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>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 - Need to understand sensitivity</td>
</tr>
<tr>
<td>Spacecraft accommodations</td>
<td>Separation signal T-0 trickle charge Environmental control within fairing Narrowband telemetry on launch</td>
<td>Desire minimal demands on launch vehicle - Need environment specs - Payload status for rapid calibration</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 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 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).

**Trend Line (No Development)**

\[
y = 11.25x + 67.791
\]

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

**Scout Program Cost-Performance Curve**

(No Scout Dev $’s)

Source: NASA CR165950/Part 1, Table LXIII, 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

- Scale Down
- Flight Rate Up

Promising – BUT sizing and performance modeling challenges remain

Sanity checks, confirm results, refine tools

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

Historical Data – Missiles

Yes - Promising

Meets Cost Goal?

Models & Tools

ACT

AML

SEER/BOE

L-LCC

Historical Data – Scout, Sub-systems

Meets 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></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of stations</td>
<td>No. of steps</td>
<td>Unique Elements</td>
<td>Infrastructure</td>
<td>No. of steps</td>
<td></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

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- 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

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**Flight Rate Sensitivity**

- **Cost-per-Flight ($M/Flt)**
- **Annual Flight Demand (Flts/Yr)**
Concept 1 baseline for technology & life cycle assessment

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Concept 2 baseline for technology & life cycle assessment

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