A High Stiffness Boom to Increase the Moment-Arm for a Propulsive Attitude Control System on FalconSat-3

17th Annual AIAA/USU Conference on Small Satellites

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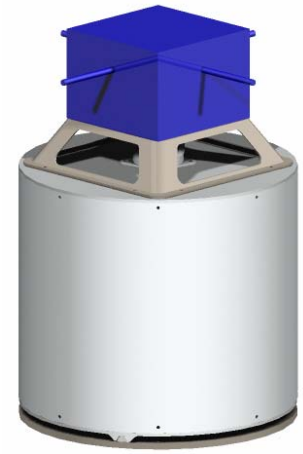
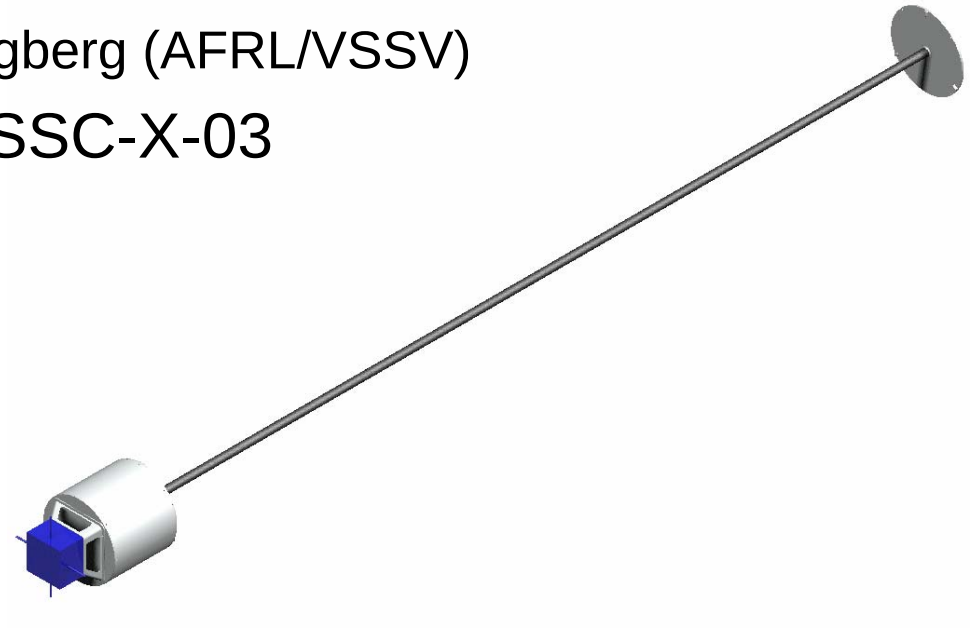
SSC-X-03





Development Team

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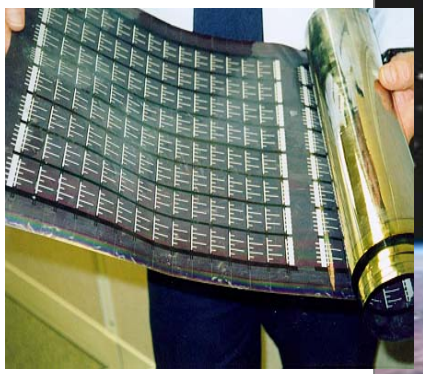
Background: PowerSail

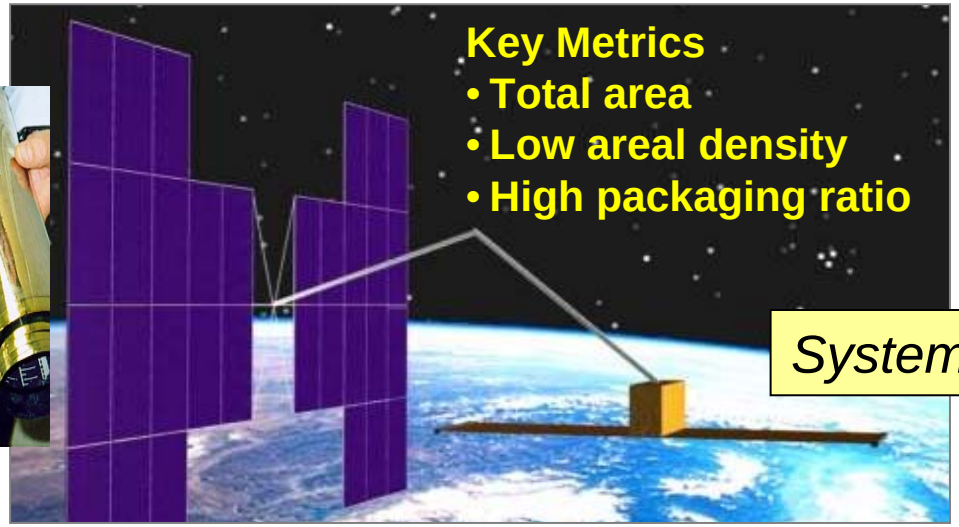
Application for Large Solar Arrays

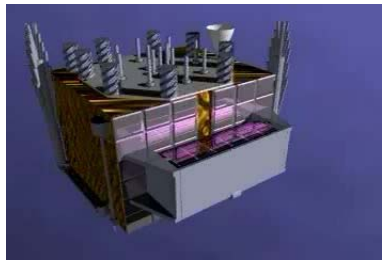
Thin Film PV Blankets

- *Radiation tolerance & annealing*
- *Low mass*
- *Low cost*

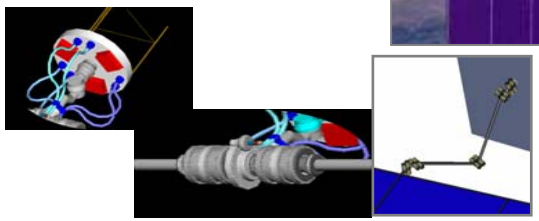


Innovative concepts for structural support & deployment

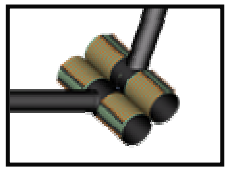




System-level Concepts



Isolation mechanisms and other joints



Technology development themes:

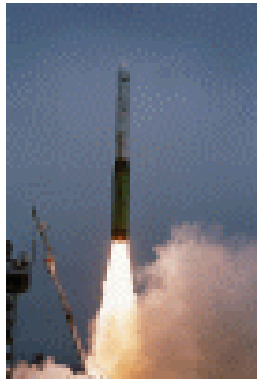
- Deploy large structures from compact volumes
- Structural isolation and control
- Improving fundamental knowledge and models

FalconSat-3 Mission

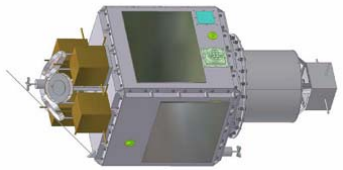
Payloads

- PLANE – Characterize local plasma noise
- FLAPS – Plasma spectrometer
- MPACS – Micro-electric thruster

Boom-related Mission Requirements
Attitude control < 1 degree per axis
Tip-off aversion / envelope constraints



Launch MLV-06



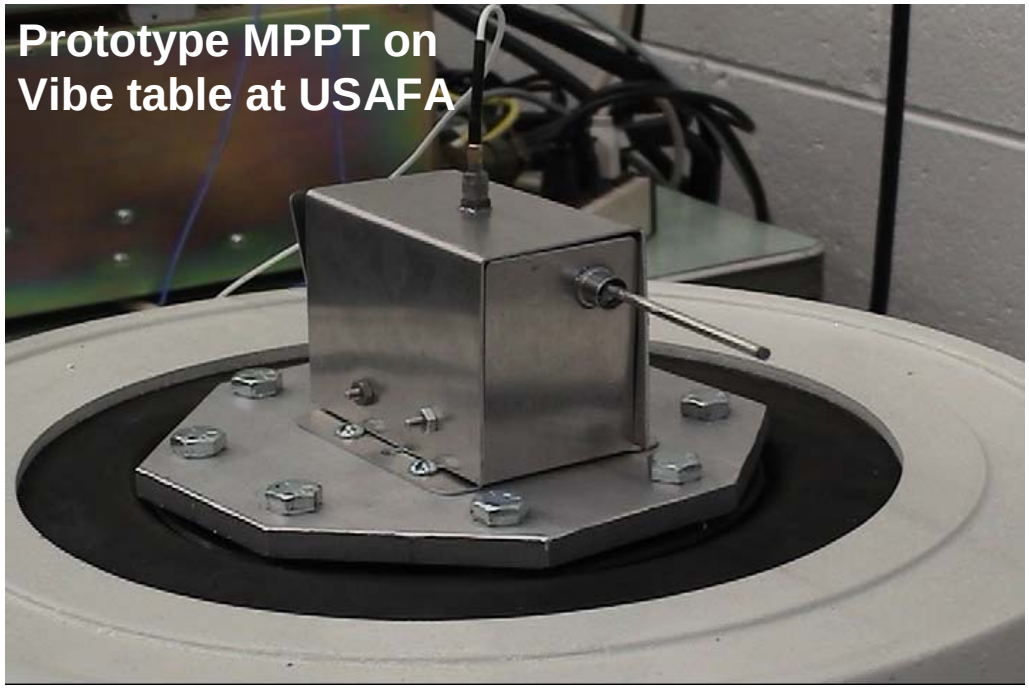
Launch interface

- ESPA (EELV Secondary Payload Adapter)
- Lightband (PSC) & Shock Ring (CSA)

MPACS Thruster

Micro-Propulsion Attitude Control System

- Total mass ~2.1kg (4.6lb_m)
- 25 μN•s (5.6 μlb_f•s) impulse
- Thrust duration 2-5 μs
- 2Hz operating frequency
- 10 watt power draw
- Boom–bus command lines
- Power supplied by boom battery box

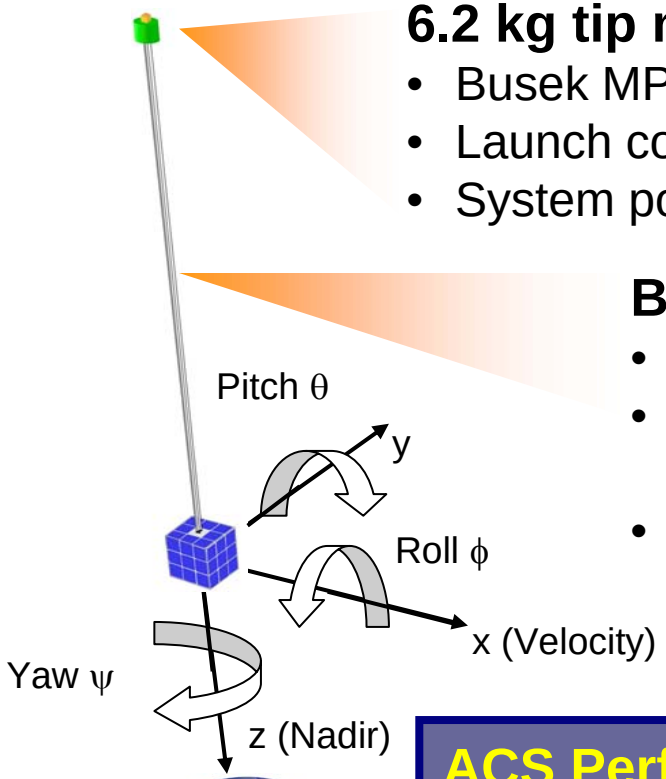


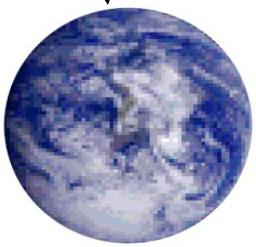
How much can thruster effectiveness be increased by increasing the moment arm?

System Concept & Features

6.2 kg tip mass
- Busek MPACS 2-axis thruster
- Launch containment for boom
- System power conditioning

Boom
- Nominal length ~ 4m (156 in)
- Telescoping central tube for stabilization during deployment
- CTD Elastic Memory Composite (EMC) structure





ACS Performance
- Passive gravity-gradient stability
- MPACS damps pitch and roll oscillations
- Increased thruster actuation authority

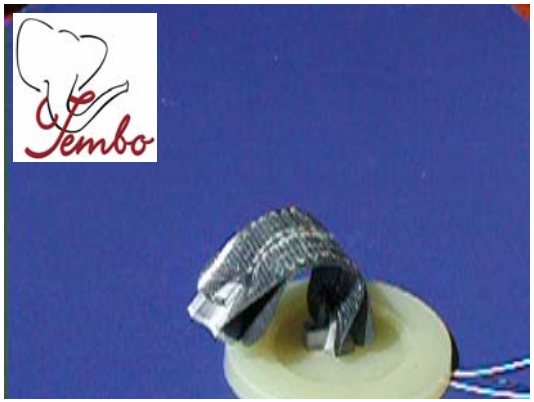
SRC Qwknut Separation Device

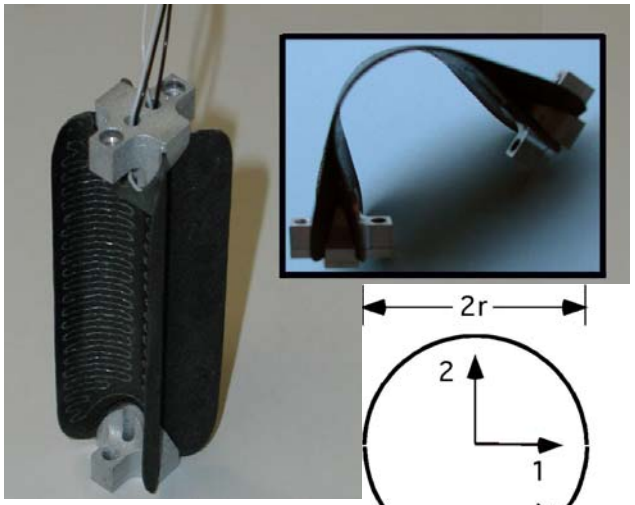
Packaged Configuration

Elastic Memory Composites

- **CTD's TEMBO™ shape memory resins**
  - Exhibit high strain, stiffness, and damping during deployment
  - Components require low actuation energy
  - Leads to simple mechanisms with lower part counts

- **EMC Tape Design**
  - Semi-cylindrical tapes w/ heated folding regions
  - Tapes can be sized to meet strength and stiffness requirements
  - Verifiable by FEA
  - **)(** or **( )** configurations





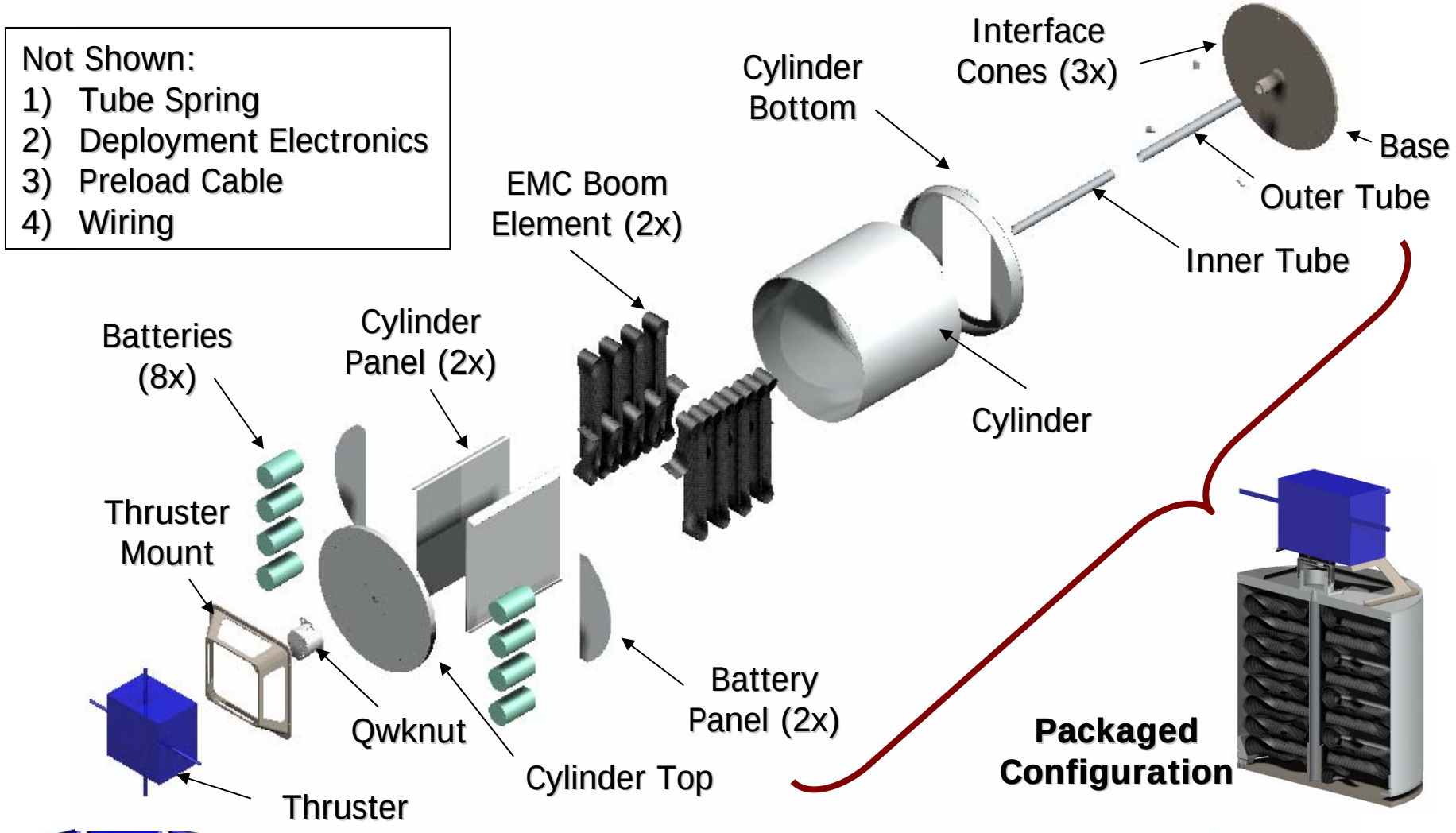
Nominal design:
r = 0.5", t = 0.015"

$A = 2\pi rt$

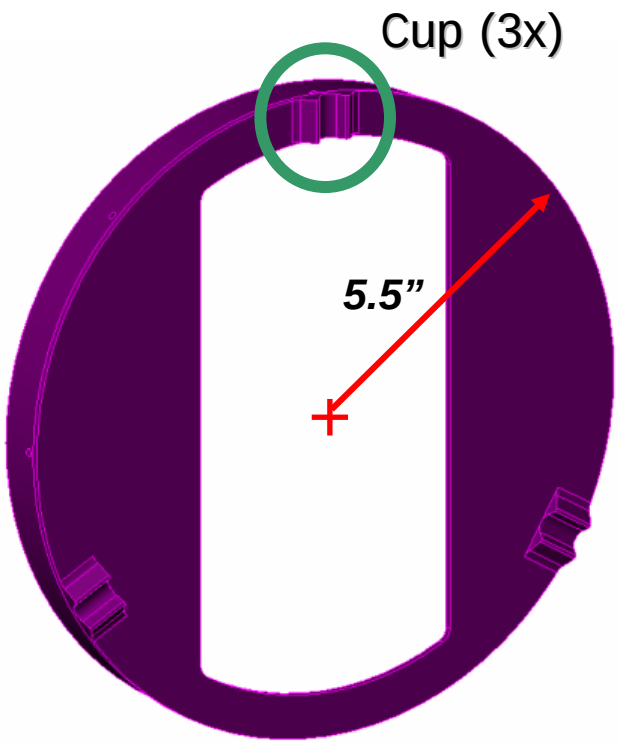
$I_1 = I_2 = \pi r^3 t$

Boom Components

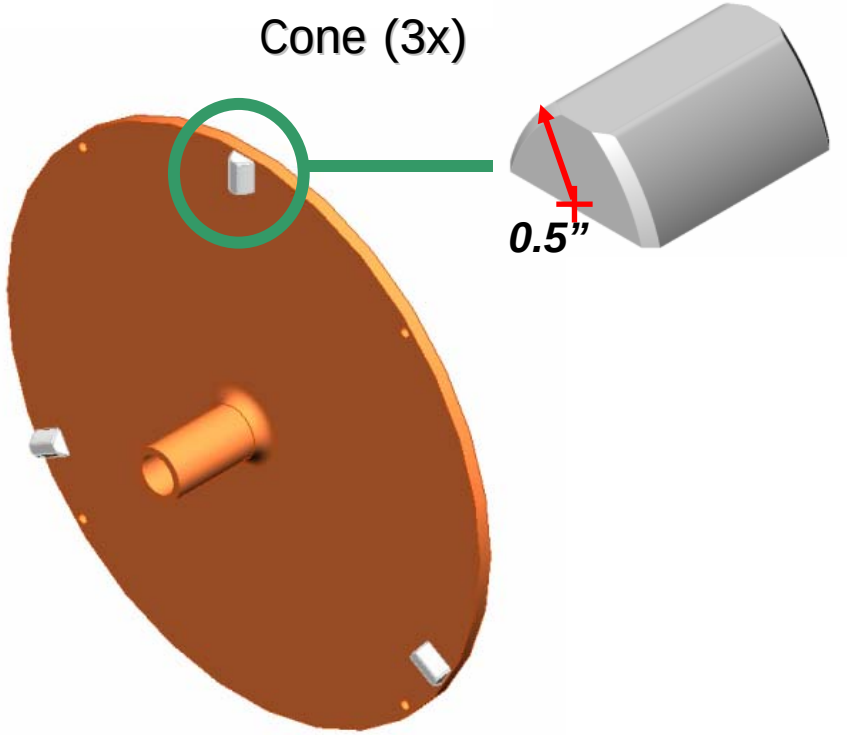
Not Shown:
1) Tube Spring
2) Deployment Electronics
3) Preload Cable
4) Wiring



Mechanical Interface



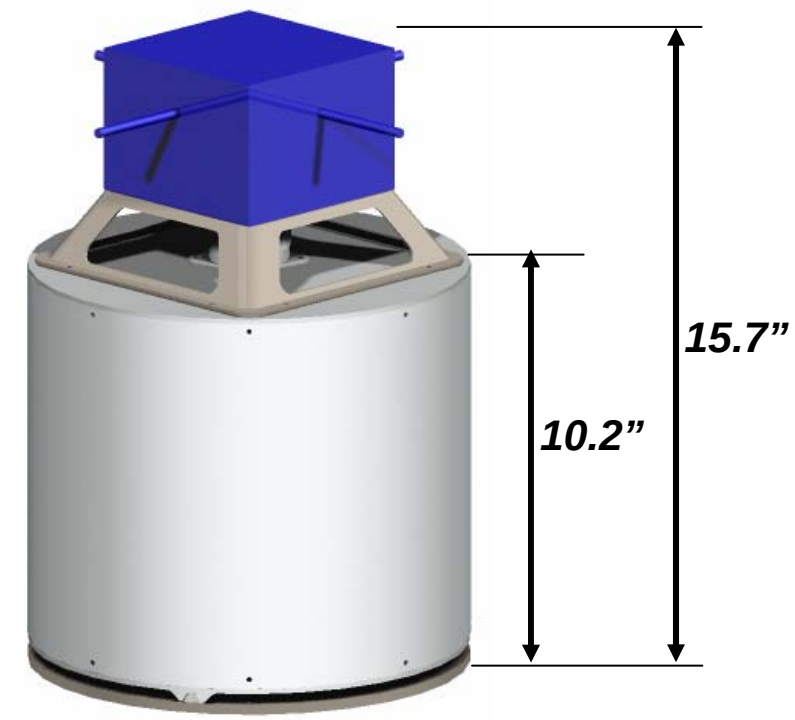
Cylinder bottom plate



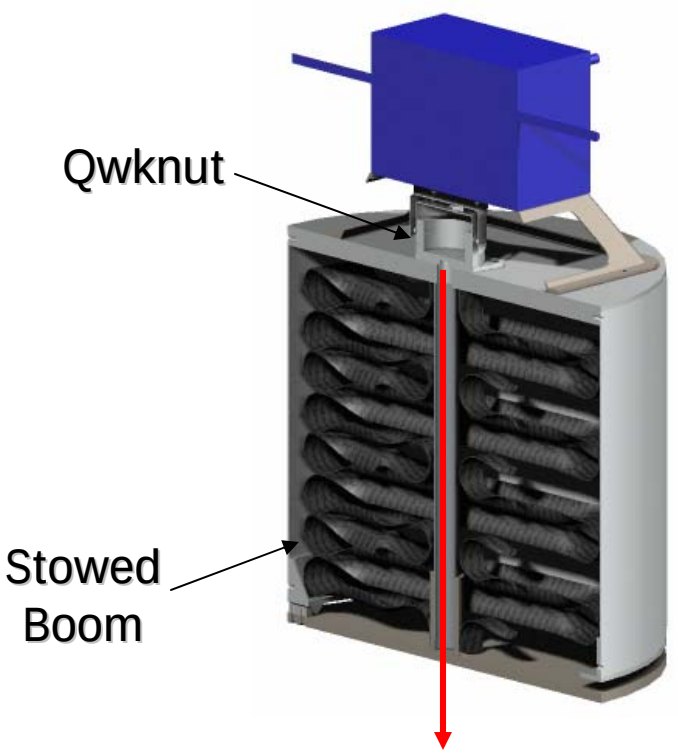
Base plate interface to FalconSat

Interface restricts deployment kinematics and damps vibrations

Stowed Configuration



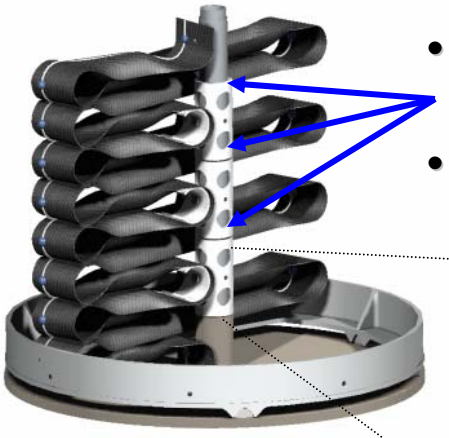
Reaction Load (3x)
Cup/Cone interface



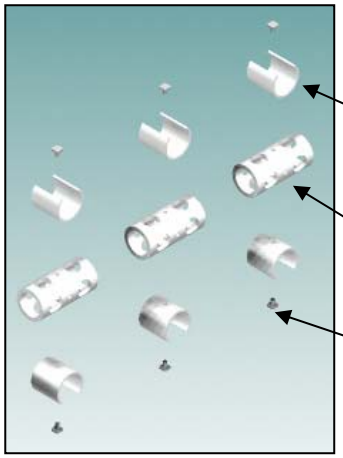
Qwknut preloaded
thru center of tubes

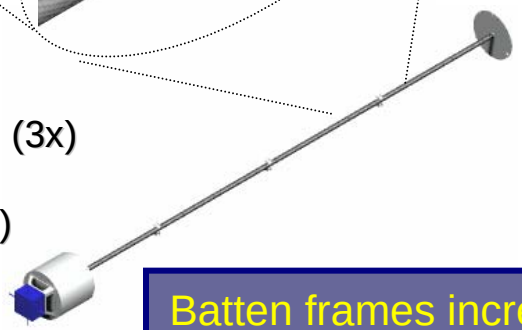
Boom System Packaging

Battens for stiffening



- Batten frames secure boom sections to central support in stowed configuration
- Boom tape guides aid in stowing and securing tape elements





Wire Routing

- Twisted shielded pairs
- Wiring routed along exterior of boom tapes
- Wiring secured with low-outgassing adhesive

Batten frames increase stiffness by reducing effective boom length

Parts List and Mass Estimate

Component	Material	Density (lb/in^3)	Density (grams/cm^3)	Volume (in^3)	Volume (cm^3)	Mass (grams)	Contingency	Adjusted Mass (grams)	Qty	Total Mass (grams)
Sepnut Assy	-	-	-	-	-	200.00	5%	210.00	1	210.00
Thruster Assy	-	-	-	-	-	2000.00	5%	2100.00	1	2100.00
Cable Assy	-	-	-	-	-	46.00	20%	55.20	1	55.20
Battery	-	-	-	-	-	150.00	5%	157.50	8	1260.00
Base	7075 AL	0.101	2.796	11.210	183.699	513.56	20%	616.27	1	616.27
Interface Cone	300 SST	0.286	7.916	0.055	0.901	7.14	20%	8.56	3	25.69
Cylinder Bottom	7075 AL	0.101	2.796	11.145	182.634	510.58	20%	612.70	1	612.70
Cylinder	6061 AL	0.098	2.713	10.329	169.262	459.15	20%	550.97	1	550.97
Cylinder Top	7075 AL	0.101	2.796	12.313	201.774	564.09	20%	676.91	1	676.91
Cylinder Panel	6061 AL	0.098	2.713	3.159	51.767	140.42	20%	168.51	2	337.02
Battery Base Plate	6061 AL	0.098	2.713	0.677	11.094	30.09	20%	36.11	2	72.23
Thruster Stand	7075 AL	0.101	2.796	3.028	49.620	138.72	20%	166.47	1	166.47
Outer tube	7075 AL	0.101	2.796	0.950	15.568	43.52	20%	52.23	1	52.23
Inner Tube	7075 AL	0.101	2.796	0.860	14.093	39.40	20%	47.28	1	47.28
Spring	300 SST	0.286	7.916	0.035	0.574	4.54	20%	5.45	1	5.45
Composite Boom	-	-	-	-	-	145.00	20%	174.00	2	348.00
Batten Frame	6061 AL	0.098	2.713	0.500	8.194	22.23	20%	26.67	3	80.01
Fasteners and Coatings	-	-	-	-	-	50.00	20%	60.00	4	240.00

System Mass (grams) =	7456.4

Total estimated mass ~ **7.5 kg**

~ **6.2 kg** of the mass is at the tip after deployment.

Modeling & Analysis

Structural Behavior

Develop model of boom design for future analysis

$$f \approx \frac{1}{2\pi}\sqrt{\frac{3EIG}{M_{tip}l^3}} \approx \frac{1}{2\pi}\sqrt{\frac{3\pi Er^3tG}{M_{tip}l^3}} \approx 0.26\,Hz$$

Determine and correlate calculation for fundamental frequencies

- First torsional mode
- Bending modes
- Bending-torsion coupling
- Lateral buckling mode and strength
- Deflection magnitudes

Torsion Mode
0.13 Hz

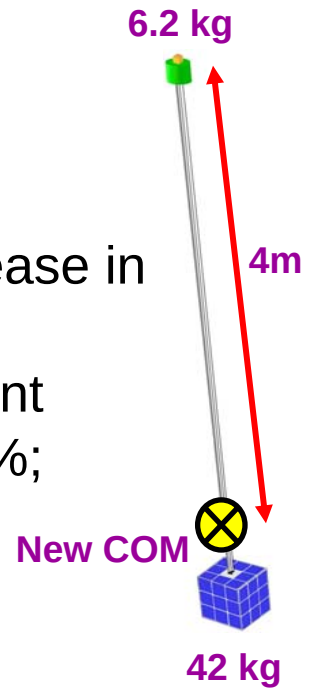
1st Bending mode
0.21 Hz

FalconSat System Impacts

- Structures
  - Stowed system frequency > 100 Hz
  - Deployed system frequency ~ 0.2 Hz (spectral middle ground between attitude control and gravity gradient librations)
- Thermal
  - CTE < 5 ppm/ºC to avoid thermal snap
  - Conductivity paths between thruster and FalconSat-3
- C&DH and Communications
  - Deployment telemetry
  - MPACS command and control
  - Boom dynamic data (optional experiment)
  - Total # of channels TBD

FalconSat System Impacts

- Power
  - Boom battery pack power budget (drain on main bus)
  - Fault monitoring
- Attitude Determination & Control
  - New moment arm / old moment arm ~4.0/0.25 = 16x increase in thruster authority
  - New mass distribution: I/I_0 ~ 60x; enhanced gravity gradient
  - Drawback: angular accelerations achieved decrease ~80%; slower response times
- Operational impacts
  - System deployment operations (sequencing and deploy time)
  - Deployment dynamic envelope (angles & angle rates)



Summary

Development

- Design concept is mature
- Contractors are meeting delivery schedule (September ’04)
- The design has been shown through initial analysis to meet requirements as currently defined

Performance

- High-stiffness boom deploys from a compact volume (11” diameter x 10” height cylinder)
- Boom tip provides platform for a variety of components & payloads
- Localized power available at low impact to host satellite
- *FalconSat-3 Mission:* MPACS thruster actuation authority increased by a factor of 16; gravity gradient stability added; however, control responses dramatically reduced