National Aeronautics and
Space Administration

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The Next Generation of Explorers





Rocket Structures

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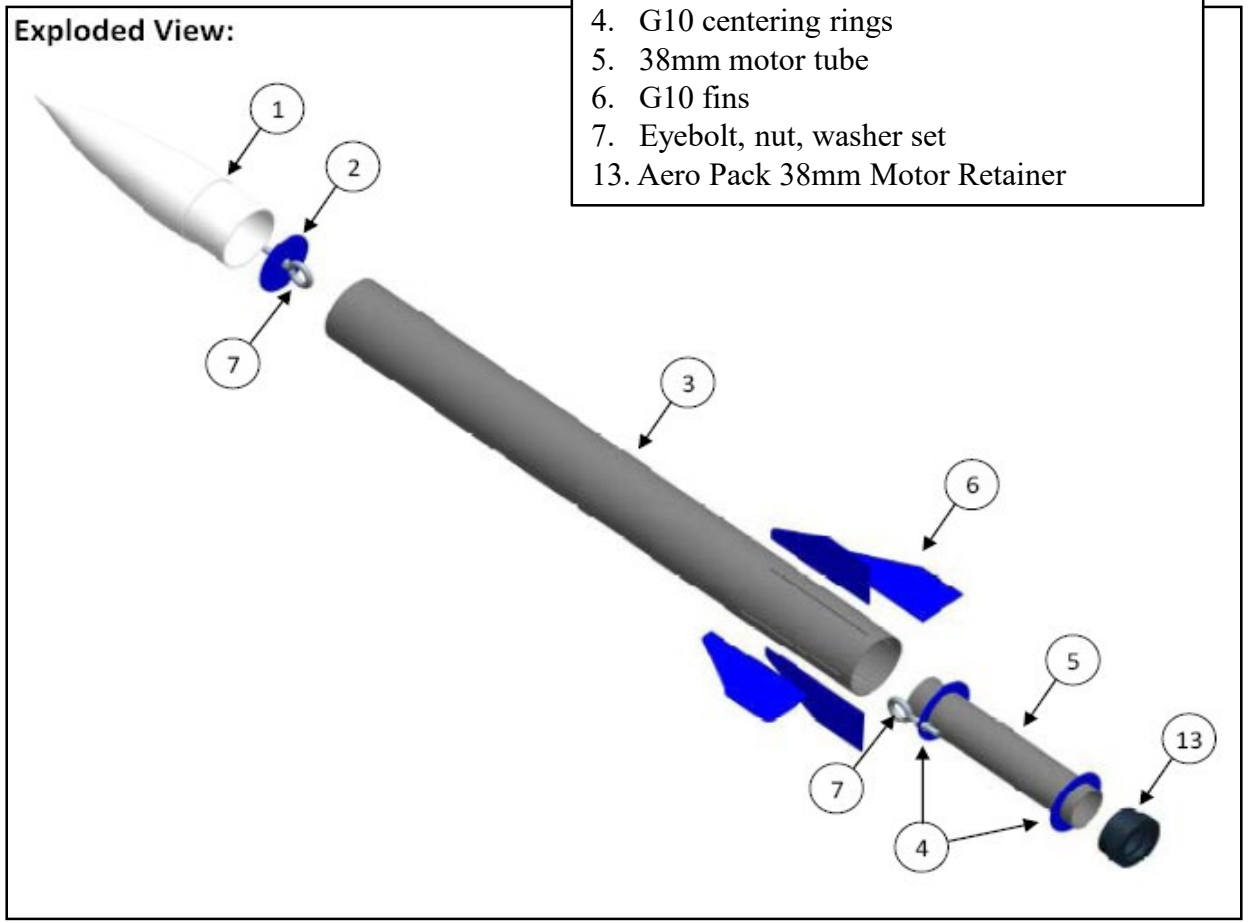
Hardware

Parts:

- All high powered rockets have the same basic parts.
- From the outside of a rocket, only a few are visible
  - Nose cone
  - Airframe
  - Fins
  - Rail Buttons
  - Motor Retainer
- On the inside of a rocket, there are:
  - Couplers
  - Motor Tubes
  - Centering Rings
  - Bulk plates /Bulkhead

Parts List:

1. Fiberglass nose cone
2. G10 nose cone bulk plate
3. Pre-slotted body tube
4. G10 centering rings
5. 38mm motor tube
6. G10 fins
7. Eyebolt, nut, washer set
13. Aero Pack 38mm Motor Retainer



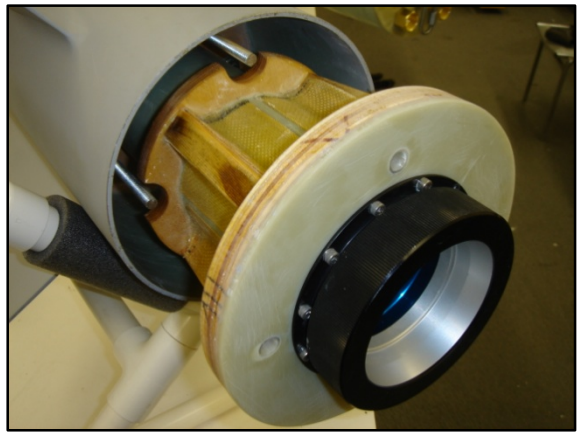
Hardware

Subassemblies:

- A subassembly is an assembled unit designed to be incorporated with other units into a finished product
- The nose cone can be considered a subassembly
- A *booster subassembly*, sometimes called a "*fin can*", is built from:
  - A section of airframe
  - a motor tube
  - centering rings
  - bulk plates
  - fins
  - motor retainers
  - sometimes couplers

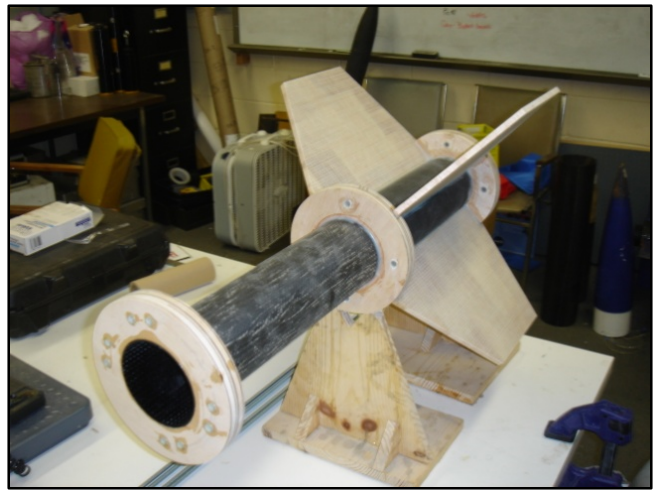
The nose cone subassembly has a removable plate on the bottom for access to the interior volume where a payload can be carried.





The motor tube subassembly is removable so the builder can inspect the fin tangs and centering rings between flights.

The fin can subassembly is ready for installation into a custom made carbon fiber airframe.



Hardware

Nose Cones:

- Forward most section of a rocket, missile, or aircraft
- Can be the payload or used to shield payload until deployment
- Shape chosen for minimum aerodynamic resistance (drag)

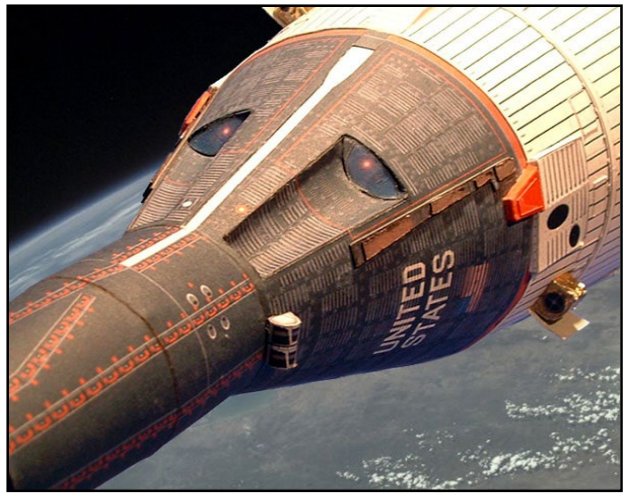
Typical HPR nose cone shapes:

- Conical, Ogive, Elliptical

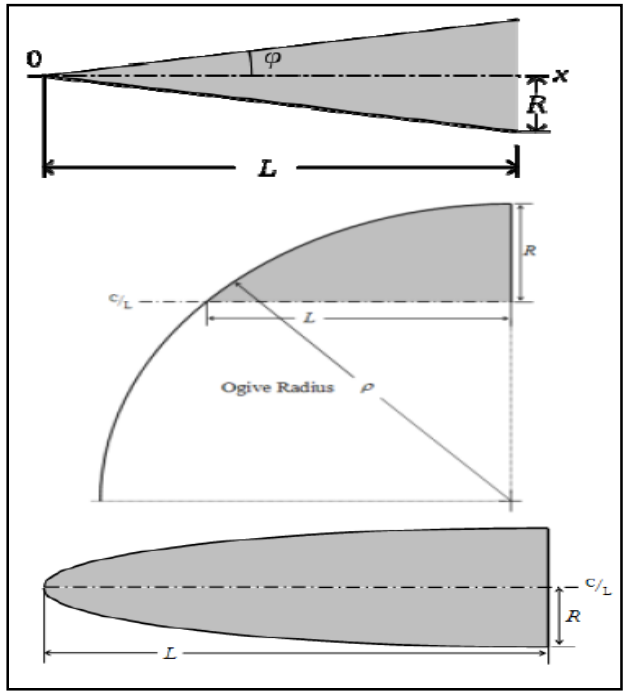
Typical HPR nose cone materials:

Composite: made of two different materials with different properties. The new material has better performance characteristics than the original materials on their own.

- **Fiberglass** –glass and plastic. Strong and affordable
- **Carbon fiber** – polymer resin and tiny carbon fibers. Very lightweight and strong
- **Urethane plastic** – not brittle, has greater elasticity and strength that regular plastic.







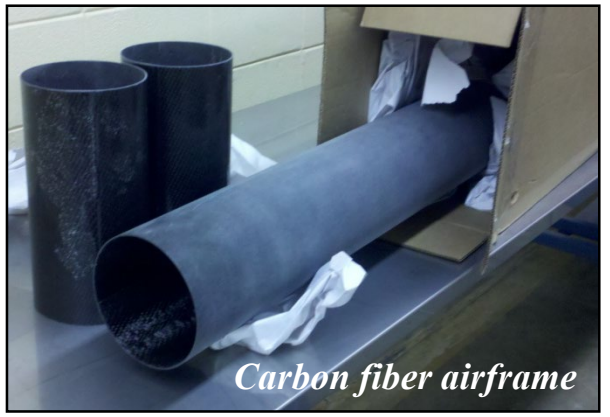


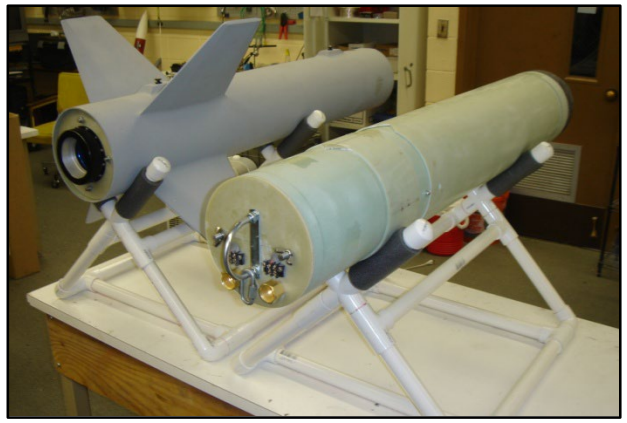
Hardware

High powered rocket airframes are typically made of non-metallic, high strength to weight ratio composite materials like carbon fiber, fiberglass, phenolic and PVC. (NAR rules) Paper and cardboard will not handle the loads of high powered rocket motors unless they are sufficiently reinforced with composite materials.

Airframe:

- Generally smooth thin walled cylinders with a high length to diameter ratio
- Encompass the rocket's propulsion system, recovery system, electronics, and payload
- Nose cone fitted to the forward end
- A set of fins are mounted towards the aft end.
- For *Minimum Diameter* rockets, the airframe also serves as the motor tube


Carbon fiber airframe



Typical HPR airframe materials:

- **Fiberglass**
- **Carbon fiber**
- **Phenolic** – resin impregnated, spiral wrapped, heat cured tube; stronger than cardboard, helps strengthen fiberglass and carbon fiber.
- **PVC** –polyvinyl chloride, widely used, strong and inexpensive

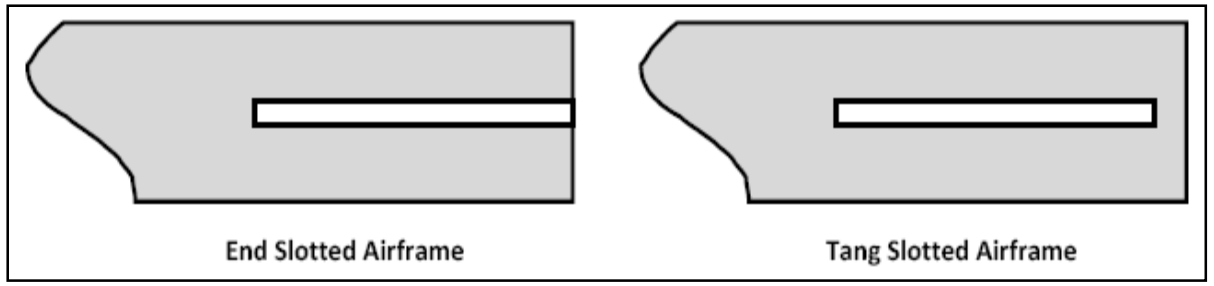


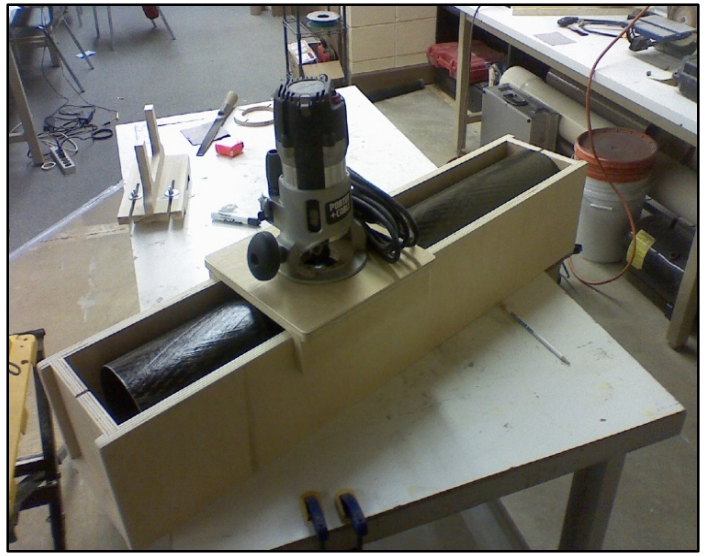
On large launch vehicles, the airframe is the outer surface of large pressurized fuel and oxidizer tanks.

Hardware

Airframes:

- Generally, fin slots in airframes come one of two ways:
  - **End Slotted**
  - **Tang Slotted**
- End slotted airframes
  - the fin slot is cut all the way to the end and the airframe can be slipped over a booster subassembly.
- Tang slotted airframes
  - The fin slot is stop before the end of the airframe
  - The fins have to be epoxied on after the motor tube subassembly is installed.





A jig is any device used to maintain, mechanically, the correct position relationship between a piece of work and the tool.

The rocket you can build from the workshop is tang slotted.

Hardware

Couplers:

- Joins multiple segments of airframe
- Its *Outer Diameter (OD)* is equal to the *Inner Diameter (ID)* of the airframe
- make a good place to store electronics

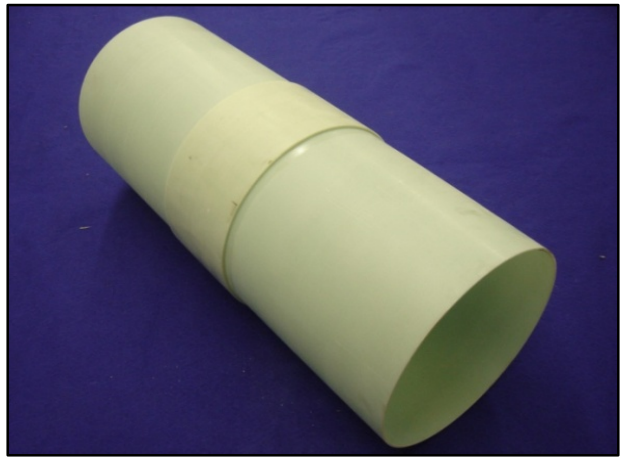
Typical HPR coupler materials:

- Fiberglass
- Carbon fiber
- Phenolic

Generally, rocket builders follow the convention that when joining airframes with a coupler, the coupler should extend at least one airframe diameter into each joined segment. So, if you were to join two 6 inch diameter airframes, you would need a coupler at least 12 inches long.



The *avionics bay* in the photo is built from a 12 inch long coupler with a 4 inch *collar* in the center. The collar allows direct access to the switches that power on the altimeters. This coupler joins two airframe segments that contain the recovery system by clicking into place with quick connect snap buttons.





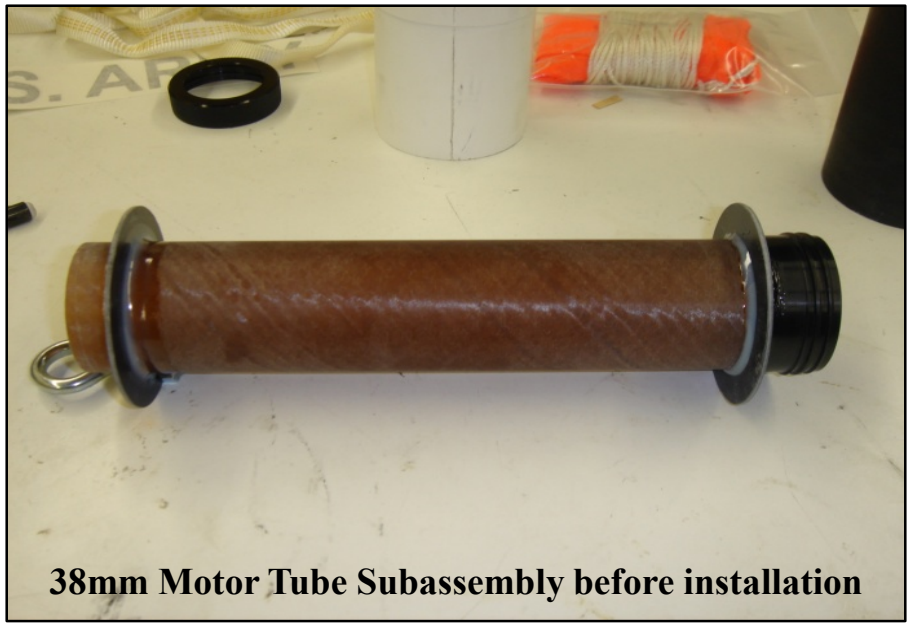
Hardware

Motor Tubes:

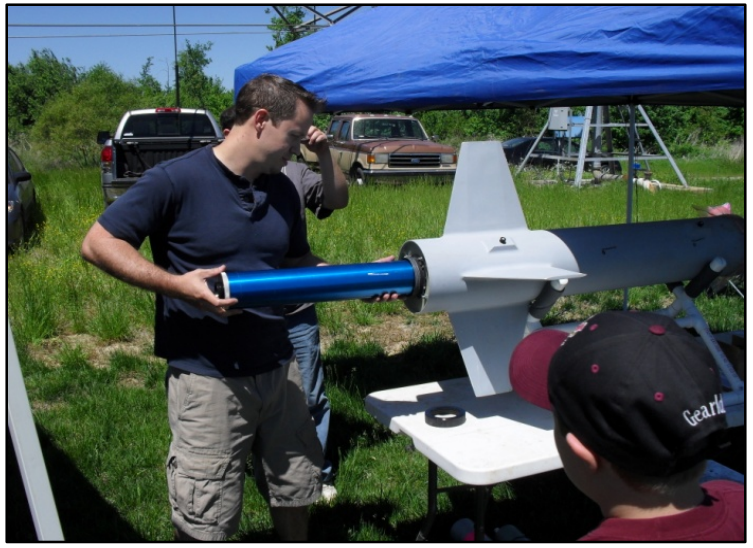
- Any tube inside of a rocket that is intended to fit a rocket motor
- Diameters are typically called out in millimeters and refer to the maximum diameter motor it is design to hold
  - 38mm
  - 54mm
  - 75mm
  - 98mm
- Larger HPR motor tubes may only encompass half of the tube because a full length motor tube can be heavy

Typical HPR motor tube materials:

- Fiberglass
- Carbon fiber
- Phenolic



38mm Motor Tube Subassembly before installation



Hardware

Motor Retainers:

- Any device that positively retains the rocket motor case inside of the rocket prohibiting it from falling out during flight
- There are many commercial motor retainers available for every size motor
- It is also very common for rocket builders to fashion their own motor retainer





In this workshop, you will be provided an Aero Pack 38mm motor retainer. The Aero Pack motor retainer base epoxies to the bottom end of a motor tube. The threaded cap screws on to the base after the motor has been installed into the motor tube.

Hardware

Centering Rings:

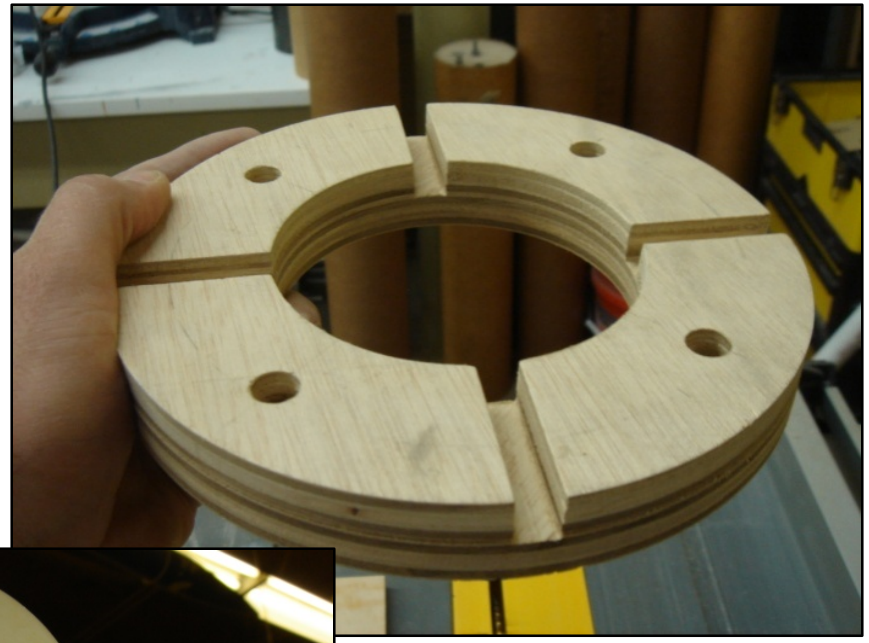
- Are used to concentrically align small tubes, like motor tubes, inside of an airframe
- and take many shapes depending on the number of inside tubes that are to be aligned

Bulk Plates / Bulkheads:

- Circular disks that fit inside of tubes to separate volumes
- serve as the mounting structure for other components

Typical HPR CR & BP materials:

- Birch Plywood
- Fiberglass
- Carbon Fiber

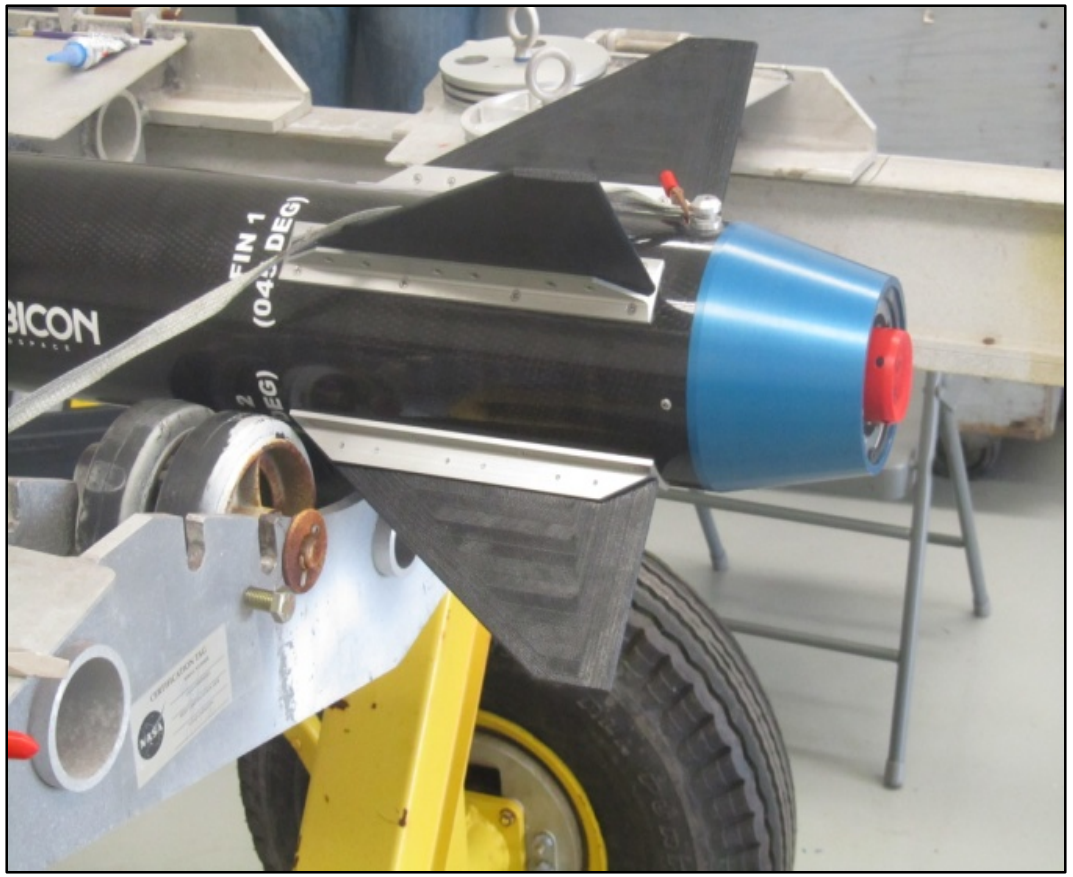




Hardware

Fins:

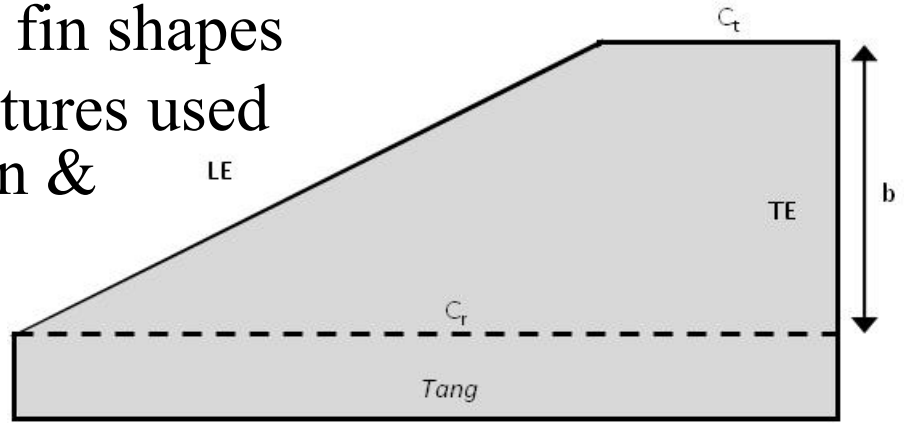
- Most rocket fins are designed with:
  - low aspect ratios (AR < 4)
  - taper ratio between 0.2 and 0.4
    ideal for minimum induced drag (δ)
- Typically fins Materials:
  - G10 fiberglass
  - Carbon fiber
  - Plastics
  - Plywood
- More complex fins are composites of two or more of these materials

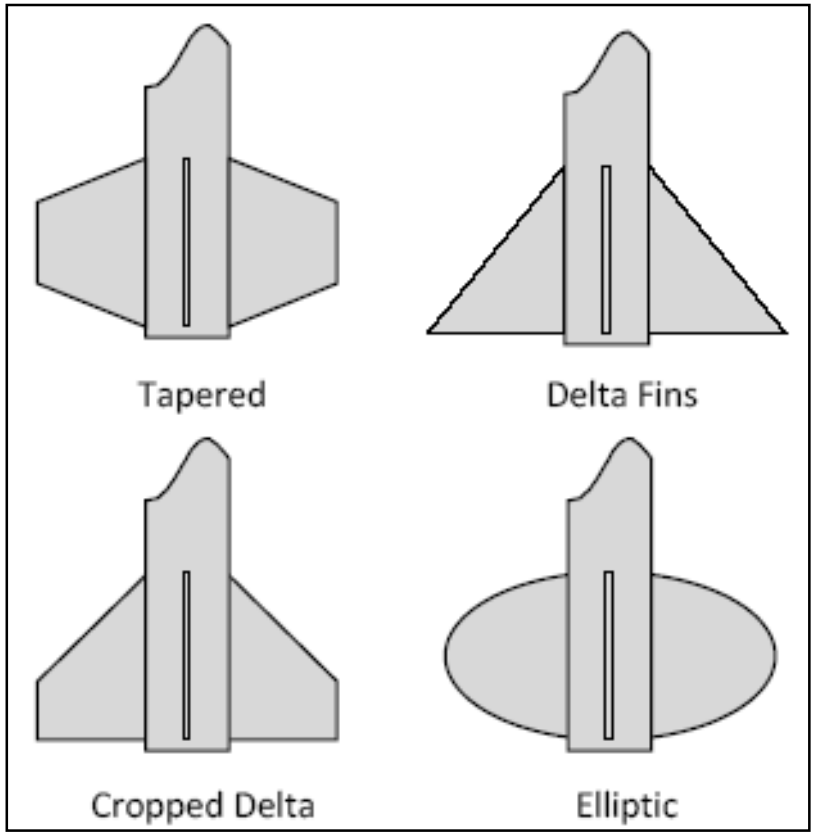


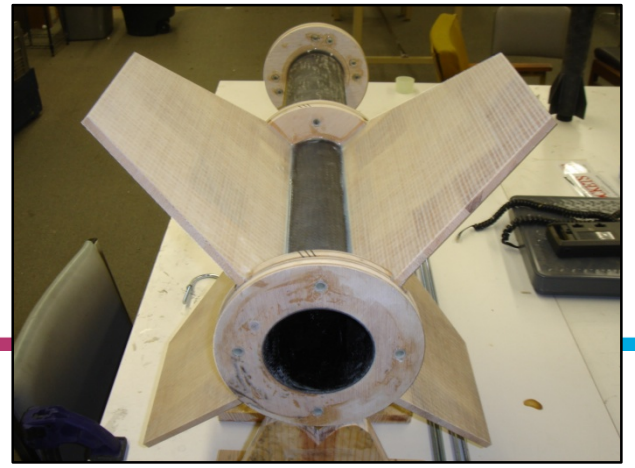
Hardware

Fins:

- Flat fixed stabilizing structures extending from the body of a rocket that give stability in flight
- There are four common fin shapes
- Each fin has several features used to characterize its design & performance:
  - Tip chord (c_t)
  - Root chord (c_r)
  - Span (b)
  - Leading Edge (LE)
  - Trailing Edge (TE)
  - Aspect ratio (AR)



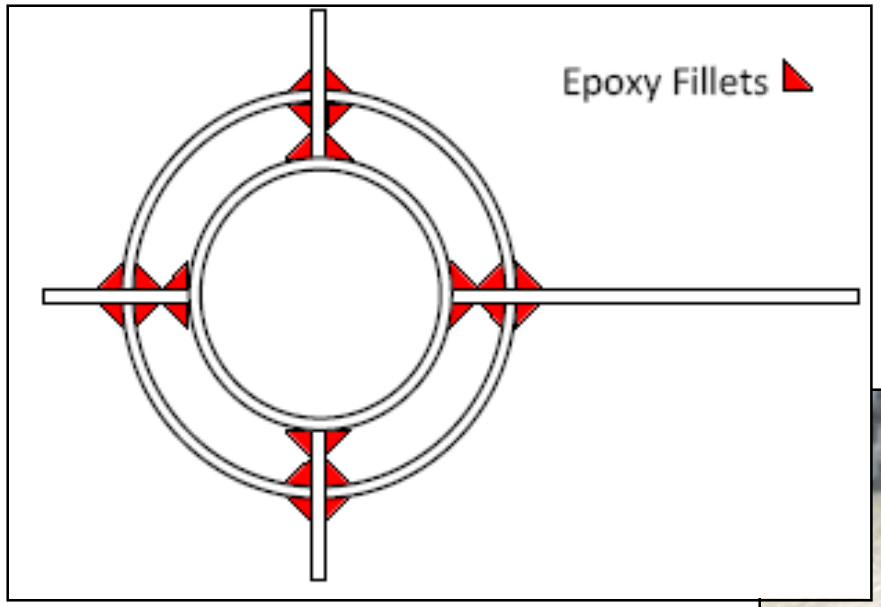


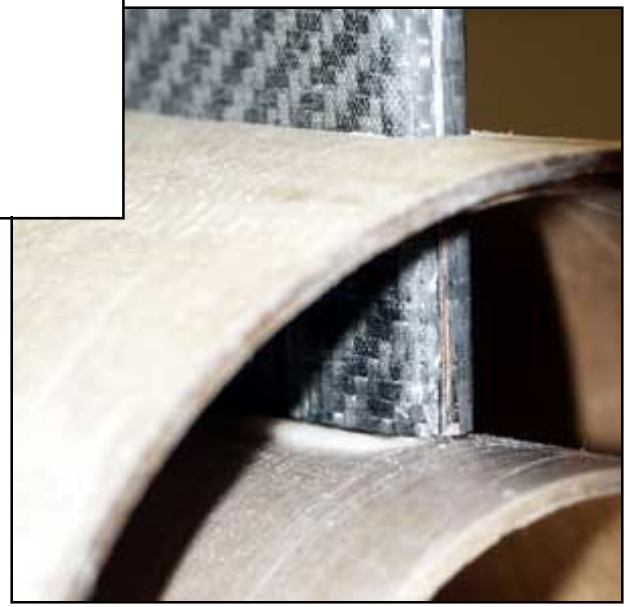


Construction Technique

Through-The-Wall (TTW):

- Widely used fin mounting technique
- The fin tang passes through a slot in the airframe and epoxies flush against the motor tube
- Epoxy fillets are applied on every side of each joint.





Construction Techniques

Epoxy:

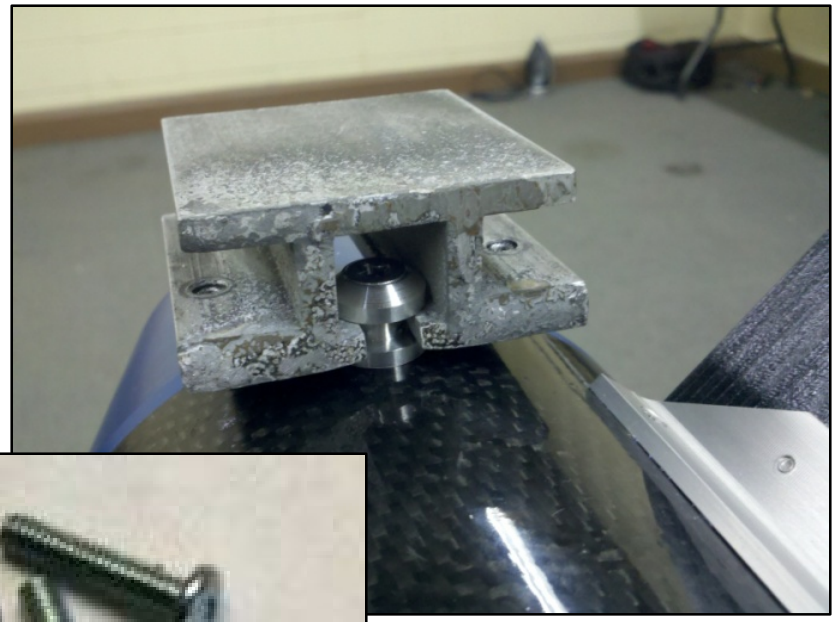
- Epoxies are two part adhesive systems – 1) resin and 2) curing agent
- Chemically react to cure/harden and adhere materials together
- Mixing epoxy can prove to be messy
- Time critical task that require some technique and planning to maximize use



Hardware

Rail Buttons:

- Most HPRs use rails / not rods
- Require rail buttons
- Usually hard smooth plastics
- Slides freely inside channel of extruded aluminum
- Constrains the rocket's movement until sufficient velocity is achieved that the fins become effective for flight stability
- Two rail buttons are required and one is typically located:
  - Near the bottom of the booster or center of pressure
  - Near the center of gravity
- Should be rigidly mounted to the rocket
  - Large washer and nut inside airframe near a CR.

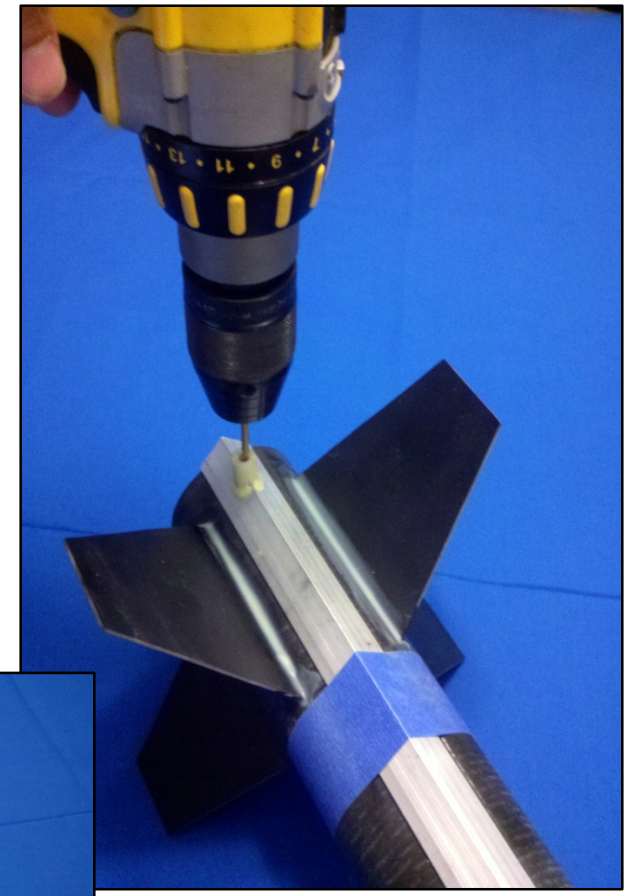




Construction Technique

Rail Button Jig:

- Simple tool to accurately and quickly repeat rail button alignment
- Made from a length of angled aluminum with drill bit alignment guides
- The angled aluminum will align itself when laid flush on the airframe
- Tape the jig in place with some masking tape
- Drill the forward and aft rail button screw holes with the desired size drill bit
- Small rail buttons usually use a #8 size machine screw





Structural Testing

Development Testing:

- Developmental tests are conducted during the design phase of the project
- Generally only a representative test of a component of a subsystem
  - Verify that the hardware will perform as required
  - Develop a manufacturing method conceived of in the early design process before committing resources to the development of the flight hardware

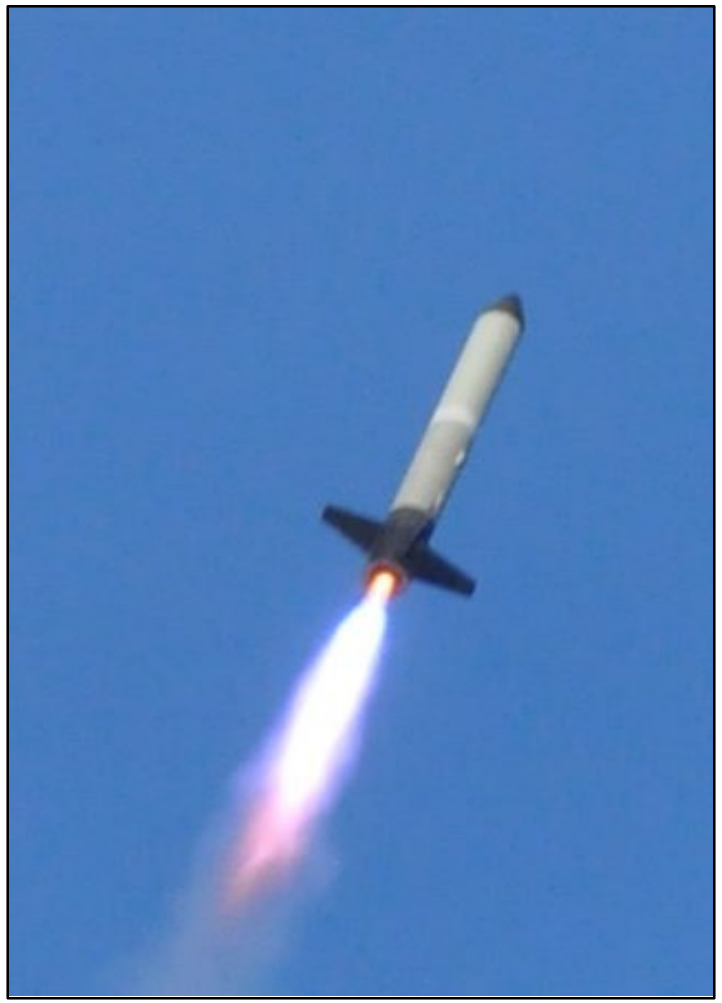


Qualification Testing:

- Qualification test are conducted at the end of the design process
- These tests are generally flight components or entire systems
- Once Qual Tests are completed, the components or systems can be classified as approved for flight



Forces on a Rocket

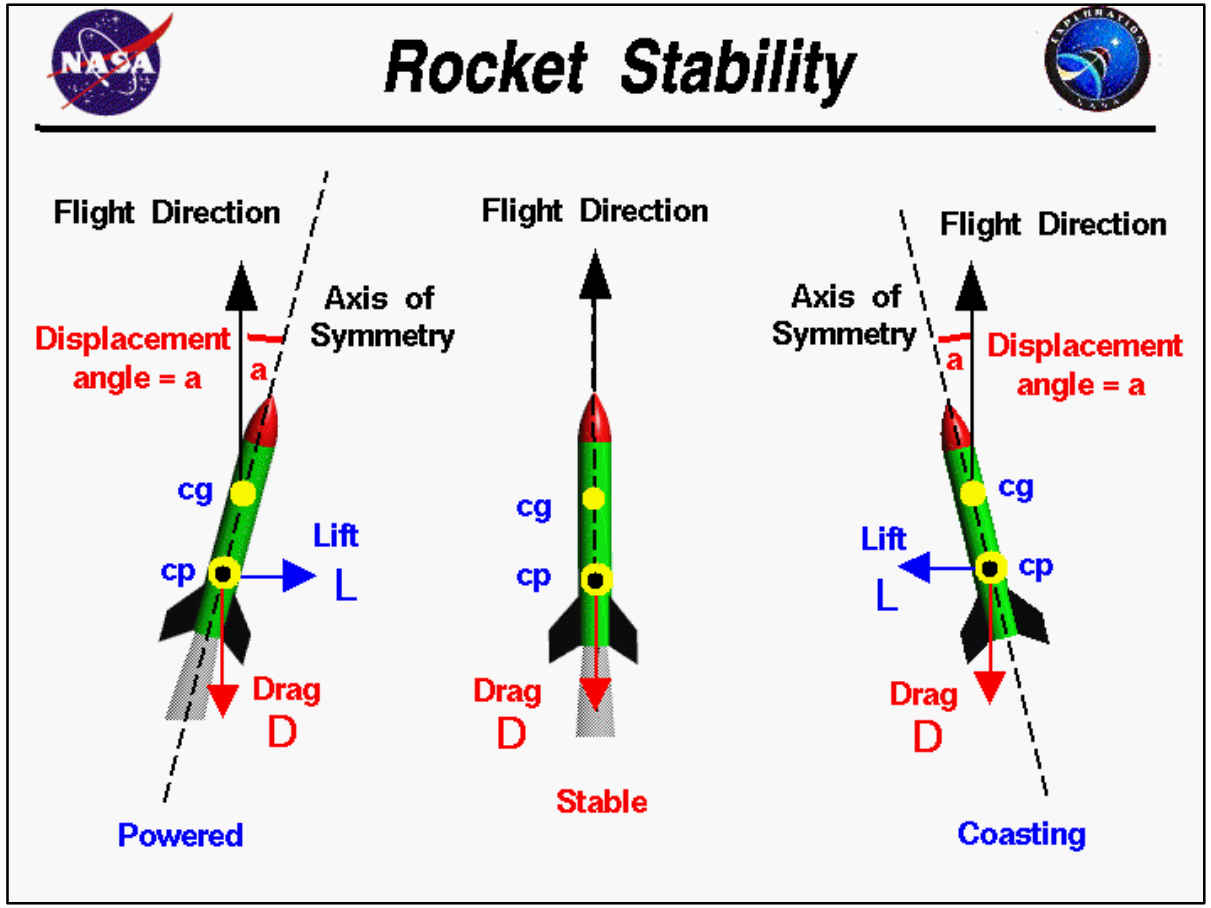


- In flight, a rocket is subjected to four forces:
  - *Weight* - always directed towards the center of the earth and acts through the center of gravity
  - *Thrust* – Opposes *Weight* depends on the mass flow rate through the engine and the velocity and pressure at the exit of the nozzle
  - *Lift* - act through the center of pressure
  - *Drag* –depends on the shape, size, and velocity of the rocket and on properties of the atmosphere
- Summation of these forces, accounting for the direction, results in a net external force on the rocket
- The resulting motion of the rocket is described by Newton's laws of motion
  - **Newton's 1st Law:** Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.
  - **Newton's 2nd Law:** The relationship between an object's mass m, its acceleration a, and the applied force F is F = ma.
  - **Newton's 3rd Law:** For every action there is an equal and opposite reaction.

Stability

Stability:

- An object is directionally stable if tends to return to its original direction in relation to the oncoming medium (water, air, etc.) when disturbed away from that direction
- Also called “weather vaning”
- Without stability, a rocket would tumble end over end, spin, or orient itself at a high angle of attack and the rocket may experience structural failure
- **A rocket is considered stable if its *Center of Gravity (CG)* is at least one body diameter in front of its *Center of Pressure (CP)*.**



Stability

$$S.M. = \frac{\bar{X}_{CP} - \bar{X}_{CG}}{Body\ Diameter} \geq 1.0$$

Static Margin:

- Or *Margin of Stability* describes the directional stability of a rocket
- Recall:
  - An object is directionally stable if tends to return to its original direction in relation to the oncoming medium (water, air, etc.) when disturbed away from that direction and
  - A rocket is considered stable if its *Center of Gravity (CG)* is at least one body diameter in front of its *Center of Pressure (CP)*.

- Generally, it is desirable to have a static margin of 1.5 to 2.0. A rocket is considered over stable if it has a static margin of 3.0 or greater.
- An over stable rocket will lean or "weather vane" further into the wind and not travel as high.
- Generally, the CG will move forward as a solid rocket motor burns, causing the rocket to become more stable.

Stability

Center of Gravity (CG):

The Center of Gravity of rigid body is the mean location of all the masses in a system

- The CG can be determined analytically or empirically
- The analytical method requires accounting for:
  - The individual point masses that compose the system
  - their location in the system as measured from the tip of a rocket's nose cone
- The average of their positions weighted by their masses is the location of the center of gravity

Component	Weight (W_i) (oz.)	Station ($\bar{X}_i$) (in.)
Fiberglass Nosecone	3.4	6.5
Nosecone Mass	2	1
G10 Nosecone Bulkplate	0.3	10.5
Nosecone Eye-Bolt	0.8	10.5
Pre-slotted Fiberglass Airframe	7.7	21
12' Shock Cord	2	18
30" Parachute	1	15
9x9 Chute Protector	0.5	18
Forward G10 Centering Ring	0.2	26
Forward Centering Ring Eye-Bolt	0.2	26
38mm Motor Tube	2.3	31
G10 Fins (4x)	1.9	31
Aft Centering Ring	0.2	34
Aero Pack 38mm Motor Retainer	0.8	34
CT1 Pro 38-2G Case	3.5	30
CTI H225 Motor Reload	6.8	30

$$(1)\ \bar{X}_{CG}W_{CG} = \sum_{i=1}^{n} W_i\bar{X}_i = W_1\bar{X}_1 + W_2\bar{X}_2 + W_3\bar{X}_3 + \cdots$$

$$(2)\ W_{CG} = \sum_{i=1}^{n} W_i = W_1 + W_2 + W_3 + \cdots$$

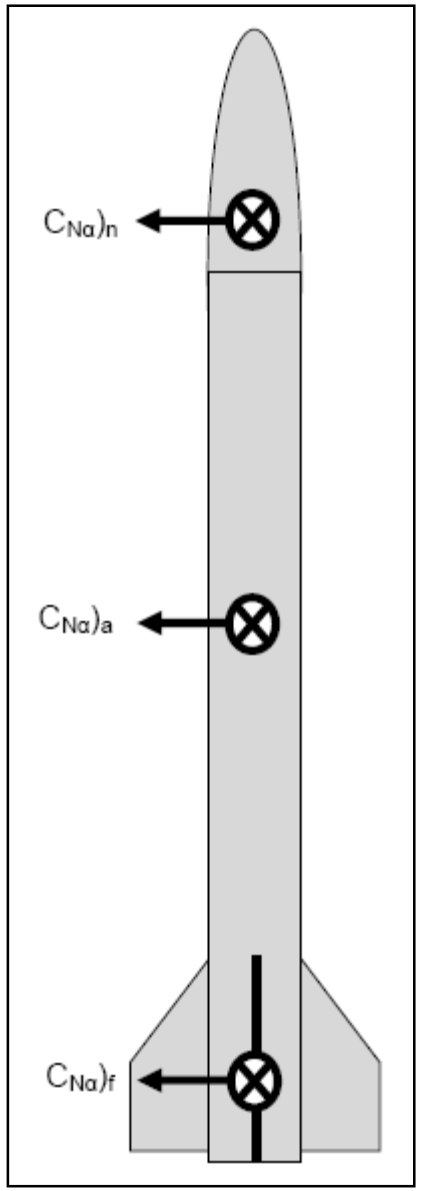
$$(3)\ \bar{X}_{CG} = \frac{\bar{X}_{CG}W_{CG}}{W_{CG}}$$

Stability

Center of Pressure (CP):

Aerodynamic forces act on all parts of the rocket. Those aerodynamic forces act through a single point called the Center of Pressure (CP).

- CP can be determined by regional influence using algebraic forms of the Barrowman equations and accounting for:
  - Each primary component's Normal Force ($C_{n\alpha}$)
  - Their location in the system as measured from the tip of a rocket's nose cone
- The basic assumptions used to calculate the theoretical CP for a rocket are:
  - The angle of attack (α) of the rocket is near zero (less than 10^{o})
  - The speed of the rocket is much less than the speed of sound
  - The air flow over the rocket is smooth and does not change rapidly
  - The rocket is thin compared to its length (L >> D)
  - The nose of the rocket comes smoothly to a point
  - The rocket is an axially symmetrical rigid body
  - The fins are thin flat plates



Questions?