University CubeSat Programs – A (Pipe) Dream?

Open Source CubeSat Workshop - Keynote
Pauline Faure – December 9, 2021

CAL POLY

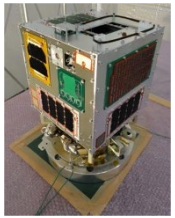
ETOILES
Educational Technologies for Open and Interactive Learning via the Engineering of Small Spacecraft

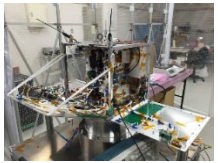
Email: pfaure@calpoly.edu

Introduction

WHO AM I? *I dunno, a lifelong quest…*

2010 – 2018 Kyushu Institute of Technology, Japan





HORYU-IV – Project manager

September 2018 - Cal Poly SLO, U.S.

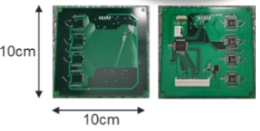
Research Activities – Aqiwo; Deep space communications; High power; Propulsion; and more…

August 2021 – ETOILES creation

Teaching – Spacecraft Design Course; Systems Engineering; Aerospace beyond Engineering

HORYU-II – Payload development

Capacity building with Malaysia and Sudan



CAL POLY and AEROSPACE ENGINEERING DEPARTMENT

Cal Poly San Luis Obispo

- 1 of 23 campuses of the California State University system
- 6 colleges, 150 undergraduate majors and minors, 50 graduate programs (Master only, no-PhD)
- Quarter-based academic year (moving to semester by 2025)
- 22,000+ undergraduate and graduate students (95% of students employed or going to grad school within 9 months of graduation)

Aerospace Engineering Department

- Ranked 2nd by U.S. News and World Report's 2021 out of 220 public and private undergraduate engineering schools in the U.S. where PhD are not offered
- **Personnel:** 10 tenure/tenure-track faculty, 2 full-time lecturers, 3 research staff, 1 administrative coordinator, 1 equipment technician
- **Students:** 450 undergraduates and 50 graduates
  - 20% female; 20% under-represented minority
  - About 2 students out of 3 choose Astronautics concentration

ETOILES LABORATORY

Educational Technologies for Open and Interactive Learning via the Engineering of Small Spacecraft

- Established in August 2021 (no website yet, working on it!)
- **Mission:** Create open-source and educational small spacecraft technologies to enable interactive learning for individuals from varied educational and professional background
- **Vision:** Become prime center for space systems engineering in support of California's upskilling efforts and aerospace small businesses
- 50 undergraduate and graduate students from AERO, EE, CPE, ME, IME, PHYS, MATH
- **Research Projects:**
  - Aqiwo – Controlled spacecraft platform
  - PowerSat – Selected by NASA CSLI for launch 2023-2025
  - Nano-reaction control system
  - X-band communication system
  - Digital engineering – Concept design tool, AR
- **Industry Partners:**
  - Maverick Space Systems Inc., San Luis Obispo, U.S.A.
  - Deployables Cubed GmbH, Munich, Germany

MAVERICK Space Systems

DCUBED

ETOILES

Educational Technologies for Open and Interactive Learning via the Engineering of Small Spacecraft

CubeSat Programs – The Dreamy Part

CUBESATS DEVELOPMENT IMPACT

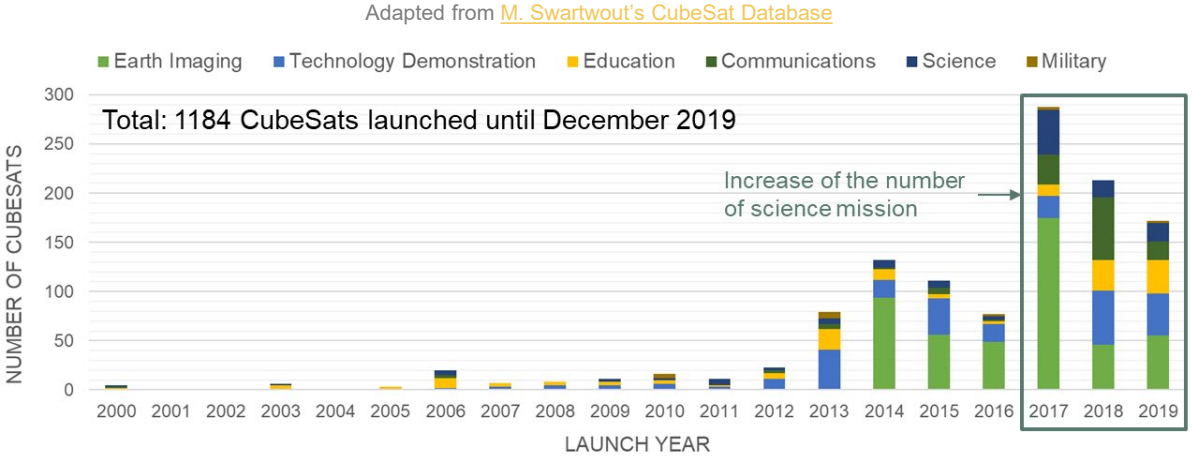
- CubeSat Design Specification, de facto standard for CubeSats established and maintained by Cal Poly
- 1500+ CubeSats launched since early 2000s (CubeSats Database)
- Global impact of CubeSats*

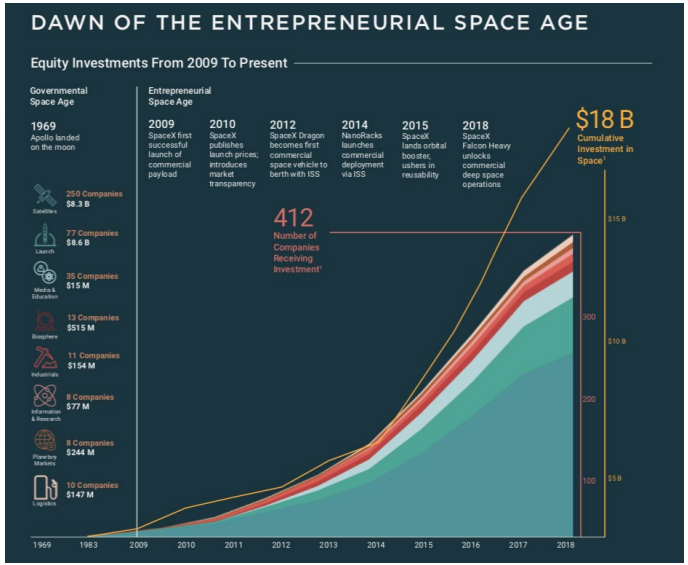
	Before 1999	1999-2003	2004-2020
Number of countries owning a satellite	7	23	71
Number of countries for which 1st satellite owned was a CubeSat	0	0	20** Launch timeframe: 2009-2020

Source: Union of Concerned Scientists Satellite Database (last accessed on November 25, 2021)
***About 42% of the new countries owning a satellite from 2004*

CUBESATS DEVELOPMENT IMPACT

- Global impact of CubeSats *(continue…)*



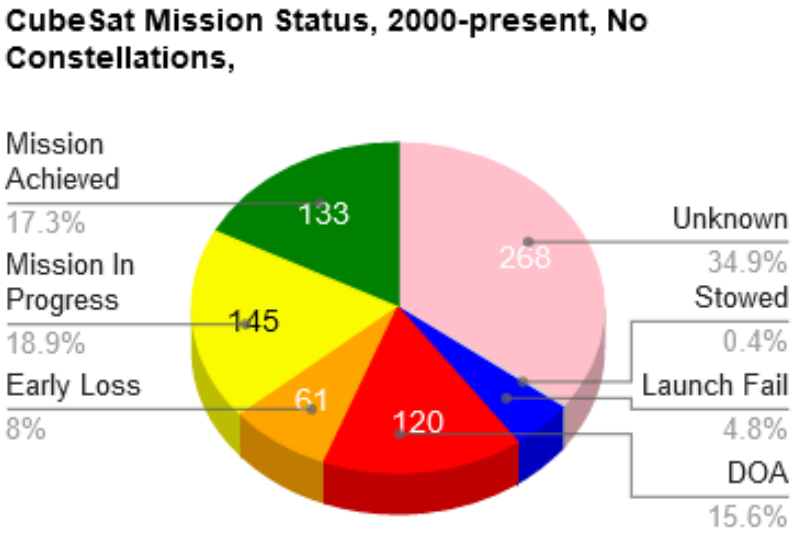


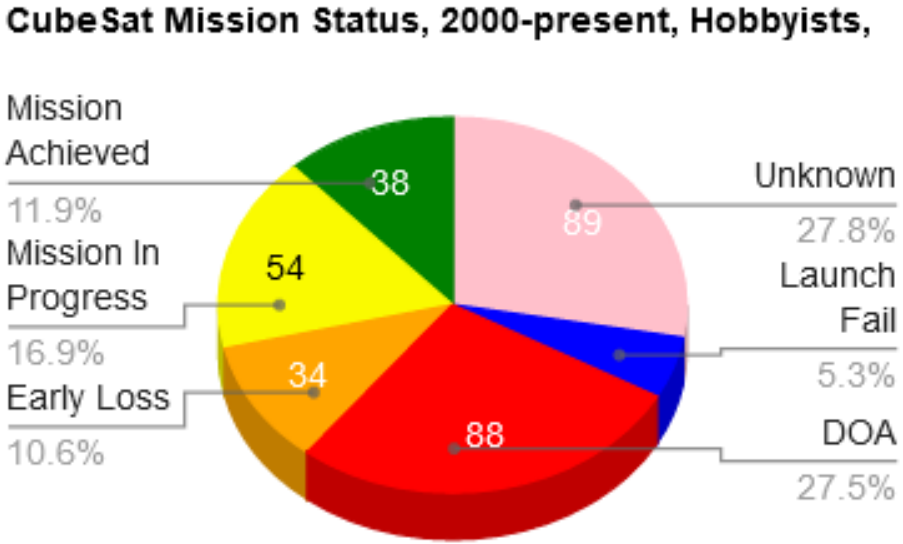
Space News, Caleb Henry, February 4, 2019,
https://spacenews.com/space-startup-investments-continued-to-rise-in-2018/

CubeSat Programs – The Pipe Dreamy Part

UNIVERSITY CUBESATS DEVELOPMENT IMPACT

- The other flip of the coin…





Adapted from M. Swartwout's CubeSat Database

CHALLENGES OF UNIVERSITY-BASED SATELLITE PROGRAMS

Challenges*	Ideal Countermeasures	Practical Situation
Knowledge transfer	• Tie satellite development to senior projects, master, or PhD theses • Have permanent professionals to support satellite programs	• Not all required developmental aspects of a satellite is worth a senior, master, or PhD thesis • Most programs cannot sustain permanent professionals
Variety of duties	• Link curricula to satellite development • Support students and professionals involved in satellite development	• Satellites 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 satellite Project • Avoid having too many functionalities on one printed circuit board	• Launch is unknown, milestones are delayed, satellite 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 satellite project	• Documentation and its handling is an after thought

University-based satellite 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

Where to go from there?

GO BACK TO THE FUNDAMENTALS

- Universities' main role is to educate
- No need to launch a spacecraft to educate
- Can simulate experience of spacecraft development life cycle

Case for Educational Controlled Spacecraft Platform

CAL POLY AQIWO PROJECT OBJECTIVES

Cal Poly Aqiwo project is a practical open-source spacecraft platform to educate on engineering and non-engineering principles inside and outside a classroom

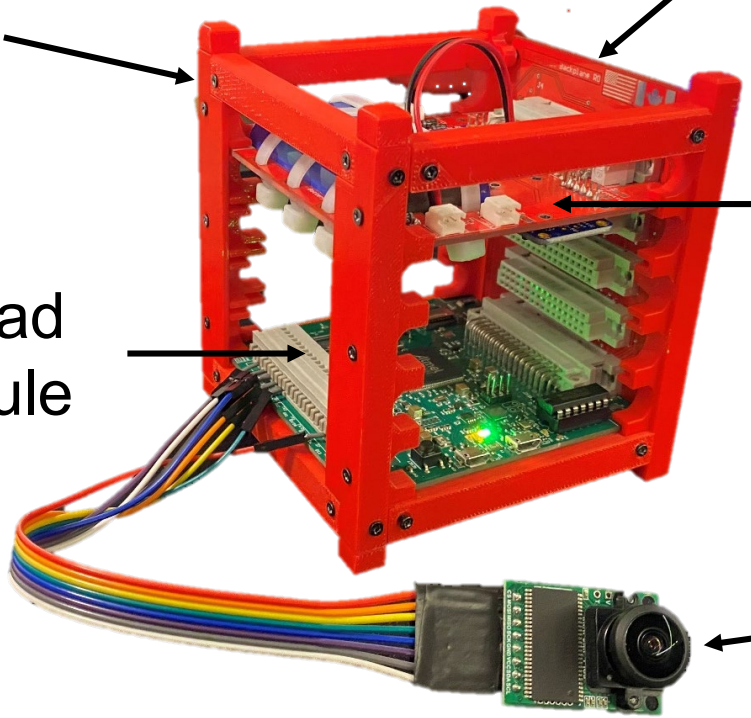
- Support curricula and professional training development
- Provide hands-on space systems engineering platform
- Foster good practices for space systems engineering
- Facilitate access to space for new comers

SUPPORTING CURRICULA DEVELOPMENT

- Main mission of a university is to educate and train tomorrow's workforce
- Spacecraft 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**
Spacecraft System 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	-
Spacecraft System 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 AQIWO PLATFORM Mk I



Backplane

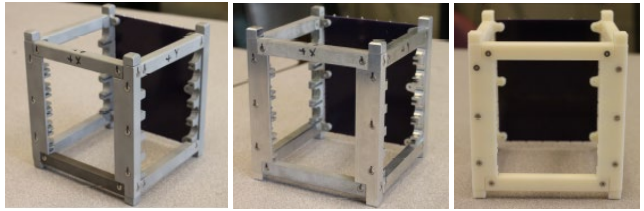
Structure

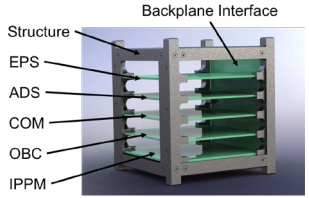
Electrical power subsystem

Integrated payload processing module

Arrays of sensors; here, VIS camera module

CAL POLY AQIWO PROJECT OVERVIEW





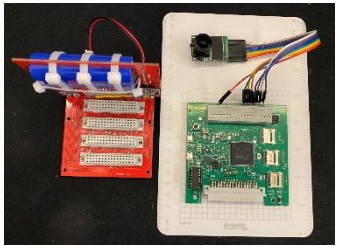
Summer 2019
Project Start

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

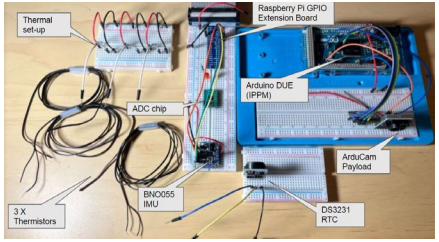
Mk III and Beyond Development
- 3U kit
- New payloads considerations
- Mk II lessons learned implementation



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



A Decade of Lessons Learned in Brief

LESSONS (RE)LEARNED

- Developing flight-mission at non-PhD granting universities is non-ideal
  - High student turnover
  - Funding is scarce
  - Knowledge transfer is arduous
  - Juggle with variety of responsibilities

- Ensure university has proper ITAR/EAR/IP information handling infrastructure in place

- Tie spacecraft development to senior projects, Master or PhD theses
  - Ensure students write their thesis prior to start a job…

- Identify funding opportunities (and get them!) to support individuals involved in project

- ICs crisis makes development even more difficult
  - Select several options, buy several of them if budget allows it

Summary

UNIVERSITY CUBESAT PROGRAMS – A (PIPE) DREAM?

It can (and will) be when we underestimate what needs to be done within a certain time frame, while overestimating the actual involvement people can have

But…

UNIVERSITY CUBESAT PROGRAMS – A (PIPE) DREAM?

… it doesn't have to be

Ultimately, (non-PhD granting) universities main goal is to educate. A controlled spacecraft platform accessible as part of the university curriculum can enable access to hands-on based space systems engineering without the anxiety to comply with a launch date and requirements

- Teach technical notions related to engineering and non-engineering
- Foster knowledge acquisition and retention for a wider range of learners
- Support students well-being while improving on the quality of their education
- Be aware and mindful of constraints and define project scope and schedule accordingly

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