The NanoSat revolution: Observations from the front lines
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Cal Poly Activities

• Create & Maintain CubeSat Standard

• Develop Cal Poly CubeSats (CP series)
  – 9 CubeSats launched + 3 CubeSat in Development

• Integrating and Launching CubeSats
  – Successfully Completed 18 Launch Campaigns
    • >100 CubeSat integrated, >50 P-PODs
    • 13 Different launch vehicles and 8 ranges
Tyvak: Small Start-Up

• Commercialize Advanced NanoSat Systems
• Develop Advanced Nano-Sat Missions
• Commercial Launch Services
CubeSat Standard

- PicoSatellite (Small)
- Simple Standard
  - Manageable by universities

- P-POD Deployer
  - Protect Primary & Launch Vehicle
  - Launch Vehicle Flexibility
  - Simplicity
  - 3 CubeSats (or 3U spacecraft)

- Developed by Cal Poly Students
Successful Standard

• >200 CubeSats in LEO
  – >10 Vehicles (Russia, US, India, Europe, Japan) +ISS
  – Regular Launches Available
  – Increasing Capability

• Large Developer Community
  – University Leadership
  – Government / Industry
  – Worldwide
  – NEW PLAYERS!!
    • Companies / Countries / Universities
Great Standard

- Hit the bullseye
Great Standard

• Hit the bullseye (Not Really)

• Created the bullseye around standard
• Benefits from standardization
CubeSat: Revolution or Evolution?

• Evolution:
  Smaller Spacecraft

• Revolution:
  New Way of Doing Space
  – Higher Risk Tolerance
  – More Flexible Launches
  – Higher Numbers
  – Lower Cost / Complexity
  – Standardization
  – COTS Electronics
Industry Evolution

- Initially universities using minimal funds (2000)
- Global growth of university programs: NRO Colony I & II, NASA Edison...
- Initial VC investment in commercial missions: SkyBox (2009), Planet Labs (2010)
- VC Funding explosion: Nanosatisfied/Spire, Dauria/Canopus, Altius Space Machines & Satellogic, Outernet...
- Gov. Missions: USAF SENSE, NSF Space Weather...
- Funding sources: University, Government, Private firms

Tyvak
Standard Evolution

• Growing Standard

1U

3U

6U

• Increasing Performance and Mission Capability
  – Also Increased Cost & Criticality
Observations

• This is not a new thing
  – Surrey, AmSat, Shuttle Gas Can, . . .

• CubeSat took it to a new level
  – Standardization
  – Worldwide Interest
  – Electronics Revolution
  – Very High Performance/cost ratio
CubeSats are Unique

- SMALL
- LOW COST
- HIGHLY INTEGRATED
- COTS PARTS
- RISK TOLERANT
- MANY LAUNCHES
- FAST SCHEDULE
CubeSats are Unique

- Not Independent Characteristics

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Traditional Space

- Limited High-Cost Launch
- Low Risk Tolerance
- Higher Cost/Mass
- High Redundancy
- Increased Complexity
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Traditional Space

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- Cost-Growth Spiral
- OK for Big Space
Traditional Spacecraft Launch Path

- Early Launch Vehicle Selection
- Launch Vehicle Influences Spacecraft
- Long Term Planning
- OK for Big Spacecraft
Current System

- Develop Spacecraft Without Firm Launch
- Include CubeSat Accommodations without Firm Payloads
- Standardization is Key
VIDEO
Standardized Small Space

- Frequent Low-Cost Launch
- High Risk Tolerance
- Low-Cost/Mass High Numbers
- Limited Mission Requirements
- Decreased Complexity

Tyvak - A Tenami Orbital Corporation
Standardized Small Space

- Innovation Spiral
- Complements Big Space

Keys

- Frequent Low-Cost Launch
- High Risk Tolerance
- Limited Mission Requirements
- Decreased Complexity
- Low-Cost/Mass High Numbers
Next Step

• Dedicated NanoSat Launch vehicles (NLV’s)
• Move away from Primary payload dependency
  – Constellations
  – Dedicated Orbits
• Match CubeSat risk/cost posture
• Ongoing development: DARPA-ALASA, Rocket Labs, Firefly, Virgin Galactic, S3, . . .
COTS PARTS
What Are We Doing?

Bring Commercial Electronics Revolution To Space
Spacecraft Trends

- Standard Space view
- Bigger sometimes required by physics (Aperture)
CubeSat Initial Conditions

Performance

Mass / Volume

1U

3U
- CubeSat Standard was a hard barrier to growth
- Forced “Guerrilla Space” approach
Creative mission and system design
High performance COTS parts
Redefined risk-posture
Current State

- Following commercial electronics revolution
- Not close to performance limits
Component Trends

Performance

Initial CubeSat Components Trend

Initial CubeSat Components Trend

M
Commercial Electronics Application Example

SRI’s CubeSat Tiny Ionospheric Photometer (CTIP)

- Original Instrument: NRL Tiny Ionospheric Photometer System (TIPS) on COSMIC Satellite
  - 3000 cm$^3$, 2.3 Kg and 7.6 W Orbit Average
CubeSat Instrument

- CTIP: <1000 cm³, <1 Kg and 2-3W Orbit Average
- Matches TIPS Performance

![CubeSat Instrument](image)
Electronics Trends

Performance

Mass / Volume / Power

Trend over time
• Improving performance while reducing size
• Exponential increase in performance at 1U and 3U
ADC Example

Performance vs. Mass / Volume

Latest Trend
Result: Enhanced Growth

- New large form factors benefit from previous size restrictions and resulting innovation
Next Step

• Highly Integrated Systems
  – Eliminate subsystem divisions
  – Follow Cellphone/Laptop principles
Mission Enabler
Optical Satellites

12U Satellite (NEVEL)
Ground Resolution Detail: 2.5 Meters

6U Multispectral Satellite

Ground Resolution Detail: 3.3 meters narrow model, 15 meters wide model
Light Sail
Interplanetary Missions

ASU’s
LunaH-Map

JPL’s MarCO
Interplanetary Missions

UCSC
NanoSwarm
Conclusions

• Standardization Works
• COTS can do more than we thought and outpace space specific systems
• Higher Risk allows for fast development pace
• Smaller simpler spacecraft feasible
• Constrains can be creativity engines

All these can apply to entire space industry
Lessons Learned

• Do Not Ignore Crazy Ideas
  – Difficult to Identify Brilliant Ones
• Innovation Is Unexpected
  – Outside Tech Road-Map
  – New Players
  – Initially Ignored
• Question Standard Practice
• Small Teams are Powerful
Lessons Learned

• What is Worthwhile Academic Research?
  – Applied Research (Undergrads?)
  – No Clear Fast Publication Path
  – Unfunded

• Is Academia Crazy-Idea Friendly Enough?
  – Can Revels Survive?
  – Can we Train the Next Revels?

• Cross Discipline Collaboration is a Must
Lessons Learned

• Risk is OK sometimes
• Do not Give Up
• Fun is Important Motivator
• Unintended Consequences can be Good
  – Keep your eyes open
• Seen It Before
  – Apple, Google, . . .
Thank You

Questions?