THE POTENTIAL ROLE OF SMALL SATELLITES, CUBESATS, CONSTELLATIONS, AND HOSTED PAYLOADS IN DESIGNING THE FUTURE EARTH OBSERVING SYSTEM ARCHITECTURE

COMMITTEE ON EARTH SCIENCE AND APPLICATIONS FROM SPACE (CESAS)
September 17-19, 2014
NAS Building, 2101 Constitution Ave NW, Washington, DC

Perspectives on SmallSats and CubeSats

Thomas Sparn
Dr. Peter Pilewskie
## Designing the Future Earth Observing System Architecture Agenda

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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<tbody>
<tr>
<td>10:45</td>
<td>Discussion with Bryant Cramer, former Associate Director of the USGS and former NASA ESD Deputy Director (tentative)</td>
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<tr>
<td>11:30</td>
<td>Discussion with Walter Scott, Digital Globe and Committee</td>
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<td>12:15</td>
<td>Lunch</td>
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<tr>
<td>1:15</td>
<td>Earth Science with Hosted Payloads and Small Sat Constellations Lars Dyrud, Draper Laboratory</td>
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<tr>
<td>2:00</td>
<td>Discussion with Bill Swartz, PI RAVAN, Johns Hopkins Applied Physics Laboratory</td>
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<td>2:45</td>
<td>Break</td>
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<tr>
<td>3:00</td>
<td>Perspectives on SmallSats and CubeSats Tom Sparn and Peter Pilewskie University of Colorado/Laboratory for Atmospheric &amp; Space Physics (LASP)</td>
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<tr>
<td>4:00</td>
<td>Discussion with John Scherrer, Project Manager for CYGNSS, Southwest Research Institute</td>
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<td>4:45</td>
<td>Roundtable Discussions: Committee and Guests</td>
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<tr>
<td>5:30</td>
<td>Adjourn for the Day</td>
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THURSDAY, SEPTEMBER 18th

LASP Open Data

Sparn/Pilewskie 2
Perspectives on SmallSats and CubeSats Outline

2. Examples of SmallSat/CubeSat implementations
3. Disaggregation of LEO Earth Observing Systems (EOS) using SmallSat Capability
4. Science impacts and implication of using SmallSats on EOS
5. Risk Assessment for EOS using SmallSats and CubeSats
6. Issues with proliferation of small spacecraft
Tipping Point for Successful Design of Disaggregated Critical LEO Earth Observing Space Systems
**Current State of Small Satellite Technology**

**Small Satellite Class Definitions**

<table>
<thead>
<tr>
<th>Satellite Class</th>
<th>Mass Range</th>
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<tbody>
<tr>
<td>Small satellite</td>
<td>100 and 500 kg (220 and 1,100 lb),</td>
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<tr>
<td>Micro satellite</td>
<td>10 and 100 kg (22 and 220 lb)</td>
</tr>
<tr>
<td>Nano satellite</td>
<td>1 and 10 kg (2.2 and 22.0 lb)</td>
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<tr>
<td>Pico satellite</td>
<td>0.1 and 1 kg (0.22 and 2.20 lb),</td>
</tr>
<tr>
<td>Femto satellite</td>
<td>10 and 100 g (0.35 and 3.53 oz)</td>
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**LASP experience**

In Building and flying Satellite Systems

- **“CubeSat”**

- Many Nano-satellites are based on the “CubeSat” standard
  - Consists of any number of 10 cm x 10 cm x 10 cm units
  - Each unit, or “U”, usually has a volume of exactly one liter
  - Each “U” has a mass close to 1 kg and not to exceed 1.33 kg
    - (e.g. a 3U CubeSat has mass between 3 and 4 kg)

- Micro-satellites, such as the LASP Micro Bus (LMB), are larger and more capable but often share common avionic components with Nano-satellites

**We are in the “Age of ”U”**
Projection Estimates for Small Satellites

2013 Projection estimated:
- 93 nano/microsatellites would launch globally in 2013;
  - 92 nano/microsatellites actually launched
- An increase of 269% over 2012

2014 Projection: A significant increase in the quantity of future nano/microsatellites needing a launch.
- 260 nano/microsatellites
- An increase of 300% over 2013

2015 – 2016 Projection:
- Currently 650 future nano/microsatellites (1 – 50 kg)
- Currently 48 future (2014+) picosatellites (< 1 kg)
- An increase of 134% over 2014 (reaching maximum capacity of launch availability)

Acknowledgment:
Many statistics and data are provided by the SpaceWorks Enterprises, Inc. (SEI) Satellite Launch Demand Database (LDDB). The LDDB is an extensive database of all known historical (2000 – 2013) and future (2014+) satellite projects with masses between 0 kg and 10,000+ kg.
## Characteristics of SmallSat’s

<table>
<thead>
<tr>
<th>Small Satellites</th>
<th>Micro Satellites</th>
<th>Cube/Nano Satellites</th>
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<tbody>
<tr>
<td>$20M-$80M</td>
<td>$3M-$18M</td>
<td>$100K-$2M</td>
</tr>
<tr>
<td>Robust Propulsion</td>
<td>Limited Propulsion</td>
<td>Very limited Propulsion</td>
</tr>
<tr>
<td>Redundancy available</td>
<td>Selective Redundancy</td>
<td>Single String</td>
</tr>
<tr>
<td>Very Accurate Pointing</td>
<td>Accurate Pointing</td>
<td>Good Pointing</td>
</tr>
<tr>
<td>Substantial Launch Vehicle</td>
<td>Shared Ride or Small Launch Vehicle</td>
<td>Shared Ride in many readily available P-POD</td>
</tr>
<tr>
<td>High Data Capability</td>
<td>High Data Rate</td>
<td>Low Data Rate</td>
</tr>
<tr>
<td>Very Large Apertures</td>
<td>Large Apertures</td>
<td>Small Apertures</td>
</tr>
</tbody>
</table>
Nano Satellite/CubeSat Applications and Associated Examples

Scientific Research
Phonesat 1.0
Mass: 1 kg
Launched: 4/2013

Technology
SwampSat
Mass: 1.2 kg
Launched: 11/2013

Earth Observation
Dove 2
Mass: 5.5 kg
Launched: 4/2013

Education
ArduSat
Mass: 1 kg
Launched: 8/2013

Weather Monitoring
CSSWE
Mass: 5 kg
Launched: 09/2012

Astronomy
BRITE-PL
Mass: 7 kg
Launched: 11/2013
Examples of Concepts to expand the capabilities of Cubesat Nano/Microsatellites

1. Tension / Compression Members
2. 8 element carpenter tape deployment
3. Long Tension / Compression Members
4. Precision Rails (miniature linear bearings and guides)
5. Modified Carpenter Tape Hinge Deployment
Microsatellite Applications and Associated Examples

STPSAT-3 with TCTE

SSTL-100

STPSAT-1

LASP Micro Bus (LMB)
TOMC (concept)
Micro Satellites Capabilities and Cost

- Earth Climate Hyperspectral Observatory
  - Implemented on a Microbus
  - Continuous global 100m hyperspectral imaging (5Tbytes/day)
  - Low cost launch <$15M
  - Low cost capable bus $5.5M
  - Extremely capable instrument $23M

- CICERO
  - Implemented on a Microbus
  - Continuous global radio occultation observations
  - Low cost ESPA launch <$5M
  - Low cost capable bus $5.5M
  - Extremely capable instrument $7M

Instrument Costs Exceed Bus and Launch costs
Risk Assessment for EOS using SmallSats and CubeSats

• For current Earth Observing systems, the chief risks are most often not technical they are programmatic
  – Financial risk due to large systems costs and continuity of funding issues
  – Continuity risks due to schedule drivers of complex systems integration

• Disaggregation reduces single year cost impacts and growth
• System risk due to catastrophic failure is reduced by overlapping “constellation” of measurements
• Continuity risk reduced by having overlapping space systems
Mission Constellation Estimated Reliability

- Mission estimated reliability at four years is 0.78, dropping to 0.74 at year 5.
- The design goal of maintaining the mission reliability above 0.70 is achieved with a good margin.
Implementation Cost Profile

Total and Spectral Solar Irradiance 25 year Acquisition Through TOMC Implementation

- Earliest launch possible in 2018 if funding starts in FY 2015.
- Funding higher in first 3 years to establish hardware programs.
- Production of instruments, spacecraft and launch vehicle sustained over program.
- 25 years of CDR data production and archiving and operations.

22 Years of TSI and SSI Climate Data Records

$229M
<10M/year average

5 Spacecraft Constellation Implemented of 25 years
Why Take a risk?

• The TSIS instruments represent a substantial investment in design, calibration and implementation. ($49M)

• Copy costs for existing instruments are much lower and calibration facilities are developed and in-place. ($5.5M/TIM 6.5M/SIM copy cost)

• Larger expenditure does not guarantee successful launch.
  – Challenger loss (Sparten Halley)
  – Glory loss (Glory/TIM instrument)
Solar Irradiance Climate Data Record (CDR) Availability Risk (TOMC Provides 22+ years CDR)

- A constellation of multiple overlapping space missions provide a reliable operational system to monitor data.
- Funding risk is reduced because of low yearly expenditure.
- A large number of potential de-scopes provide planned flexibility for the future.
High Reliability Low Cost Access to Space

Evolved Expendable Launch Vehicle Secondary Payload Adapter, or ESPA ring.

Low Cost Rocket Design
Super Strypi

- Super Strypi heritage from Sounding Rockets and Missile defense systems
- Three-stage solid propellant motor stack.
- Fin & spin stabilized vehicle, with attitude control system.
- Optimized motor design: exceeds payload objectives.
- Maximize performance & minimize cost by simplifying design & manufacturing process.
- Meet quick response launch requirement.

ESPA allows up to six secondary satellites, up to 400 pounds each, to "share a ride to space" on Delta IV or Atlas V launch vehicles while carrying a large primary satellite.
The TOMC implementation is less than half the cost of large missions, with a system level reliability as implemented through a constellation of small low-cost spacecraft higher than large missions.
Issues With Proliferation of Small Spacecraft

1. Each spacecraft requires a uplink/downlink frequency allocation
2. Each spacecraft becomes “orbit debris” and occupies a potential orbital slot
3. Capability limited based on the laws of physics and there is a general “push” to reduce requirements
4. There will be more “failures” due to the implementation cost/risk choice. Although the system reliability will remain the same or better than large mission approach