Flight Testing of a Low-Cost De-orbiting Device for Small Satellites

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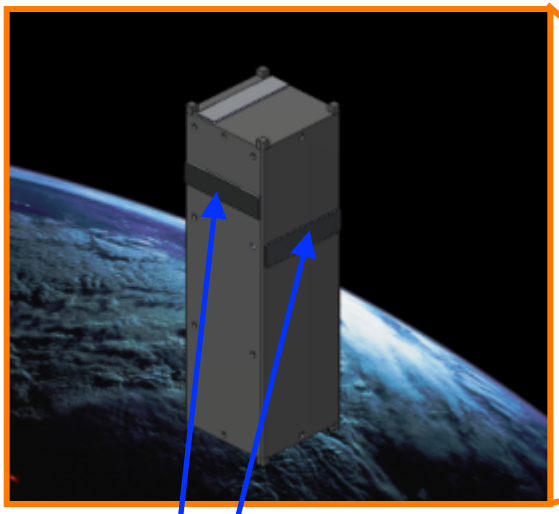
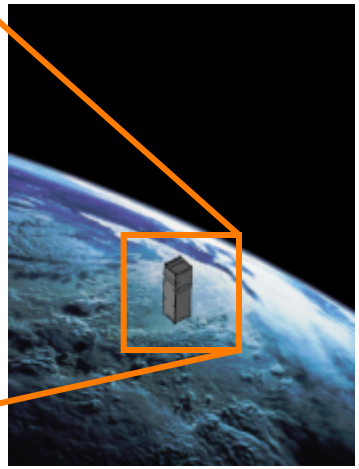
Orbital Debris Problem

- **>21,000 objects larger than 10cm being tracked by U.S. Space Surveillance Network**
- **NASA Specification NASA-STD-8719.14**
  - **All new satellites must have known re-entry plan**
  - **25 years until atmospheric reentry**

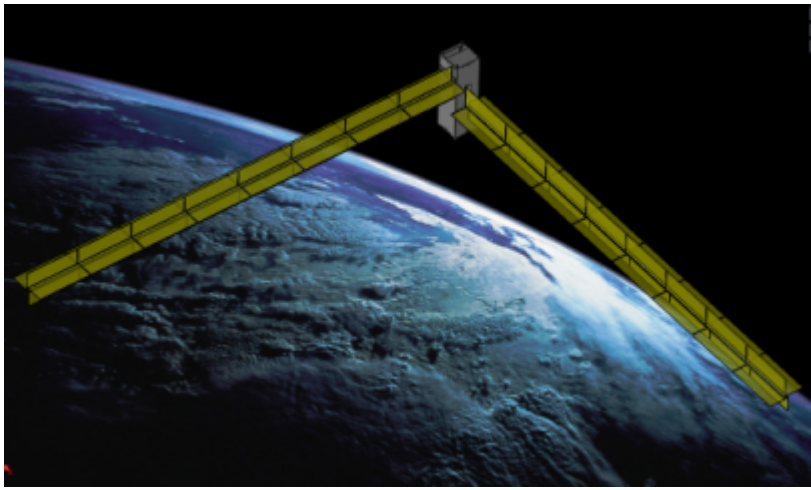
RODEO
Roll-Out DE-Orbiting devices



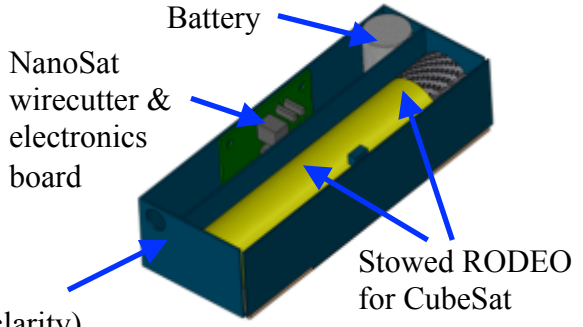
Stowed RODEO Modules



Stowed



Deployed



Key Technology is Rolled Composite Boom

- Multifunctional
- High Specific Stiffness
- Simple & Reliable; few moving parts

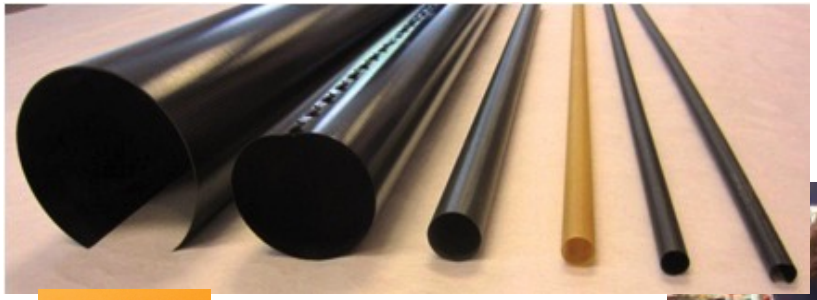
Concept of Operations

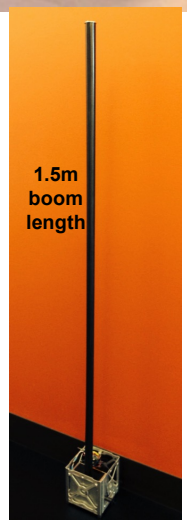
- **Inside the RODEO™ housing is a very simple electronic circuit board and battery. The board only has two inputs and a ground wire.**
  - **The first input is to initiate a commanded release by supplying spacecraft voltage.**
  - **The second input supplies a very small trickle charge to the battery and resets a timer circuit so that RODEO™ will remain stowed. However, if the spacecraft loses functionality and stops supplying the trickle charge, the timer circuit initiates and begins counting. After a pre-determined period of time with no trickle charge supplied, the timer circuit executes an automatic command to deploy the RODEO™ drag sail.**
- **Once the command to deploy is sent (either manually or via the timer circuit) an internal hot wire will release the spring-loaded hinged door, and the RODEO™ de-orbit wing will deploy.**
  - **Deployment occurs via the single-degree of freedom composite roll-out boom that is restrained by the hinged door of the RODEO™ canister.**

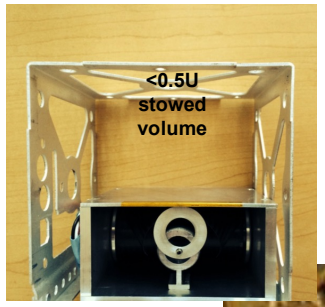
Scale-able & Modular Deployable Booms

CTD has developed a family of boom configurations that can meet most mission needs

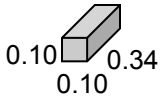
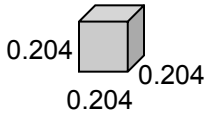
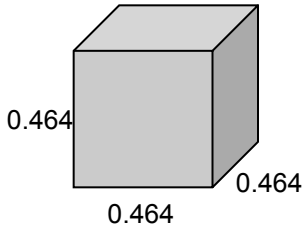
- **Size**
  - **0.25” to 10” diameter**
  - **Up to 75ft (22m) in length**
- **Architecture**
  - **Open, overlapped, Slit-lock, zipper**
- **Deployment method**
  - **SMP, motorized, strain energy driven**







Sizing Analysis Summary

System	Satellite Mass (kg)	RODEO Area*	
		25 years	5 years
3U CubeSat 	6.00	**0.150 m^2**	**1.16 m^2**
Nanosatellite 	15.0	**0.526 m^2**	**3.23 m^2**
ESPA-Class Small Satellite 	100	**3.74 m^2**	**27.85 m^2**

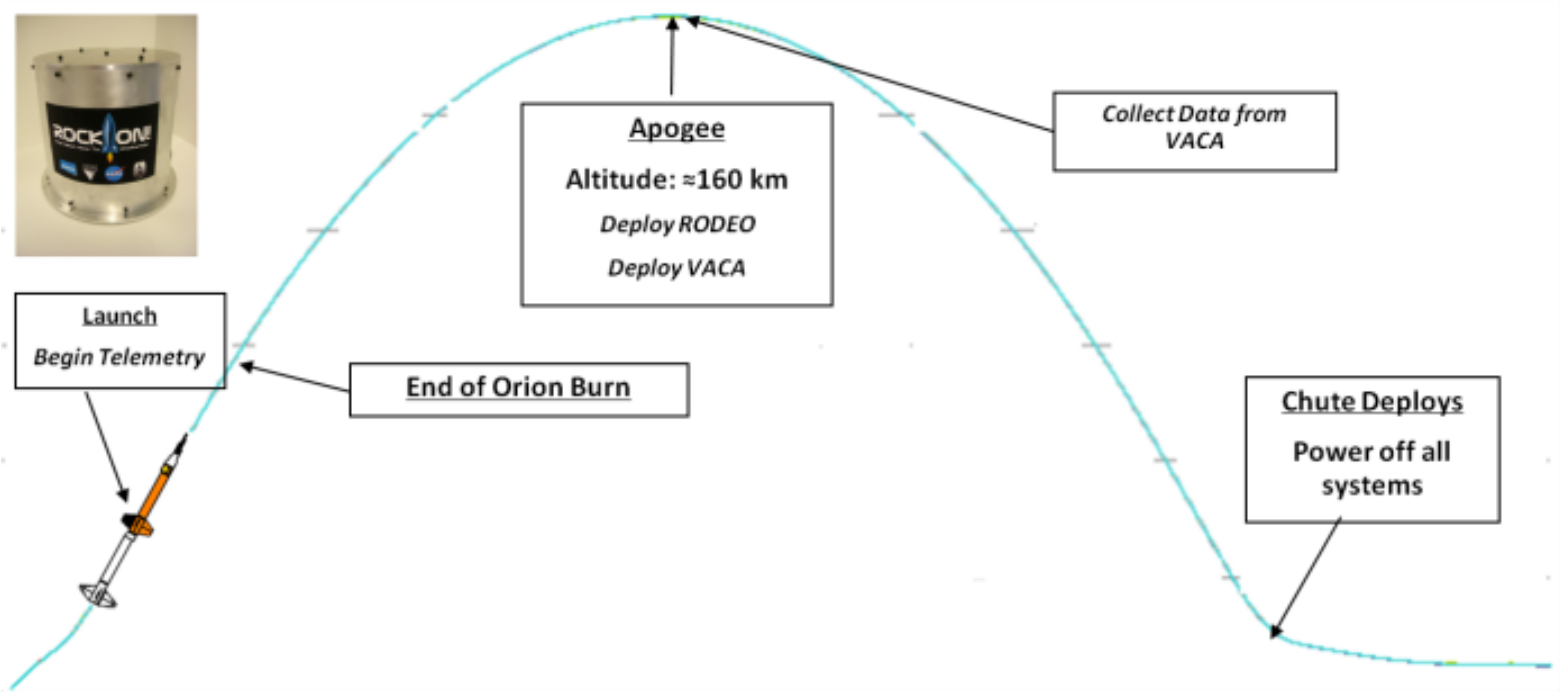
*Assumed no other deployables; Random tumbling; Orbital Eccentricity = 0; Orbital Inclination 27 deg.

RODEO Mass & Volume

Satellite	RODEO Performance Metrics	
	Stowed Volume	System Mass
3U CubeSat (6kg)	140 cm^3	96 g
Nanosatellite (15kg)	175 cm^3	131 g
Small Satellite (100kg)	270 cm^3	472 g

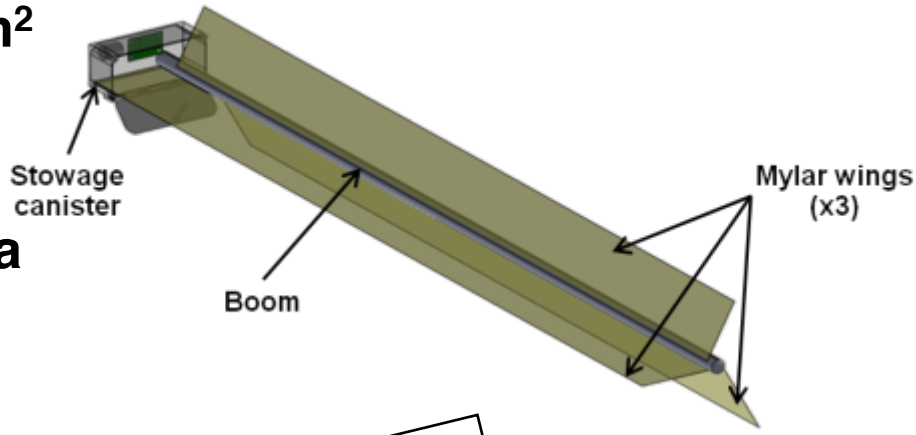
RocketSat-8 Flight Experiment

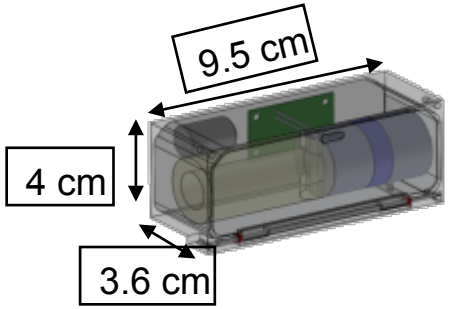
- Eighth RocketSat student project at the Colorado Space Grant Consortium (COSGC) since the program began in 2006
- Sub-orbital rocket launched out Wallops Flight Facility in August 2012
- Launch achieved 180 seconds of stable microgravity at an altitude of approximately 160 km



Flight Configuration

- **Flight configuration provides 0.15m^2**
  - **Sufficient area to de-orbit a 3U CubeSat in 25 years**
- **Three wings 120º apart provide area in multiple planes**
- **Wings wrapped around to one side of boom for stowage**



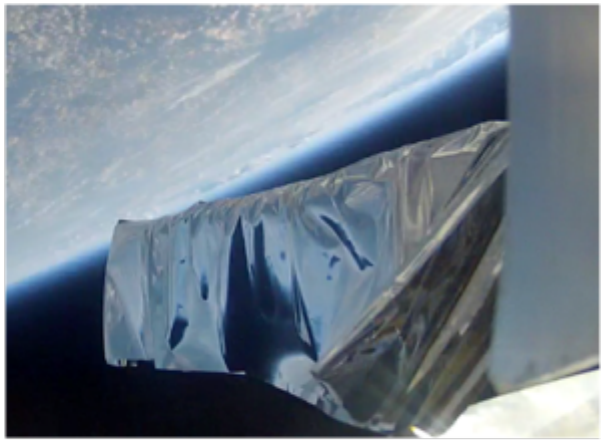


Deployment Video

Flight Test

Beginning of Deployment

Mid-Deployment



Fully Deployed

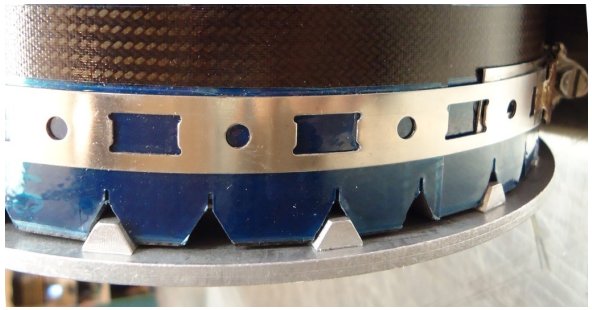
- **Full deployment achieved**
- **Deployment was off-nominal**
  - **Moisture absorption due to extended exposure (a few weeks) to extremely high humidity prior to launch**
  - **Would not be an issue for orbital flight**

Recent Improvements

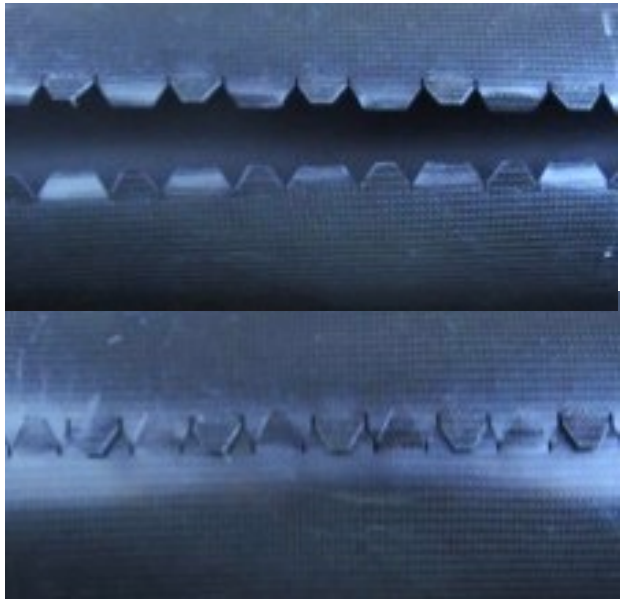
- Alternative polymer matrix used in composite boom
  - Higher glass transition temperature
  - Low moisture absorption and reduction of moisture-induced effects
- Incorporation of Slit-Lock™ for improved stiffness and stability
- Root-rolled instead of tip-rolled boom design
  - Both motor-driven and strain-energy driven designs demonstrated

Slit-Lock™

- Results in a closed cross-section that improves performance
- Significantly increases bending & torsional stiffness/stability
- Edge features interlock upon deployment and remain engaged over all temperature ranges & loading cases
- Design provides a positive closing force at seam during the entire deployment
- Notches are “keyed” in the deployment mechanism to prevent “blooming”, provides precise rate control and enables high axial loads to be driven into boom

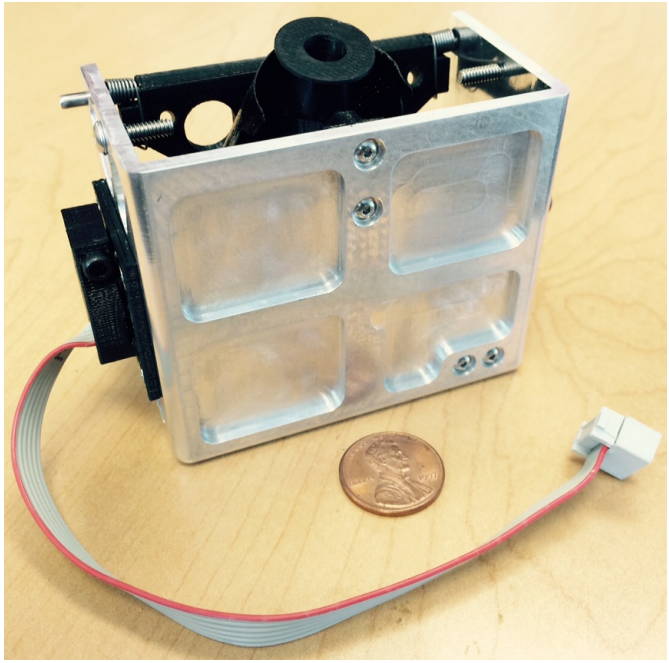


US Patent #8,863,369



Prototype Hardware

- Prototype has been fabricated
  - 0.5” diameter, 1.5m long
  - Incorporates Slit-lock
  - Motor driven
  - 175g, 3” x 2.5” x 1.5” envelope
- Technology can be used for a wide range of applications
  - Deployment actuator and structure for solar array, solar sail, drag sail, etc.
  - Gravity gradient boom
  - Instrument boom
  - Etc.



Conclusions

- Most responsible and pro-active way to mitigate orbital debris is to incorporate a de-orbiting device
- RODEO leverages lightweight, morphing composite structures to enable a low cost, proven, de-orbit solution
- RODEO deployed successfully from a sounding rocket as part of the Rocket-Sat X flight experiment
  - Off-nominal deployment caused by moisture saturation, would not be an issue for orbital flight
- Deployable boom technology is being improved upon and can be used for a wide range of applications
- Please come by CTD's booth (#50) at SmallSat conference to see some cool hardware!