Recovery Systems

Tripoli Minnesota

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Agenda

- Overview
- Dual Deployment Designs
- Avionics Bays
- Electronics & Ejection
- Attachment Points
- Parachutes & Packing
- Summary

Overview

- Why use Dual Deployment?

You're Verno
1. To stay out of mosquito infested swamps.

✓ 2. To reduce the drift distance

Unless … ensuring that the vehicle remains in the recovery area as specified by the Tripoli Safety Code.

You're Bill
3. So those with bad hips don't have to walk so far.

Overview

- Two Stage Recovery Philosophy
  - Initial Rapid Controlled Descent
    - Descent Rate ≈ 100 ft/sec
    - Techniques: Flat Spin, Body Separation, Streamer, Parachute
  - Slow Final Descent
    - Descent Rate ≈ 20 ft/sec
    - Techniques: Parachute

Failure Modes

#1 Cause of Failure is Recovery!

Attachment Points

- Quick Links not Connected or Left Open
- Poor Knot Selection
- Inadequate Hardware

Deployment

- Too Small/Not Tested
- Incorrect Altimeter Setup
- Loss of Power
- Electrical Wire Disconnects

Parachute, Bridle, etc.

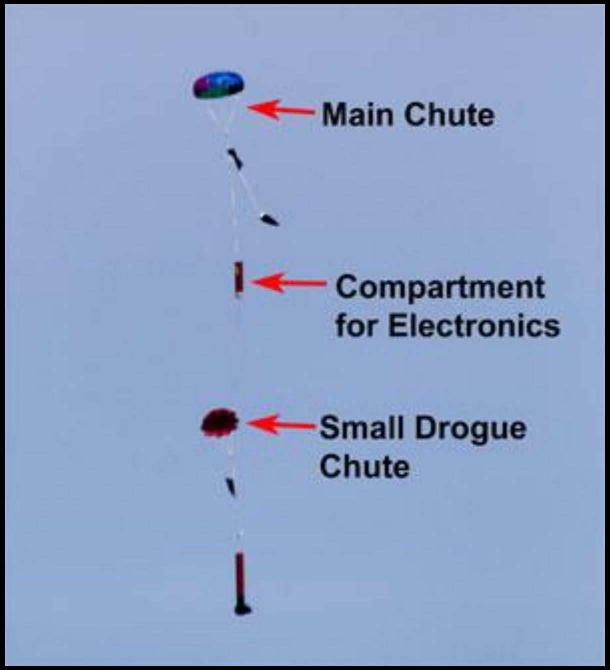
- Improperly Folded
- Improperly Sized
- Inadequately Protected
- Fatigue Considerations

Related Failures

- Drag Separation
- Zippers
- In Flight Self Impact
- Shear Pin Failure

Dual Deployment Designs

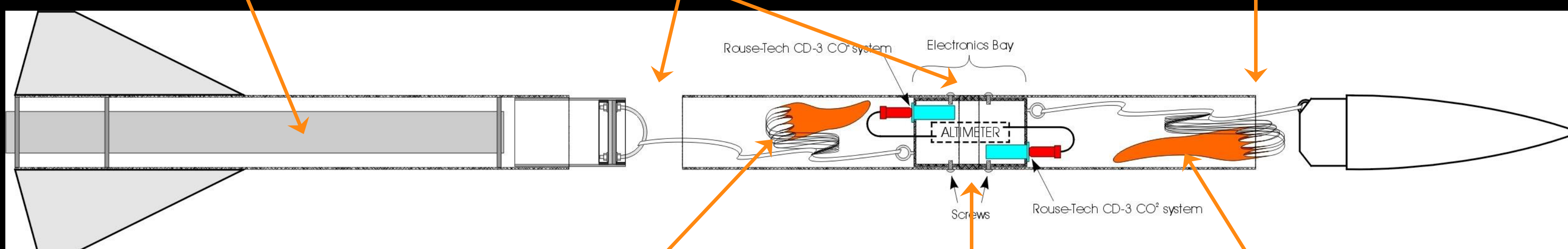
- **Design Approaches**
  1. Split Airframe Deployment
  2. Inline Deployment
  3. Rear Deployment
  4. Hatch Deployment



Split Airframe

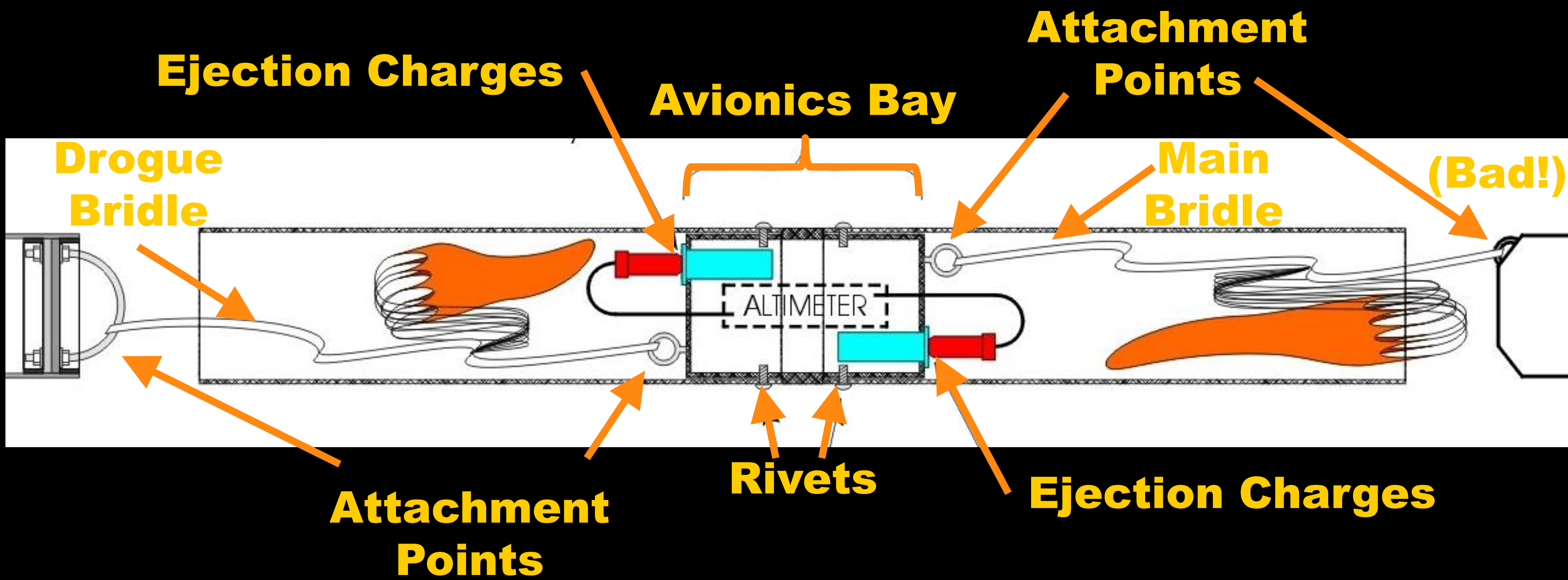
Typical & Most Popular Design

Booster Section **Airframe Splits** **Top of Airframe**



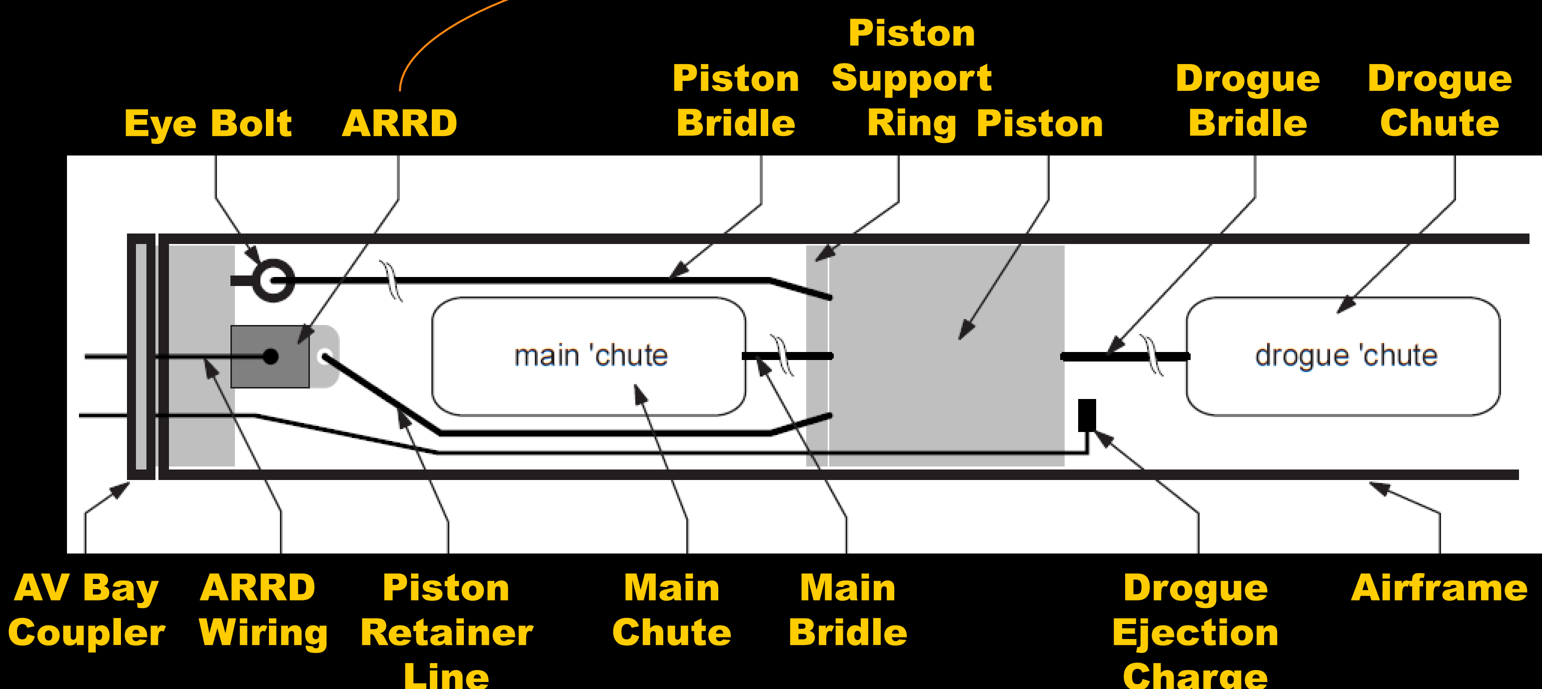
Drogue Chute **AV Bay** **Main Chute**

Split Airframe

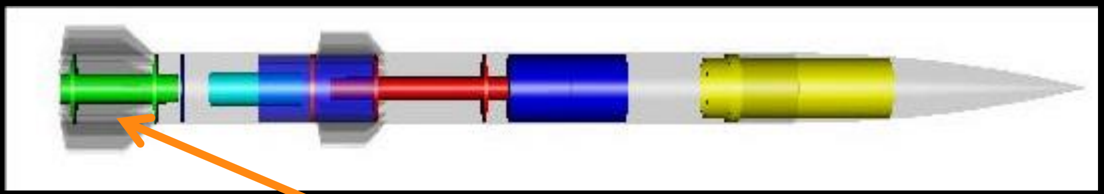


Inline

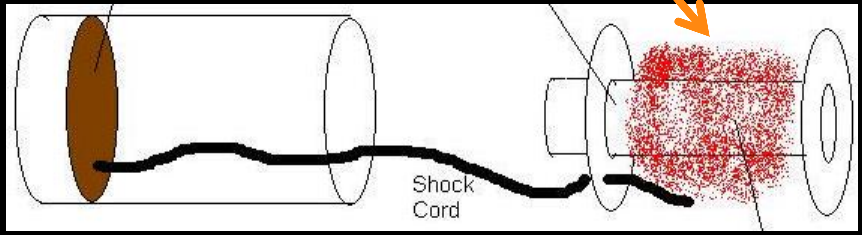
Typical Design



Rear



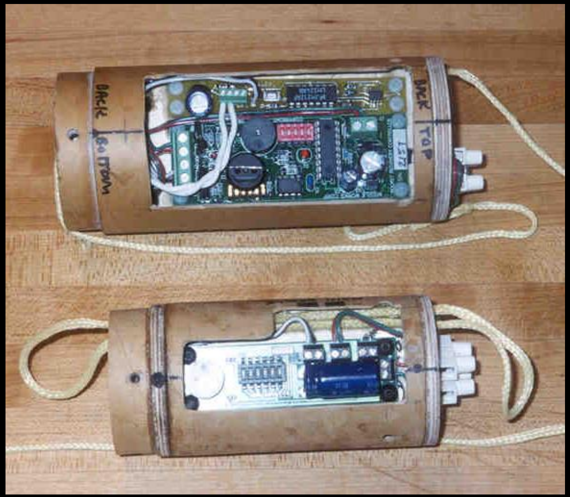
Parachute



Hatch

Avionics (AV) Bays

- Design Philosophies
  - Redundant Systems (if possible)
  - Complete System Independence
    - Power
    - Switches
  - Separate Power Sources
    - Altimeter
    - Pyro Channels
  - Ease of Use!



AV Bay

Internal Components

- **Avionics Mount**
  - **Usually a Sled**
  - **Z-Axis Alignment**
- **Internal Sled Support**
  - **Rods & Tube/Eyes**
  - **Slotted Bulkheads**

AV Bay

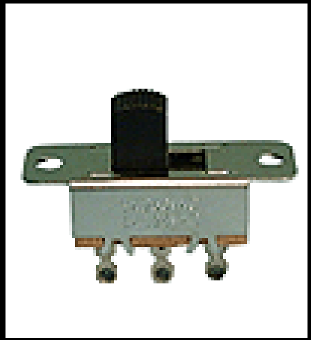
Power Systems

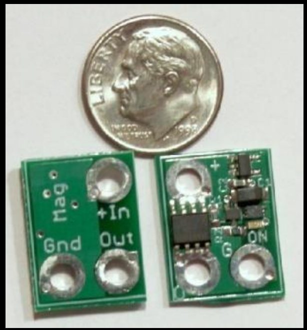
- **Batteries**
  - **9V Duracell or Werker (Soldered)**
  - **LiPo recommended for some systems**
- **Battery Mounts**
  - **Connections always at Aft**
  - **Immovable on all 3 axis**
    - **Zip Tie/Velcro/Mechanical Fasteners**

AV Bay

Switches

- Mount Internally
  - More Aerodynamic
  - Avoids Shearing
- Wiring
  - Solder
  - Terminal Blocks





- Must be Vibration/Bounce Resistant
- Mount with "On" in the Down Position

AV Bay

Static Ports

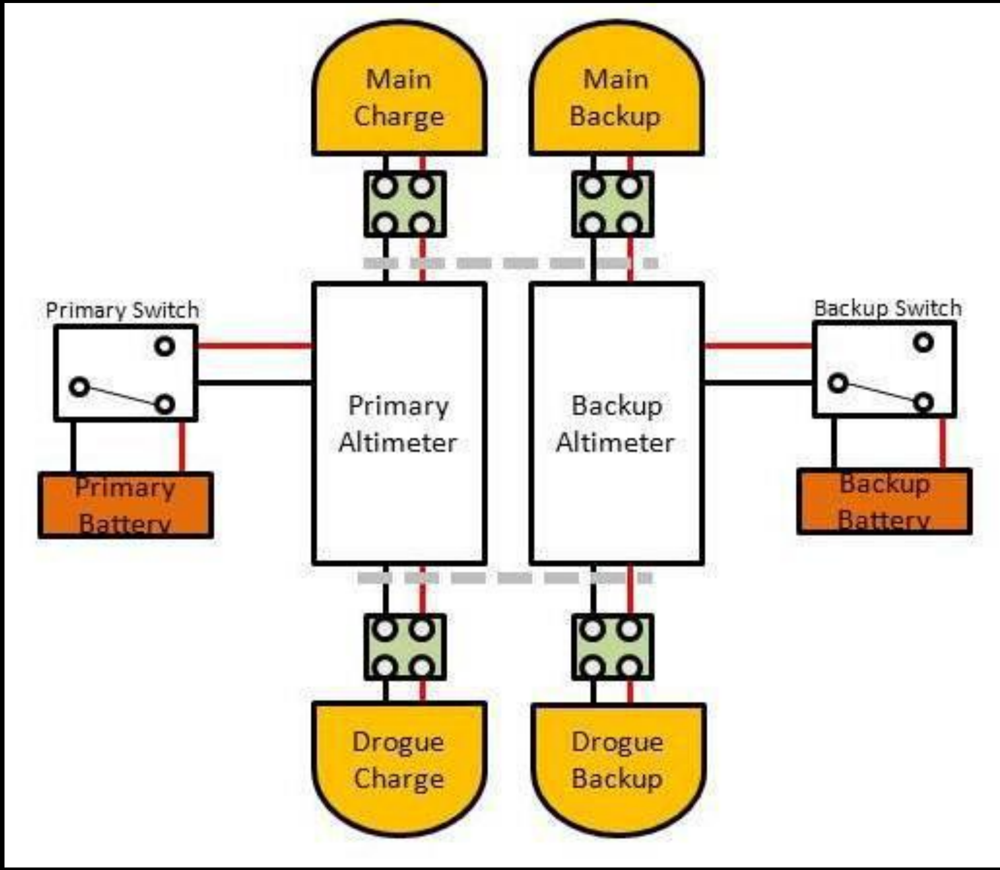
- Required for Barometric Sensors
- Recommend 3 or more ports
- Port Sizing
  - D_P=Diameter of Port
  - V_{AB}=Volume of AV Bay
  - N_P=Number of Ports

$$D_p = 2 * \sqrt{\frac{\left(\frac{V_{AB}}{800}\right)^2}{N_P}}$$

Electronics

- Dual Deployment Altimeters
  - Always have a Barometric Sensor
  - May have Accelerometers, GPS, or Timers
  - Ex. Co-Pilot, Marsa54, XTRA, …
- Timers, etc may be used but are not recommended.

Electronics



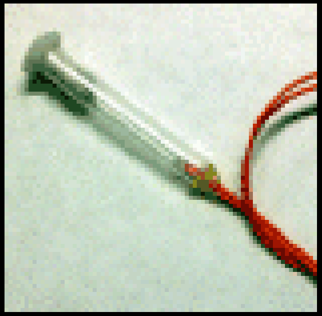
Electronics

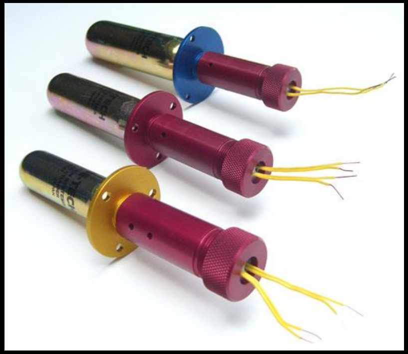
Altimeter Configuration

- Altimeter Dependent but …
- 1st Deployment (Drogue) at Apogee
- 2nd Deployment (Main) at ??? ft AGL
  - Parachute Opening Time
    - Parachute Size
    - Bridle Length
  - Wind Conditions

Ejection Charges

- Under 25,000 feet
  - Solutions include Canisters or Surgical Tubing
  - Typically on AV Bay Bulkhead
- Over 25,000 feet or CO_2
  - Requires Airtight Chamber





Ejection Charges

- Sizing Based on Parameters
  - Deployment Volume
  - Shear Pin Size & Number
    - No Shear Pins - Coefficient of Friction
  - Mass of Ejected Components
  - Desired Ejection Velocity
  - Contingency Factor

Ejection Charges

- **Ejection Pressure (P_E)**

$$P_E = \frac{\left(\frac{W_{NC}}{g} * \frac{v_{NC}}{\Delta t} + MAX(N_{SP} * \tau_{SP}, minF_{NC})\right)(1 + C)}{A_{NC}}$$

W_{NC} = Weight of Nose Cone
v_{NC} = Velocity of Nose Cone
N_{SP} = Number of Shear Pins
τ_{SP} = Pin Shear Strength
F_{NC} = Nose Cone Force
C = Contingency Factor
A_{NC} = Area of Nose Cone Base

- **Nose Cone Force (F_{NC})**

$$F_{NC} = P_E * A_{NC}$$

- **Requisite Black Powder using Ideal Gas Law (m_{BP})**

$$m_{BP} = \frac{P_E * V_{RB}}{R_{BP} * T_{BP}}$$

V_{RB} = Volume of Recovery Bay
R_{BP} = BP Specific Gas Constant
T_{BP} = BP Combustion Temperature

Ejection Charges

- **Online Calculators Inadequate**
  - **Don't Handle Shear Pins**
  - **Don't Handle Nose Cone Mass**
  - **Don't Handle Desired Exit Velocity**

Constants			Rocket Parameters			Ejection System		
Variables	Values	Units	Variables	Values	Units	Variables	Values	Units
OneLiter	61.023744	in^3	EjectionBayLength	13	in	NoseConeEjectionVelocity	10	ft/sec
PoundstoGrams	453.59237	gm	EjectionBayRadius	1.3	in	NoseConeMinimumForce	25	lbs
B_pCombustionTemperature	3,307	°Rankine	ShearPinType	Key Hole	in	Contingency	20%	
B_pSpecificGasConstant	265.92	in lbf/lbm mole R(Bar)	ShearPinsInstalled	3				
NewtontoPound	0.224961492	lbs	NoseConeWeight	2.5	lbs			
g	9.80665	m/s^2				EjectionPressure	47.97918139	psi
MeterstoFeet	3.280839895	ft	Area	5.309292	in^2	NoseConeForce	254.735464	lbs
MeterstoInches	39.37007874	in	Volume	1.131048	liters	Bp Required	1.708100057	grams
NylonUltimateTensileStrength	75,000,000	N m^{-2}	ShearPinBreakPoint	63.67849	lb			
Nylon2-56	0.003166922	in^2						
Nylon4-40	0.005089576	in^2						
NylonKeyHole	0.00585	in^2						

Attachment Points

- **Use Appropriate Hardware**

- **Don't Use**

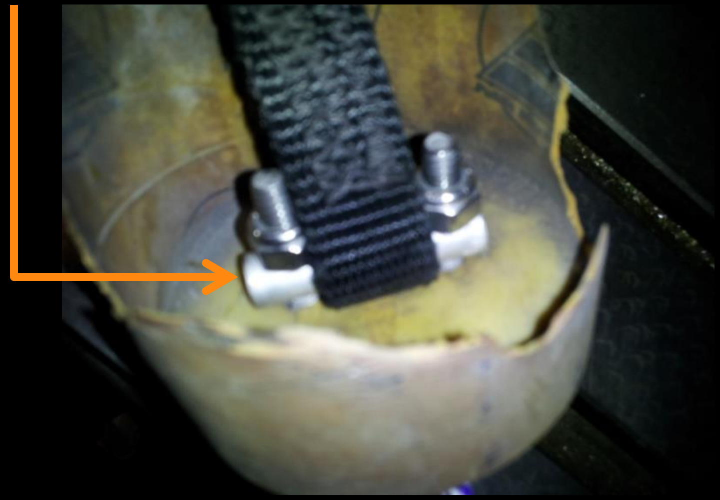
Plastic Loops - Recipe for Disaster

Attachment Points

- Apogee deployments typically experience 20 to 25g's
- Validate Strength of Materials
  - Hardware Working Load Limit (WLL)
  - WLL/Weight = X g's (Maximum)
  - Evaluate Bulk Plates and Joints

Attachment Points

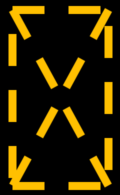
- Install Correctly
  - Use Washers to Distribute Load
  - Fabricate needed Parts
  - Secure Nuts
    - Loctite
    - Nylon Inserts
    - Cotter Pins



Attachment Points

Bridle (Shock Cord)

- Knots
  - Bowline
  - Follow Thru Figure 8
  - Others significantly weaken cord
- Sewn Loops (Stronger than Knots)
  - Thread Material same as Bridle
  - Use Rectangle with Cross Pattern



Attachment Points

Bridle (Shock Cord)

- Provide Thermal Protection
- Don't Ignore Material Fatigue & Thermal Shock
  - Replace Periodically (every 10 flights or less)

Parachutes & Packing

- Drogue Chute
  - High Velocity Deployment Implies Higher Strength Requirements
- Main Chute
  - Shock Forces Controllable based on Drogue Chute Selection
- Provide Thermal Protection
  - Heat Shield, Deployment Bag, Cellulose, Piston, Baffles or use Kevlar Materials

Parachutes & Packing

- Parachute Sizing $S = \frac{2W}{v_e^2 * C_d * \rho}$
- where:
  - W = Total Weight
  - v_e = Desired Descent Velocity
  - C_D = Parachute Drag Coefficient
  - ρ = Air Density
  - S = Surface Area of Parachute
    - Diameter determined by Shape

Parachutes & Packing

Folding Instructions

1. Fold with shroud lines as shown
2. Make one last fold over shroud lines
3. Fold top end over end until you reach the bottom edge
4. Connect to bridle
5. Insert thermal protection
6. Insert into airframe

Summary

- Success Factors
  - Physical Design & Construction
  - Proper Sizing & Testing
    - Charges, Parachutes, Bridles, Hardware
  - Avionics Configuration
  - Use of Appropriate Materials
    - Thermal Protection, Fatigue Assessment
  - Checklist, Checklist, Checklist

What can happen?

References

- Modern High Power Rocketry 2; Canepa, Mark; Trafford Publishing, 2005

Selected Websites

- http://www.offwegorocketry.com/
- http://www.tripolimn.org/links