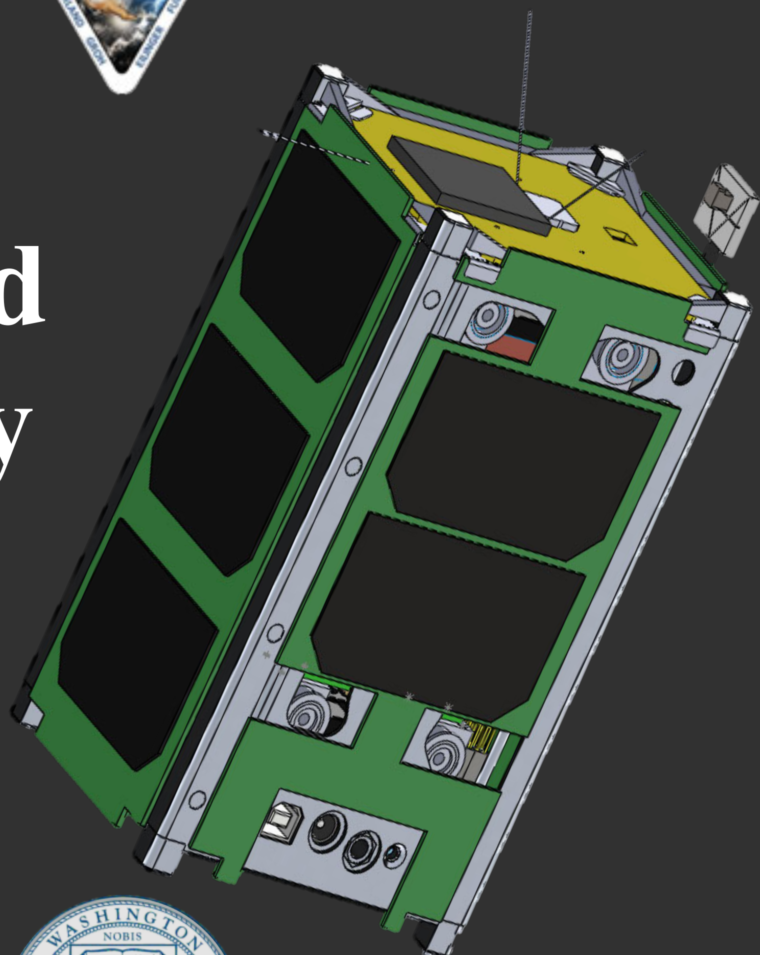
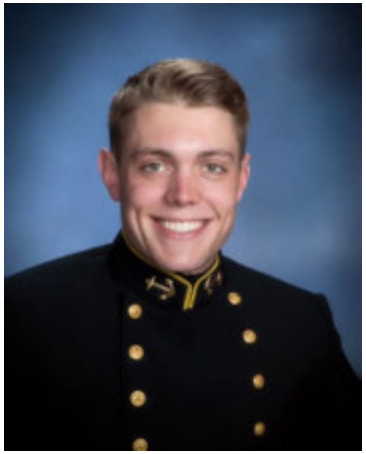
Communications and Thruster Technology



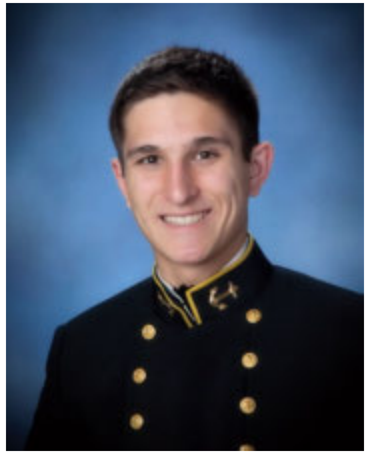
Uriah Eilinger John Furseth
Scott Hannah Will Teater

21 April 2016

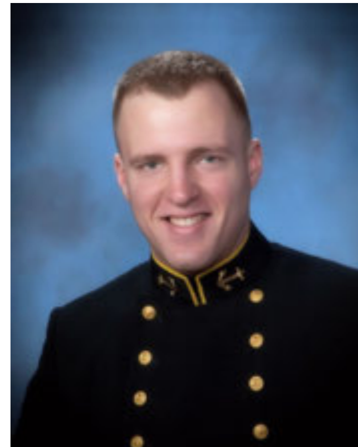
Design Team



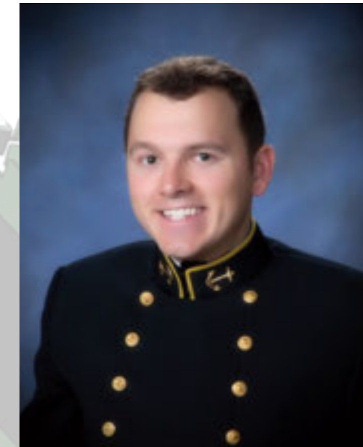
Uriah Eilinger
Team Lead & Systems



Jon Furseth
Integration & Testing



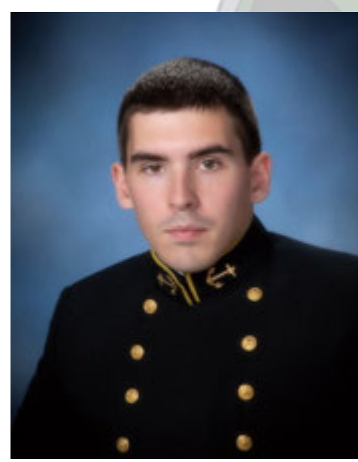
Jake Groh
Testing & Documentation



Ben Cumberland
Release Mechanism

Scott Hannah
Asst. Team Lead & Comms

Cullen Hanks
Propulsion & Design



Will Teater
Solar Panel & EPS

Matt Driskell
PSK-31

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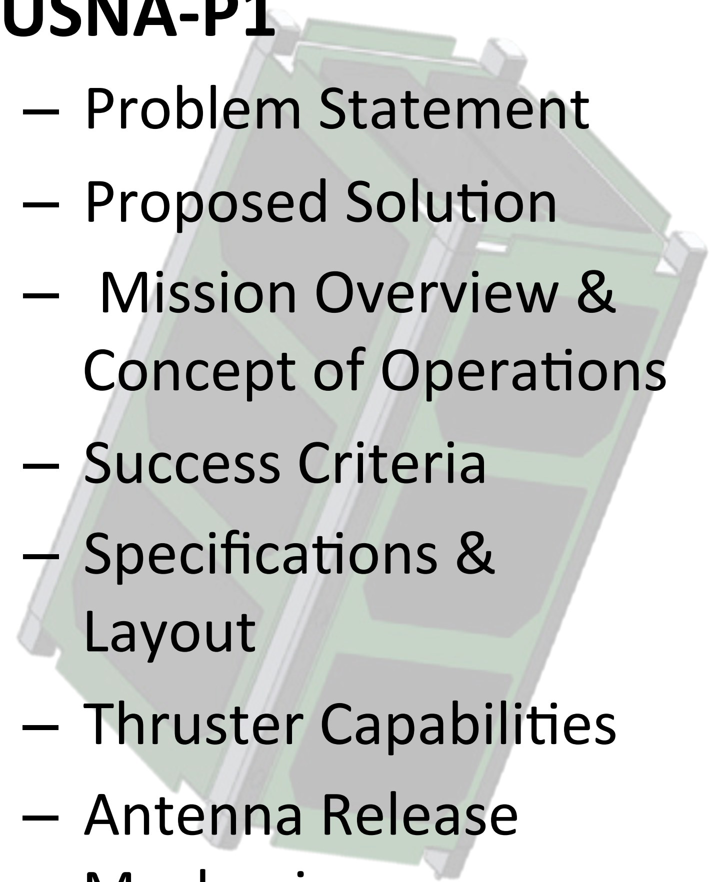
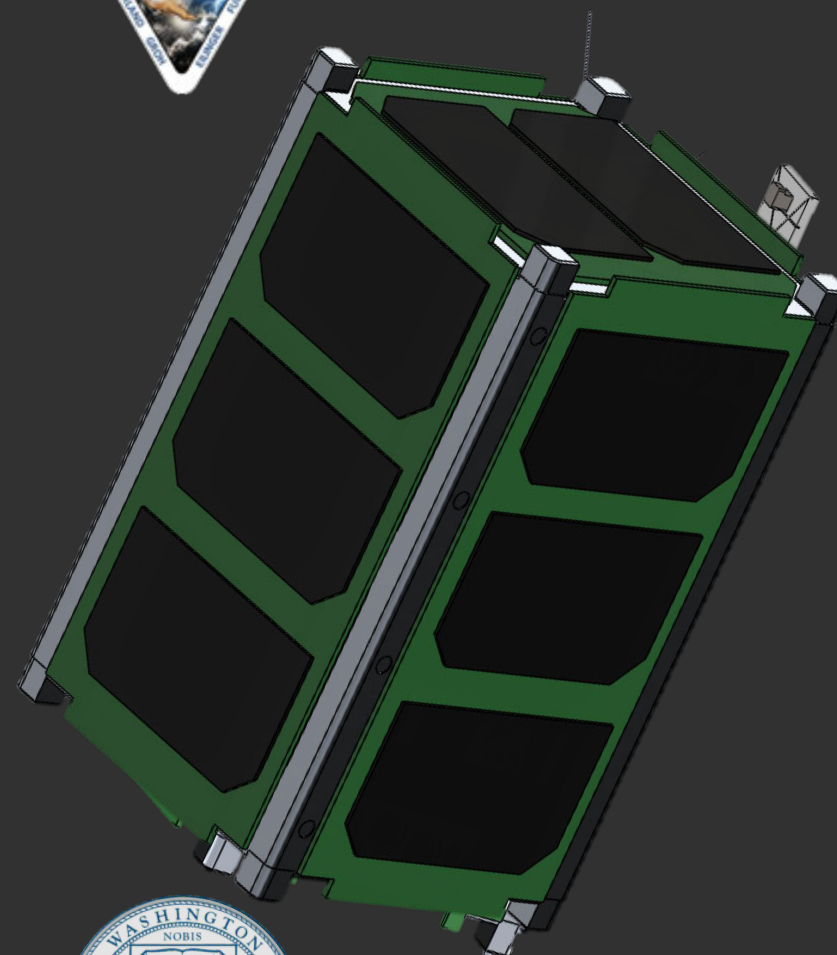


PSAT-2

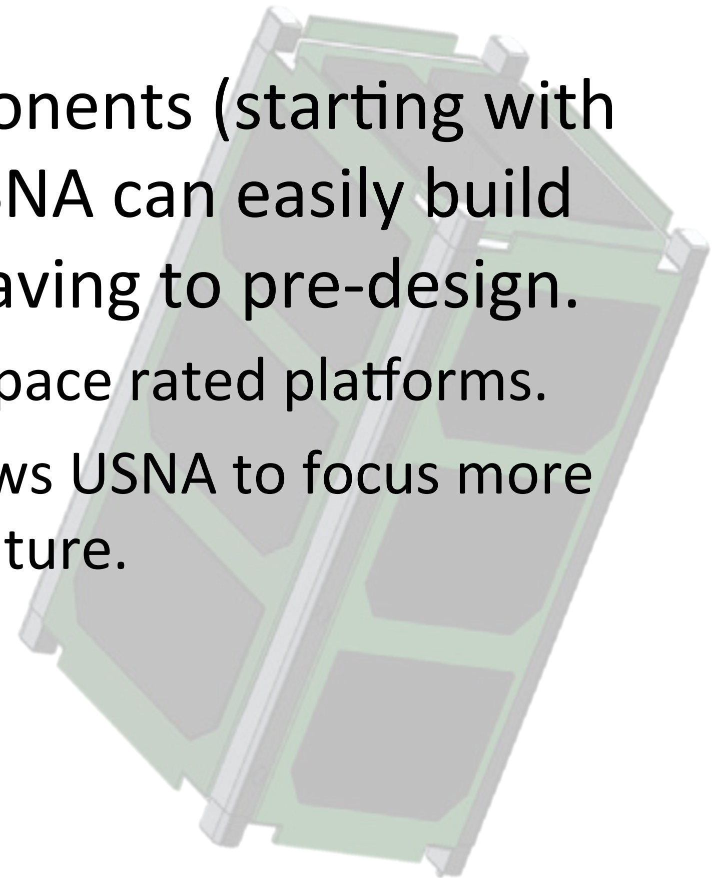
United States Naval Academy



Problem Statement

- USNA has had several CubeSat designs but little to no standard design that have been continued from previous satellites.
- Instead of putting time in developing a payload, USNA has to put time in developing a satellite platform.
- Designing and building a satellite platform cuts back on time and funding that could otherwise be devoted to scientific and technological research.

Proposed Solution

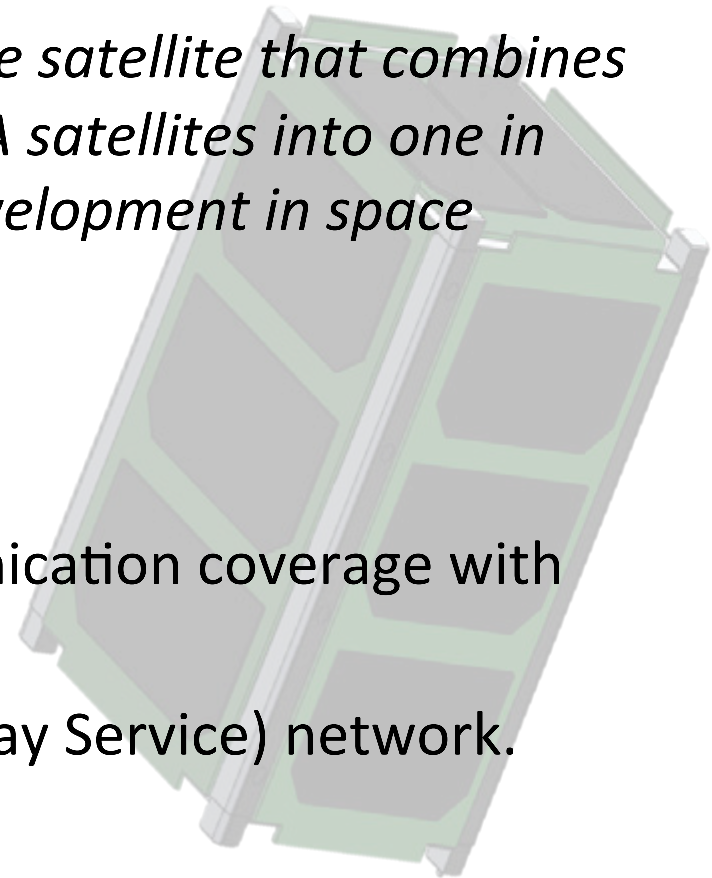


- Design standard CubeSat components (starting with communications board) that USNA can easily build with accessible parts without having to pre-design.
  – Still gives experience in building space rated platforms.
  – However, faster process that allows USNA to focus more on payload development in the future.

Mission & Objectives

Mission

"Develop a cost effective and reliable satellite that combines the capabilities of several past USNA satellites into one in order to pave the way for future development in space technology and mission diversity."

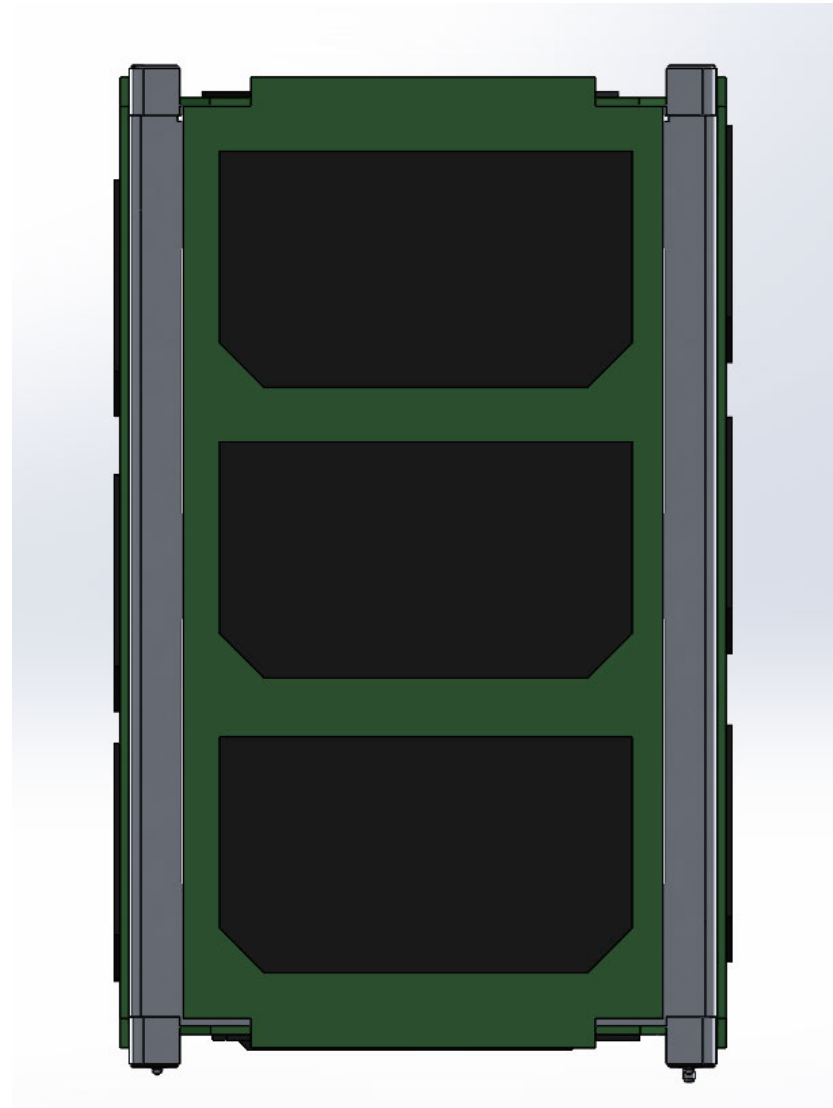


Objectives

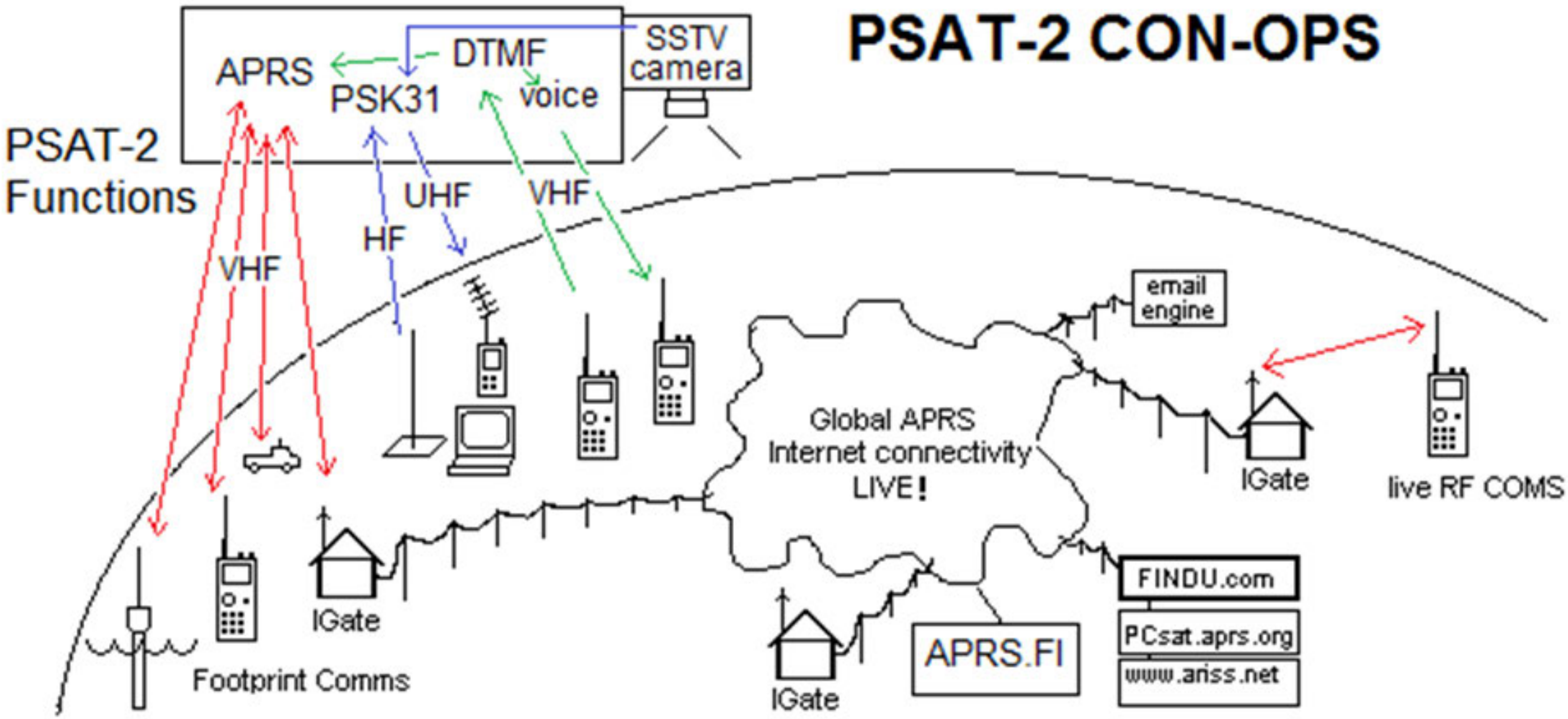
1. Provide a reliable radio communication coverage with the following capabilities:
    1. APRS (Automated Packet Relay Service) network.
    2. PSK-31 transponder.
    3. DTMF-decoding.
2. Design standard CubeSat control boards that can be used on future DoD satellites in a variety of configurations.

Stack Specifications

Parameter	Value
Size:	10cm x 10cm x 15cm
Mass:	2.0 kg
Average Power	3.5 W
Bus Voltage:	7 V
Comms:	VHF Uplink/Downlink 145.825 MHz UHF Downlink 435.6 MHz
Attitude Control:	2 axis, magnetorquers
Payload Data Interface:	APRS, DTMF, PSK-31

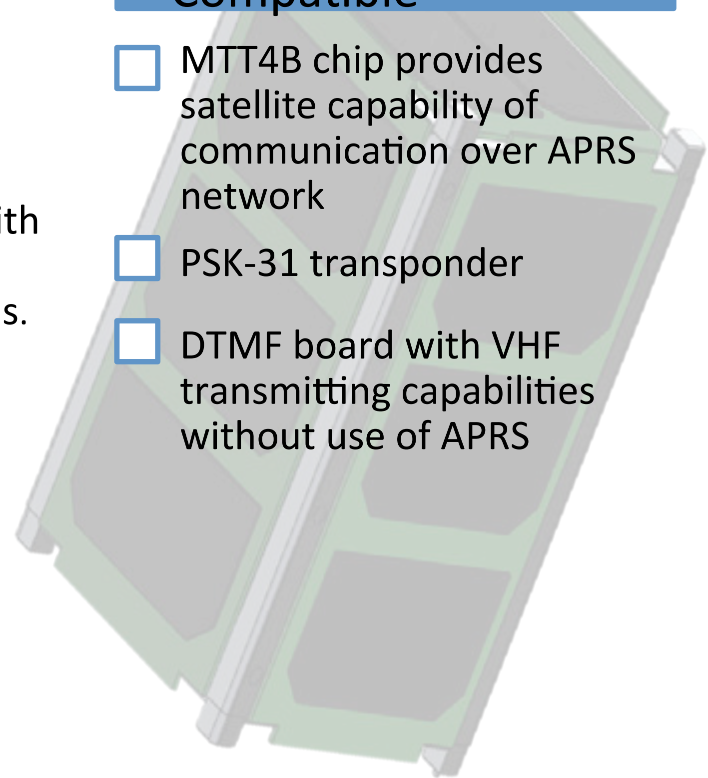


Mission Concept of Operations

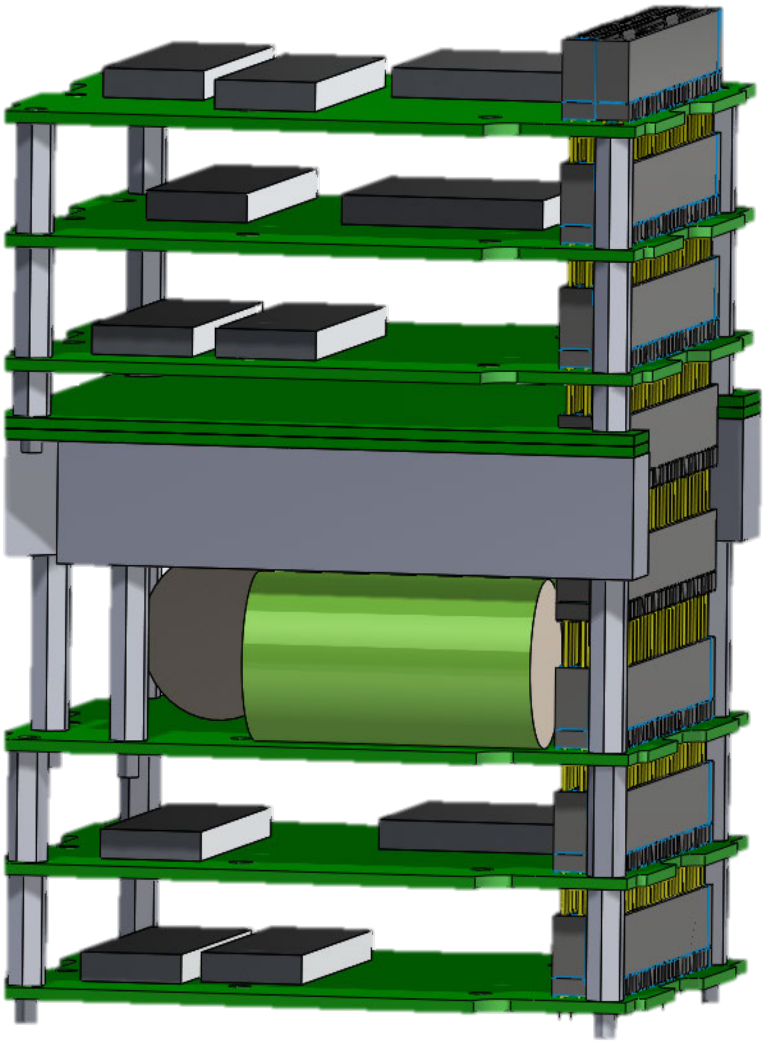


Success Criteria

75% Global Coverage	>90% Availability	APRS, PSK, DTMF Compatible
☐ Operational CubeSat in LEO	☐ Communications board with VHF and UHF transceivers ☐ Operational CubeSat with communications link to multiple ground stations.	☐ MTT4B chip provides satellite capability of communication over APRS network ☐ PSK-31 transponder ☐ DTMF board with VHF transmitting capabilities without use of APRS



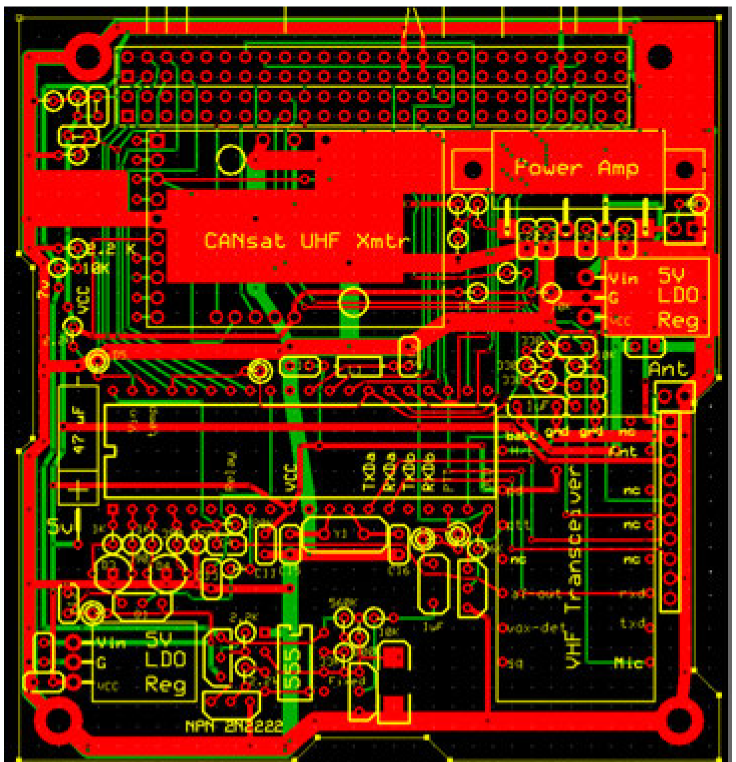
Stack Layout

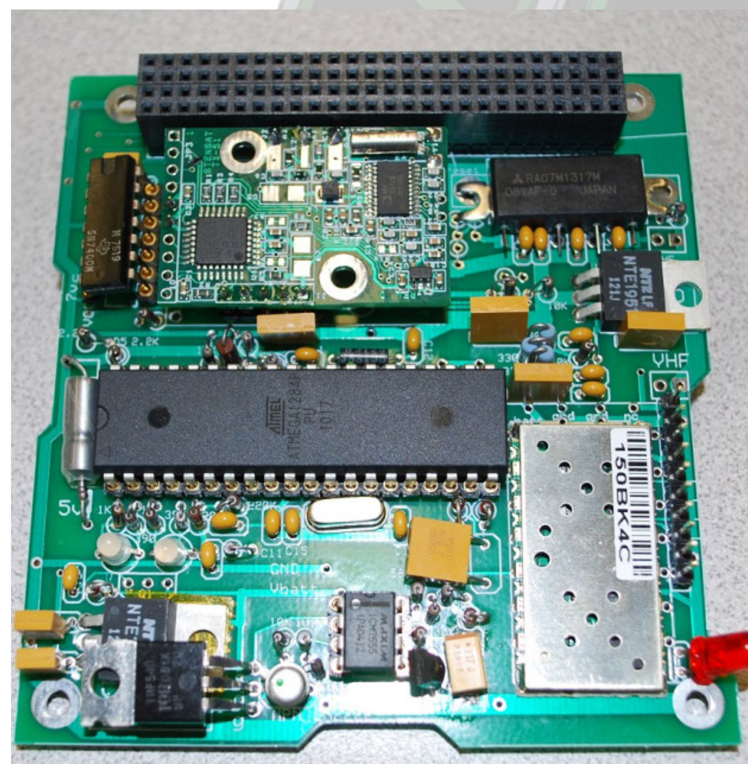


ADCS BOARD	In-house design by Will Teater
DTMF/VOICE BOARD	In-house design by Matt Driskell
PSK-31 BOARD	Outside board from Brno University.
STAINLESS STEEL BALLAST	~0.5” stainless steel to keep batteries in place and increase moment of inertia.
EPS/BATTERY BOARD	5 NiCd Batteries produce 1350 mA-hr/battery to EPS board.
COMMS BOARD	In-house designed by Scott Hannah
MOTHERBOARD	CubeSat Kit Motherboard

Communications Board

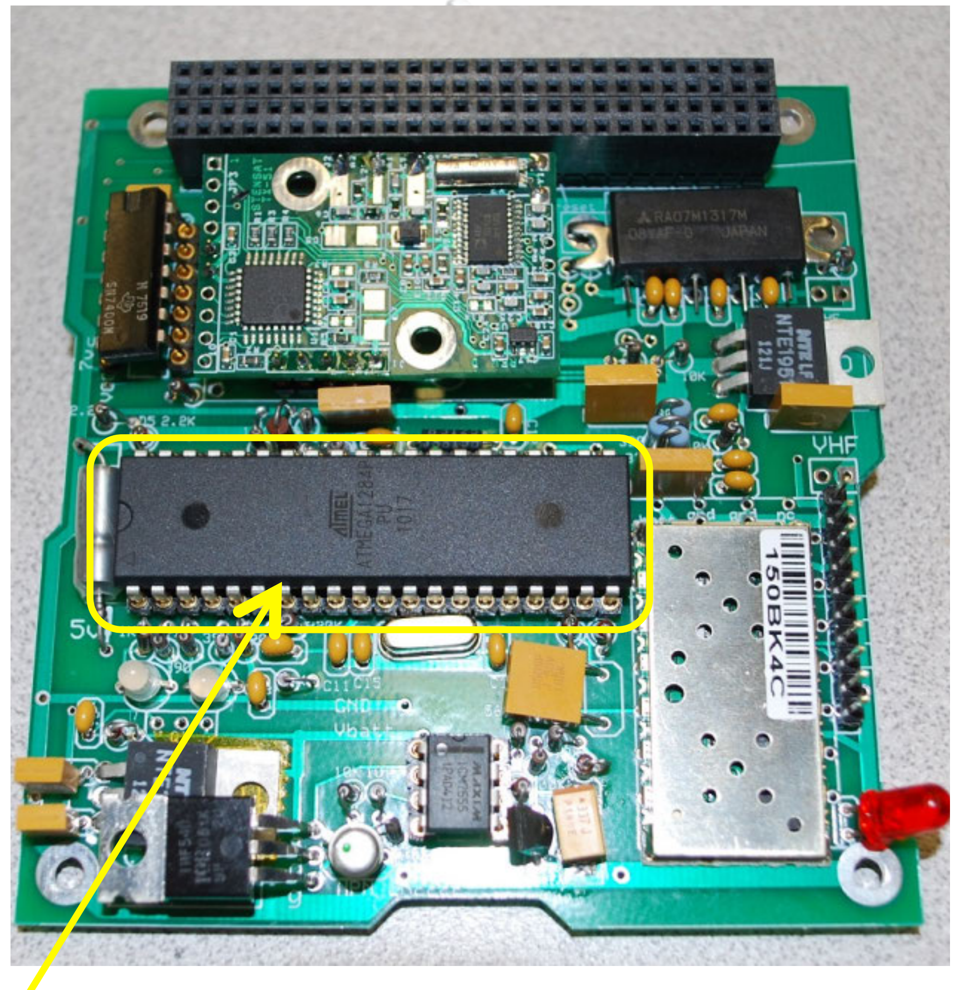
- In-house design that evolved from the MTT4B communications board made by Byonics.
- Equipped with MTT4 chip, VHF transceiver, and UHF transmitter.





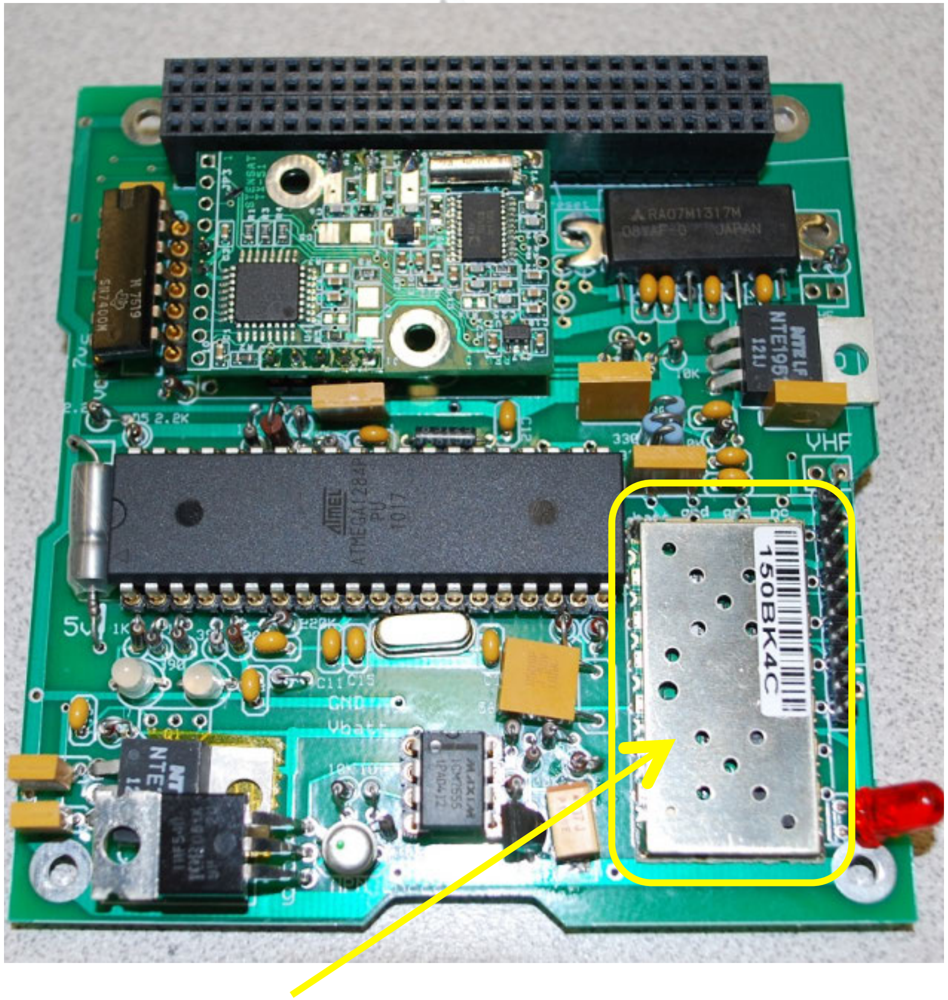
Communications-MTT4

- Programmable high level digipeater.
- 5 analog inputs used for telemetry.
- 8 digital outputs to other boards on satellite.
- Serial port for uplink and downlink between other boards and ground.



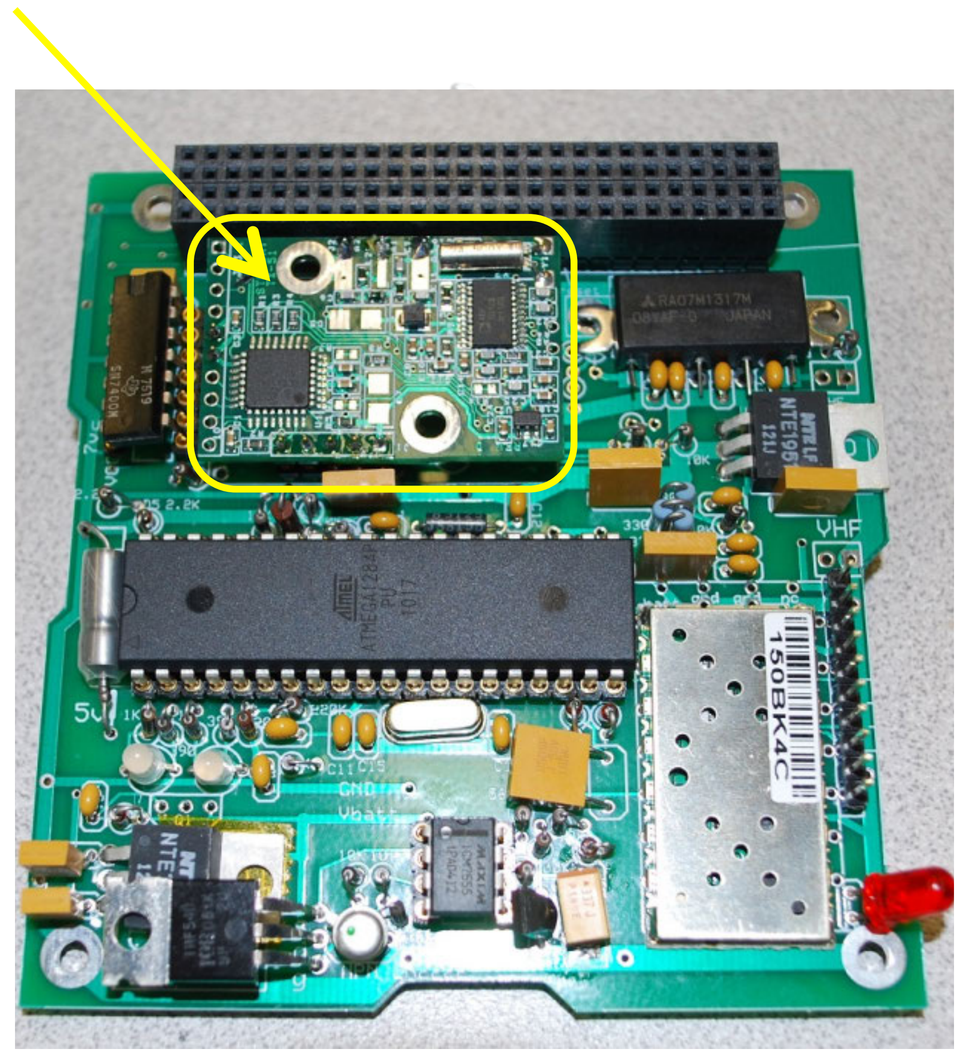
Communications-VHF Transceiver

- Primary uplink and downlink for MTT4.
- VHF transceiver communicates over 145.825 MHz amateur radio frequency.
- Operating voltage of 5V.



Communications-UHF Transmitter

- Not mission critical to PSAT-2.
- Testing concept of a high data rate downlink for future use.
- Communicates over 430 MHz frequency.
- Capable of serial interface rate of 38.4K bps.
- Operating voltage of 5V.

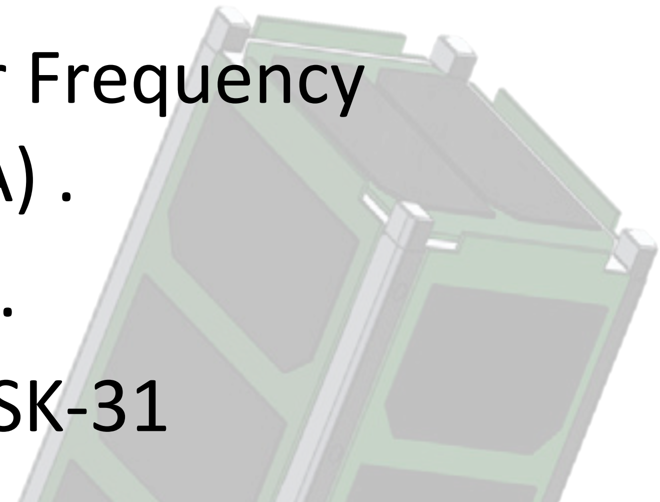


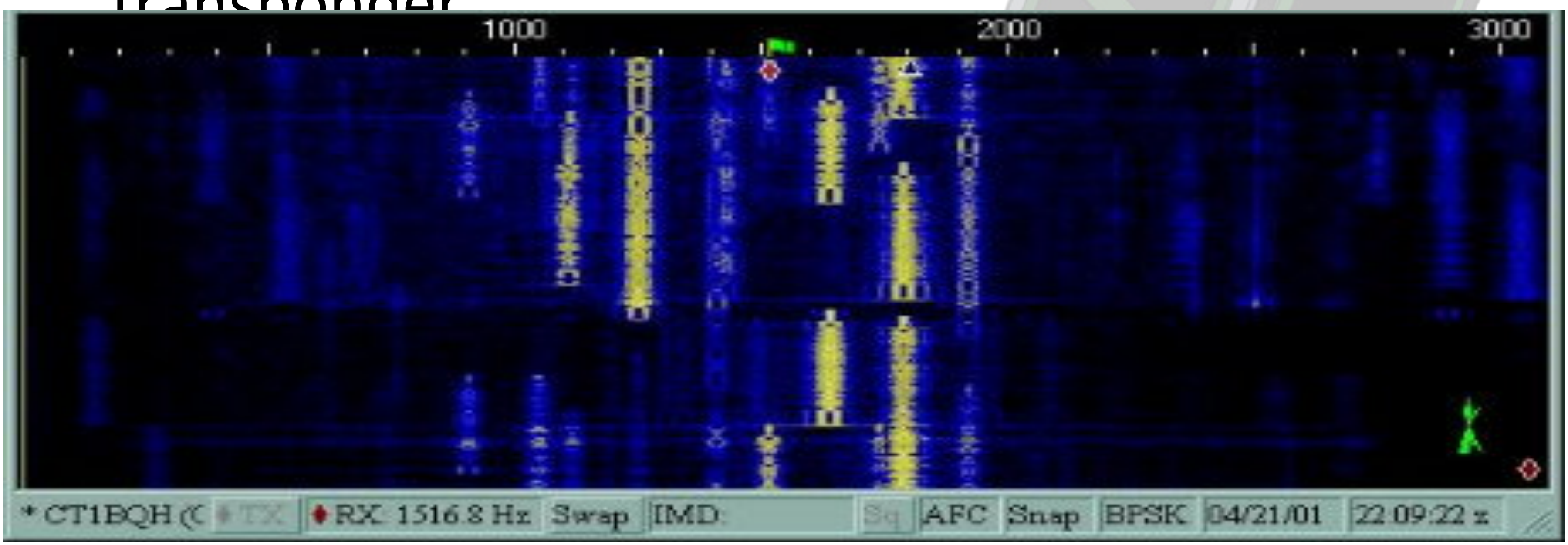
DTMF/Voice Decoding

- Stands for "Dual-tone Multi-Frequency."
- Opens satellite communications access to anyone with almost any VHF radio that has a DTMF keypad.
- This allows users to send their position, status, or message without having to use the more expensive APRS radios.
- Communicates over 145.980 MHz frequency to minimize data collision with APRS.

PSK-31 Transponder

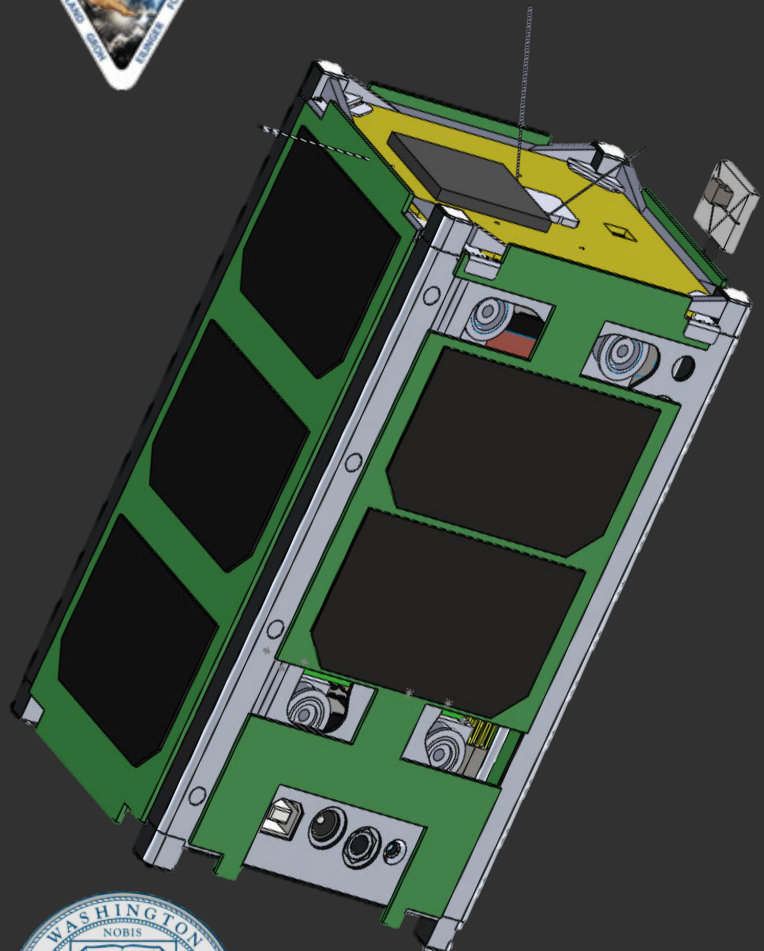
- Amateur radio payload from outside source.
- PSK-31's mission is a multi-user Frequency Division Multiple Access (FDMA) .
- Data rate close to typing speed.
- SSTV camera integrated with PSK-31 transponder





USNA-P1

United States Naval Academy



Mission & Objectives

Mission

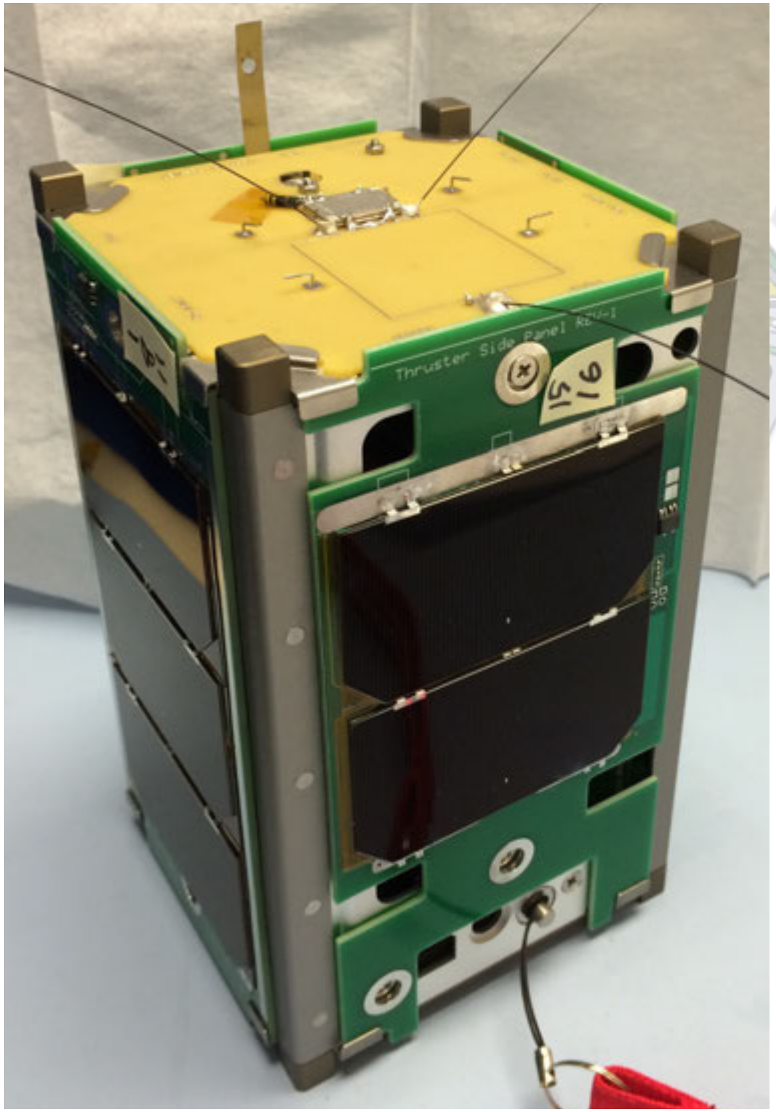
"Implement a newly designed micro propulsion system on a nanosat in order to confirm its functionality and test its operating parameters for potential use in future platforms needing a more versatile method of propulsion."

Objectives

1. Integrate micro-cathode thruster into a CubeSat platform.
2. De-tumble the satellite to test attitude control.
3. Conduct a spin-up / de-spin.
4. Point satellite to demonstrate rotational control.
5. Perform end-of-life delta-V maneuver.

USNA-P1 Overview

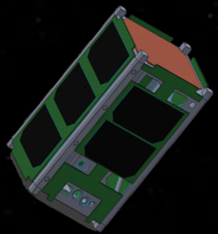
Parameter	Value
Size:	10cm x 10cm x 15cm
Mass:	2.0 kg
Average Power	3.5 W
Bus Voltage:	7 V
Comms:	VHF Uplink/Downlink 145.825 MHz UHF Downlink 435.6 MHz
Attitude Control:	3 axis control
Payload	4 Micro-Cathode Thrusters



Concept of Operations Orbits

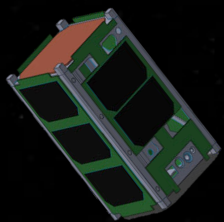
Stage 1:

USNA-P1 is ejected from launch vehicle and tumbles into LEO.



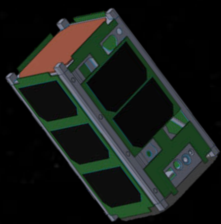
Stage 2:

When $\omega \leq 15$, thrusters fire to gain control of and detumble USNA-P1.



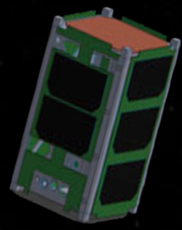
Stage 3:

USNA-P1 conducts spin-up and de-spin experiments to aid in determining thruster capabilities.



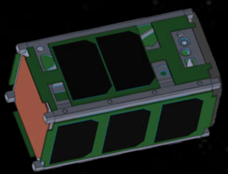
Stage 4:

Thrusters conduct attitude change in order to test thruster pointing capabilities.



Stage 5:

Nearing end-of-life, continue testing thruster capabilities and conduct an orbit change to de-orbit the USNA-P1.



Success Criteria

Integrated Thrusters

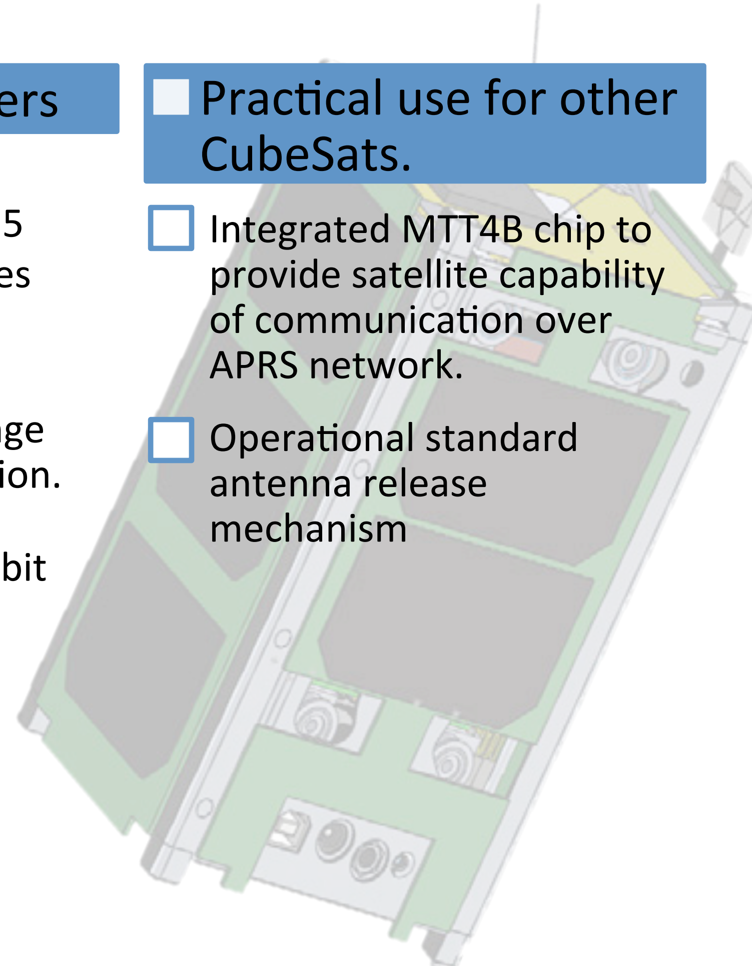
- Occupy < 0.75U.
- Weigh < 25% of total CubeSat.

Functional Thrusters

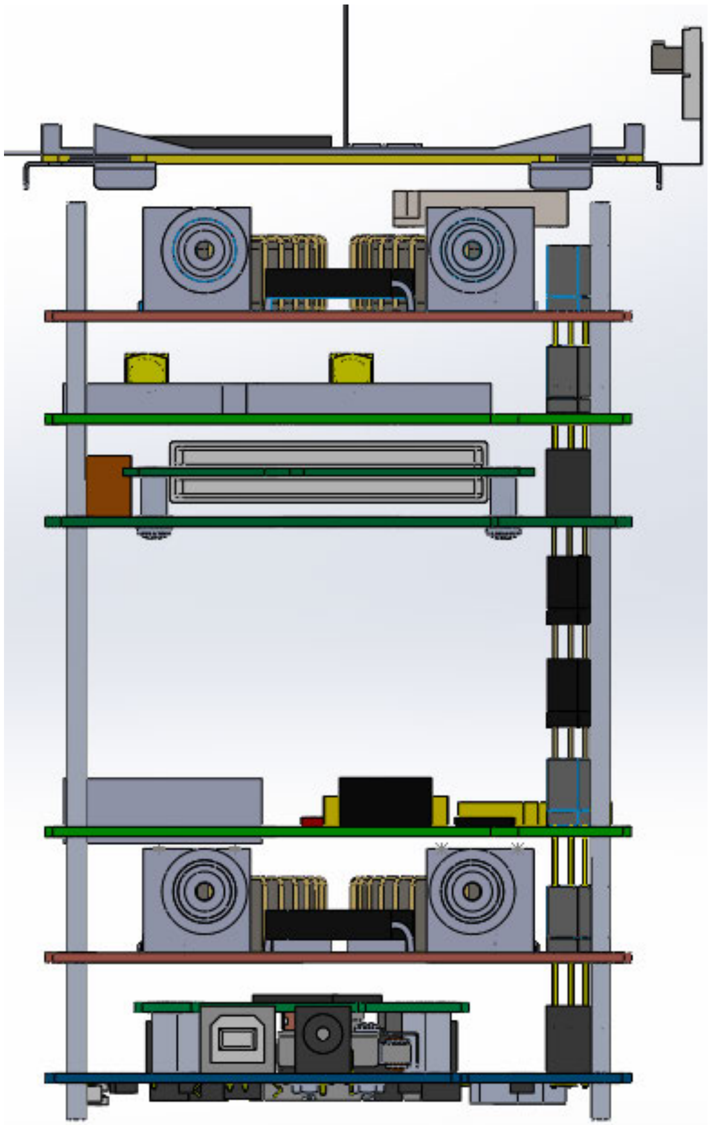
- Thrusters fire at $\omega \leq 15$ deg/s and decreases spin rate.
- Thruster successfully conduct attitude change from original orientation.
- Thrusters decrease orbit size.

Practical use for other CubeSats.

- Integrated MTT4B chip to provide satellite capability of communication over APRS network.
- Operational standard antenna release mechanism



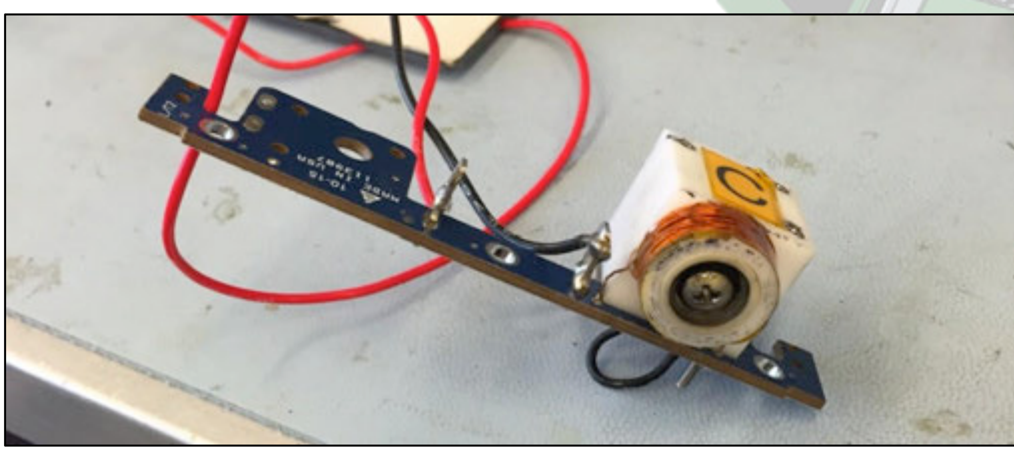
Current Status



RELEASE MECHANISM	In-house design by Ben Cumberland.
THRUSTER BOARD	Designed and built by George Washington University.
COMMS BOARD	In-house designed by Scott Hannah.
EPS BOARD	Clyde Space 3rd Generation EPS
INTERFACE BOARD	In-house design that includes gyro, camera, & magnetometers.
THRUSTER BOARD	Designed and built by George Washington University.
MOTHERBOARD	CubeSat Kit Motherboard

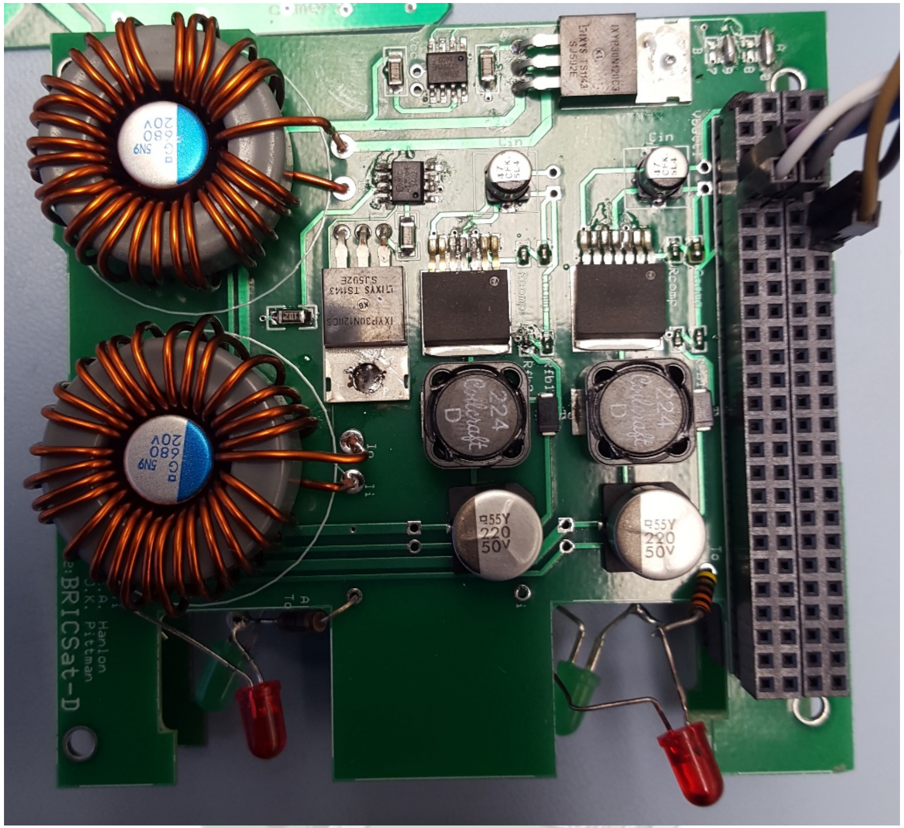
Thrusters

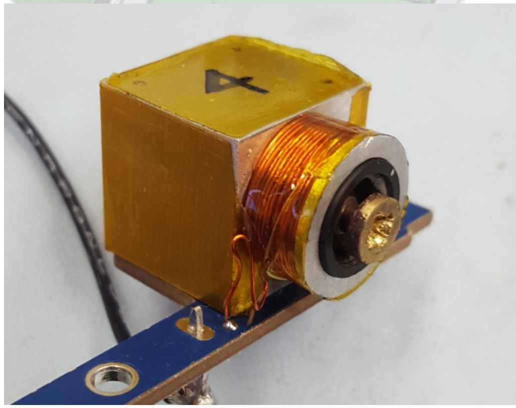
- Micro-arc thrusters designed by George Washington University.
- Thruster control board thruster platform designed and developed in house at USNA.
- Produce such small thrust, micro-gravity air resistance needed for complete test.



Thrusters

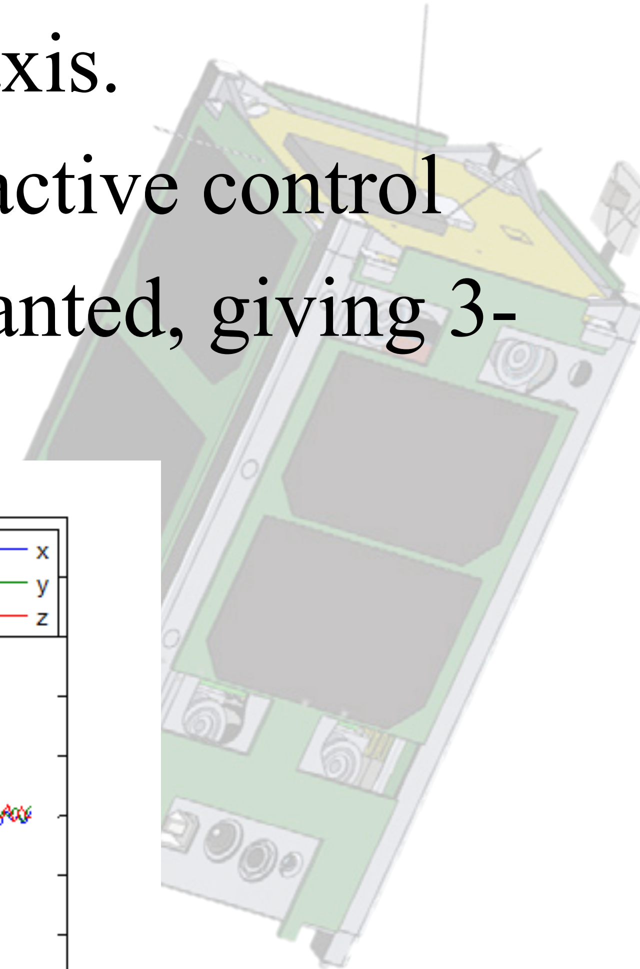
- Thruster Parameters
  - 2μN thrust average per pulse
  - 0.1 W/pulse
  - Nickel rod as propellant
  - Max pulse rate: 25 Hz

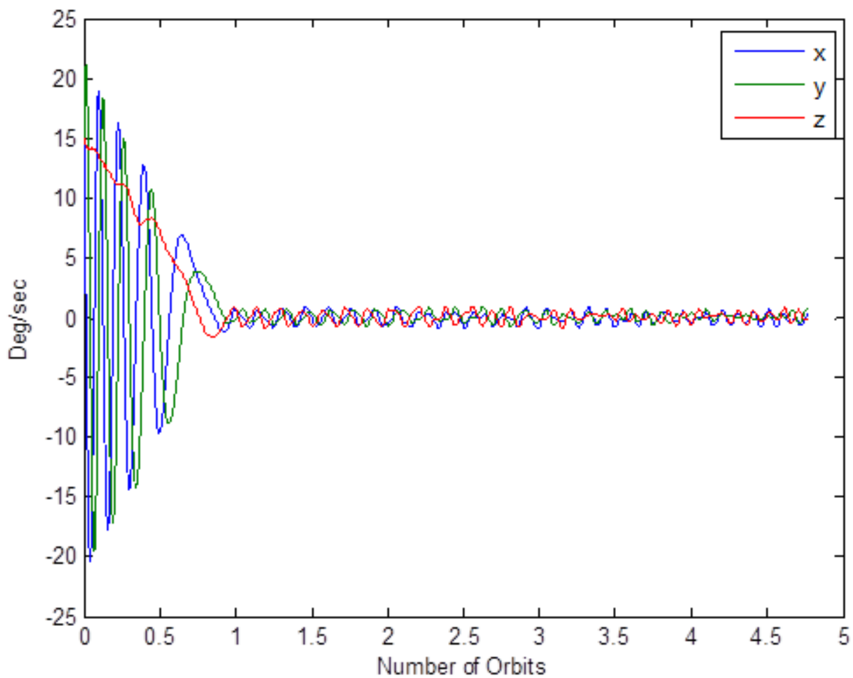




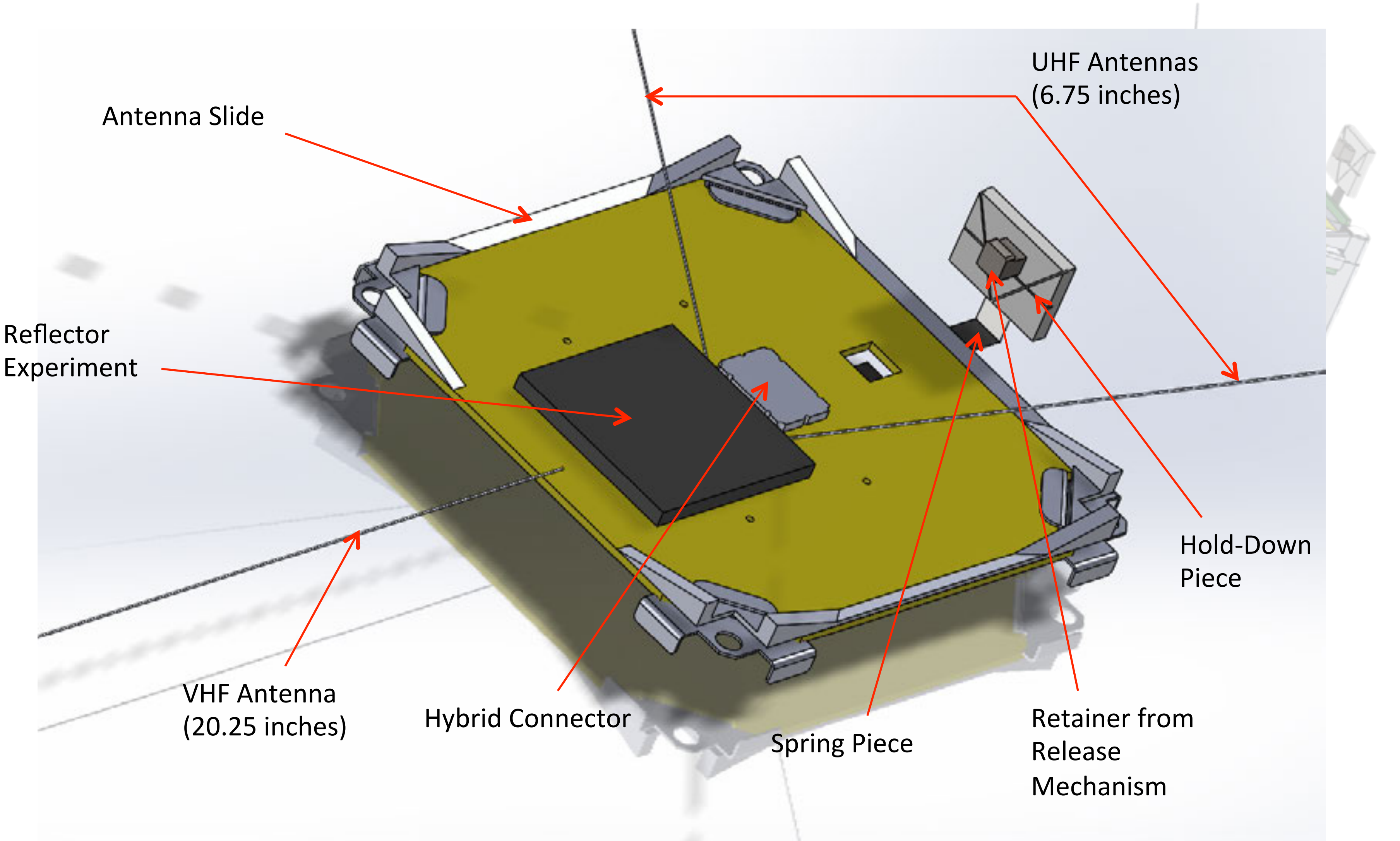
Thruster Detumbling

- Detumble to $\omega \leq 3_{deg/sec}$ in each axis.
- Original design gave two axis active control
- Most recent design, thrusters canted, giving 3-axis control.





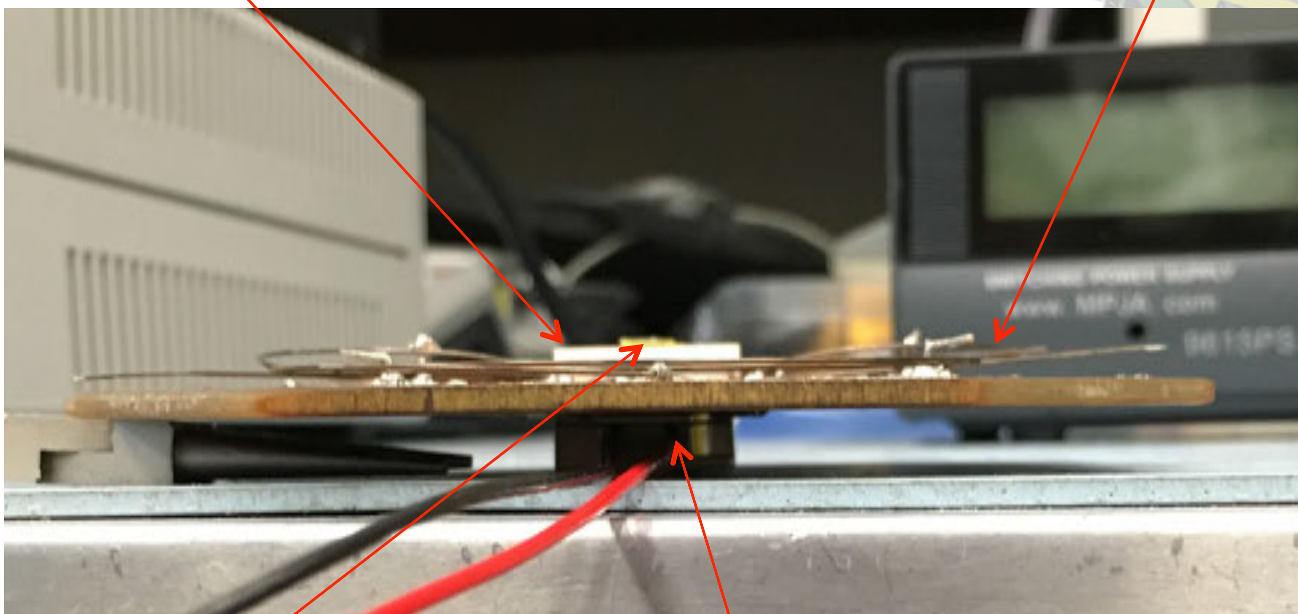
Release Mechanism



Release Mechanism

Hold-Down Piece

Antennas
(Against Board)



Spring Piece
(on other side
of board)

Release Mechanism

Success Criteria USNA-P1

✔ Integrated Thrusters

- ✔ Occupy < 0.75U.
- ✔ Weigh < 25% of total CubeSat.

☐ Functional Thrusters

- ☐ Thrusters fire at $\omega \leq 15$ deg/s and decreases spin rate.
- ☐ Thruster successfully conduct attitude change from original orientation.
- ☐ Thrusters decrease orbit size.

✔ Practical use for other CubeSats.

- ✔ Integrated MTT4B chip to provide satellite capability of communication over APRS network.
- ✔ Operational standard antenna release mechanism

Success Criteria PSAT-2

☐ 75% Global Coverage

☐ Operational CubeSat in LEO

☐ >90% Availability

☐ Communications board with VHF and UHF transceivers

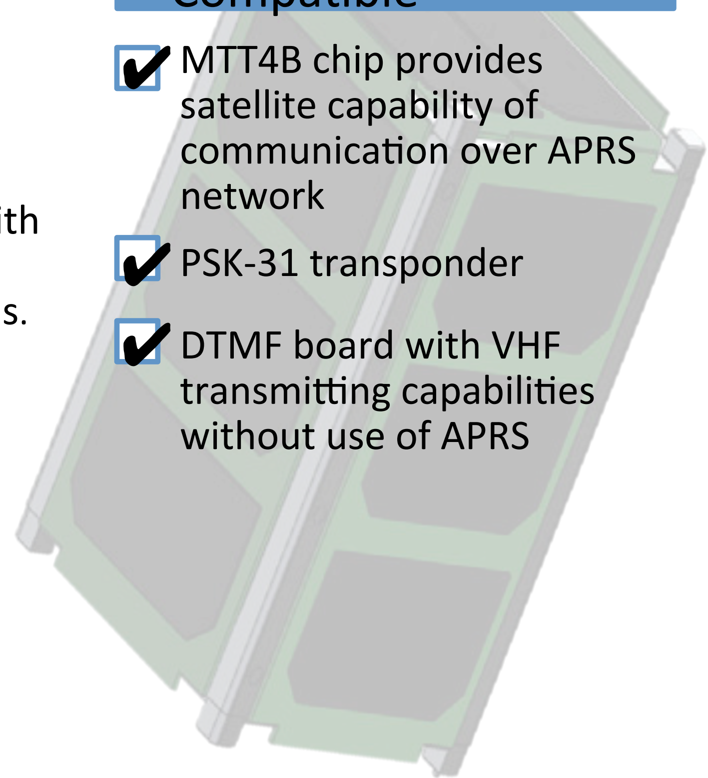
☐ Operational CubeSat with communications link to multiple ground stations.

✔ APRS, PSK, DTMF Compatible

✔ MTT4B chip provides satellite capability of communication over APRS network

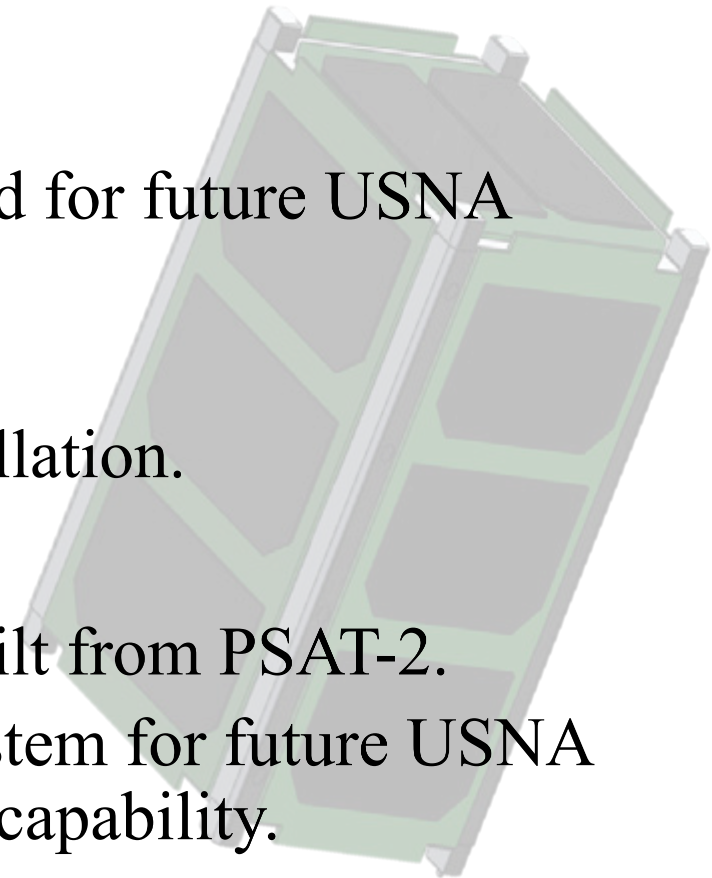
✔ PSK-31 transponder

✔ DTMF board with VHF transmitting capabilities without use of APRS



Impact

- PSAT-2
  - Creates a standard comms board for future USNA CubeSats.
  - APRS, DTMF, PSK-31.
  - Adds to USNA CubeSat constellation.
- USNA-P1
  - Uses standard comms board built from PSAT-2.
  - Tests new micro-propulsion system for future USNA CubeSats – expanding mission capability.
  - Adds to USNA CubeSat constellation.



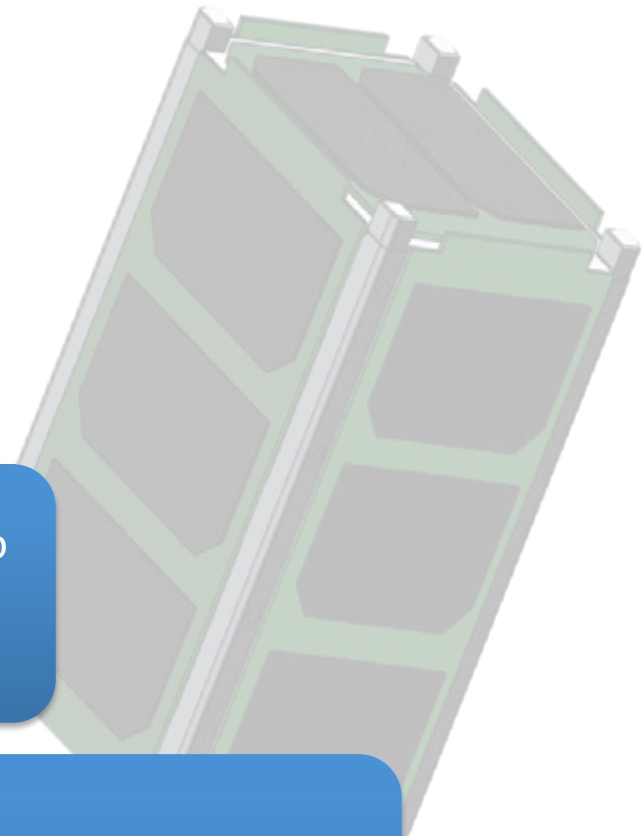
Launch Campaign

Conduct final testing (May)

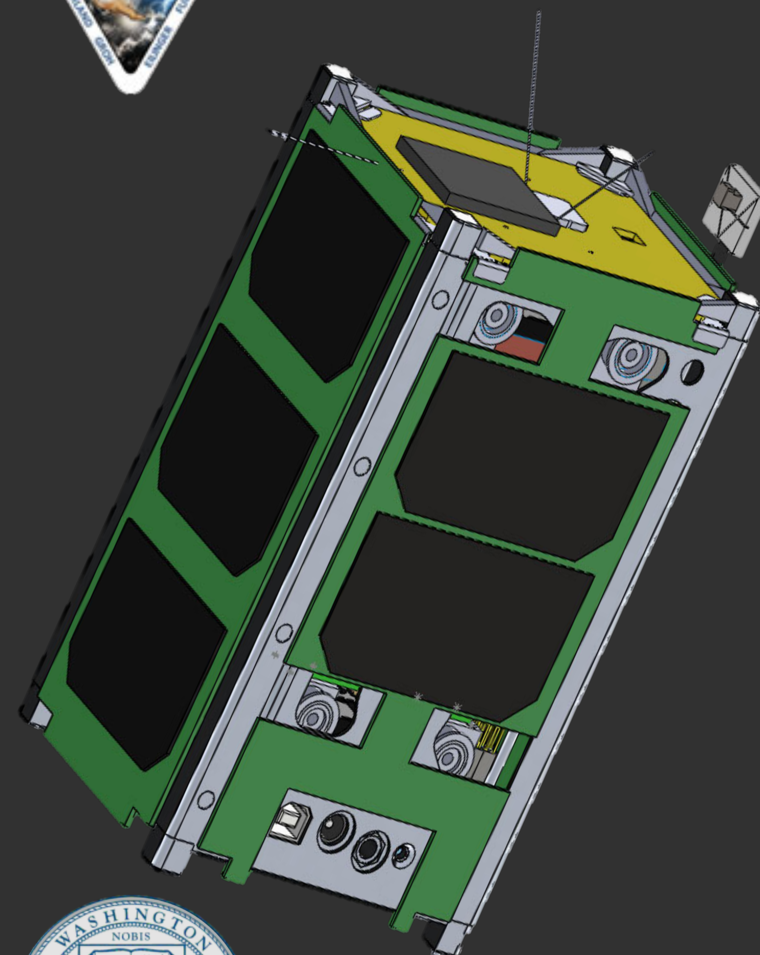
→ Connect with ground stations before launch (June-November)

→ Pack & deliver to launch site (December)

→ Launch 2017



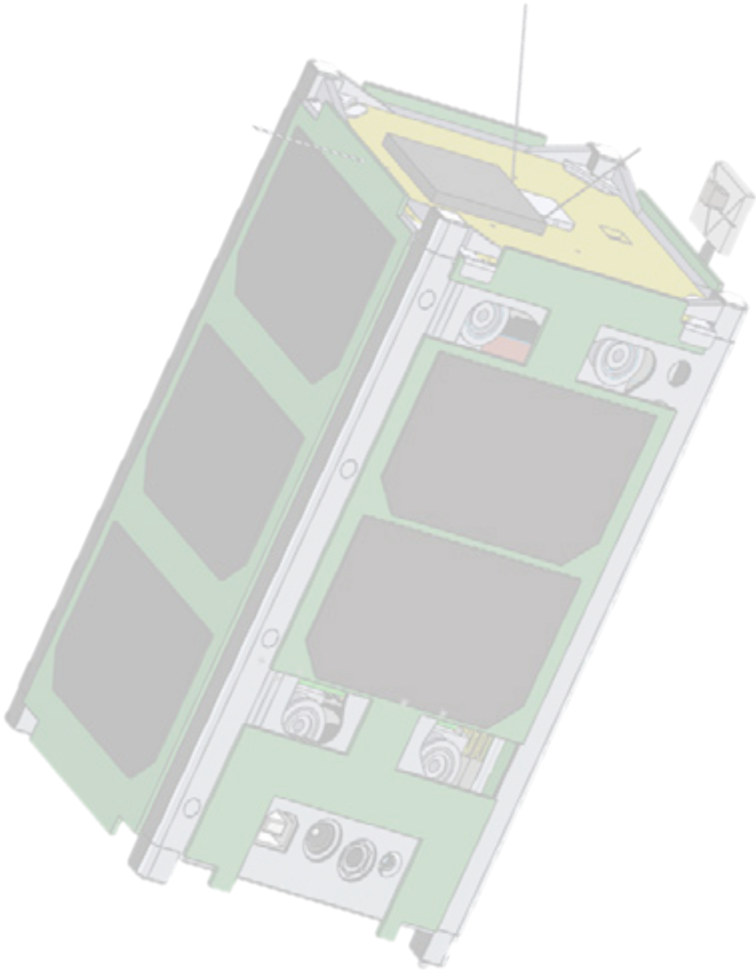
Questions?



United States Naval Academy

Mass Budget USNA-P1

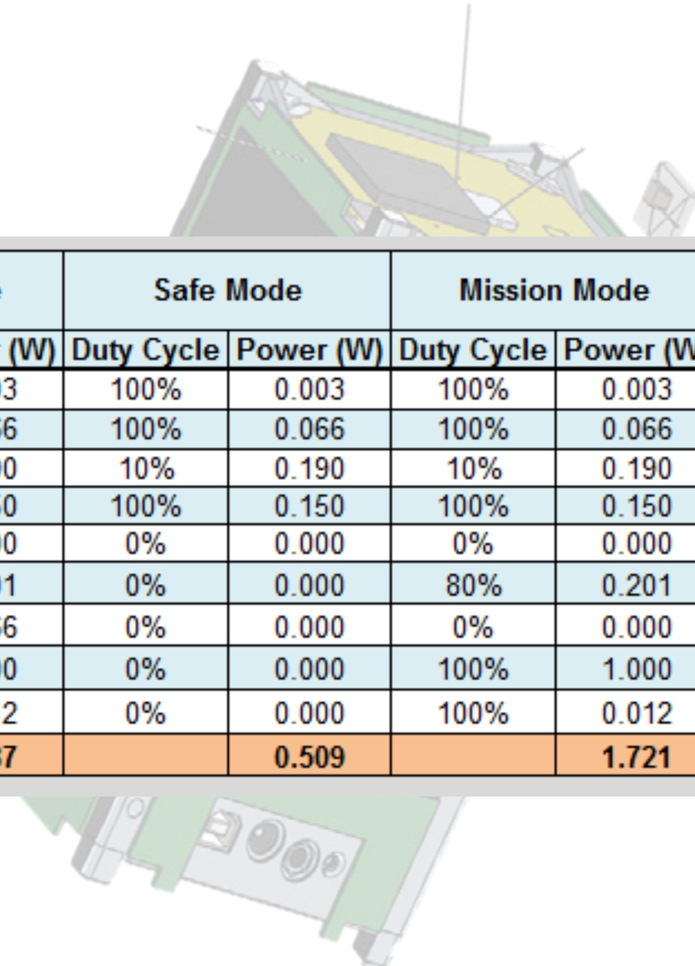
Subsystem	Mass (kg)	% of Sat.
Motherboard + Processor	91	5.36%
1.5 Unit Skeleton Frame	98	5.77%
Top Plate (solid)	52	3.06%
Bottom Plate (skeleton)	40	2.36%
M3 Rods	24	1.41%
Margine (wiring, epoxy etc.)	250	14.73%
Communications Board	75	4.42%
Thrusters (25g/thruster, x4)	96	5.66%
Thruster Board	272	16.03%
Deployment Mechanism	65	3.83%
FRS board	100	5.89%
Interface Board	72	4.24%
Clyde 1.5 EPS Board	163	9.61%
Bottom Solar Panel	47	2.77%
Side Solar Panel thruster (x1)	60	3.54%
Side Solar Panels (x3)	192	11.31%
Total	**1697**	**100.00%**



Power Budget USNA-P1

Time Summary							
Total time of orbit	94.000	min					
Time in ecplise	33.000	min					
	1980.000	sec					
	35.11%	% total orbit					
Time in sunlight	61.000	min					
	3660.000	sec					
	64.89%	% total orbit					
Output of Solar Panels	3.164	W					
Available power deilvered to bus	2.373	W	**MISSION MODE**				
Available power deilvered to bus	2.413	Wh	**Safe**	**Thruster**	**Initial**	**Normal**	**Mission**
Average power consumption		W	0.509	1.187	0.761	0.827	1.721
Average power consumption		Wh	0.797	1.860	1.193	1.296	2.697
Power used during elcipse		Wh	0.280	0.653	0.419	0.455	0.947
Power used during sunlight		Wh	0.517	1.207	0.774	0.841	1.750
Battery capactiy required during ecplipse		Wh	0.280	0.653	0.419	0.455	0.947
Battery required output		Wh	0.311	0.726	0.465	0.506	1.052
Battery capactiy available		Wh	2.000	2.000	2.000	2.000	2.000
Battery needed to recharge		Wh	0.311	0.726	0.465	0.506	1.052
Remaining power during sunlight		**Wh**	**1.584**	**0.480**	**1.173**	**1.066**	**-0.389**
Power System Efficiency Figures							
Path from solar arrays to bus	75.00%	efficiency					
Path from solar arrays to battery	100.00%	efficiency					
Path from battery to bus	90.00%	efficiency					
Efficiency of solar cells	75.00%	efficiency					

Power Budget USNA-P1



System	Unit Module	Operating Power (W)	Normal Mode		Thruster Mode		Safe Mode		Mission Mode	
			Duty Cycle	Power (W)	Duty Cycle	Power (W)	Duty Cycle	Power (W)	Duty Cycle	Power (W)
CS	Motherboard	**0.00275**	100%	0.003	100%	0.003	100%	0.003	100%	0.003
	Processor	**0.066**	100%	0.066	100%	0.066	100%	0.066	100%	0.066
Payload	Comms transmit	**1.900**	10%	0.190	10%	0.190	10%	0.190	10%	0.190
	Comms Receive	**0.150**	100%	0.150	100%	0.150	100%	0.150	100%	0.150
	Thrusters	**0.400**	10%	0.040	100%	0.400	0%	0.000	0%	0.000
	Gyro/MAG	**0.2508**	80%	0.201	80%	0.201	0%	0.000	80%	0.201
	Camera	**0.330**	20%	0.066	20%	0.066	0%	0.000	0%	0.000
	Motor	**1.000**	0%	0.000	0%	0.000	0%	0.000	100%	1.000
	Arduino	**0.0118**	100%	0.012	100%	0.012	0%	0.000	100%	0.012
Total		**4.211**		**0.827**		**1.187**		**0.509**		**1.721**

Link Budget

Downlink

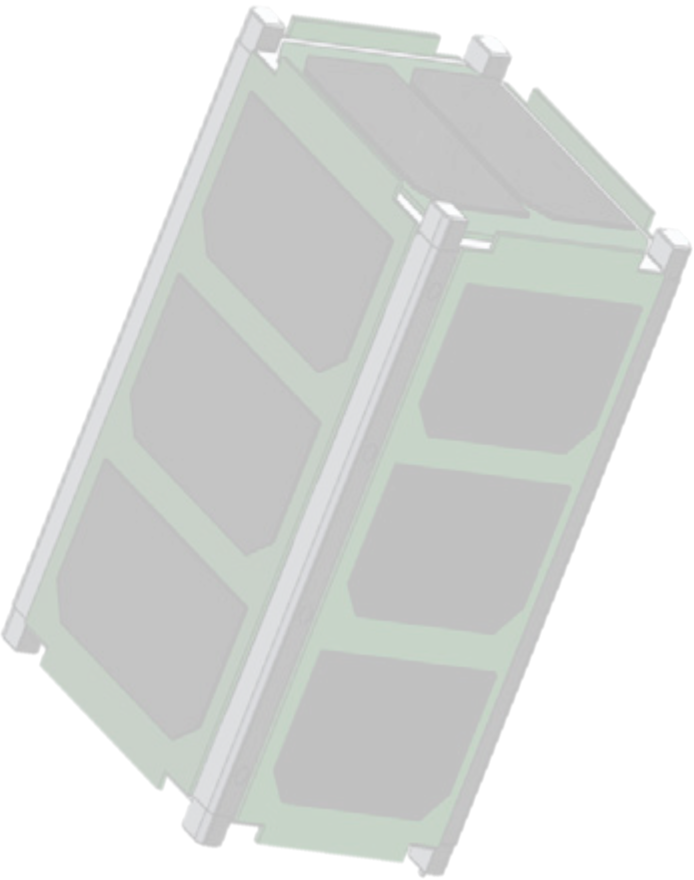
Overhead Scenario (90° El)		Horizon Scenario (10° El)	
Frequency (MHz)	145.8	Frequency (MHz)	145.8
Range (above 30deg, km)	1600	Range (10° El, km)	2500
Space Loss (overhead, dB)	-139.8	Space Loss (10° elevation, dB)	-143.7
Power_transmitter of satellite (dB	3.01	Power_transmitter of satellite (dB	3.01
Gain_Transmitter_Antenna (dB)	0	Gain_Transmitter_Antenna (dB)	0
Gain_Receiver_Antenna OMNI (dB	0	Gain_Receiver_Antenna (dB)	0
P_r (overhead, dB)	-136.8	P_r (10° El, dB)	-140.7
P_r (overhead, dBm)	-106.8	P_r (10° El, dBm)	-110.7
RX Threshold Groundstation (dBm	-116	RX Threshold Groundstation (dBm	-116
Margin (overhead, dBm)	9.18	Margin (10° El, dBm)	5.3

Uplink

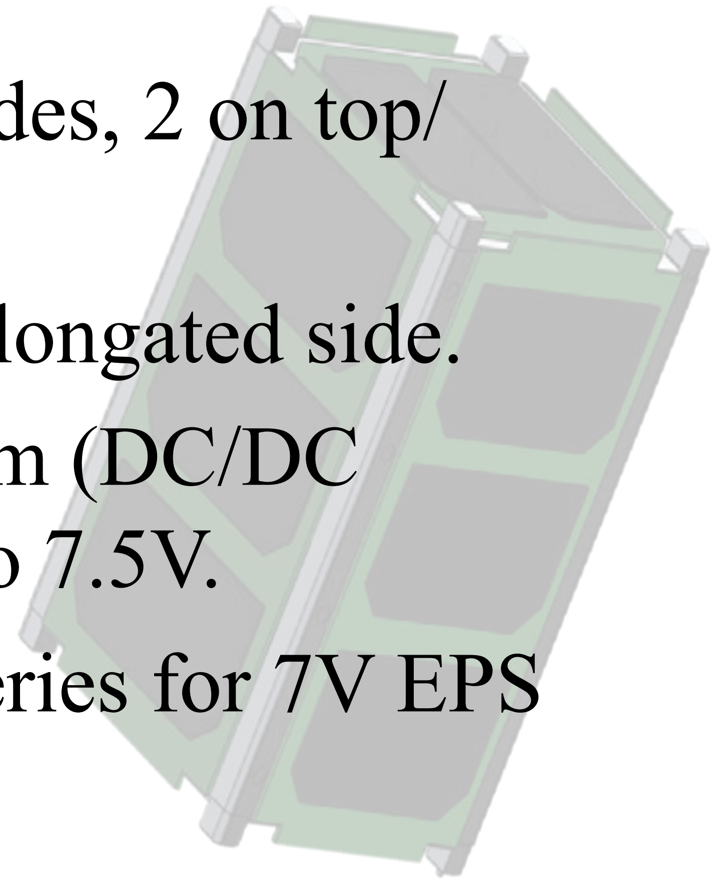
Overhead Scenario (90° El)		Horizon Scenario (10° El)	
Frequency (MHz)	145.8	Frequency (MHz)	145.8
Range (30° El, km)	1600	Range (10° El, km)	2500
Space Loss (30° elevation, dB)	-139.8	Space Loss (10° elevation, dB)	-143.7
Power_transmitter rickover (dBW)	13.01	Power_transmitter rickover (dBW)	13.01
Gain_Receiver_Antenna (dB)	0	Gain_Receiver_Antenna (dB)	0
Gain_Transmit_Antenna (dB)	0	Gain_Transmit_Antenna (dB)	0
P_r (30° El, dB)	-126.8	P_r (10° El, dB)	-130.7
P_r (30° El, dBm)	-96.82	P_r (10° El, dBm)	-100.7
RX Threshold Satellite (dBm)	-114	RX Threshold Satellite (dBm)	-114
Margin (30° El, dBm)	17.18	Margin (10° El, dBm)	13.3

Mass Budget PSAT-2

Subsystem	Mass (kg)	% of Sat.
ADCS Board	158	7.87%
1.5 Unit Skeleton Frame	98	4.89%
Margine (wiring, epoxy etc.)	200	9.98%
Comms Board	85	4.24%
DTMF / Voice Board	65	3.23%
PSK-31 Board/Camera	59	2.94%
Ballast	750	37.44%
NiCad Batteries	245	12.23%
EPS Board	145	7.24%
Bottom Solar Panel	47	2.35%
Side Solar Panels (x4)	152	7.59%
Total	**2003**	**100.00%**

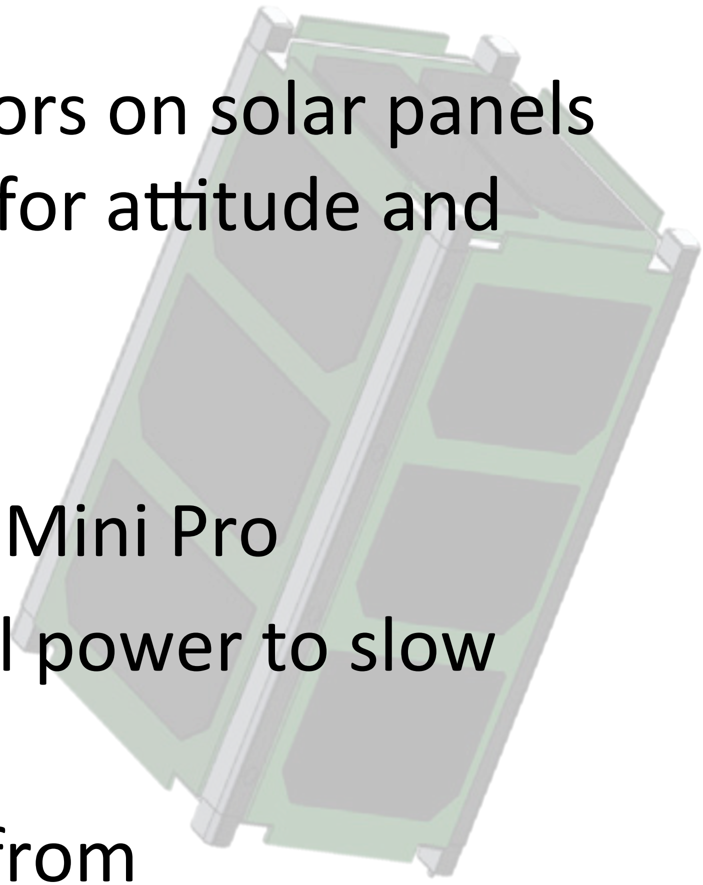


Support System – EPS/Solar Panels



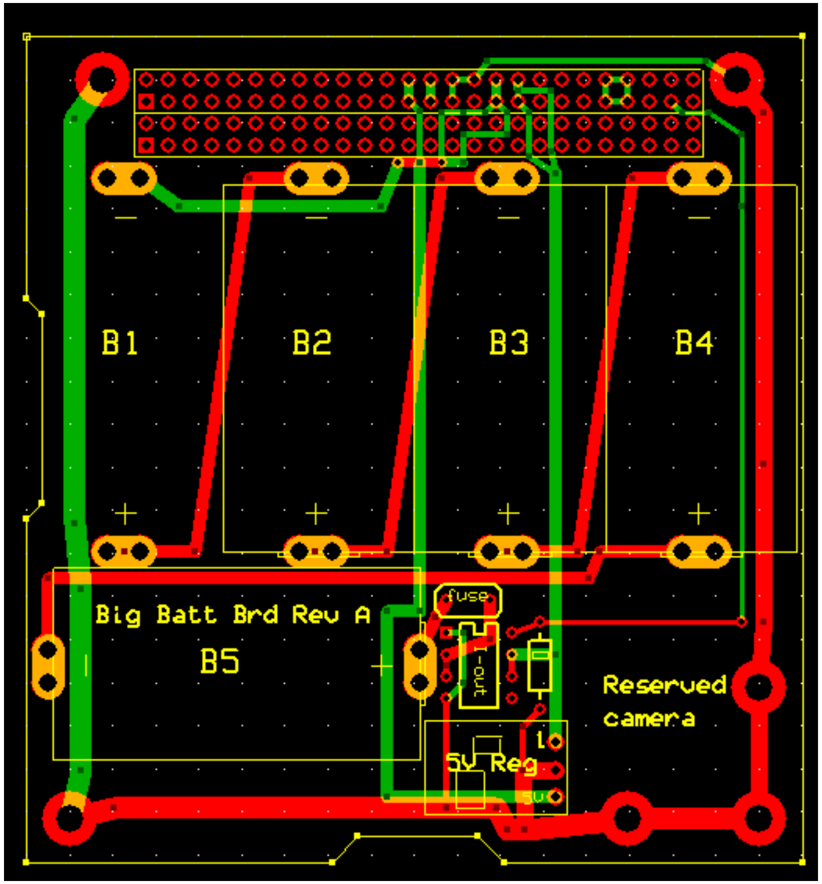
- 3 solar cells on elongated sides, 2 on top/ bottom sides (total of 16).
- 7.2V operating voltage on elongated side.
- 4.8V produced on top/bottom (DC/DC converter steps voltage up to 7.5V.
- 5 1.4V NiCad batteries in series for 7V EPS power supply.

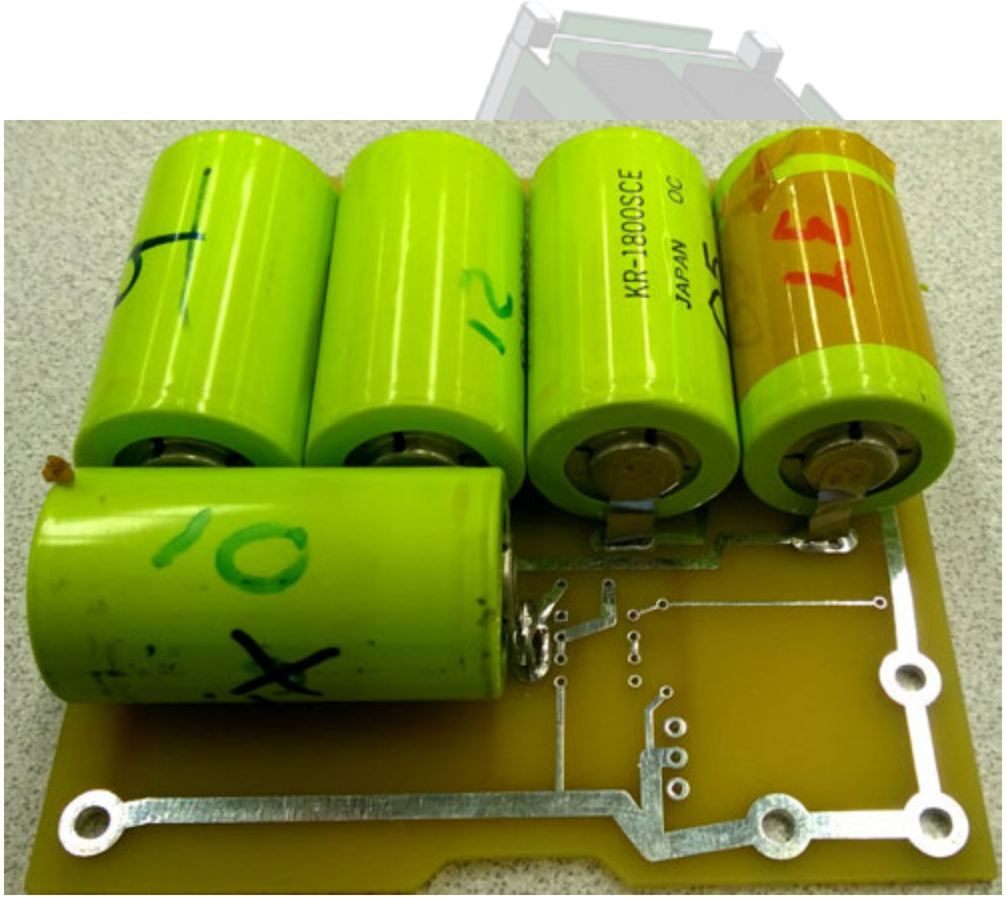
Support System – ADCS



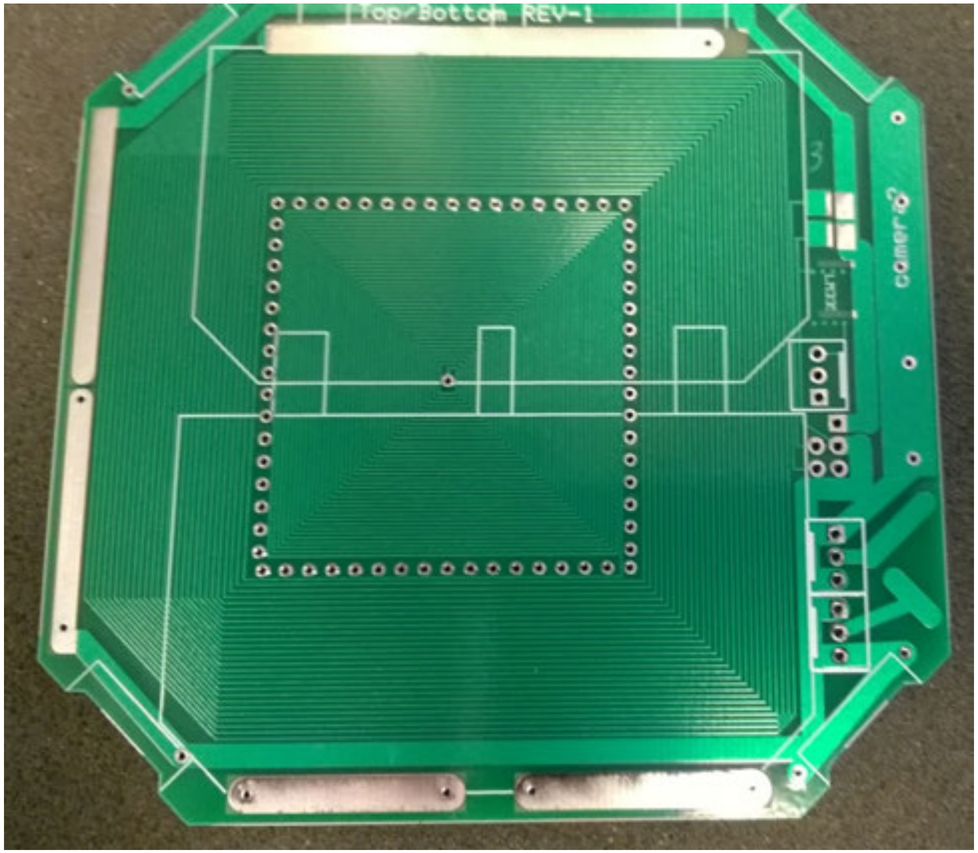
- Relies on input from sun sensors on solar panels and magnetometer on board for attitude and rate determination.
- Interchangeable processors
  - Basic Stamp 2 and Arduino Mini Pro
- Manages magnetic torque coil power to slow rotation rates.
- Also monitors input currents from solar cells and battery output current.

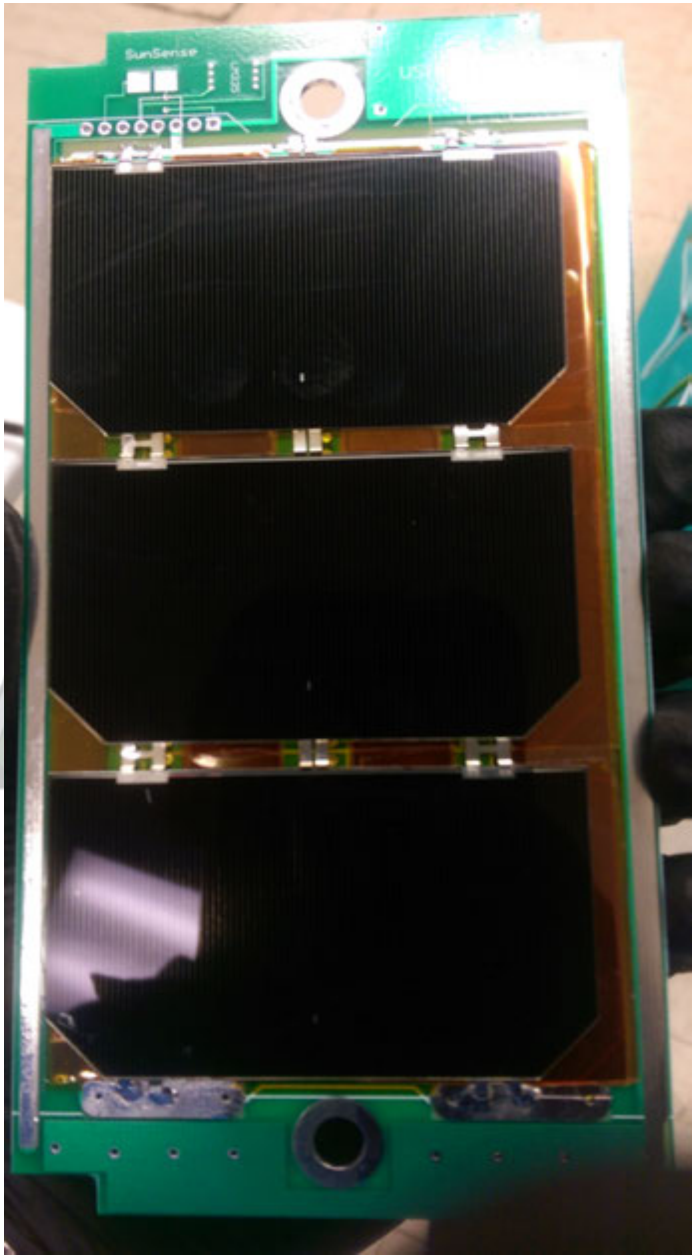
Support System – EPS





Support System – Solar Panels





Release Mechanism