



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 400 km Altitude	Target values within range of interest 0° - 98° Incl., 350 – 650 km Alt.
Launch Latitude	38°	Wallops; close to target inclination 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 ±1° Orbit inclination	Accuracies are not critical for many small and very small spacecraft - Need to understand sensitivity
Spacecraft accommodations	<ul style="list-style-type: none"> • Separation signal • T-0 trickle charge • Environmental control within fairing • Narrowband telemetry on launch 	Desire minimal demands on launch vehicle - Need environment specs - Payload status for rapid calibration
Load/Environment Limits (Payload)	20 g axial acceleration 5 g lateral acceleration	Need to determine limits on payload
Launch cost (recurring)	<\$2M/launch <\$1M/launch (stretch goal)	Goal Assumes annual flight rate of 12
Responsiveness	<48 hours call-up time <24 hours call-up time (stretch goal)	Goal – Relates to military ops Source: ALASA and SWORDS
Launch Reliability	0.9	Can accept lower reliability due to very low satellite cost

Assumptions

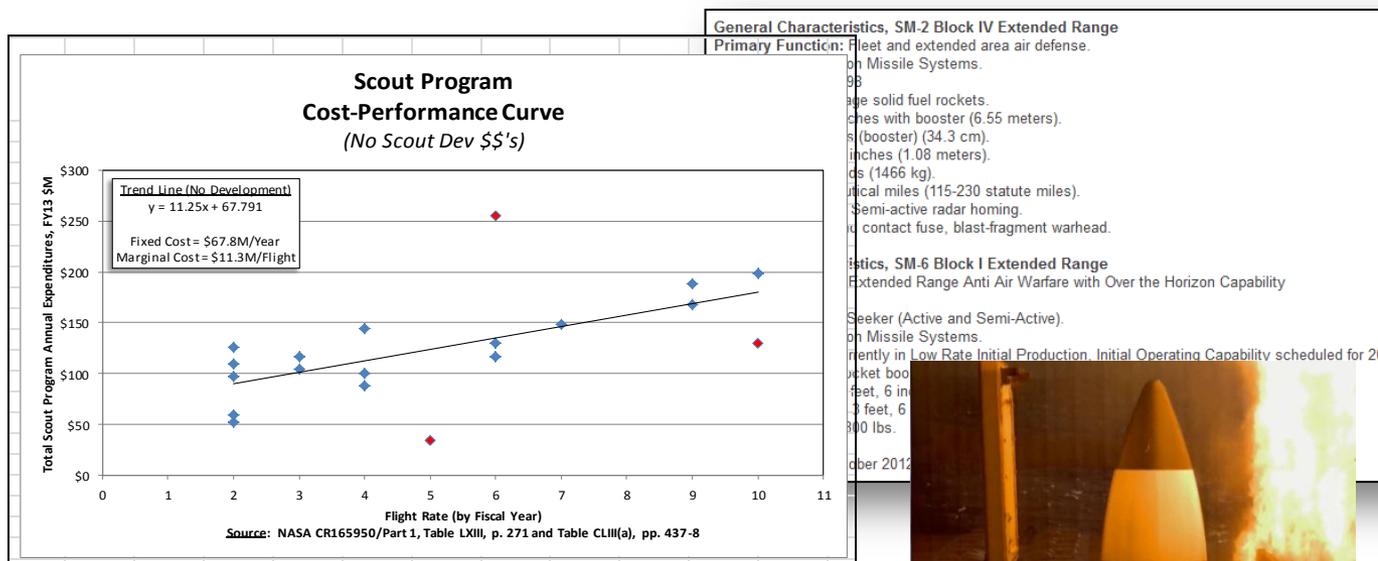
- Assume state-of-the-art technologies and business-as-usual practices as a baseline for vehicle concepts
- Maintain payload capabilities through vehicle resizing
- Recurring launch cost goal assumed to include recurring manufacturing and operations (including launch), fixed and variable costs, but not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

General Characteristics, SM-2 Block IV Extended Range
Primary Function: Fleet and extended area air defense.
on Missile Systems.
BB
age solid fuel rockets.
ches with booster (6.55 meters).
s (booster) (34.3 cm).
nches (1.08 meters).
ds (1466 kg).
ical miles (115-230 statute miles).
Semi-active radar homing.
U contact fuse, blast-fragment warhead.

Statistics, SM-6 Block I Extended Range
Extended Range Anti Air Warfare with Over the Horizon Capability
Seeker (Active and Semi-Active).
on Missile Systems.
rently in Low Rate Initial Production. Initial Operating Capability scheduled for 201



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 1 st & 2 nd 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

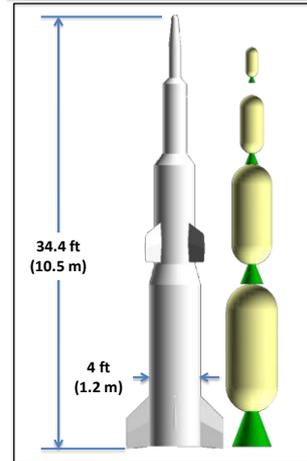
- Baselines span a range of relevant approaches
 - Sufficient detail to allow assessment of the technology and life cycle drivers of interest
 - Phase I summer 2013 task centered mostly on Concept 1 – a 4 stage solid
- Reference concept Scout studied extensively

Scout
 Historical
 4-stage Solid

 Payload: 200 kg



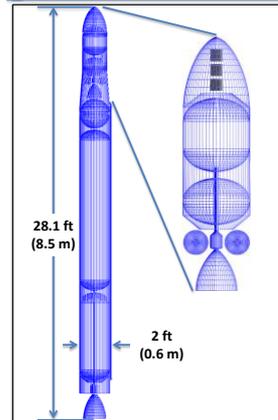
Concept 1 Definition (NL001) – Preliminary



- 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 & 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

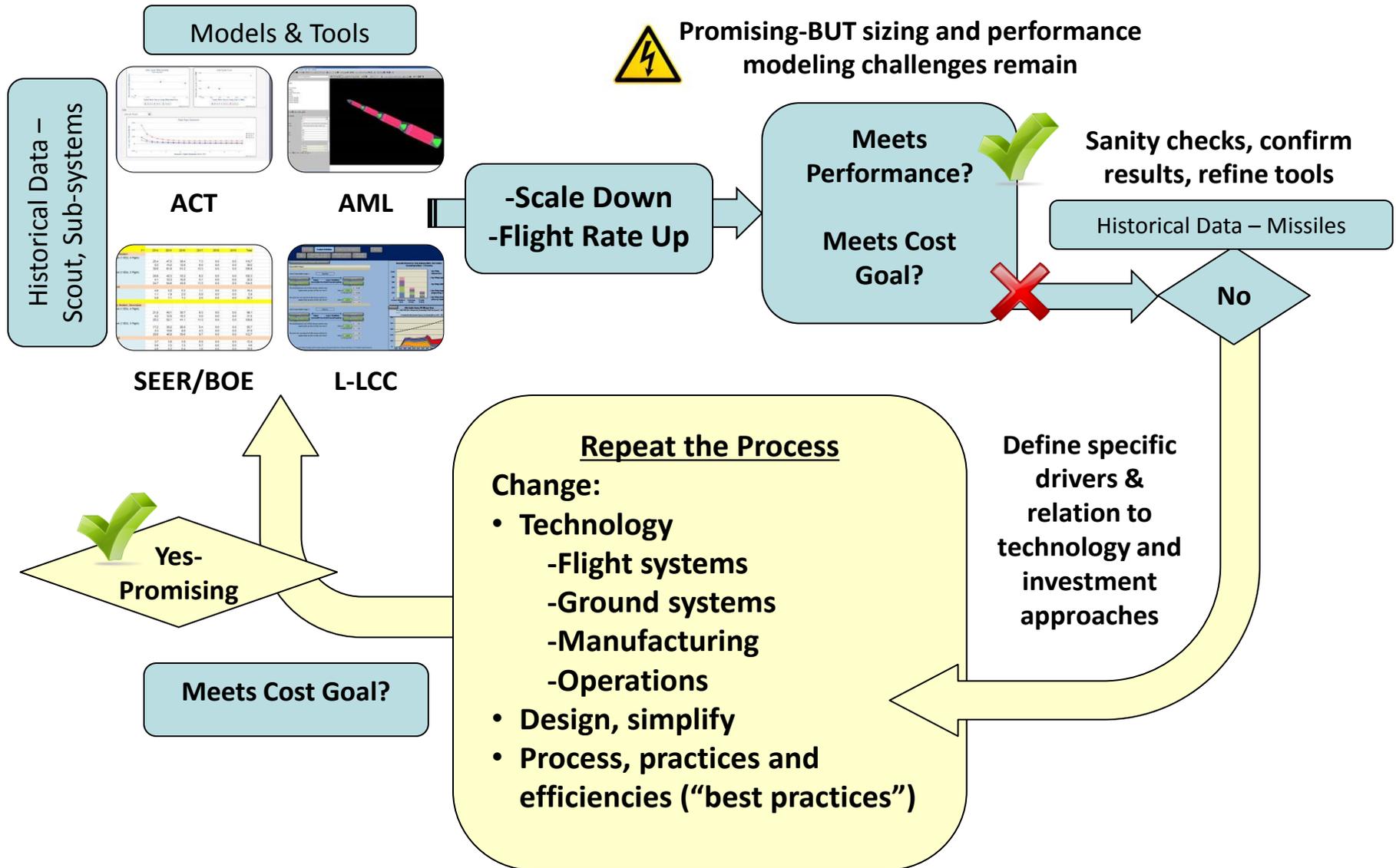


Concept 2 Definition (NL002) – Preliminary



- 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 & 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

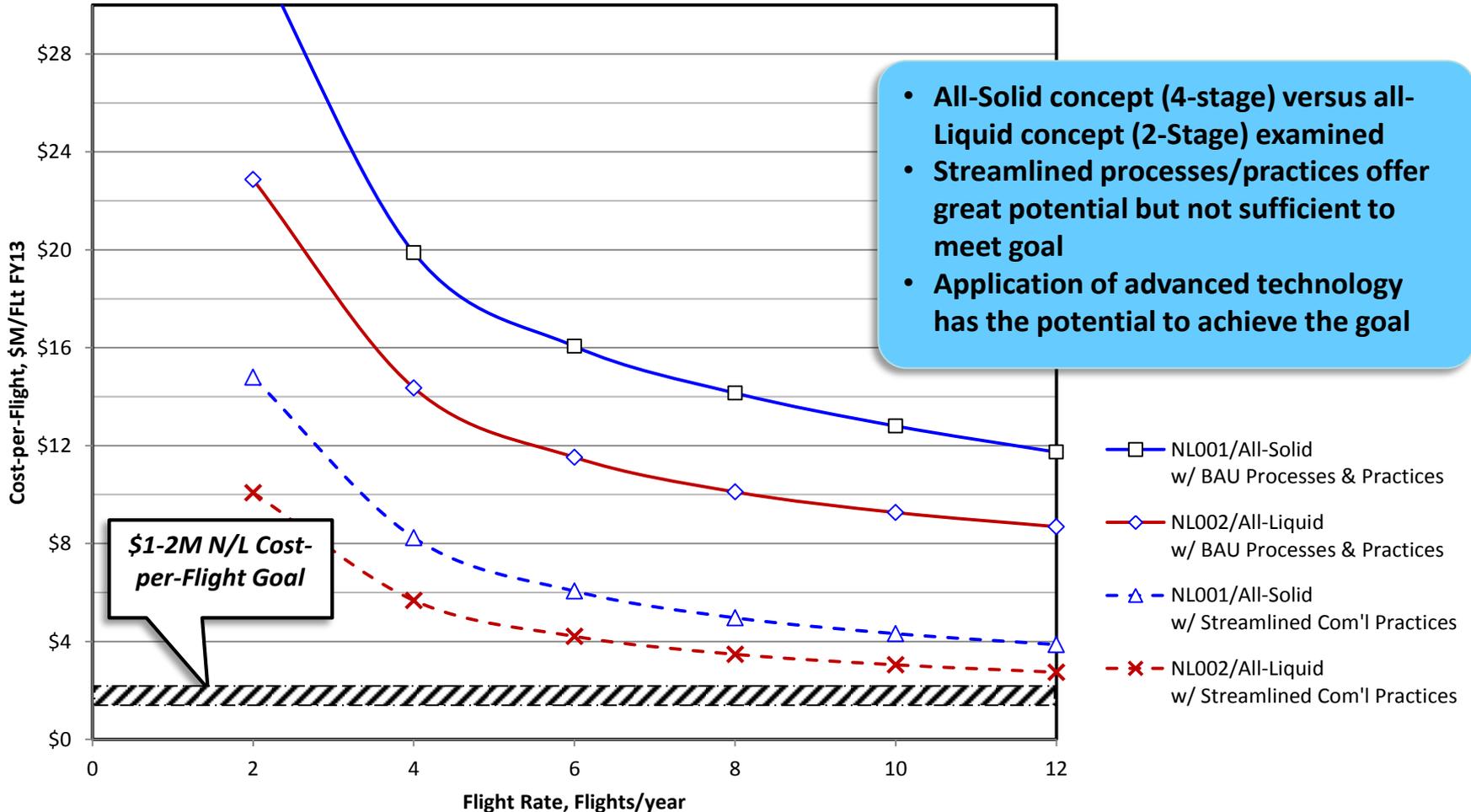
Assessment Process – Summary



Results – Example

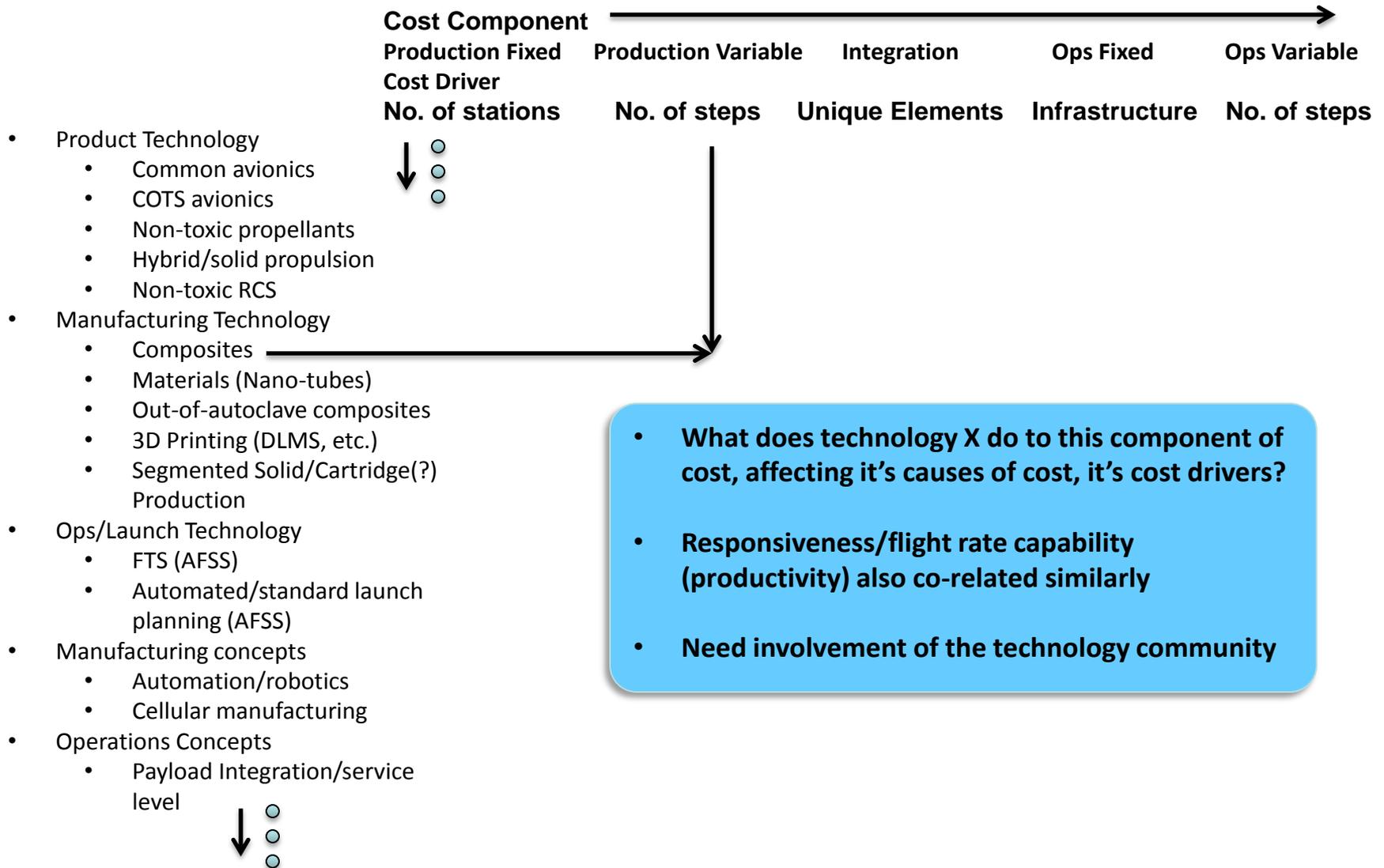


N/L Cost-per-Flight Sensitivities



Forward Work

• Technology Assessment





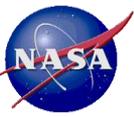
Forward Work

- 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.



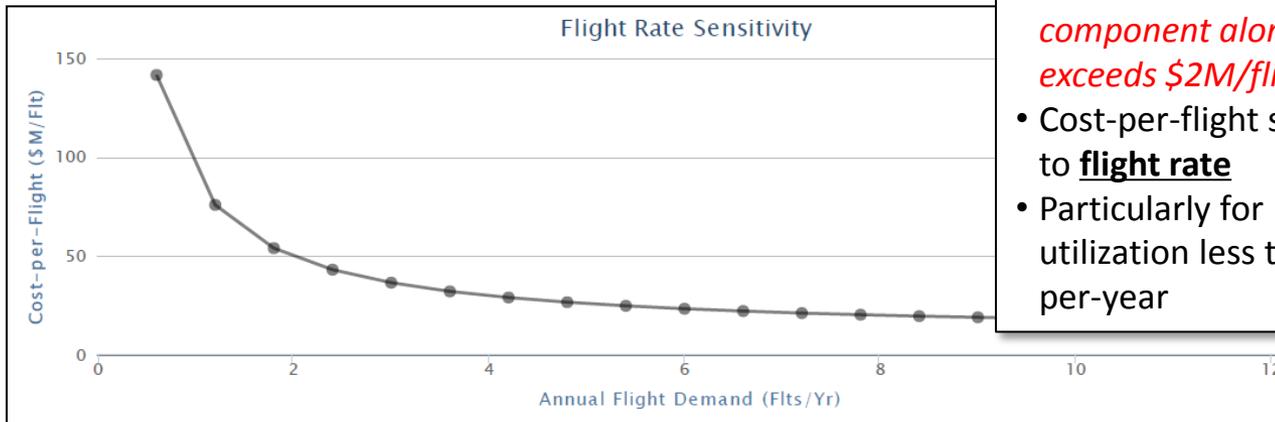
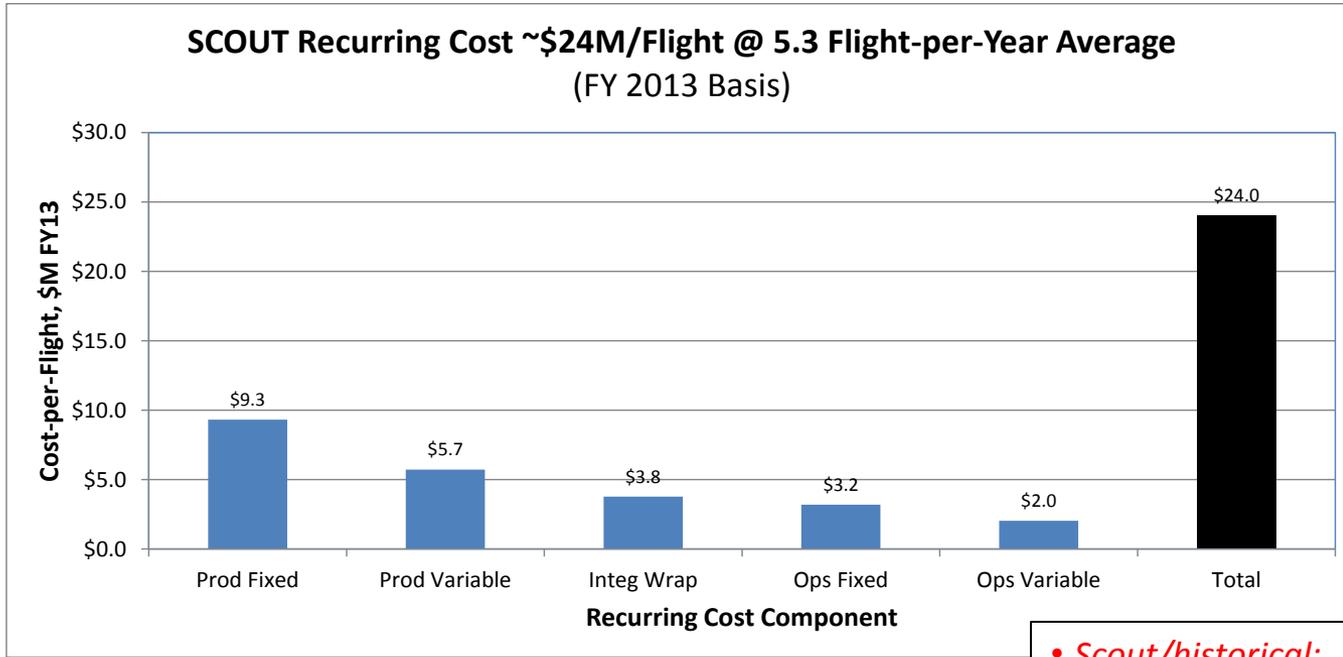
Backup



Launch Capability - Current

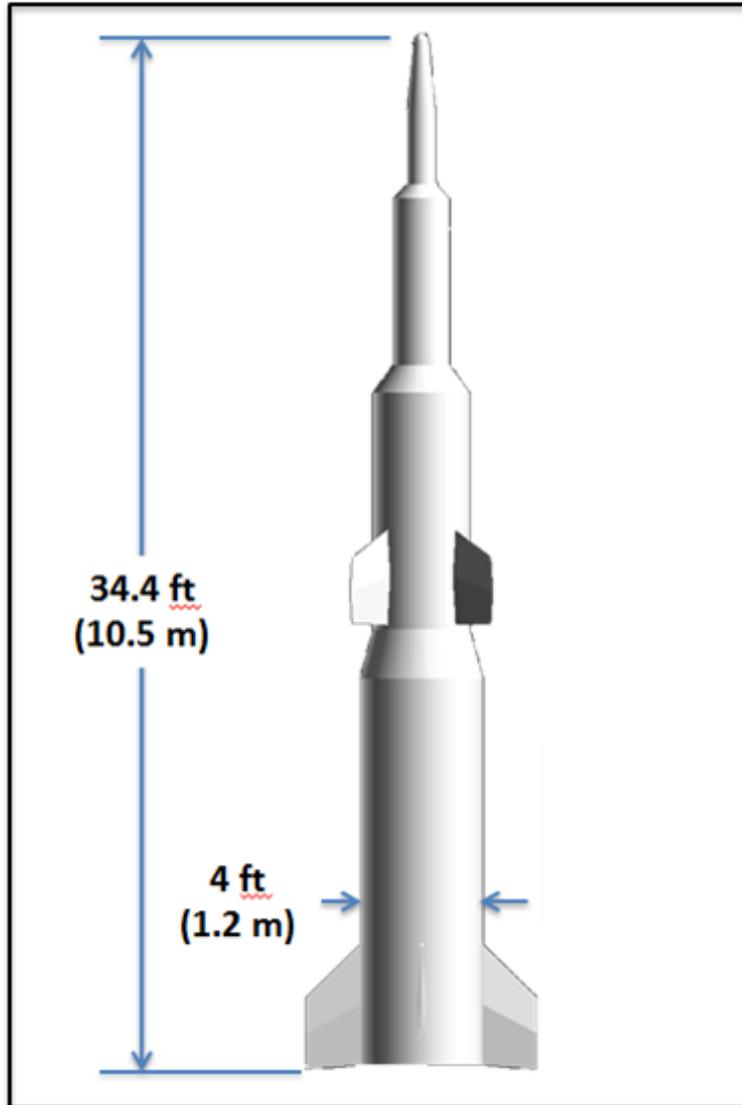
- Current dedicated small-sat launchers do not meet the needs of nanosat community
 - e.g., Pegasus XL/Minotaur (443-1735kg/LEO) @ \$40-\$50M/launch
 - Additionally, contract to launch time 18 months or more
- Rideshare opportunities are cheap but very constraining
 - As secondary payload, constrained 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



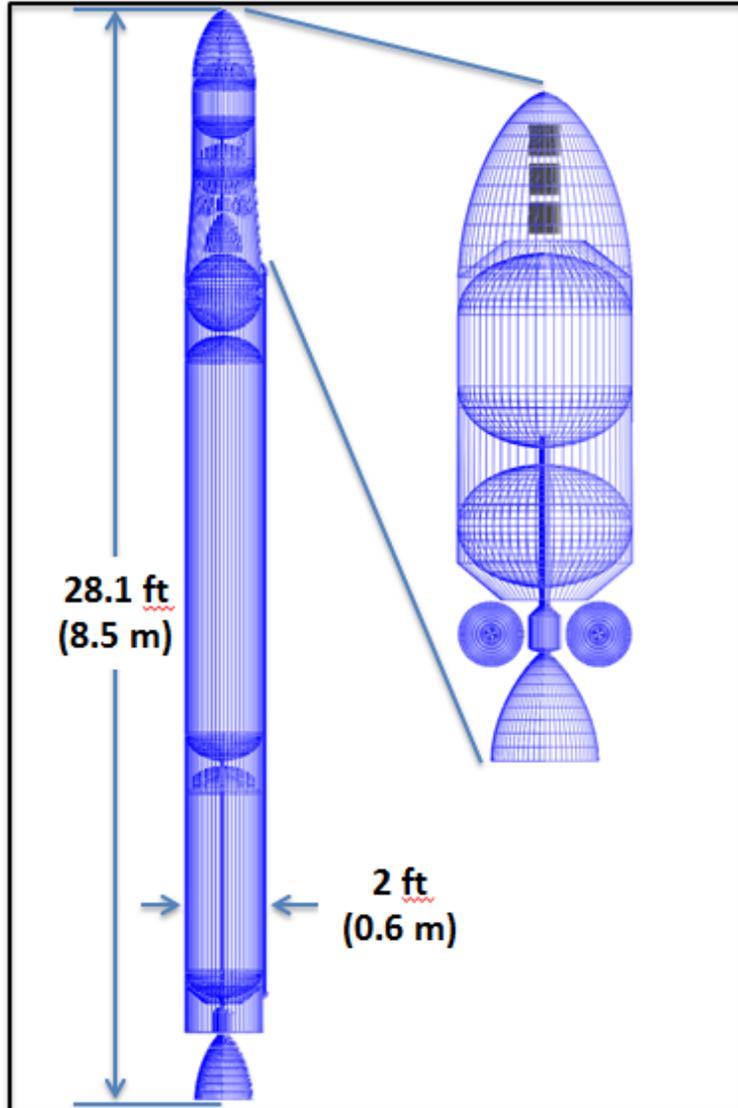
- *Scout/historical: Smallest recurring cost component alone exceeds \$2M/flight*
- Cost-per-flight sensitive to **flight rate**
- Particularly for utilization less than 5 per-year

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
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