CubeSat Balloon Drag Devices: Meeting the 25-Year De-Orbit Requirement

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Best CubeSat Deorbit Options for 25-Year Orbit Lifetime

- CubeSat ballistic coefficients fall into a narrow range (see graph)
- **No reentry device needed below ~700-km**
- Balloon is best option for altitudes between 700 and 900-km
- Propulsion followed by balloon deployment is best for altitudes between 900 and ~1400-km
- Direct reentry burn for altitudes above ~1400 km (no need to "stop" at 900 km to deploy a drag device)

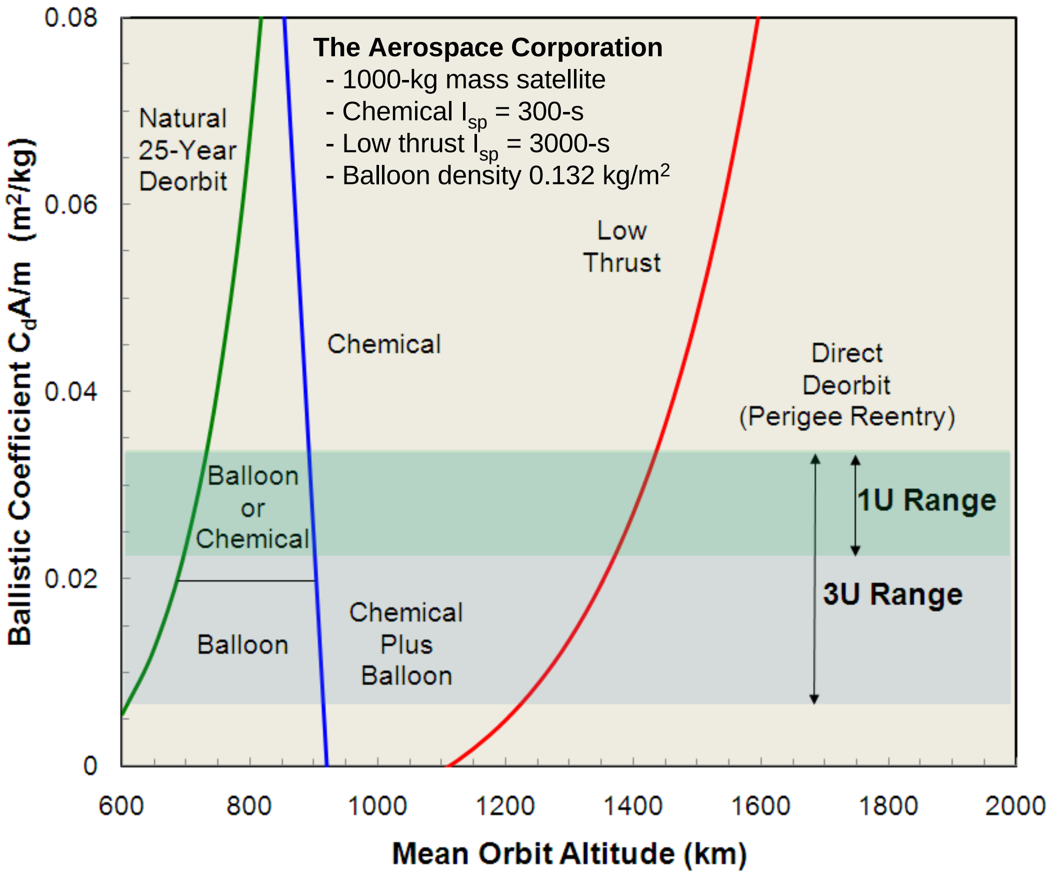
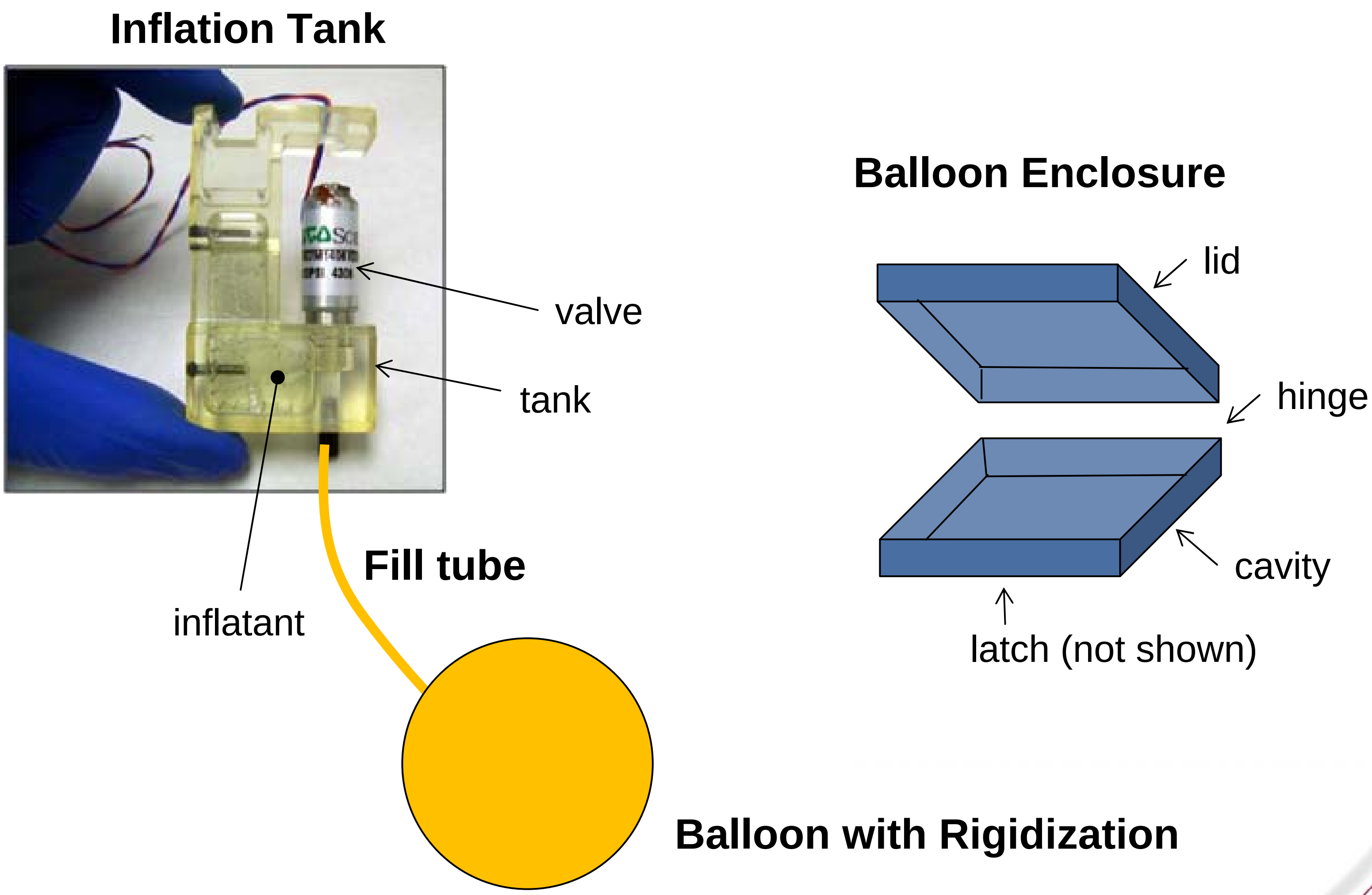


Chart adapted from: "Atmospheric Reentry Disposal for Low-Altitude Spacecraft," K.W. Meyer and C.C. Chao, J. of Spacecraft and Rockets, Vol. 37, # 5, pp. 670-674, Sept-Oct 2000.

Drag enhancement up to 900 km but propulsion is required above that.

Balloon Subsystem Constituents



Four parts to a deorbit balloon subsystem: tank, fill tube, balloon, enclosure

Balloons: What a Drag!

- Each oxygen atom that hits the balloon imparts an impulse:

  $M_{oxygen} * V_{relative} \sim 2 \times 10^{-22}$ *N-s*

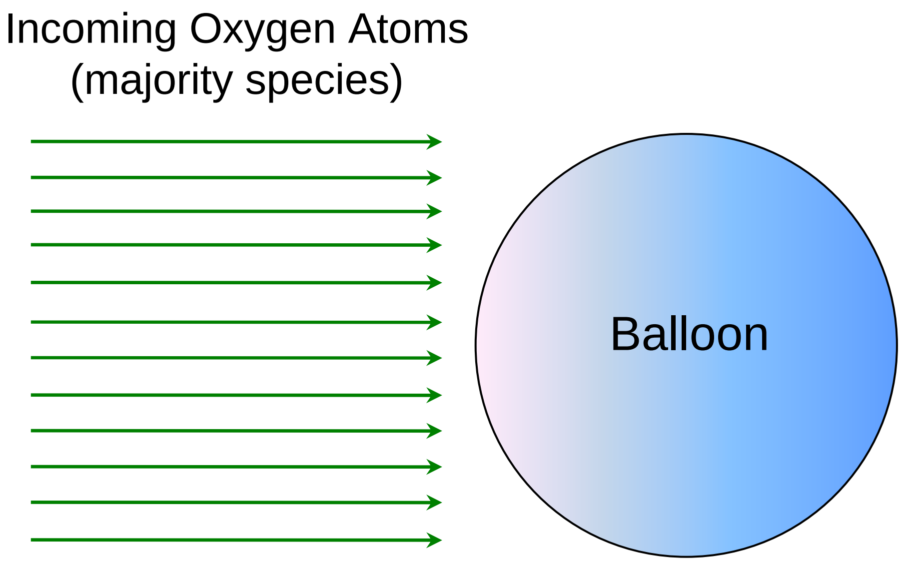
- Each oxygen atom that hits the balloon also removes some Kapton:

  4.3×10^{-24} grams/oxygen atom

- Mass loss is therefore roughly proportional to total impulse:

  1-gram Kapton ~ 47 N-s impulse

- Required impulse to reach 200-km "burnup" altitude is a function of starting altitude and spacecraft mass, e.g, 430 N-s for a 1-kg Cubesat initially at 1000-km

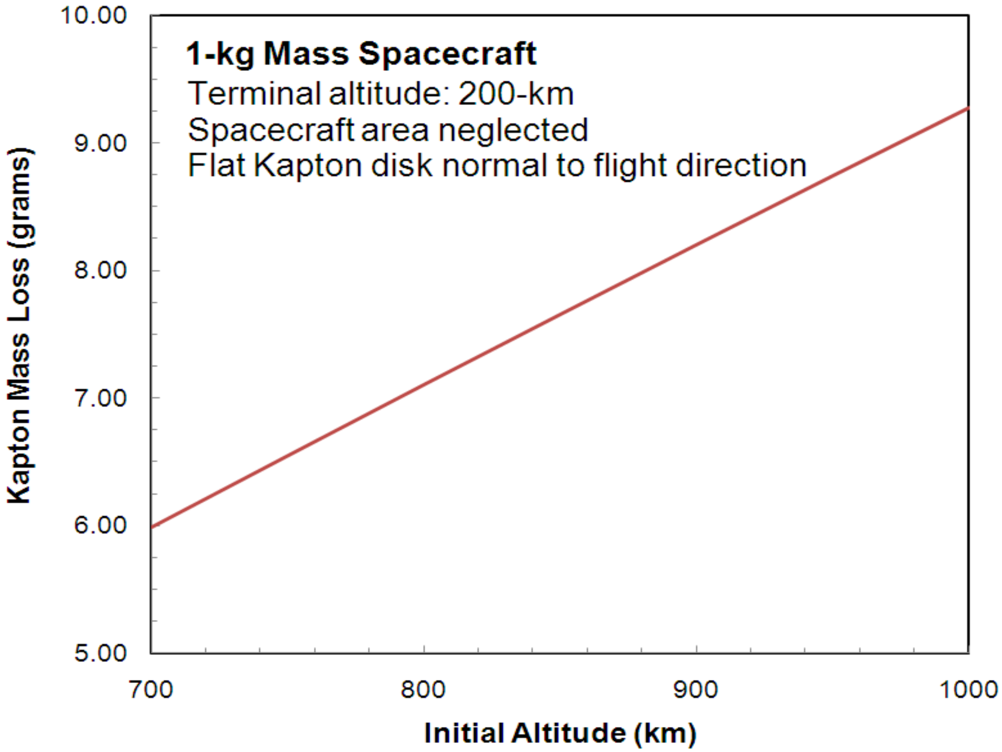


$V_{relative}$ = 7.78-km/s @ 200-km altitude,
7.35-km/s @ 1000-km altitude
~ 7.5-km/s between 200 and 1000-km

Mass loss due to atomic oxygen erosion is a function of spacecraft mass and initial altitude, not balloon size.

Step 1: Quantifying Balloon Erosion

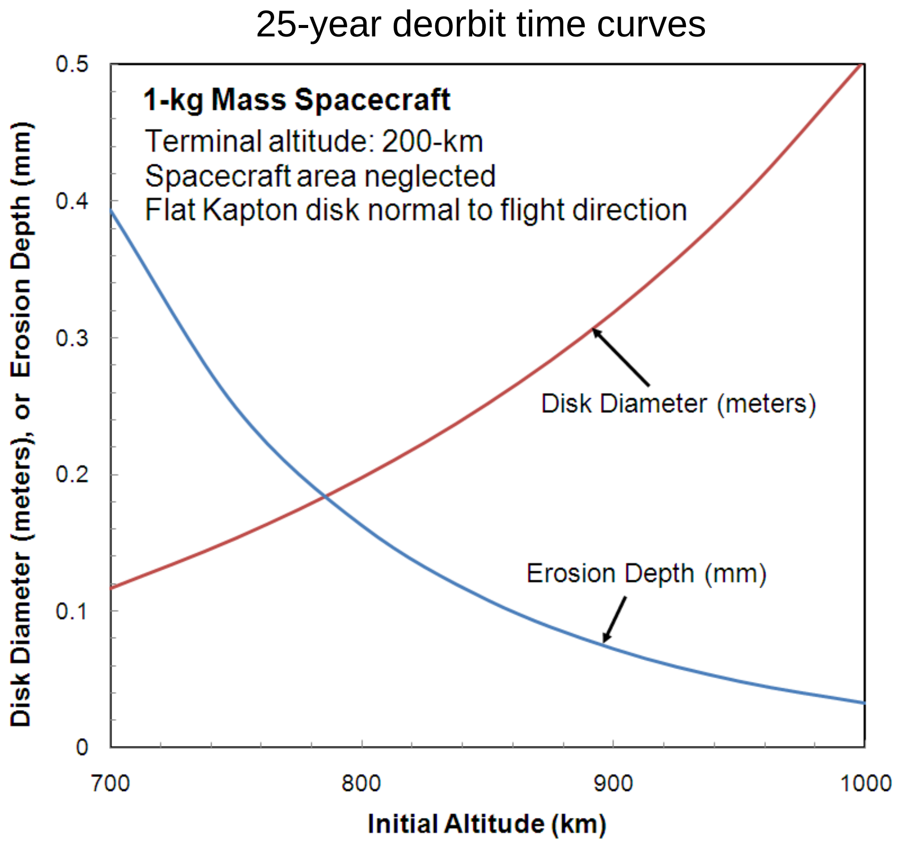
- Kapton mass loss for a 1-kg mass spacecraft is a function of starting altitude (see chart)
- For other spacecraft masses, multiply chart result by spacecraft mass in kilograms
- Aluminized materials will fare better, but cracks in aluminum from packing, will expose the polymer
- Total projected area and geometric configuration (disk, sphere, etc.) due not influence mass loss to first order



A "1U" CubeSat Kapton drag device must lose 6-grams in order to drop from 700-km to a 200-km terminal altitude.

Step 2: Deorbit Rate: Sizing the Balloon

- Projected area determines the rate of descent, and hence orbital lifetime
  - *Complex calculations include atmospheric density as a function of altitude and time*
- Use 25-year results presented in chart at right
  - *Projected area is important, not total surface area*
- Use larger projected area for faster deorbit
  - *Mass loss is unaffected by increased area because total exposure time to oxygen is reduced*



Example: A 0.5-meter diameter drag device composed of 0.004" thick Kapton will deorbit a 1U CubeSat from 1000-km altitude in less than 25 years.

Step 3: Balloon wall thickness OR larger balloon

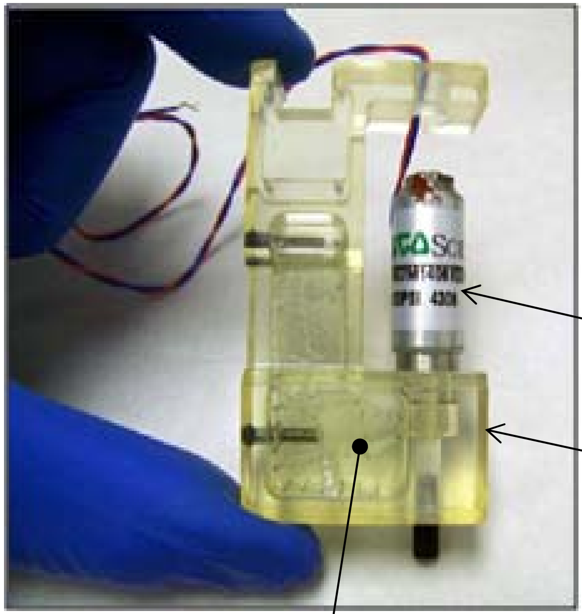
- Kapton thickness can calculated from **required** projected area and Kapton mass loss (plotted on previous chart)
  - *Kapton thickness should be larger than the calculated erosion depth to provide material margin*
- A larger balloon, **but with the same mass** as calculated in Step 2, will decrease de-orbit time.
  - *Thinner Kapton required*

Thicker walled smaller balloon or thin walled larger balloon = SAME eroded mass

Step 4: How much to fill

- Store a saturated liquid
  - *- Try SUVA 236fa*
  - *- Valve will need neoprene seals*
- *Expansion ratio ~10,000:1*
  - *- 0.1 cc liquid will fill 0.1m^3 balloon*
  - *- 15 Pa pressure inside balloon (Enough to expand a 2' dia., ~0.1-m^3 balloon)*

Inflation Tank

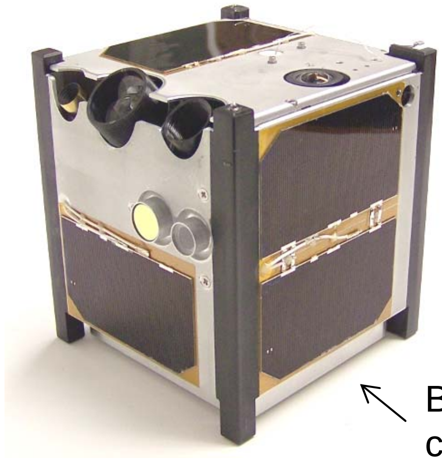


You don't need much pressure, or inflation material, to fill a balloon on-orbit.

AeroCube Deorbit Balloons

Balloon compartment

AeroCube-2
2007, 700 km alt



AeroCube-3
2009, 450 km alt

Balloon compartment

- *Kapton balloon 8-mils thick*
- *23-cm pillow shape*
- *Balloon subsystem vol = 103-cm^3*
- *Balloon subsystem mass = 110-g*
- *Balloon avg cross section = 0.05-m^2*
- *Satellite died after 1 day – did **not** deploy or inflate balloon*
- *Ballistic Coefficient = 0.1-m^2/kg*

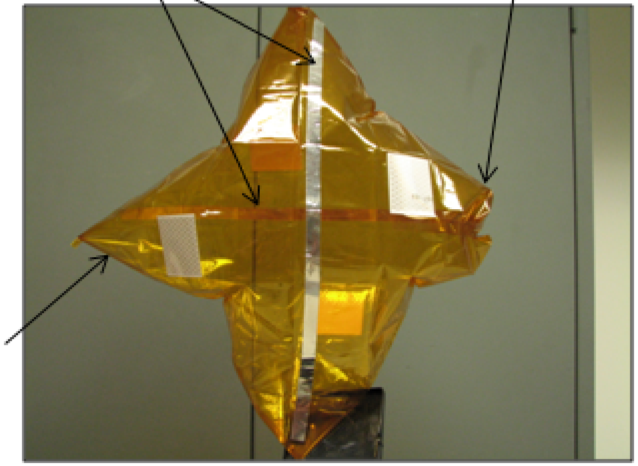
- *Mylar balloon 1-mil thick, aluminized*
- *0.6-m diameter*
- *Balloon subsystem vol = 155-cm^3*
- *Balloon subsystem mass = 117-g*
- *Balloon avg cross section = 0.28-m^2*
- *Balloon deployed but did not inflate*
- *Ballistic Coefficient = 0.5-m^2/kg*

Inflating balloons is harder than it looks

Example #1: The AeroCube-2 Balloon

- Geometry: Pillow-shaped (square)
  - Simple to build and stow
- Material: Kapton film + Kapton tape
  - Good thermal properties
- Benefits
  - Self-rigidizes with aluminum strips (**Gas loss due to micrometeroid punctures is thus not an issue**)
  - Incorporates a “Tape Valve” to relieve excess pressure during fill
  - Fill-tube made of heat-shrink, covered and joined to balloon with Kapton tape
- Drawbacks
  - Erosion by atomic oxygen
  - Asymmetric cross section

Fill Tube

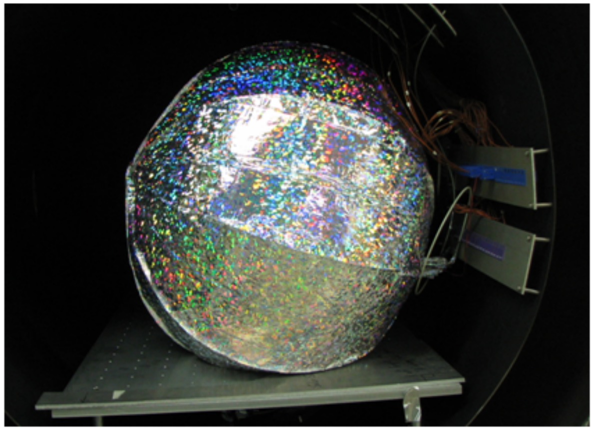


The AeroCube-2 balloon was Kapton

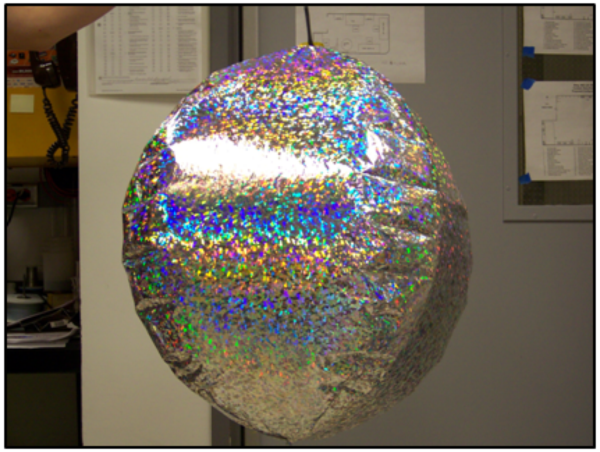
Example #2: The AeroCube-3 Balloon

- Geometry: Round
  - Uniform cross section
- Material: Aluminized Mylar
  - Runs hot
- Benefits
  - Sealed using industry method (party balloons) of melting inside polyethylene layers
  - Thinner and more flexible material (thus larger balloon)
  - Resistant to atomic oxygen
- Drawbacks
  - Need special machines to make
  - Separate over-pressure valve
  - Hard to fold efficiently
  - Less self-rigidizing than AC2 thus more sensitive to micrometeroid punctures

Eight-Gore Version (Not Flown)



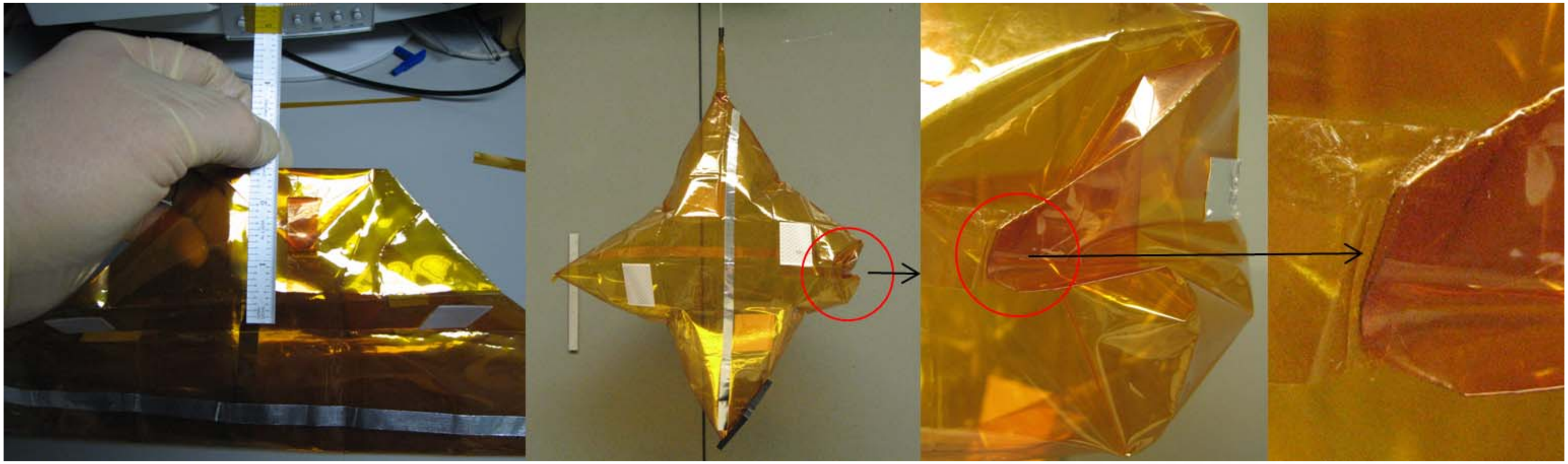
Four-Gore Flight Version



The AeroCube-3 balloon was larger but thinner

Tech Tip #1: 2-D Pressure Relief "Tape Valve"

- Passive relief of excess gas (to prevent bursting)
- Consumes very little volume, eliminates pressure regulator
- Easily integrated into pillow-style balloons
- Incorporated into the last fold of the balloon as it inflates
- Designed to open when the balloon has been pressurized to a specific geometry

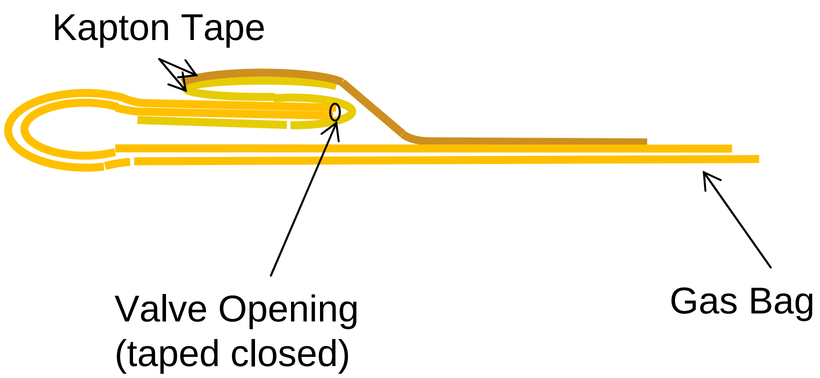


During Assembly   Inflation/Rigidization   Valve Open

A simple, inexpensive relief valve to prevent balloon over-inflation.

Tech Tip #1: 2-D Pressure Relief "Tape Valve" (Con't)

- Tip of a corner is clipped to produce a hole (here about 10-mm)
- Tape is folded over hole, sealing it closed
- Tape is arranged to immobilize last fold until balloon is nearly inflated to its final shape
- Inflation pressure pulls tape to open valve as the last corner unfolds – by then the balloon is rigid



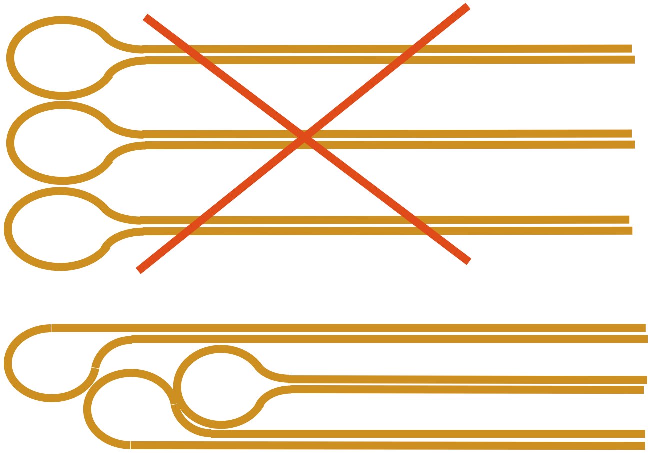
Stowed

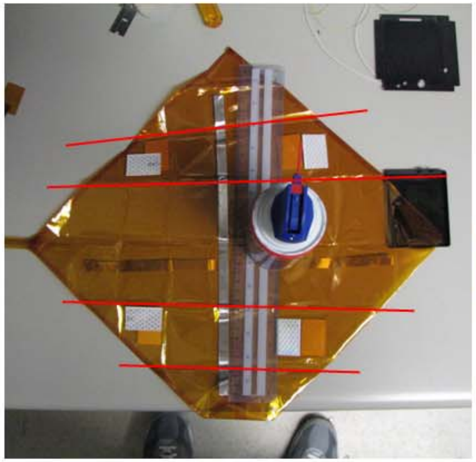
Deployed / Venting

Once inflated, the relief valve remains open. Aluminum strips taped to the Kapton film maintain balloon shape.

Tech Tip #2: Balloon Packing

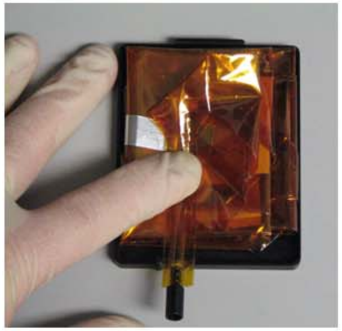
- Bulk usually comes from folds, not material thickness – stagger edges to reduce bulk for a given balloon size
- Avoid orthogonality where practical (don't be square, exactly)
- Arrange folds in a "W" shape rather than rolling-up





W-fold strategy

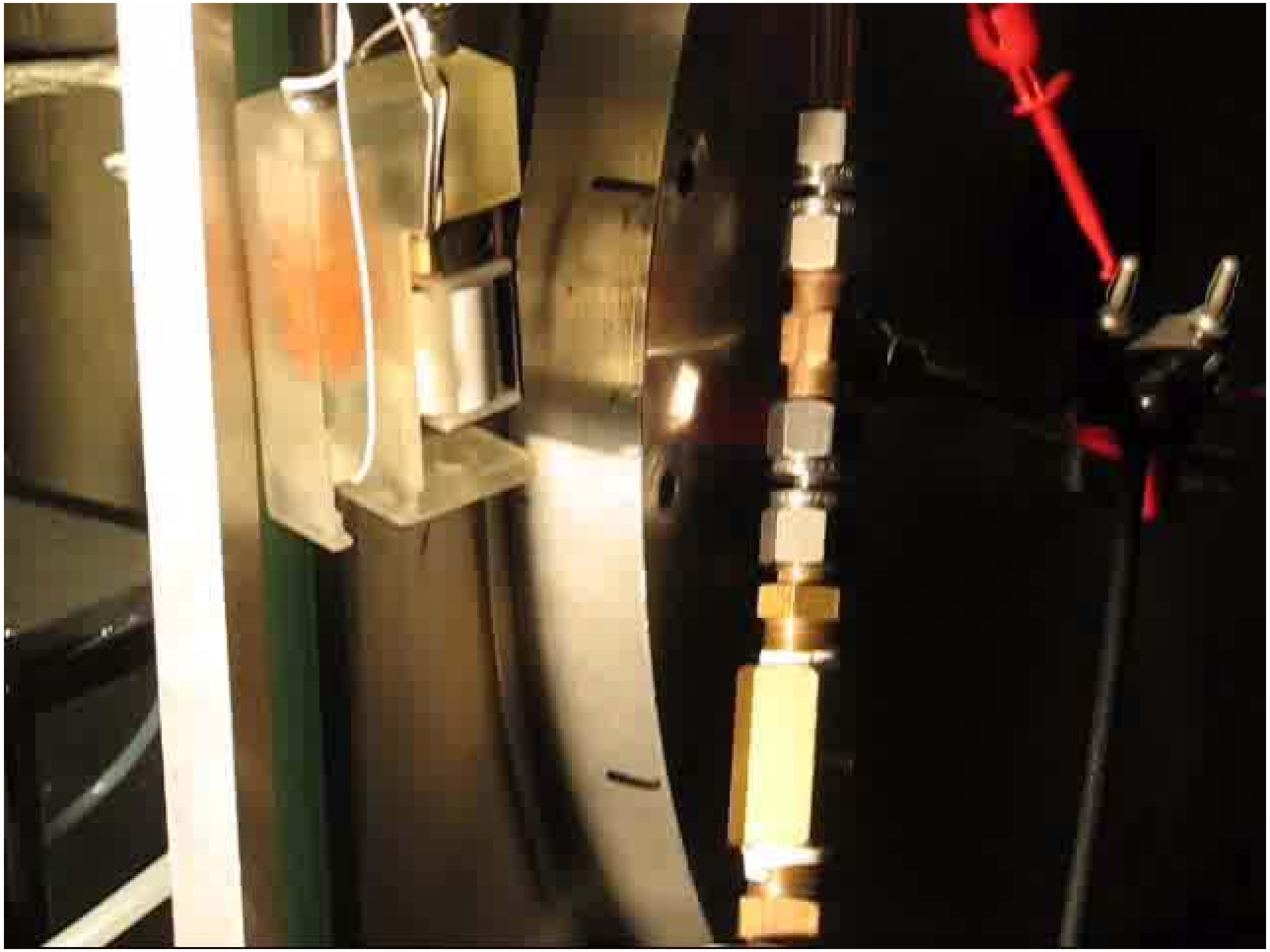
Balloon Folded Into Lid



Finished folding

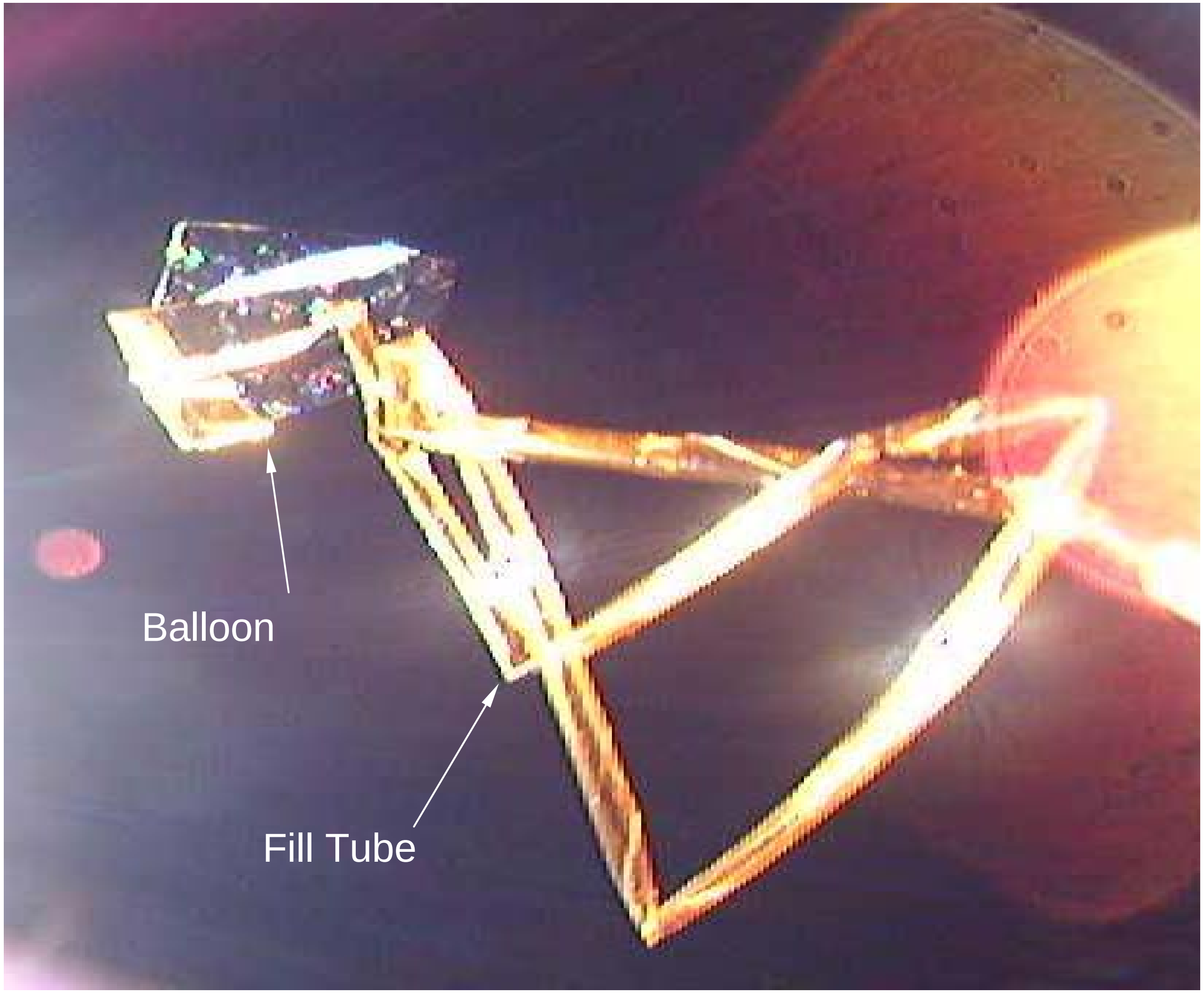
Efficient balloon packaging requires some thought.

AeroCube 2 Balloon Fill Test (in vacuum)



0.1-cc of liquid @ 0º C will fill up a 2-ft diameter balloon to 15 Pa @ -40º C.

AC3 Balloon Deployed (nice to have a camera onboard)



Drag has increased by 2x. (An inflated balloon would have been 12x).

Conclusions & Acknowledgements

- Above 700 km, a deorbit device for CubeSats is required
- The balloon diameter will determine how quickly deorbit occurs
- Polymer eroded mass is constant
  - Quicker deorbit = less erosion depth over a larger balloon
  - Slower deorbit = more erosion depth over a smaller balloon
- Aluminized polymers will not erode but cracks are susceptible
- A balloon subsystem typically has four main parts

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