NASA Perspectives on CubeSat Technology and Highlighted Activities

SNAP Nanosatellite / CubeSat Subject Matter Expert Exchange
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With David Pierce NASA HQ SMD
& Andrew Petro NASA HQ STMD

1/29/16
NASA’s Perspective for CubeSats

- NASA has recognized the value of CubeSats as technology demonstration platforms, and for providing hands-on training to future scientists and engineers.
  - Reliable access to space for timely science measurements;
  - Mature technologies and lowering risk for infusion into flight programs;
  - These new, cost effective and capable platforms show the potential to provide new tools to address significant science goals.

- NASA views cubesats as scalable platforms, from:

<table>
<thead>
<tr>
<th>Size</th>
<th>Discipline</th>
<th>orbit</th>
<th>Access to Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>1U, 1 ½ U, 2U</td>
<td>Education, Technology</td>
<td>LEO</td>
<td>CSLI, DoD, ISS, Commercial</td>
</tr>
<tr>
<td>3U, 6U</td>
<td>Science, Technology</td>
<td>LEO, GEO, GTO</td>
<td>CSLI, DoD, ISS, Commercial</td>
</tr>
<tr>
<td>6U</td>
<td>Science, Technology</td>
<td>Earth Escape</td>
<td>SLS/EM-1, and future SLS flights</td>
</tr>
</tbody>
</table>

- Research Grants (less than Class D) NPR 7120.8 platforms
- AO, Flight Project (Class D) NPR 7120.5E platforms
NASA has organized an integrated and flexible set of CubeSat program elements, leveraging evolving platform capabilities and frequent access to space to the benefit of the NASA research community, including:

- Conducting Earth and Space science investigations, and developing precursor instrument technologies for future science measurements. (SMD)
- Developing and demonstrating new small spacecraft technologies and capabilities for NASA’s missions in science, exploration and space operations. (STMD)
- Providing launch opportunities to the U.S. CubeSat Community (academia, government, and non-profits). (HEOMD)
- Sponsoring missions to address strategic knowledge gaps for exploration. (HEOMD)
- Coordinating frequency management and licensing for all NASA related missions. (HEOMD-SCaN)
Two NASA CubeSat Studies

STUDY #1: Internal NASA Study of New Opportunities for Low-Cost Science Instruments, Platforms, and Mission Architectures
Chairs: Michael Seablom/SMD and Andy Petro/STMD

(a) Investigate current paradigm shifts in the miniaturization of science instruments and disruptive small satellite platform technologies;

(b) Determine the potential for novel approaches that could break the cycle of “larger but fewer” expensive missions;

(c) Identify key SMD science measurement requirements that could be satisfied through such paradigms;

(d) Identify technology gaps to address through solicitations to remove barriers to alternative paths.

STUDY # 2: SMD sponsored NAS Study Achieving Science Goals with CubeSats
SSB Ad Hoc Committee
Chair: Thomas H Zurbuchen, University of Michigan

(a) Review the current state of scientific potential and technological promise of CubeSats;

(b) Review the potential of CubeSats as platforms for obtaining high-priority science data;
   - From recent decadal reviews, Science priorities in 2014 NASA Science plan

(c) Provide a set of recommendations on how to assure scientific return on future federal agency support of CubeSat programs;
## NASA Science Sponsored Small Spacecraft Solicitations

<table>
<thead>
<tr>
<th>Solicitation Name</th>
<th>Award amount</th>
<th>Anticipated Selections/Year</th>
<th>Discipline</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMD/ROSES/ H-TIDeS/APRA</td>
<td>$2M - $4M</td>
<td>2-3</td>
<td>Science / Instrument Technology</td>
</tr>
<tr>
<td>SMD/PSD SIMPLEx</td>
<td>$5.6M</td>
<td>Multiple awards ~ every 2 years</td>
<td>Planetary Science</td>
</tr>
<tr>
<td>SMD/ESTO InVEST</td>
<td>$1.5M</td>
<td>3</td>
<td>Earth Science Technology</td>
</tr>
<tr>
<td>SMD/Earth Venture-Instrument</td>
<td>$30M for Cubesat mission</td>
<td>Multiple Awards every 2-3 years</td>
<td>Earth Science</td>
</tr>
<tr>
<td>SMD/Earth Venture-Mission</td>
<td>$160M (incl. launch)</td>
<td>Multiple Awards every 2-3 years</td>
<td>Earth Science</td>
</tr>
<tr>
<td>SMD/Explorer MO</td>
<td>$60M</td>
<td>Multiple awards every 2-3 years</td>
<td>Astrophysics</td>
</tr>
<tr>
<td>SMD/HOPE-TO</td>
<td>$800K</td>
<td>1 award annually</td>
<td>Training</td>
</tr>
<tr>
<td>SMD/OE/USIP</td>
<td>$200K</td>
<td>Multiple awards every 2 years</td>
<td>Student Training</td>
</tr>
</tbody>
</table>
Small Innovative Missions for Planetary Exploration (SIMPLEx)

SIMPLEx (ROSES, Dec. 2014) – First PSD solicitation that supports development of planetary science investigations using an interplanetary CubeSat. There were 2 missions selected:

Lunar Polar Hydrogen Mapper (LunaH-Map) –
PI: Hardgrove, ASU – 6U CubeSat to create detailed map to date of the moon’s water deposits; fully characterize the water content at the lunar South Pole in preparation for exploration.

CubeSat Particle Aggregation and Collision Experiment (Q-PACE) –
PI: Colwell, UCF – 2U CubeSat to explore the fundamental properties of low-velocity particle collision in microgravity to better understand mechanics of early planetoid development. ISS Launch in 2017.

In addition, there were 3 studies selected:

SIMPLEx Mars Orbiter (Malin/Malin Space Science Systems);
Hydrogen Albedo Lunar Orbiter (HALO) (Collier/NASA GSFC); and
Diminutive Asteroid Visitor using Ion Drive (DAVID) (Landis/NASA GRC)
# NASA CubeSats Summary

<table>
<thead>
<tr>
<th>NASA CubeSats</th>
<th># of Missions</th>
<th># of CubeSats</th>
<th>Discipline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Science Mission Directorate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Astrophysics Division</td>
<td>1</td>
<td>1</td>
<td>Science (1)</td>
</tr>
<tr>
<td>• Earth Science Division</td>
<td>14</td>
<td>15</td>
<td>Science (1); Technology (9); Training (1)</td>
</tr>
<tr>
<td>• Heliophysics Science Division</td>
<td>6</td>
<td>7</td>
<td>Science (6)</td>
</tr>
<tr>
<td>• Planetary Science Division</td>
<td>5</td>
<td>6</td>
<td>Science (3); Technology (3)</td>
</tr>
<tr>
<td><strong>Space Technology Mission Directorate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Small Spacecraft Technology Program</td>
<td>10</td>
<td>26</td>
<td>Technology (26)</td>
</tr>
<tr>
<td><strong>Human Exploration and Operations Mission Directorate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Advanced Exploration Systems</td>
<td>6</td>
<td>6</td>
<td>Technology (6)</td>
</tr>
</tbody>
</table>

![NASA CubeSat Missions Chart](chart.png)
NASA’s CubeSat Launch Initiative (CSLI) provides launch opportunities to educational, non-profit organizations and NASA Centers who build small satellite payloads that fly as auxiliary payloads on previously planned or commercial missions or as International Space Station deployments.
# Measures Of Success

<table>
<thead>
<tr>
<th>CSLI Call #</th>
<th># Proposals Received</th>
<th># Adjusted Selected</th>
<th># Available Manifest</th>
<th># Manifested</th>
<th># Launched</th>
<th>% Launched &amp; Manifested</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Selection</td>
<td>6</td>
<td>4</td>
<td></td>
<td>4</td>
<td>11</td>
<td>100%</td>
</tr>
<tr>
<td>CSLI - 1</td>
<td>16</td>
<td>12</td>
<td></td>
<td>16</td>
<td>11</td>
<td>100%</td>
</tr>
<tr>
<td>CSLI - 2</td>
<td>25</td>
<td>12</td>
<td>1</td>
<td>11</td>
<td>11</td>
<td>100%</td>
</tr>
<tr>
<td>CSLI - 3</td>
<td>33</td>
<td>25</td>
<td>2</td>
<td>5</td>
<td>11</td>
<td>64%</td>
</tr>
<tr>
<td>CSLI - 4</td>
<td>34</td>
<td>18</td>
<td>4</td>
<td>11</td>
<td>1</td>
<td>67%</td>
</tr>
<tr>
<td>CSLI - 5</td>
<td>22</td>
<td>16</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>25%</td>
</tr>
<tr>
<td>CSLI - 6</td>
<td>22</td>
<td>13</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td><strong>158</strong></td>
<td><strong>110</strong></td>
<td><strong>9</strong></td>
<td><strong>23</strong></td>
<td><strong>43</strong></td>
<td><strong>63%</strong></td>
</tr>
</tbody>
</table>

- **Adjusted Selected** - After adjustments made to selected CubeSats from recent survey of selectees, along with CubeSats chosen to fill open slots.
- **Available to Manifest** – CubeSats ready for final testing and integration; typically launch occurs ~ 9 months after the **Available to Manifest** date.
- **Note: Of payloads ready to be manifested, 88% are launched or manifested**
Deep-space CubeSats: SLS EM-1 Secondary Payloads

The Space Launch System (SLS) will launch 13 secondary payloads on the first flight of SLS / Exploration Mission (EM)-1 in mid-2018.

- **HEOMD/AES CubeSats** - CubeSats selected by AES to close key Strategic Knowledge Gaps (SKGs).

- **STMD Centennial Challenges** - 3 payloads riding will be the winners of NASA’s Cube Quest Challenge, designed to foster innovation in propulsion and communications techniques.

- **Science Mission Directorate** – selected 2 investigations to fly on EM-1
  - Planetary: LunaH-Map, Dr. Hardgrove, ASU
  - Heliophysics: CuSP, Dr. Desai, SwRI

- SLS will be an important step in the ability to launch Interplanetary CubeSats; future flights may carry even larger/more complex payloads for science experiments and/or technology demonstrations to deep space.
NASA Communication & Navigation Support

NASA’s Space Communication and Navigation Program has initiated activities to support the small sat community including assessing long-term capabilities and potential collaborative activities

(a) SCaN’s Near Earth Network (NEN) is planning to support several cubesat missions and several are in the planning and compatibility phase with launches in 2016

(b) SCaN is reviewing potential options to streamline some of the planning phase activities to keep costs minimal for small sat missions

(c) SCaN is initiating a review of architecture and development needs, and such assessments will consider various options such as:

1) Work with the community to identify potential standardization of communication and navigation services across various networks;

2) Enhance the existing SCaN networks to support the potential large numbers of small sats and to contain costs;

3) Utilize commercial ground networks that are increasingly deploying systems to support small satellites.
Space Technology Perspective
Small Spacecraft Technology
SPACE TECHNOLOGY MISSION DIRECTORATE

Small, Affordable, Rapid, & Transformative

Objectives:

- Develop and demonstrate new capabilities employing the unique features of small spacecraft for NASA’s missions in science, exploration and space operations
- Promote the small spacecraft approach as a paradigm shift for NASA and the larger space community.

Flight Demonstration Projects in:

- Advanced Radio and Laser Communications
- Formation Flight and Autonomous Docking
- Smallsat swarms for space science missions
- Low-cost satellite buses
- Propulsion

Implemented through:

- Directed NASA projects
- Contracts with private industry
- University-NASA partnerships
- Collaboration with SBIR and other programs

Five Phonesats flown in 2013-14
Seven demo missions planned for 2015-16 with 16 satellites and one suborbital capsule

www.nasa.gov/smallsats
Small Spacecraft Technology – Flight Demonstrations

- **Phonesat 1/2b**
  - April 2013

- **Phonesat 2.4 & 2.5**
  - November 2013 & April 2014

- **EDSN**
  - March 2014

- **Nodes**
  - April 2014

- **OCSD A**
  - March 2015

- **B & C**
  - Oct 2015 & May 2016

- **CPOD**
  - Aug 2015

- **ISARA**
  - Aug 2015

- **Maraia**
  - (Suborbital)

- **Pathfinder Tech Demonstrators & Isat**
  - Nov 2015

**Key Dates**

- **2012**
  - Nov 2015

- **2013**
  - March 2014
  - March 2015
  - Aug 2015
  - Nov 2015

- **2014**
  - Phonesat 2.4 & 2.5
  - November 2013 & April 2014

- **2015**
  - OCSD A
  - B & C
  - Oct 2015 & May 2016
  - ISARA
  - Aug 2015
  - Nov 2015

- **2016**
  - CPOD
  - Late 2016
  - ISARA
  - May 2016

**Abbreviations**

- **EDSN**: Edison Demonstration of Smallsat Networks
- **ISARA**: Integrated Solar Array and Reflectarray Antenna
- **OCSD**: Optical Communications and Sensor Demonstration
- **CPOD**: Cubesat Proximity Operations Demonstration
Edison Demonstration of Smallsat Networks
EDSN and Nodes

NASA Ames, Montana State U and Santa Clara U

Demonstration of autonomous network communications with multiple low-cost satellites based on smartphone processors (Phonesat heritage)  EDSN: 8 cubesats, Nodes: 2 cubesats
Each includes a high-energy particle detector

EDSN Launch – Nov 2015
Nodes Launch – Dec 2015 to ISS

Flight Unit Assembly

Autonomous Network Control

Nodes

Crosslink Negotiation

Downlink Notification
Optical Communications and Sensor Demonstration OCSD

Aerospace Corporation

Dramatic improvement in space to ground laser communications with 1.5U cubesats - plus proximity operations, laser ranging and tracking, and propulsion.

Launches – Oct 2015 and May 2016
Cubesat Proximity Operations Demonstration
CPOD

Tyvak LLC

Formation flight, proximity operations and autonomous rendezvous and docking with two 3U cubesats.

Launch – Mid-to-late 2016
Integrated Solar Array and Reflectarray Antenna
ISARA

JPL, Aerospace Corporation, Pumpkin Inc.
Increased Ka-band communication and potential radar remote sensing for low-cost but effective science missions
Launch – May 2016

Technology being used for MARCO cubesat deep space radio relay demonstration
Small Earth Return Vehicle
Maraia

Technology Development for the Maraia Earth Return Capsule
Flight to 380,000 ft. altitude, Mach 3.5
Partners: NASA JSC, KSC, and Up Aerospace
Launched in Nov 2015 from Spaceport America
Iodine Hall Thruster Demonstration

Isat

NASA Marshall with NASA Glenn and Busek Co.

Isat will mature the technology for using iodine propellant with a small Hall Effect thruster and demonstrate its operation in space. This technology will enable high ΔV primary propulsion for small spacecraft.

12U cubesat

Target launch in late 2017
Pathfinder Technology Demonstrator

NASA Ames and NASA Glenn with industry partners for cubesat bus and technology payloads

The Pathfinder Technology Demonstrator series will demonstrate spacecraft technologies in low Earth orbit including new systems for propulsion, precise pointing, and high-data-rate communications.

NASA intends to procure a series of commercially-provided cubesat buses for these missions.

Technology payloads are being developed through SBIR and Tipping Point contracts and other sources are possible.

6U cubesat

Target date for first launch is 2017
## Propulsion Technology Development Projects
### 2013 NRA Awards – Partnership with Flight Opportunities

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Concept</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerojet (MPS-120)</strong></td>
<td></td>
<td><strong>Green prop version selected for Tipping Point contract</strong></td>
</tr>
<tr>
<td><strong>Description:</strong> CHAMPS Module. Provides a 1U high impulse propulsion module using hydrazine (high impulse), used for orbit transfer/de-orbit in LEO. Requires Hydrazine waiver.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Busek (RF Iodine thruster)</strong></td>
<td></td>
<td><strong>Continuing work as Phase 2 SBIR</strong></td>
</tr>
<tr>
<td><strong>Description:</strong> 3 cm thruster shown (can run both Iodine or Xenon). Provides for 3 cm dia. RF-Ion thruster using solar electric propulsion, and Iodine (initially solid) as propellant, low pressure, high impulse, and low thrust. Thruster using Xenon is at TRL 5.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Busek (Green Propulsion)</strong></td>
<td></td>
<td><strong>TRL 5 in 1.5 to 2 Years</strong></td>
</tr>
<tr>
<td><strong>Description:</strong> Development of a cubesat level green propellant (alternate to hydrazine), uses a bellows tank and ionic electrolysis of liquid propellant (TRL 5 for the thruster)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Aerospace (Hybrid Rocket Motor)</strong></td>
<td></td>
<td><strong>TRL 5 in 2.5 Years</strong></td>
</tr>
<tr>
<td><strong>Description:</strong> Development of a cubesat level Hybrid rocket motor using N$_2$O and a solid propellant in a 1U tank configuration</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MSNW, LLC (ICE Thruster)</strong></td>
<td></td>
<td><strong>TRL 5 in 2 to 3 years</strong></td>
</tr>
<tr>
<td><strong>Description:</strong> Development of an inductively coupled electromagnetic thruster (ICE) for cubesat propulsion</td>
<td></td>
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</tr>
</tbody>
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Smallsat Technology Partnerships

Cooperative agreements with US universities to develop and/or demonstrate new technologies and capabilities for small spacecraft in collaboration with NASA

2014-2015: 11 projects – two proceeding with cubesat flights

Montana State/Goddard
Radiation-tolerant Processor

California State-Northridge/JPL
Low-Temperature Capacitor Flight Demo

2016-2017: 8 new projects including:

- Ka-band radio
- Low-cost atomic clock
- Inflatable deorbit device
- Cryo-cooler and active thermal control
- Micro-thruster
- Solar sail control system

Michigan
Arkansas
Utah State
Purdue
Vermont
Illinois
Maryland

Goddard
Ames
JPL
Marshall
Additional Technology Research and Development

SBIR Phase II
Laser communications - Fibertech
RF ion thruster with iodine - Busek

SBIR CRP
Miniature electrospray thruster - Busek

Early Career Projects
Lightweight solar arrays - NASA Marshall and NeXolve
Autonomous on-orbit assembly of nanosats - NASA Langley and Cornell University

2015 Tipping Point Awards
1 N thruster with green propellant - Aerojet
Hydros thruster - Tethers Unlimited
Hyper-XACT star tracker - Blue Canyon
Reaction Sphere attitude control system - Northrop Grumman

Small Spacecraft Technology Working Groups
Propulsion Working Group – generated recommendations in 2015
Planning additional groups for Communications, Attitude Control, Power & Thermal, and Software
Small Spacecraft Technology
State of the Art Report

• Compiled for the SST Program by Ames Engineering with inputs from the larger community
• Originally published in October 2013
• New update completed in December 2015
• Annual update intended, broad participation desired
• Link to report on STMD/SSTP website: www.nasa.gov/smallsats
Future Technology Interests

• Small Solar Electric Propulsion
  Earth orbit and beyond

• Science & Communications Satellite Networks

• Inspector/Explorer Cubesats
  Earth orbit and beyond

• Small Entry Vehicles and Testbeds

• Simple, Low-Cost Deorbit

• Nano-Launcher Capability
The Cubesat Opportunity

• Should not over-sell or over-reach

  BUT

• Constrained size is driving innovation

• Providing more spaceflight experience, for more people, earlier, and more often

• Valuable as a platform for component flight testing and proof-of-concept demonstrations

• Possible new mission niches