2015 NASA Cost Symposium

AMES Cost Model
Ames Micro/Nanosatellites Cost Model

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Tommy Paine, Code CP, Division Chief
thomas.c.paine@nasa.gov, (650) 604-4943

Michael (Sok Chhong) Saing, Booz Allen Hamilton, Code CP, Cost Analyst/Economist
sokchhong.saing@nasa.gov, (650) 604-2321
OUTLINE

• Market Assessment – Micro/Nanosatellites
• Development Process
• AMES Cost Model Overview
• Data Collection Plan
• Discussion and Feedback
Observations

• Cubesats are growing in popularity

• Micro/nanosatellite projects cost data are very limited to the available public

• Design and development cost drivers are rapidly changing to adapt to orbiting environments

• Science/Technology, Systems Integration and Testing (SI&T), Mission Operations, and Ground Data Systems (GDS) are specific to each project and there is not enough category cost data to rely on analogous cost yet
AMES Cost Model Characteristics

- **Motivation:** Fill in the void for the lack of commercially available micro/nanosatellite (<50 kg) cost model

- **Goal:** Develop an analogous and parametric base cost estimate for micro/nanosatellite development. (up to 14kg and 6U cubesat form factor)

- **Capabilities:**
  - Cubesat spacecraft bus cost estimate
  - Project level cost estimate aligns to NASA’s WBS
  - Cost Phasing
  - Risk Analysis
  - Inflation adjustments

- **Two Types of Cost Estimate:**
  - Self design with user input hardware parameters
  - Preload existing heritage design with options to modify, delete, and/or add additional components as needed (e.g. Level of Modification (options): no modification, minor, major)
Cost Model Development Methodology and Process

1. Conduct market analysis needed for cost model
2. Sketch preliminary cost model framework output based on need
3. Collect project data – Cost, Technical Design, Project Management and Schedule
4. Allocate data to NASA WBS Standards NPR 7120.5E
5. Define and normalize data
6. Analyze statistical relationships
7. Generate relevant cost data and parameters into model
8. Verify and validate. Repeat steps #5 to 8 if necessary to refine estimate.

We are here
Nano/ Microsatellite Market Overview/Assessment

Low Earth Orbit (LEO) Spacecraft excluding Missions to ISS

- Average spacecraft mass is significantly reduced when removing missions to ISS
- Still demonstrates the continual decrease in average spacecraft mass

Updated Report January 2015: Follow-up to 2014 forecast, and by comparison from 2014 to 2013 actuals, there was a 72% increase.
## Past and Present NASA ARC Micro/Nanosatellite Missions

<table>
<thead>
<tr>
<th>Year (CY)</th>
<th>Form Factor (U)</th>
<th>Mission Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>3</td>
<td>GeneSat</td>
</tr>
<tr>
<td>2008</td>
<td>3</td>
<td>PreSat</td>
</tr>
<tr>
<td>2008</td>
<td>3</td>
<td>NanoSail-D1</td>
</tr>
<tr>
<td>2009</td>
<td>6</td>
<td>Pharmasat</td>
</tr>
<tr>
<td>2010</td>
<td>3</td>
<td>O/OREOS</td>
</tr>
<tr>
<td>2011</td>
<td>1</td>
<td>PhoneSat1 beta</td>
</tr>
<tr>
<td>2011</td>
<td>3</td>
<td>NanoSail-D2</td>
</tr>
<tr>
<td>2012</td>
<td>1</td>
<td>Tech Ed Sat</td>
</tr>
<tr>
<td>2013</td>
<td>1</td>
<td>PhoneSat 1</td>
</tr>
<tr>
<td>2013</td>
<td>1</td>
<td>PhoneSat 2 beta</td>
</tr>
<tr>
<td>2013</td>
<td>3</td>
<td>Tech Ed Sat 3p</td>
</tr>
<tr>
<td>2014</td>
<td>1</td>
<td>PhoneSat 2.5</td>
</tr>
<tr>
<td>2014</td>
<td>3</td>
<td>SporeSat-1</td>
</tr>
<tr>
<td>2014</td>
<td>3</td>
<td>KickSat</td>
</tr>
<tr>
<td>2015</td>
<td>6</td>
<td>EcAMSat</td>
</tr>
<tr>
<td>2015</td>
<td>1.5</td>
<td>EDSN</td>
</tr>
<tr>
<td>2015</td>
<td>1.5</td>
<td>NODEs</td>
</tr>
<tr>
<td>2015</td>
<td>3</td>
<td>SporeSat2</td>
</tr>
<tr>
<td>2016</td>
<td>3</td>
<td>KickSat2</td>
</tr>
<tr>
<td>2016</td>
<td>3</td>
<td>SLPS-3 (ISS Project)</td>
</tr>
<tr>
<td>2016</td>
<td>3</td>
<td>SLPS-4 (ISS Project)</td>
</tr>
<tr>
<td>2017</td>
<td>6</td>
<td>BioSentinel</td>
</tr>
<tr>
<td>TBD</td>
<td>TBD</td>
<td>Propulsion Pathfinder</td>
</tr>
</tbody>
</table>

### NASA ARC Nano/Microsatellites Cubesat Form Factors (U)

### NASA ARC Nano/Microsatellites Applications Types
- Science: 42%
- Technology: 21%
- Communication: 29%
- Education: 8%
- N/A: 8%

### NASA ARC Nano/Microsatellites Operating Altitudes (km)
- 1450km: 50%
- 451-650km: 17%
- N/A: 8%

### NASA ARC Nano/Microsatellites Launch Year by Year
- 2013: 17%
- 2014: 13%
- 2015: 17%
- 2016: 13%
- 2017: 6%
- TBD: 25%

### NASA ARC Nano/Microsatellites Classification by Mass (kg)
- Nano (1-10kg): 75%
- Micro (11-50kg): 4%
- Unknown: 4%

### NASA ARC Nano/Microsatellites Average Orbit Power (W)
- N/A - Battery: 4%
- 4.6W: 42%
- 13W: 25%
- TBD: 25%

Note: ARC on average launches 3 nanosats/year

Key:
- TBD: Project still in progress
- N/A: Not available
Systems Requirements

• Shall Estimate Cost based on Form Factors (U) – 1U, 1.5U, 2U, 3U, 6U
• Shall Estimate Cost by NASA’s WBS Elements: 1-3, 9-10 (“Wraps”)
• Shall estimate cost Phase B/C/D
• Shall provide optional Phasing Cost Plan/Funding Profile
• Shall take into account various types of hardware: flight units, engineering units, flatsat, spares
• Shall provide cost risk analysis
• Shall provide cost estimate by: a) build (MEL) b) existing heritage with options to modify
• Shall estimate based on orbit destination (LEO, GEO, L-1, etc…)
• Shall be able to automate inflation based on NASA’s inflation rates
AMES Cost Model Flow Architecture*

*Preliminary design
### Desired Output Results

**Project Level Cost**

<table>
<thead>
<tr>
<th>WBS Description</th>
<th>FY15$ in K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Project Management</td>
<td>$874</td>
</tr>
<tr>
<td>2 Systems Engineer</td>
<td>$911</td>
</tr>
<tr>
<td>3 Safety &amp; Miss. Assur</td>
<td>$935</td>
</tr>
<tr>
<td>4 Science</td>
<td>$862</td>
</tr>
<tr>
<td>5 Payload</td>
<td>$750</td>
</tr>
<tr>
<td>6 Spacecraft</td>
<td>$1,193</td>
</tr>
<tr>
<td>7 Mission Ops</td>
<td>$777</td>
</tr>
<tr>
<td>8 Launch Services</td>
<td>$935</td>
</tr>
<tr>
<td>9 Ground Data System</td>
<td>$874</td>
</tr>
<tr>
<td>10 System Integration &amp; Testing</td>
<td>$874</td>
</tr>
<tr>
<td>11 EPO</td>
<td>$90</td>
</tr>
<tr>
<td><strong>Subtotal (B/C/D)</strong></td>
<td>$9,078</td>
</tr>
<tr>
<td><strong>Phase A</strong></td>
<td>$1,816</td>
</tr>
<tr>
<td><strong>Total (Phase A-D)</strong></td>
<td><strong>$10,893</strong></td>
</tr>
<tr>
<td>Reserve</td>
<td>$2,723</td>
</tr>
<tr>
<td><strong>Grand Total with Reserve (A-D)</strong></td>
<td><strong>$13,616</strong></td>
</tr>
</tbody>
</table>

*Parametric Estimate, xx% of B-D*
Desired Output Results
Spacecraft Hardware Cost

<table>
<thead>
<tr>
<th>Spacecraft Subsystem</th>
<th>Estimated Total Cost, FY15$ in K</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guidance, Navigation, and Control</td>
<td>$172</td>
<td>14%</td>
</tr>
<tr>
<td>Command &amp; Data Handling</td>
<td>$209</td>
<td>18%</td>
</tr>
<tr>
<td>Telemetry, Telecomm. &amp; Control</td>
<td>$131</td>
<td>11%</td>
</tr>
<tr>
<td>Propulsion</td>
<td>$59</td>
<td>5%</td>
</tr>
<tr>
<td>Electrical Power Subsystem</td>
<td>$250</td>
<td>21%</td>
</tr>
<tr>
<td>Structure and Mechanical</td>
<td>$125</td>
<td>10%</td>
</tr>
<tr>
<td>Thermal</td>
<td>$47</td>
<td>4%</td>
</tr>
<tr>
<td>Contract fee</td>
<td>$199</td>
<td>17%</td>
</tr>
<tr>
<td><strong>Total Hardware Cost</strong></td>
<td><strong>$1,193</strong></td>
<td></td>
</tr>
</tbody>
</table>
Desired Output Results
Phasing Expenditure Plan

Phasing Expenditure Plan

Expenditure Dollars, not Budget. See other table for Budget.

<table>
<thead>
<tr>
<th>AO (1) or Directed (0)</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>GFE Hardware</td>
<td>2</td>
</tr>
<tr>
<td>Months duration (to last)</td>
<td>48</td>
</tr>
<tr>
<td>Months from SRR to PDR</td>
<td>5</td>
</tr>
<tr>
<td>SRR Date</td>
<td>1/1/2015</td>
</tr>
<tr>
<td>Last Launch</td>
<td>1/1/2020</td>
</tr>
<tr>
<td>Total Mission (no launch) Cost (BYS)</td>
<td>13816</td>
</tr>
<tr>
<td>Base Year</td>
<td>2015</td>
</tr>
</tbody>
</table>

Example: AMES Cubesat Projection - Expenditure Phasing Cost

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>% time (100% at last launch)</th>
<th>% BY cost (100% at last launch)</th>
<th>Annual Cost (BYS, K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>19%</td>
<td>18%</td>
<td>$2,203</td>
</tr>
<tr>
<td>2017</td>
<td>44%</td>
<td>44%</td>
<td>$3,227</td>
</tr>
<tr>
<td>2018</td>
<td>69%</td>
<td>70%</td>
<td>$3,165</td>
</tr>
<tr>
<td>2019</td>
<td>94%</td>
<td>94%</td>
<td>$2,935</td>
</tr>
<tr>
<td>2020</td>
<td>113%</td>
<td>111%</td>
<td>$2,066</td>
</tr>
</tbody>
</table>

0 0% 0% $0
0 0% 0% $0
0 0% 0% $0
0 0% 0% $0
0 0% 0% $0
0 0% 0% $0
0 0% 0% $0
0 0% 0% $0
0 0% 0% $0
0 0% 0% $0

Booz | Allen | Hamilton
Desired Output Results
Uncertainty Risk Probability Analysis

Risk Analysis

<table>
<thead>
<tr>
<th>Risk and Uncertainty Analysis</th>
<th>Cumulative Prob, % and $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enter xth-%tile Cost Here from Simulation</td>
<td>$13,429</td>
</tr>
<tr>
<td>Recommended Reserve, %</td>
<td>23%</td>
</tr>
<tr>
<td>Recommended Reserve, $</td>
<td>$2,536</td>
</tr>
</tbody>
</table>

Example: AMES Cubesat Cost Risk Analysis

- 80th-%tile: $9,290

Cumulative Probability, %

Total Cost, $
Data Collection Plan

• Provide an easy input questionnaire template for the project missions for the PM, SE, and or cost resource for the project (such as CM who does the purchase request).
  • To minimize time for the partners, most info request will be filled out as they are publicly available information. Just need them to verify.

• Example of questionnaire for the PM/SE/Cost Resource:
  • Launch Date and Vehicle, Mission Type (Com. Sci., Tech, Edu)
  • Destination – LEO, LEO-ISS, Planetary, etc..
  • Development Time (months) and milestone dates
  • Design Life
  • Form Factor - # of U’s
  • “C3PO” – Comm (Up/Down/Cross-Link), Power (EPS), Propulsion, Pointing (ADCS/GNC), Operations (autonomy), Struc. (deployable), C&DH (processors)
  • Total Project Cost, FTE/WYE, Contributions, SC subsystems
Addressing Cost Model Development Challenges

- Determine design and mission parameters to cost relationships
- Determine common cost estimating relationships (CERs) from traditional small spacecraft (>50kg) for application of micro/nanosatellites cost estimate
- Cost factors for different types of orbits – Suborbital, LEO, LEO-ISS, GEO, etc..
- Cost factors for modifying COTS (i.e. Major Modification, Minor Modification, No Modification)
- Determine cost savings from using design heritage
- Determine cost scaling factor pattern (example – cost of 3U will double if designed to 6U).
Development Process

Where we’ve been:

• Set the requirements
• Began socializing to the Ames, cost community, and subject matter experts
• Explored other parametric tools – PRICE TP (Space Mission Catalog), SEER, NASA’s Project Cost Estimating Capability (PCEC), The Aerospace SSCM (Small Satellite Cost Model)

Where we are currently:

• Collecting cost, project, and technical data.
• Continuing to socializing ideas to the Ames and cost community

Path Forward:

• Continuing to gather and collect cost, project, and technical data (10 projects)
• Normalize and analyze collected data results and validity to the cost tool
• Continue to leverage expertise from the cost community
• Generate data into cost model and test preliminary model by Fall 2015 (depending on data collected)
Summary

• Increase Demand of micro/ nanosatellites calls for a need for more efficient and accurate cost estimates

• Development Process

• AMES Cost Model Overview

• Data Collection Plan
Acknowledgement

• **NASA ARC Community:**
  • Paul Agnew, Chief Financial Officer (CFO), Ames Research Center
  • Jay Bookbinder, Director of Programs and Projects
  • David Korsmeyer, Director of Engineering
  • Leon Shen, Associate, Booz Allen Hamilton
  • Chad Frost, Division Chief, Mission Design Division
  • Deborah Westley, Program Manager, Chief Scientist Office
  • Elwood Agasid, Chief Technologist, Mission Design Division
  • Andrea Nazzal, Deputy Program Manager, PESS Contract
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  • Joe Mrozinski (JPL)
  • Mark Jacobs (Victory Solutions)
  • Nani Tosoc (NASA LARC)
Thank You

Questions, Discussions and Feedback

Contacts:

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Back-up Slides
Past and Present NASA ARC Cubesats Mission

Key:
TBD: Project still work in progress
N/A: Not available
Past and Present NASA ARC Cubesats Mission

NASA ARC Nano/Microsatellites Class by Mass

- Nano (1-10kg)
- Micro (11-50kg)
- TBD

NASA ARC Nano/Microsatellites Average Orbit Power

- 1-3W
- 4-6W
- Unknown Power, W
- TBD
- N/A - Battery

Key:
TBD: Project still work in progress
N/A: Not available
Top 10 Project Missions to start out with

- GeneSat
- PharmaSat
- O/OREOS
- Nano-Sail D2
- PhoneSat 2.4
- PhoneSat 2.5
- EcAMSat
- EDSN
- NODEs
- SporeSat1
- SporeSat2
Nano/Microsatellite Market Overview/Assessment

Nano/Microsatellite Trends by Purpose (1 – 50 kg)

More than half of future nano/microsatellites will be used for Earth observation and remote sensing purposes (compared to 10% in 2013)

A smaller proportion of technology development/demonstration nano/microsatellites will be built in 2014 (31% vs. 55% in 2013)