Life Cycle Analysis of Dedicated Nano-Launch Technologies

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Motivation

- Technology advancements have enabled small cheap satellites that can perform useful functions
- Potential customers include commercial, academia, civil government and DOD
- Currently, the main option for getting these payloads into LEO is through ride share, limiting launch opportunities
- A proposed alternative approach is dedicated nano-satellite launch vehicles operated at an affordable price
  - NASA to invest and enable the development of related technologies

First of many CubeSats deployed from the International Space Station by NanoRacks in February 2014. [nanoracks.com/nanoracks-deploys-two-small-satellites/](https://nanoracks.com/nanoracks-deploys-two-small-satellites/)
Key Takeaways

• Limited experience base for this class of launch vehicles

• Estimated to cost 10s of $M per launch in business-as-usual approaches

• Launch vehicle scale reductions *alone* do not enable the goal of < $2M recurring launch cost

• Preliminary analysis shows that nano-launcher technology investments can significantly improve dedicated nano-launch capabilities

• *The combination of technologies and efficient commercial approaches can enable the goal of < $2M recurring launch cost*
Project Team, Objective

- Inter-center, inter-agency team formed
  - NASA LaRC SACD/VAB – Performance, Design, Costing
    - John Martin (lead), Roger Lepsch, Hernani Tosoc
  - NASA KSC – Life Cycle Cost (LCC) Estimation, Modeling
    - Edgar Zapata, Carey McCleskey, Robert Johnson, Eddie Santiago
  - Air Force Research Lab – Costing Tools, Technology Data
    - Greg Moster, Bruce Thieman

- Identify primary cost drivers for small launch vehicles (nano-small payload class, 5-100 kg)
- Identify technology and concept opportunities to significantly reduce launch cost
- Determine feasibility of achieving goal of < $2 M for a dedicated launch capability
  - Cost goal established in 2013 NESC nano-launcher assessment study conducted by R. Garcia
  - DARPA ALASA and US Army SWORDS each set goal of $1M per launch
Related Investments

- Government
  - ALASA (DARPA) – 45 kg, air-launch
  - SWORDS (Army) - 25 kg, mobile ground launch
  - Super Strypi (Sandia-USAF/SMC) – 300 kg, rail launch

- Commercial (partial listing)
  - Garvey Aerospace – non-toxic liquid, rail launch
  - Scorpius – pressure fed liquid
  - Raytheon – solid (developing a $2M small sat launcher to fly under wing of F-15)
  - Generation Orbit/Space Propulsion Group (SPG) – hybrid
    - NEXT (NASA) – 15 kg (3x3U,) $2.1M single flight services contract
  - Ventions, Inc. – micro turbo pumps, vortex combustion
  - Whittinghill Aerospace - hybrid
Nano-satellite Market Summary

- Price-of-entry with traditional, larger satellites, and their larger launchers, coupled with NASA budgetary pressures, driving small-sat innovation

- Universities currently dominate the Nano-sat/cube-sat field
- NASA and 2DoD also creating demand
  - NASA Cube-Sat Launch Initiative (CSLI)
  - Most CSLI awards to date have been to universities
- DoD spurring supply/launchers (SWORDS, ALASA)
- Private sector also responding with supply/launchers (Garvey, Raytheon, etc.)
- Private sector small-sat/cube-sat field is growing fast
  - Likely to dominate future market-and soon
  - Demand being driven by increasing and envisioned small-sat capabilities
  - Small-sats as an increasingly accessible, participatory technology
## Study Requirements

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE / RANGE</th>
<th>NOTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Orbit:</td>
<td>45° Inclination 400 km Altitude</td>
<td>Target values within range of interest 0° - 98° Incl., 350 – 650 km Alt.</td>
</tr>
<tr>
<td>Launch Latitude</td>
<td>38°</td>
<td>Wallops; close to target inclination Others: KSC, Vandenberg, Airlaunch</td>
</tr>
<tr>
<td>Payload mass on orbit</td>
<td>5 kg</td>
<td>Mass of free-flying, deployed spacecraft (range of 5 – 50 kg)</td>
</tr>
<tr>
<td>Insertion accuracy</td>
<td>±75 km orbit altitude ±1° Orbit inclination</td>
<td>Accuracies are not critical for many small and very small spacecraft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Need to understand sensitivity</td>
</tr>
<tr>
<td>Spacecraft accommodations</td>
<td>Separation signal</td>
<td>Desire minimal demands on launch vehicle</td>
</tr>
<tr>
<td></td>
<td>T-0 trickle charge</td>
<td>- Need environment specs</td>
</tr>
<tr>
<td></td>
<td>Environmental control within fairing</td>
<td>- Payload status for rapid calibration</td>
</tr>
<tr>
<td></td>
<td>Narrowband telemetry on launch</td>
<td></td>
</tr>
<tr>
<td>Load/Environment Limits (Payload)</td>
<td>20 g axial acceleration 5 g lateral acceleration</td>
<td>Need to determine limits on payload</td>
</tr>
<tr>
<td>Launch cost (recurring)</td>
<td>&lt;$2M/launch &lt;$1M/launch (stretch goal)</td>
<td>Goal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Assumes annual flight rate of 12</td>
</tr>
<tr>
<td>Responsiveness</td>
<td>&lt;48 hours call-up time</td>
<td>Goal – Relates to military ops</td>
</tr>
<tr>
<td></td>
<td>&lt;24 hours call-up time (stretch goal)</td>
<td>Source: ALASA and SWORDS</td>
</tr>
<tr>
<td>Launch Reliability</td>
<td>0.9</td>
<td>Can accept lower reliability due to very low satellite cost</td>
</tr>
</tbody>
</table>
Assumptions

• Assume state-of-the-art technologies and business-as-usual practices as a baseline for vehicle concepts

• Maintain payload capabilities through vehicle resizing

• Recurring launch cost goal assumed to include recurring manufacturing and operations (including launch), fixed and variable costs, but not up-front, non-recurring development

• Assume Poly Pico-satellite Orbital Deployer (P-POD)
  • Have deployed > 90% of all CubeSats to date
  • 100% of all CubeSats since 2006

• Standard payload accommodations
  • No services, no customizing
  • Akin to rideshare accommodations
  • “No trickle charging, spot purging or driving cleanliness requirements” (Re. Space-X Secondary Payloads Hosting)
Assessment Process – Reference, Historical, Sanity Checks

- Quantitative and Qualitative Reference Systems
  - NASA Scout (ACT and LCC top-down modeling, anchors/baselines)
  - Aerospace sub-systems (SEER bottoms-up modeling, baselines)
  - Pegasus XL, Minotaur, Surface-to-Air missiles (at Nano-Launcher scale, for costs, lot sizes, etc.), Atlas/Falcon (for contrasts in practices), and previous assessments (Kibbey).

\[ y = 11.25x + 67.791 \]

- Fixed Cost = $67.8M/Year
- Marginal Cost = $11.3M/Flight

**Trend Line (No Development)**

**Scout Program Cost-Performance Curve**

*(No Scout Dev $S's)*

Source: NASA CR165950/Part 1, Table LX III, p. 271 and Table CL III(a), pp. 437-8

**Scout – Historical (inflation adjusted)**

Used in ACT and LCC Model

**Surface-to-Air Missile Specification Costs, Scale, etc. used as Reference**

SEER uses a processed dataset, based on proprietary data assembled by Galorath Incorporated, which contains approximately 3000 projects of assorted types.

**Sub-systems datasets Used in SEER Model**
Assessment Process – Baselines & Reference

- Define **baseline** concepts to conduct assessments
  - Span the range of relevant approaches and technologies for a dedicated 5kg payload nano-launcher
  - Reflect current approaches and state of art technologies
  - To be modeled to a fidelity sufficient for the technology trades of interest
- Develop **reference** concepts to benchmark assessment metrics
  - Identify cost drivers using reference concepts
- Perform technology trades/assessments on baseline concepts to address cost drivers
- Provide technology impacts and investment recommendations

<table>
<thead>
<tr>
<th>Baseline Concept</th>
<th>Launch Mode</th>
<th>Baseline Features/Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 stage solid motor design</td>
<td>Rail</td>
<td>Spin stabilized 1st &amp; 2nd stages, Attitude control upper stages</td>
</tr>
<tr>
<td>3 stage pressure fed liquid</td>
<td>Pad</td>
<td>Pressure fed LOX/RP, TVC, Composite tanks/structure, etc.</td>
</tr>
<tr>
<td>3 stage hybrid motor design</td>
<td>Pad</td>
<td>HTPB fuel, Composite structure, TVC, etc.</td>
</tr>
</tbody>
</table>
Assessment Process – Baselines & Reference

• Baselines span a range of relevant approaches
  • Sufficient detail to allow assessment of the technology and life cycle drivers of interest
  • Phase I summer 2013 task centered mostly on Concept 1 – a 4 stage solid

• Reference concept Scout studied extensively

Scout
Historical
4-stage Solid
Payload: 200 kg

Concept 1 Definition (NL001) – Preliminary
- Baseline Design and Technology Assumptions
  - Payload Mass: 10 kg (5 kg target)
  - Configuration: 4-Stage, Expendable
  - Launch Mode: Rail launch
  - Propulsion: All solid
  - Propellants: HTPB
  - Structures: All composite
  - Guidance & Ctrl: Spin/Fin stabilized + ACS
  - FTS: Destruct (stages 3 & 4 only)
  - Vehicle Integration: Horizontal
  - Acquisition Concept: Traditional/Gov.
  - Manufacturing/Ops/Launch Approach: Traditional/Business-As-Usual

- Performance Characteristics
  - Dry Mass: 630 kg
  - Gross Mass: 8130 kg

Concept 2 Definition (NL002) – Preliminary
- Baseline Design and Technology Assumptions
  - Payload Mass: 9 kg (5 kg target)
  - Configuration: 2-Stage, Expendable
  - Launch Mode: Pad launch
  - Propulsion: Pressure-fed – He w/HX
  - Propellants: LOX, RP-1 (mix ratio 2.6)
  - Structures: All composite
  - Guidance & Ctrl: TVC – Battery/EMA
  - FTS: Thrust cutoff + Destruct
  - Vehicle Integration: Horizontal
  - Acquisition Concept: Traditional/Gov.
  - Manufacturing/Ops/Launch Approach: Traditional/Business-As-Usual

- Performance Characteristics
  - Dry Mass: 255 kg
  - Gross Mass: 1800 kg
Assessment Process – Summary

**Models & Tools**

- Scale Down
- Flight Rate Up

**Promising-BUT sizing and performance modeling challenges remain**

- Meets Performance?
- Meets Cost Goal?

**Sanity checks, confirm results, refine tools**

**Historical Data – Missiles**

- Yes-Promising
- Meets Cost Goal?

**Repeat the Process**

Change:
- Technology
  - Flight systems
  - Ground systems
  - Manufacturing
  - Operations
- Design, simplify
- Process, practices and efficiencies (“best practices”)

**Define specific drivers & relation to technology and investment approaches**
Results – Example

N/L Cost-per-Flight Sensitivities

- All-Solid concept (4-stage) versus all-Liquid concept (2-Stage) examined
- Streamlined processes/practices offer great potential but not sufficient to meet goal
- Application of advanced technology has the potential to achieve the goal

$1-2M N/L Cost-per-Flight Goal

Flight Rate, Flights/year

Cost-per-Flight, $M/Flt FY13

NL001/All-Solid
w/ BAU Processes & Practices

NL002/All-Liquid
w/ BAU Processes & Practices

NL001/All-Solid
w/ Streamlined Com'l Practices

NL002/All-Liquid
w/ Streamlined Com'l Practices
Forward Work

- **Technology Assessment**

<table>
<thead>
<tr>
<th>Cost Component</th>
<th>Production Fixed</th>
<th>Production Variable</th>
<th>Integration</th>
<th>Ops Fixed</th>
<th>Ops Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Driver</td>
<td>No. of stations</td>
<td>No. of steps</td>
<td>Unique Elements</td>
<td>Infrastructure</td>
<td>No. of steps</td>
</tr>
</tbody>
</table>

  - **Product Technology**
    - Common avionics
    - COTS avionics
    - Non-toxic propellants
    - Hybrid/solid propulsion
    - Non-toxic RCS
  
  - **Manufacturing Technology**
    - Composites
    - Materials (Nano-tubes)
    - Out-of-autoclave composites
    - 3D Printing (DLMS, etc.)
    - Segmented Solid/Cartridge (?)
    - Production
  
  - **Ops/Launch Technology**
    - FTS (AFSS)
    - Automated/standard launch planning (AFSS)
  
  - **Manufacturing concepts**
    - Automation/robotics
    - Cellular manufacturing
  
  - **Operations Concepts**
    - Payload Integration/service level

  - What does technology X do to this component of cost, affecting it’s causes of cost, it’s cost drivers?
  
  - Responsiveness/flight rate capability (productivity) also co-related similarly
  
  - Need involvement of the technology community
Forward Work

• Design and analyze all concepts identified in Phase I task to a higher level of fidelity including additional concepts

• Develop refined life cycle cost estimates for all concepts

• Continue to develop technology assessment/modeling process (including tech prioritization output formats)

• Gather and organize information on potential technologies to enable assessments at systems level

• Explore nano-satellite market segments and study various business case scenarios
In Closing

• Promising evidence that a dedicated nano-launcher can reach a recurring manufacturing + launch goal of ~$1M-$2M a launch.
• Our assessment points in specific directions suitable for NASA investments, technology:
  • To increase flight rate capability of a resulting infrastructure & organization
  • To reduce production/operations infrastructure and their fixed costs
• System level cost drivers should inform system level investments.
  • Technical: reduced scale of systems only get recurring costs so far.
    • Small scale does not assure low costs.
    • Distinct functional hardware/software requirements must be addressed.
  • Non-technical: market or flight rate assumptions only get recurring costs so far.
    • High flight rate does not assure low costs.
    • A highly productive infrastructure/organization will yield a low recurring cost, and a price, that should encourage more flight demand, but flight rate demand alone will not resolve recurring cost issues.
Backup
Launch Capability - Current

• Current dedicated small-sat launchers do not meet the needs of nanosat community
  • e.g., Pegasus XL/Minotaur (443-1735kg/LEO) @ $40-$50M/launch
  • Additionally, contract to launch time 18 months or more

• Rideshare opportunities are cheap but very constraining
  • As secondary payload, constrained to primary mission orbit and schedule
  • Current commercial rideshare rates:
    • $100K - $600K for nanosat (1-10 kg),
    • $600K-$3M for microsat (10-100 kg),
    • $3M-$8M for smallsat (100-500 kg)
  • Contract to launch time still 18 months or more
Recurring Cost Insight

SCOUT Recurring Cost ~$24M/Flight @ 5.3 Flight-per-Year Average
(FY 2013 Basis)

- Scout/historical: Smallest recurring cost component alone exceeds $2M/flight
- Cost-per-flight sensitive to flight rate
- Particularly for utilization less than 5 per-year
Baseline Design and Technology Assumptions

- **Payload Mass**: 10 kg (5 kg target)
- **Configuration**: 4-Stage, Expendable
- **Launch Mode**: Rail launch
- **Propulsion**: All solid
- **Propellants**: HTPB
- **Structures**: All composite
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- **Acquisition Concept**: Traditional/Gov.
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Performance Characteristics

- **Dry Mass**: 630 kg
- **Gross Mass**: 8130 kg
Concept 2 baseline for technology & life cycle assessment

- **Baseline Design and Technology Assumptions**
  - **Payload Mass:** 9 kg (5 kg target)
  - **Configuration:** 2-Stage, Expendable
  - **Launch Mode:** Pad launch
  - **Propulsion:** Pressure-fed – He w/HX
  - **Propellants:** LOX, RP-1 (mix ratio 2.6)
  - **Structures:** All composite
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