National Aeronautics and
Space Administration

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The Next Generation of Explorers







Student Launch – Recovery Systems

Zachary Koch
SL Safety Engineer

Recovery Systems

Hardware

Single Event Recovery Systems

Dual Event Recovery Systems

Altimeters

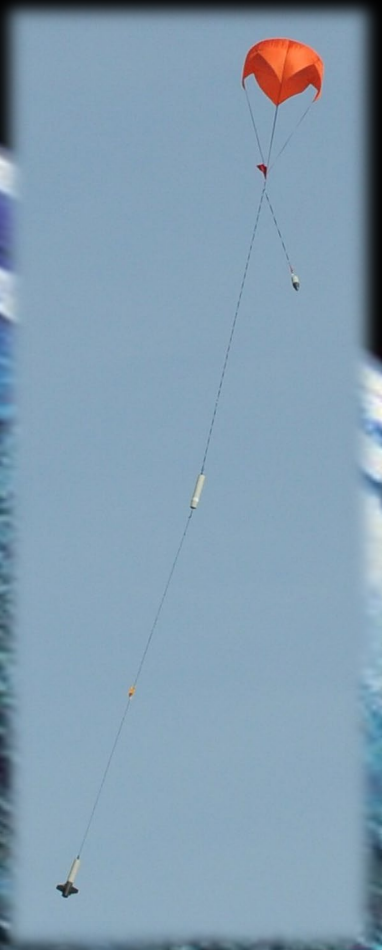
Switches

Ejection Charges

Parachute Selection

Parachute Folding Instruction

Recovery Systems Testing







Hardware

Parachutes:

- The most commonly used recovery device in high powered rocketry
- A high drag device that retards the high speed descent of the rocket by producing a force that opposes the weight of the rocket
- The effectiveness (or drag) of a parachute depends on:
  - Velocity
  - Air density
  - Surface or "reference" area
  - Drag coefficient
- Typically have three major features:
  - Canopy
  - Support lines
  - Steel connector link



$$D = {}^{1}/_{2}\,\rho V^{2} S C_d$$

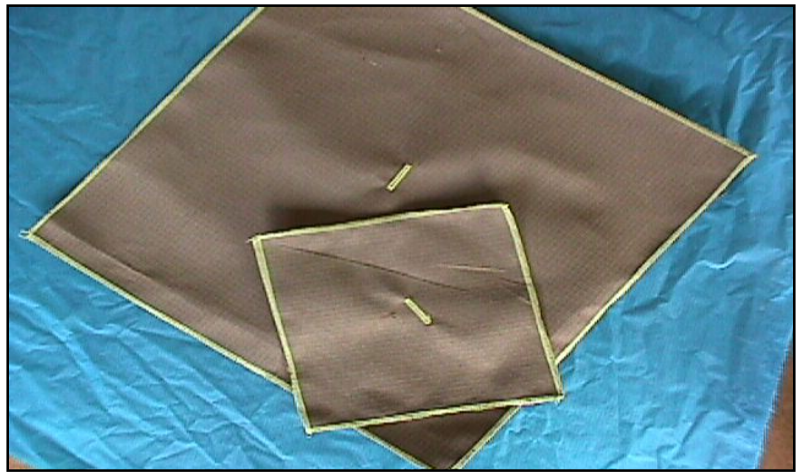
Drag coefficient:
A dimensionless quantity that is used to quantify the drag of resistance of an object in a fluid environment such as air

Parachute Protectors:
A flameproof Aramid cloth or Kevlar cloth will protect the parachute from these hot gases and burning debris.

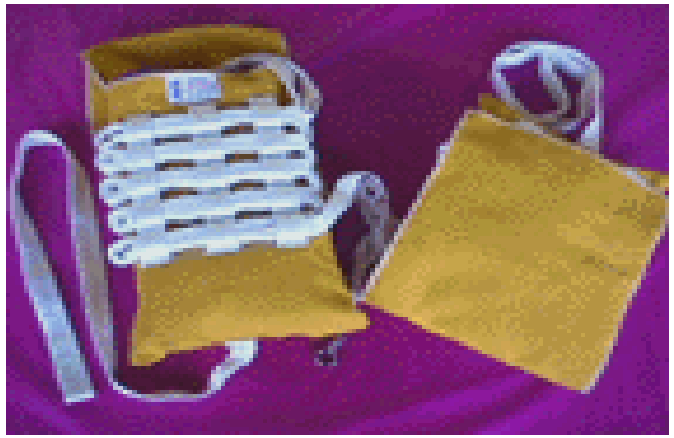
Hardware

Parachute Protectors:

- Nylon is susceptible to melting and charring
- Necessary to protect parachutes
- Typical materials for Parachute Protectors:
  - Aramid/Kevlar
  - Kevlar/Fiberglass
- Other Options:
  - Pistons
  - Deployment Bags (D-Bags or Free Bags)

















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Hardware

Recovery Harness:

- A long length of cord that attaches structural components that separate as part of the recovery system
- Each end is typically secured by quick-link to a *u-bolt* or *eye-bolt* that is rigidly mounted to a bulkplate on an avionics bay, nose cone, or booster
- The length of shock cord required will be the subject or empirical testing and evaluation
- Your workshop rocket has 12 feet of shock cord
- An L3 type rocket may require more than 100 feet or shock cord





Typical materials for shock cords:

- Aramid/Kevlar
- Kevlar/Fiberglass
- Nylon

Shock Cords – Kevlar vs Nylon

Nylon



Kevlar



Considerations:

- Economics
- Strength
- Stretchiness
- Durability
- Preference

Hint: Watch for “strap” vs “tubular”.

Hint: Be weary of manufacturer ratings, size is usually your best reference.

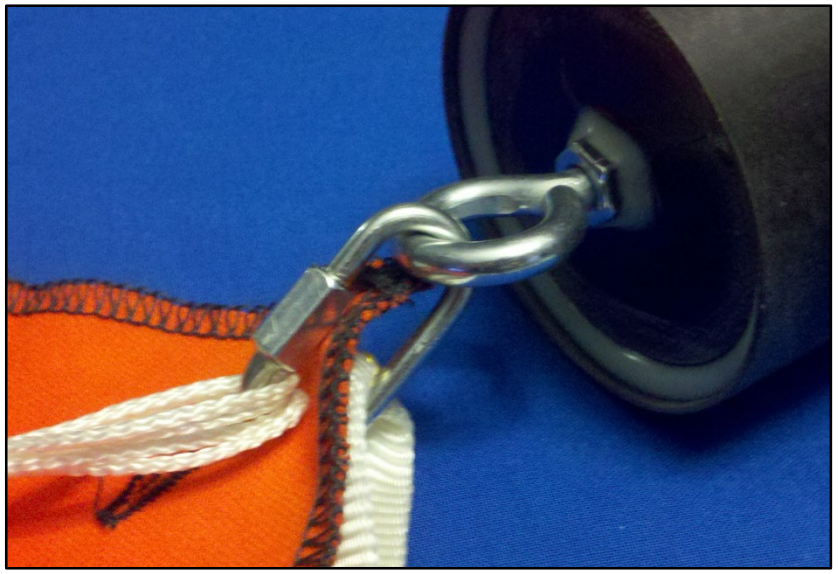
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Hardware

Quick Links:

- Make connecting and rigging a recovery system very easy
- Many different types of quick links available commercially
- Always use quick-links with a locking gate
- Take care in choosing a quick-link that will safely carry the maximum expected load
  - Too small of a quick-link may yield under heavy loading when the main parachute opens





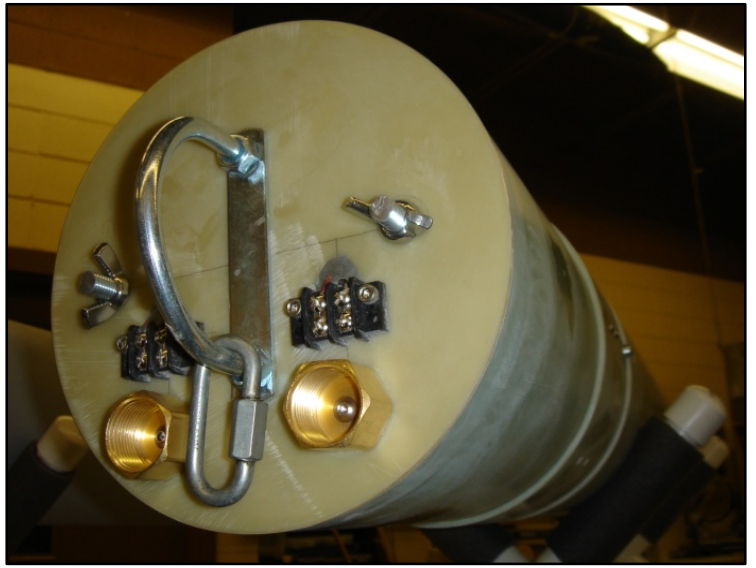
Hint: Stick with Stainless Steel.

Hardware

Eye-Bolts & U-Bolts:

- Hard points on rocket's structures for attaching recovery system
- Typically mounted on bulkplates and/or centering rings
- U-bolts are preferred on large rockets
- **Eye-bolts should be closed and/or welded closed**





Other Hardware

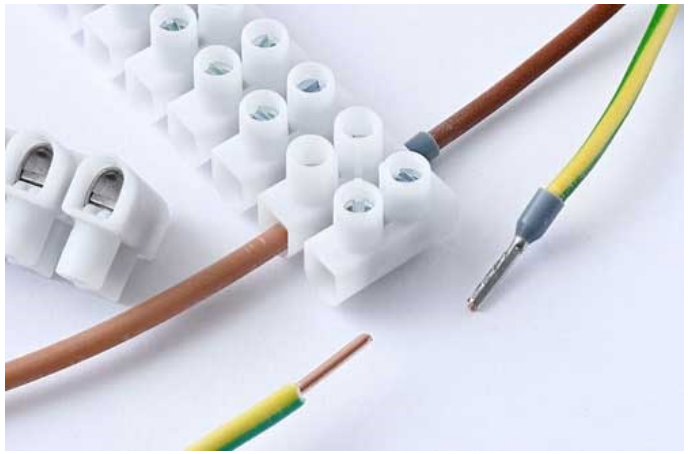














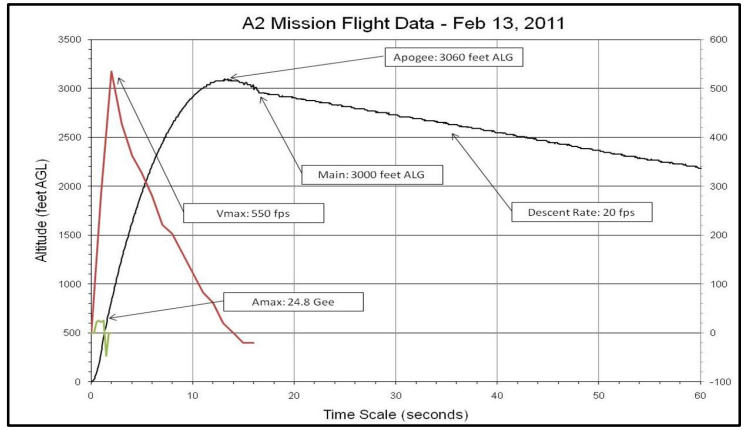


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Single Event Recovery Systems (SERS)

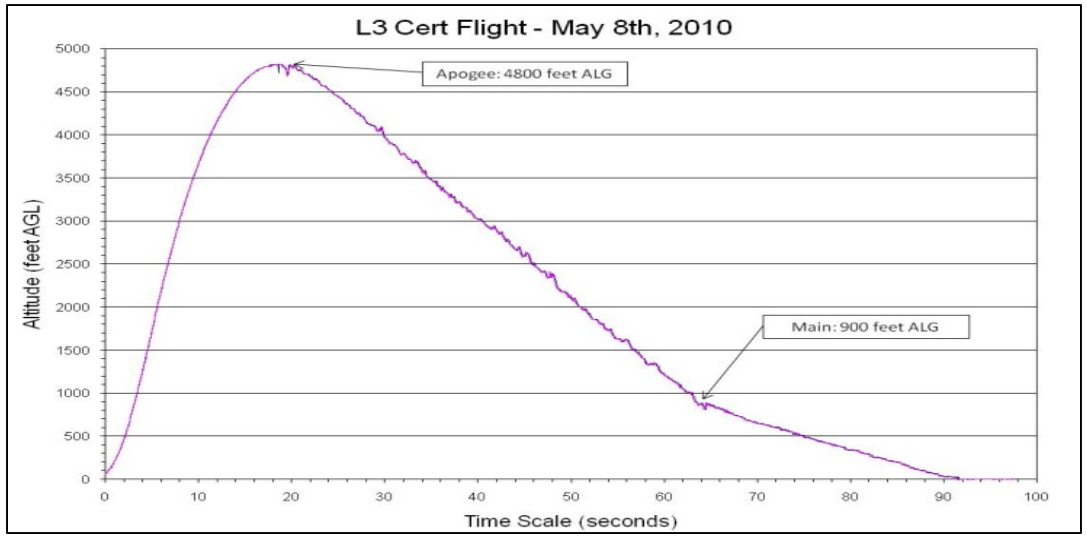
- A typical S*ingle Event Recovery System* ejects a parachute at apogee
- This can most commonly be achieved by using a motor ejection charge
- Most low to mid power rocket motors have this capability
- At motor ignition, the propellant and a delay grain begin to slowly burn
- Once it burns through, the ejection charge is set off and the parachute is deployed
- SERS is the simplest recovery system and is good for low altitude flights on small launch fields and high altitude flight on very large launch fields

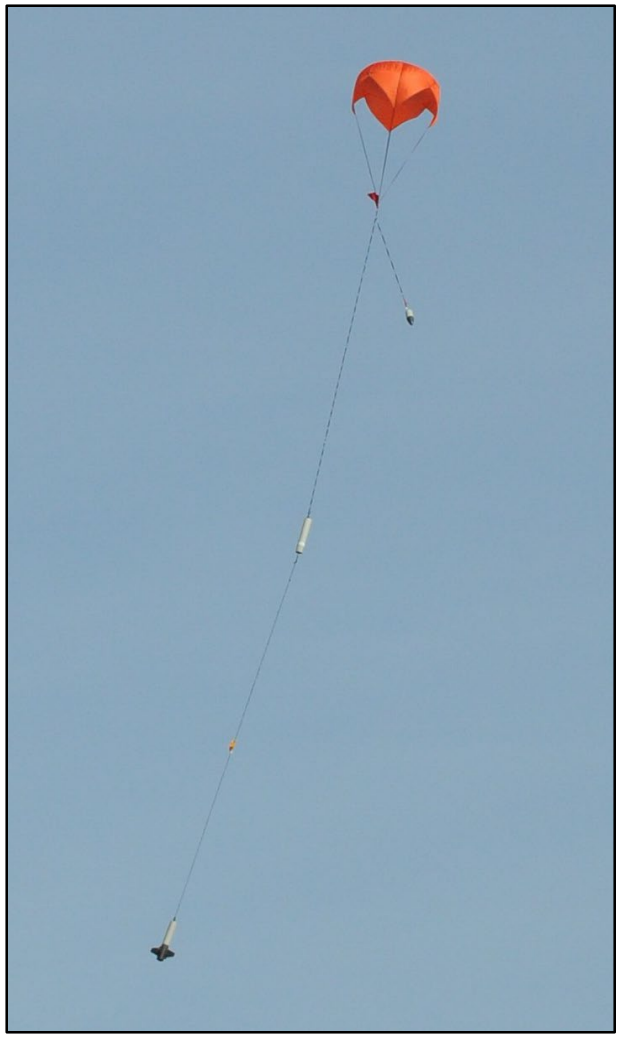




Dual Event Recovery Systems (DERS)

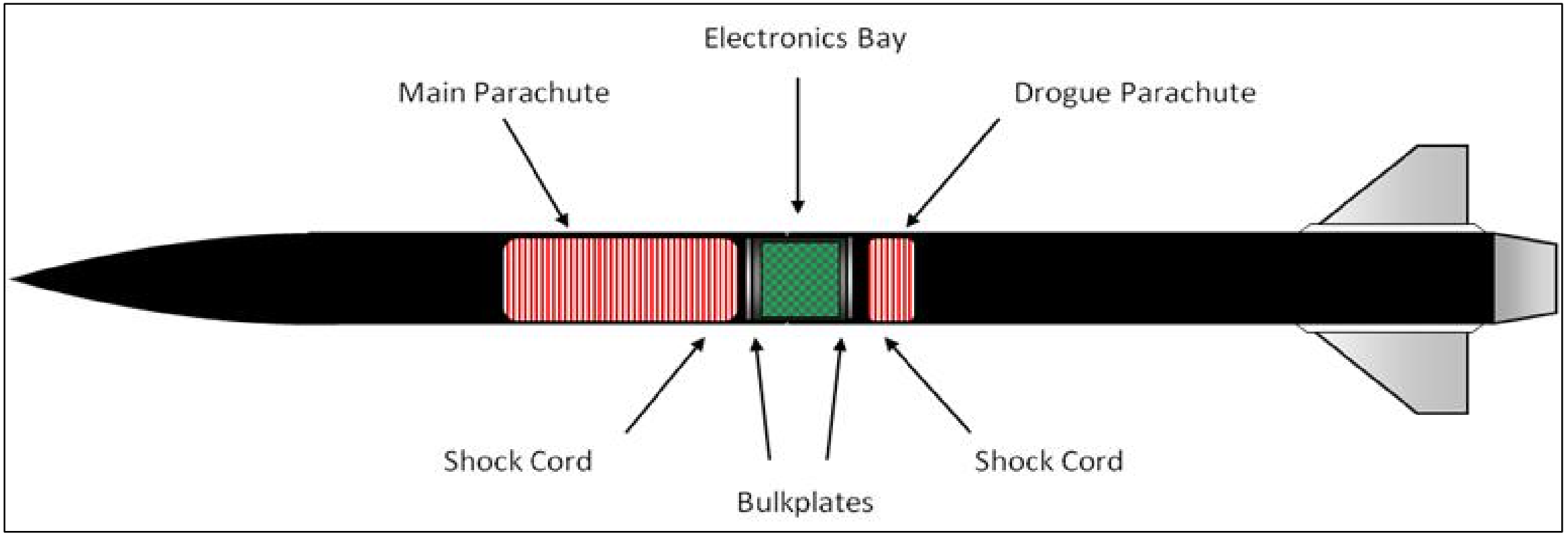
- **Your Student Launch Project rocket is required to use a *Dual Event Recovery System***
- 1st event at apogee
- 2nd event at much lower altitude
  - Typically 500-1000 feet *Above Ground Level (AGL)*
  - Requires electronics do to so
- Significantly reduces the recovery area





Dual Event Recovery Systems (DERS)

General System Layout:

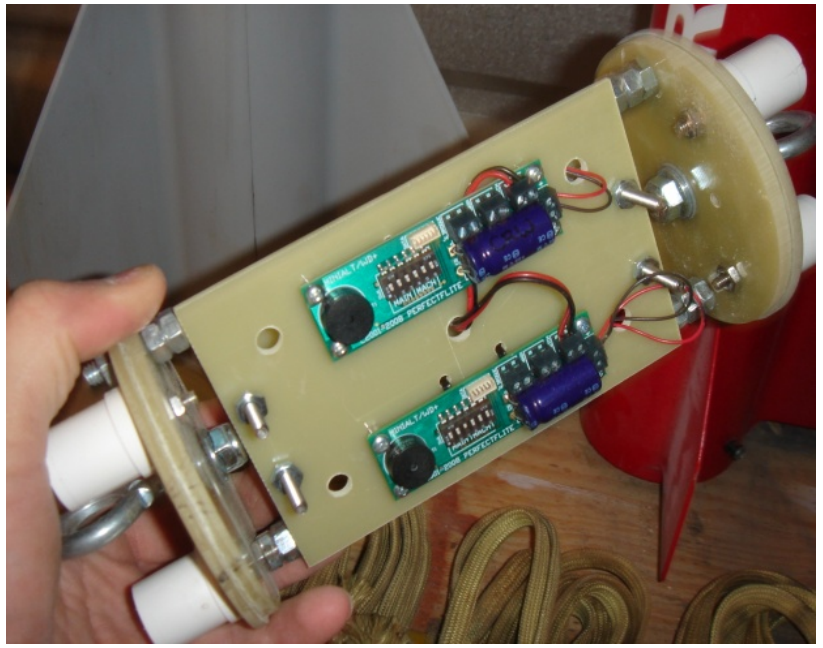


Dual Event Recovery Systems (DERS)

The Avionics Bay

- Subsystem of a high powered rocket that typically contains altimeters, batteries, and switches
- A typical E-Bay is comprised of three structural components: the *housing,* a forward and aft *end-cap* and an *avionics sled*



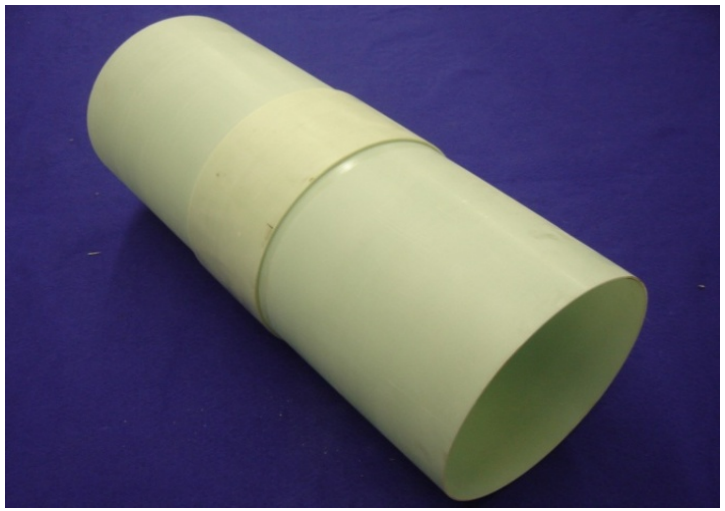


Dual Event Recovery Systems (DERS)

Avionics Bay Housing

- Typically built from a coupler tube
- Can have a collar made from a segment of airframe epoxied to the middle of the couple
  - Allows direct access to the switches that power on the altimeters
  - Supports static pressure ports that equalize the housing's interior pressure with the exterior atmosphere
- Generally, when joining airframes with a coupler, the coupler should extend at least one airframe diameter into each joined segment

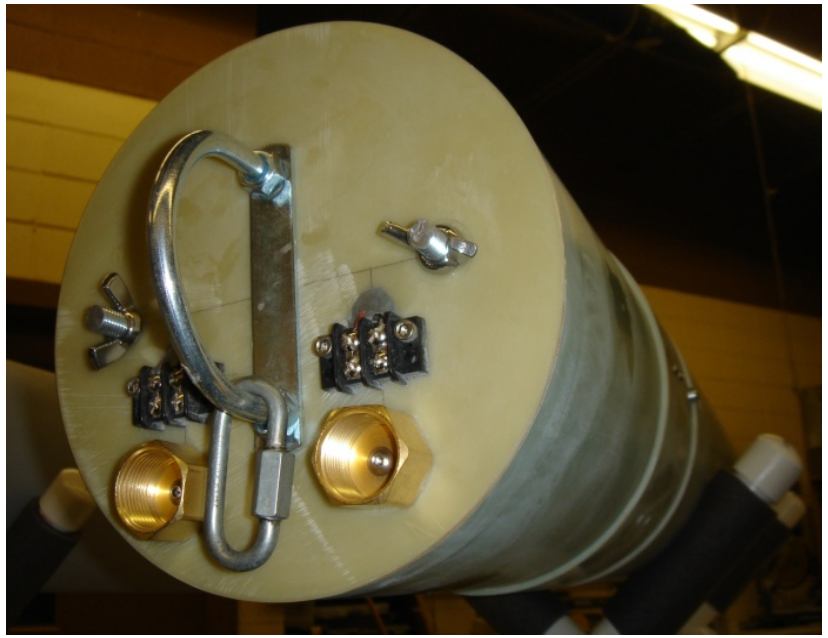




Dual Event Recovery Systems (DERS)

End Caps (i.e. removable bulkheads)

- Close out the housing separating the rocket's volumes
- Support the recovery harness hard mounts, charge cups, and all-threads
- The all-threads act as a two-force member that connect both end-caps and carry the recovery harness load through the E-Bay
- End-caps should create a good seal around the end of the housing to prevent hot gas seepage from the ejection charges
- Typical Materials:
  - G-10 fiberglass
  - Plywood



Dual Event Recovery Systems (DERS)

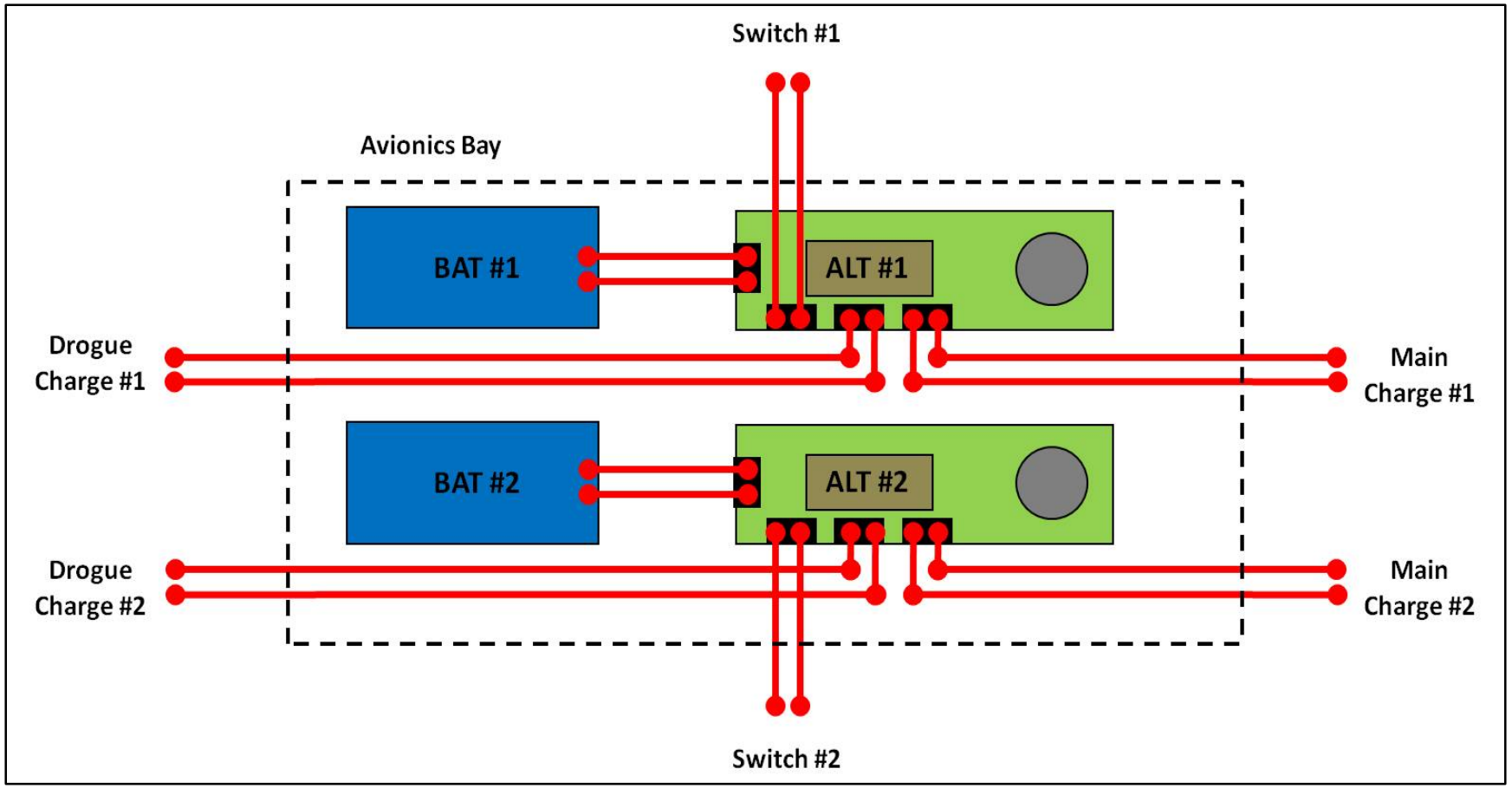
Avionics Sled

- Sliding onto the all threads that connect the end plates - like a sled
- The avionics electronics, batteries, and switches are mounted to the sled and wired together to form systems
- Typical Materials:
  - G-10 fiberglass
  - Plywood



Dual Event Recovery Systems (DERS)

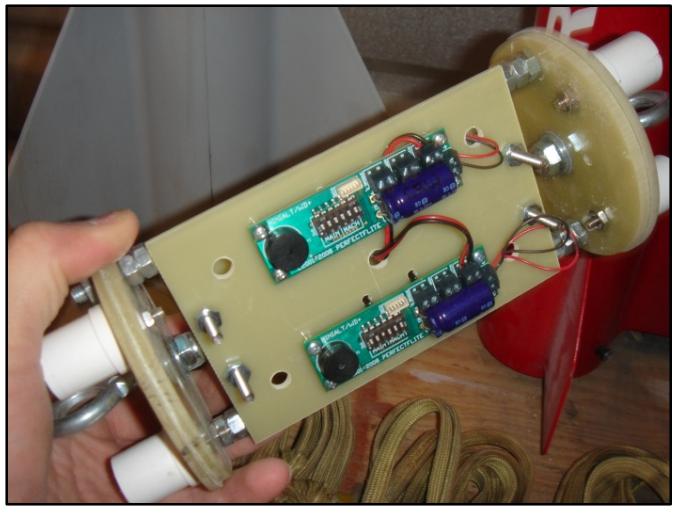
General Electronics Layout:

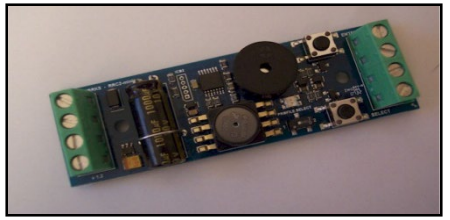


Recovery Electronics

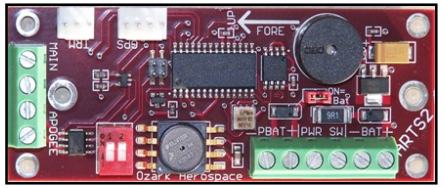
Altimeters

- *Dual Event Recovery Systems* require the use of electronic devices called *Altimeters*
- Determine altitude and initiate recovery events
- **Your Student Launch Project rocket should have no less than two commercially available, independent, redundant altimeters**
- It is recommended that each altimeter have a dedicated battery and on-off switch
- This setup will greatly reduce the likelihood of a recovery system failure
- Typically, altimeters require 9V-12V of electricity
- Altimeters, generally inside of the rocket's avionics bay, need to sample the outside air pressure
- Your rocket will need static pressure port along the outside to allow the inside pressure to equalize to the outside pressure









Recovery Electronics

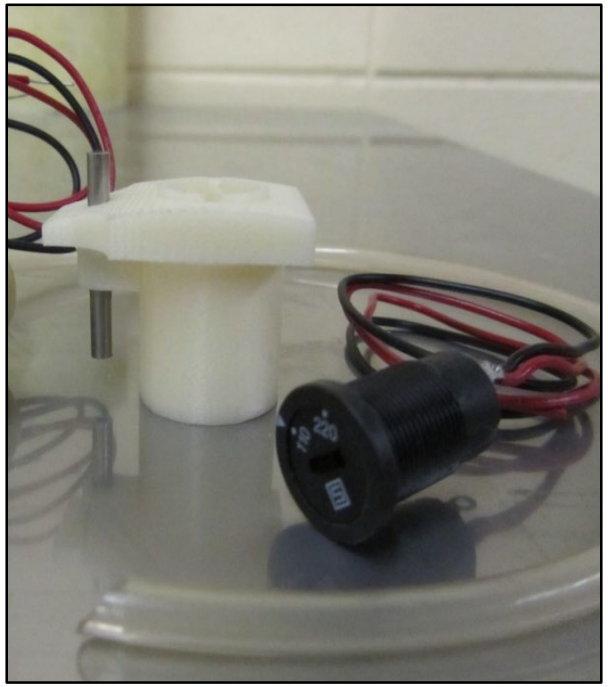
Batteries

- **The NASA Student Launch Projects official handbook requires that your rocket have a *minimum* pad stay time of two hours**
  - That means that your electronics should be able to remain switched on and reliably operate if the rocket remains on the pad for up to one hour on the pad before launch
- Two main types of batteries:
  - Primary - designed to be used once and discarded when they are exhausted
  - Secondary - designed to be rechargeable and used multiple times
- Benefits of primary batteries:
  - Cost less than secondary batteries
  - Don't require sophisticated chargers to recharge them
  - Lower "*self discharge*" rates than secondary batteries
- Benefits of secondary batteries:
  - Weight less than primary batteries
  - Manufacturers can shape them however they please
  - Greatly increased run time
- **Improper use or charging of some secondary batteries can result in fire or explosion**

Recovery Electronics

Switches

- Typically rocket builders prefer to power up electronics from outside the rocket
- Safety feature for pressure & g-switch activated recovery systems
- Maximizes battery life
- Surface mounted to airframe or mounted inside rocket with access hole or panel
- Two categories of switches typically used on high powered rockets:
- *Single Pole Single Throw (SPST),* is a simple of-off switch where the two terminals are either connected together or disconnected from each other
- *Dual Pole Single Throw (DPST)* is equivalent to two SPST switches controlled by a single mechanism. In these two categories, there are toggle switches, push button switches, and selector switches



Ejection Charge Sizing

- A black powder charge is the most common and reliable method of ejecting a parachute from your rocket
- Hot gases that pressurize the rocket's airframe and exert a net force on the bulkplate of the nose cone
- This net force will eject the nose cone, shock cord, and parachute out of the rocket airframe
- This all happens because the rocket is obeying the *Idea Gas Law*
  - P is the absolute pressure of the gas
  - V is the volume occupied by the gas
  - N is the amount of substance (black powder)
  - R is the gas constant
  - T is the absolute temperature



$$PV = NRT$$

Ejection Charge Sizing

- The equation can be reordered to solve for N directly and known values substituted
- The design pressure is determined by the desired net force on a surface divided by the area of that surface
- Typical net force values for a 4 inch diameter rocket range from 100 lbf - 200 lbf
  - This translates to a typical pressure range of 8psi – 16psi

$$Pressure: P = {}^{F}/_{A} = {}^{200\ lbf}/_{\pi\ (2in)^2} = 16\ psi \qquad Volume: V = \pi R^2 L = 12.5 in^2 L$$

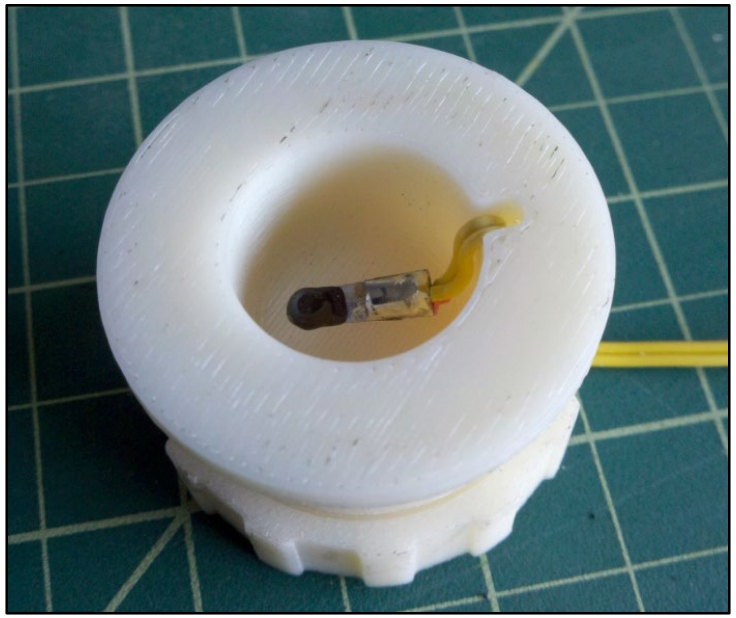
- Black Powder charge amounts are typically reported in the unit grams
  - Recall that there are 454 grams in 1 pound

$$Black\ Powder: N = \frac{PV}{RT} = \frac{16psi * 12.5in^2 L}{266\ {}^{in\ lbf}/_{lbm} * 3307°R}\left(\frac{454\ grams}{1\ lbf}\right) = 0.1L$$

- The reduced equation for this case, states that 0.1 grams of Black Powder is needed for every 1 inch of airframe containing the recovery system
  - If L = 20 inches, then 2.0 grams of black powder is needed to eject the recovery system

E-Matches

- Universal initiator of many rocketry pyrotechnics and motors
- typically made from a thin nichrome (nickel-chromium) wire laminated to a small non conductive flake of fiberglass
- Each end is soldered to one wire of a two conductor solid core copper shooter wire
- The nichrome bridge is dipped into a pyrogen formula that dries hard and looks like a match, hence the name
- Typically high current or low current
- **Kits for making your own e-matches can be purchased on the internet – NOT TO BE USED IN NASA STUDENT LAUNCH**
- Can be purchase from most vendors on launch day



Hint: Some distributors use other names. E-match are considered a "bad word".

Shear Pins

- Generally used on mid to high powered rockets to prevent *dynamic separation* or premature/incomplete deployment of the recovery system
- Dynamic separation occurs when a rockets separates in the coasting phase because the different sections are decelerating at different speeds
- An example would be when a rocket's booster section separates from the forward airframe or nose cone because the fin drag or the base drag effects creates a significant enough force to overcome the frictional force keeping the sections together
- Rocket builders generally use small nylon machine screws as shear pins
  - #2-56 nylon machine screw has an average shear strength of 25 lbs
  - #4-40 nylon machine screw has an average shear strength of 40lbs

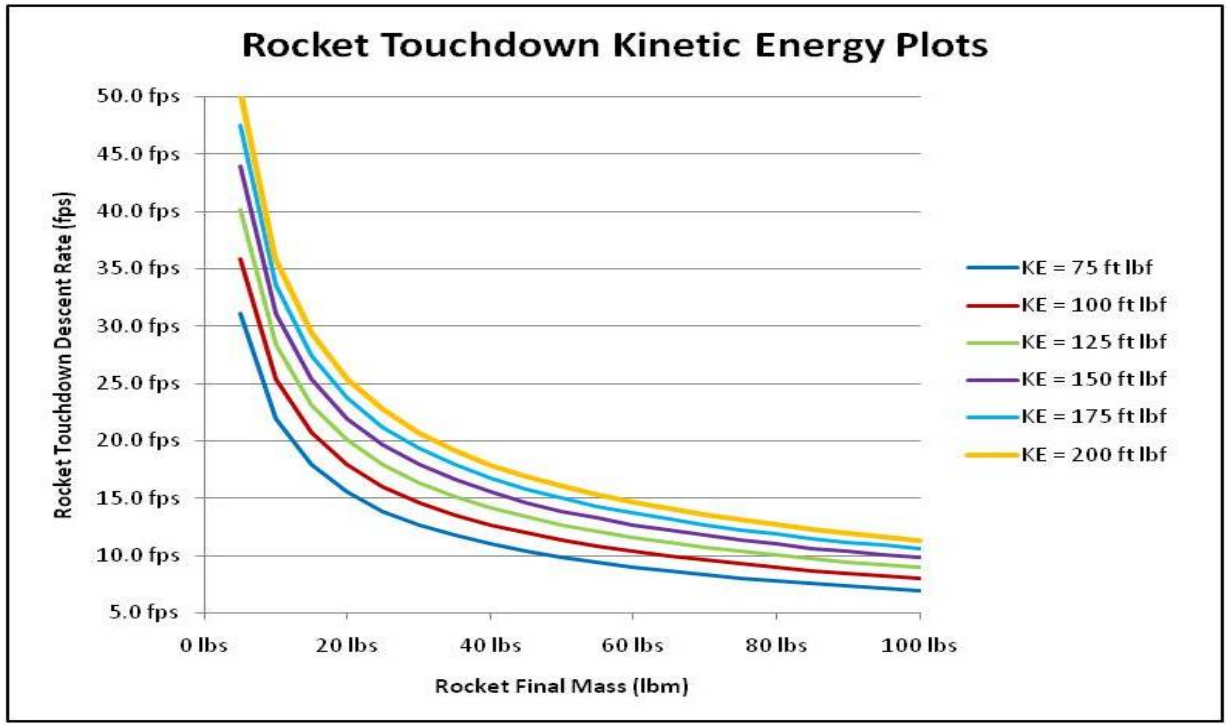


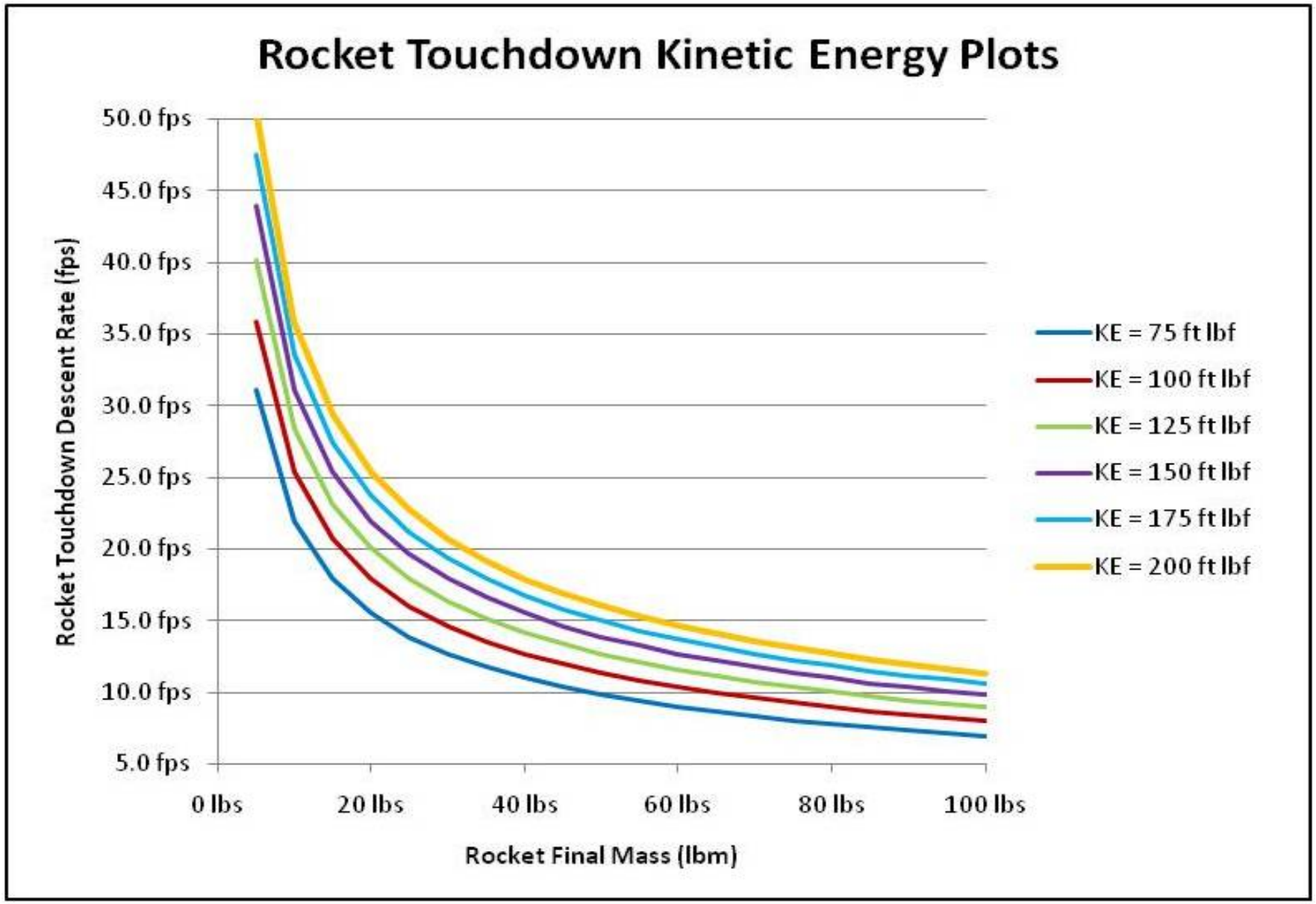
Parachute Selection

Kinetic Energy (KE)

- Energy of motion
- There are many forms of KE
- Focus on translational motion –motion linearly from point A to point B.
- KE is a scalar quantity
- Typically units:
  - foot-pounds force (ft-lbf) [English]
  - Joules (J = Nm) [SI]
- The KE of an object is dependent upon two variables:
  - Mass (m)
  - Speed (V)

$$KE = \frac{1}{2} mV^2$$



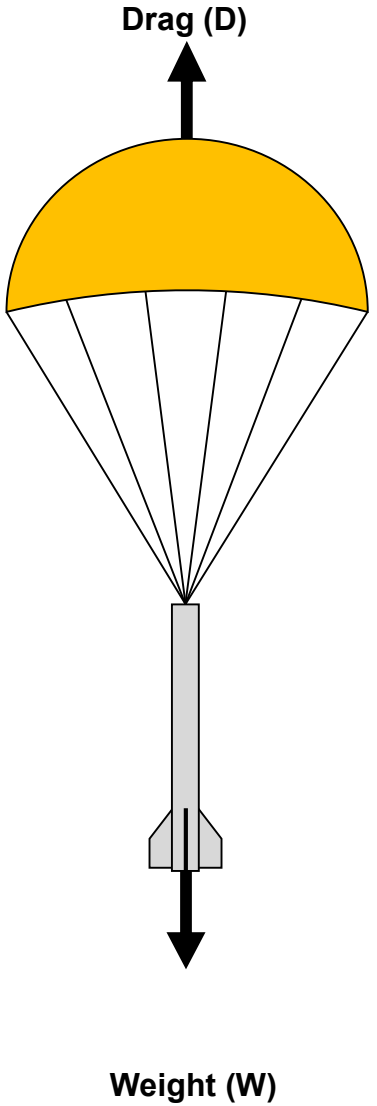

Rocket Touchdown Kinetic Energy Plots
50.0 fps
45.0 fps
40.0 fps
35.0 fps
30.0 fps
25.0 fps
20.0 fps
15.0 fps
10.0 fps
5.0 fps
Rocket Touchdown Descent Rate (fps)
0 lbs
20 lbs
40 lbs
60 lbs
80 lbs
100 lbs
Rocket Final Mass (lbm)
KE = 75 ft lbf
KE = 100 ft lbf
KE = 125 ft lbf
KE = 150 ft lbf
KE = 175 ft lbf
KE = 200 ft lbf

Parachute Selection

Parachute Selection

- The rocket and parachute obey Newton's 2nd Law of Motion
  - The relationship between an object's mass m, its acceleration a, and the applied force F is F = ma
- The basic assumptions used to calculate the descent rate of a rocket are:
  - The rocket descends at a constant speed (steady state)
  - The rocket moves simply downward (constrained to z-axis)
  - The atmosphere is a continuum. (constant air density)
- If you make these assumptions, there are only two forces acting on the rocket – Weight and Drag

$$\Sigma F_z = D - W = ma = 0 \ (steady\ state)$$



Parachute Selection

- Recall that drag is determined by:
  - Velocity
  - Air density
  - Reference area
  - drag coefficient (c_d)

$$D = {}^{1}/_{2}\rho V^2 S C_d$$

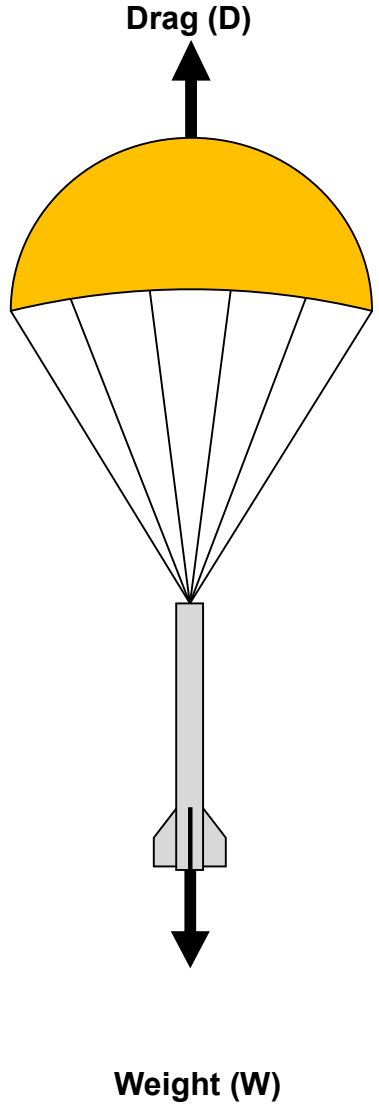
- Substituting the drag equation, Newton's 2nd Law becomes

$$W = D = {}^{1}/_{2}\rho V^2 S C_d$$

- The equation is reordered to solve for the reference area (S):

$$S = {}^{2W}/_{\rho V^2 C_d}$$

- Make an initial guess for the rocket's weight and set your drag coefficient to 2.0 and solve
- you can determine a range to begin shopping for parachutes



Parachute Selection

- Perform the calculations again using the specific parachutes reference area and the manufacturer's calculated drag coefficient
- (Descent Velocity = 18 ft/s)

$$S = {}^{2W}/_{\rho V^2 C_d} = \frac{2 * 20lbm}{0.075\,{}^{lbf}/_{ft^3} * 18\,{}^{ft}/_{s} * 2.0}\left(\frac{32.2\ lbm}{{}^{lbf \cdot s^2}/_{ft}}\right) = 26.5 ft^2$$

- For this case, the rocket will require a parachute that has an area of 26 ft^2
- Your design will continue to mature and you will need to re-evaluate your parachute selection as you get better estimates for your rocket's weight

….and now some simpler methods

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Selecting a parachute

Manufacturer Data

STANDARD 'CHUTES	X-TYPE 'CHUTES
9" 1-2 OZ.	10" 2-3 OZ.
12" 2-3 OZ.	18" 4-12 OZ.
15" 3-5 OZ.	24" .75-1 LB.
18" .5-1 LB.	30" 1-1.75 LB.
24" 1-1.75 LB.	36" 1.5-2.5 LB.
30" 1.75-3 LB.	42" 2.5-3.5 LB.
36" 3-5 LB.	48" 3.5-4.5 LB.
45" 5-7 LB.	54" 4.5-5.5 LB.
50" 7-9 LB.	60" 5.5-7.5 LB.
58" 9-12 LB.	70" 7.5-9.5 LB.
70" 12-18 LB.	80" 9.5-12.5 LB.
84" 18-24 LB.	90" 12.5-17.5 LB.
96" 20-32 LB.	
120" 32-50 LB.	





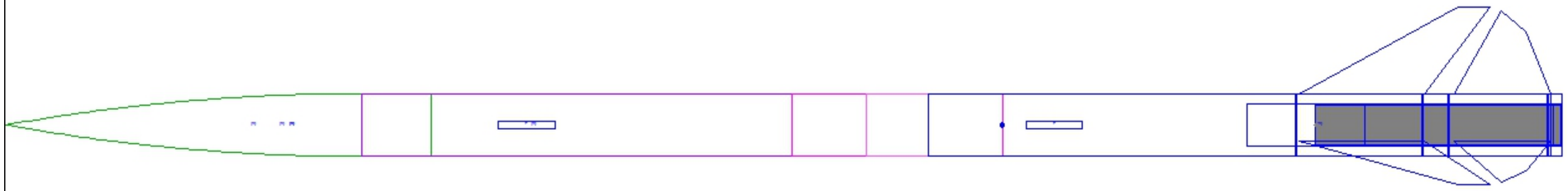
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SkyAngle™ Parachutes	Cd	feet/sec. 17	20	25
Classic/Classic II 20	0.80	0.7	1.0	1.5
Classic/Classic II 24	1.16	1.0	1.4	2.2
Classic/Classic II 28	0.93	1.5	2.0	3.2
Classic/Classic II 32	1.14	2.1	2.8	4.4
Classic/Classic II 36	1.34	2.7	3.7	5.7
Classic/Classic II 44	1.87	4.4	6.1	9.5
Classic/Classic II 52	1.46	6.8	9.5	14.8
Classic/Classic II 60	1.89	10.2	14.2	22.1
CERT-3™ Drogue	1.16	1.0	1.4	2.2
CERT-3 Large	1.26	16.2	22.4	35.0
CERT-3 Xlarge	2.59	32.6	45.2	70.6
CERT3 XXLarge	2.92	60.0	83.1	129.8
weight load (lbs.) for given descent rate (@ sea level)				

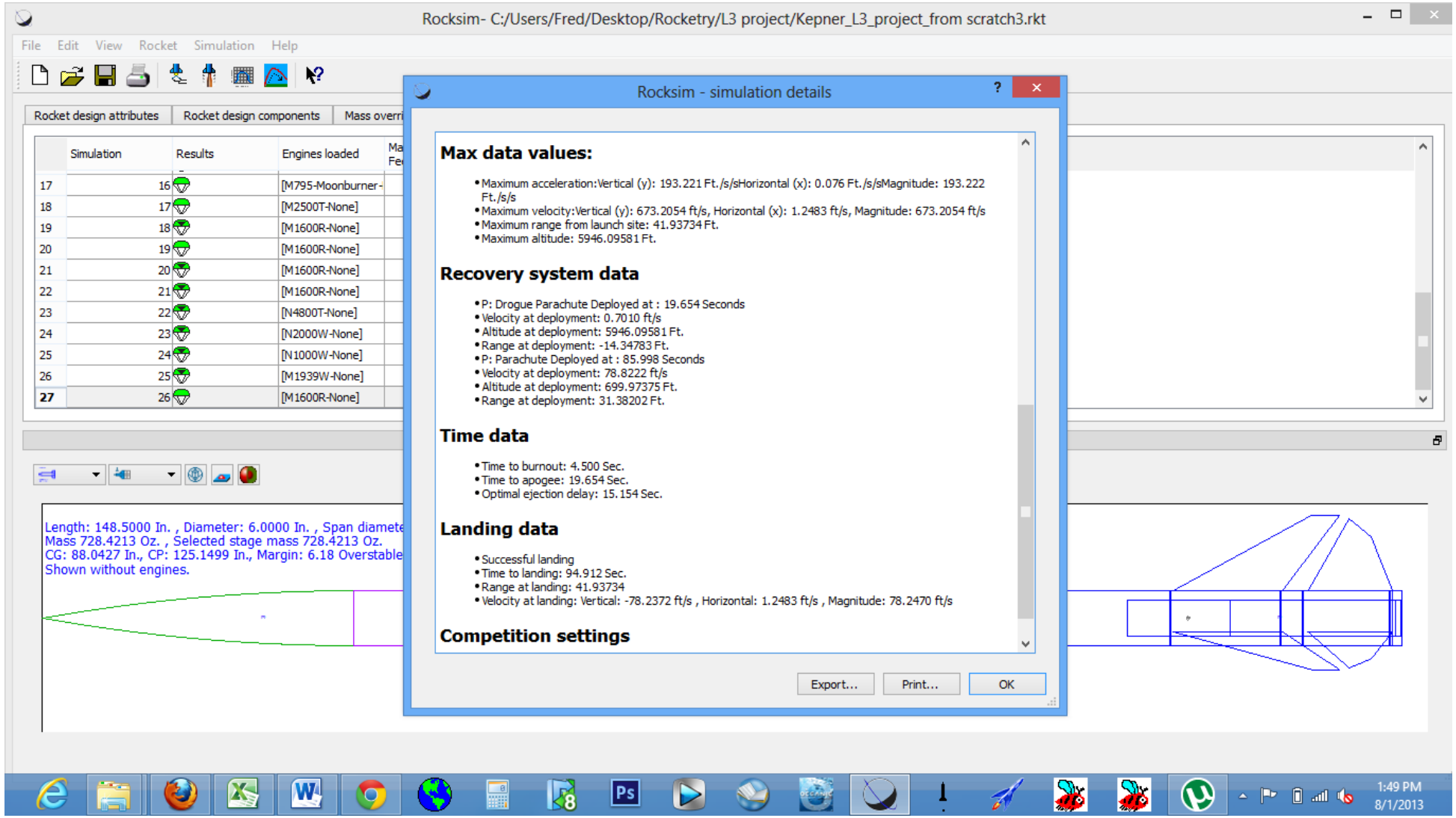
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Manufacturer charts are great but other tools are also available.

Length: 148.5002 In. , Diameter: 6.0000 In. , Span diameter: 22.5000 In.
Mass 913.3517 Oz. , Selected stage mass 913.3517 Oz.
CG: 95.1147 In., CP: 125.1104 In., Margin: 5.00 Overstable
Engines: [M1419W-None,]



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FRUITY CHUTES
Professional Aerospace Recovery Solutions

Parachute Descent Rate Calculator

This tool will plot the descent rate of two parachutes around the weight you specify. To use the tool:

- Enter the parachute model you want to plot. The primary chute goes on the left side. The optional chute to compare with goes on the right. Leave this blank if you do not want a second chute plotted. The form fields with the chute's diameter and Cd (coefficent of drag).
- You can override the diameter or the Cd to test how a different chute would perform or how Cd affects performance.
- Enter the target weight. The default is 11 lbs (5Kg). The plot will then graph the parachute performance based on weight.
- Hit return to update the plot after you override values. Or press "Update" after changing any values.
- Compare our chutes alongside the products of other manufactureres.

*** IMPORTANT NOTE ABOUT REFERENCE DIAMETER**: Reference Diameter is used to calculate the descent velocity drag area. For Fruity Chutes parachutes, this diameter is the same as the opening diameter of the chute. Th parachute is calculated as Pi * D / 4, where D is the reference diameter. For flat sheet chutes like Top Flight, the reference diameter is the flattened diameter of the chute - again the diameter quoted by the manufacturer. Fo manufacturers, the chute's size is measured by the distance (circumference) across the canopy. Or in some cases it's just a model number and we are not sure of the exact size. This includes Rocket Man, Spherachute, Sky Ar TAC chutes. For these the equivalent reference diameter is calculated based on the geometry of the canopy while in flight. This then becomes the reference diameter used to calculate the descent velocity. For these chutes the diameter is different from the size of the manufacturer. For example, a Spherachute 120" parachute has an equivalent diameter if 76.4 inches. However, the Cd of the Spherachute parachute is set to 1.5 so the resulting the manufacturers data. For these chutes the Cd is adjusted so the resulting descent rate matches the manufacturer's published rates for that model. This has occasionally caused some confusion for people using the calcul manufacturers' chutes.

Manufacturer:

Fruity Chutes

Manufacturer:

select manufacturer to compare (click here)

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Manufacturer:

Fruity Chutes

Model:

IFC-60-S - 60 in Iris Ultra Compact with Spectra lines

Reference Diameter (in)*:

60.0000

Cd (Projected):

2.20

Target Weight (lbs):

11

Manufacturer:

select manufacturer to compare (click here)

Compare Model:

select parachute to compare (click here)

Reference Diameter (in)*:

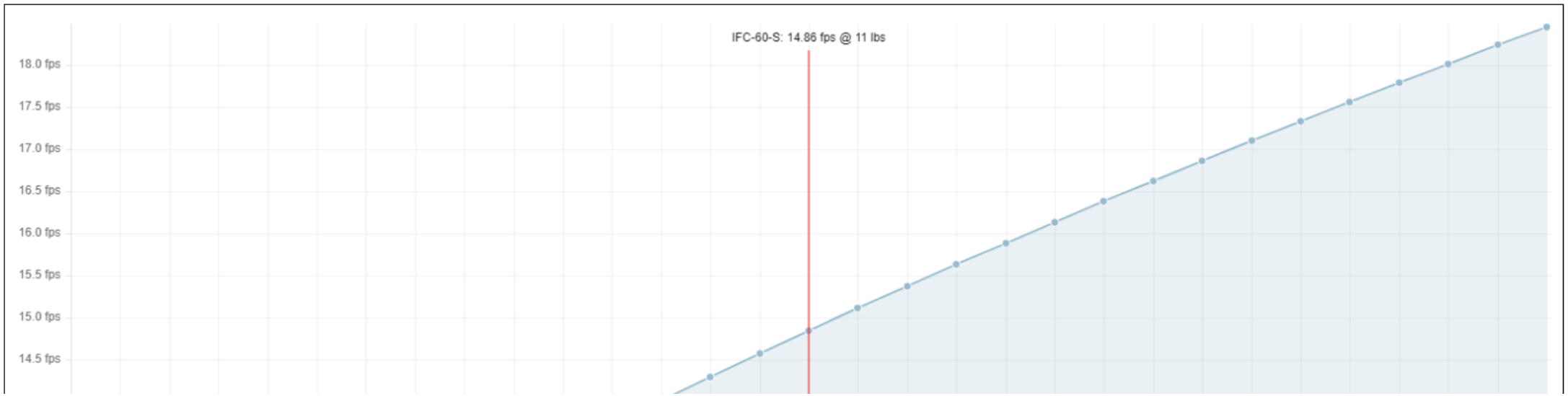
Cd (Projected):

Units:

Imperial

Update

Descent Rate vs Weight



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Make sure your parachute (and other recovery materials) will fit in your rocket

"Rocket Recovery Redefined"

SkyAngle™ Parachutes -- Minimum Tube Compartment Length* (in inches)

*(When folded and packed per instructions. Does not include shock cord, suspension lines, FreeBag, Nomex® pad, wadding, etc. Measurements are nominal.)

Tube Size	29mm	38mm	54mm	2.56in	3.00in	3.90in	5.50in	6.00in	7.51in	11.41in
Chute Size										
Classic 20	*	8*	6	6	6	<6	-	-	-	-
Classic II 20	*	10*	7*	7	7	<6	-	-	-	-
Classic 24 (NEW!)	*	12	11	8	<7	-	-	-	-	-
Classic II 24	See CERT-3™ Drogue									
Classic 28	*	*	7	7	7	<7	-	-	-	-
Classic II 28	*	*	10	10	10	<10	-	-	-	-
Classic 32 (NEW!)	*	*	11	10	8	<8	-	-	-	-
Classic II 32 (NEW!)	*	*	12	11	10	<9	-	-	-	-
Classic 36	*	*	10*	10	8.5	<9	-	-	-	-
Classic II 36	*	*	*	11	10	<10	-	-	-	-
Classic 44	*	*	*	9	8	9	-	-	-	-
Classic II 44	*	*	*	12*	11	10	<10	-	-	-
Classic 52	*	*	*	*	11	9	<9	-	-	-
Classic II 52	*	*	*	*	13	10	<10	-	-	-
Classic 60	*	*	*	*	14	11	<11	-	-	-
Classic II 60	*	*	*	*	*	12	<12	-	-	-
CERT-3™ Drogue	*	*	7	7	7	<7	-	-	-	-
CERT-3 L	*	*	*	*	*	17	12	10	8	5
CERT-3 XL	*	*	*	*	*	25	15	14	11	5
CERT-3 XXL	*	*	*	*	*	33	25	16	12	6

* = Does not fit, or very tight fit. - = Easy fit, minimum space required.

(rev 9/02)

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Recovery System Testing

Vacuum Chamber Testing:

- Proves pressure based rocket altimeter functional
- Can be as simple as a single altimeter in a mason jar using a marinade syringe to pull the air out
- Or as complex as a full systems test of the entire rocket recovery system
- A simple visual indicator of an altimeter's health can be a Christmas tree light wired in to the ejection charge terminal blocks



Recovery System Testing

Ejection Charge Testing

- Conduct several ejection charge tests before flight
- Best way to assess:
  - Ejection charges are of sufficient size
  - Assess the configuration effectiveness
- Success criteria:
  - Both main and drogue systems deployed as expected
  - The parachutes are extracted from the airframe
  - The parachutes and shock cords are suitably protected from the ejection charge
- The tests proved the design ready for flight



Questions?