Achieving Science with CubeSats: Thinking Inside the Box

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Key Elements of Charge to Committee

- Develop a **summary of status**, capability, availability, and accomplishments in the government, academic, and industrial sectors

- Recommend **potential near-term investments** that could be made to improve the capabilities and usefulness of CubeSats for scientific return and to enable the science communities’ use of CubeSats

- Identify a set of **sample priority science goals** that describe near-term science opportunities
Overview

1. Based on detailed analysis of available data
2. Recognized similarity to disruptive innovation
3. Analysis of science publications: CubeSats can do high priority science
4. Science potential in all science divisions to varying degrees. However, not every application is appropriate for CubeSats.
5. Potential is materialized if a number of conditions are fulfilled
   1. Technology and connections to industry
   2. Policy issues
   3. Programmatic and management issues
US CubeSats Launched – by Mission Type

- **Imaging**
- **Communication**
- **Technology**
- **Education**
- **Science**

### US CubeSats Launched – by Mission Type

**Education**

- NSF
- NASA
- DOD

**Commercial**

- NSF
- NASA
- DOD

**Year**

- 2000
- 2001
- 2002
- 2003
- 2004
- 2005
- 2006
- 2007
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
- 2014
- 2015
**Concept of a Disruptive Innovation**

- “Process by which a product or service takes root initially in simple applications at the bottom of a market and then relentlessly moves up market […].” Clayton Christensen, 1995

- Has been used to describe many shifts in the economy
  - Personal computers (that disrupted the mainframe computer industry)
  - Cellular phones (that disrupted fixed line telephony)
  - Smartphones (that continue disruption of multiple sectors, computers, digital cameras, telephones, and GPS receivers)

- End-state and especially level of disruption is unclear at beginning
CubeSats Share Characteristics of Disruptive Innovations

- **Performance.** Early CubeSats were essentially “beepsats”
- **Cost.** Hardware for a basic CubeSat can be purchased for a few tens of thousands of dollars
- **Users.** CubeSats are introducing students and other participants to space technology; introducing the potential for new functionalities such as stop-and-stare and multi-hundred/thousand swarm systems
- **Speed.** CubeSats began as platforms for technology testing, and are being considered for advanced missions such providing real-time relay communication
- **Origin.** Introduced by educators not the stalwarts of aerospace
- **Enabling technology.** Propelled by advances in software, processing power, data storage, camera technology, compression and solar array efficiency
- **Development models.** Adopted by entrepreneurs using fly-test-refly and other lean manufacturing technology and business models

End-state and especially level of disruption CubeSats may create is unclear
What CubeSats Can Enable

- They are standardized – creation of supply chain
- They are cheaper - conduct of higher risk activities, “fly-learn-refly” paradigm
- Enables new mission types, especially high-risk orbits and secondary lines of sights, as well as targeted science
- Enables creation of entirely new architectures, especially constellations and swarms
Conclusion: CubeSats have already produced high-value science, as demonstrated by peer-reviewed publications in high-impact journals. {…}
CubeSat Example for High-Risk Orbits, with other Mission

Colorado Student Space Weather Experiment (CSSWE)
Example: Constellations/Swarms

Cyclone Global Navigation Satellite System (CYGNSS)

Not a CubeSat, but CubeSat enabled
Constellations for Space Weather

“Instrumenting Space” through Distributed Architectures
Example: Targeted Science: 1 Instrument, 1 Question

LunaH Map
SIMPLEx Program
<table>
<thead>
<tr>
<th>Science Discipline</th>
<th>Enabling Technology</th>
<th>Example Application</th>
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</thead>
<tbody>
<tr>
<td><strong>Solar and Space Physics</strong></td>
<td><strong>Propulsion</strong></td>
<td>Constellation deployment and maintenance, formation flight</td>
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<td></td>
<td><strong>Sub-arcsecond attitude control</strong></td>
<td>High resolution solar imaging</td>
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<td></td>
<td><strong>Communications</strong></td>
<td>Missions beyond low Earth orbit</td>
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<td></td>
<td><strong>Miniaturized field and plasma sensors</strong></td>
<td>In-situ measurements of upper atmosphere plasmas</td>
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<td><strong>Earth Science</strong></td>
<td><strong>Propulsion</strong></td>
<td>Constellations for high-temporal resolution observation and orbit maintenance</td>
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<td></td>
<td><strong>Miniaturized sensors</strong></td>
<td>Stable, repeatable and calibrated datasets</td>
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<tr>
<td></td>
<td><strong>Communications</strong></td>
<td>High data rate</td>
</tr>
<tr>
<td><strong>Planetary Science</strong></td>
<td><strong>Propulsion</strong></td>
<td>Orbit insertion</td>
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<td></td>
<td><strong>Communications, Comm Infrastructure</strong></td>
<td>Direct/indirect to Earth communications</td>
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<td><strong>Radiation-tolerant electronics</strong></td>
<td>Enhanced survival in planetary magnetospheres, long duration flight</td>
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<td><strong>Deployables</strong></td>
<td>Enhanced power generation beyond Mars</td>
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<td><strong>Propulsion</strong></td>
<td>Constellations for interferometry, distributed apertures</td>
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<td><strong>Deployables</strong></td>
<td>Increase aperture and thermal control</td>
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<td></td>
<td><strong>Miniaturized sensors</strong></td>
<td>UV and X-ray imaging</td>
</tr>
<tr>
<td><strong>Physical and Biological</strong></td>
<td><strong>Thermal control</strong></td>
<td>Stable payload environment</td>
</tr>
</tbody>
</table>
Illustrating Speed of Development: Attitude Control

Best CubeSat Attitude Accuracy
Arcsec (degrees)

360000
(10°)

3600
(1°)

360
(0.1°)

36
(0.01°)

Year


Many Science Missions Enabled

CubeSat Missions

Missions in Progress or Proposed
Policy Issues Considered

- Regulatory framework for CubeSats is nearly identical to that of large spacecraft
- Issues particularly affecting or potentially limiting the development of CubeSats as a science tool
  - Orbital debris
  - Communications
  - Launch vehicles
  - Other restrictions affecting the community, such as ITAR, etc.
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Download full report at: goo.gl/osCSQ3
Full presentation: goo.gl/fQXXYp

Questions, Comments?