Comparison of CubeSats, CubeSat Swarms and Classical Earth Observation Satellites In LEO

Christopher Robson

With Special Thanks To: University of Alberta Engineering and Science, ISSET, AlbertaSat
Introduction: Chris Robson

- 5\textsuperscript{th} Year Mechanical Engineering Co-Op at the University of Alberta
- 2012 – 2014: Project Manager of Ex-Alta 1 Satellite for AlbertaSat
- Currently: Lead of the Mechanical Design Team for Ex-Alta 1
Goal Today

1. Show that for the majority of earth observation missions flying in low earth orbit (LEO), Cube Satellite Swarms are the best choice and Micro Satellites are a close second.

2. The choice between the two comes down to the payload.

3. Show that R&D into the miniaturization of space technologies for use on CubeSat’s is valuable.

Note: CubeSat’s are limited in their capacity to host payloads.
1. Introducing the issue, the question and why the answer is important.

2. Determination of cost, risk and schedule.

3. Discuss advantages and disadvantages.

4. Discuss additional factors.

5. Conclusion
Space is expensive!

- Launch
  - Space Environment
  - No Spacecraft Repair
Economic, scientific and social potential of space is huge!

[1]
The Underlying Issue

Historically, the cost of space is an entry barrier. As a result, we have been unable to take full advantage of the potential of space.

[1]
1999 - California Polytechnic State University introduces the Cube Satellite Standard.
What is a Cube Satellite?

- 10x10x10 cm = 1U
- Standardized
- Modular
- Units of 1U, 2U, 3U and up!
CubeSat Launches Per Year From 2000 - 2014
For Earth observation missions flying in LEO, in terms of cost, schedule and risk, which are better?

Cube Satellites

Classical Satellites

Photo Credit: Andy Kale

[1]
Why is this important?

To take advantage of the potential of space we must reduce cost, schedule and risk.
The Question Revisited

For Earth observation missions operating in low Earth orbit, in terms of cost risk and schedule, which is better?

1. 3U Cube Satellite (CS)
2. 50 X 3U Cube Satellite Swarm (CSS)
3. Micro Earth Observation Satellite (EOS)
4. Small EOS
5. Large EOS
Calculation of Cost: Assumptions

- Cost is always in 2014 CAD.
- Based on conceptual design phase estimation techniques for space missions [4].
- Operational costs and overhead are not considered.

<table>
<thead>
<tr>
<th>3U Cube Satellite</th>
<th>50 X 3U Cube Satellite Swarm</th>
<th>Micro Satellite</th>
<th>Small Satellite</th>
<th>Large Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 kg</td>
<td>50 X CS</td>
<td>10-100 kg</td>
<td>101 - 500 kg</td>
<td>&gt;500 kg</td>
</tr>
</tbody>
</table>
Average development, unit and launch cost per kg obtained from literature [4] for year 2010.

<table>
<thead>
<tr>
<th></th>
<th>Development Cost per kg</th>
<th>Construction Cost per kg</th>
<th>Launch Cost per kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average FY2014</td>
<td>$462,720</td>
<td>$81,553</td>
<td>$15,683</td>
</tr>
<tr>
<td>(CAD)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Data from the Union of Concerned Scientists satellite data base. [5] Obtained development, construction and launch cost average for micro, small and large EOS.

<table>
<thead>
<tr>
<th>Name of Satellite, Alternate Names</th>
<th>Launch Mass (kg.)</th>
<th>Dry Mass (kg.)</th>
<th>Development Cost FY2014 (CAD)</th>
<th>Construction Cost FY2014 (CAD)</th>
<th>Launch Cost FY2014 (CAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WNISat-1 Weather News Inc. Satellite 1)</td>
<td>10</td>
<td>10</td>
<td>$4,627,199</td>
<td>$815,532.81</td>
<td>$156,832</td>
</tr>
<tr>
<td>DX-1 (Dauria Experimental 1)</td>
<td>27</td>
<td>27</td>
<td>$12,493,436</td>
<td>$2,201,938.59</td>
<td>$423,446</td>
</tr>
<tr>
<td>ORBCOMM FM-10 (ORBCOMM A2)</td>
<td>45</td>
<td>22</td>
<td>$10,179,837</td>
<td>$1,794,172.18</td>
<td>$705,743</td>
</tr>
<tr>
<td>ORBCOMM FM-11 (ORBCOMM A3)</td>
<td>45</td>
<td>22</td>
<td>$10,179,837</td>
<td>$1,794,172.18</td>
<td>$705,743</td>
</tr>
</tbody>
</table>

Example of data from UCS satellite data base
• 3U CubeSat.
• Based on 4 kg mass.
• Launch mass based on the need to add a deployment pod (~ 2 kg).

[1] 3U CubeSat and Deployment Pod
## Cost Summary

<table>
<thead>
<tr>
<th>FY2014 (CAD)</th>
<th>3U CubeSat</th>
<th>50 X 3U CubeSat Swarm</th>
<th>Micro</th>
<th>Small</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development Cost (000)</td>
<td>$1,850</td>
<td>$1,850</td>
<td>$11,200</td>
<td>$129,000</td>
<td>$325,000</td>
</tr>
<tr>
<td>Construction Cost (000)</td>
<td>$326</td>
<td>$16,300</td>
<td>$1,980</td>
<td>$22,800</td>
<td>$57,300</td>
</tr>
<tr>
<td>Launch Cost (000)</td>
<td>$94</td>
<td>$4,700</td>
<td>$701</td>
<td>$5,440</td>
<td>$11,000</td>
</tr>
<tr>
<td>Total Mission Cost (000)</td>
<td>$2,270</td>
<td>$22,900</td>
<td>$13,900</td>
<td>$158,000</td>
<td>$393,000</td>
</tr>
<tr>
<td>Total Cost for Each Additional Unit (000)</td>
<td>$420</td>
<td>$420</td>
<td>$2,680</td>
<td>$28,300</td>
<td>$68,300</td>
</tr>
</tbody>
</table>
Risk Exposure = Risk Probability x Risk Impact

• Only risks that vary significantly between different platforms considered.

• Only risks to mission failure considered.

• Risks determined prior to mitigation actions.

• Mitigation actions increase cost and schedule.
## Determination of Risk: Risks

<table>
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<tr>
<th>Risk</th>
</tr>
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<tbody>
<tr>
<td>Launch Vehicle Destruction</td>
</tr>
<tr>
<td>Schedule Estimation Error</td>
</tr>
<tr>
<td>Budget Estimation Error</td>
</tr>
<tr>
<td>Damage to Single Spacecraft in Orbital</td>
</tr>
</tbody>
</table>
1. CSS have a lower exposure to risk because of the advantage of their numbers.

2. This analysis is not about reliability, classical satellites are more reliable than CubeSats.

3. To decrease risk, we must take mitigative actions which take more time and money.
# Risk Summary and Discussion

## Exposure

<table>
<thead>
<tr>
<th>Risk Description</th>
<th>3U CubeSat</th>
<th>50 3U CubeSat Swarm</th>
<th>Micro</th>
<th>Small</th>
<th>Large</th>
</tr>
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<tbody>
<tr>
<td>Launch Vehicle Destruction</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Schedule Estimation Error</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Budget Estimation Error</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>Damage to Single Spacecraft in Orbit</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total Exposure</strong></td>
<td><strong>14</strong></td>
<td><strong>10</strong></td>
<td><strong>14</strong></td>
<td><strong>23</strong></td>
<td><strong>36</strong></td>
</tr>
</tbody>
</table>
## Determination of Schedule

<table>
<thead>
<tr>
<th>Time</th>
<th>Cube Satellite</th>
<th>Cube Satellite Swarm</th>
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<tr>
<td><strong>Development Time [2]</strong></td>
<td>2.5 Years</td>
<td>2.5 Year</td>
<td>2.5 Years</td>
<td>10 Years</td>
<td>15 Years</td>
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<tr>
<td><strong>Construction Time per Satellite [2]</strong></td>
<td>6 months</td>
<td>6 months</td>
<td>1 year</td>
<td>3.5 Years</td>
<td>5 Years</td>
</tr>
<tr>
<td><strong>Operation Time per Satellite [2]</strong></td>
<td>5 Years</td>
<td>5 Years</td>
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Advantages and Disadvantages: CubeSats

**Advantage**
- Standardized design.
- Availability of space qualified commercial off the shelf components (COTs).
- Low cost.
- Small schedule.

**Disadvantage**
- Type of payload is limited by size, power, pointing requirements and communications.
- Few actions to mitigate risk.
Advantages and Disadvantages: CubeSat Swarm

**Advantage**

- Same as CubeSats.
- Low risk.
- Flexible swarm number
  - Coverage area
  - Cost
  - Number of payloads
  - Reliability

**Disadvantage**

- Same as CubeSats.
- Resources required for construction.
Advantages and Disadvantages: Earth Observation Satellites

Advantage

• Customizable.
• Few payload limits.
• Lots of actions to mitigate risk.
• Space heritage of technologies.
• Half a century of expertise.

Disadvantage

• Cost is high and inflexible, this increases with satellite size.
• Risk of mission failure is high and increases with satellite size.
### Summary of Data

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1. Cost, schedule and risk for small and large EOS is significantly higher than the other cases.

2. A single CS has the lowest cost, the lowest schedule and a low risk. However, limitations to risk mitigation actions and on capacity to fly payloads are significant.
Discussion: CSS’s vs. Micro EOS’s

• Micro has smaller cost, but CSS’s have budget flexibility.

• CSS’s have lower overall risk.

• Comparable schedule for both.

• CSS’s have a significantly higher coverage area and a greater number of sampling points.

BUT!
Primary reason to have satellites is to host payloads.

CubeSats and CubeSat Swarms are limited in their capacity to host payloads.
Discussion: Limited by Payload

- Small form factor.
- Limited amount of power.
- Limited amount of communication.
- Pointing accuracy may be a concern.
However, as the CubeSat demonstrates, technological advances allow for miniaturized and optimized space systems and sensors.

Heavy focus on R&D is needed to expand the range of applications for CubeSats.
Conclusion

1. For most applications, CSS are the best choice and Micro EOS are a close second.
2. Payload limitations are the deciding factor.
3. R&D in space systems and sensors miniaturization and optimization will greatly increase the range of applications for CubeSats.
Acknowledgements:

- AlbertaSat Faculty and Team Members
- U of A Engineering and Science
- Institute for Space Science Exploration and Technology (ISSET)

For references please see slides 34 and 35.

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[1] Photos obtained through open licences.


