Life Cycle Analysis of Dedicated Nano-Launch Technologies

Commercial and Government Responsive Access to Space Technology Exchange

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

Scout Program Cost-Performance Curve
(No Scout Dev $$'s$$)

Trend Line (No Development)
y = 11.25x + 67.791
Fixed Cost = $67.8M/Year
Marginal Cost = $11.3M/Flight

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

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

Scout – Historical (inflation adjusted)
Used in ACT and LCC Model

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

**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

**Scout**

Historical

4-stage Solid

Payload: 200 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

- Scale Down
- Flight Rate Up

Promising-BUT sizing and performance modeling challenges remain

Yes - Promising

Models & Tools

Historical Data – Scout, Sub-systems
ACT
AML
SEER/BOE
L-LCC

Sanity checks, confirm results, refine tools

Historical Data – Missiles

Meet Cost Goal?

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

No

Define specific drivers & relation to technology and investment approaches

Meet Cost Goal?

Meet Performance?

Meets Cost Goal?
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
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(?)

- **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
Concept 1 baseline for technology & life cycle assessment

- **Baseline Design and Technology Assumptions**
  - **Payload Mass**: 10 kg (5 kg target)
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- **Performance Characteristics**
  - **Dry Mass**: 630 kg
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Concept 2 baseline for technology & life cycle assessment

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  - **Configuration**: 2-Stage, Expendable
  - **Launch Mode**: Pad launch
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