Differential Drag Control of Miniature Satellites using Origami Concepts

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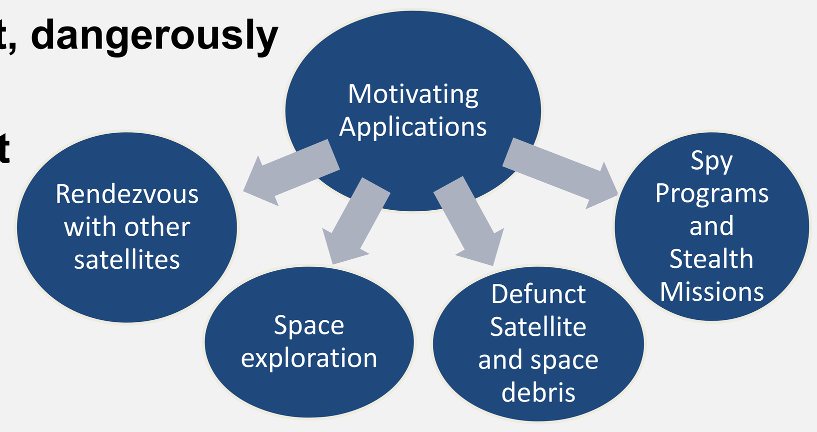
Motivation

Current Spacecraft Maneuvering: Propulsion Systems

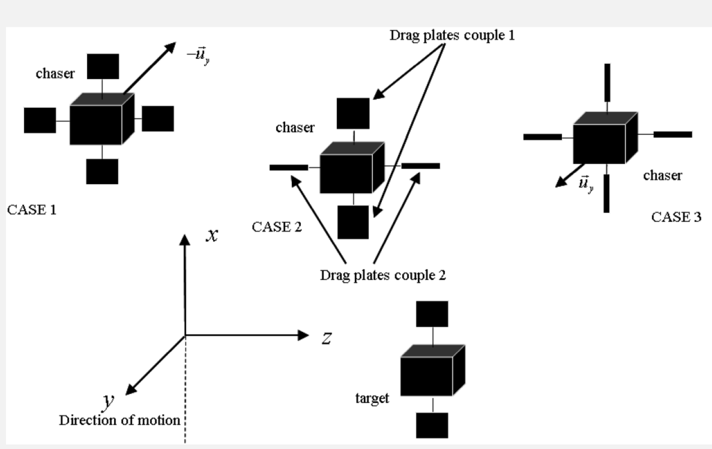
- Mission life limited by fuel
- This fuel is expensive: ~$5000/lb to transport it to Low Earth Orbit (<600km)
- Excess heat, dangerously flammable
- Volume cost
- Detectable



Proposed Solution

Deploying a differential drag surface to alter relative velocity and position of the satellite.

Theory of Differential Drag



Control of basal surface area to maneuver target and chaser satellites.

Equations:

- *Relative dynamics between chaser and target:*

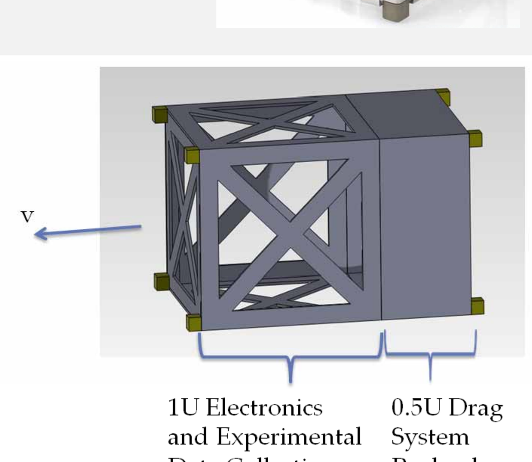
$$\begin{cases} \Delta\ddot{x} = 2(\omega c)\Delta\dot{y} + (5c^2 - 2)\omega^2\Delta x + u_x \\ \Delta\ddot{y} = -2(\omega c)\Delta\dot{x} + u_y \\ \Delta\ddot{z} = -q^2\Delta z + 2lq\cos(qt - \varphi) + u_z \end{cases}$$

- *Acceleration on a spacecraft due to atmospheric drag:*

$$\bar{a} = \left(-\frac{\rho S C_D}{2m} V^2\right)\hat{V} \qquad \bar{a} = [0 \quad u_y \quad 0]$$

Project Goal

To fly two 1.5 U CubeSats of identical design to test differential drag maneuvering in low earth orbit



Low Earth Orbit < 600 km

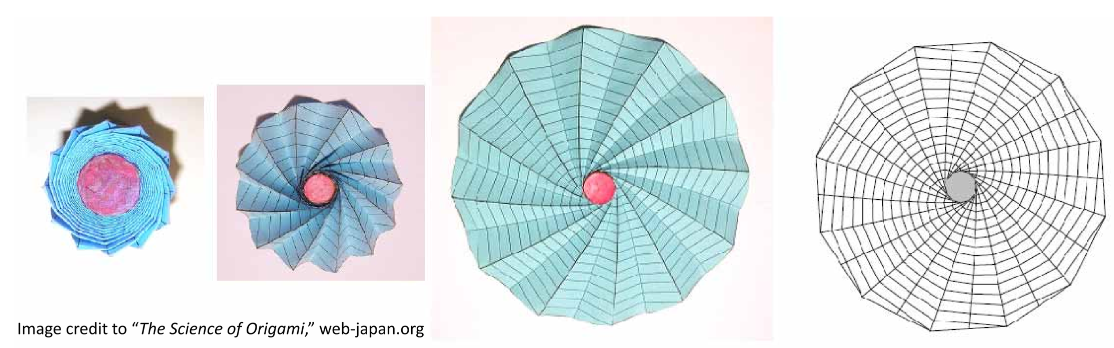
1U ≈ 10cm x 10cm x 10cm

Design incorporates ~1U for electronics and data collection and ~.5U payload for differential drag system

Design Details

Design 1: Origami - Based Flasher Sail

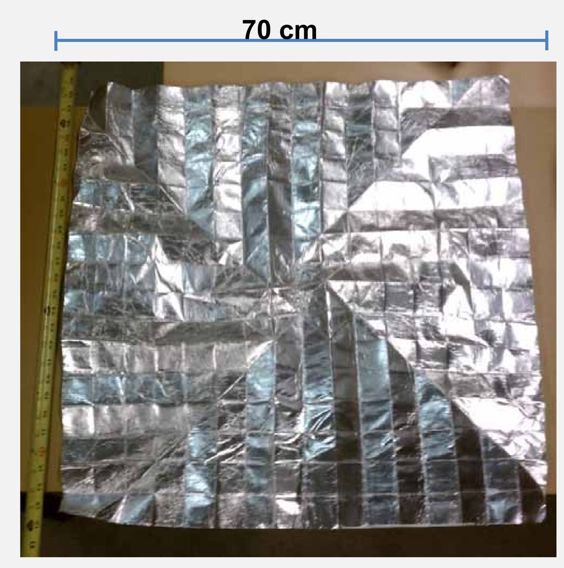
The Power of Origami



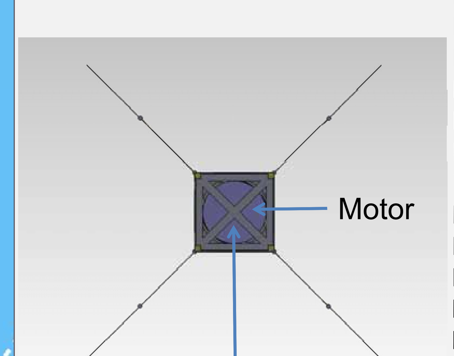
- Origami is a precision folding method
- Large open surface area to folded volume ratio

Folded Flasher

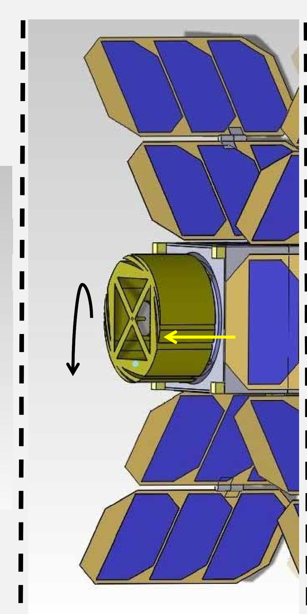
Origami techniques compress 0.5m² surface area flasher into a 0.5U payload volume.



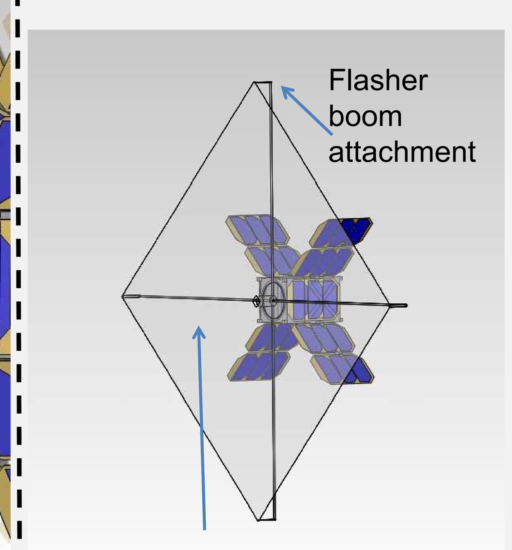
Flasher Deployed



Stowed Flasher



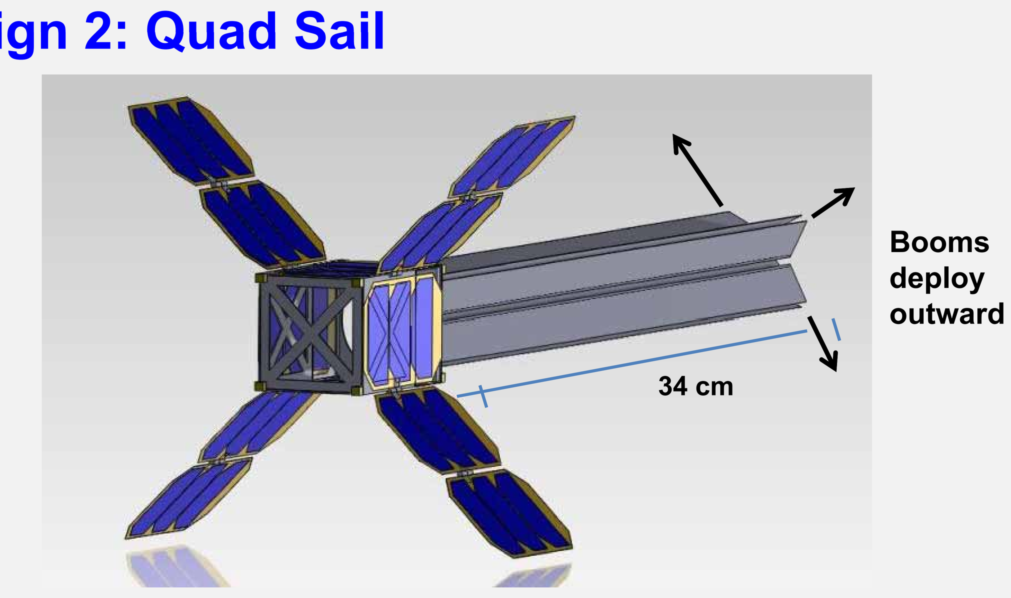
Flasher exiting CubeSat, rotates to deploy



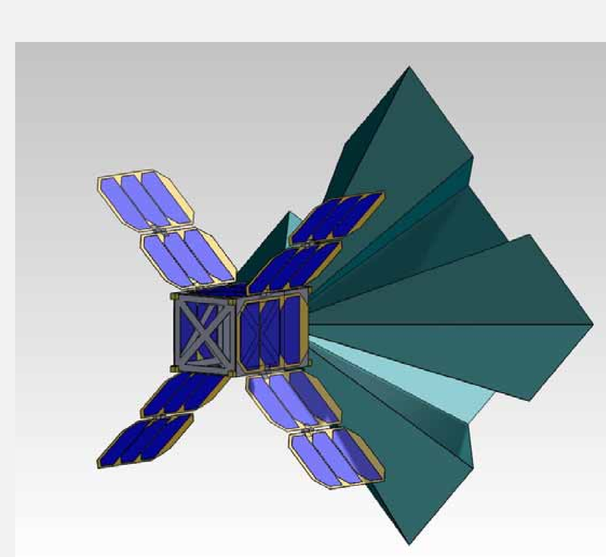
Clear Mylar Deployed Flasher

Maneuvering Technique: Center rotation fans out flasher, increasing surface area

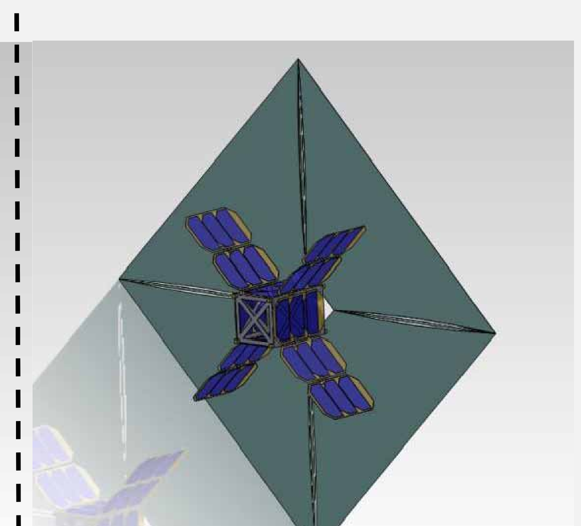
Design 2: Quad Sail



Four telescopic booms will extend out of the stowed CubeSat and open the drag surface.



As Booms Open, Sail Unfolds



Quad Sail Deployed

Maneuvering Technique:
Effective drag area is controlled by the boom angle

While the open drag surface of the Quad sail looks similar to that of the Flasher, the deployment techniques differ.

Ongoing Research

1. Sail Material Selection

Design considerations:

- Minimal outgassing
- -30 to +70°C Operating Range
- "Foldable" with minimal wear (small but concrete plastic deformation)

Candidate Materials:

- Mylar
- Kapton
- Melinex

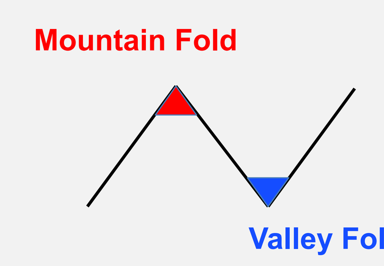
Image credits to technoltape.com, solarguard.com, falkiners.com respectively

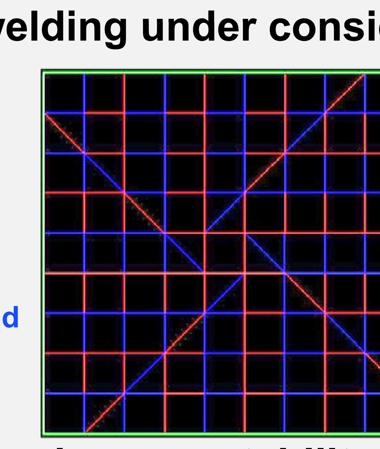
Material	Ultimate Strength (S_{UT}) (kpsi)	Coefficient of Thermal Expansion (α) (in/in/°C)	Folding Endurance (MIT, cycles)
Mylar® (125µm thick)	~30	$17x10^{-6}$	>2500
Kapton® (25µm thick)	~33	$20x10^{-6}$	>285,000
Melinex® (125µm thick)	~25	$19x10^{-6}$	>20,000

2. Manufacturing Processes

Challenges:

- Design 1:
  - Embedding stiffening members into body while maintaining sail integrity
  - Ultrasonic welding under consideration





Carbon Fiber Layup Map

- Design 2: Collapsing repeatability – "ironing process"

3. Design of Deployment Train

- Actuation methods and process
- Gear Trains

4. Component Testing

NASA General Environmental Verification Specification: A "Worst-case" Vibration Profile

Frequency (Hz)	ASD Level (G^2/Hz)	
	Qualification	Acceptance
20	0.026	0.013
20-50	+6 dB/oct	+6 dB/oct
50-800	0.16	0.08
800-2000	-6 dB/oct	-6 dB/oct
2000	0.026	0.013
Overall	14.1 G_{rms}	10.0 G_{rms}

All components will be tested to the above profile

Participating Labs

ADAMUS

Advanced Autonomous Multiple Spacecraft Laboratory

Director: Prof. Riccardo Bevilacqua

NANO-M3 DESIGN LAB

Nano/Micro-Scale Manufacturing and Material Design Laboratory

Director: Prof. Johnson Samuel

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