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
Brian Engberg (AFRL/VSSV)
SSC-X-03
Development Team

AFRL

VS

PR

USAFA
Falconsat Team

LtCol Jerry Sellers
C1C Pamela Fetchko

Starsys Research Corporation

Jeff Harvey
Jon Evans

Composite Technology Development, Inc.

Mark Lake
Michael Tupper
Wil Franics

Busek, Inc.

Vlad Hruby
**Background: PowerSail**

*Application for Large Solar Arrays*

**Thin Film PV Blankets**
- Radiation tolerance & annealing
- Low mass
- Low cost

**Innovative concepts for structural support & deployment**

**Key Metrics**
- Total area
- Low areal density
- High packaging ratio

**Isolation mechanisms and other joints**

**System-level Concepts**

**Technology development themes:**
- Deploy large structures from compact volumes
- Structural isolation and control
- Improving fundamental knowledge and models

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

Launch MLV-06
MPACS Thruster

Micro-Propulsion Attitude Control System

- Total mass ~2.1kg (4.6lbm)
- 25 $\mu$N•s (5.6 $\mu$lb•s) impulse
- Thrust duration 2-5 $\mu$s
- 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

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

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

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

- Batteries (8x)
- Cylinder Panel (2x)
- Thruster Mount
- Qwknut
- Cylinder Top
- Battery Panel (2x)
- Interface Cones (3x)
- Base
- EMC Boom Element (2x)
- Outer Tube
- Inner Tube
- Cylinder Bottom
- Cylinder
- Packaged Configuration

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Mechanical Interface

Cup (3x)  Cone (3x)

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

10.2”

15.7”

Stowed Boom
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

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System Mass (grams) = 7456.4

Total estimated mass ~ 7.5 kg
~ 6.2 kg of the mass is at the tip after deployment.
Develop model of boom design for future analysis

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

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/°C 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 \(\approx 4.0/0.25 = 16x\) increase in thruster authority
  – New mass distribution: \(I/I_0 \approx 60x\); enhanced gravity gradient
  – Drawback: angular accelerations achieved decrease \(\approx 80\%\); 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