Basics of Rocketry

Prepared for:
NASA Student Launch Initiative
And
Team America Rocketry Challenge

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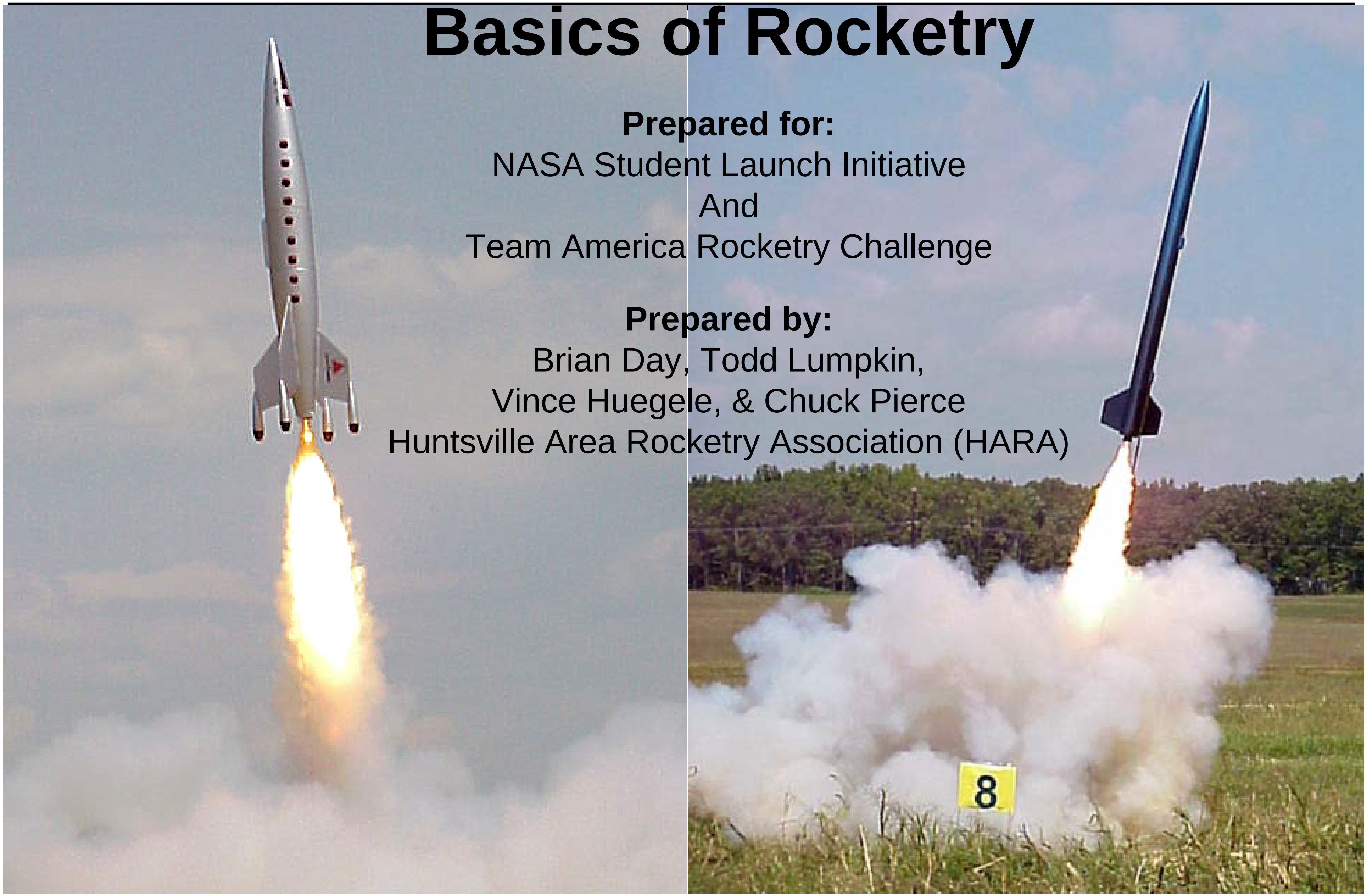
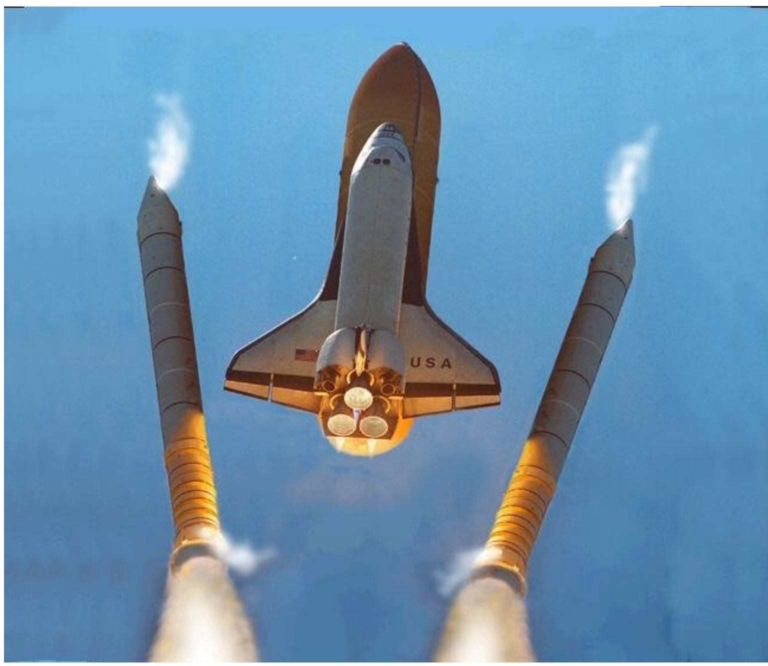


Contents

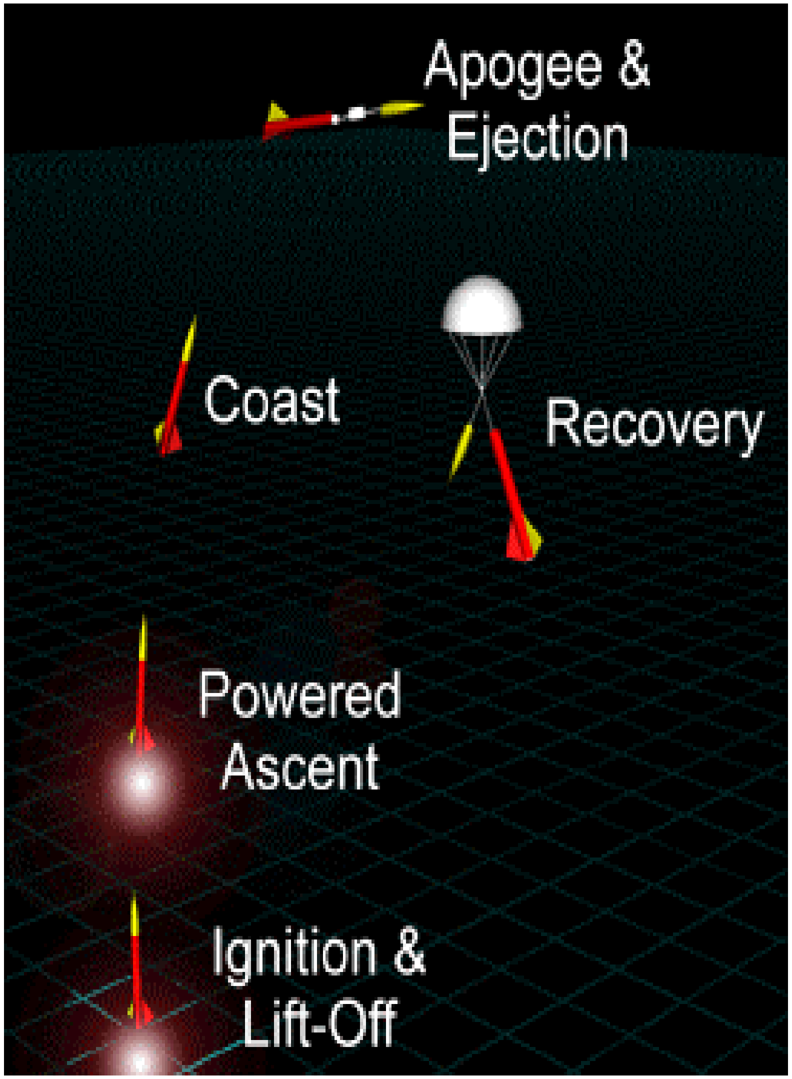
Types of Rockets

- **Missiles (military use)**
- **Space Vehicles (manned and unmanned)**
- **Sounding Rockets**
  - **Sub-orbital**
  - **Research**
  - **Weather**
- **Amateur (hobby)**


Phases of Rocket Flight

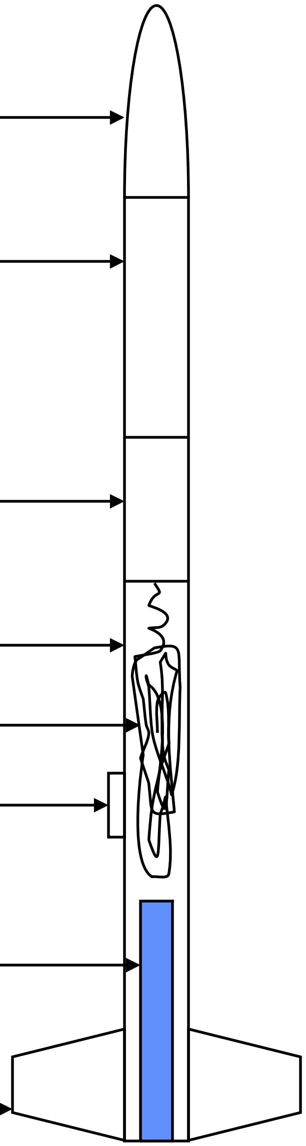
- Preparation (very important!)
- Ignition and Liftoff
- Powered Ascent
- Coast
- Recovery System Deployment
- Descent
- Recovery



Courtesy: Rocket Vision

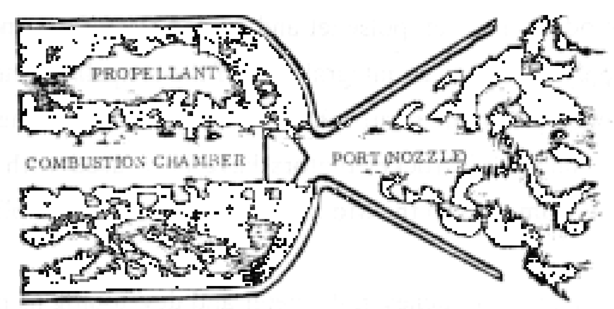
Components of a Typical Rocket

- Nosecone
- Payload
- Electronics (optional)
- Body tube
- Recovery System / harness
- Launch lug
- Motor
- Fins



Propulsion Basics

- **What causes a rocket to move?**
  - **Newton's Third Law of Motion:**
    - **For every action there is an equal and opposite reaction**
- **Rocket motor = energy conversion device**
  - **Matter (solid or liquid) is burned, producing hot gases.**
  - **Gases are accumulated within the combustion chamber until enough pressure builds up to force a part of them out an exhaust port (a nozzle)**
  - **Thrust is generated by a pressure buildup within the combustion chamber and by mass ejection through the nozzle.**
  - **Combustion chamber geometry, throat diameter, and nozzle geometry govern performance and efficiency**

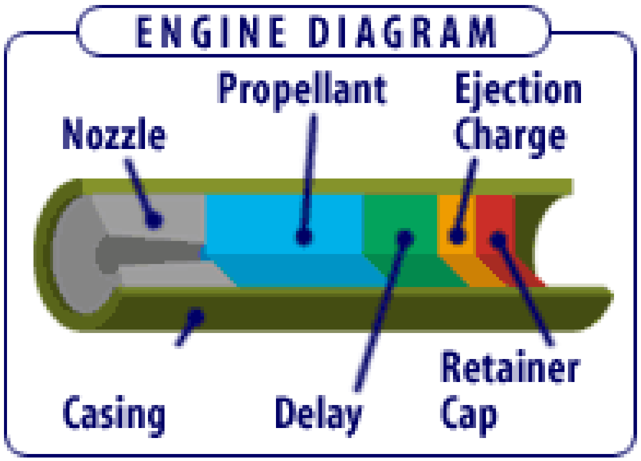


Propulsion (cont)

- **Rocket propellant consists of two components:**
  - **Fuel**
  - **Oxidizer**
- **Rocket Motor Types:**
  - **Liquid Propellant**
    - **Both fuel and oxidizer are separately stored liquids**
    - **Mechanically complex, expensive, not generally used by amateurs**
    - **Examples: LH2/LOX, kerosene/LOX, alcohol/H2O2**
  - **Solid Propellant**
    - **Both fuel and oxidizer are mixed together as a solid mass.**
    - **Examples: black powder, ammonium perchlorate propellant**
  - **Hybrid**
    - **Typically solid fuel, liquid oxidizer**
      - Nitrous Oxide (NO2) is a preferred oxidizer due to its availability and its willingness to ‘donate’ oxygen for combustion
    - **Examples: plastic/NO2, cellulose/NO2, PVC/NO2**
    - **Several designs available for amateur use**

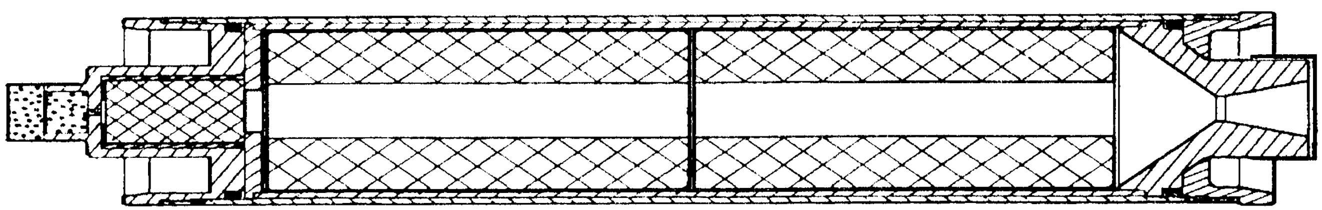
Propulsion (cont)

- **Black Powder Solid Rocket Motors**
  - Estes and Quest model rocket motors
  - 1/4A through E impulse
  - Single Use
  - End Burning propellant
  - Advantages:
    - No regulatory issues
    - Easy availability (Most hobby stores, many discount dept. stores)
    - Low cost
    - Easy to ignite (Estes/Quest controller, several AA batteries)
  - Disadvantages
    - Low efficiency (specific impulse)
    - Age constraints (temperature cycles)

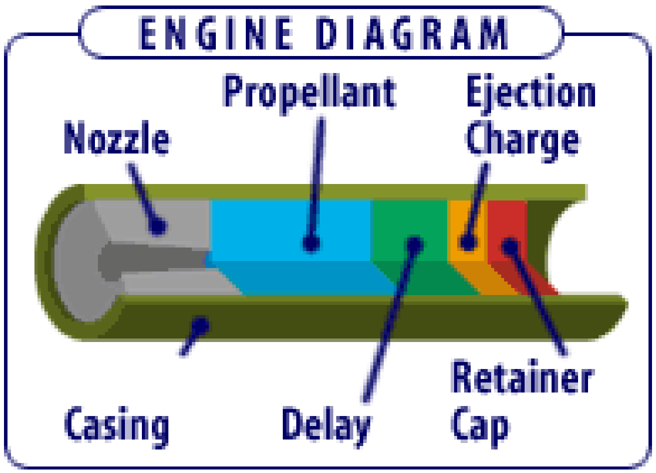


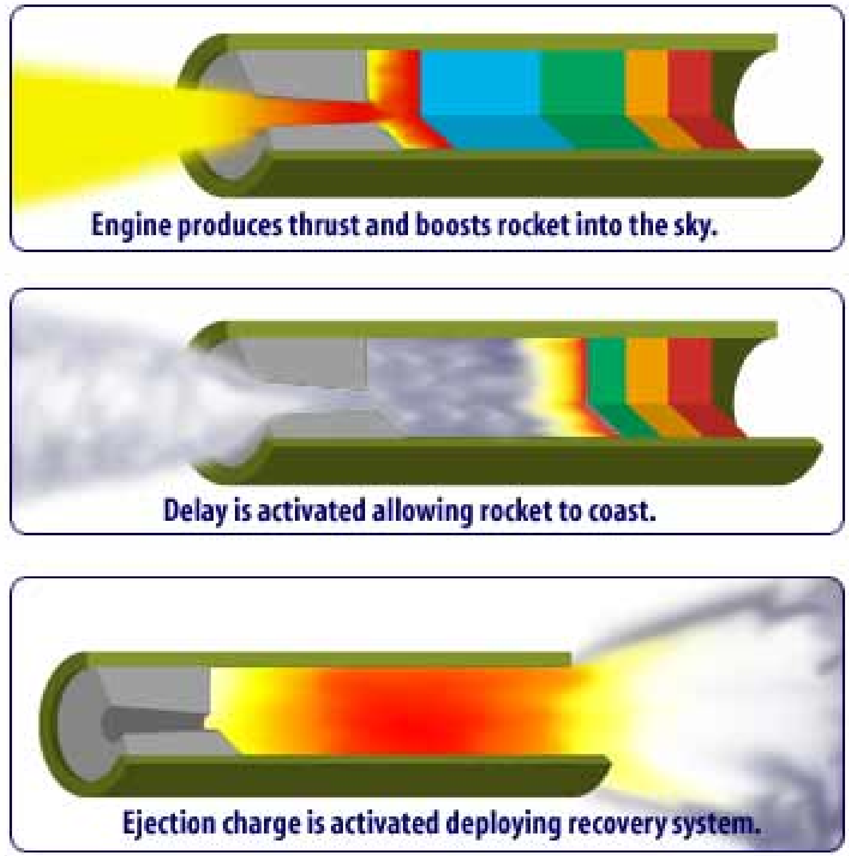
Propulsion (cont)

- **Ammonium Perchlorate Solid Rocket Motors**
  - **Similar to Shuttle Solid Rocket Booster propellant**
  - **Commercial ammonium perchlorate -based (composite) motors**
    - **Single use and reloadable**
    - **Core Burning propellant**
  - **Advantages:**
    - **Ease of use (especially single use motors)**
    - **Good availability (Most hobby shops specializing in RC, mail order)**
    - **Low initial cost**
  - **Disadvantages**
    - **Higher recurring (per flight) cost**
    - **Regulatory issues (BATF permits for large motors)**
      - Greater than 62.5g of propellant, and greater than 80N of avg thrust
    - **Propellant age constraints (moisture effects)**



Solid Rocket Motor





Courtesy: eHobbies.com

Propulsion (cont)

- **Photos of commercially available composite motors (AeroTech, Inc.)**

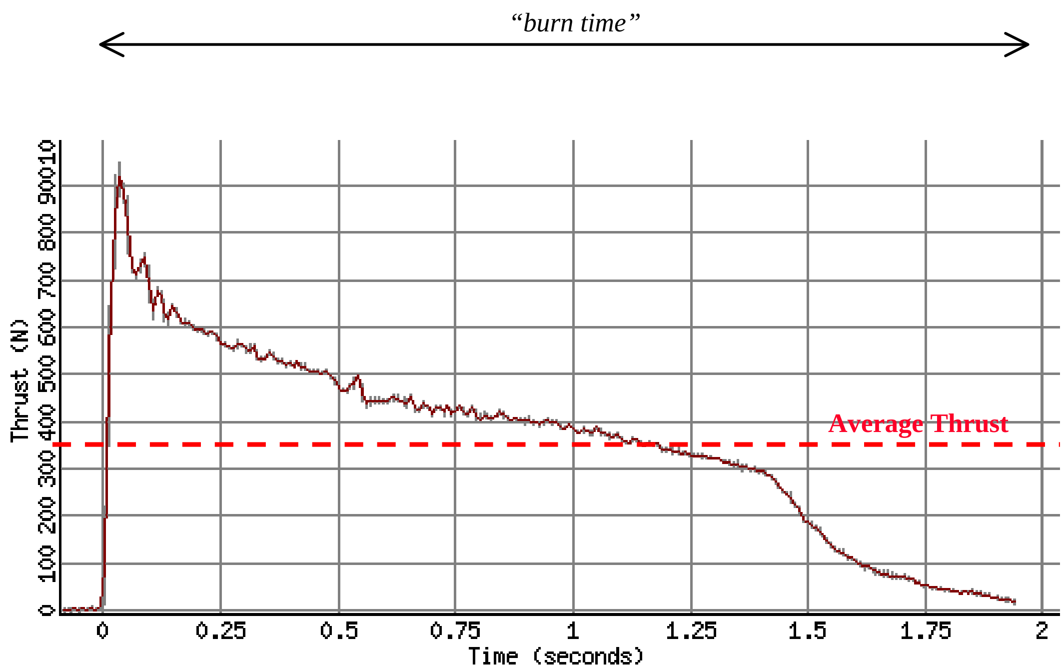
Typical single use high power rocket motor

Reloadable motor set, with reload kit

Propulsion (cont)

- **Rocket Motor Parameters**
  - **Thrust**
    - Instantaneous force due to rocket exhaust through nozzle
    - Measured in Newtons [N] (metric) or pounds (English)
  - **Impulse**
    - Total energy expended by a rocket motor over the course of its burn
    - Area under the "thrust curve", measured in Newton*Seconds (Ns)
  - **Sample Motor Data:**

Manufacturer	AeroTech
Mfr. designation	J350W-M
Motor diameter	38 *mm*
Total impulse	157 #*-sec*, 698.4 *Ns*
Specific impulse	187 #*-sec*/#
Maximum thrust	207 *pounds*, 920.8 *N*
Average thrust	88.7 *pounds*, 394.6 *N*
Ejection delay	none
TMT designation	J394-9 (9% J)
Calculated burntime	1.8 *seconds*
Motor length	13.25 *inches*, 337 *mm*
Total weight	1.453 *pounds*, 0.660 *Kg*
Propellant weight	0.839 *pounds*, 0.381 *Kg*

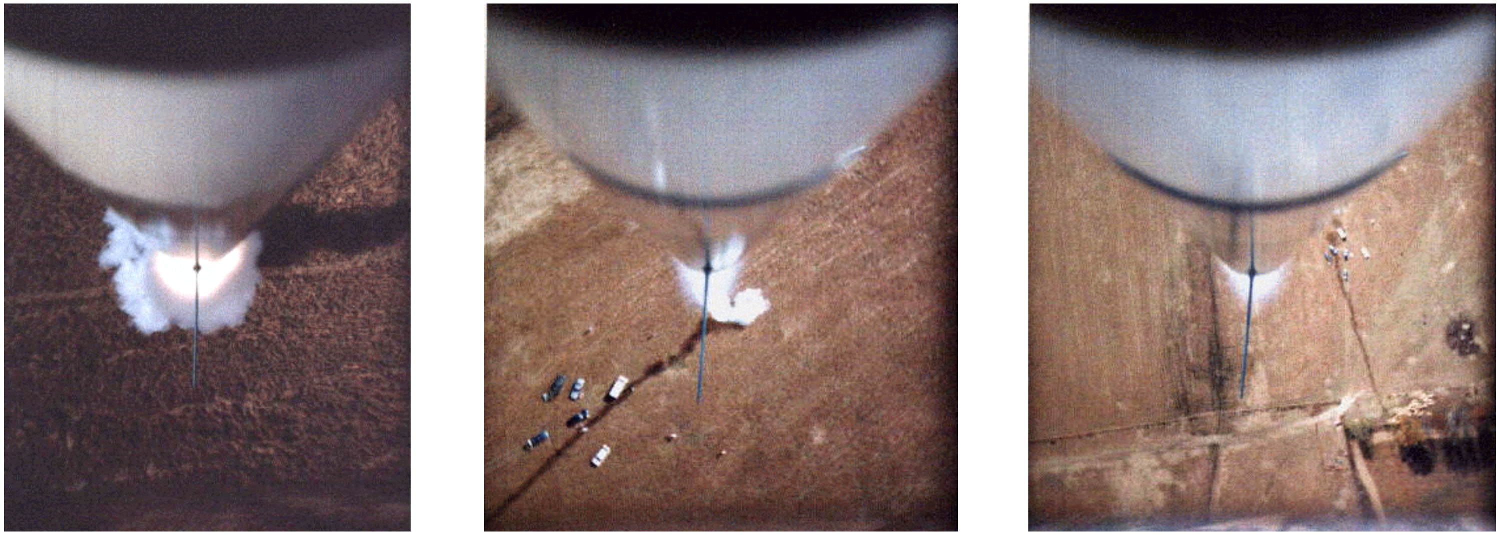


Propulsion (cont)

- **Rocket Motor Designations**
  - **Rocket Motors are designated with a 3-part code:**
    - **A letter specifying the total impulse range**
    - **A number specifying the average thrust (in Newtons)**
    - **A number specifying the delay, in seconds, from motor burnout to the time an ejection charge is fired**
  - **Example: J350-10**
    - **"J" impulse range (640 – 1280Ns)**
    - **350 Newtons (approx 80 pounds) average thrust**
    - **10 second delay from motor burnout to ejection**
- **Rocket motors designated "H" and higher are considered "High Power" and require certification**
- **Motor data for all certified model and high-power rocket motors may be found at:**
  - **http://www.thrustcurve.org**

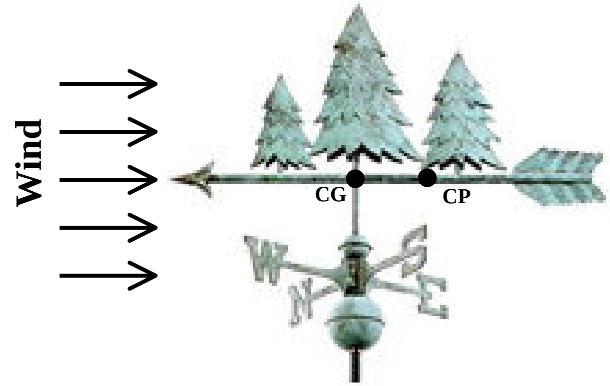
Thrust:Weight ratio

- **Rule of thumb for safe liftoff velocity:**
  - **Minimum 5:1 thrust:weight ratio**
  - **Example: the J350 in our previous example could safely lift a rocket weighing about 16 pounds**



Rocket Stability

- **Defined by relationship between Center of Gravity (C_g) and Center of Pressure (C_p)**
- **Center of Gravity (C_g)**
  - **Equal mass on either side of the Cg**
  - **Found by balancing the rocket (pivot point)**
    - **Must have motor and payload installed**



- **Center of Pressure (C_p)**
  - **Equal cross-sectional area on either side of the C_p**
  - **Calculated by computing area of rocket components**
  - **Also calculated by using Barrowman equations**
  - **Several computer simulation software packages available for free or nominal charge (Vcp, RockSim, WinRoc…)**

- **To be stable, the C_g must be *IN FRONT OF* the C_p**
  - **Usually a safety margin of at least one body tube diameter (caliber)**

Rocket Stability

- **In flight, if a rocket starts to rotate, the air pressure due to the "relative wind" on the rocket will push on the C_p, causing the rocket to rotate around its C_g.**
  - **STABLE: If the C_p is behind the C_g, the rocket will straighten itself out.**
  - **UNSTABLE: If the C_p is in front of the C_g, the rocket will keep rotating.**
- **In general, an unstable rocket can be made stable by:**
  - **Adding weight to the front of the rocket (moves C_g forward)**
  - **Enlarging the fins (moves C_p aft)**
  - **Moving the fins further aft (moves C_p aft)**
- **In general, as propellant burns away, the C_g moves forward, causing stability to improve during the flight.**
  - **Hybrid motors are a notable exception due because oxidizer tank is often forward of the CG**

Rocket Flight

- **What forces affect a rocket during flight?**
  - Thrust
    - Dependent on motor selection
  - Weight
    - Dependent on materials and construction
  - Drag
    - Increases with square of diameter (frontal area)
    - Increases with square of velocity
    - Increases with "roughness" of finish (Cd)
- **Summary of factors which determine altitude:**
  - Diameter
  - Weight
  - Finish
  - Motor burn characteristics
  - Velocity (higher speed => greater drag => less altitude)

Determining (Predicting) Rocket Performance

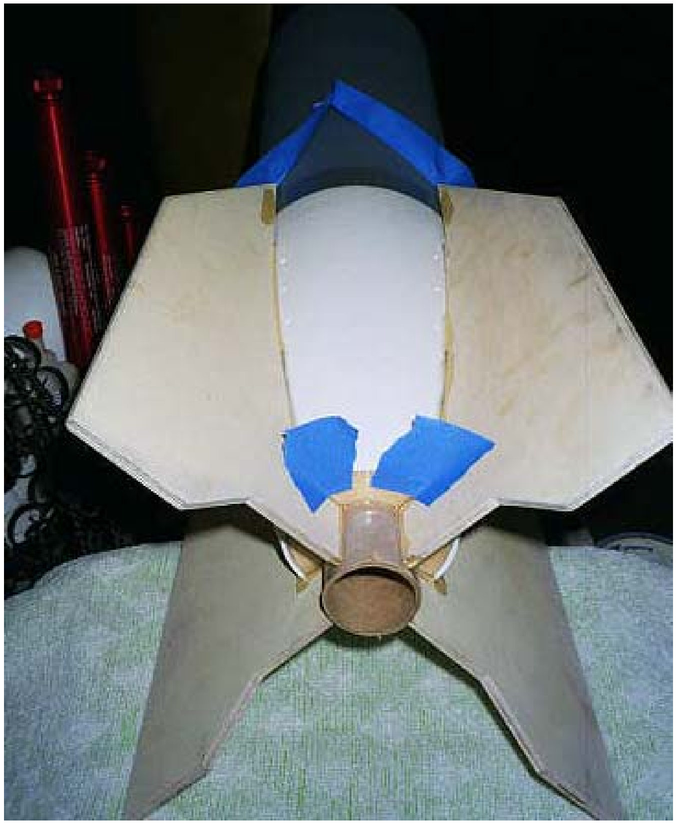
- **Simulators available to predict rocket performance given design and motor parameters**
  - ALT4 — MS-DOS simulation
  - CompuRoc — Macintosh simulation
  - RockSim — Windows design and simulation
  - SpaceCAD — Windows design and simulation
  - Vcp — Windows design
  - WinRoc — Windows design and simulation
  - wRASP — Windows simulation
  - Spreadsheets — D-I-Y simulations
- **Many available for free download from Web**
  - http://www.thrustcurve.org
  - http://mywebpages.comcast.net/rocket_time/hara/utility.htm

Construction Materials

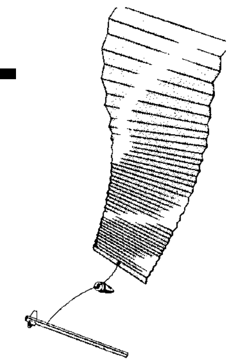
- **Body Tubes**
  - Cardboard
  - Paper Phenolic
  - Laminated Cardboard or Phenolic (fiberglass, KevLar, carbon)
  - Fiberglass
  - Polycarbonate
  - PVC
- **Nose cones**
  - Balsa or bass wood
  - Injection-molded plastic
  - Fiberglass
- **Fins and centering rings**
  - Plywood
  - Fiberglass
  - PVC

Construction Materials (cont)

- **Hardware (larger rockets)**
  - Stainless steel eye-bolts, U-bolts, nuts, washers, etc.
- **Recovery harness materials (shock cord)**
  - Tubular nylon webbing (recommended)
  - Tubular Kevlar
  - Bungee
  - Nylon rope
  - Rule of thumb: Non-elastic harnesses should be at least 5 times as long as airframe length
- **Adhesives**
  - 20-30 minute epoxy
  - Carpenter glue
  - Cyanoacrylate (CA) (limited use)
  - PVC cement



Recovery Methods



- **Tumble recovery**
  - **Extremely small, lightweight models only!**
    - **Usually suitable for booster stages in 2-stage rockets**
- **Streamer recovery**
  - **Suitable for lightweight rockets and "drogue" recovery of two-stage deployments**
- **Parachute recovery**
  - **Most common way to recover model and HPR rockets**
- **Two-stage parachute deployment**
  - **Typically involves electronic altimeter**
  - **Deploy small chute or streamer at apogee for fast descent**
  - **Deploy larger main chute at low altitude for soft landing**
  - **Often used for high flights and delicate payloads (such as eggs)**
- **Helicopter recovery**
- **Glider recovery**
- **Radio-controlled recovery**

Electronic Deployment

- Electronic altimeters, accelerometers and timers may be used to deploy recovery systems
- Often used with motor ejection as a backup
- Electronic device fires an electric match (squib), which ignites a small black powder charge
- Charge pressurizes body tube, causing the rocket to separate
- Many altimeters support two-stage deployment by firing a charge after detecting apogee (measuring changes in air pressure), then firing a second charge at a predetermined lower altitude
- Quantity of black powder to pressurize a given volume can be calculated by formulae available at:
  - http://mywebpages.comcast.net/rocket_time/hara/bp.htm
  - http://www.knology.net/~cpierce/modelrockets/misc/EC_calculator.xls

Parachute Recovery

- **Recommend rip-stop nylon chutes**
- **Wadding, baffle, piston or Nomex required to prevent burning of chute material**
- **Commercial vendors (there are many others…):**
  - **Sky Angle**
  - **Top Flight Parachutes**
  - **Rocketman (http://the-rocketman.com)**
  - **Public Missiles, Ltd. (PML) (http://www.publicmissiles.com)**

Altitude Determination

- **Visual Tracking (Theodolites)**
  - **Geometric calculations based on elevation angle at apogee**
  - **Requires at least 2 people as trackers**
  - **Method available on HARA web site:**
    - **http://mywebpages.comcast.net/rocket_time/hara/archives/tracking.htm**

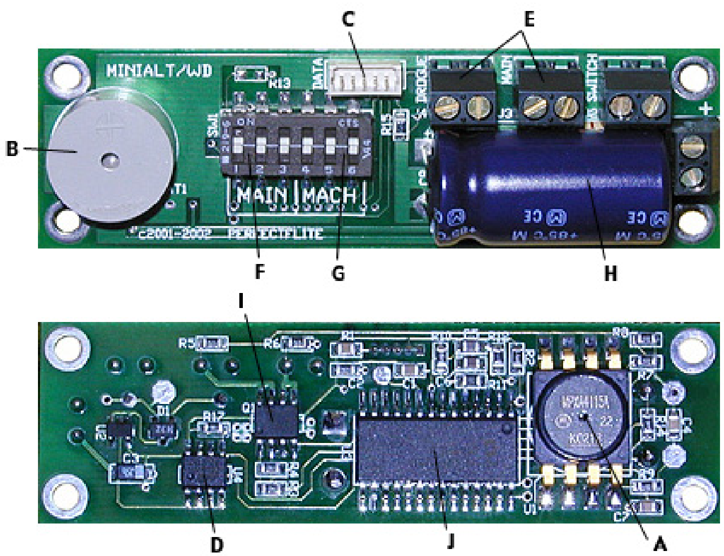
- **Electronic Altimeters**
  - **Barometric pressure decreases with altitude**
  - **Microcontroller measures output of pressure transducer**
  - **Must be vented to outside air, generally in a sealed compartment with a hole to the outside of the airframe**
  - **Record peak altitude (AGL), typically "beep" the result**
  - **Some can record altitude samples for download to PC**
  - **Can be used to fire ejection charges for single or 2-stage deployment**
  - **Commercial vendors (cheaper units start around $90):**
    - **Missile Works, Adept, Transsolve, Olsen, PerfectFlite**

Some Commercial Electronic Altimeters

Adept ALTS2-50K

BlackSky AltAcc
(combination Altimeter / Accelerometer)

Olsen FCP Altimeter

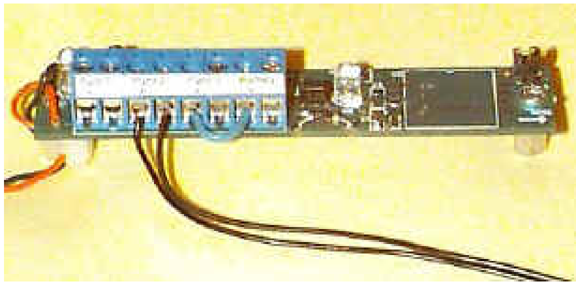


PerfectFlite MAWD

Missile Works RRC2
barometric altimeter

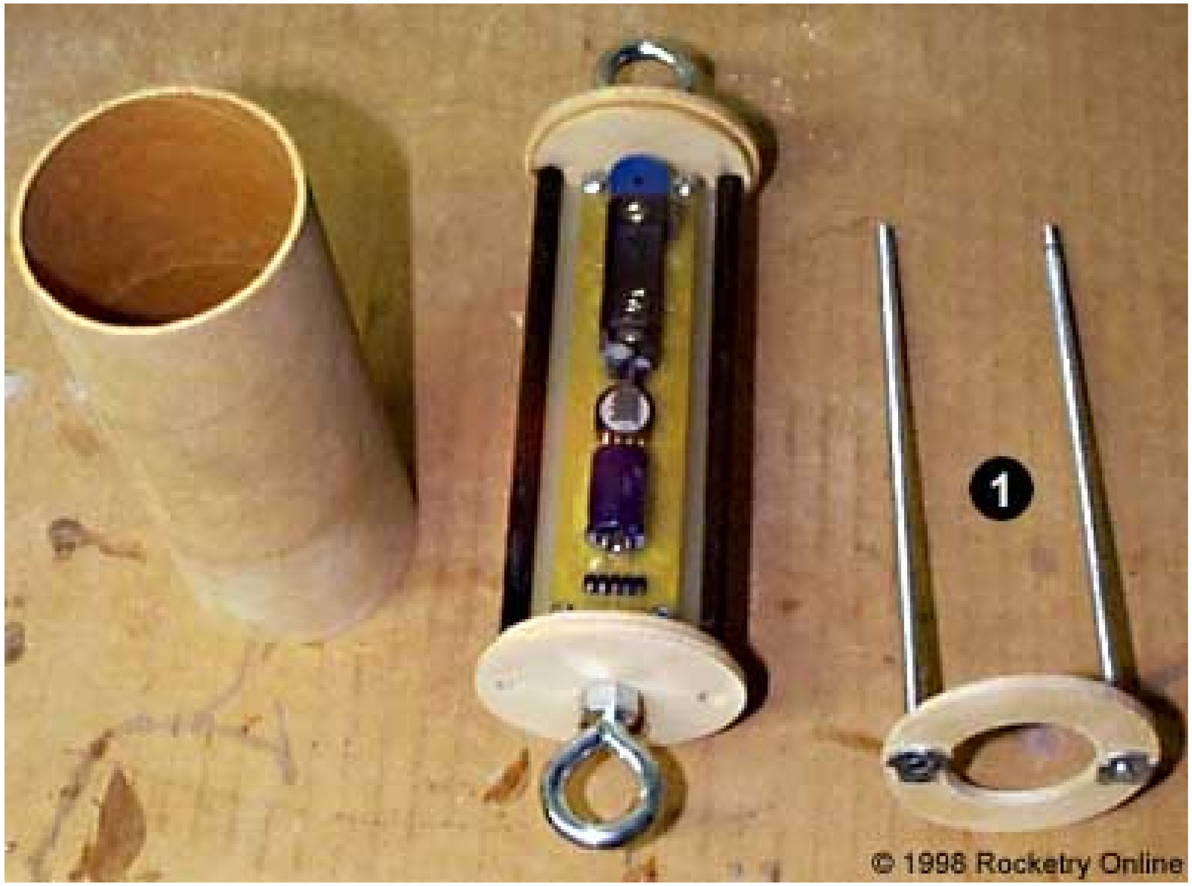
Altitude Determination (cont)

- **Electronic Accelerometers**
  - Measure motion of rocket vs. time
  - Do not require vent port (unless accompanied by baro altimeter)
  - Can be used to fire ejection charges for single or 2-stage deployment
  - Most can record samples during flight for download into PC
  - Somewhat more expensive than altimeters (~$150)
  - Note: Accelerometers typically cannot be used with hybrid motors (due to 'ratty' combustion)
  - Commercial vendors:
    - Cambridge
    - BlackSky
    - Emmanuel Avionics
    - Pratt Hobbies



Pratt Hobbies G-Wiz Accelerometer

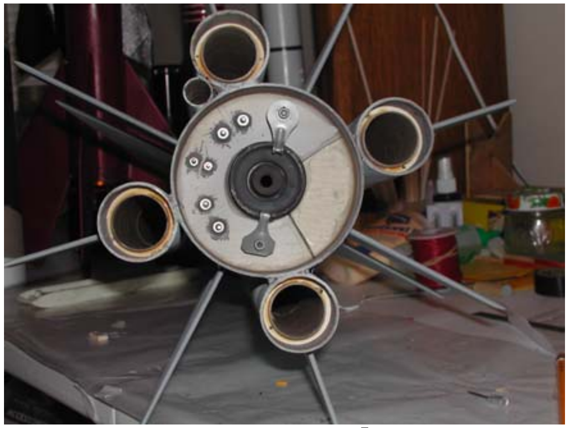
Typical Electronics Compartment



Courtesy: Rocketry Online

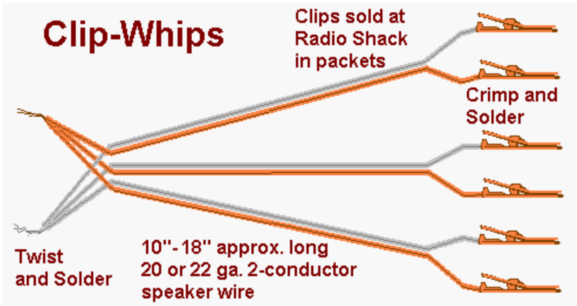
Multiple Motors: Clusters

- **Definition of a Motor Cluster**
  - 2 or more motors ignited at the same time (parallel burn)
- **Igniter Clips (AKA, Clip Whip)**
  - Must be wired for parallel motor ignition
  - Serial (daisy chain) clip whip will NOT work
  - Must manage amperage for cluster ignition
    - Easy to ignite multiple BP motors
    - Much harder to ignite multiple AP and hybrid motors



5-motor cluster
(only core motor installed)

- **Total Thrust**
  - Sum of thrust from individual motors
- **Total Impulse**
  - Sum of impulses from individual motors
- **Concerns**
  - Igniting all motors in cluster
    - Must consider engine-out scenario (lift-off thrust)
    - Try to maintain a 5:1 T/W with one engine out



Multiple Motors: Staging

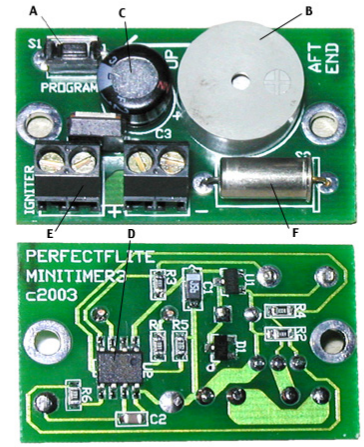
- **Definition of a Motor Staging**
  - **2 or more motors ignited one after the other (serial burn)**
- **Staging Black Powder Motors**
  - **Booster motor directly ignites Sustainer Motor**
    - **AKA, CHAD (CHeap And Dirty) Staging**
  - **B6-0, C6-0, C11-0, D12-0 are booster motors**
- **Staging Ammonium Perchlorate Motors**
  - **Should use timer or g-switch to ignite AP Sustainer motor(s)**
  - **Must use very-low current igniter(s)**
    - **Compatible with timer (and battery)**
  - **CHAD staging is unreliable for AP motors**
- **Concerns**
  - **Must manage booster stage recovery**
    - **Estes class boosters are low concern (light weight)**
    - **High-power boosters are much heavier**

TLP Nike-Ajax and SM3 (electronic staging)

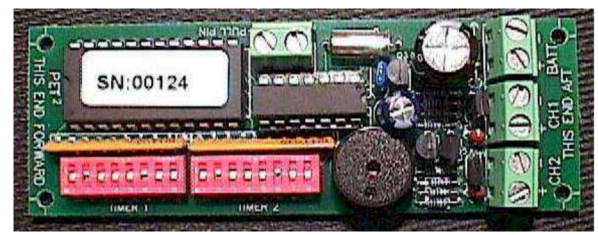
Estes CC Express (CHAD staging)

Timers

- **Function**
  - Applies battery power at a specified time after launch
- **Timer Initiation (start of timing) methods**
  - Break wire
  - Accelerometers
    - Not recommended for use with hybrid motors
  - Barometric
- **Low cost ($15 to $40)**
- **Commercial vendors:**
  - Perfect Flite
  - Missile Works
- **Concerns**
  - ‘Weak’ timer batteries may not supply enough amperage to ignite motors, especially AP motors



PerfectFlite MT3G



Missileworks PET2

Launch Equipment

- **HARA uses following launch controllers:**
  - 10 channel console
  - 8 channel console
  - 4 channel console
  - Hypertek controller
- **HARA uses following launch pads:**
  - 1/8" through ¾" stainless steel launch rods
  - Black Sky standard and heavy duty launch rails
  - Multi-pad custom PVC supports
  - Rocket Vision Quad-Pod launch pads
  - "Tripoli" High Power pads

"Quad Pod" launch pads
Courtesy: Rocketry Online

Certification

- **Level I**
  - **Allows holder to purchase and fly motors in the H & I class**
- **Level II**
  - **Allows holder to purchase and fly motors in the J – L range**
- **Level III**
  - **Unlimited**
- **High-power flyers must be 18 years of age to certify**



Regulatory Issues

- **FAA**
  - **CFR, Title 14, Chapter I, Part 101.21 to 101.25**
    http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_14/14cfr101_00.html
  - **Rockets over 1 pound**
    - **Notify nearest ATC tower**
  - **Rockets over 3.3 pounds or 125g of propellant**
    - **Waiver must be filed in advance with FAA**
  - **(All HARA launches have pre-filed waiver to at least 8000’ AGL)**
- **BATF**
  - **Low Explosives User Permit (LEUP) required to purchase and/or store ammonium perchlorate motors (greater than 62.5 g of propellant (HPR motors))**
  - **Must be 18 years of age to obtain permit**
  - **(No permit required for hybrid motors)**
  - **(No permit required for G and below solid motors)**

Resources

- **Handbook of Model Rocketry – *G. Harry Stine***
- **Model Rocket Design and Construction – *T. Van Milligan***
- **High Power Rocketry Magazine**
- **Sport Rocketry Magazine**
- **Extreme Rocketry Magazine**
- **Huntsville Area Rocketry Association (HARA) – http://hararocketry.org**
- **National Association of Rocketry (NAR) – http://www.nar.org**
- **Tripoli Rocketry Association (TRA) – http://www.tripoli.org**
- **Rocketry Online – http://www.rocketryonline.com**
- **Thrust Curves – http://www.thrustcurve.org**
- **AeroTech, Inc. – http://www.aerotech-rocketry.com**
- **Black Sky – http://www.blacksky.com**
- **eHobbies.com – http://www.ehobbies.com**
- **Magnum Hobbies – http://www.magnumrockets.com**
- **Missile Works – http://www.missileworks.com**
- **PerfectFlite – http://www.perfectflite.com**
- **Public Missiles, Ltd. – http://www.publicmissiles.com**
- **Rocketman – http://the-rocketman.com**
- **Star Rocketry (Hypertek) – http://www.starrocketry.com**

NAR Model Rocketry Safety Code (G motors or less)

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.
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.
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.

Model Rocketry Safety Code (cont)

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. If my model rocket weighs more than one pound (453 grams) at liftoff or has more than four ounces (113 grams) of propellant, I will check and comply with Federal Aviation Administration regulations before flying.**
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.**
11. **Recovery Safety. I will not attempt to recover my rocket from power lines, tall trees, or other dangerous places.**

Model Rocketry Safety Code (cont)

LAUNCH SITE DIMENSION TABLE

Total Impulse All Engines (Newton-Seconds)	Equivalent Motor Type	Minimum Site Dimensions (ft.)
0.00 – 1.25	1/4A, 1/2A	50
1.26 – 2.50	A	100
2.51 – 5.0	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	2G’s	1,500