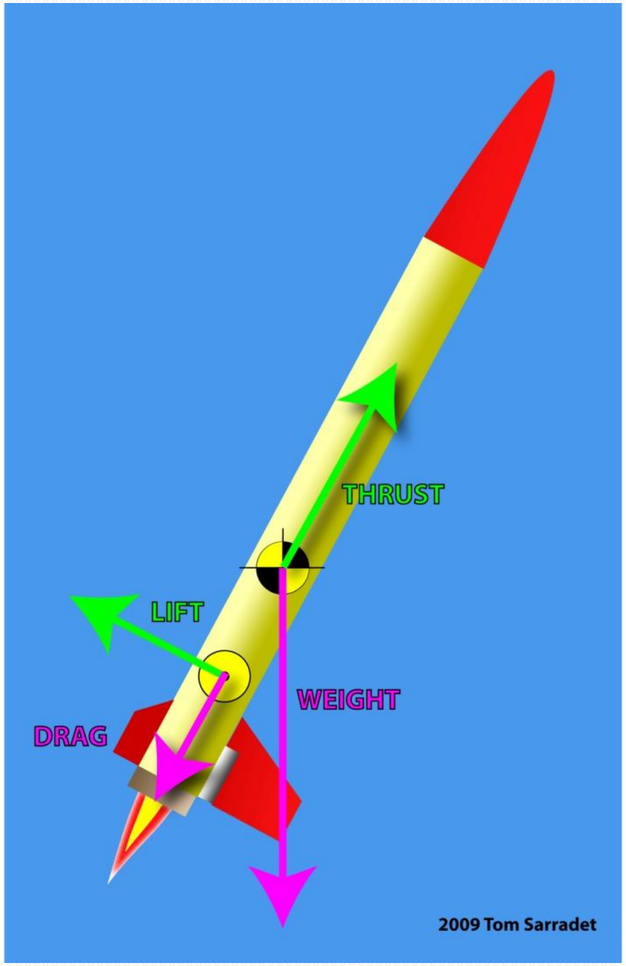
Aerodynamic Forces

- **Aerodynamic forces** are generated and act on a rocket as it **flies through** the air.
- The lift and drag act through the **center of pressure** which is the average location of the aerodynamic forces on an object.



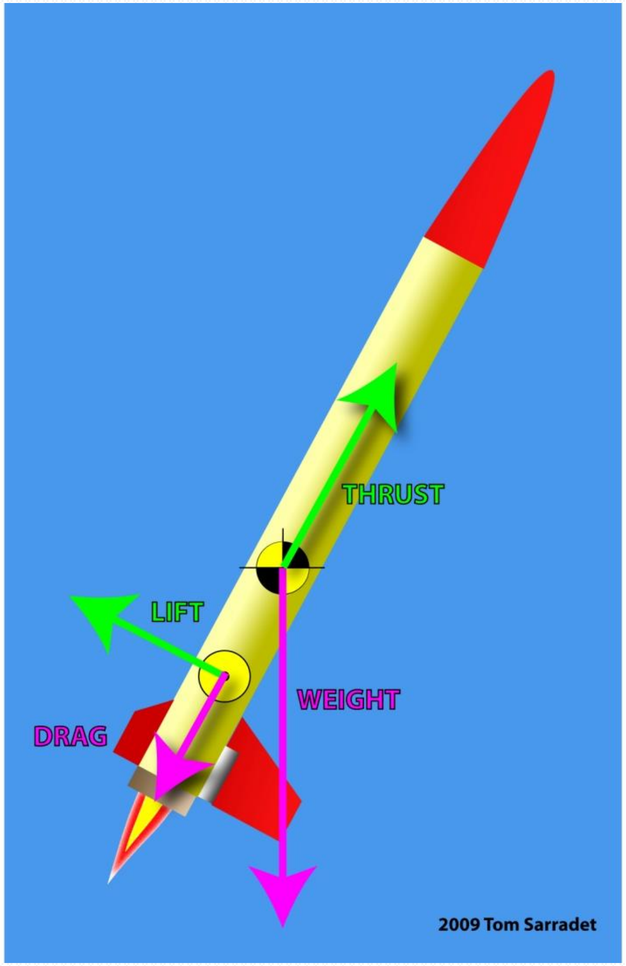
Aerodynamic Forces

- Aerodynamic forces are **mechanical forces**. They are generated by the interaction and contact of the rocket with the air.
- For **lift** and **drag** to be generated, the rocket must be moving through the air.



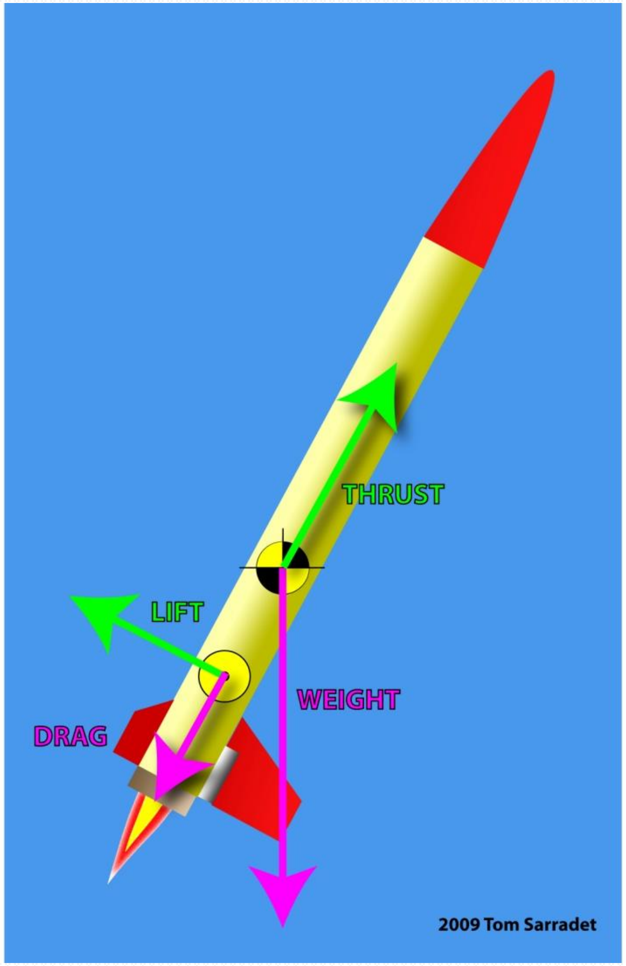
Aerodynamic Forces

- **Lift** occurs when a flow of **gas** (the air) is turned by a **solid object** (the rocket).
- The flow is turned in one direction, and the lift is generated in the opposite direction.
- For a model rocket, the **nose**, **airframe**, and **fins** can become a source of **lift** if the rocket's flight path is at an **angle**.



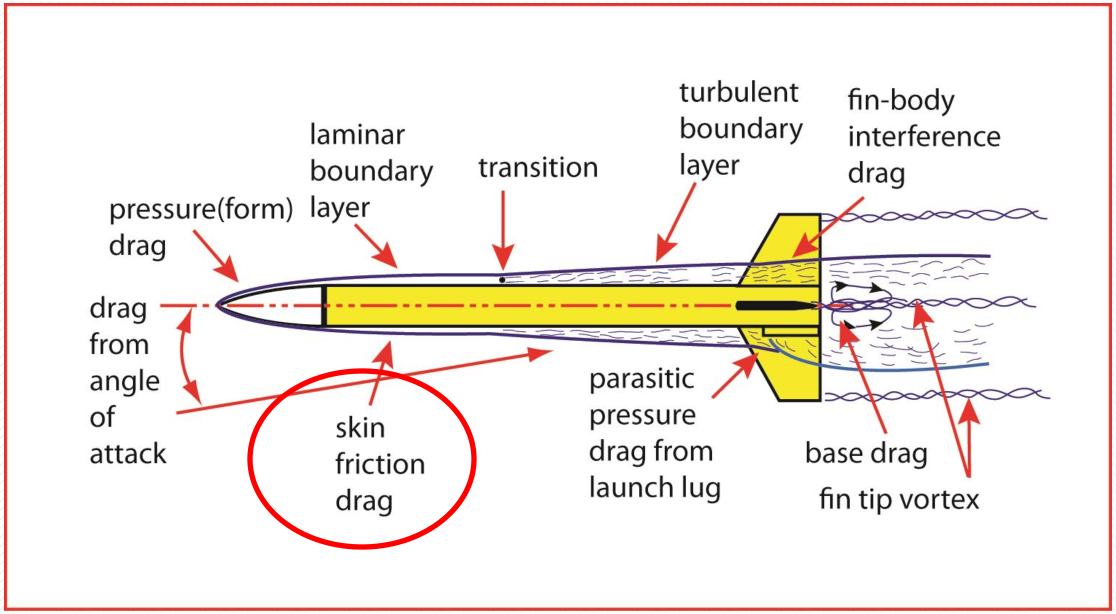
Aerodynamic Forces

- When a solid body (**the rocket**) moves through a fluid (**gas or liquid**), the fluid **resists** the motion. The rocket is subjected to an **aerodynamic force** in a direction opposed to the motion which we call **drag**.



Aerodynamic Forces

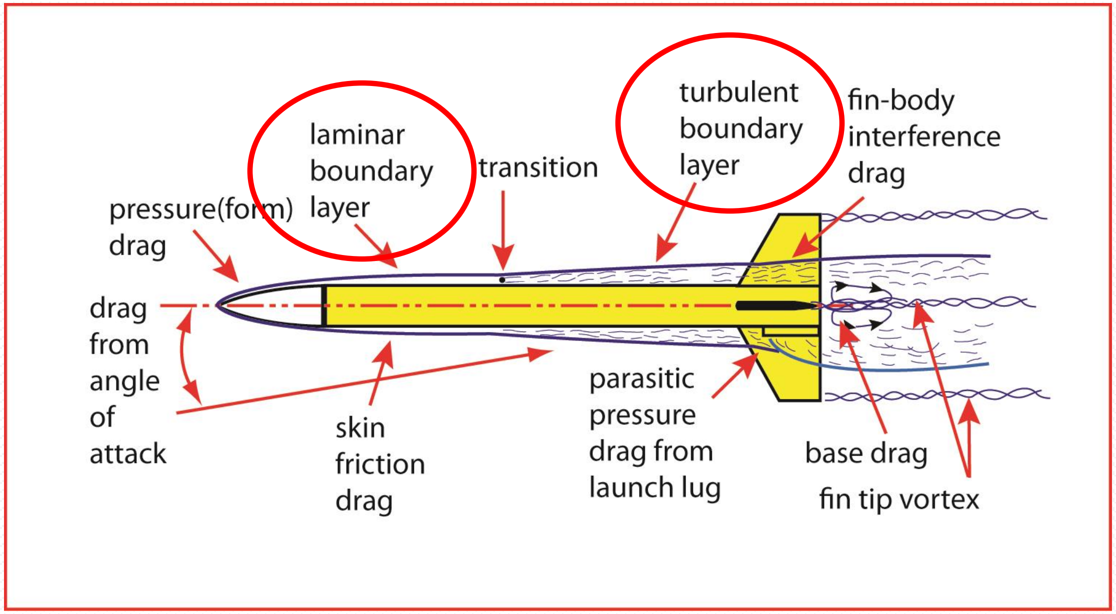
- **Drag** is **aerodynamic friction**, and one of the sources of drag is the **skin friction** between the molecules of the air and the solid surface of the moving rocket.



Aerodynamic Forces

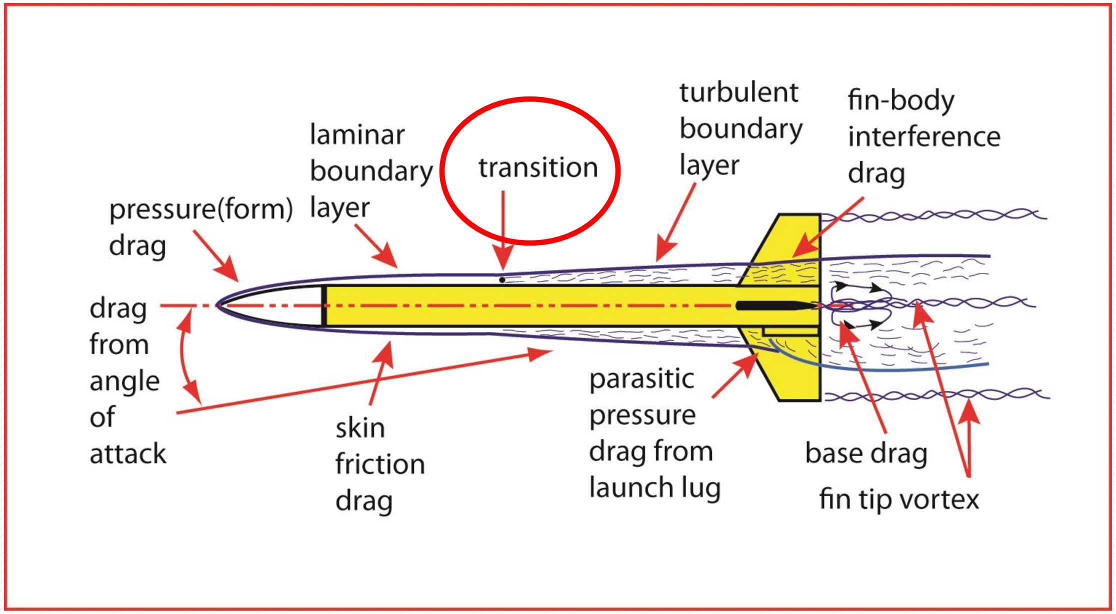
- A **boundary layer** is the layer of air in the immediate vicinity of the rocket's surface.

Boundary layers can be **laminar** (smooth flow) or **turbulent** (swirling).



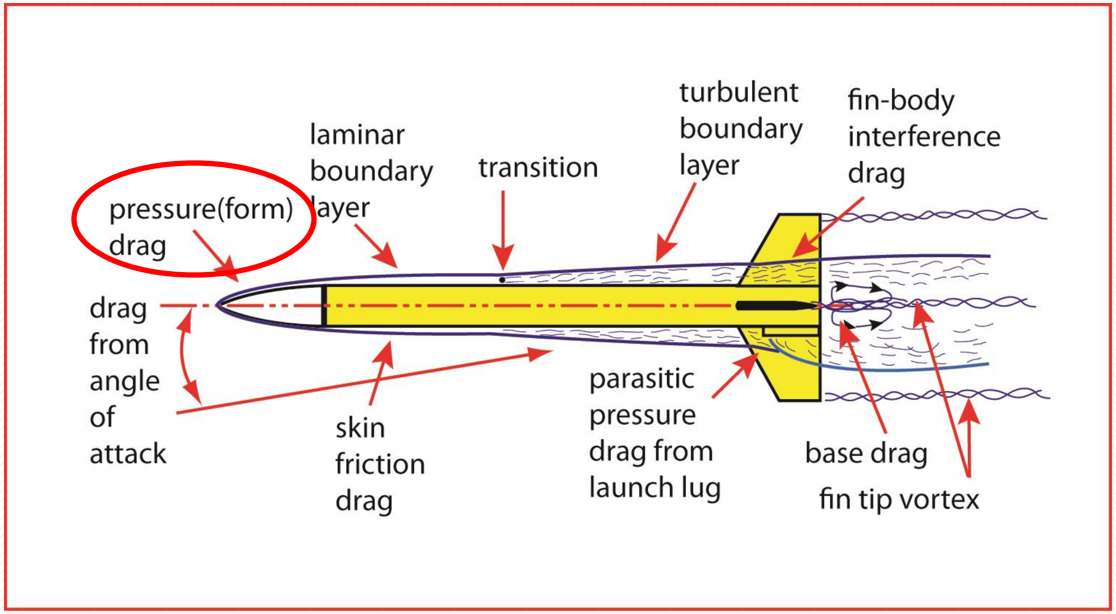
Aerodynamic Forces

- The **point** in which a laminar boundary layer becomes turbulent is called the **transition**.



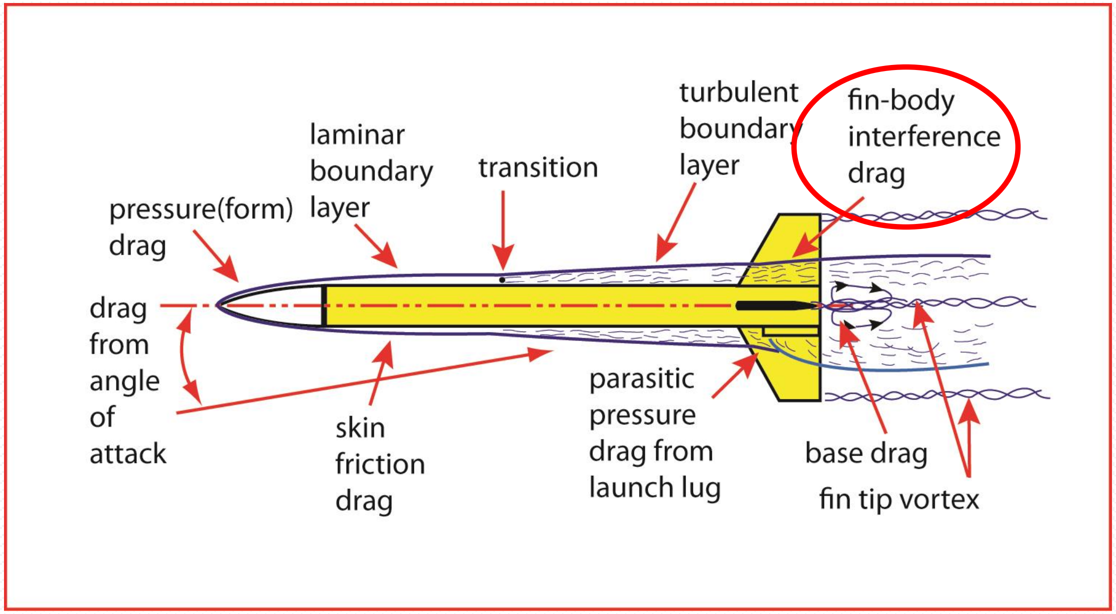
Aerodynamic Forces

- **Drag** is also **aerodynamic resistance** to the motion of the object through the fluid. This source of drag depends on the **shape** of the rocket and is called **pressure or form drag**.



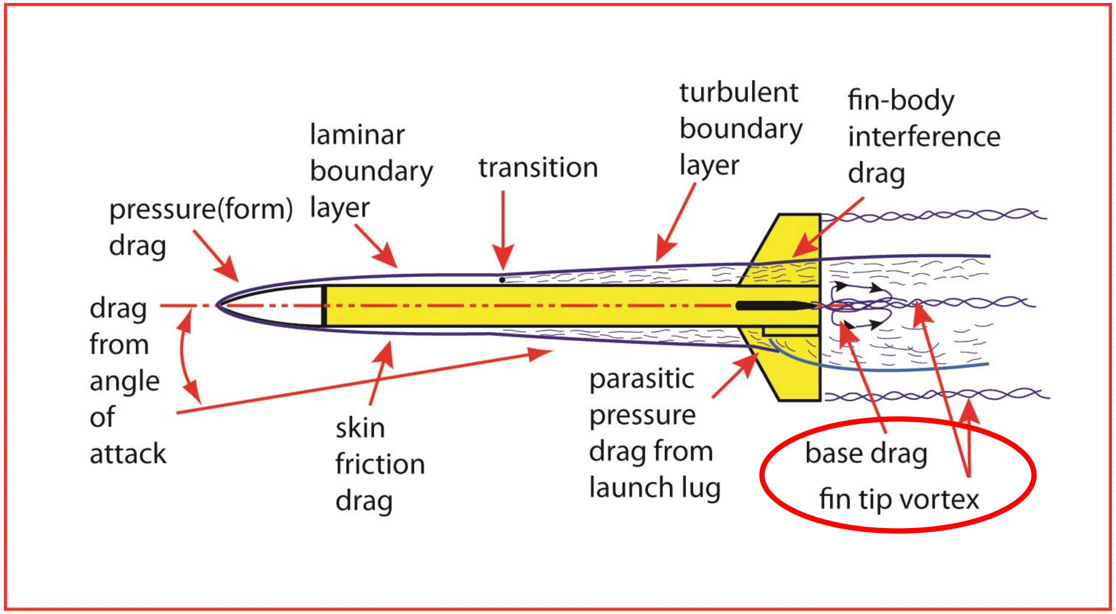
Aerodynamic Forces

- **Interference drag** occurs whenever two surfaces meet at sharp angles, such as at the fin roots. Interference drag creates a **vortex** which creates drag. Fin fillets reduce the effects of this drag.

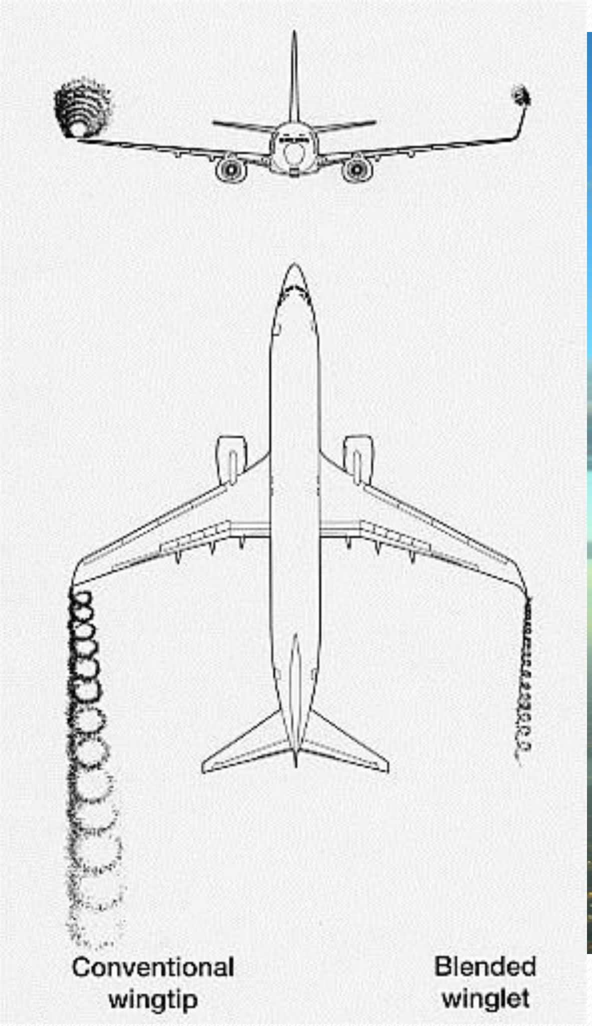


Aerodynamic Forces

- Air passing by the tips of the fins form a **fin tip vortex**. Accelerating the air into this vortex causes **drag** on the fins, and a **low** pressure area behind them. Tapered fin tips reduce this drag.

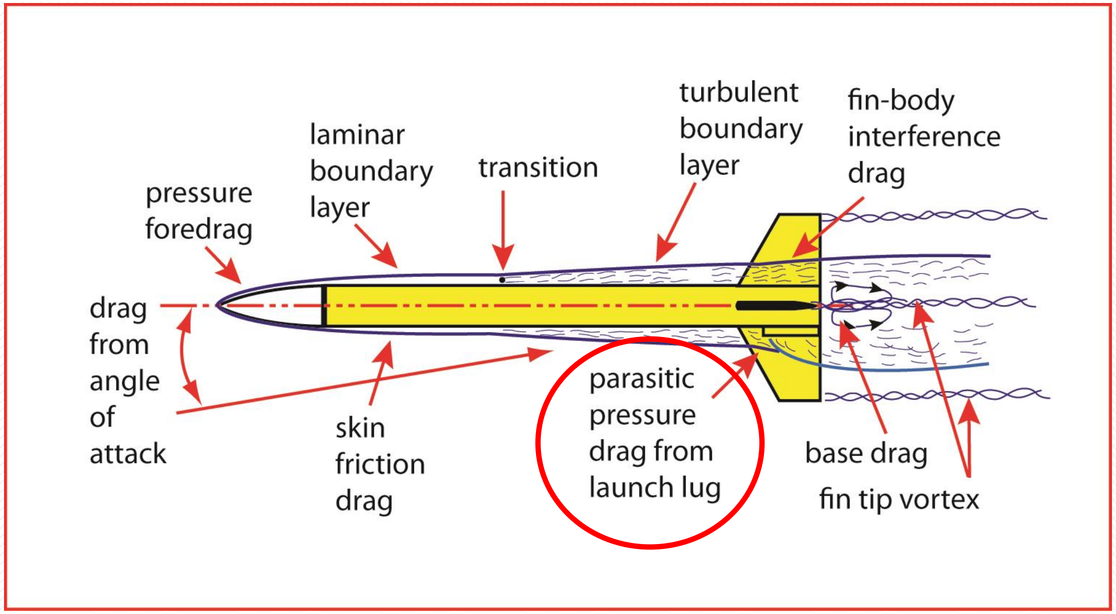


Winglets



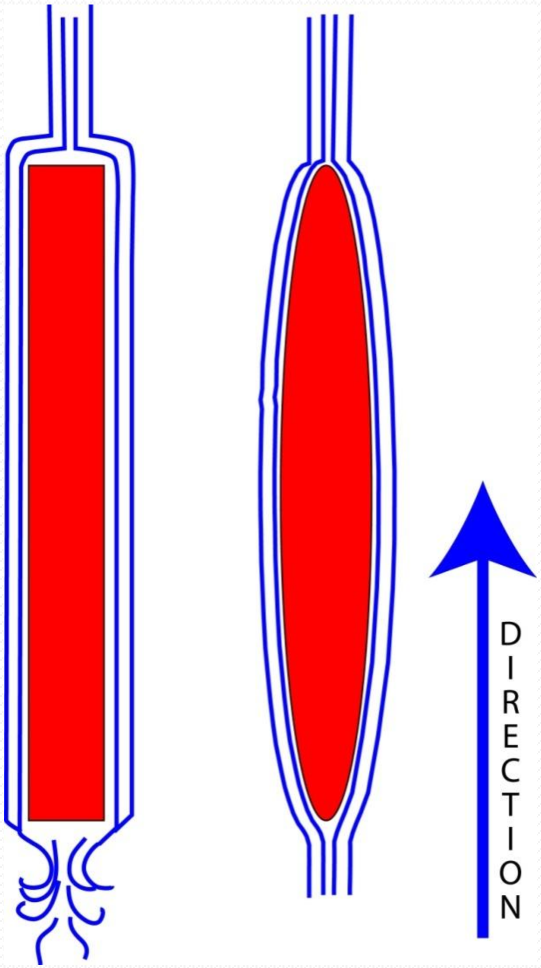
Aerodynamic Forces

- **Parasitic Drag** is produced by objects like the launch lug. The launch lug can account for **30%** of all drag. Cutting the lug's leading edge to 45 degrees reduces drag.



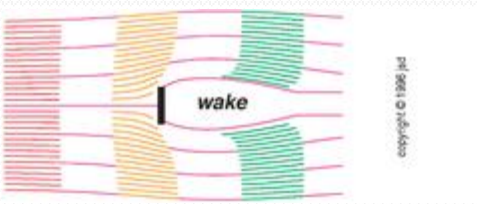
Airfoil Fins

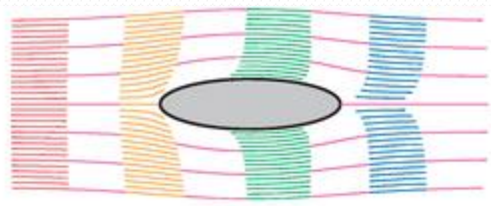
- A model rocket's fin that is **square** on the edges creates a lot of **drag** and **turbulence**.
- If the fin's leading and trailing edges are sanded in a **round shape**, called an **airfoil**, it reduces the drag.

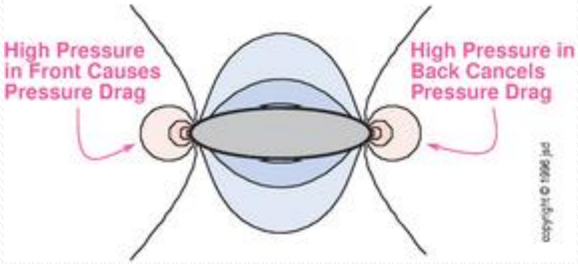


Airfoil Fins

- **airfoil shape fins** creates high pressure behind the fin and **pushes it forward**, cancelling out most of the pressure drag caused by the fins. This is called **pressure recovery**.





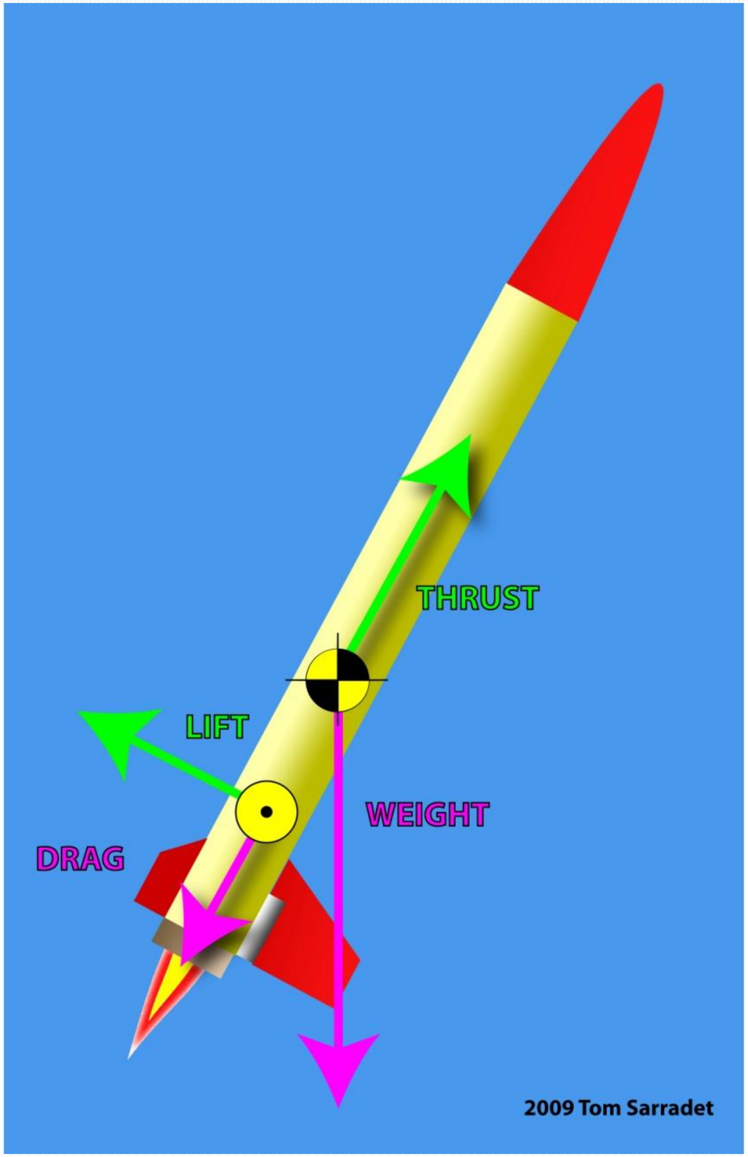


Weight

- Weight is the force generated by the **gravitational** attraction on the rocket.
- The gravitational force is a **field force**; the source of the force does **not** have to be in physical contact with the object.
- Gravity affects the rocket whether it is **stationary** or **moving** (up or down).

Thrust

- **Thrust** is the force applied to the rocket to **move it** through the air, and through space.
- **Thrust** is generated by the **propulsion system** of the rocket through the application of Newton's Third Law of Motion.
- The direction of the thrust is normally along the **longitudinal** axis of the rocket through the rocket's **center of gravity**.



LESSON LD05

ROCKET STABILITY

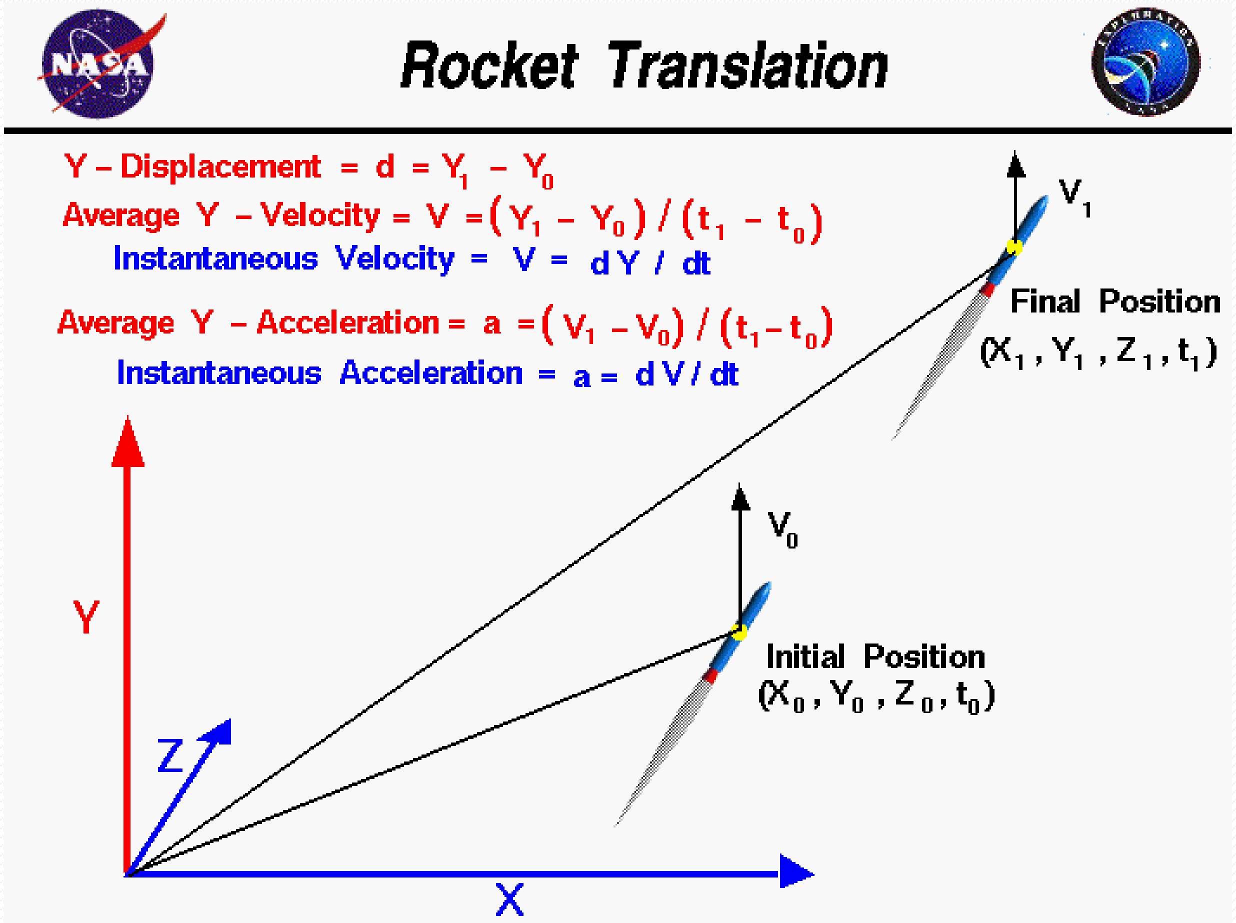
Rocket Stability

- During the flight of a model rocket, gusts of **wind** or thrust instabilities, can cause the rocket to "**wobble**", or change its attitude in flight.
- Poorly built or designed rockets can also become **unstable** in flight.
- This lesson is about what makes a rocket unstable in flight and what can be done to improve its stability.

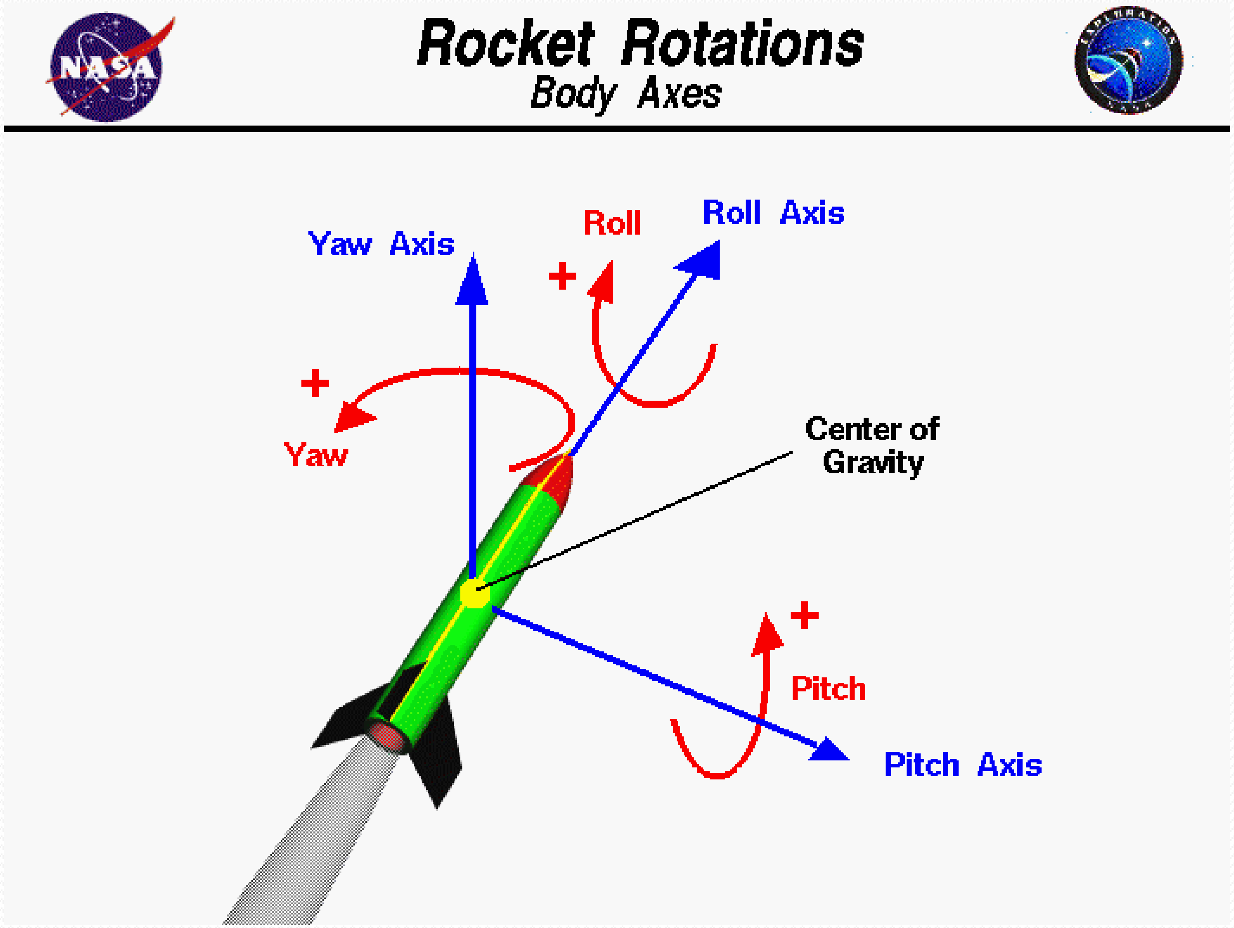
Translation and Rotation

- A rocket in flight can move two ways; it can **translate**, or change its location from one point to another, and it can **rotate**, meaning that it can roll around on its axis.

How a Rocket Translates



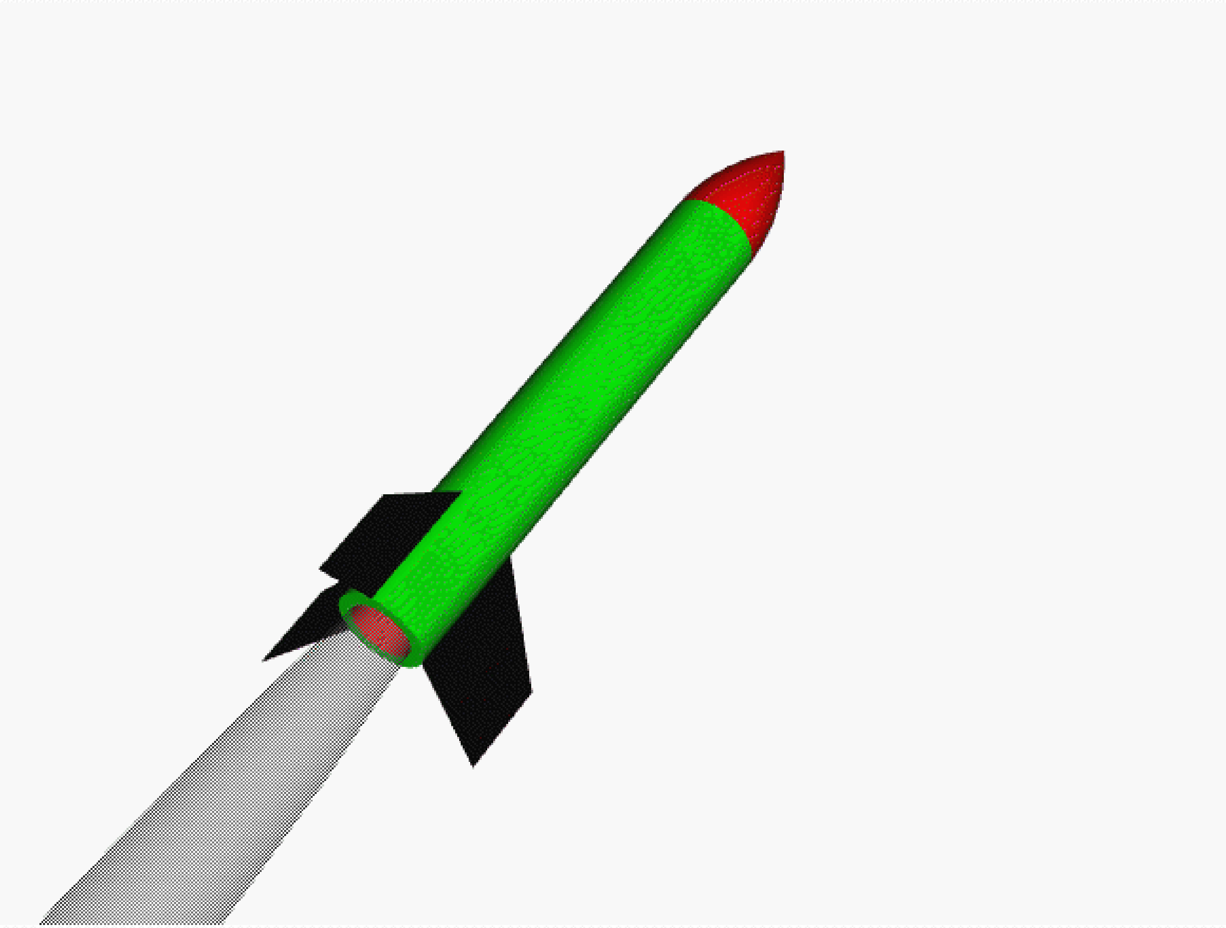
How a Rocket Rotates



Roll

- Most rockets are symmetric about a line from the tip of the nose to the center of the nozzle exit. We will call this line the **roll axis** and motion about this axis is called a **rolling motion**.
- The **center of gravity** lies along the roll axis.

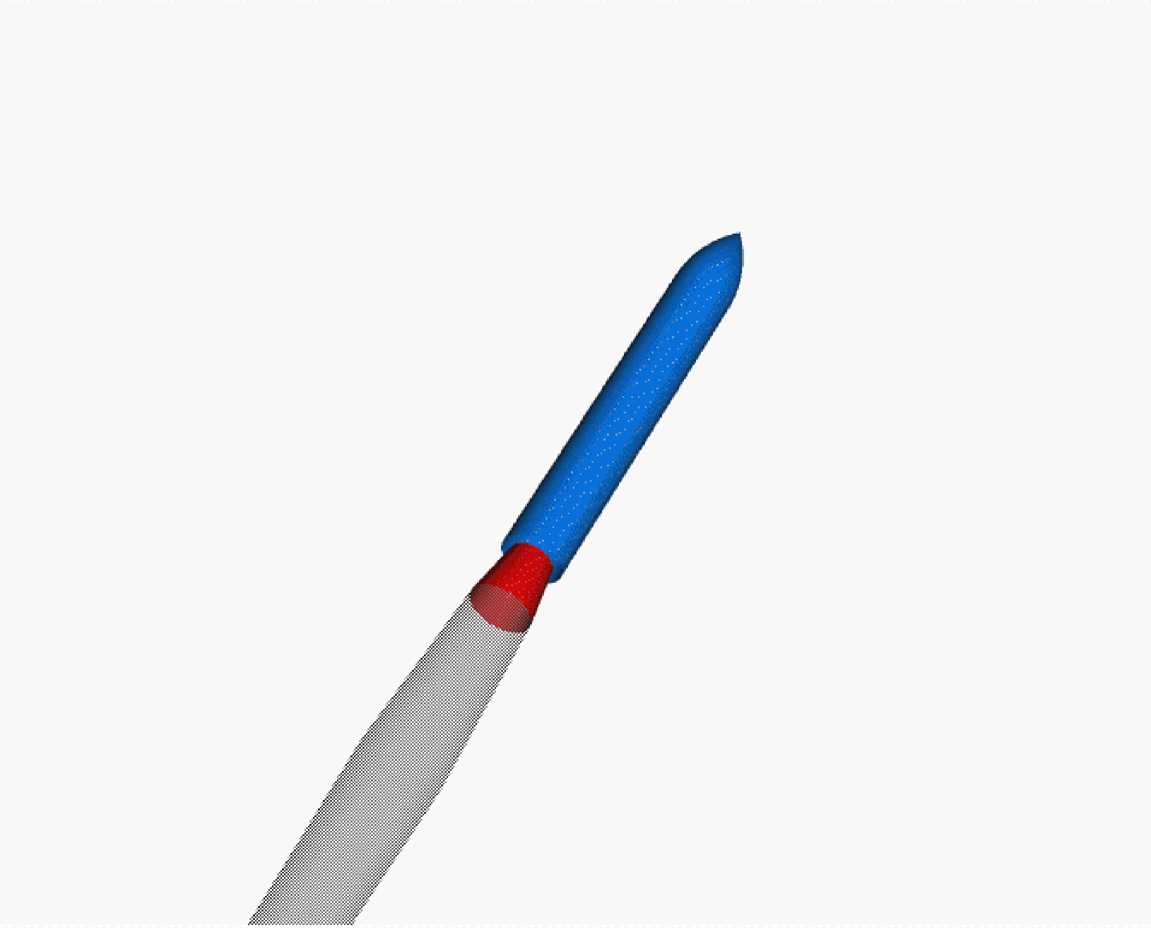
Roll



Yaw and Pitch

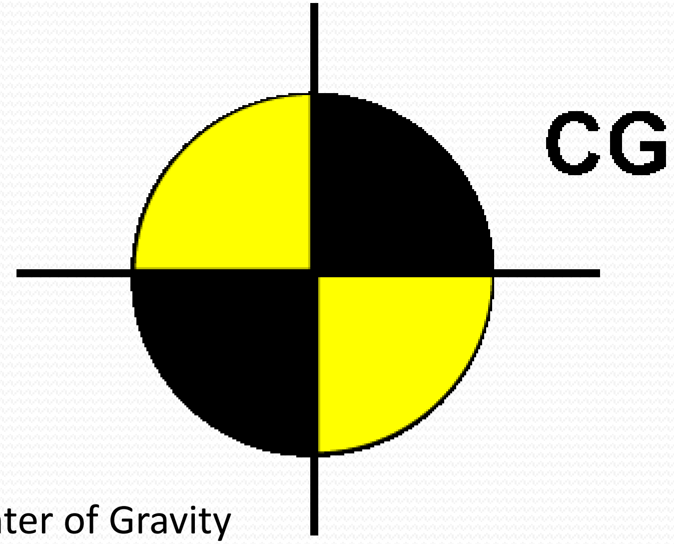
- When a rocket wobbles from **side to side**, this movement is called a **yaw motion**.
- A **pitch motion** is an **up or down** movement of the nose of the rocket.

Pitch



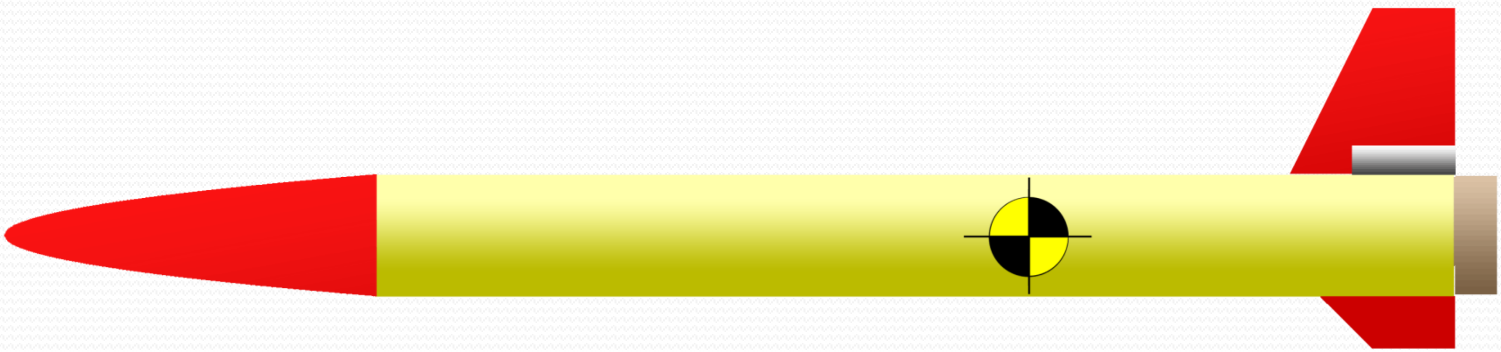
Center of Gravity - CG

- As a rocket flies through the air, it both **translates** and **rotates**. The rotation occurs about a point called the **center of gravity**, which is the average location of the weight of the rocket.



Symbol for Center of Gravity

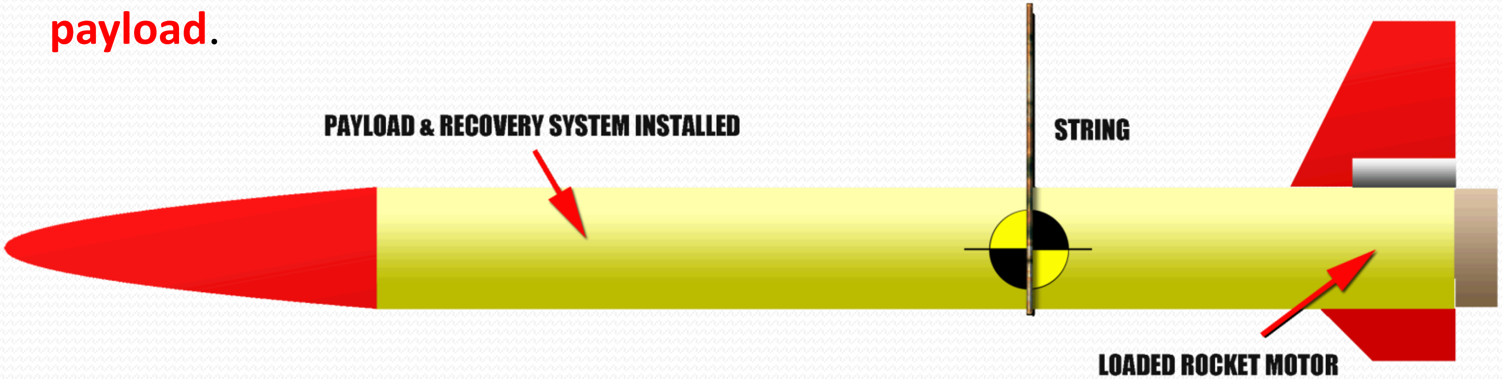
Typical Location of CG



How to Determine CG

1. Load the motor, recovery system, and payload.

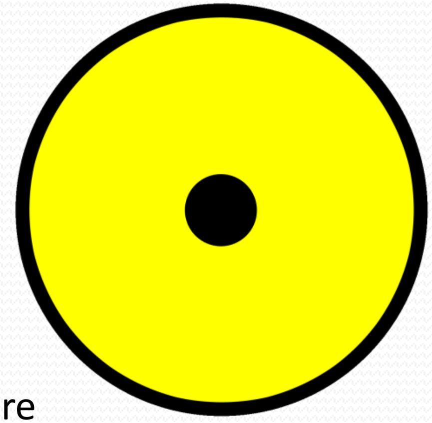
3. The location of the string is at the center of gravity.



2. Tie a string around the airframe and adjust it until the rocket is horizontally balanced.

Center of Pressure - CP

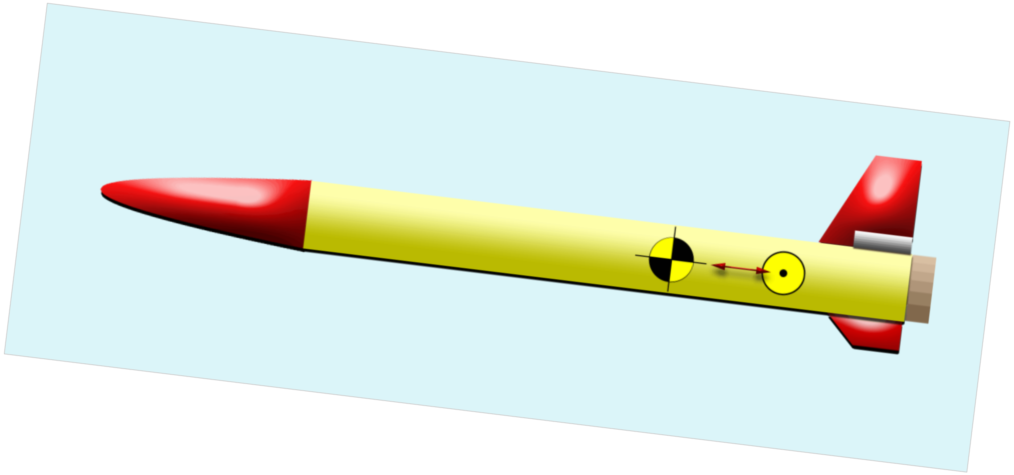
- The **average location of the pressure** on the rocket is called the **center of pressure.**
- The parts of the rocket that influences the location of the center of pressure the most are the **fins**.



Symbol for Center of Pressure

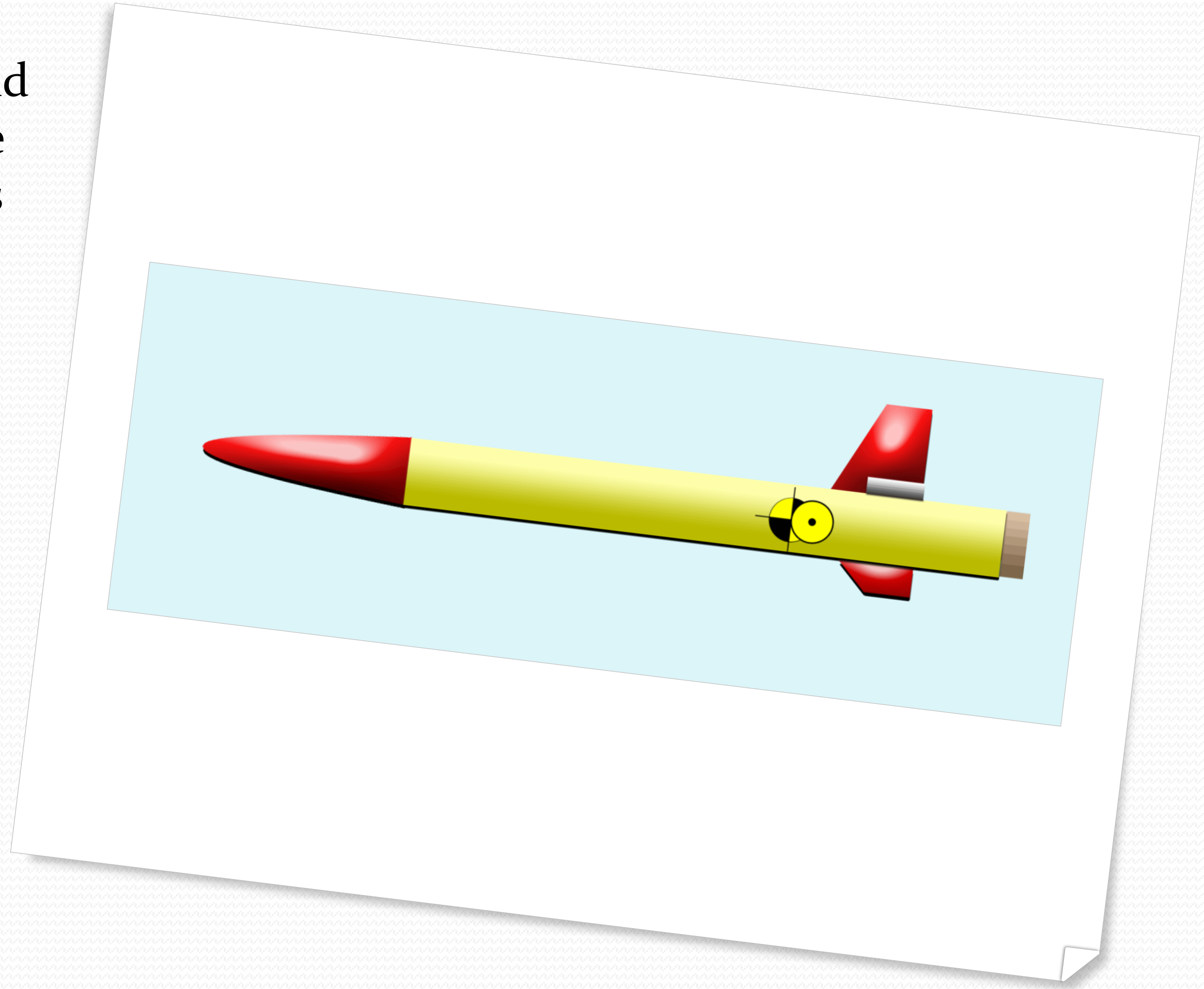
Building a Stable Rocket

If the **center of gravity is in front of the center of pressure**, the rocket will return to its initial flight conditions if it is disturbed. This is called a **restoring force** because the forces "restore" the rocket to its initial condition and the rocket is said to be **stable**.

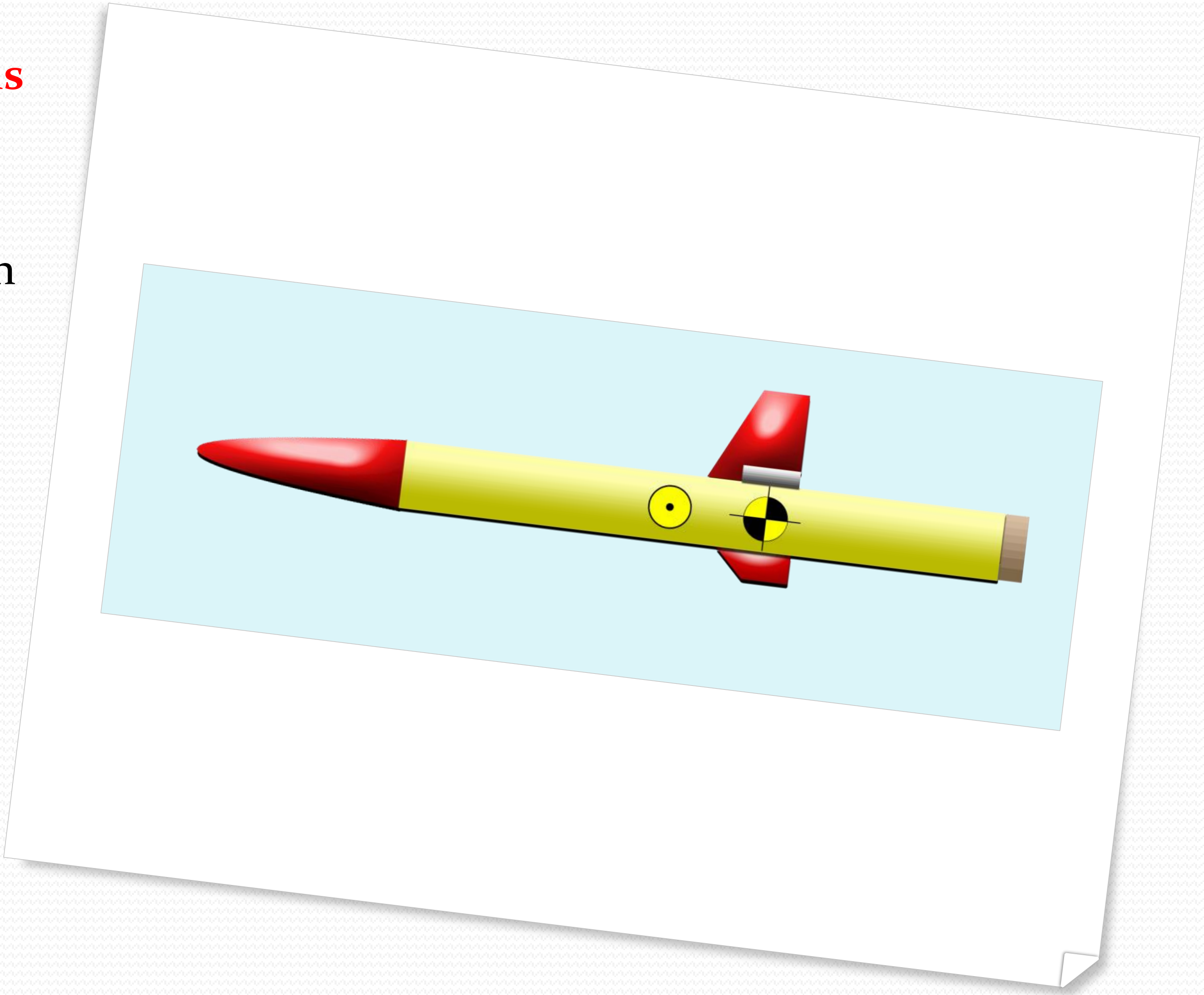


If the center of gravity and the center of pressure are in the same location, it is called **neutral stability**.

A rocket with **neutral stability** may make a stable or unstable flight depending on the forces acting on it.



If the **center of pressure is in front of the center of gravity**, the lift and drag forces maintain their directions but the direction of the torque generated by the forces is reversed. This is called a **de-stabilizing force**. Any small displacement of the nose generates forces that cause the displacement to increase. Such a flight condition is **unstable** .



Correcting Unstable Flight

To move the Center of Gravity:

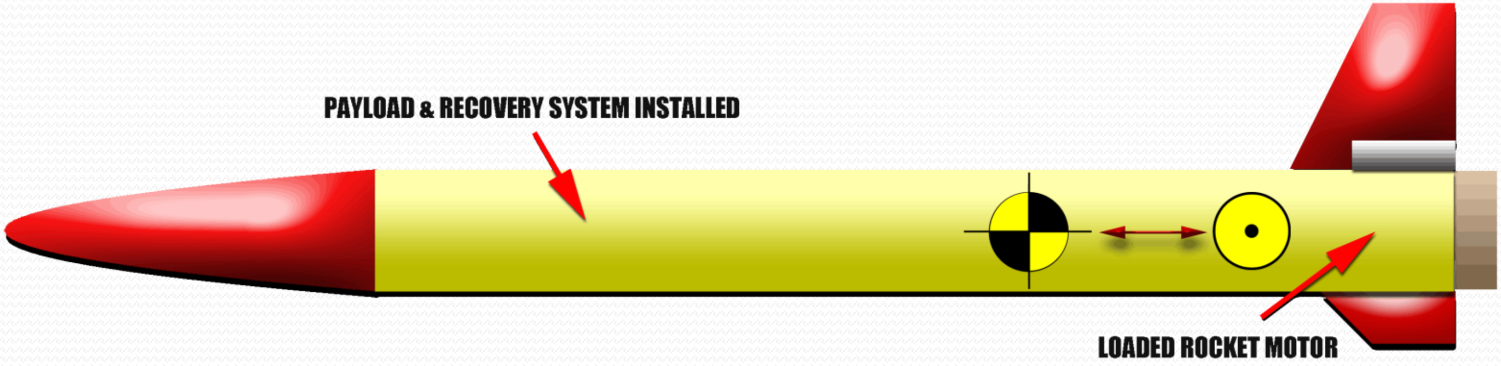
- Add or remove weight in the nose cone.
- Redistribute the Payload
- Increase or decrease airframe length.

To move the Center of Pressure:

- Increase or reduce the fin size.
- Change the shape of the fins.
- Change the location of the fins.
- Increase or decrease airframe length/diameter.

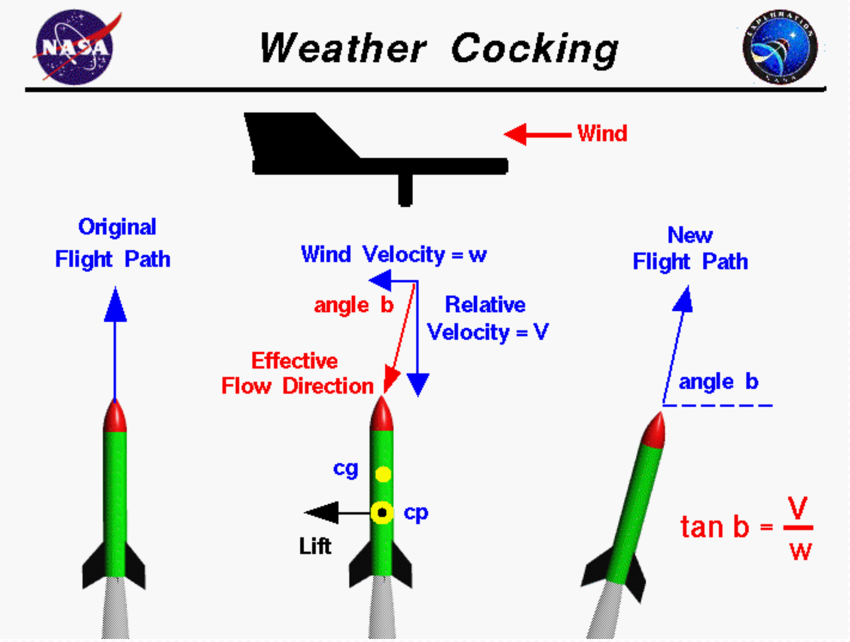
One Caliber Stability

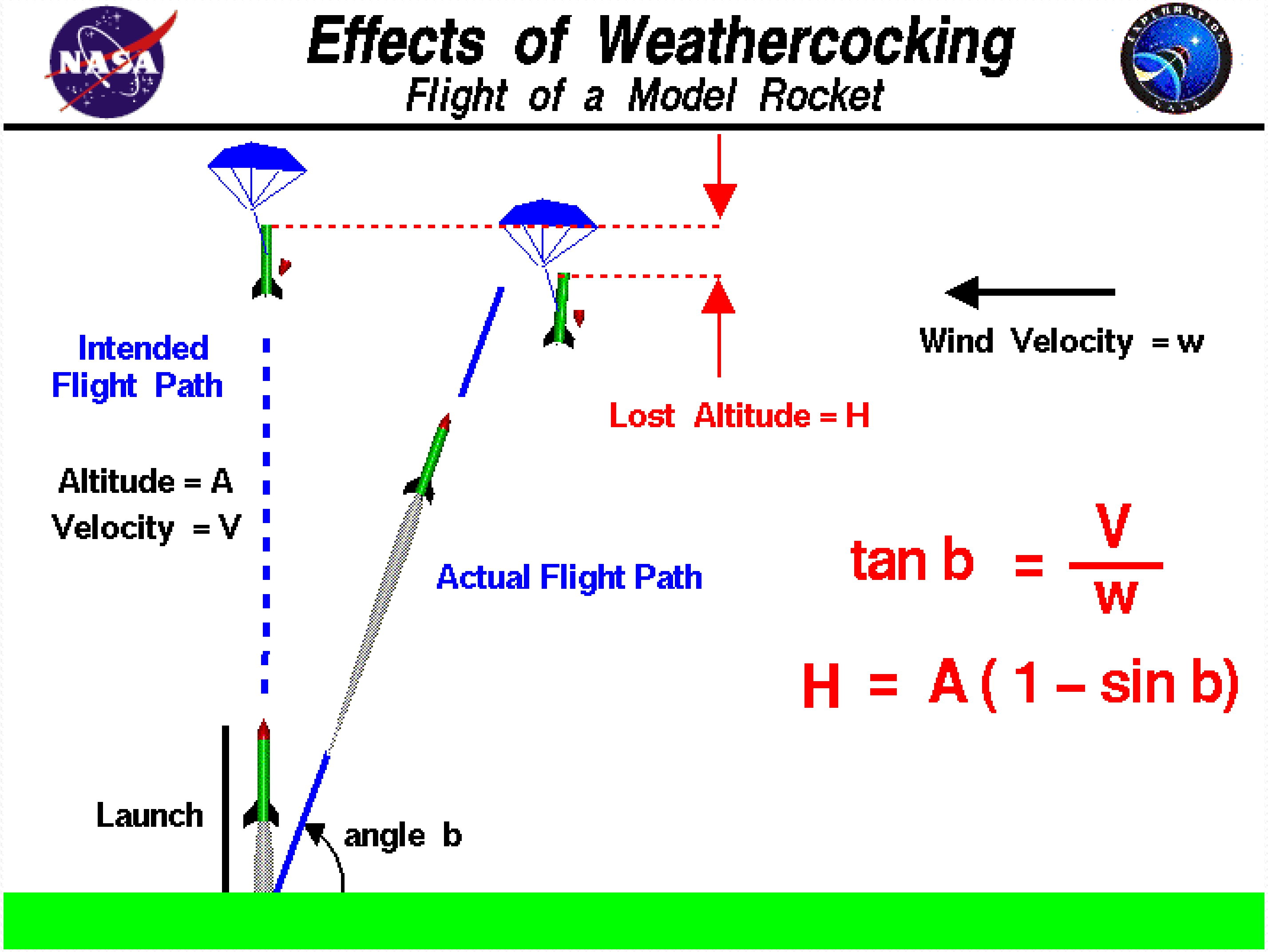
The best separation between the center of gravity is for the CP to be at least **one body tube diameter** in front of the CG. This is called **one caliber stability**.



Weather Cocking

- Following the liftoff of a model rocket, it often **turns into the wind**. This maneuver is called **weather cocking** and it is caused by forces, such as a strong wind, pushing on the side of the rocket's fins.





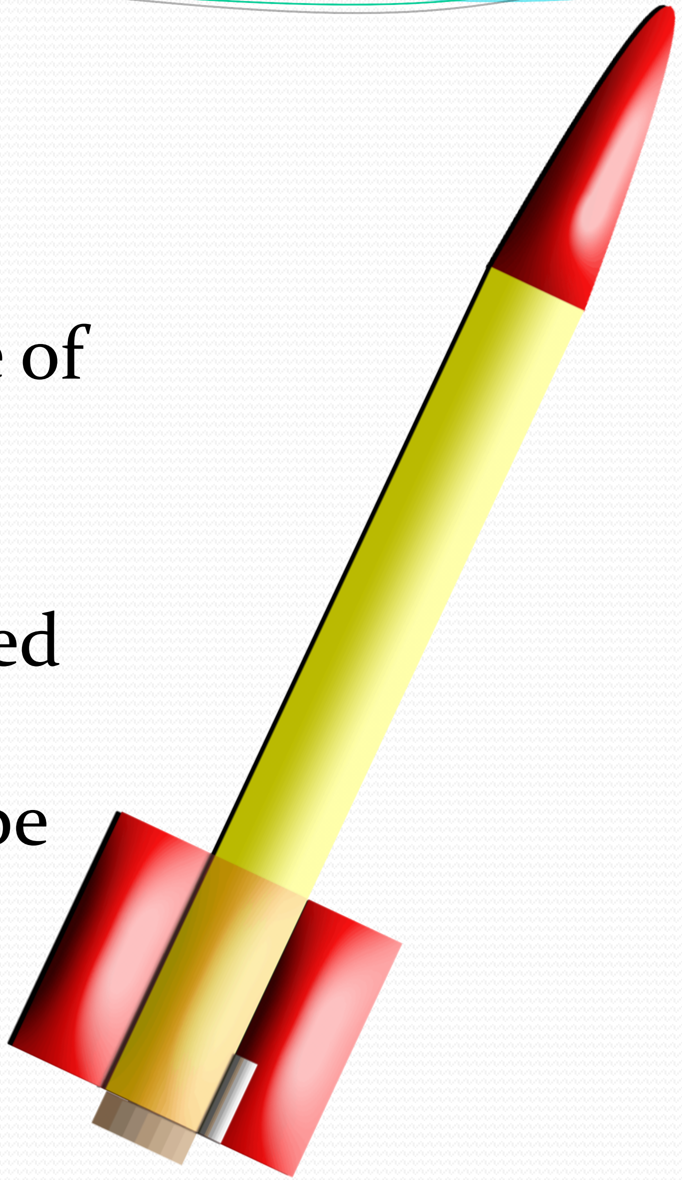
Effects of Weathercocking
Flight of a Model Rocket
Intended Flight Path
Altitude = A
Velocity = V
Launch
angle b
Actual Flight Path
Lost Altitude = H
Wind Velocity = w
$\tan b = \frac{V}{w}$
$H = A(1 - \sin b)$

Causes of Weather Cocking

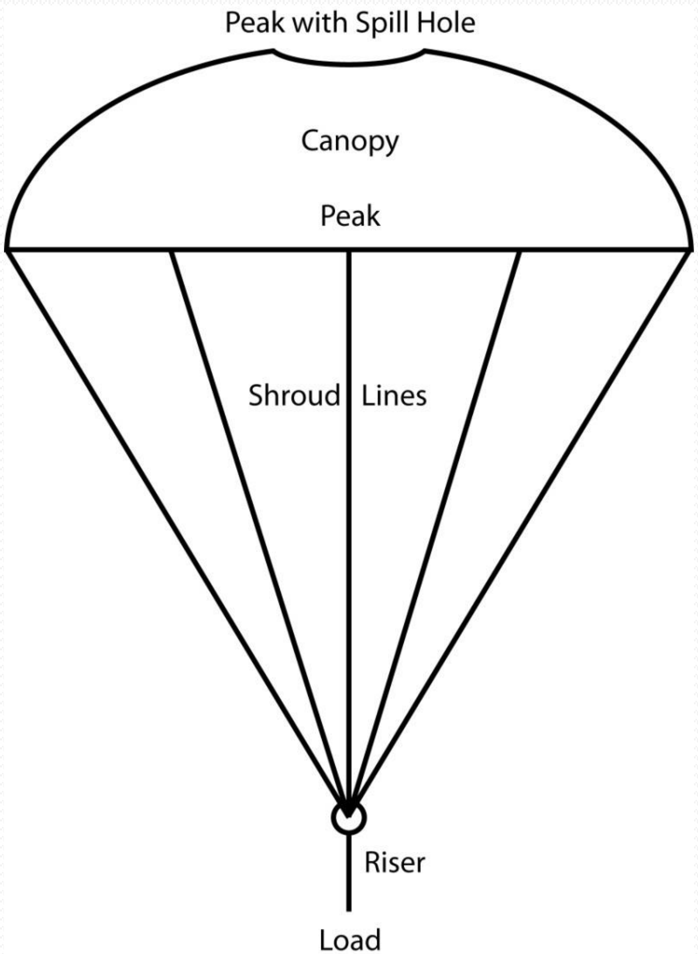
- Rockets with long airframes experience weather cocking, especially during the coast phase.
- Large fins present a larger surface area for the wind.
- Rockets with a center of gravity that is far in front of the center of pressure.

Tube Fins

- Using tube fins reduce weather cocking because of the aerodynamic side profile.
- Tube fins should be used carefully because these types of rockets tend to be unstable.



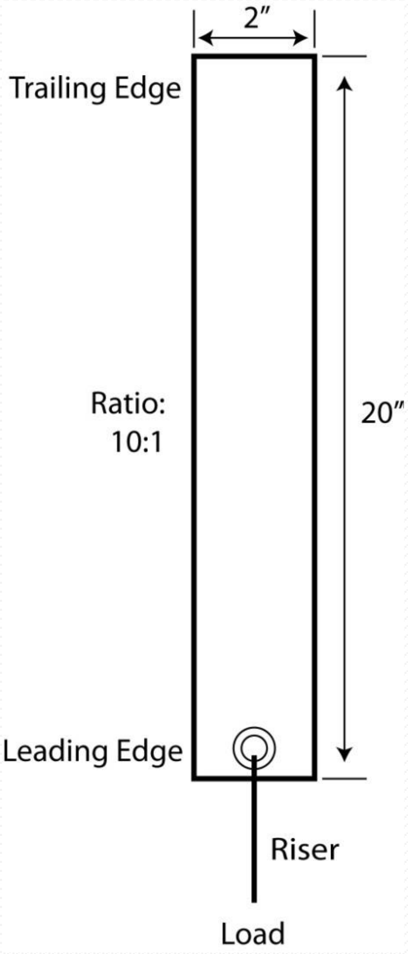
Parachute



- Parachutes are made out of **plastic**, **Mylar**, or **rip-stop nylon**.
- Shroud lines can be carpet thread or Kevlar chord.
- The **spill hole** reduces oscillation and increased descent rate.
- **Oscillation** is a swaying motion as the parachute spills air from its sides.
- Adding a **riser** lifts the parachute out of the turbulence of the rocket, but increases the risk of parachute failure.

Streamers

- Streamers are made out of **crepe paper**, **Mylar**, **Dura-Lar**, or **rip-stop nylon**.
- The best length to width radio is **10:1** to create the most drag as the streamer flaps in the wind.
- Streamer recovery is **faster** than parachute recovery and **reduces** the recovery area.



10 MINUTE BREAK

Launch Preparation

Are we launching rockets today!?!

Launching Model Rockets

Launch Day

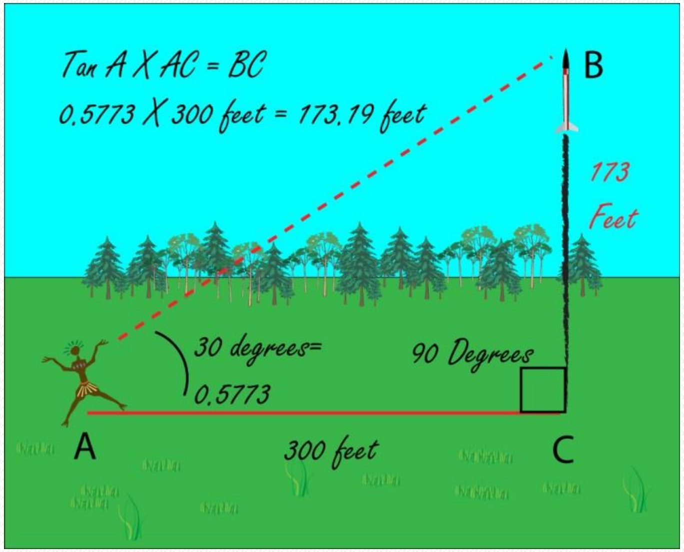
- Give as much responsibility to students as possible.
- Always maintain control.
- Expect problems so be familiar with equipment.
- Have glue and tape handy for repairs.

How to Determine Altitude

of a Model Rocket

Today's Mission

- **Mission:** Your team will determine the average velocity of the Quest Starhawk model rocket.



Summary

- Your team will launch your rockets to determine each rocket's apogee and determine the mode *(The most frequent value in the data set)* and the median *(The middle value that separates the higher half from the lower half of the data set)* averages.
- You will also determine the average velocity of the model rockets.
- Atmospheric conditions will be collected and recorded.

Materials

- **Materials:**
- A completed model rocket for each member. All rockets must have the same weight in grams.
- 2 trackers with Estes Altitracs at two separate locations
- 3 timers with stopwatches
- Class launch equipment.

Organization & Equipment

CONTROL CENTER

Flight Director
(Teacher)
2-Way Radio
Clipboard
Class Roster
List of Assignments
Countdown Procedures

StudentFlight Director
2-Way Radio
Clipboard
Countdown Procedures

Flight Controller
2-Way Radio
Clipboard
Countdown Procedures
Countdown Timer

Launch Control Specialist
Launch Controller

Communications Officer
Radios

ENGINEERING

Engineers
Launch Equipment
Model Rockets
Fire Extinguisher

Chief Engineer
Clipboard
Engineer Checklists
2-Way Radio

SECURITY & RECOVERY

Security/Recovery Team
Portable Table for CC

Security/
Recovery OIC
2-Way Radio

SCIENCE

Chief Scientist
2-Way Radio
Clipboard
Flight Log

Meteorology

Meteorologist 1
Sling Psychrometer
Stopwatch
Barometer
Thermometer
Clipboard
Meteorologist Wooksheet

Meteorologist 2
Cloud Chart
Stopwatch

Meteorologist 3
Anemometer
2-Way Radio

Flight Timers

1 each Stopwatch

Surveyors

Surveyor 1
Mearuring Wheel

Surveyor 2
Lensatic Compass

Altitude Tracking

Tracking OIC
2-Way Radio
Clipboard
Tracking Worksheet

Trackers
1 each AltiTrak

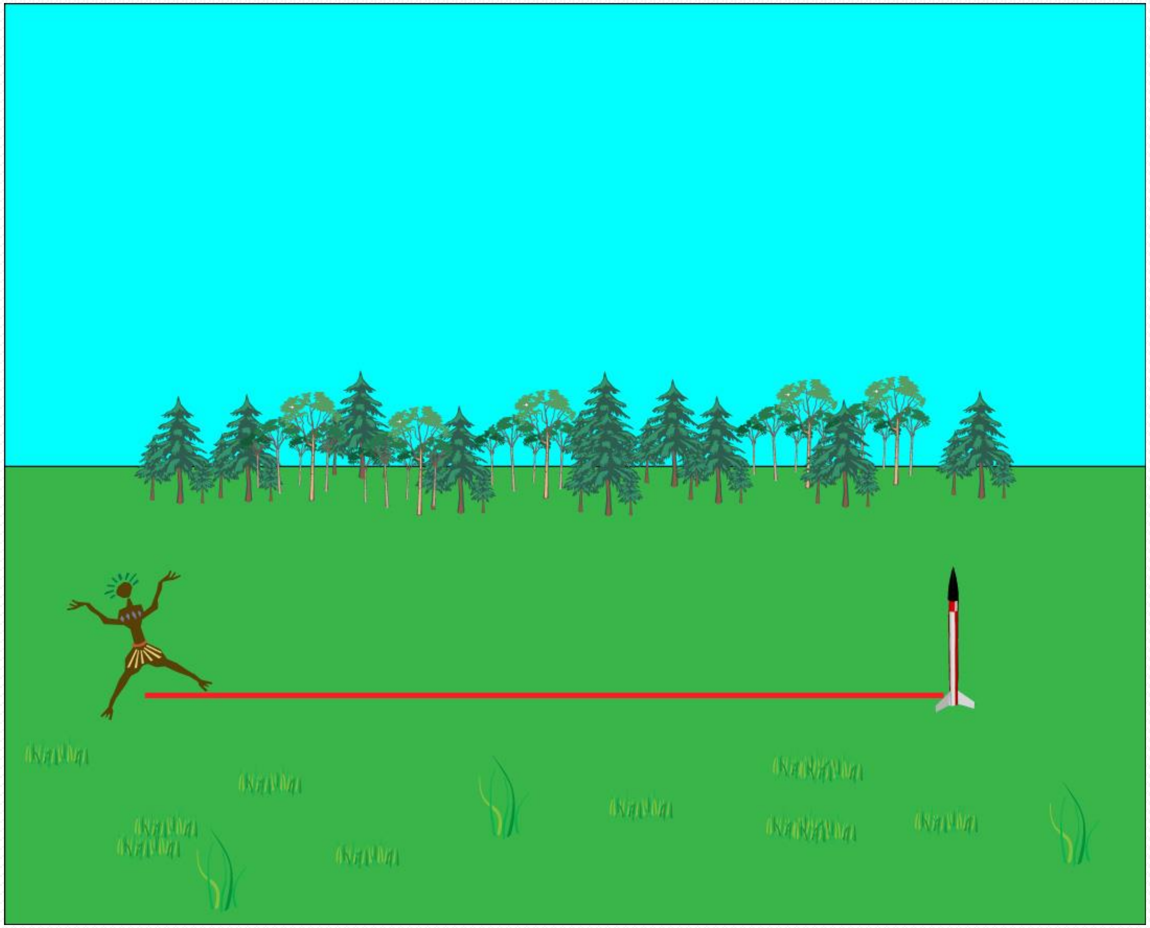
Assignments & Rotation

- Team A – Control Center
- Team B – Engineers/ Rocket Recovery
- Team C – Meteorology
- Team D – Tracking
- Team E - Timing

All teams shift down UP one assignment and firstteam moves DOWN to the last assignment: ABCDE, BCDEA, CDEAB, DEABC, EABCD

Rocket is ready to launch

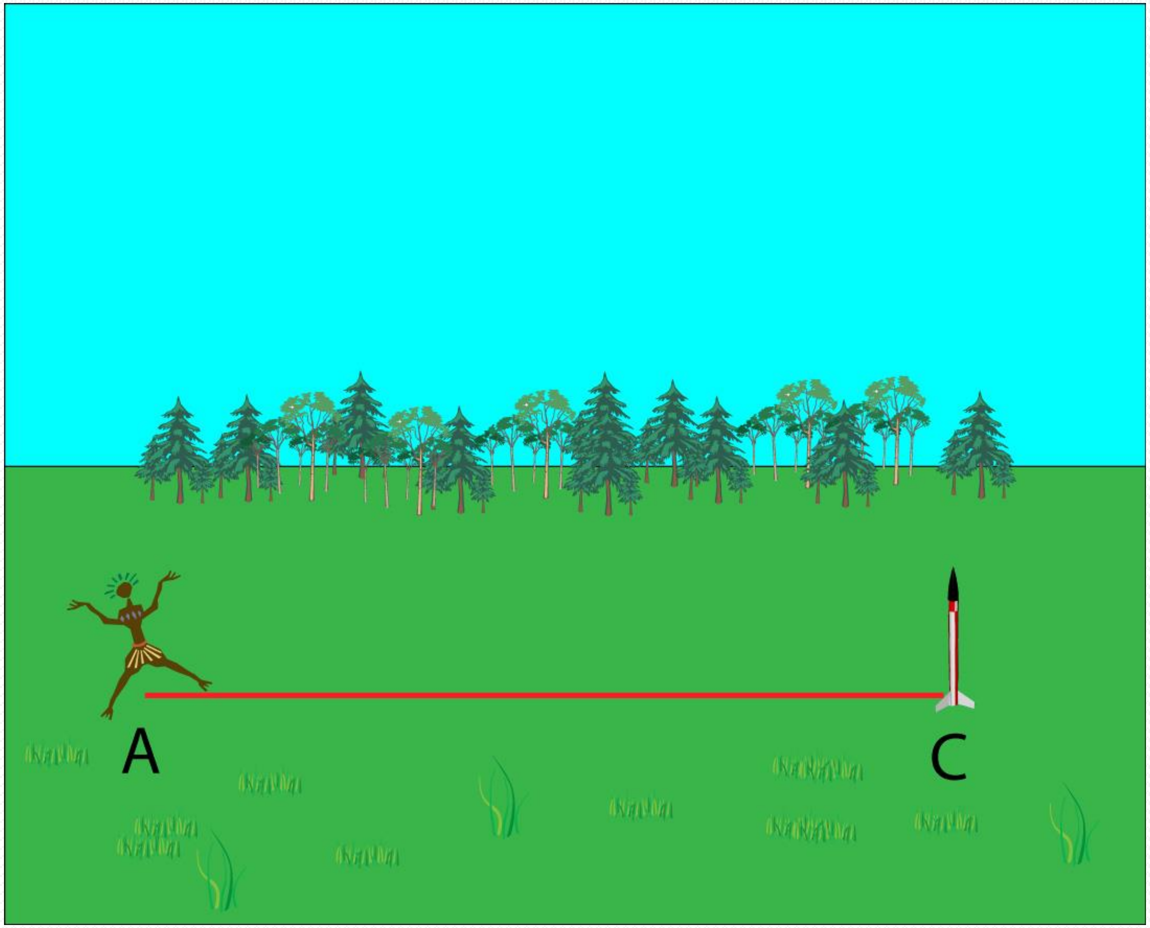
A Student with a Altitrac



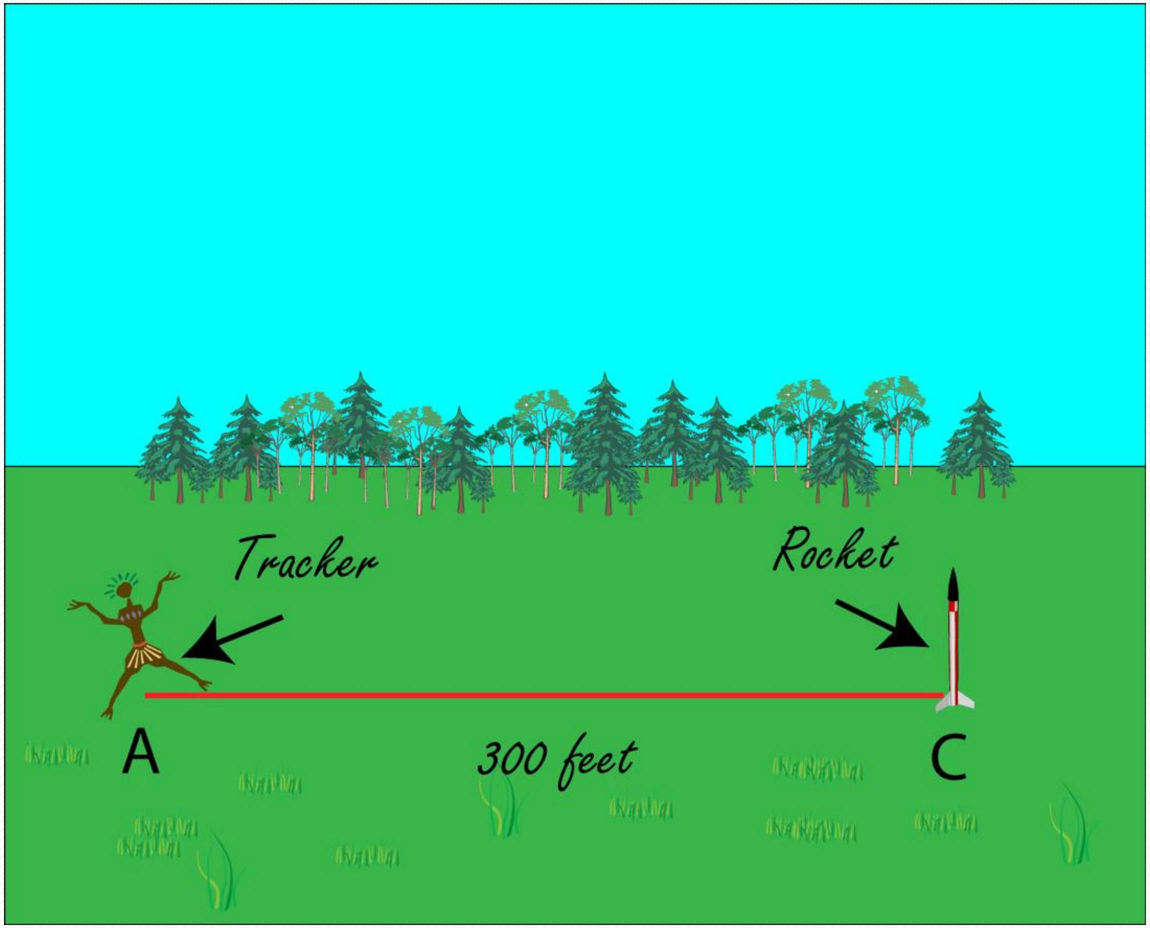
Sextant

A **sextant** is an instrument used to measure the angle between any two visible objects.

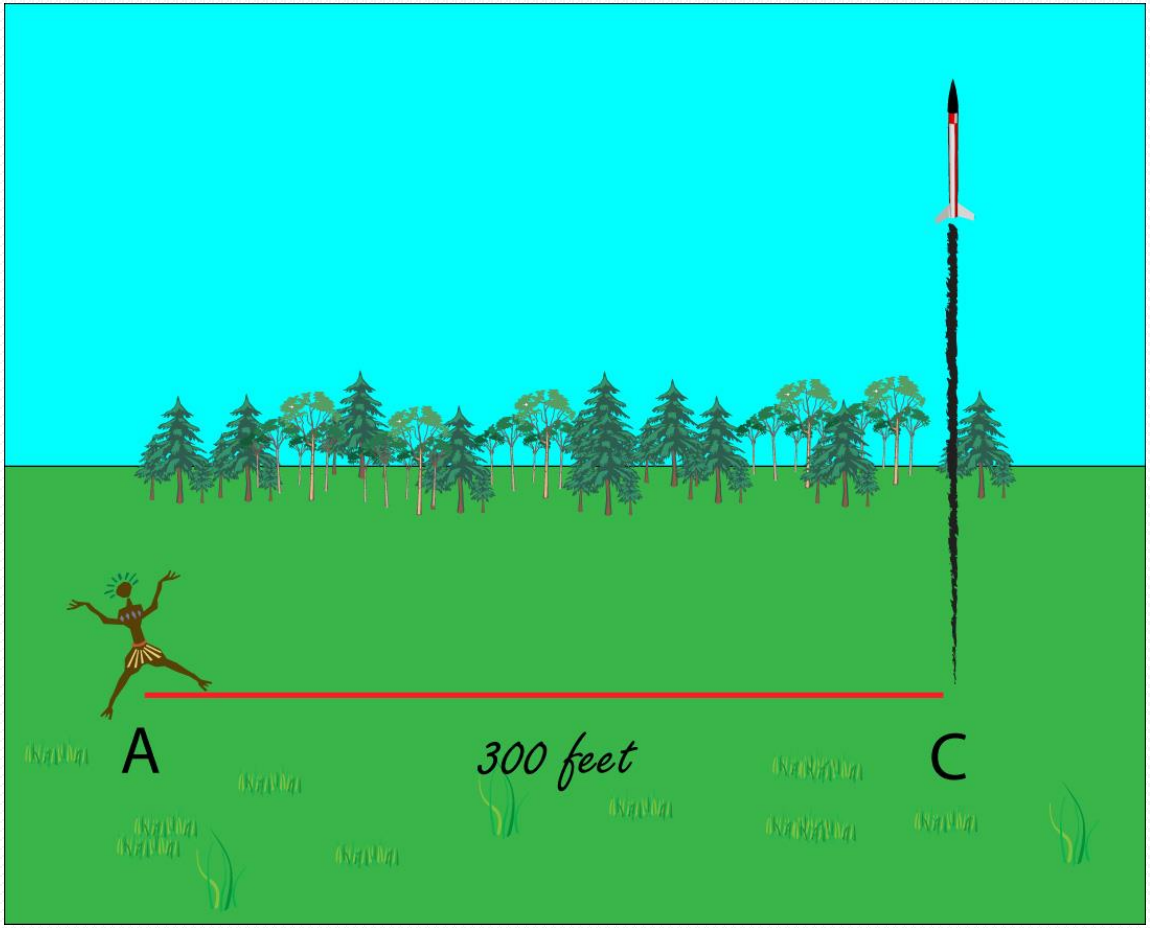
The line between student and rocket is Line AC



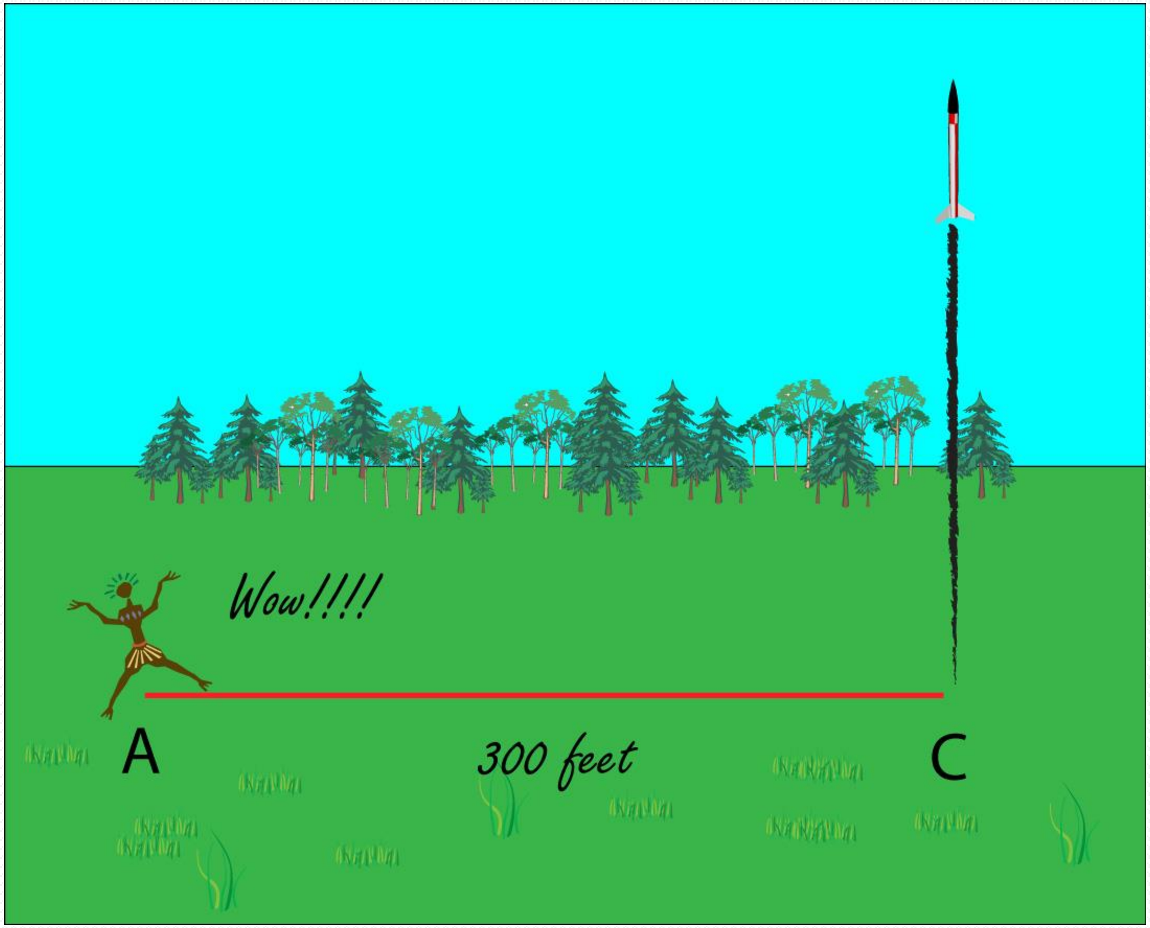
Line AC is 300 feet long



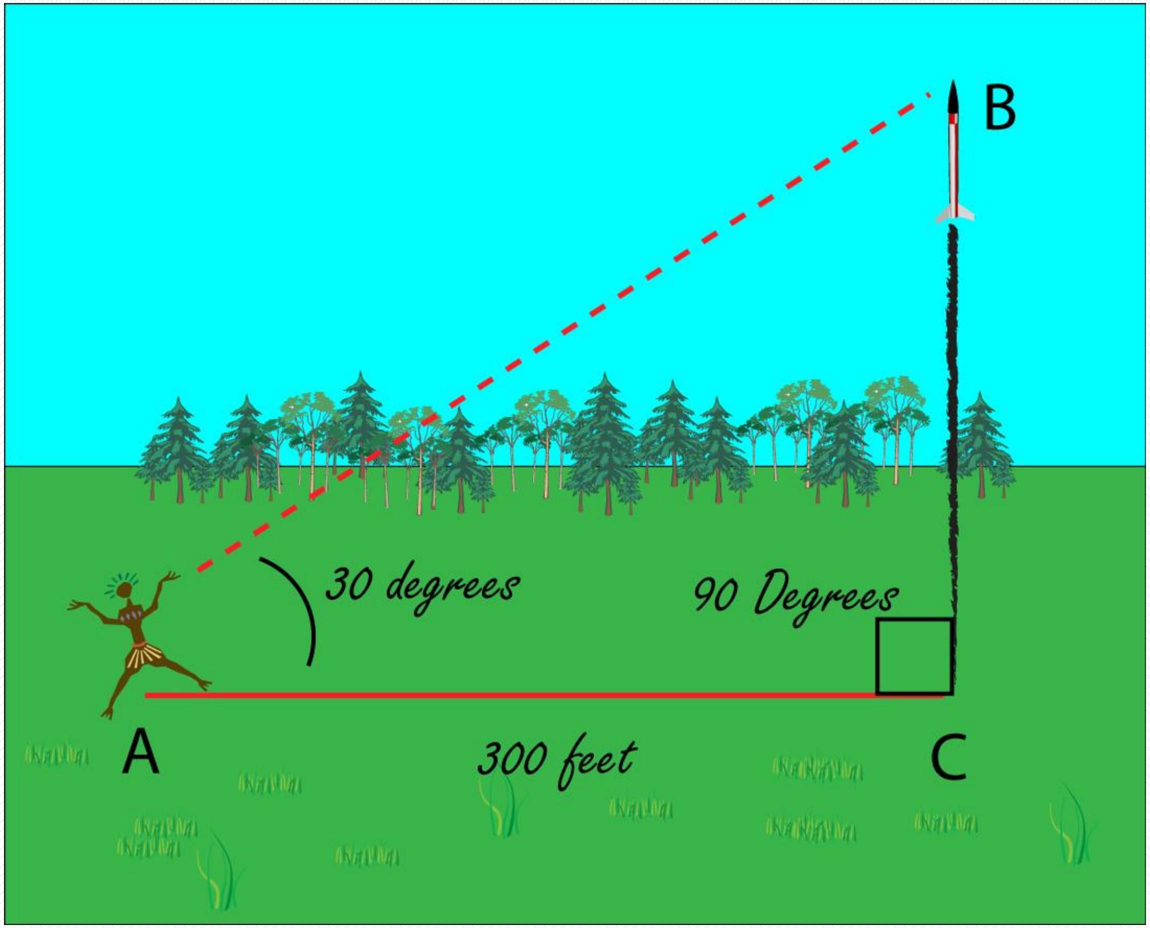
The rocket is launched



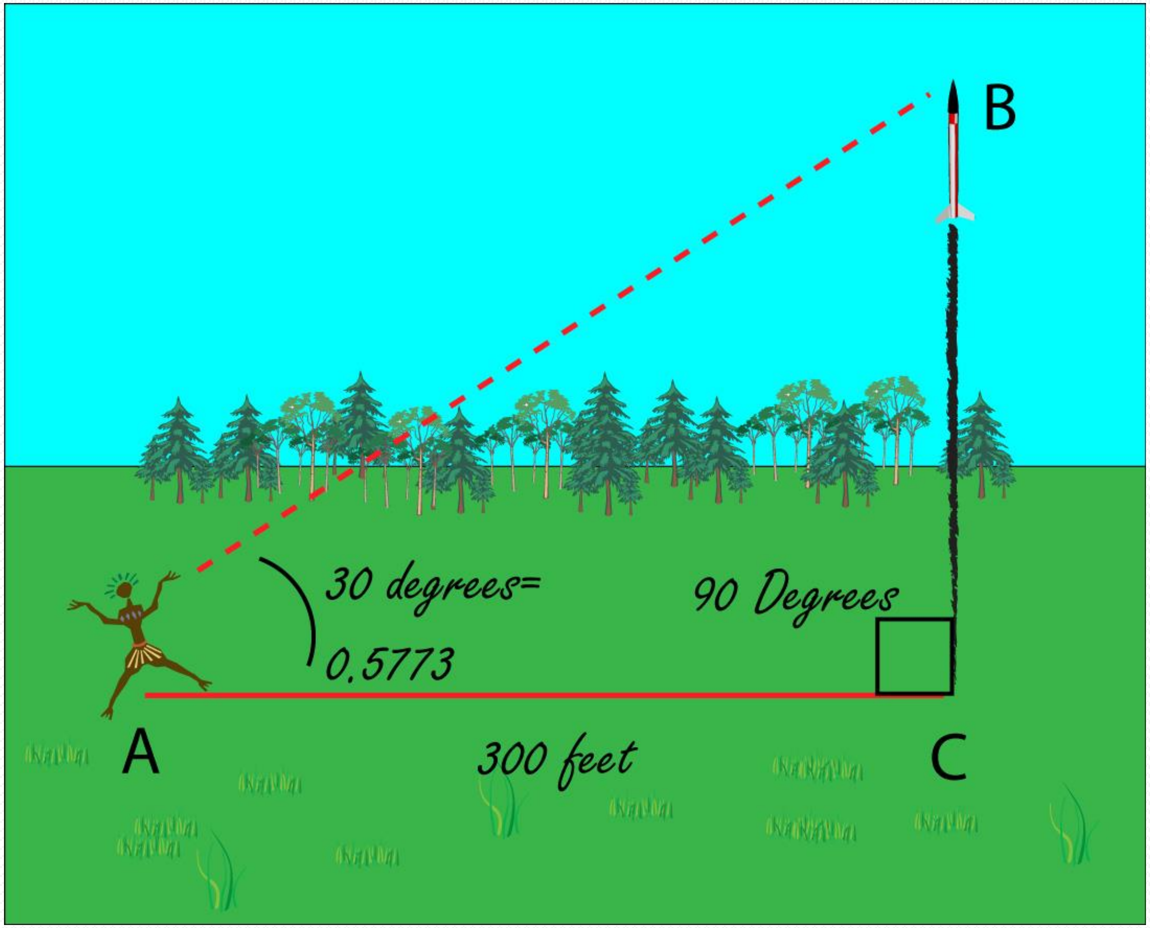
Stoked Student with Sextant



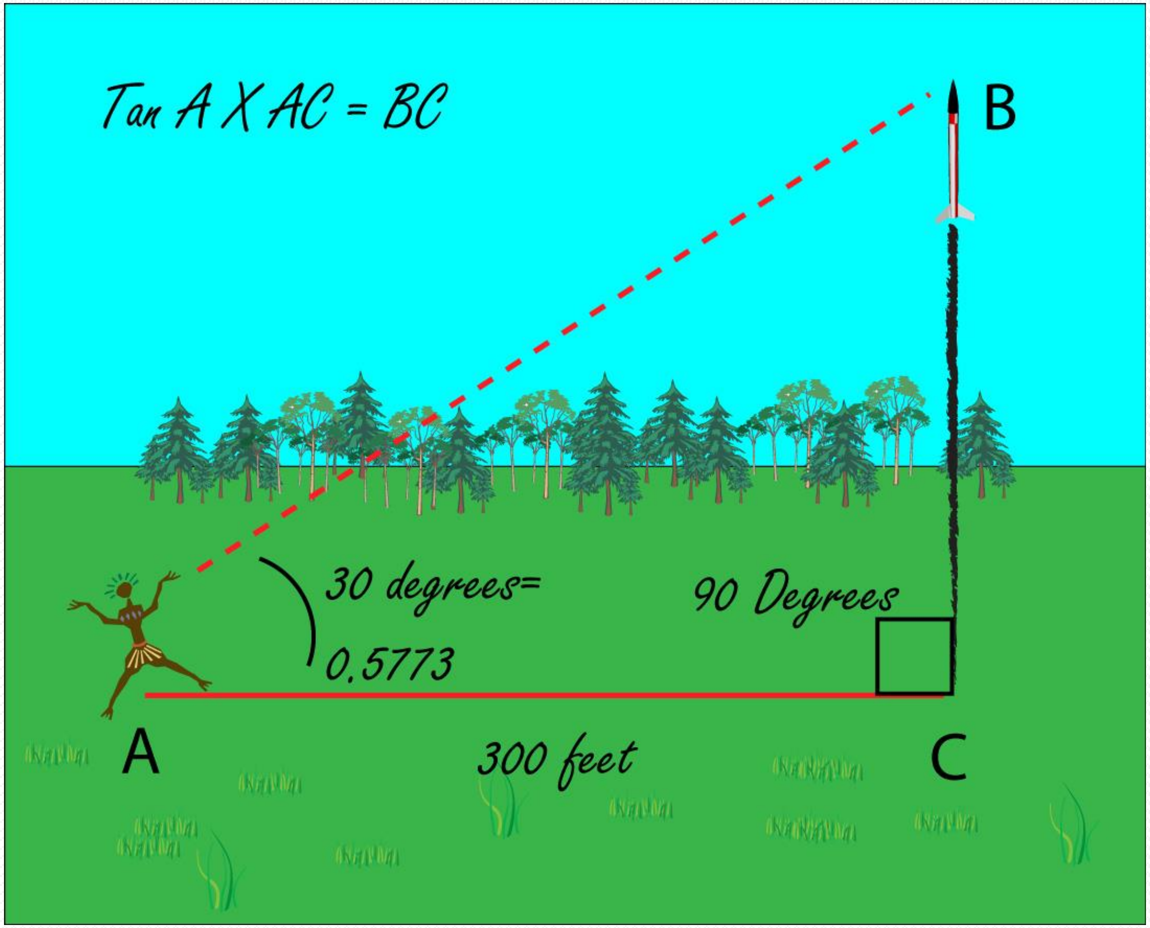
The student reads 30 degrees for Angle A



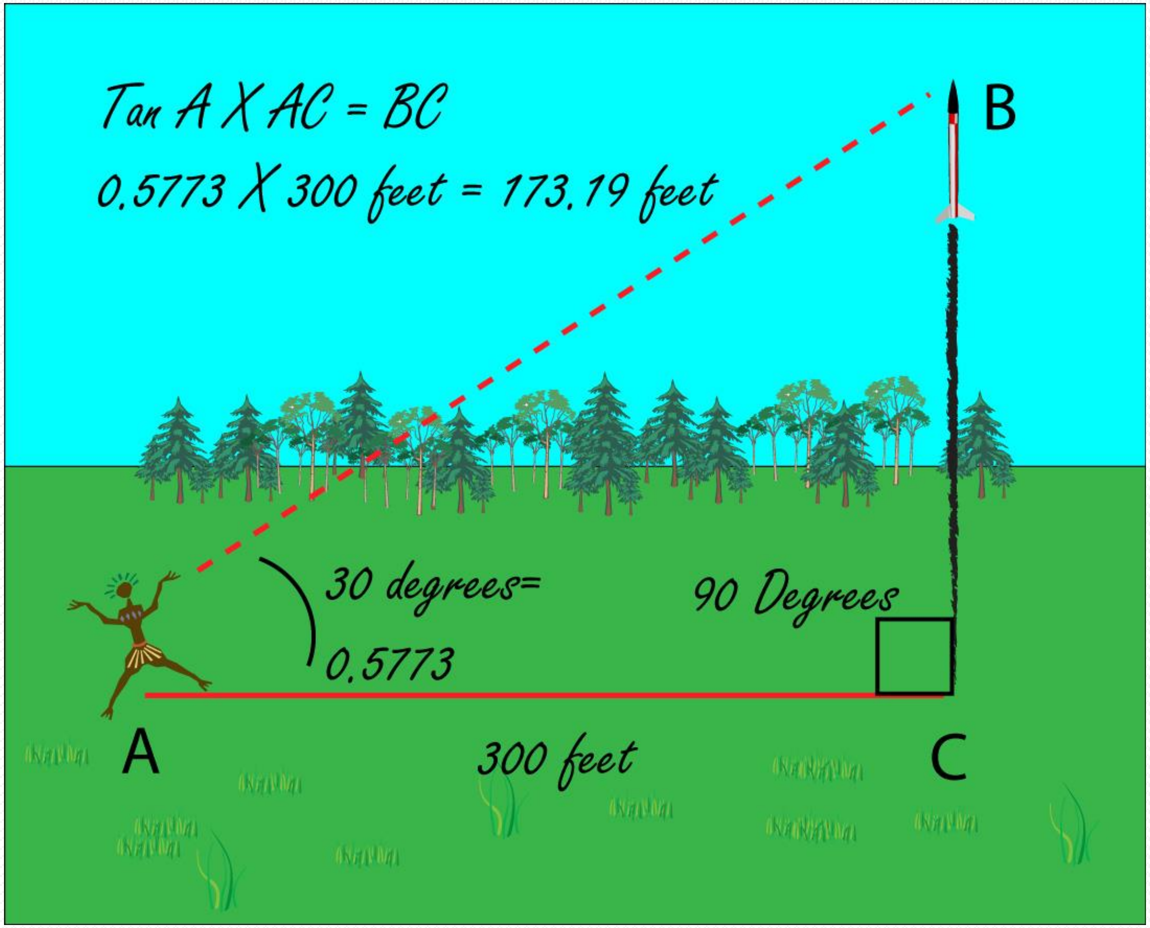
The Tangent of Angle A is 0.5773



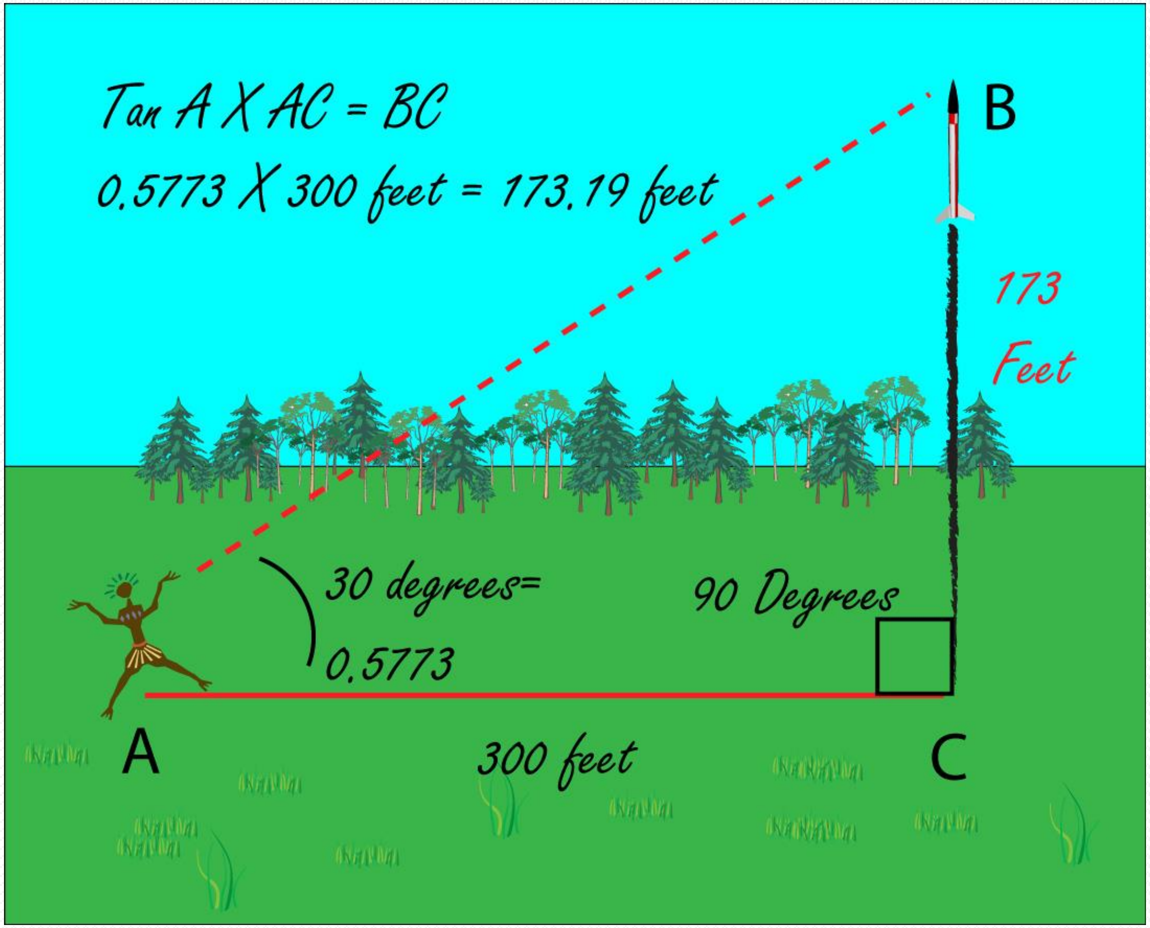
Tangent A times Line AC equals Line BC



Line BC equals 173 feet



Our rocket flew to 173 feet



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