Electrospray Mission Modeling for CubeSats

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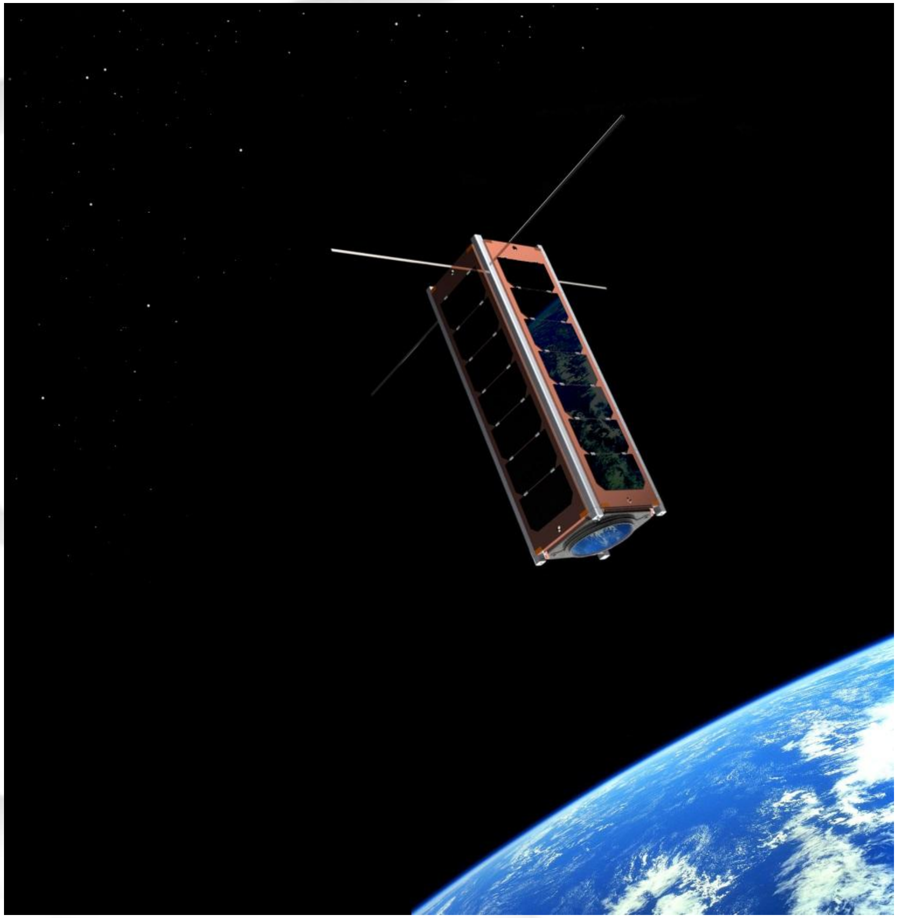
SmallSat Pre-Conference Workshop 2013

Overview

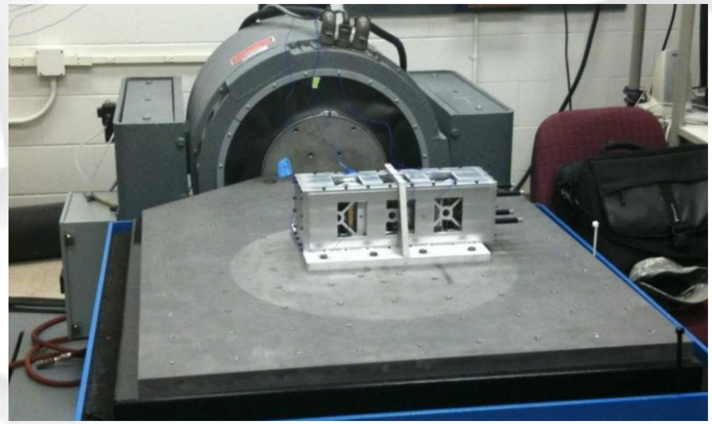
- AFIT Bus
- Electrospray Thruster Mission
- Mission Modeling Tool
- Mission Analysis
- Conclusions



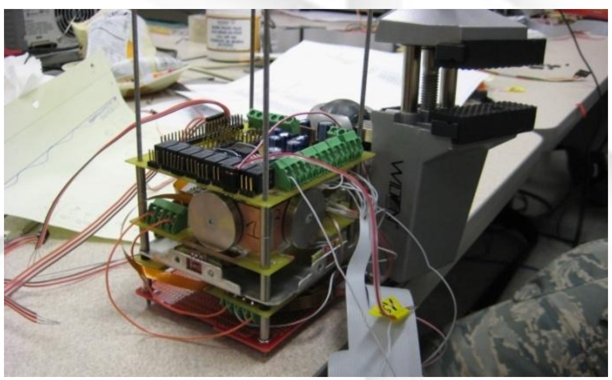
Artist Rendering of 3U CubeSat[1] (credit Clyde Space)

AFIT Bus Design

Software Development

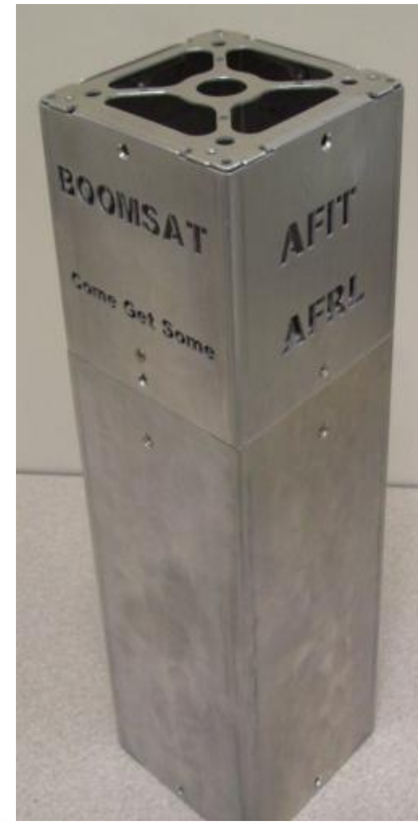


Vibration testing CubeSat inside Test-POD



Hardware Development

Thermal Vacuum Testing

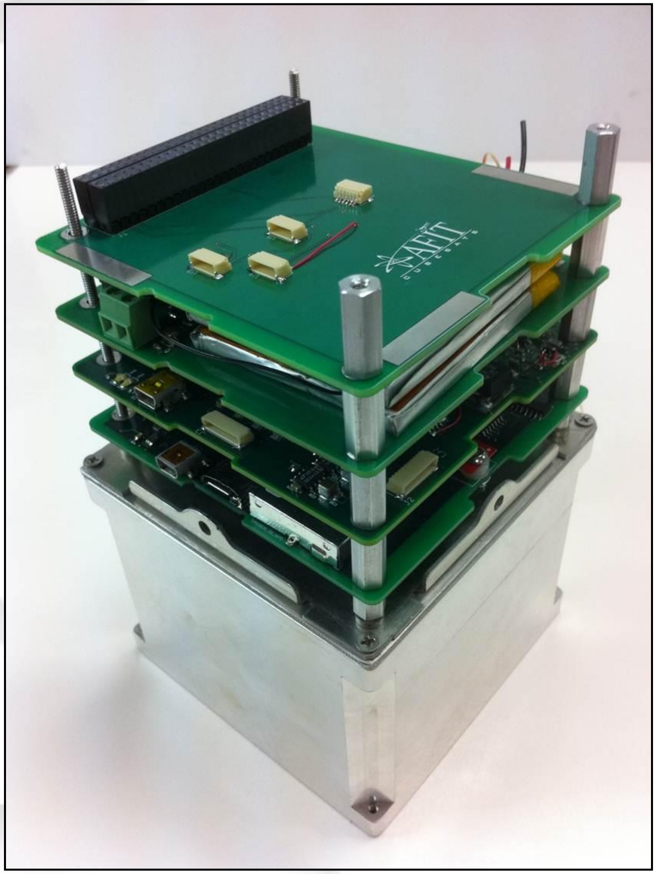


Chassis design and build

AFIT 3U Bus V2

The AFIT of Today is the Air Force of Tomorrow.

Subsystems	AFIT 3U Bus
Command and Data Handling	Power 0.8 W, Data storage 128 KB.
Attitude Determination	Gyros, accelerometers, sun sensors, magnetometers, GPS. Determination within 6 deg.
Attitude Control	Reaction wheels have 13.5 mN-s momentum storage, 10 deg/s slew rate. Magnetic torque coils.
Power	Shuttlecock config: 7.2 W average power. Bus load power: 2.58 W standby, 4.86 W ADACS on
Solar Panels	Emcore BTMJ solar cells, efficiency 22%, 3.5 W per panel.
Radio	Receive 0.2 W, Transmit 6 W. U/L 4.8 kbs, D/L 9.6 kbs.
Thermal Management	Battery heater.
Payload Envelope	1.5U: 15 by 10 by 10 cm. 1.27 kg.

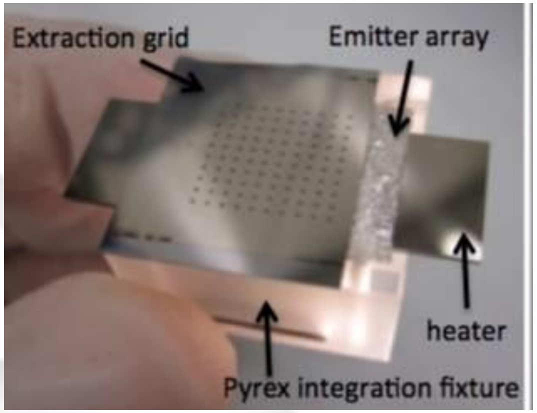


AFIT 3U Bus EDU

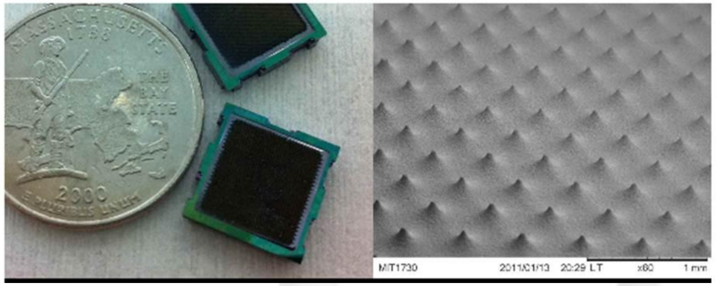
Propulsion

- Allows swarming missions and formation flying
- Can provide orbit maintenance
- Meet SWAPS requirements
- Electrospray thrusters are a promising option for CubeSats
  - High power, high delta V
  - Miniaturization

Busek Electrospray Colloid Thruster[2]



JPL Microfluidic Electrospray Propulsion (MEP) Thruster (courtesy of JPL)

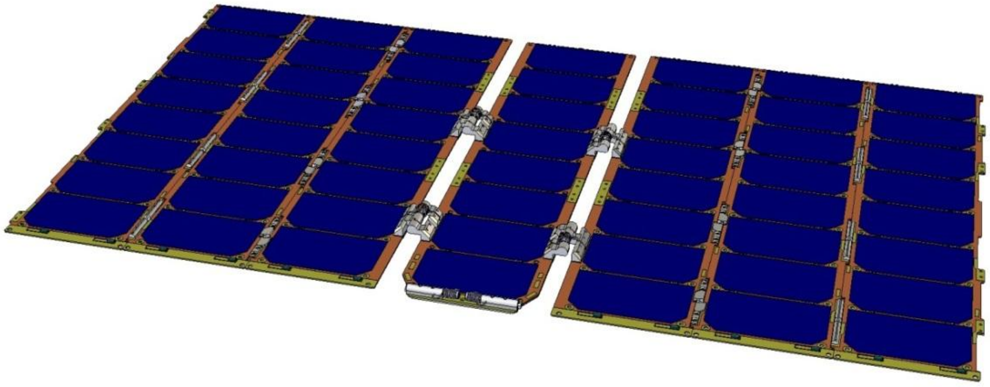


MIT iEPS (Ion Electrospray Propulsion System)[3]

AFIT Bus with Propulsion

Research Objective: Model power scenarios for AFIT 3U Bus with array of JPL MEP thrusters

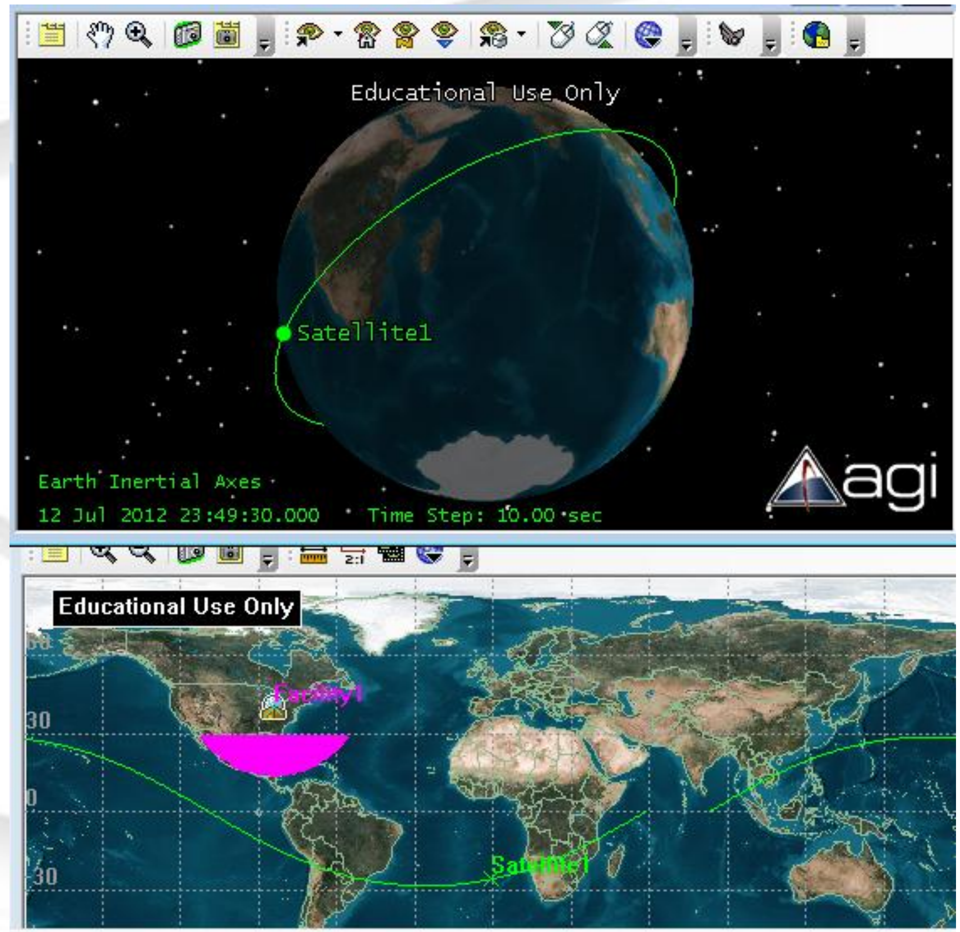
- Requirements
  - Provide enough power for thruster operation
    - Solar Arrays
    - Sun Synchronous Orbit
    - Batteries
  - Better precision for pointing maneuvers
    - Star Tracker



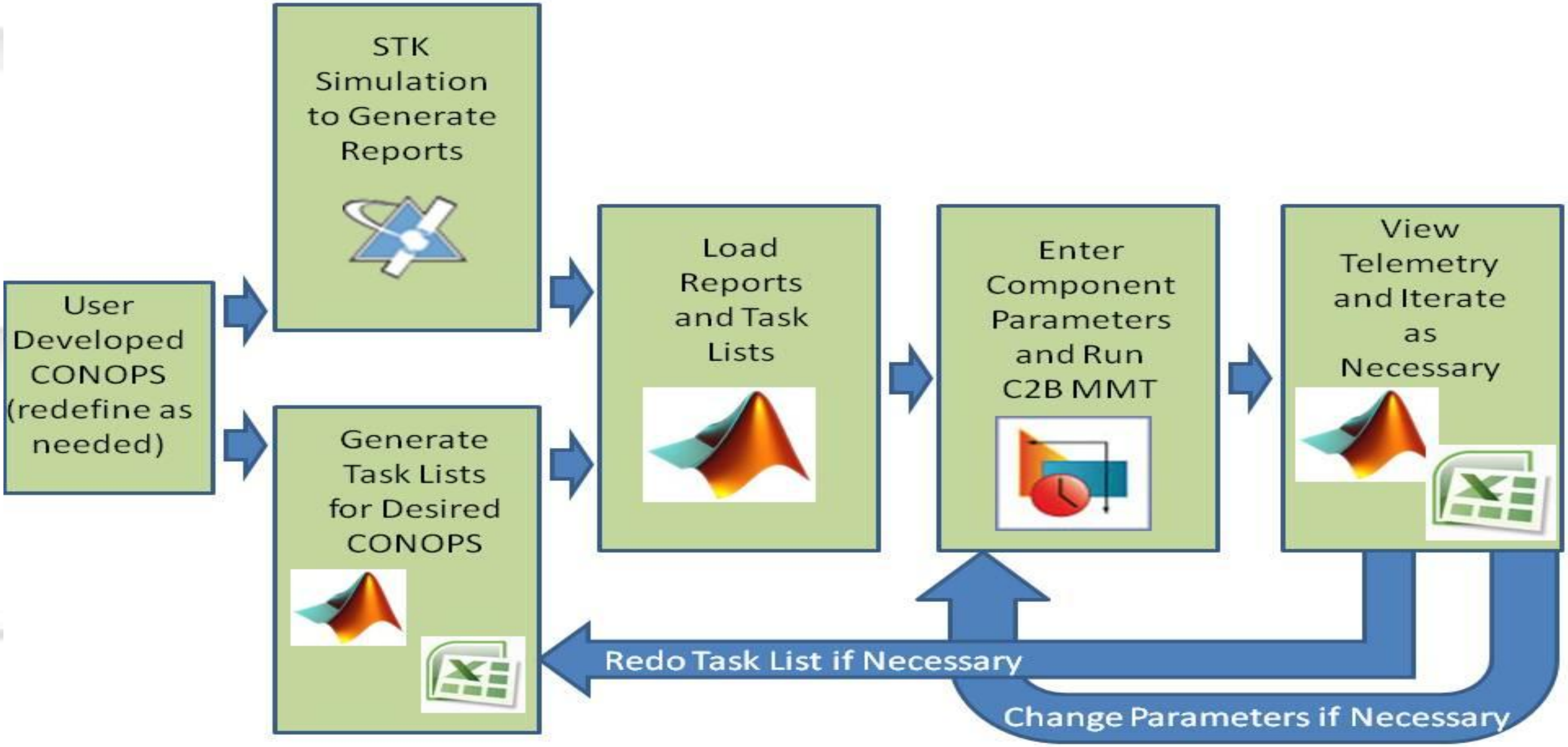
Pumpkin, Inc. 56 W Solar Array[4]

Mission Modeling Tool

- Upgraded previous AFIT simulation model tool (C2BMMT) to MMT
- Quickly analyze several satellite subsystems over a simulated period of time
- MATLAB generates task lists and imports STK reports into Simulink model that represents spacecraft
- STK orbit propagation is significantly faster than Simulink



Mission Modeling Tool



MMT Framework[5]

Mission Modeling Tool

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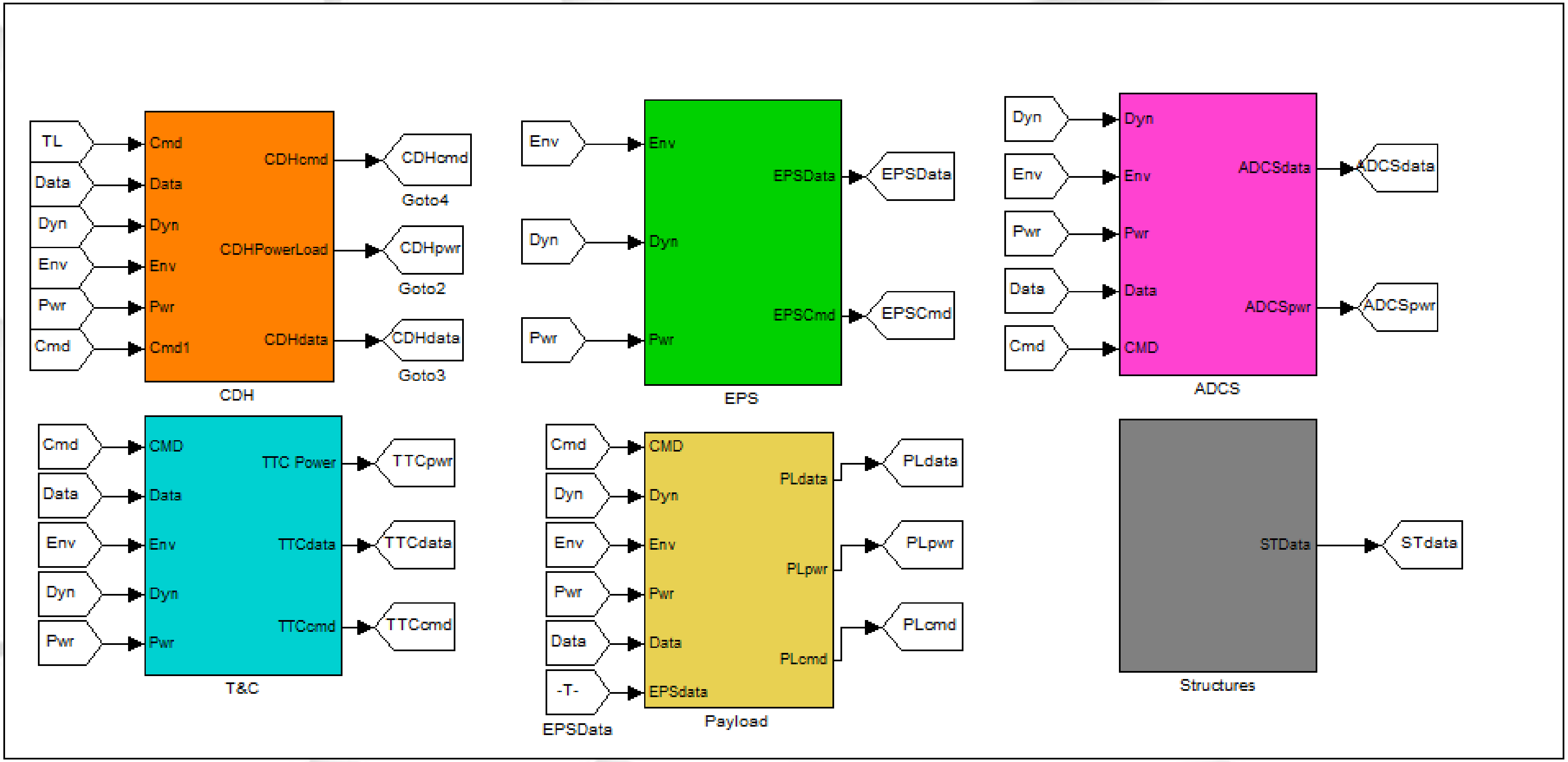


MMT Development

- Added Thruster to MMT
  - Astrogator used to simulate maneuvers in STK
  - Created "Maneuver" report
  - Thruster added to Simulink model and output telemetry
- Updated bus parameters for AFIT Bus
- High power payload
  - Added option for only on when in sunlit conditions
- Sun Safe and Survival Mode
  - Updated based on Bus Voltage
- MATLAB GUI Updates for Task List Generation
- Ability to use "Default Parameters" for Task Lists

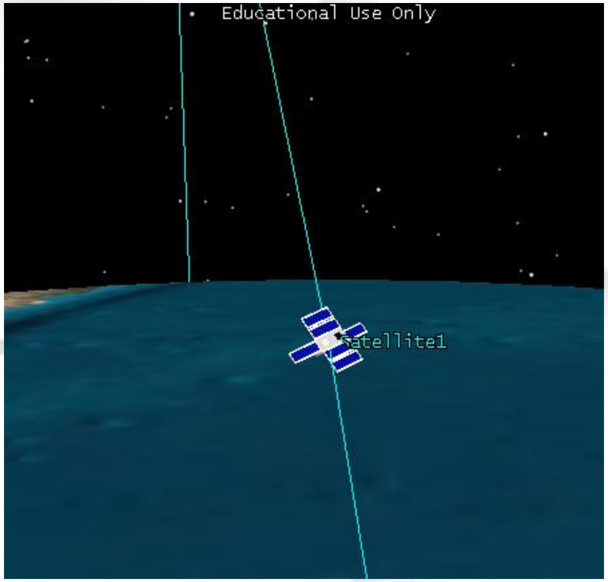
Mission Assumptions

- Thrusters
  - Array of eight MEP thrusters.
  - Primary configuration 5 on one end of spacecraft, 3 on the other end.
  - Backup configuration 4 thrusters on each end of spacecraft.
  - Each thruster requires 7 W in primary mode, 5 W in standby mode.
- Primary launch for planning purposes is 600 km SSO
- Mission has 1 year lifetime

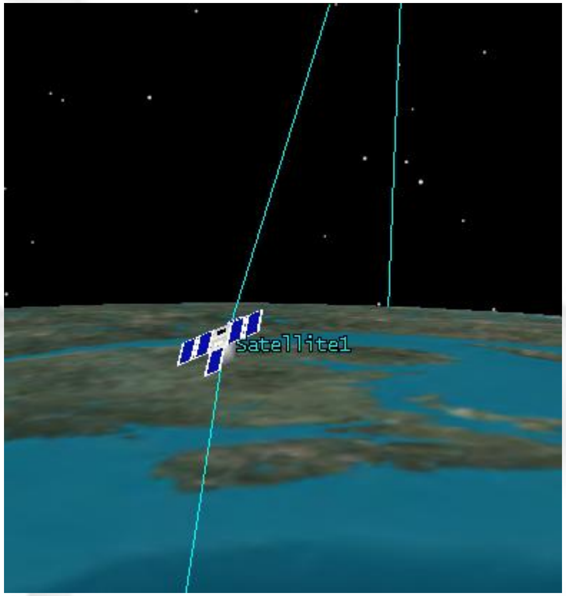
Characterize SSO

- Analyze different orientations at different LTANs
  - As secondary payload, may not be placed into optimal dawn-dusk orbit

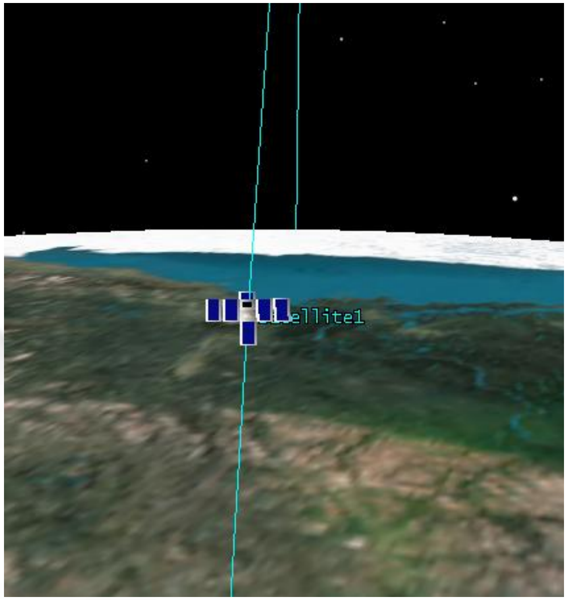
Sun Aligned



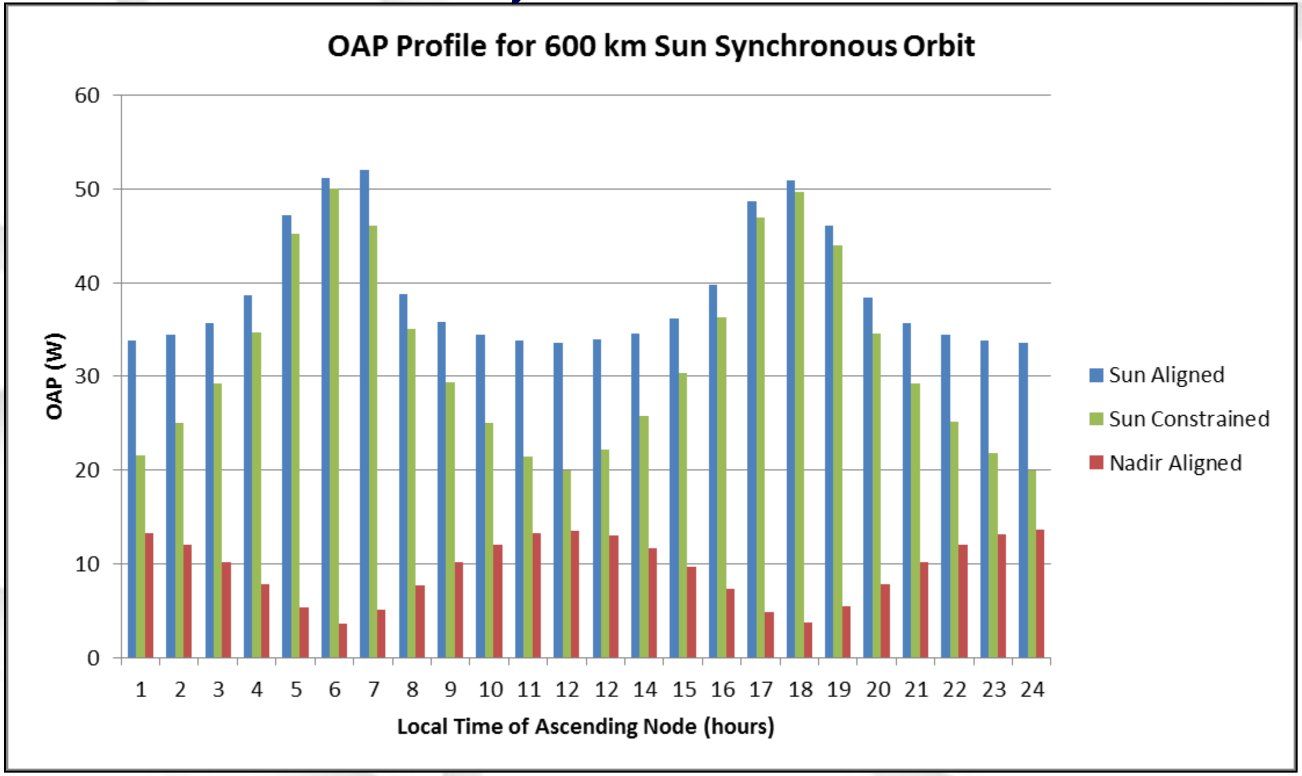
Sun Constrained



Nadir Aligned

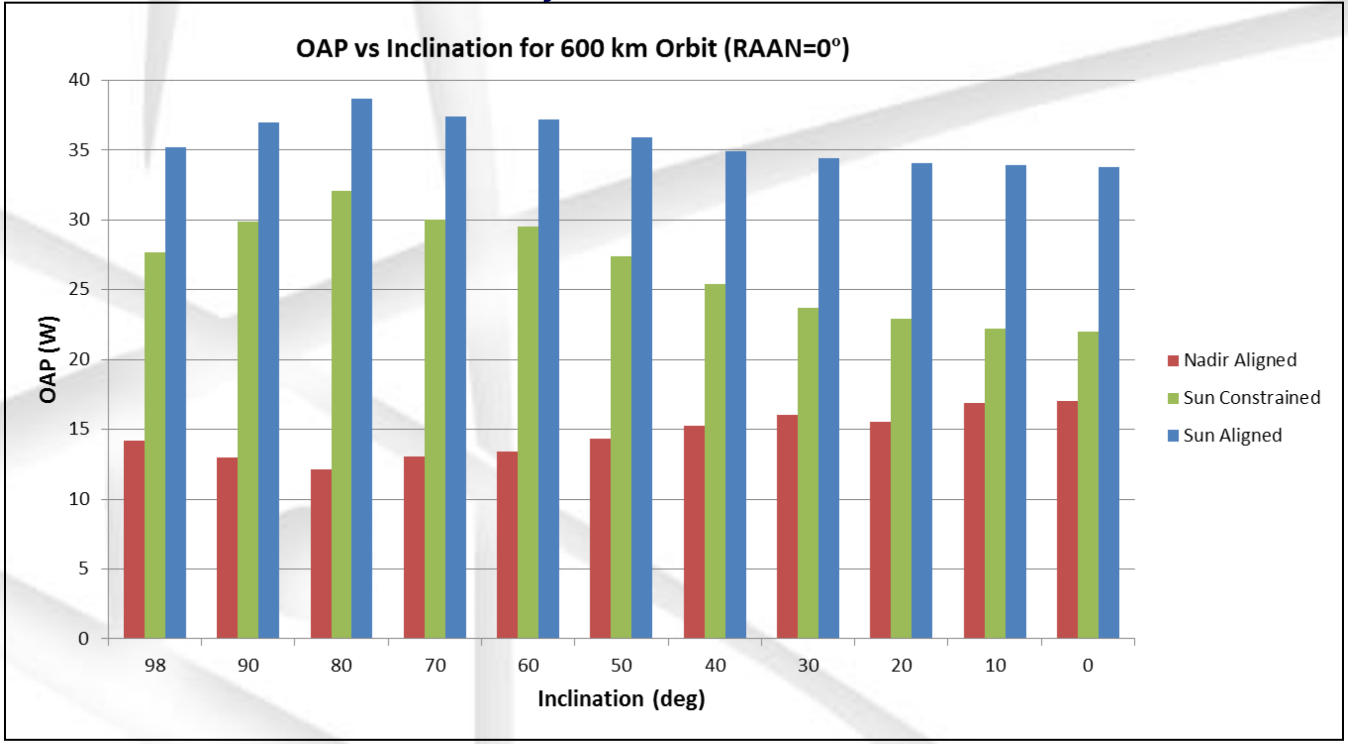


OAP vs LTAN



Profile	Max mean OAP	Min mean OAP	Average mean OAP
Sun Aligned	50.9 W	33.6 W	39.0 W
Sun Constrained	49.7 W	19.9 W	32.0 W
Nadir Aligned	13.6 W	3.6 W	9.4 W

OAP vs Inclination



Profile	Max mean OAP	Min mean OAP	Average mean OAP
Sun Aligned	38.7 W	33.8 W	35.7 W
Sun Constrained	30.0 W	22.0 W	26.6 W
Nadir Aligned	17.0 W	12.2 W	14.6 W

Pointing and ΔV Experiments

- Pointing experiments
  - Characterize performance and control authority of thruster
  - Perform single and multiple axis rotations
  - Multiple thrusters will need to be in active or standby mode
  - Finished within approximately 30 days

- ΔV experiment
  - Prove thrusters can achieve 1 km/s of ΔV on a CubeSat
  - Multiple thrusters will need to be used in active mode
  - Accomplished within remaining satellite's lifetime

Generic Power Scenarios

Scenario	Thrusters Turned On	Thrusters in Standby
Scenario 1	5, always on	0
Scenario 2	4, always on	0
Scenario 3	3, always on	0
Scenario 4	2, always on	0
Scenario 5	1, always on	0
Scenario 6	5, only when sunlit	0
Scenario 7	4, only when sunlit	0
Scenario 8	3, only when sunlit	0
Scenario 9	2, only when sunlit	0
Scenario 10	5, only when sunlit	2, only when sunlit
Scenario 11	4, only when sunlit	2, only when sunlit
Scenario 12	3, only when sunlit	2, only when sunlit
Scenario 13	2, only when sunlit	2, only when sunlit
Scenario 14	2, only when sunlit	2, always on
Scenario 15	2, always on	2, always on

Sun Constrained orientation at Maximum (0600 LTAN), Mean (1500 LTAN), and Minimum (1200 LTAN)

Generic Power Scenarios

Scenario	Final DoD (0600 LTAN)	Final DoD (1500 LTAN)	Final DoD (1200 LTAN)
Scenario 1	0%	82.92%	82.93%
Scenario 2	0%	82.90%	82.93%
Scenario 3	0%	82.88%	82.92%
Scenario 4	0%	40.80%	82.91%
Scenario 5	0%	0%	27.72%
Scenario 6	0%	82.91%	82.92%
Scenario 7	0%	20.00%	82.92%
Scenario 8	0%	0%	82.92%
Scenario 9	0%	0%	44.22%
Scenario 10	9.19%	82.92%	82.92%
Scenario 11	0%	82.92%	82.93%
Scenario 12	0%	63.31%	82.92%
Scenario 13	0%	0%	82.92%
Scenario 14	0%	82.88%	82.92%
Scenario 15	0%	82.89%	82.92%

Conclusions

- Pointing experiments
  - Scenarios 13 and 14 (two thrusters on while two are in standby)
  - Scenario 13 does not have an increasing DoD trend so is a better option
- ΔV experiment
  - Thrusters should only be turned on when in sun-soak conditions
  - Further analysis to determine what combination of thrusters should be used to reach 1 km/s ΔV

ΔV experiment

- ΔV experiment
  - MMT used to analyze how much time and propellant to achieve 1 km/s
  - Find optimal combination of thrusters for ΔV experiment
  - Assumptions: thrusters fire only in sun-soak, thrust vector along center of mass
  - Sun constrained orientation at 1500 LTAN to simulate mean conditions

ΔV experiment

- Case 1: Reached Sun safe mode in 21.8 days. Recharge segments required in-between maneuver segments.
- Case 2: Reached Sun safe mode in 65.3 days. One recharge segment required
- Case 3: Never entered sun safe mode

3/4 combination provides shortest time (177.7 days) and least fuel for primary configuration

Case	Total Time	Total ΔV
Case 1: 5 thrusters	147.16 days	0.743 km/s
Case 2: 4 thrusters	106.84 days	0.605 km/s
Case 3: 3 thrusters	94.46 days	0.455 km/s

Combinations of Thrusters	Total Time
5 / 3	200.51 days
4 / 4	168.84 days
4 / 3	188.84 days
3 / 4	177.74 days
3 / 5	202.97 days

References

1. Killian, Mike. "Artist Conception of a CubeSat in Space." 6 Aug 2013. http://www.americaspace.com/?attachment_id=13101

2. Busek Co, Inc. "Busek Electrospray Thrusters." 5 Aug 2013. http://www.busek.com/index_htm_files/70008500_revE.pdf

3. Space Propulsion Laboratory Massachusetts Institute of Technology. "ion Electrospray Propulsion System for CubeSats (iEPS)." 5 Aug 2013. http://web.mit.edu/aeroastro/labs/spl/research_ieps.htm

4. Reif, Adam, V.H. and Kalman, A., "Recent Advances in the Construction of Solar Arrays for CubeSats," CubeSat Summer Developer's Workshop, August 2010.

5. Andrews, B., "A Colony II CubeSat Mission Modeling Tool,", Master's thesis, Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, 2012.

Questions?