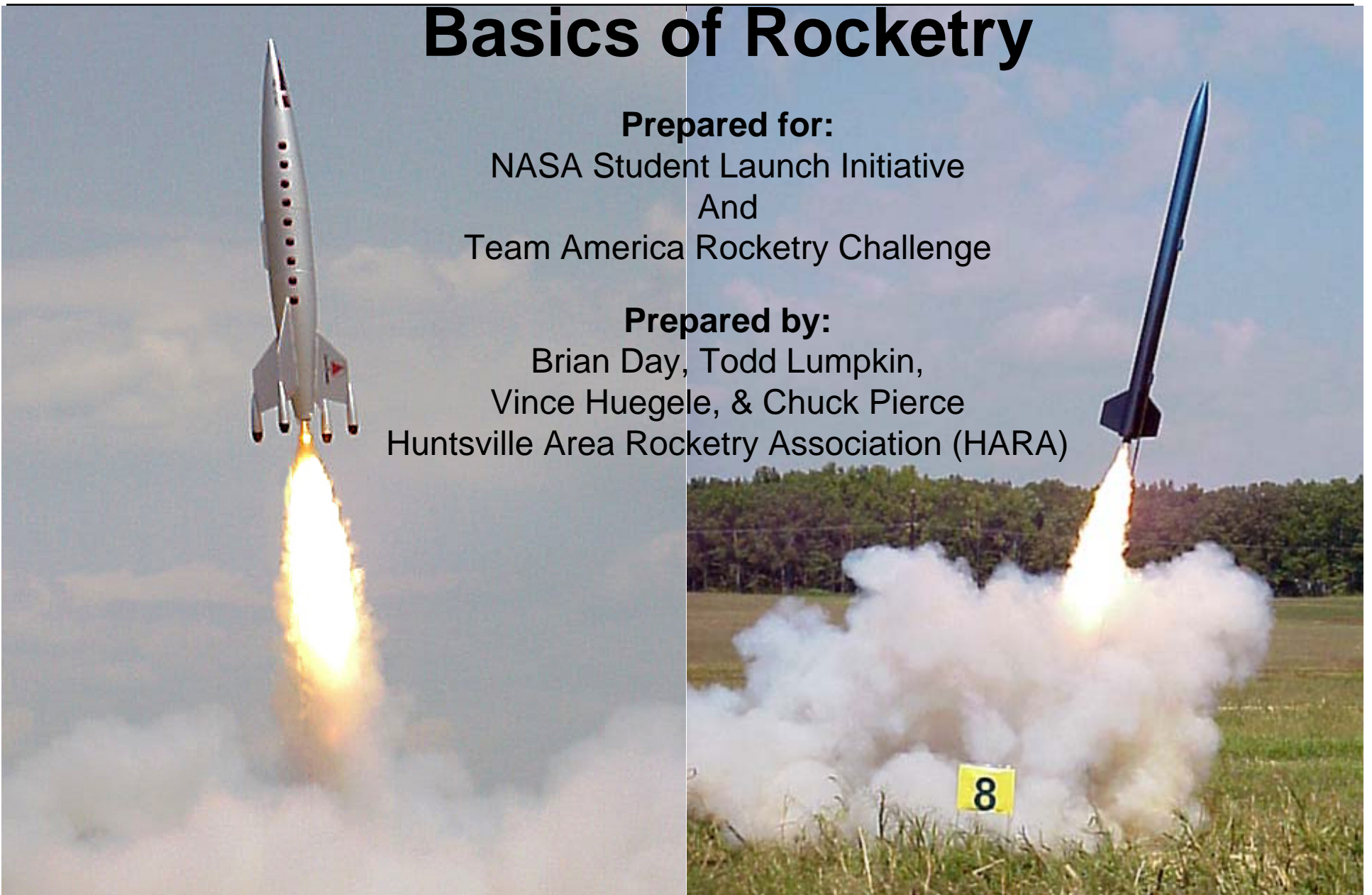


Basics of Rocketry

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

Prepared by:
Brian Day, Todd Lumpkin,
Vince Huegele, & Chuck Pierce
Huntsville Area Rocketry Association (HARA)



Contents

- **Introduction**
- **Types of Rockets**
- **Phases of Rocket Flight**
- **Components of a Typical Rocket**
- **Propulsion**
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- **Computer Aided Design and Simulation**
- **Construction**
- **Recovery**
- **Altitude Determination**
- **Multiple Motors**
- **Timers**
- **Launch Equipment**
- **Certification**
- **Regulatory Issues**
- **Resources**
- **Safety Codes and Procedures**
- **Appendix A: Student Launch Initiative**
- **Appendix B: Team America Rocketry Challenge**
- **Appendix C: Who Are These Guys?**



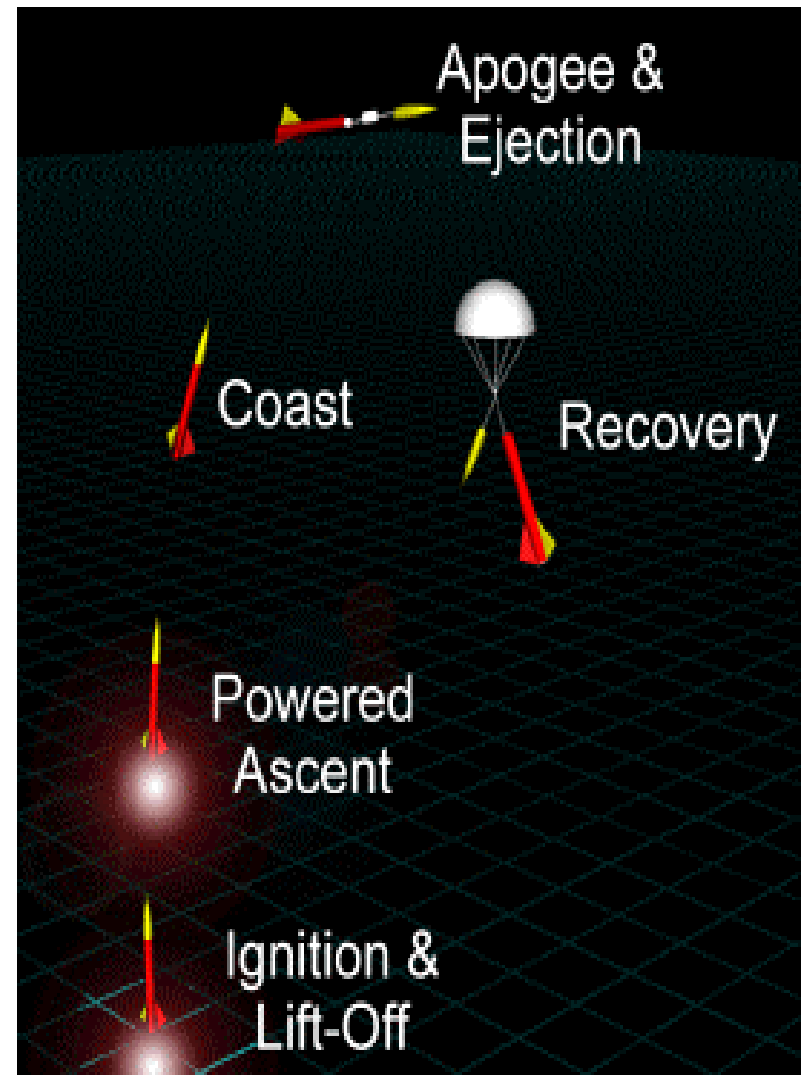
Types of Rockets

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



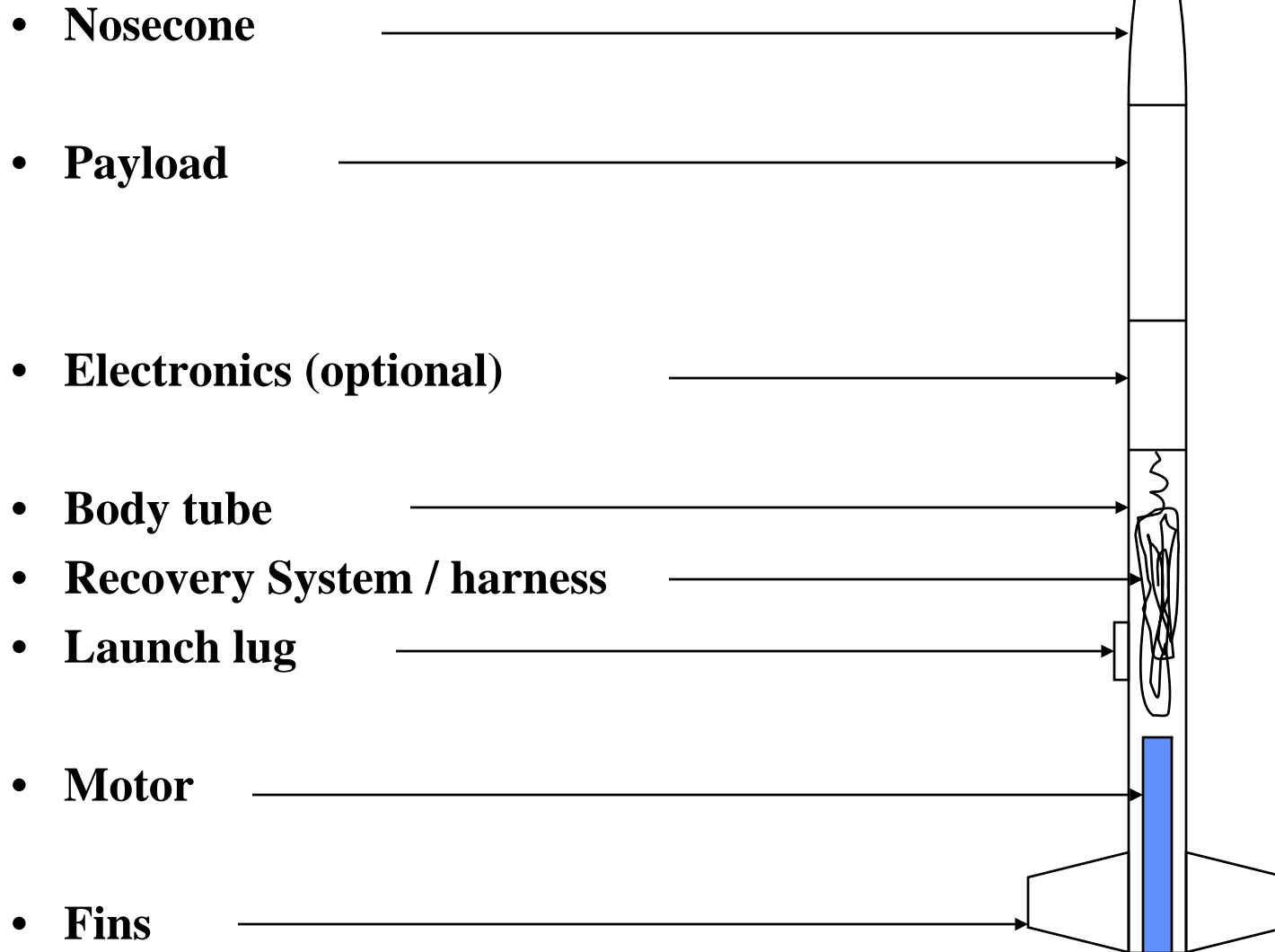
Phases of Rocket Flight

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



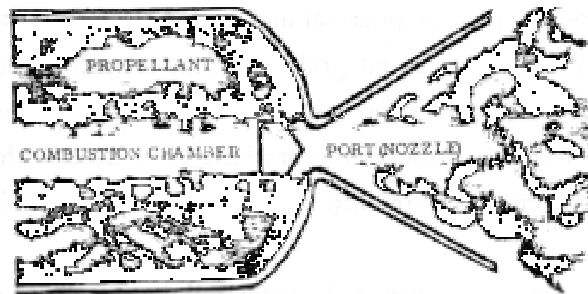
Courtesy: Rocket Vision

Components of a Typical Rocket



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



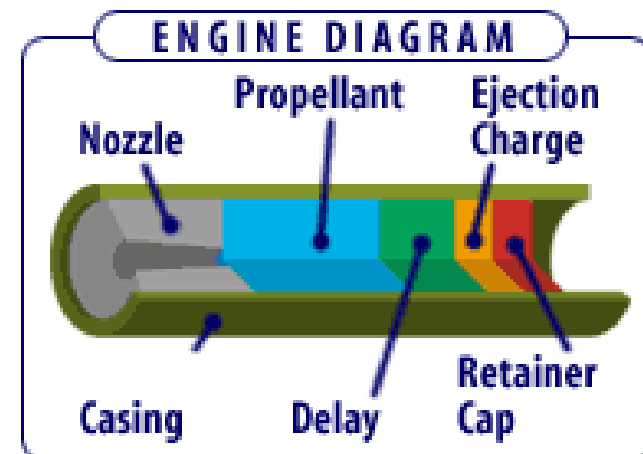
Propulsion (cont)

- **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)

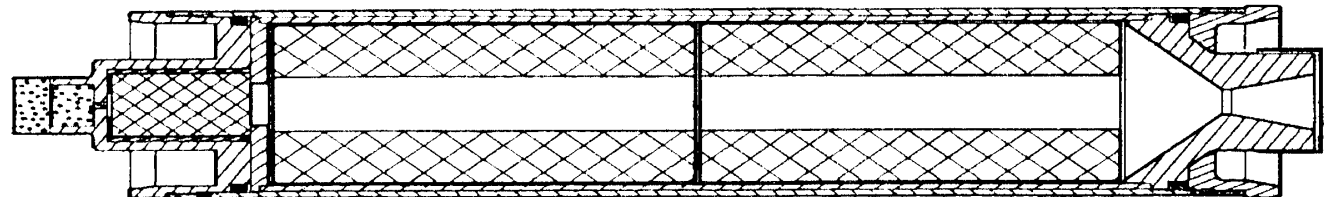
- **Black Powder Solid Rocket Motors**

- 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)

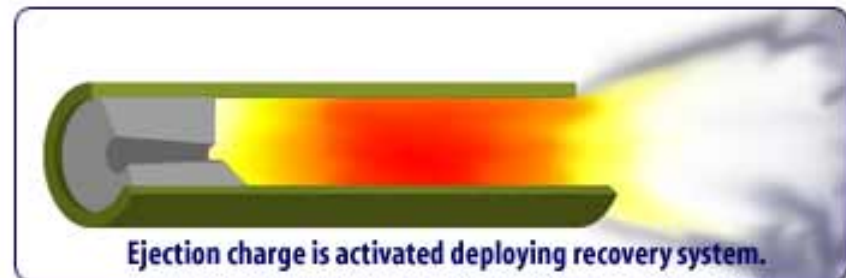
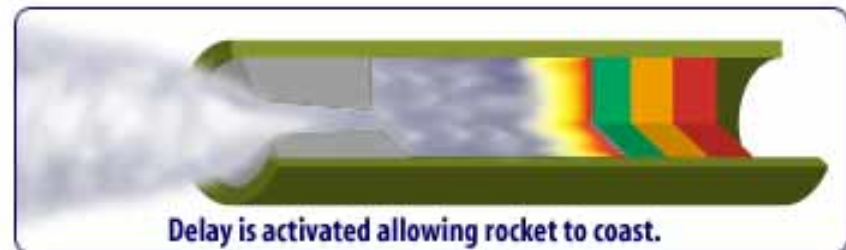
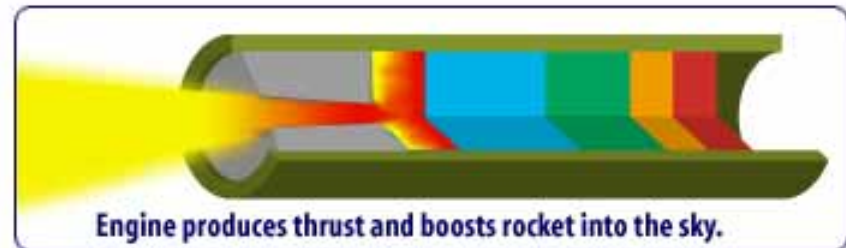
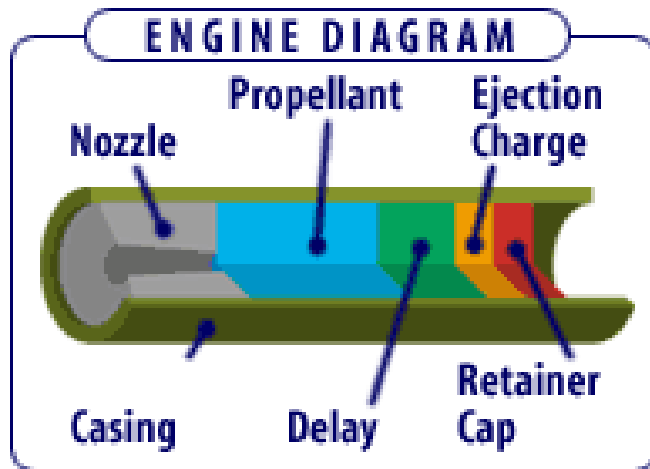


Propulsion (cont)

- **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)

- **Hybrid Rocket Motors**

- **Commercially available from following manufacturers:**

- Hypertek - Rattworks
 - AeroTech - West Coast Hobbies

- **“H” through “N” total impulse**

- Cost per flight savings begin at about J impulse (compared to AP solid motors)

- **Advantages:**

- No regulatory issues (plastic and industrial gases)
 - Lower recurring cost than composites (per flight)

- **Disadvantages**

- Higher startup costs
 - Reuseable metal motor hardware
 - Special ground support equipment
 - NO₂ supply, fill ground support equipment
 - Oxidizer tank adds weight to rocket
 - Lower performance (specific impulse and thrust) than available in solid composite motors
 - Must decrease rocket weight to compensate for lower thrust
 - No “motor ejection charge” – must use other means
 - Static stability decreases as motor burns (rule of thumb)



Propulsion (cont)

- **Commercially available hybrid motors (Hypertek):**



(photo courtesy: Star Rocketry)

Propulsion (cont)

- **Hypertek Hybrid Rocket Motor Launch System**
 - Includes nitrous oxide tank, gaseous oxygen tank, solenoid-actuated fill valves, high voltage transformer for ignition



Propulsion (cont)

- **Rocket Motor Parameters**

- **Thrust**

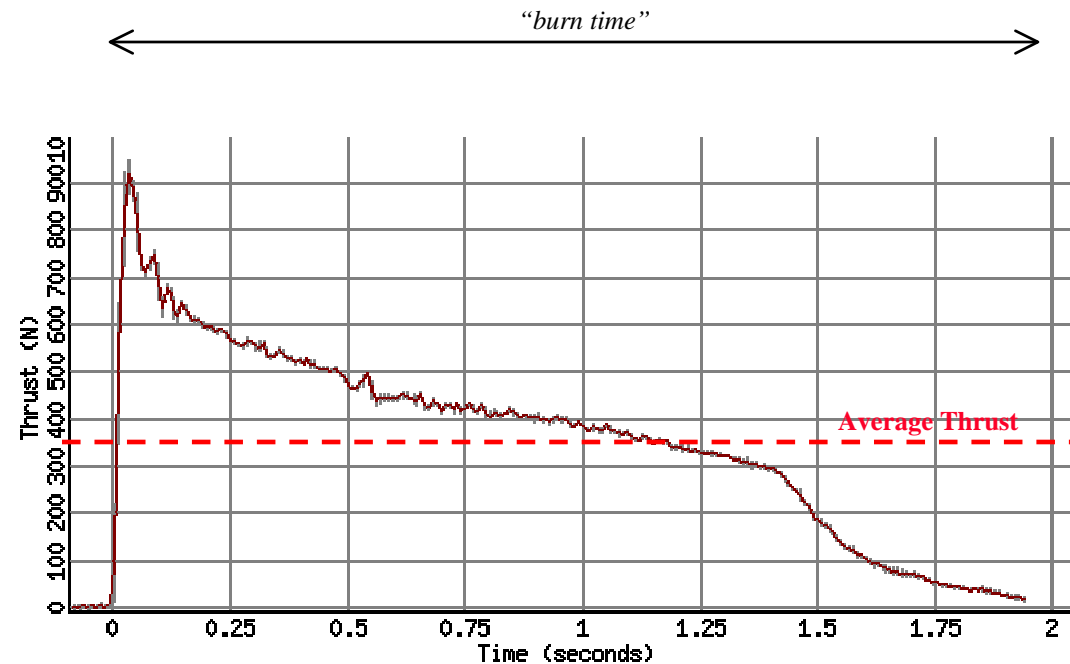
- Instantaneous force due to rocket exhaust through nozzle
 - Measured in Newtons [N] (metric) or pounds (English)

- **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

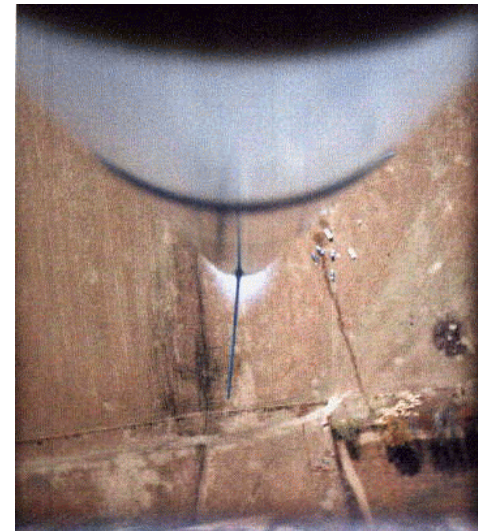
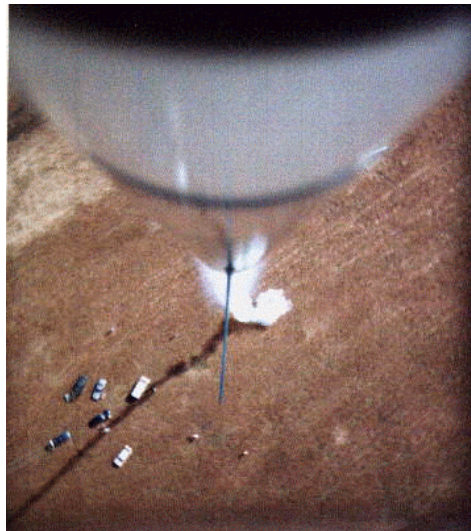
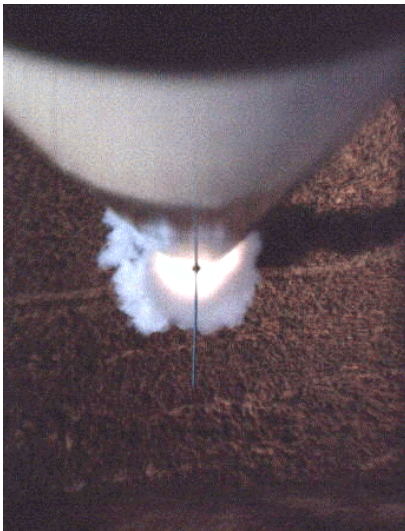


Propulsion (cont)

- **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>

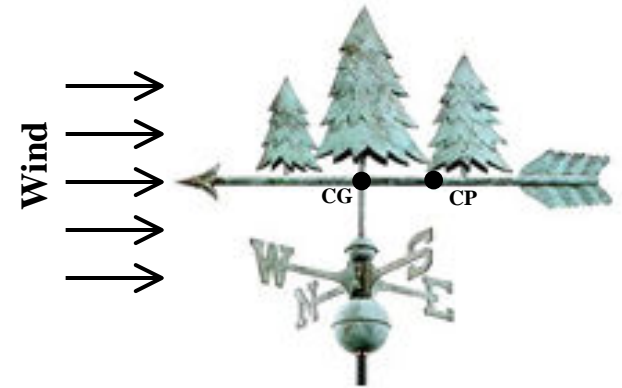
Thrust:Weight ratio

- **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 C_g
 - 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 (C_d)
- **Summary of factors which determine altitude:**
 - Diameter
 - Weight
 - Finish
 - Motor burn characteristics
 - Velocity (higher speed \Rightarrow greater drag \Rightarrow 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

Sample Design Software (VCP)

VCP V1.64 CP/CG Calculator [C:\VCP\PURPLE.CP]

File Add Component Tools Options View Window Help

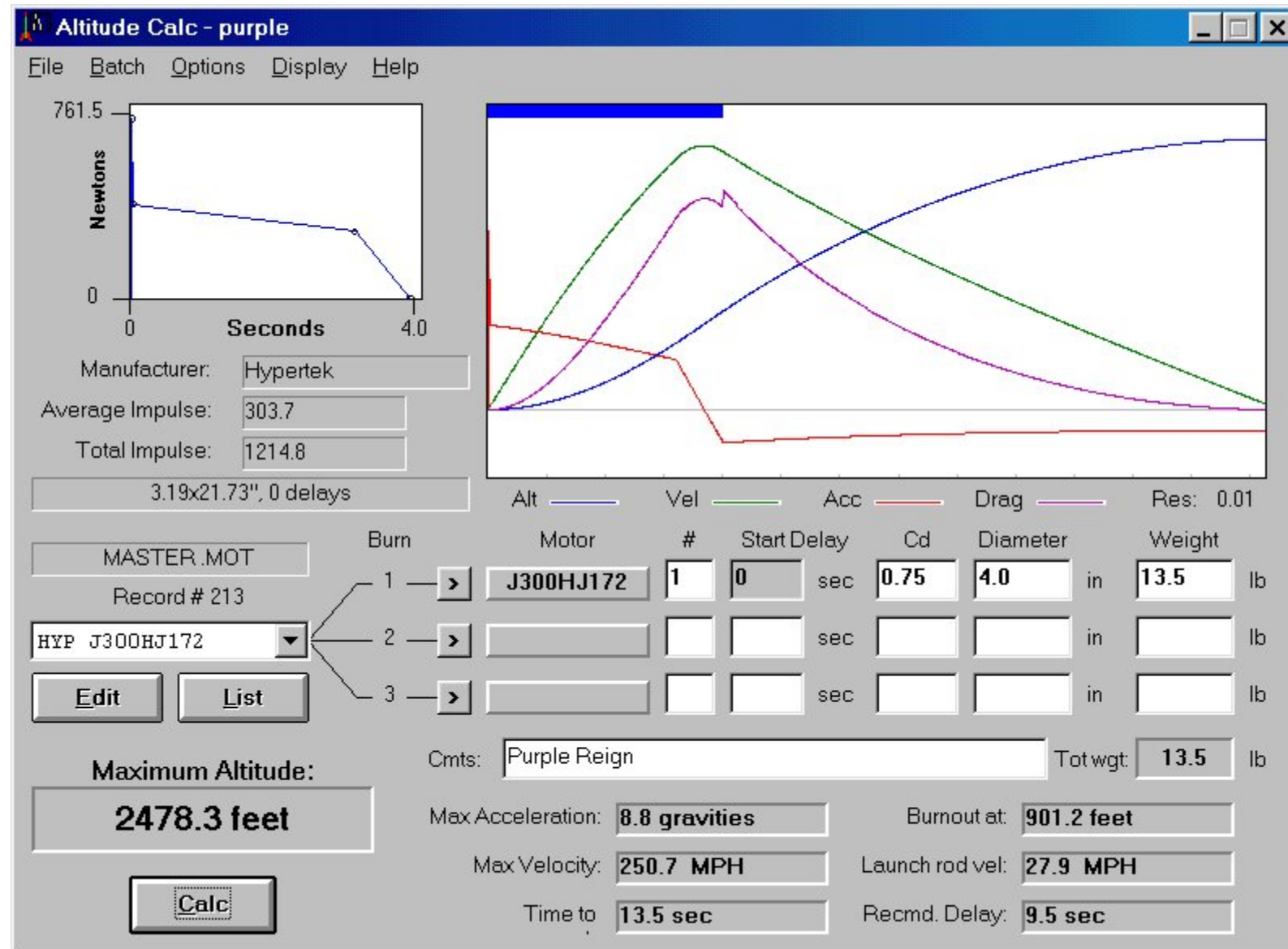
Nose Cone Trans Sec Fin Unit Mass Item

Vehicle Description: "Purple Reign" Notes

Component Description	Mass ounces	Mass Position inches	Rel Aero Force Coef	Force Position inches	Rel Aero Force Moment @Sustain CG
<u>Nose Cone</u>			2.000	76.945	
<u>Trans Sec 1</u>			-0.875	-0.833	
<u>Fin Unit 1</u>			8.411	4.958	
<u>Fin Unit 2</u>			6.445	10.917	
<u>Sustainer</u>	Σ Mass	C. G.	ΣCNa	C. P.	
			15.982	16.687	
	Length	Diameter		L/D	Margin
	86.500	4.000 in		21.63	Cal

Pgm Mode: CP Only Eqn Mode: Barrowman Disp Units: in/oz

Sample Flight Simulation Output (WinRoc)



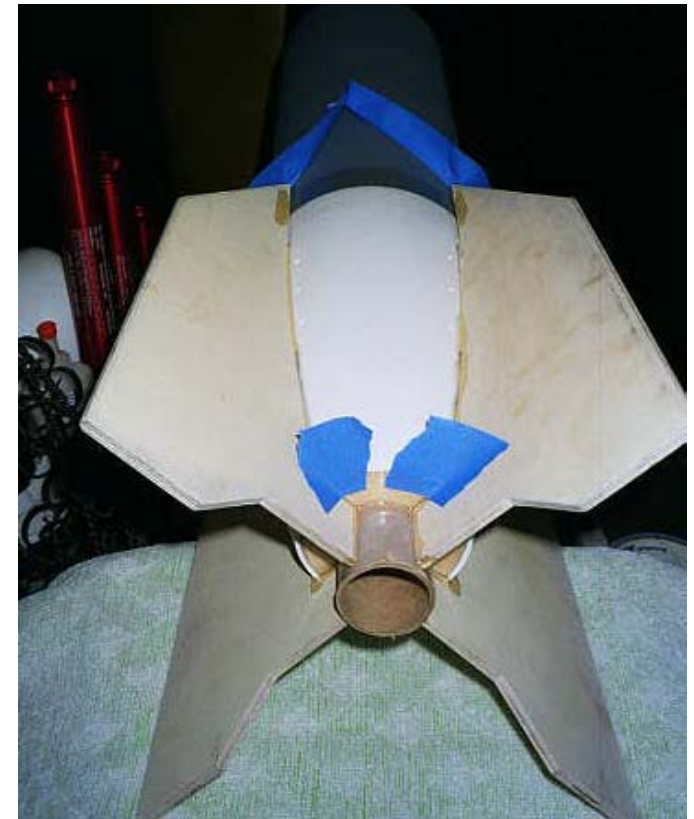
Construction Materials

- **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



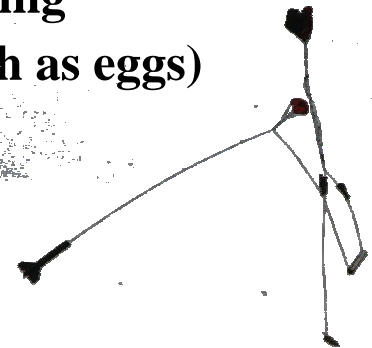
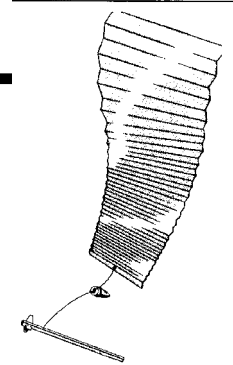
Construction Materials (cont)

- **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**

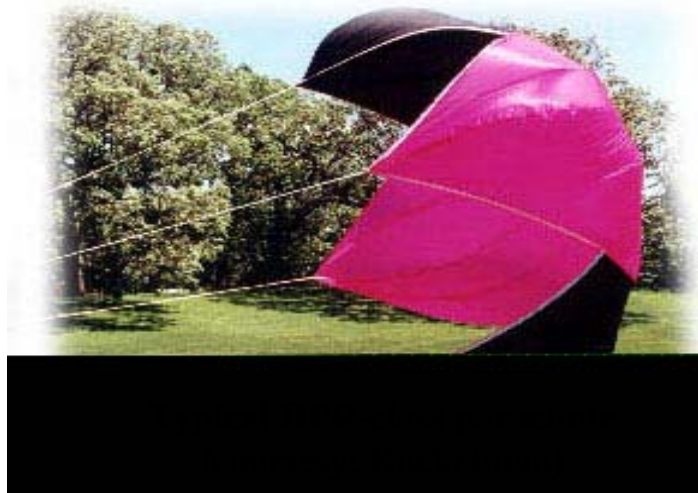


Electronic Deployment

- **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



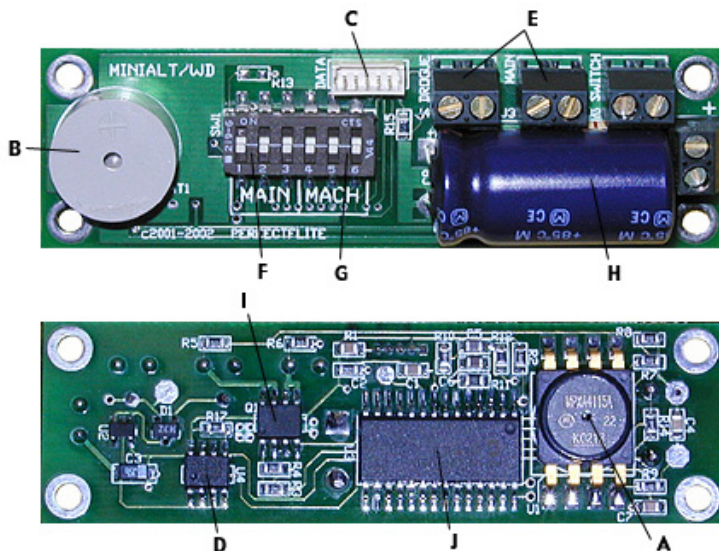
Adept ALTS2-50K



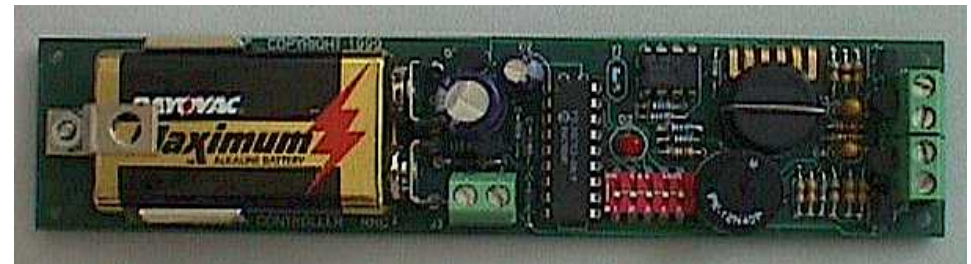
BlackSky AltAcc
(combination Altimeter / Accelerometer)



Olsen FCP Altimeter



PerfectFlite MAWD

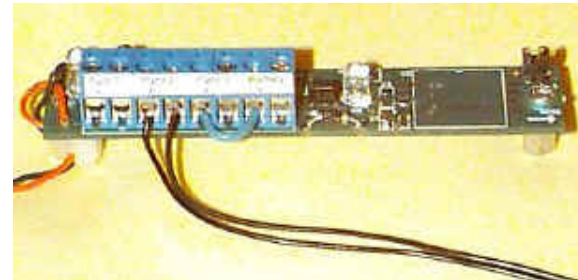


Missile Works RRC2
barometric altimeter

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

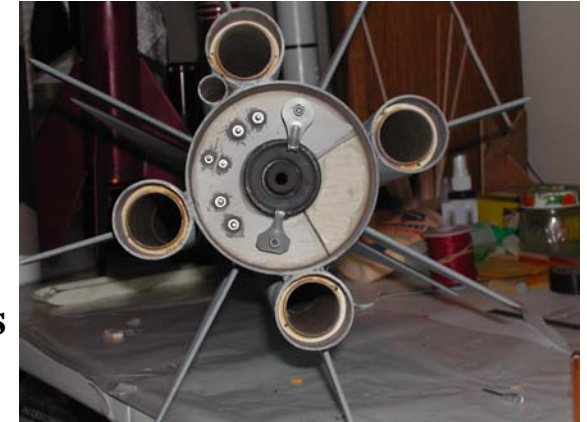
Typical Electronics Compartment



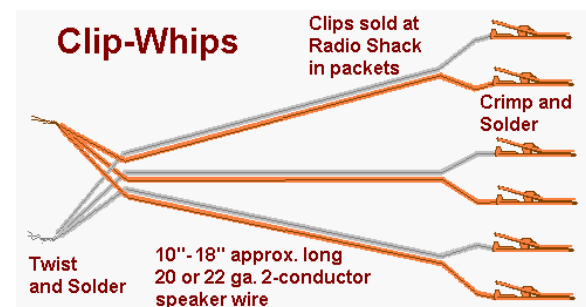
Courtesy: Rocketry Online

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
- **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



5-motor cluster
(only core motor installed)



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



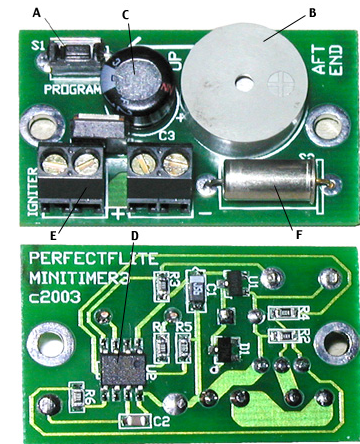
TLP Nike-Ajax and SM3
(electronic staging)



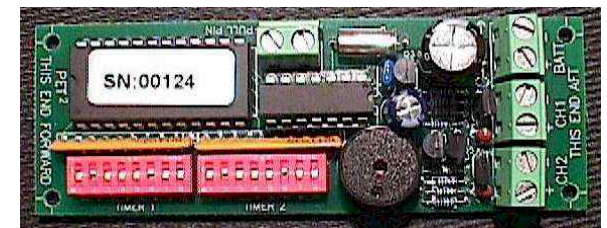
Estes CC Express (CHAD staging)

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 3/4" 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

NAR High Power Rocketry Safety Code

1. Certification. I will fly high power rockets only when certified to do so by the National Association of Rocketry.
2. Operating Clearances. I will fly high power rockets only in compliance with [Federal Aviation Regulations Part 101](#) (Section 307, 72 Statute 749, 49 United States Code 1348, "Airspace Control and Facilities," Federal Aviation Act of 1958) and all other federal, state, and local laws, rules, regulations, statutes, and ordinances.
3. Materials. My high power rocket will be made of lightweight materials such as paper, wood, rubber, and plastic, or the minimum amount of ductile metal suitable for the power used and the performance of my rocket.
4. Motors. I will use only commercially-made, NAR-certified rocket motors in the manner recommended by the manufacturer. I will not alter the rocket motor, its parts, or its ingredients in any way.
5. Recovery. I will always use a recovery system in my high power rocket that will return it safely to the ground so it may be flown again. I will use only flame-resistant recovery wadding if wadding is required by the design of my rocket.
6. Weight and Power Limits. My rocket will weigh no more than the motor manufacturer's recommended maximum liftoff weight for the motors used, or I will use motors recommended by the manufacturer of the rocket kit. My high power rocket will be propelled by rocket motors that produce no more than 40,960 Newton-seconds (9,204 pound-seconds) of total impulse.
7. Stability. I will check the stability of my high power rocket before its first flight, except when launching a rocket of already proven stability.
8. Payloads. My high power rocket will never carry live animals (except insects) or a payload that is intended to be flammable, explosive, or harmful.
9. Launch Site. I will launch my high power rocket outdoors in a cleared area, free of tall trees, power lines, buildings, and dry brush and grass. My launcher will be located at least 1,500 feet from any occupied building. My launch site will have minimum dimensions at least as great as those in the Launch Site Dimension Table. As an alternative, the site's minimum dimension will be one-half the maximum altitude of any rocket being flown, or 1,500 feet, whichever is greater. My launcher will be no closer to the edge of the launch site than one-half of the minimum required launch site dimension.

High Power Rocketry Safety Code (cont)

10. Launcher. I will launch my high power rocket from a stable launch device that provides rigid guidance until the rocket has reached a speed adequate to ensure a safe flight path. To prevent accidental eye injury, I will always place the launcher so the end of the rod is above eye level or I will cap the end of the rod when approaching it. I will cap or disassemble my launch rod when not in use and I will never store it in an upright position. My launcher will have a jet deflector device to prevent the motor exhaust from hitting the ground directly. I will always clear the area for a radius of ten feet around my launch device of brown grass, dry weeds, or other easy-to-burn materials.
11. Ignition System. The system I use to launch my high power rocket will be remotely controlled and electrically operated. It will contain a launching switch that will return to "off" when released. The system will contain a removable safety interlock in series with the launch switch. All persons will remain at a distance from the high power rocket and launcher as determined by the total impulse of the installed rocket motor(s) according to the accompanying Safe Distance Table.
12. Launch Safety. I will ensure that people in the launch area are aware of the pending high power rocket launch and can see the rocket's liftoff before I begin my audible five-second countdown. I will use only electrical igniters recommended by the motor manufacturer that will ignite rocket motors within one second of actuation of the launching switch. If my high power rocket suffers a misfire, I will not allow anyone to approach it or the launcher until I have made certain that the safety interlock has been removed or that the battery has been disconnected from the ignition system. I will wait one minute after a misfire before allowing anyone to approach the launcher.
13. Flying Conditions. I will launch my high power rocket only when the wind is no more than 20 miles per hour and under conditions where the rocket will not fly into clouds or when a flight might be hazardous to people, property, or flying aircraft. Prior to launch, I will verify that no aircraft appear to have flight paths over the launch site.
14. Pre-Launch Test. When conducting research activities with unproven designs or methods I will, when possible, determine the reliability of my high power rocket by pre-launch tests. I will conduct the launching of an unproven design in complete isolation from persons not participating in the actual launching.
15. Launch Angle. I will not launch my high power rocket so its flight path will carry it against a target. My launch device will be pointed within 20 degrees of vertical. I will never use rocket motors to propel any device horizontally.
16. **Recovery Hazards. If a high power rocket becomes entangled in a power line or other dangerous place, I will not attempt to retrieve it. I will not attempt to catch my high-power rocket as it approaches the ground.**

High Power Rocketry Safety Code (cont)

LAUNCH SITE DIMENSION TABLE

Total Impulse All Engines (Newton-Seconds)	Equivalent Motor Type	Minimum Site Dimensions (ft.)	Equivalent Dimensions
160.01 -- 320.00	H	1,500	
320.01 -- 640.00	I	2,500	Half mile
640.01 -- 1,280.00	J	5,280	One mile
1,280.01 -- 2,560.00	K	5,280	One mile
2,560.01 -- 5,120.00	L	10,560	Two miles
5,120.01 -- 10,240.00	M	15,840	Three miles
10,240.01 -- 20,480.00	N	21,120	Four miles
20,480.01 -- 40,960.00	O	26,400	Five miles

High Power Rocketry Safety Code (cont)

SAFE DISTANCE TABLE

Total Impulse All Engines (Newton-Seconds)	Equivalent Motor Type	Minimum Distance From Rocket With Single Motor (ft.)	Minimum Distance From Rocket With Multiple Motors (ft.)
160.01 -- 320.00	H	100	200
320.01 -- 640.00	I	100	200
640.01 -- 1,280.00	J	100	200
1,280.01 -- 2,560.00	K	200	300
2,560.01 -- 5,120.00	L	300	500
5,120.01 -- 10,240.00	M	500	1,000
10,240.01 -- 20,480.00	N	1,000	1,500
20,480.01 -- 40,960.00	O	1,500	2,000

Appendix A

Student Launch Initiative (SLI)

Launch a rocket with a $\frac{1}{2}$ lb payload to an altitude of 1 mile and recover it all safely.

SLI - Project Goals

- **Launch a rocket with a 1/2 lb payload to an altitude of 1 mile and recover safely.**
- **Learn about rocketry.**
- **Learn about project management.**
- **“Experience” engineering process.**
- **Learn how to work as a team.**
- **Build foundation for future projects.**

SLI - Project Structure

- **Project Management**
 - **Resource Assignments**
 - **Cost control**
 - **Scheduling and tracking**
 - **Organize Design Reviews**
 - **Customer (NASA) Interface, Status Updates**
- **Engineering**
 - **Requirements**
 - **Design**
 - **Implementation**
 - **Engineering Test**

SLI - Project Structure (*continued*)

- **Quality Assurance/Safety**
 - **Specification compliance**
 - **Safety Compliance**
 - **Design Reviews**
 - **Test Procedures**
 - **Defect Tracking**
 - **Change Management**

- **Public Relations**
 - **Interface to school administration**
 - **Interact with Media**
 - **Web Page**

SLI - Engineering Problem Breakdown

- **Airframe**
 - **Diameter**
 - **Length**
 - **Weight**
 - **Design**
 - **Material Selection and Acquisition**
 - **Construction**
- **Propulsion**
 - **Source: commercial or developed**
 - **Type: Solid or Hybrid**
 - **Storage and regulation**

SLI - Engineering Problem Breakdown (*continued*)

- **Recovery**

- **Type: Single or Dual deployment**
- **Ejection control: Motor or electronic**
- **Ejection Backup: motor, timer, redundancy**
- **Parachute type and sizing**
- **Parachute protection: baffle, wadding, nomex, piston**
- **Ground testing**
- **Safety measures**

- **Payload accommodations**

- **Weight limit**
- **Size limits**
- **Mounting**

SLI - Engineering Problem Breakdown (*continued*)

- **Electronics**
 - **Type: Accelerometer, altimeter, timer**
 - **Data recording?**
 - **Mounting**
- **Flight testing**
 - **FAA waiver**
 - **BATF approved storage for solid motors**
 - **Field availability**

SLI - Conclusion

1. **ORGANIZE!**
2. **Assign resources where they are best suited.**
3. **Spend significant amount of time in requirements and design. *Implementation should be a no-brainer!***
4. **Do it right the first time! (Epoxy is unforgiving!)**
5. **Ground test when possible.**
6. **Ask questions. I'll be glad to answer them!**

Appendix B

Team America Rocket Challenge (TARC)

TARC - Problem Statement (scope of work)

Launch a two-stage rocket, carrying a payload of two raw eggs, to exactly 1250 feet (AGL) and recover the rocket safely and with the eggs unbroken.

TARC - Project Goals

- **Launch a two-stage rocket, with 2 raw eggs as the payload, to exactly 1250 feet (AGL) and recover rocket and eggs safely**
- **Learn about rocketry.**
- **Learn about project management.**
- **“Experience” engineering process.**
- **Learn how to work as a team.**
- **Build foundation for future projects.**
- **Potentially win large cash prizes for sponsoring schools and large scholarships for team members.**

TARC - Project Structure

- **Project Management**
 - **Gather Entry Fee**
 - **Resource Assignments**
 - **Cost control**
 - **Scheduling and tracking**
 - **Organize Design Reviews**
 - **Coordinate and conduct certifying flights**

- **Engineering**
 - **Requirements**
 - **Design**
 - **Implementation**
 - **Ground Test(s)**
 - **Flight Test(s)**
 - **Certifying Test(s)**

TARC - Project Structure (*continued*)

- **Quality Assurance/Safety**
 - **Specification compliance**
 - **Safety Compliance**
 - **Design Reviews**
 - **Test Procedures**
 - **Flight Procedures**

- **Public Relations**
 - **Interface to school administration**
 - **Solicit corporate sponsors**
 - **Interact with Media**
 - **Web Page**

TARC - Engineering Problem Breakdown

- **Airframe**
 - **Booster Diameter**
 - **Booster Length**
 - **Booster Fin Shape**
 - **Sustainer Diameter**
 - **Sustainer Length**
 - **Sustainer Fin Shape**
 - **Weight**
 - **Design**
 - **Material Selection and Acquisition**
 - **Construction**

- **Propulsion**
 - **Source: commercial or developed**
 - **Booster Motor Selection: BP or Solid, specific motor designation**
 - **Sustainer Motor Selection: specific BP motor designation**
 - **Sustainer Motor Ignition: CHAD, or timer or accelerometer**
 - **Storage and regulation (should not be applicable to G and below motors)**

TARC - Engineering Problem Breakdown (*continued*)

- **Recovery**

- **Booster recovery: tumble, high-drag device**
- **Sustainer ejection control: Motor or electronic, or both**
- **Sustainer ejection Backup Desired: motor, timer, redundancy**
- **Sustainer parachute type and sizing**
- **Sustainer parachute protection: baffle, wadding, nomex, piston**
- **Payload recovers with Sustainer or via a separate parachute**
- **Ground testing**
- **Safety measures**

- **Payload accommodations**

- **Weight limit**
- **Size limits**
- **Mounting and protection during flight and recovery/landing**

TARC - Engineering Problem Breakdown (*continued*)

- **Electronics**

- **Altimeter model is specified by TARC rules**
- **Timer needed for Sustainer ignition?**
- **Apogee ejection or staged recovery (to decrease drift)**
- **Mounting**
- **Initiation switch mounting/access**

- **Flight testing**

- **FAA NOTAM (if rocket lift-off weight is between 1 and 3.3 lbs)**
- **Suitable Test Field availability**

TARC - Conclusion

1. **ORGANIZE!**
2. **Assign resources where they are best suited.**
3. **Spend significant amount of time in requirements and design. *Implementation should be a no-brainer!***
4. **Do it right the first time! (Epoxy is unforgiving!)**
5. **Ground test when possible.**
6. **Ask questions. I'll be glad to answer them!**

Appendix C

Who Are These Guys?

Who is this guy, Brian Day?

- Model rocketry experience during childhood
- Grew up during the “Space Race” – Mercury, Gemini, Apollo, etc.
- Strong interest in math and science through high school
- Bachelor of Science, Electrical Engineering, Lehigh University (PA), 1980
- Design Engineer, Texas Instruments, Defense Systems and Electronics Group, Dallas, TX, 1980-1992, various missile guidance and radar programs
- Sr. Staff Engineer, New Technology, Huntsville, AL, 1992 – present, Commanding and telemetry systems supporting Chandra X-ray Observatory and International Space Station
- Rekindled interest in model and high-power rocketry as adult
- President, Huntsville Area Rocketry Association (HARA), 1997 – 2001
- Contact via email:
 - bday@knology.net.net
 - brian.day@msfc.nasa.gov



Vince Huegele and Brian Day with the HARA Patriot, flown with an AeroTech K550 composite motor

Who is this Todd Lumpkin guy?

- Model rocketry experience during childhood
- Grew up during the “Space Race” – Mercury, Gemini, Apollo, etc.
- Strong interest in math and science through high school
- Bachelor of Science, Computer Science, UAH, 1985
- Master of Science, Computer Science, UAH, 1994
- 15 years as an embedded software engineer in industrial, space, and telecommunications industries
- Current: Software Engineer, Sapphire Communications, Inc.
- Rekindled interest in rocketry as a result of introducing son to rocketry
- Vice-President, Huntsville Area Rocketry Association (HARA), 2000 – present; member since 1998
- NAR HPR Certification Level II
- Contact via email:
 - toddl1962@knology.net



Myself and Oscar Valent preparing my scratch-built “Purple Reign” rocket for my Level II certification flight on a J300 Hypertek Hybrid motor

Who is this guy, Chuck Pierce?

- **Model rocketry experience during childhood**
- **Grew up during the “Space Race” – Mercury, Gemini, Apollo, etc.**
- **Strong interest in math and physics through high school**
- **Bachelor of Science, Mechanical Engineering, Louisiana Tech University, 1987**
- **Master of Science, Engineer Management, University of Central Florida, 1996**
- **15 years as Liquid Propulsion Engineer with NASA**
 - 10 years as Shuttle OMS/RCS Test Engineer at KSC
 - 5 years as In-space Liquid Propulsion System Development Engineer at MSFC
 - Current: Sr. Engineer, In-space Liquid Propulsion Systems
- **Rekindled interest in model and high-power rocketry as adult**
- **Member of NAR and TRA, with Level 2 Certification**
- **President, Huntsville Area Rocketry Association (HARA), 2002 to present**
- **Contact via email:**
 - cpierce@knology.net
 - charles.pierce@nasa.gov



**Yours truly with my full-scale Rapier at LDRS 2002. The Rapier weighed 24 lbs and flew to 4300' with a Hypertek hybrid L610 motor.
Photo by Nadine Kenney**

Who is this guy, Vince Huegele?

- **Model rocketry experience during childhood, first Estes flight in 1965**
- **Strong interest in math and science through high school**
- **Bachelor of Science, Physics, Lipscomb University, 1978**
- **Masters of Engineering Science, Univ. of Tennessee Space Institute, 1984**
- **Optical Physicist at MSFC since 1981.**
 - Developed windows for the International Space Station
 - Involved with optics projects, such as the James Webb Space Telescope
- **Involved with NASA classroom rocketry education since 1988, conducting teacher workshops, demonstration and contest launches, and developing school rocketry programs**
- **President, Huntsville Area Rocketry Association (HARA), 1986 – 1996; Senior NAR Advisor 1997 to present.**
- **Member of NAR since 1984**
- **Level 2 HPR Certification**
- **Contact via email: vinson.huegele@nasa.gov**

