Achieving Science with CubeSats: Thinking Inside the Box

Committee Chair: Thomas H. Zurbuchen, University of Michigan
Vice Chair: Bhavya Lal, IDA Science and Technology Policy Institute
Study Director: Abigail Sheffer, Program Officer, SSB
Committee Membership

Julie Castillo-Rogez, Jet Propulsion Laboratory, Caltech
Andrew Clegg, Google, Inc.
Bhavya Lal, (Vice Chair), IDA Science and Technology Policy Inst.
Paulo Lozano, Massachusetts Institute of Technology
Malcolm Macdonald, University of Strathclyde
Robyn Millan, Dartmouth College
Charles D. Norton, Jet Propulsion Laboratory, Caltech
William H. Swartz, Johns Hopkins University, Applied Physics Lab
Alan M. Title, Lockheed Martin Space Technology Adv. R&D Labs
Thomas N. Woods, University of Colorado Boulder
Edward L. Wright, University of California, Los Angeles
A. Thomas Young, Lockheed Martin Corporation [Retired]
Thomas H. Zurbuchen (Chair), University of Michigan
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

Number of CubeSats

Year

0 20 40 60 80 100 120


- Imaging
- Communication
- Technology
- Education
- Science

Commercial ➔

NASA ➔

DOD ➔

NSF ➔

Education ➔
International Participation

- United Kingdom 4
- South Korea 4
- Italy 4
- Germany 9
- Denmark 9
- Japan 18
- All Others 50

United States 327
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 Christenson, 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
# Enabling Technology by Science Discipline

<table>
<thead>
<tr>
<th>Science Discipline</th>
<th>Enabling Technology</th>
<th>Example Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solar and Space Physics</strong></td>
<td><strong>Propulsion</strong></td>
<td>Constellation deployment and maintenance, formation flight</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-arcsecond attitude control</strong></td>
<td>High resolution solar imaging</td>
</tr>
<tr>
<td></td>
<td><strong>Communications</strong></td>
<td>Missions beyond low Earth orbit</td>
</tr>
<tr>
<td></td>
<td><strong>Miniaturized field and plasma sensors</strong></td>
<td>In-situ measurements of upper atmosphere plasmas</td>
</tr>
<tr>
<td><strong>Earth Science</strong></td>
<td><strong>Propulsion</strong></td>
<td>Constellations for high-temporal resolution observation and orbit maintenance</td>
</tr>
<tr>
<td></td>
<td><strong>Miniaturized sensors</strong></td>
<td>Stable, repeatable and calibrated datasets</td>
</tr>
<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>
</tr>
<tr>
<td></td>
<td><strong>Communications, Comm Infrastructure</strong></td>
<td>Direct/indirect to Earth communications</td>
</tr>
<tr>
<td></td>
<td><strong>Radiation-tolerant electronics</strong></td>
<td>Enhanced survival in planetary magnetospheres, long duration flight</td>
</tr>
<tr>
<td></td>
<td><strong>Deployables</strong></td>
<td>Enhanced power generation beyond Mars</td>
</tr>
<tr>
<td><strong>Astronomy and Astrophysics</strong></td>
<td><strong>Propulsion</strong></td>
<td>Constellations for interferometry, distributed apertures</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-arcsecond attitude control</strong></td>
<td>High resolution imaging</td>
</tr>
<tr>
<td></td>
<td><strong>Communications</strong></td>
<td>High data rate</td>
</tr>
<tr>
<td></td>
<td><strong>Deployables</strong></td>
<td>Increase aperture and thermal control</td>
</tr>
<tr>
<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°) - CubeSat Missions
- 3600 (1°) - CubeSat Missions
- 360 (0.1°)
- 36 (0.01°) - Missions in Progress or Proposed

Year
- 2006
- 2008
- 2010
- 2012
- 2014
- 2016
- 2018

Many Science Missions Enabled
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.
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