# 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

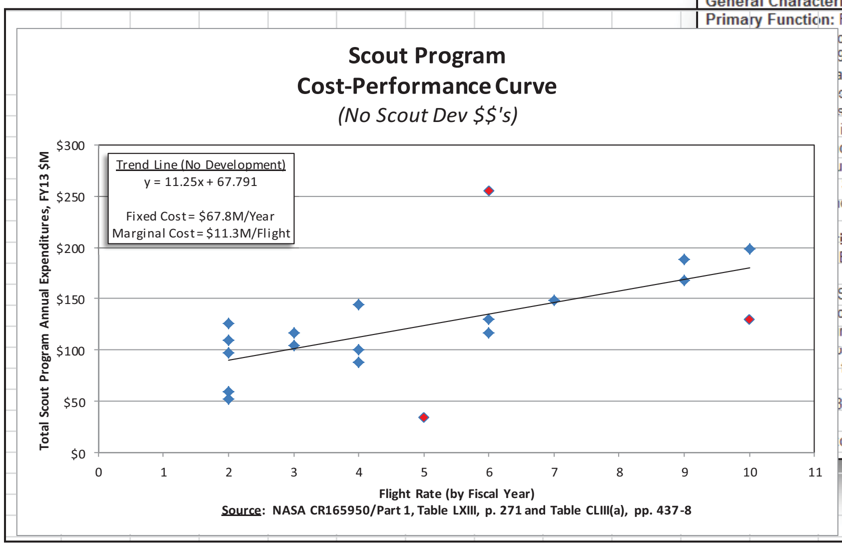
| PARAMETER | VALUE / RANGE | NOTE |
|---|---|---|
| Target Orbit: | 45° Inclination<br>400 km Altitude | Target values within range of interest<br>0° - 98° Incl., 350 – 650 km Alt. |
| Launch Latitude | 38° | Wallops; close to target inclination<br>Others: KSC, Vandenberg, Airlaunch |
| Payload mass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

# Assumptions

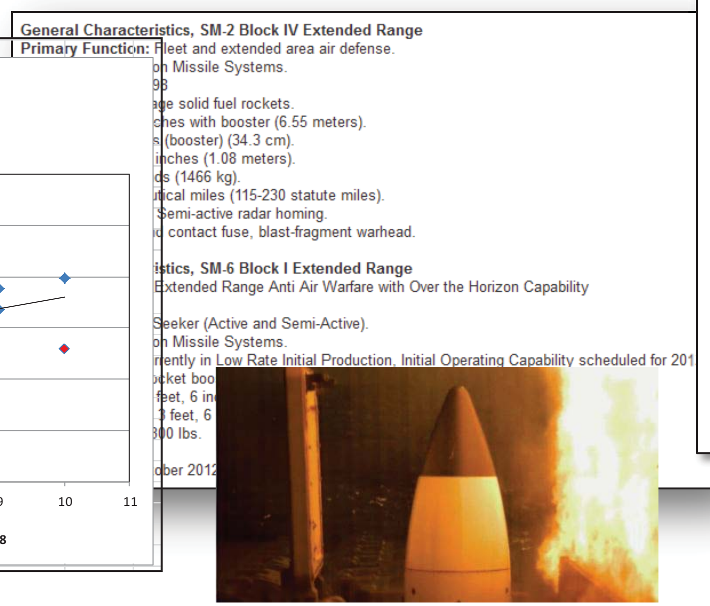
- Assume state-of-the-art technologies and business-as-usual practices as a baseline for vehicle concepts
- Maintain payload capabilities through vehicle resizing
- Recurring launch cost goal assumed to include recurring manufacturing and operations (including launch), fixed and variable costs, but not 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 – 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

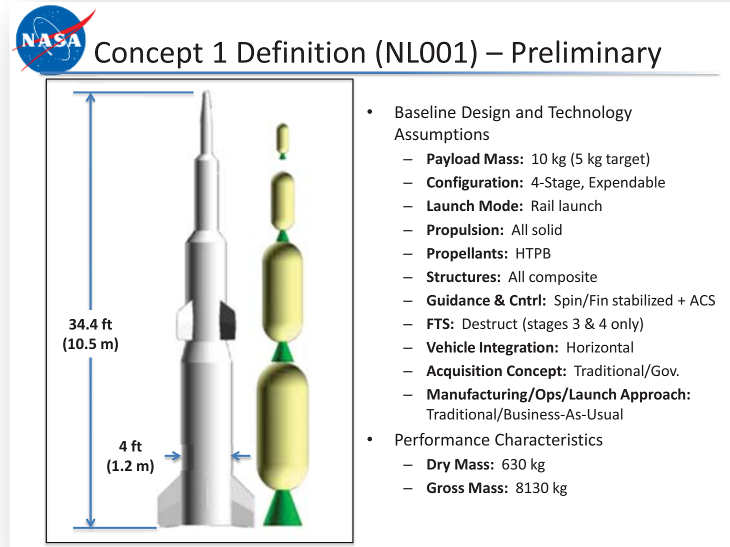
- Define baseline concepts to conduct assessments
  - Span the range of relevant approaches and technologies for a dedicated 5kg payload nano-launcher
  - Reflect current approaches and state of art technologies
  - To be modeled to a fidelity sufficient for the technology trades of interest
- Develop 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

| Baseline Concept | Launch Mode | Baseline Features/Assumptions |
|---|---|---|
| 4 stage solid motor design | Rail | Spin stabilized 1st & 2nd stages, Attitude control upper stages |
| 3 stage pressure fed liquid | Pad | Pressure fed LOX/RP, TVC, Composite tanks/structure, etc. |
| 3 stage hybrid motor design | Pad | HTPB fuel, Composite structure, TVC, etc. |

# 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

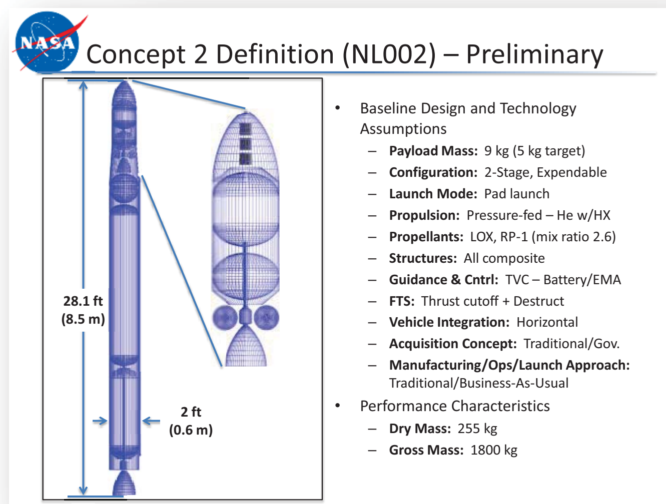
- Reference concept Scout studied extensively



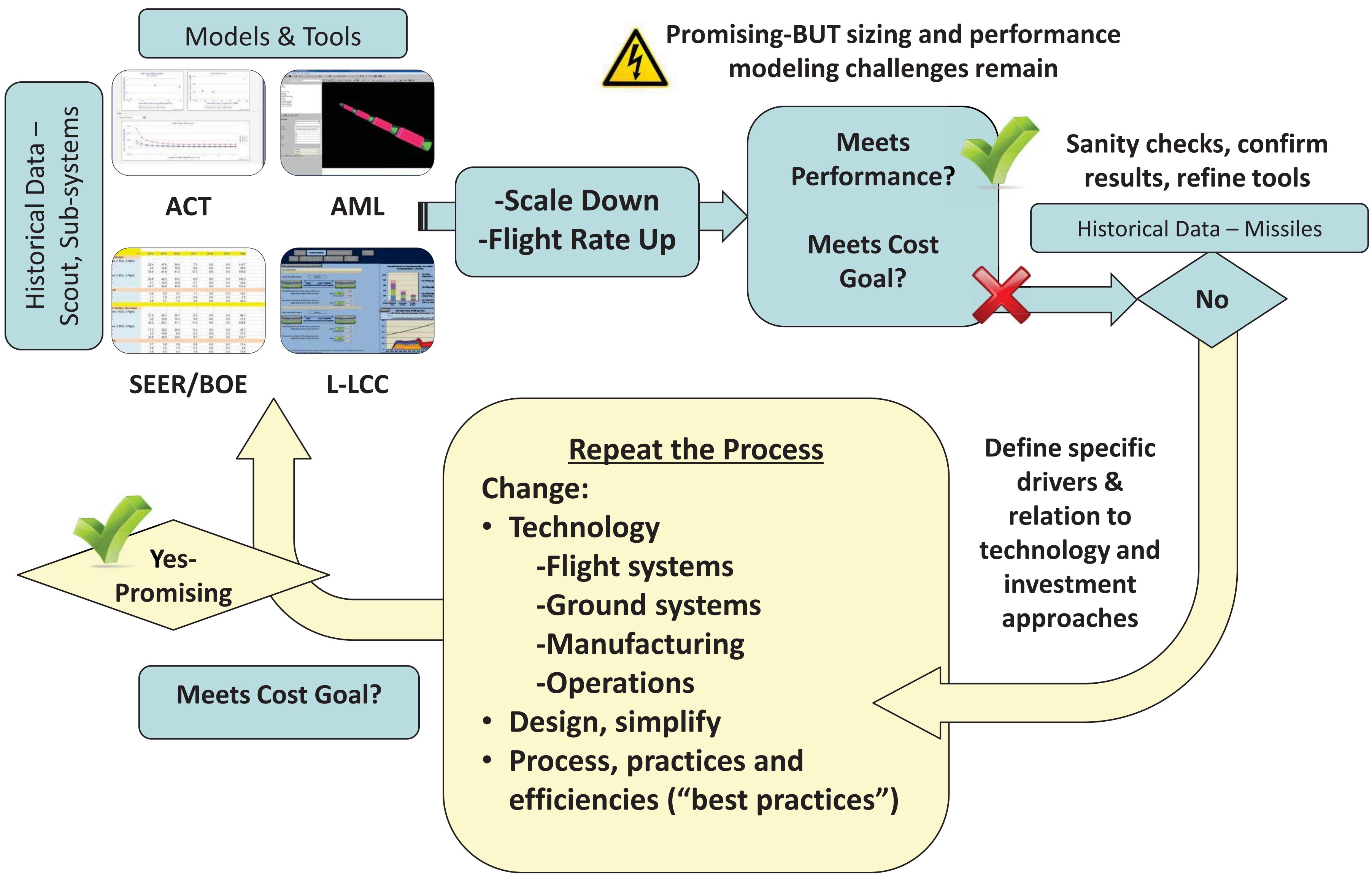

<u>Scout</u>
Historical
4-stage Solid

Payload: 200 kg

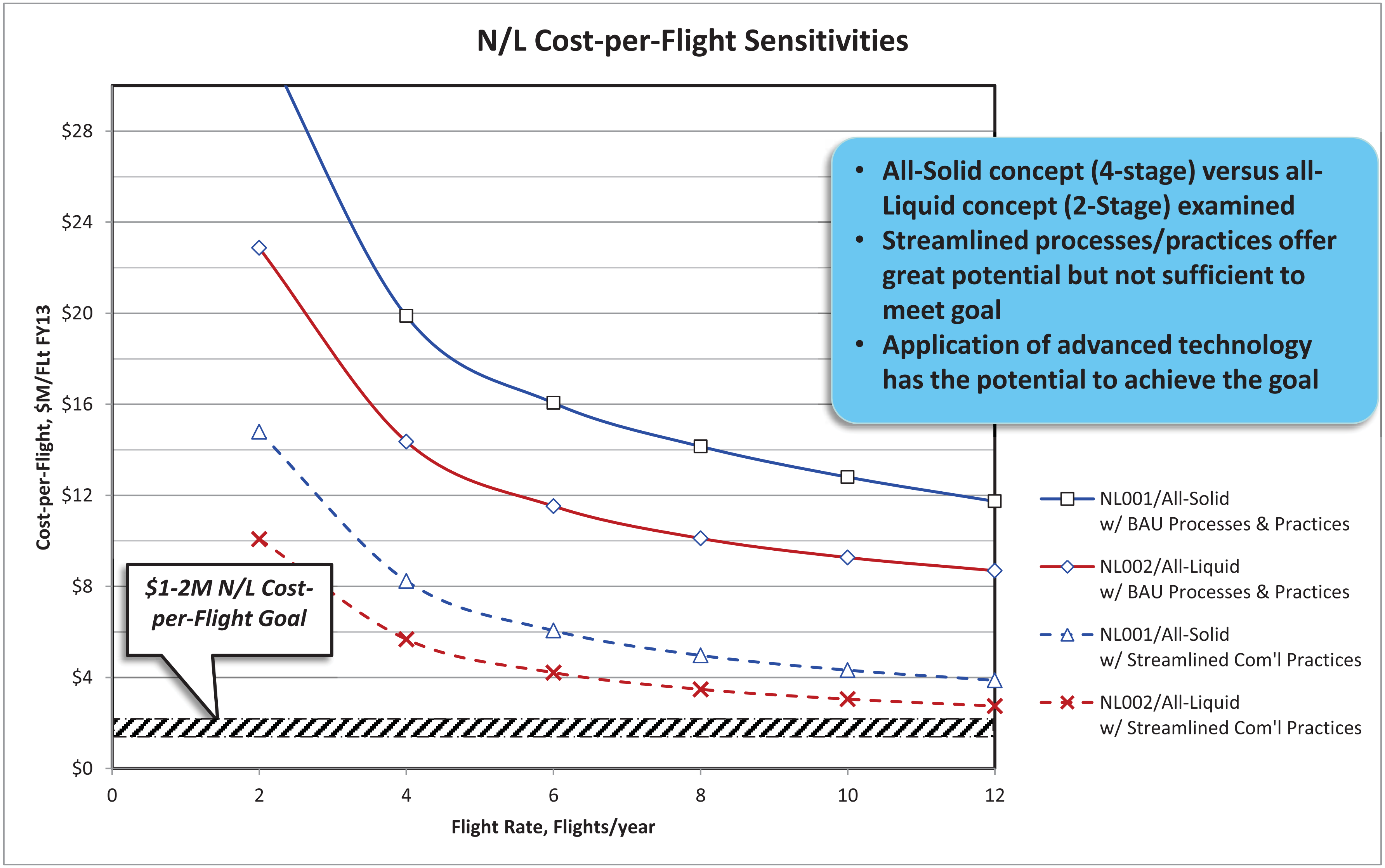
75 ft
(23 m)



# Assessment Process – Summary



# Results – Example




- **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**

# Forward Work

- **Technology Assessment**

| | Production Fixed | Production Variable | Integration | Ops Fixed | Ops Variable |
|---|---|---|---|---|---|
| **Cost Component** | **Production Fixed** | **Production Variable** | **Integration** | **Ops Fixed** | **Ops Variable** |
| **Cost Driver** | **No. of stations** | **No. of steps** | **Unique Elements** | **Infrastructure** | **No. of steps** |

- 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.

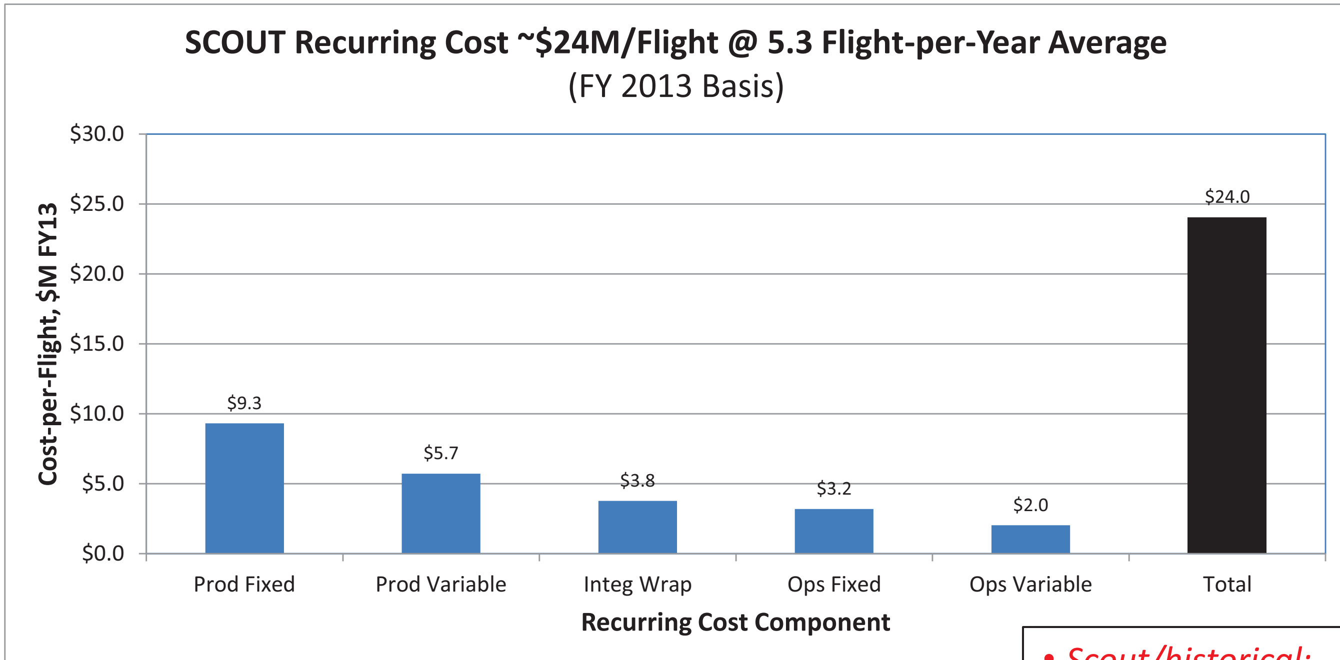
# Backup

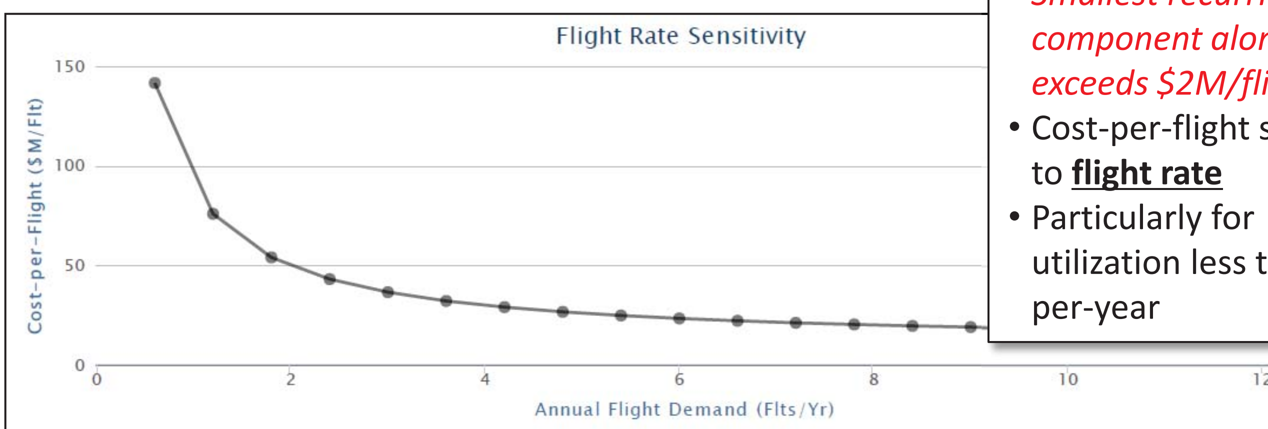
# Launch Capability - Current

- 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

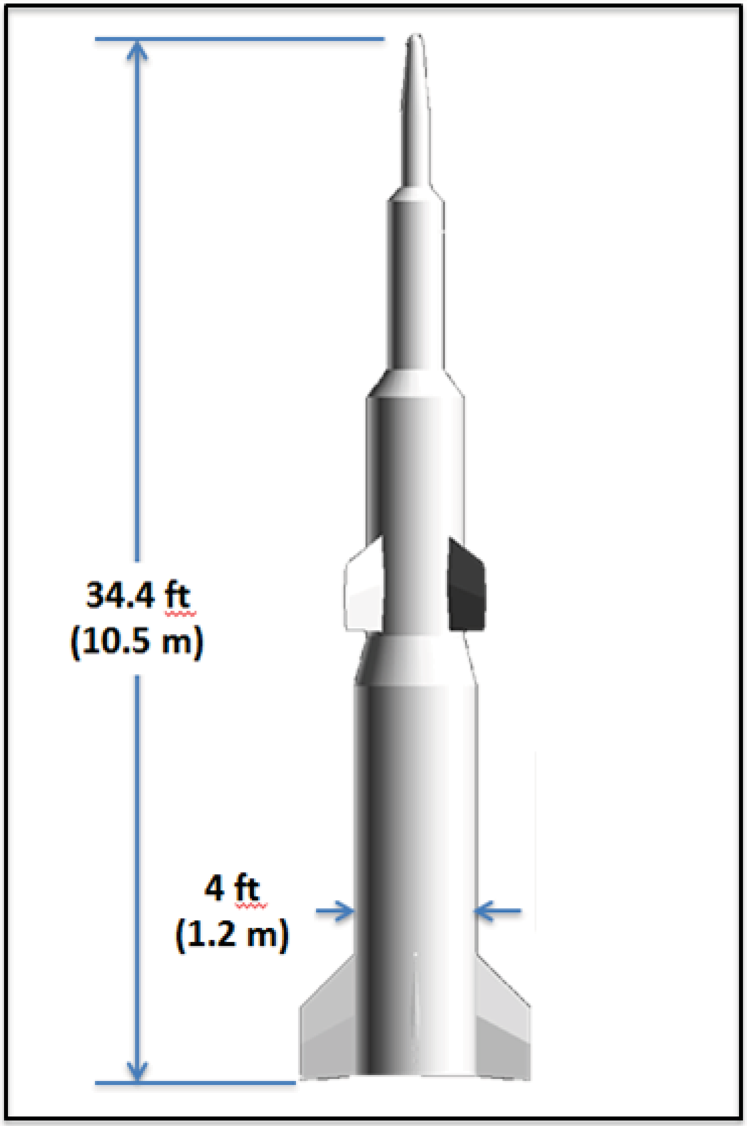
# Recurring Cost Insight



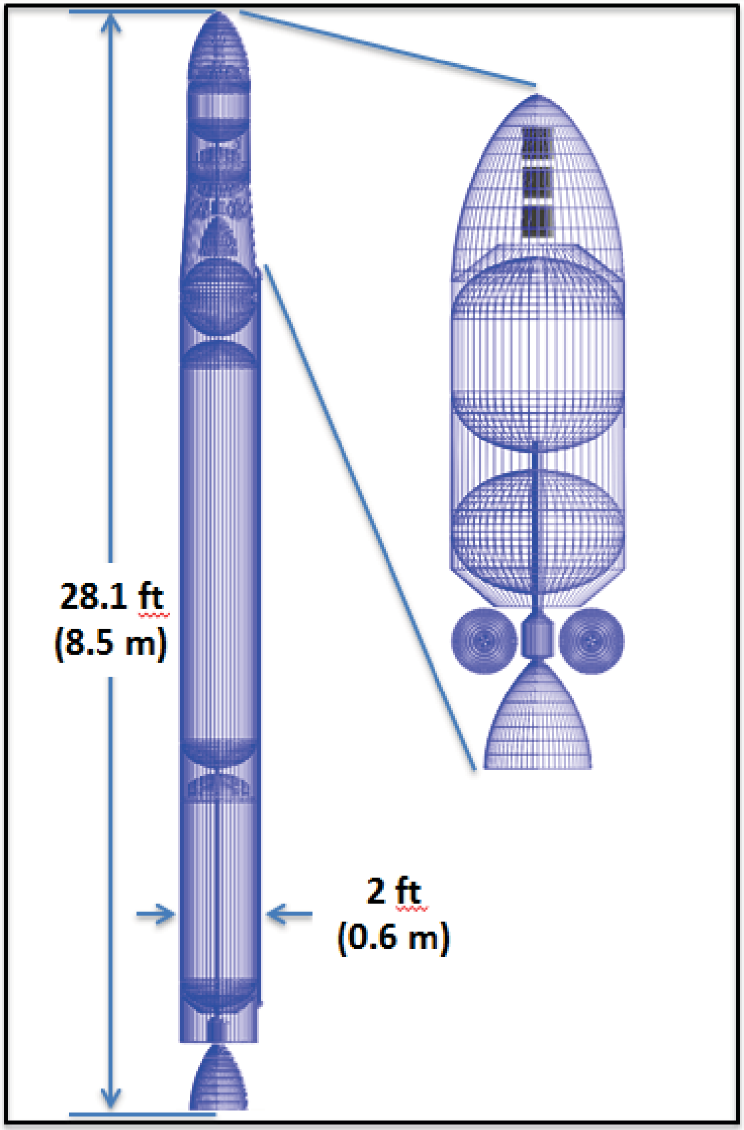

- *Scout/historical: Smallest recurring cost component alone exceeds $2M/flight*
- Cost-per-flight sensitive to **flight rate**
- Particularly for utilization less than 5 per-year

# Concept 1 baseline for technology & life cycle assessment




- Baseline Design and Technology Assumptions
  - **Payload Mass:** 10 kg (5 kg target)
  - **Configuration:** 4-Stage, Expendable
  - **Launch Mode:** Rail launch
  - **Propulsion:** All solid
  - **Propellants:** HTPB
  - **Structures:** All composite
  - **Guidance & Cntrl:** 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 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
  - **Guidance & Cntrl:** 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