Cal Poly CubeSat Kit – A Technical Introduction to Mk I

35th Annual Small Satellite Conference
Coordinating Successful Educational Programs
Pauline Faure – August 10, 2021

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CHALLENGES OF UNIVERSITY-BASED CUBESAT PROGRAMS

Challenges*	Ideal Countermeasures	Practical Situation
Knowledge transfer	• Tie CubeSat development to senior projects, master, or PhD theses • Have permanent professionals to support CubeSat programs	• Not all required developmental aspects of a CubeSat is worth a senior, master, or PhD thesis • Most programs cannot sustain permanent professionals
Variety of duties	• Link curricula to CubeSat development • Support students and professionals involved in CubeSat development	• CubeSats are multidisciplinary and students are at different stages of their education when they join • Particular to non-PhD granting universities, most time is dedicated to teaching, not research
Feeling of ownership	• Define launch date and other milestones throughout CubeSat Project • Avoid having too many functionalities on one printed circuit board	• Launch is unknown, milestones are delayed, CubeSat project lengthens • Volume is constrained, functionalities are integrated on the least number of printed circuit boards as possible
Documentation	• Record, maintain, store, and centralize documentation related to a CubeSat project	• Documentation and its handling is an after thought

CubeSat programs are not only about educating on technologies, but also educating about good space engineering practices, while balancing a wide array of duties for students and staff

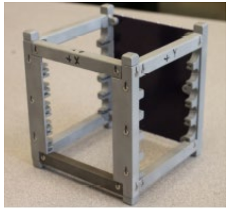
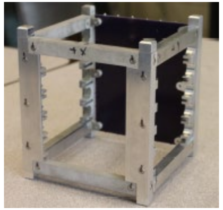
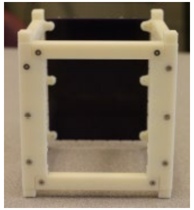
*Challenges extracted from: E. Honoré-Livermore, *CubeSats in University: Using Systems Engineering Tools to Improve Reviews and Knowledge Management*, Procedia Computer Science 153 (2019), pp.63-70

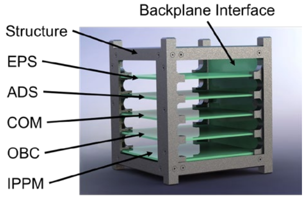
CREATING OPPORTUNITIES FROM CHALLENGES

- Main mission of a university is to educate and train tomorrow's workforce
- CubeSats are multidisciplinary in nature and hands-on based curricula can be created for various engineering, and non-engineering, disciplines

		Engineering Majors				
		EE	**CPE**	**AERO**	**ME**	**MATE**
CubeSat Flight Segment	**EPS**	- Solar energy conversion - Circuitry for power generation, storage, distribution, and regulation	-	- Power budget - Design drivers for power generation, storage, distribution, and regulation	- Spacecraft configuration	- Coatings - Polymers and ceramics
	STRU	- Spacecraft configuration - Launch environment	-	- Spacecraft configuration - Structural analysis	- Structural analysis - Vibration environment - Statics and dynamics	- Material selection - Material characterization - Structural analysis
	THER	- Analog circuit	-	- Space environment - Heat transfer - Orbits	- Heat transfer - Thermal analysis, testing, and management	- Thermodynamics - Coatings - Polymers and ceramics
	OBC	- Microprocessor/ Microcontroller-based system design - Digital design	- Operating system, flight software, and programming - Digital design - Embedded system design	- Mission planning - Mission architecture	-	-
	COM	- RF circuitry - RF verification methods	- Data structure - Communication standard - Programming	- Link budget - Mission planning - Orbits	- Spacecraft configuration	-
	ADCS	- Electromagnetism	- Programming	- Pointing budget - Control law - Orbits	- Torques and mechanical disturbances	-
CubeSat Flight Segment Interfaces		- Ground segment: definition; mission operations; mission planning; mission architecture - Launch vehicle: integration; launch environment; range safety - Regulations: RF licensing; Earth remote sensing licensing; orbital debris				
Others		- Project management: schedule; budget; multidisciplinary team management; Teamwork - Systems engineering: requirements; work breakdown structure; assembly, integration, and test; risks analysis				

CAL POLY CUBESAT KIT PROJECT OVERVIEW



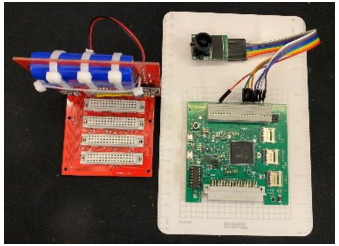
Summer 2019
Project Start

Mk I Development
- Structure
- Backplane
- Integrated Payload Processing Module (IPPM)
- Electrical Power Subsystem (EPS)
- Payloads (fish-eye lens camera, thermal sensors, inertial measurement unit, etc.)

End June 2021
Mk I Planned Completion

Summer/Fall 2022
Mk III Development Start

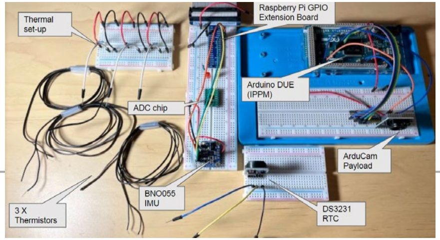
Mk III and Beyond Development
- 3U kit
- New payloads considerations
- Mk II lessons learned implementation



Fall 2020
Mk II Development Start

Mk II Development
- Structure
- Backplane
- IPPM
- EPS
- Attitude Determination Subsystem (ADS)
- On Board Computer (OBC)
- Communication subsystem (Comm)
- Payloads (fish-eye lens camera, spectroscopy sensor, luminosity sensor, etc.)

Summer/Fall 2022
Mk II Planned Completion



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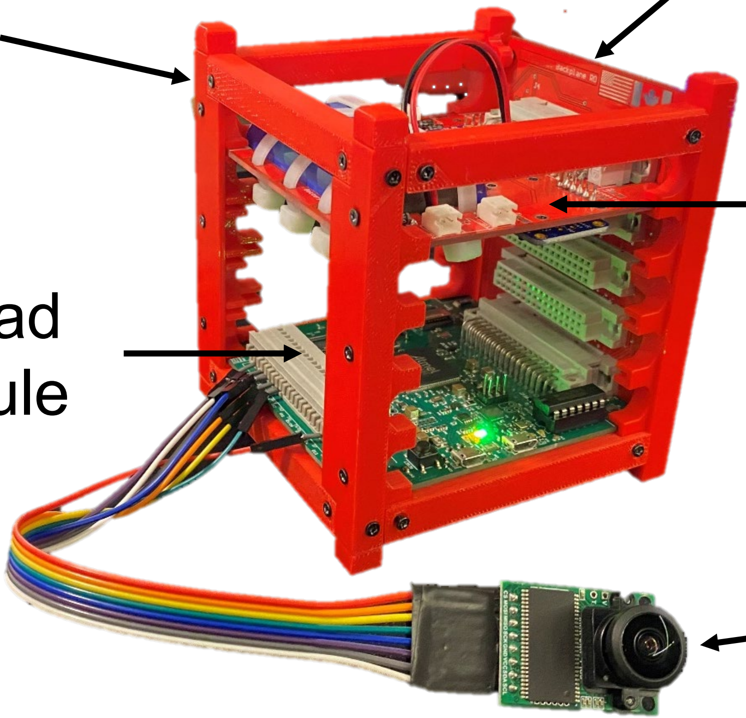
CAL POLY CUBESAT KIT Mk I



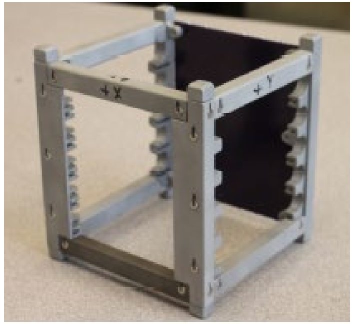
STRUCTURE

Design drivers considerations:

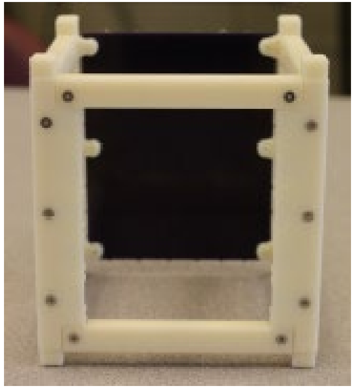
- Additive and subtractive manufacturing possible
- Ease of structural elements assembly/disassembly
- Capability to sustain launch environment

Modular Chassis	Backplane/Card-slot Internal Configuration
• Without side panels, open faces enable to reach out to some components • Number of fasteners to remove to disassemble a board is reduced • Chassis elements can be replaced independently of one another	• Only board of interest has be disassembled when needed • Number of fasteners to secure a board to chassis is reduced

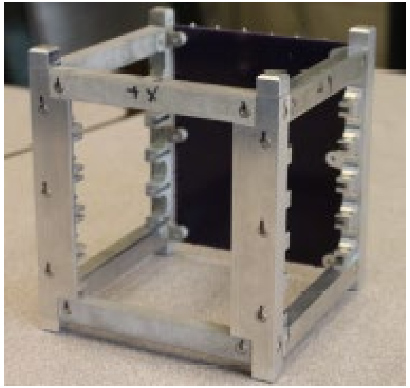
AlSi10Mg
Additively manufactured



ABS
Additively manufactured



Al6061
Subtractively manufactured



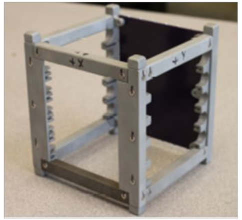
“Design, Validation, and Verification of the Cal Poly Educational CubeSat Kit Structure”, Nicholas Snyder, Masters Thesis, Cal Poly San Luis Obispo, 2020.

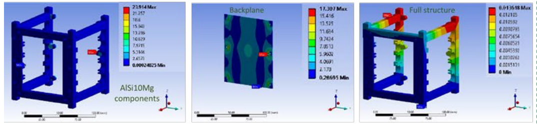
STRUCTURE

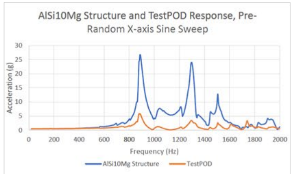
Analysis and vibration test outcomes:

- Stress built up at discontinuities, such as holes and sharp edges
- Fundamental frequency and Q-factor determination
- Workmanship verification

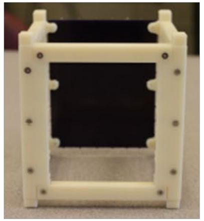
AlSi10Mg

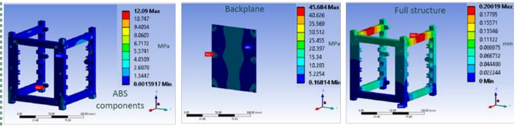


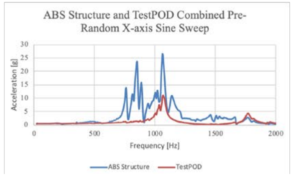




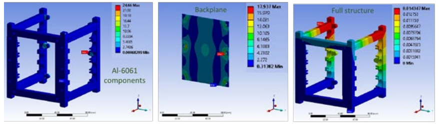
ABS

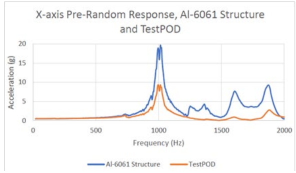


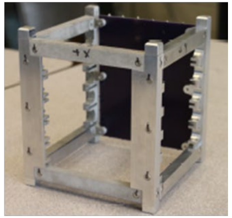




Al-6061







	AlSi10Mg	ABS	Al6061
Displacement Requirement	Less than 0.5 mm		
Experimentally Estimated Q-Factor [-]	25.30 (89.88%)*	37.31 (30.59%)*	27.20 (56.48%)*
Max. Analytical Displacement [mm]	0.01 (75.00%)*	0.20 (11.11%)*	0.01 (50.00%)*
Average Yield Strength [MPa]	270.00	33.00	276.00
Max. Analytical Stress [MPa]	23.91 (31.68%)*	12.09 (13.41%)*	24.66 (34.24%)*
Margin of Safety [-]	10.29 (298.84%)*	1.73 (17.62%)*	10.19 (63.78%)*

**Difference between analytical values obtained pre- and post-random vibration test.*

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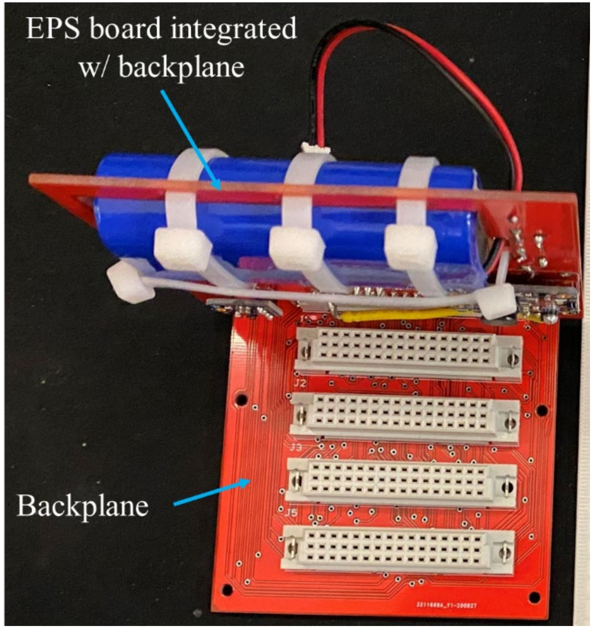
BACKPLANE and ELECTRICAL POWER SUBSYSTEM

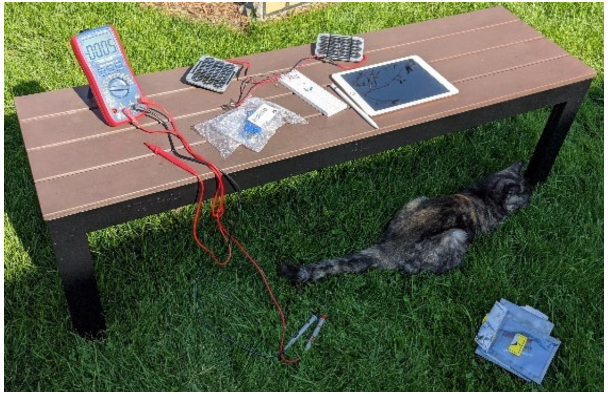
- Direct energy transfer from solar panels to batteries
- Solar panels, 2W
- Li-ion batteries, 0S3P

Backplane	EPS
• 5*48-pin DIN41612 connectors • Configurable pins	• Voltage and current measurement, INA219 • 5V0 and 3V3 rails • 18650 Li-ion batteries, 3.7V, 4,400mAh



EPS verification outcomes:

- INA219 sensor verified
- 5V0 and 3V3 rails sound
- DET circuitry, incl. battery pack, verification inconclusive



INTEGRATED PAYLOAD PROCESSING MODULE

Five payloads available:

- IMU, Adafruit BNO055
- Luminosity sensor, Adafruit TSL2591
- IR camera, Sparkfun FLIR radiometric Lepton Dev Kit 2
- Spectroscopy sensor, Sparkfun AS7265x
- VIS camera, OmniVision OV5642 with fish eye lens

IMU

Luminosity sensor

IR camera

Spectroscopy sensor

VIS camera

Focus of Mk I

"Design and Development of an Integrated Payload Processing Module for Cal Poly CubeSat Kit", Giovanni Guerrero, Masters Thesis, Cal Poly San Luis Obispo, in work (set to defend in June 2021).

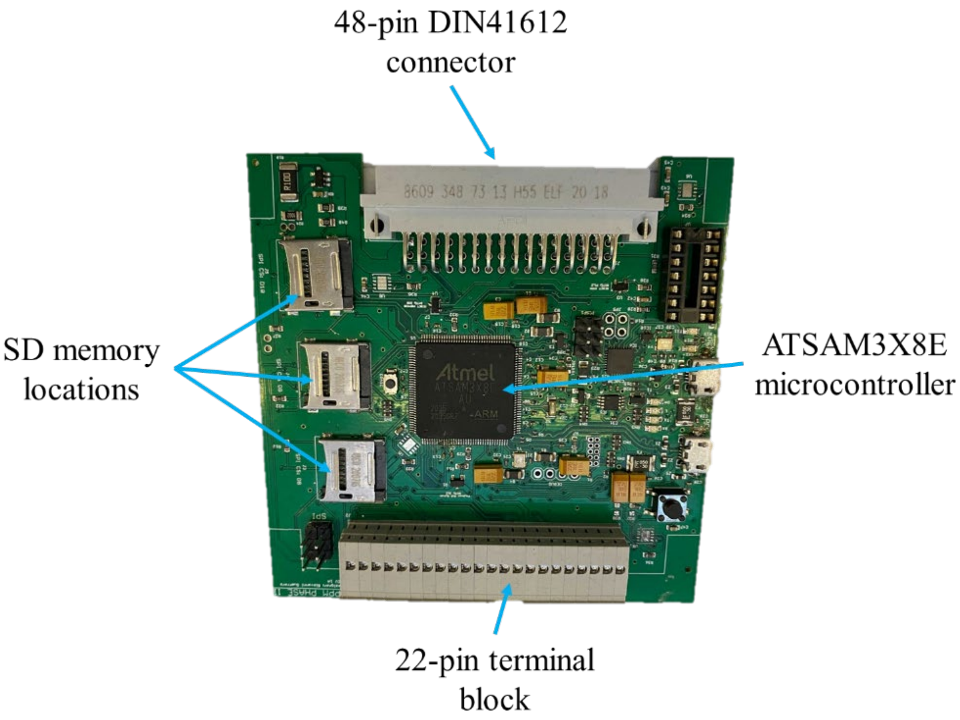
INTEGRATED PAYLOAD PROCESSING MODULE

Main functions:

- Manage payload operations
- Manage data acquired by the payloads

IPPM Characteristics

• ATSAM3X8E microcontroller
  • 54 digital input/output pins
  • 12 analog pins
  • 512kB flash memory
  • ARM processor
  • SPI, I2C, UART, and CAN capable
• 48-pin DIN41612 connector to interface with backplane
• 22-pin terminal block to interface with payloads
• 3*SD memory



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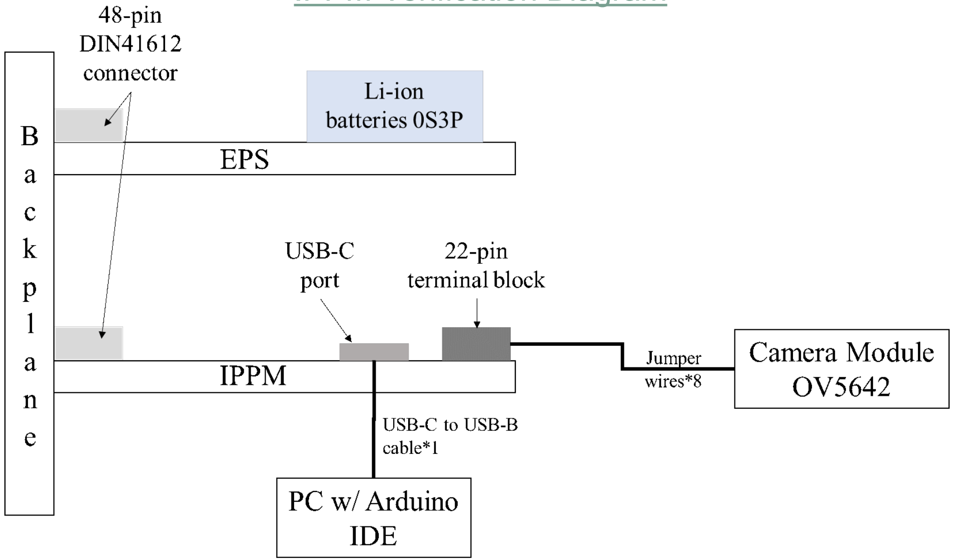
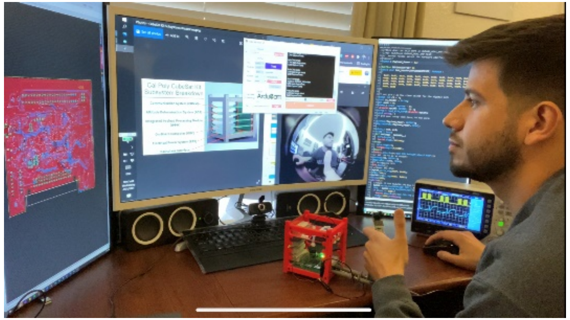
INTEGRATED PAYLOAD PROCESSING MODULE

Verification w/ EPS and Backplane outcomes:

- IPPM capable of receiving command from Arduino IDE
- IPPM capable of storing images acquired through OV5642

IPPM Verification Diagram





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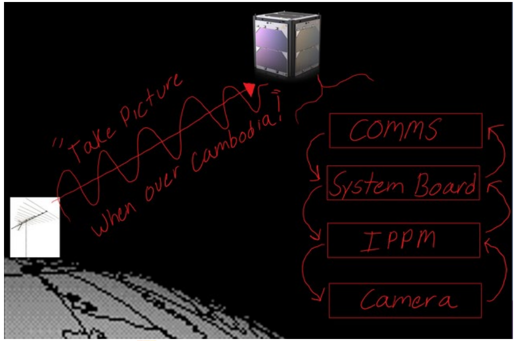
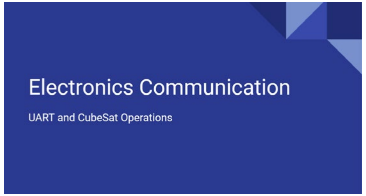
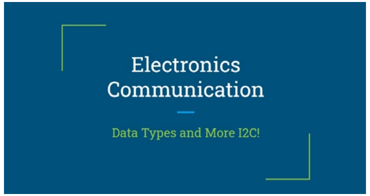
CAL POLY CUBESAT KIT Mk I IMPACT

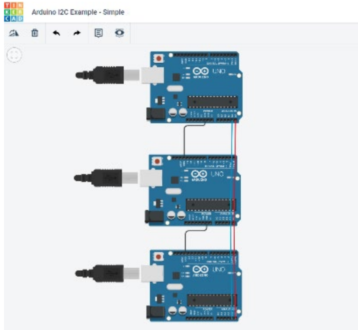
- As of August 2021, engaged:
  - 3 Cal Poly graduate students (AERO)
  - 15 Cal Poly undergraduate students (AERO, ME, EE, CPE, SE, CSC, MSCI)
  - 1 international high school, Cambodia



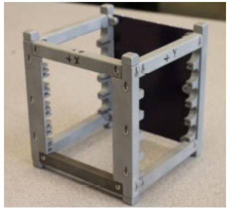
- Lectures with Cambodia's Liger Leadership Academy high school

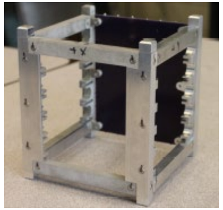


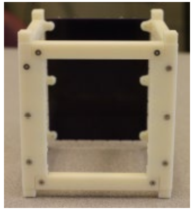


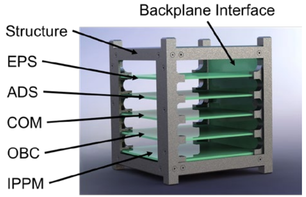


FUTURE OF CAL POLY CUBESAT KIT PROJECT









Summer 2019
Project Start

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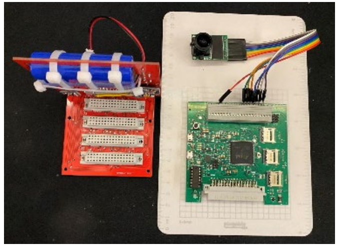
- New payloads considerations
- Mk II lessons learned implementation



Fall 2020
Mk II Development Start

Mk II Development
- Structure
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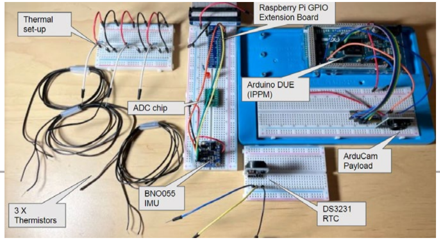
- IPPM
- EPS
- Attitude Determination Subsystem (ADS)
- On Board Computer (OBC)
- Communication subsystem (Comm)
- Payloads (fish-eye lens camera, spectroscopy sensor, luminosity sensor, etc.)

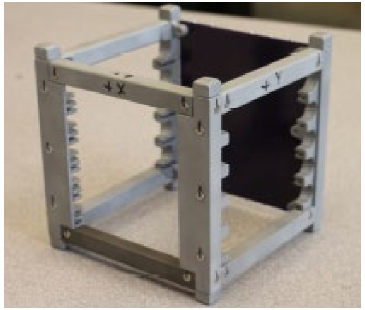
Summer/Fall 2022
Mk II Planned Completion

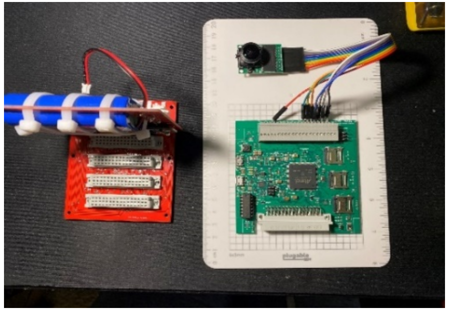


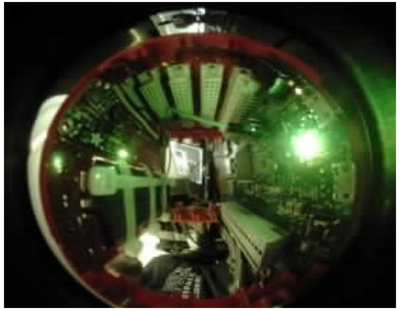
SUMMARY

Cal Poly CubeSat Kit as a practical platform to educate on engineering and non-engineering principles inside and outside a classroom

- Support curricula and professional training development
- Facilitate access to space for new comers
- Foster good practices for space engineering
- Provide hands-on space engineering platform







ACKNOWLEDGEMENTS

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- Stavros Diamantopoulos, AERO Master student, Flight software developer
- Dev Masrani, CSC Bachelor student, Flight software developer
- Gagan Thapar and Jason Beals, AERO Bachelor students, Systems engineering
- Helen Zhang and Lorenzo Pedroza, EE/CPE Bachelor students, Communications subsystem
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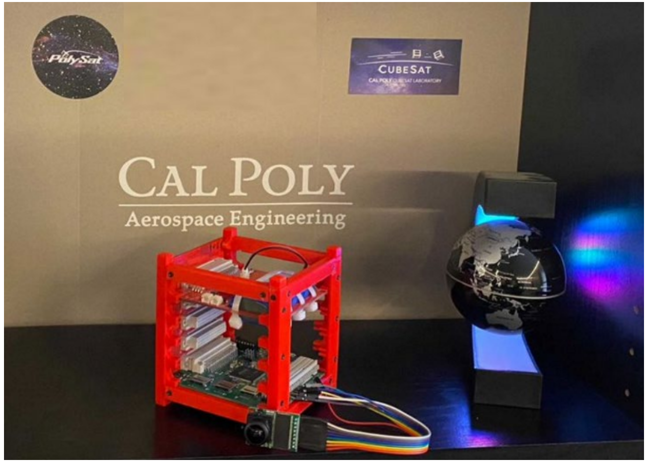

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