Nano-Launcher Technologies, Approaches, and Life Cycle Assessment Phase II

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Contents

Objectives

- Assist in understanding NASA technology and investment approaches, and other driving factors, necessary for enabling dedicated nano-launchers by industry at a cost and flight rate that (1) could support and be supported by an emerging nano-satellite market and (2) would benefit NASA's needs.

- Develop life-cycle cost, performance and other NASA analysis tools or models required to understand issues, drivers and challenges.

Phase I / 2013 Results Summary

- Gathered and analyzed *reference concepts* cost and performance data (Scout rocket, missiles, past & current small solid stages, etc.)
- Developed and analyzed *baseline concepts* to provide a systems level *context* for drivers and factors in technology and approaches
- *Developed, refined and applied models* for performance and life cycle costs at the nano-launcher scale
- Developed preliminary *analysis results, conclusions*
- Briefed stakeholders

- Phase I preliminary conclusions:

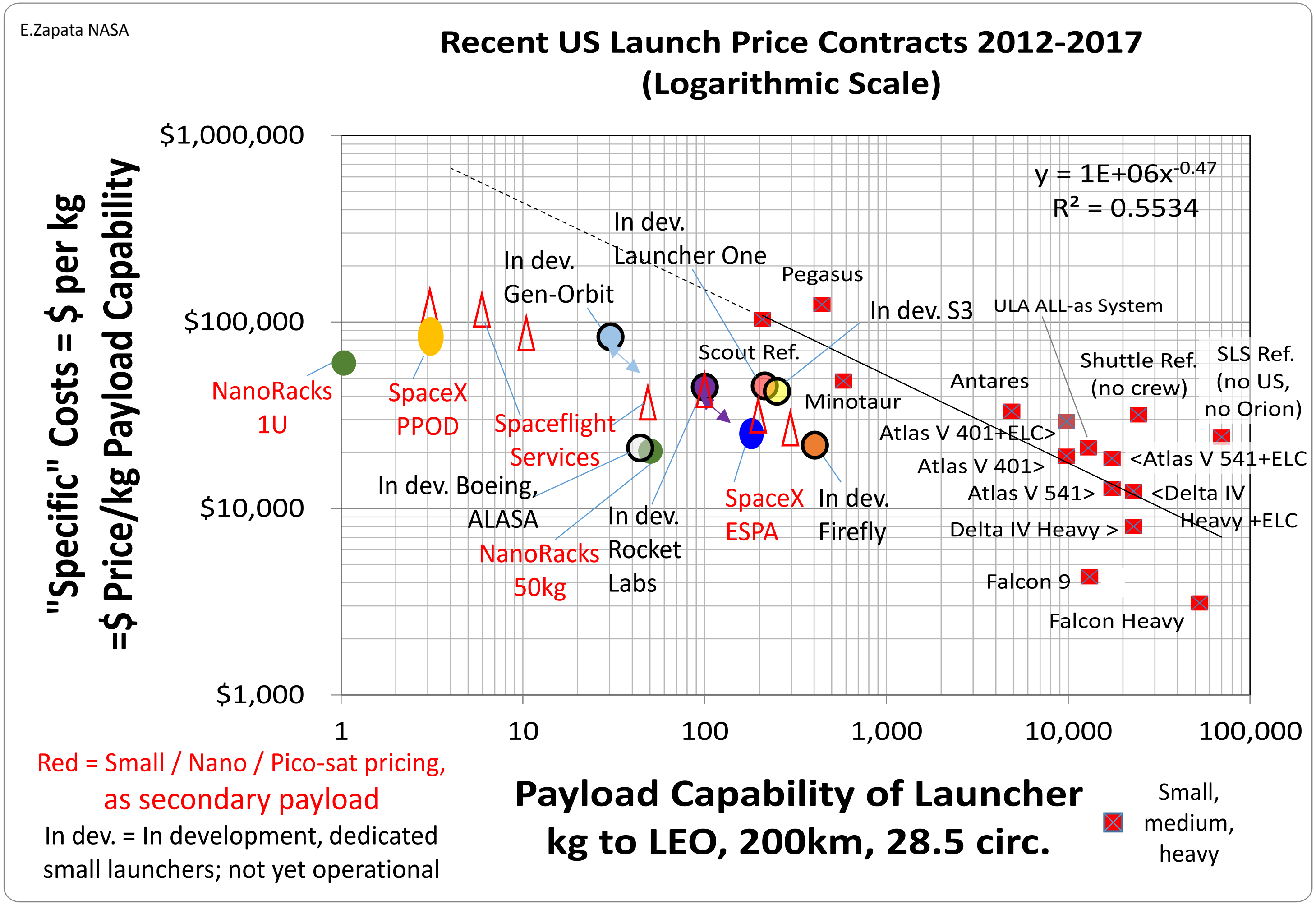
  - Reduced scale of a nano-launcher only drops recurring costs so far
  - Flight rate assumptions only drop recurring costs so far; high flight rate does not assure low marginal costs
  - The combination of the right technologies, design *and* efficient commercial processes & practices by industry should enable the goal of < $2M recurring launch cost

Changes & Events since Phase I

- December 2013: First commercial HD video from space, SkyBox
- February 2014: PlanetLabs Dove flock deployed from ISS
- *February 2014: Minotaur 1 launch with AFSS
- February 2014: Skybox subs 13 sat's to Space Systems Loral
- March 2014: DoD/DARPA ALASA award to Boeing; **45 kg for $1M incl. range
- March 2014: Army/NASA SWORDS project – re-focused on engine
- June 2014: XS-1 awards to Boeing, Northrop Grumman and Masten
  - Target payloads *"*< $5M/flight for 3 – 5000 lbs to LEO at 10+ flts/yr"*
- July 2014: FireFly announces plans for a small sat launcher
- July 2014: RocketLabs announces plans for a small-sat launcher
- July 2014: Spires (was Nanosatisfi) announces $25M in funding
  - Covering areas of earth traditionally neglected, faster revisit times
- August 2014: Skybox closes deal to be acquired by Google
- August 2014: Altius Space Machines announces plans to use ISS cargo vehicles, taken to an orbit higher than ISS on their return trips to deploy small-sats

*Previous versions / tests were assorted COTS components put together. This was integrated GPS/IMU w. Wallops software.
**DARPA charts, AFSS by SIL (under NGC sub)

State of Play – Specific Cost/kg, Supply



- About the line: The line shown is a power curve fitted by Excel to ONLY the medium launcher data (the points indicated with ☒).
- The dashed line extending the prior curve fit has been drawn manually along the same trend indicated by the equation.
- All values use prices, or for government systems, procurement costs excluding government FTE; except Shuttle-adjust to subtract FTE pending.
- Shuttle capabilities beyond the delivery of cargo as shown, such as a Remote Manipulator System, satellite-repair, satellite-return, lab-accommodations, etc., should be noted.

Distribution - Public

State of Play – Minimum Price of Entry, Supply

- "Aggregation" of demand by the supplier of the launch service
  - Dedicated nano-launchers in development will have to address *aggregation*
  - Avoids the problem of minimum price of entry -the requirement to buy the whole, maximum rocket capability even if the payload is smaller than the maximum (i.e., can't buy an Atlas by the yard; must buy the whole bolt of cloth)
  - Minimum price of entry avoided through successful aggregation
    - Many cubes from one customer; avoid having to aggregate distinct customers
    - Smaller capability; avoid having to aggregate
    - Sweet spot uncertain.

State of Play – Summary Current Prices & Capabilities for Secondary Payloads

- Nano-Racks / existing secondary payload capability defining a floor level of price expectations; 50kg and less, per "1U" (per 1kg) at $60,000/kg to $20,000/kg (if volume buyer, all of 50kg)
  - Rate: *Deployed 109 payloads from the ISS from 2009-2013
  - Max kg/year dependent on ISS cargo manifesting

- Two dedicated nano-launchers targeting near this floor include ALASA/Boeing and FireFly.
  - No apparent premium for being dedicated launchers.

- Nano-launcher study team / technology assessment goals <u>*originally*</u> set at $1M-$2M for 5kg ($400,000 - $200,000/*total* kg)
  - Assumption of a premium market for a dedicated launch
  - Using the 3U basis, goal = $333,333/kg to $666,666/kg
  - Rate: Analysis out to 20 launches per year
    - Assumption of market size

*NanoRacks website

Collaborative Discussions - Stakeholder Briefings since Phase I

- 12/19/2013 Jonathan Jones/MSFC
  - Nano-Launch Project; technology demonstration, printed solid rocket motor case parts/domes (8” diam., 18” long)
- 6/17/2014 Barry Hellman/AFRL
  - Generation Orbit Suppressed Trajectory Phase I SBIR; small-launch as a means to perform hypersonics testing
- 7/24/14 David Barnhart/DARPA
  - Tactical Technology Office; “sat-lets” concepts
- Industry; avionics subject matter experts
  - Edmund Burke, Space Information Laboratories
  - Pete Paceley, Draper Laboratory
- 9/2/2014 Charles Miller/President NexGen Space LLC
  - Market, commercial, business case perspectives
- 9/12/2014 Austin Williams, Roland Coelho/Tyvak Nano-satellite Systems Inc.
  - Small-sat & small-launch (secondary and dedicated); developers, manufacturers

Collaborative Discussions - Stakeholder Briefings since Phase I

- 9/26/14 Jay Penn, Aerospace Corporation
  - Rideshare program cost analysis (government & ULA only)
  - Analysis of Air Force costs (payments to ULA) for Air Force or related mission ESPA rings.

- Pending
  - MSFC/Nano-Launch Project
  - AFRC/RFI for dedicated small launch, flight opportunities project

Collaborative Discussions - Stakeholder Briefings since Phase I - Feedback

-No attribution; informal discussions-

“This science community …they don't feel that they can do meaningful science with a 5-10 kg satellite.”

“…need a $30-50k per unit target price…” [for a dedicated nano-launcher, for a whole avionics set, even up to 3 stages, GPS INS excluding FTS]

“Aggregation not a problem if one customer with many nano-sats; use differential drag to space them; commercial constellations…”

“NLV needed, supply is a problem, whereas sat’s need less capital to start…”

Collaborative Discussions - Stakeholder Briefings since Phase I - Feedback

-No attribution; informal discussions-

"Dedicated nano-launch solves the aggregation problem, but price expectation (coming from secondary payload prices) and perception of risk (of new launcher actually launching) are still major challenges…"

"…quite a few compelling concepts for science based nanosat constellations to provide 24-7-365 total global maps of critical science data. We only do some "Earth science" using single satellites because we are caught in the paradigm that is all we can afford to do.

**However, with the arrival of effective and useful nanosatellites, and affordable nanosat launch, we can conceive of affordable global nanosatellite constellations for ...*

[Global scale measurements of]

A) Carbon sources and sinks,

B) Earth energy balance, and

C) Weather (both GPS occultation and microwave sensors combined)"

*Also see "GEOScan Planning Workshop Report, 2011"

Collaborative Discussions - Informal Survey (Step 1)

- CRASTE 2014 - Presented Phase I Study
  - Followed up with numerous industry contacts; feedback from industry stakeholders via an informal survey on needs and technology impacts

AREA	Importance to Improving Affordability, Growing Flight Rate
Flight	
Avionics, computing - control, telemetry, communication, software	
Avionics, health - sensors, software	
Avionics, flight safety - range, termination	
Electrical - distribution, control	
Electrical - power sources	
Power - other than electrical	
Propulsion - engines, thrusters, controls, materials	
Structures - materials, thermal	
Mechanisms - actuators, latches, pyro's	
[reviewer addition]	
Ground	
Command & Control - command, control, hardware/software	
Command & Control - health management, maintenance	
Infrastructure, general - power, comm., services, other	
Infrastructure - propellants, gases	
Range - flight safety, infrastructure	
[reviewer addition]	
Processes & Practices	
Industry-Development	
Industry-Manufacturing	
Industry-Operations - integration flight/ground	
Industry-Operations - launch	
Industry-Operations - in-space	
Gov't/Range processes & requirements - first time	
Gov't/Range processes & requirements - recurring	
Gov't processes & requirements - as a customer/user	
Gov't processes & requirements - on in-space ops	
[reviewer addition]	

Responses from

- **3 small business**
  - **2 systems**
  - **1 sub-systems**
- **1 large business**
  - **systems**
- **1 large business**
  - **analysis**

Distribution - Public

Collaborative Discussions - Informal Survey (Step 2)

- After setting context, importance of an area to goals, floated technologies, requested ideas

	Industry - Development	Industry - Manufacturing	Industry - Ground Operations	Industry - Launch	Industry - In-space Operations	Gov't Processes (general)
Technology or Process/Practice	0-10	0-10	0-10	0-10	0-10	0-10

Indicate Importance to Improving this Phase of the Life Cycle

Flight

Ground

Processes & Practices

Sample Entries

Avionics - Commercial-off-the-shelf (COTS), all areas
Avionics - Commercial-off-the-shelf (COTS), smartphone derived
Avionics - Automation of Flight Safety Systems (GPS/IMU/FTS et al)
Avionics - miniaturization (IMU's et al)
Hybrid-propellants & propulsion
Non-toxic-propellants & propulsion
Mono-propellants & propulsion
Vehicle Manufacturing - composite materials, in autoclave
Vehicle Manufacturing - composite materials, out of autoclave
Vehicle Manufacturing - 3D printin ... dditive manufacturing

Collaborative Discussions - Informal Survey

- **Area Importance:**
  - **Flight**
    - Avionics - lower mass, smaller volume; computing, cabling, power supply
    - Avionics - GPS Antennas and Electronics; greater robustness
    - Avionics - Decreased cost & time for software (***across life-cycle)
    - Avionics, flight safety - range, termination
  - **Ground**
    - Range - flight safety, infrastructure
  - **Process & Practices**
    - Industry, Manufacturing
    - Gov't/Range processes & requirements - first time
- **Technology potential:**
  - **Flight**
    - Non-Toxic propellants & propulsion
    - Vehicle Manufacturing - 3D printing/additive manufacturing **(2)**
    - Vehicle Manufacturing - automation, robotics
    - Systems - Reduced stages (development, manufacturing)
    - Systems - Commonality between stages, engines et al (development, manufacturing)
    - Systems - Commonality between stage avionics (development, manufacturing)
    - Avionics - miniaturization (IMU's et al)
  - **Ground**
    - Operations - Automated, standard launch planning systems
  - **Process & Practices**
    - Lean development - best practices, commercial practices, other
    - Lean manufacturing - best practices, commercial practices, other
    - Lean operations/launch - best practices, commercial practices, other
    - Automated in-space operations **(2)**
    - Rapid mission planning tools
    - Standard payload accommodations, services & interfaces
    - Anchor tenants (*****across lifecycle)

Only the "10s" shown here

Survey included many more areas and technology than shown

Informal, not scientific

Some respondents – no 10's, but many 8's and 9's

No respondent suggested entries

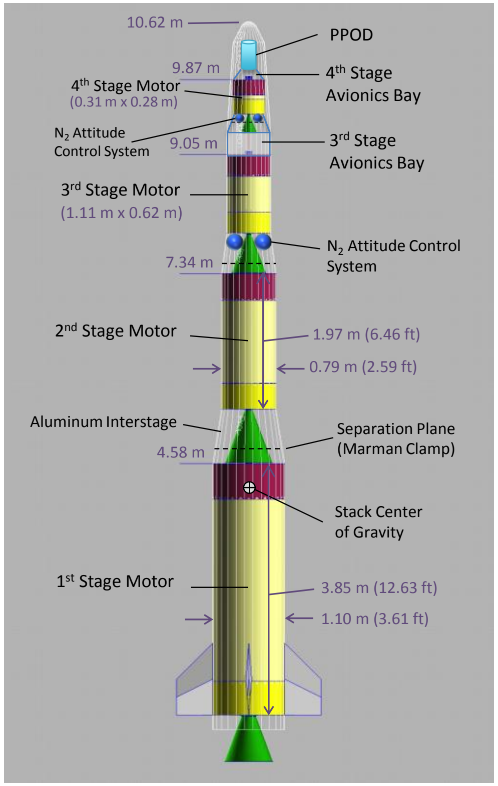
Phase II – Baseline Systems (Solids)

- Purpose: To set a context for technology assessment (*not a proposed concept)*

Variants – Payload/GLOW(kg) > 3U (4,677), 12U (5,860kg), 50kg (8,558kg), 100kg (12,302kg)

7,732kg

NL001 Top Level Description



NL001 Rev 4, 9/8/2014

DESIGN

- 4 Stage, solid motor (HTPB propellant)
- Titanium motor cases
- Aluminum inter-stages, adaptors, skirts, fins & shroud
- Spin stabilized during 1st and 2nd stage burns
- Cold gas (N2) attitude control systems on 3rd and 4th stages
- FTS and main avionics in 3rd stage forward bay
- Rail launch

Nanolauncher Avionics Concept Description r7, 10/14/2014

Mission: Wallops rail launch 45 deg inclination, 450 km orbit

4 stage solid motor

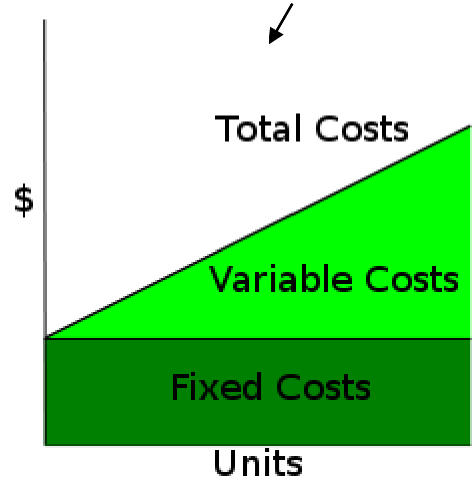
Spin stabilized 1st & 2nd stage flight with simple attitude control 3rd & 4th stages

Distribution - Public

Phase II – Life Cycle Cost (LCC) Modeling - Definitions

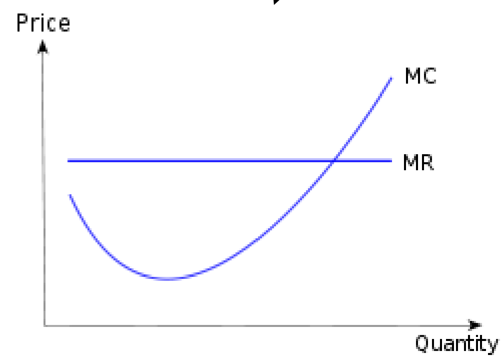
- **Definitions**: Fixed, variable and marginal costs set the stage for prices, business case, and optimum production level

Wiki on fixed/variable costs



Total costs = fixed + variable, but must specify if fixed is already spread per unit or total per year

Wiki on marginal costs



This effect was observed with the Space Shuttle
(Backup)

"A typical marginal cost curve with the marginal revenue overlaid"

Marginal cost includes fixed costs, but this also means using marginal cost estimation to try to avoid further fixed costs, to set optimum production level

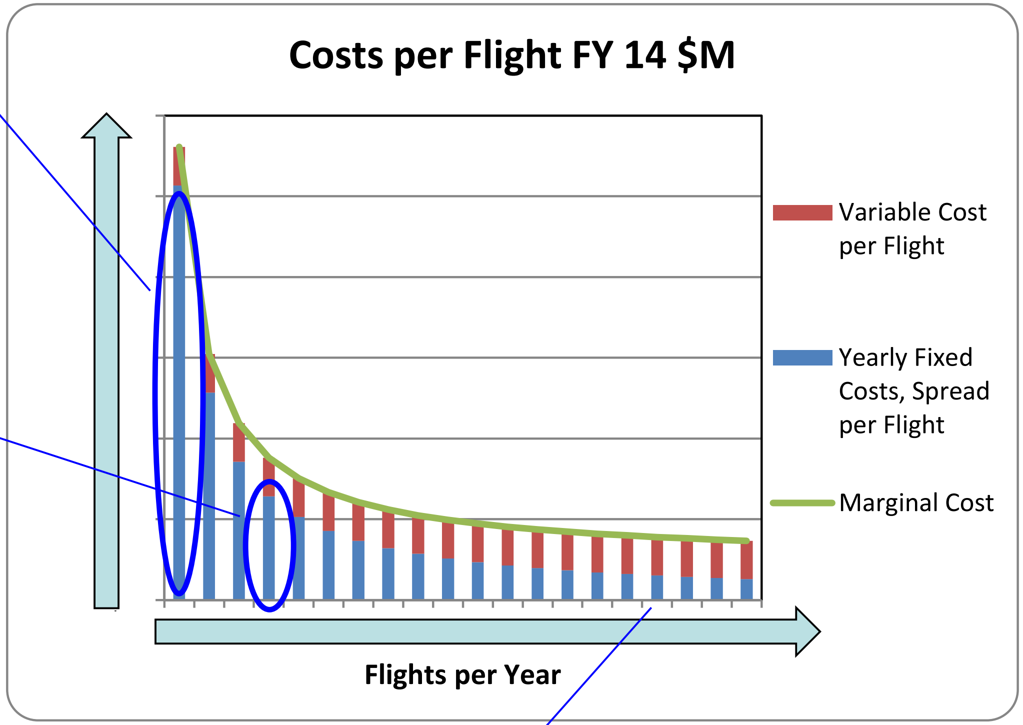
"In general terms, marginal cost at each level of production includes any additional costs required to produce the next unit. For example, if producing additional vehicles requires building a new factory, the marginal cost of the extra vehicles includes the cost of the new factory."

Phase II – Life Cycle Cost (LCC) Modeling - Interpretation

1. If only launching once a year, 100% of fixed costs would have to be recovered in pricing that one launch

2. Assuming no further fixed costs (another plant, more equipment, more fixed workforce, etc.) due to reaching max capacity, fixed costs for the year can be spread over customer flights

3. This model does make an assumption about business plans committing to X flights/year (no hiring/firing, etc. type of approaches for getting around fixed costs)



4. If pricing is based on X flight rate expectation, but customers do not show, yet prices reflected these lower expected costs – the difference will be reflected as revenue not covering costs

Phase II – Life Cycle Cost (LCC) Modeling - The Model

- ez-Launcher Life Cycle Cost Model (info)
- 1 of 3 deployed in task (others being ACT and SEER)
- Example Inputs:
  - Technical/technology/design (what)
    - Stage type (solid, etc., casing type, composite, etc., RCS type, etc.)
    - Stage, number of
    - Segments per stage (usually 1)
    - Stage scale (length, diameter)
    - System – avionics approach (unique to - > commonality)
    - System – components approach (unique -> COTS)
    - Manufacturing, tooling/equipment (hand-crafting -> automation)
    - Manufacturing, test & measurement (manual -> automated)
    - CONOPS, payloads (unique ->standard)
    - Context, supply base (few ->many)
  - Processes & Practices (how)
    - 44 key inputs, across development, manufacturing, and ops/launch
      - Design principles, lean development, enterprise maturity, supply chain management, etc.

Phase II – Life Cycle Cost (LCC) Modeling - Caveats

- Caveats that could cause the estimated/modeled results to be <u>less cost</u>
  - Unforeseen efficiencies or innovations in processes
  - Simplifications, 3-stages, variants, liquid, etc.

- Caveats that could cause the estimated/modeled results to be <u>more cost</u>
  - Industry / government barriers prove intractable, systemic
  - Government program/project management not included in fixed – variable – marginal cost view. This is industry costs only; procuring at prices reflecting these estimated costs would involve government personnel, increasing actual costs to the government, as with any customer.

- Uncertainties – <u>either direction</u>
  - Reference data (Scout, missiles, available solids, etc.) - all poor quality; outdated, different (volume of production), etc.
  - Performance (scale vs. kg to orbit)
  - Fidelity of technology inputs; relationships to specific life cycle phases/costs
    - Reduced uncertainty by the decomposition and structured modeling techniques, and prior experience modeling and estimating, but still involves unquantifiable uncertainties

Phase II – Life Cycle Cost (LCC) Modeling - Results

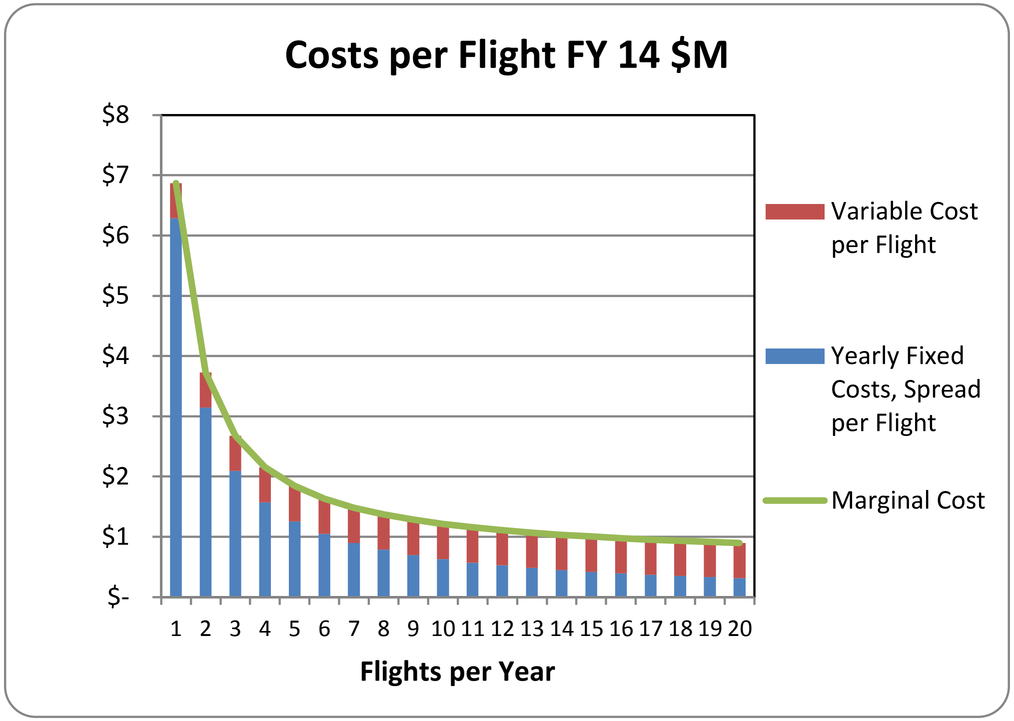
12U payload variant shown >

- @ $840K if a 20 launch demand materializes
- By end of 3rd Year ~$620K/launch (assuming 95% learning rate)
- Comparison: Spaceflight Services 12 U = $995K
- $1.2M/$880K if 10 LPY >

50kg payload variant

- $980K
- $720K by 3rd year
- Comparison: Spaceflight Services 50kg = $1,750K

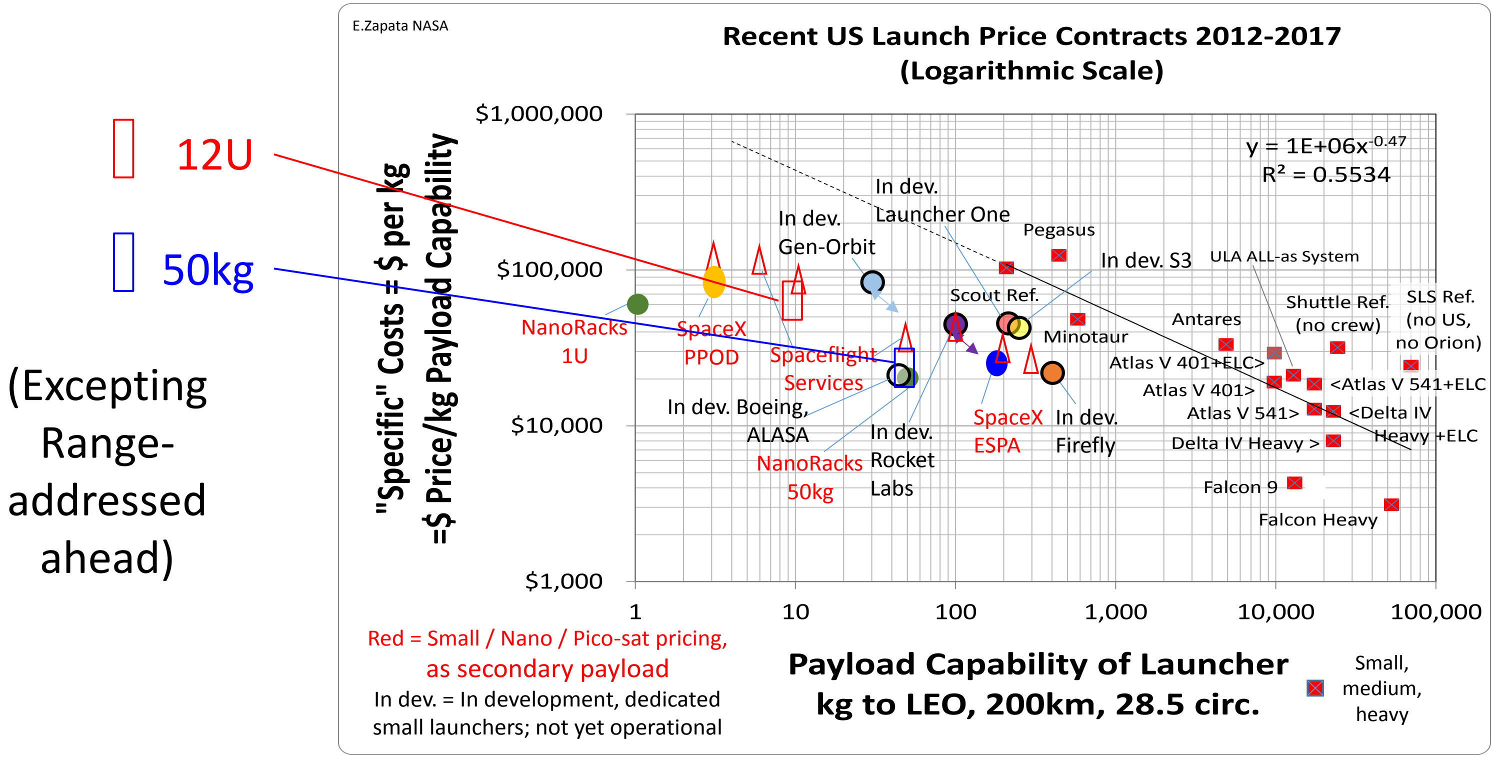
NOTE: Prices may be higher than costs



1. Model adjusts for rate/bottlenecks (optimal production may be either 16 or 32/year); no additional fixed costs before these points
   - Sweet spot carries additional assumptions and uncertainties
2. Learning may affect variable more than fixed; insufficient fidelity at this stage (applying very conservative 95% learning rate)
3. Development $29M (same uncertainties apply as w. recurring). IRR and Multiple present challenges –see Recommendations.

Phase II – Life Cycle Cost (LCC) Modeling - Summary

- Affordability and flight rate goals require a combination of improvements in technology, design and best practice/commercial practices
  - No silver bullets
- Relatively small increases in scale yield significantly more payload and revenue
- Competitive, dedicated, ground launch, nano/small launch is fully plausible

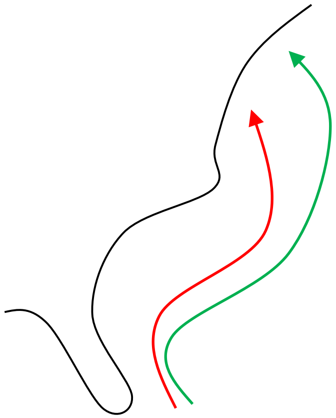


Reconciling Multiple Models

- Multiple Models Developed and Deployed -
  - ACT – Architecture Comparison Tool, top-down
  - ez-Launcher LCC Model – Nano-launch model added to existing, top-down
  - SEER – industry bottoms up model

- Results converge when reconciling / comparing model inputs, definitions, etc.

- Similar dilemma as faced by NAFCOM w. medium launch (report; appendix B)
  - A past history / data driven approach alone is inadequate for the question of identifying future directions (both what/technology & design and how/practice) offering significant life cycle cost improvements



Using multiple cost models is akin to using multiple weather models

All models have strengths, weaknesses, applicability, etc.

Using many models overcomes individual weaknesses and reduces uncertainty

Recommendations

1. Central question was the feasibility of dedicated, competitive nano-launch
    - Answer – promising, but many uncertainties
    - Recommend: Reduce uncertainty with an increased level of agency interaction with technologists, emerging space companies, and the small-sat community
        - Resources (FTE, travel, etc.)
        - Attend or sponsor forums; engage with emerging space companies, entrepreneurs, emerging NASA projects, existing industry
        - NASA technologists supporting technology assessment, analysis
        - Feed improved bearings into improved models (performance, life cycle characteristics), NASA roadmaps, and applicable decision making

2. Recommend: Agency should explore encouraging a Small-Sat/Small-Launch Industry Consortium – or other means of understanding, focusing or collecting commercial, emerging small-sat and small-launcher needs
    - Integrate these needs into agency technology roadmaps, followed by a portfolio of technology investments most likely to grow the sector
    - A sector that can serve NASA needs while also meeting emerging non-government needs

Recommendations

3. Range a significant cost and technology issue for dedicated nano-launchers

- Small, dedicated launcher price targets swamped by this singular effort/burden
  - Ops-range requirements before launch (show meets policy, analysis, risk, debris, safety plans, etc.)
  - FTS-requirements (CDS, ADS, ISDS & combo's dependent on complexity)
  - Telemetry-requirements (two valid and independent data sources; INS and Radar, Radar and GPS, GPS and INS, etc.)
  - Ops-range requirements for launch (survey, clear, air/land, holds, etc.)
- Technology directions (space based range, AFSS, enhanced/encrypted FTS, re-entry/JARSS, etc.) not entirely specific to small launch needs.

- Recommend: Overcoming system level barriers to small launch affordability and flight rate improvements, crossing flight systems, ground systems, life cycle phases, and organizations (industry, government), requires system level leadership emphasis.
- Target outcome: A test flight infrastructure / proving ground that allows for affordably demonstrating, at a high tempo, new technology and/or practices for the certification of emerging space companies.

Recommendations

4. Recommend: Dependent on the prior, the agency could explore COTS-cargo-like acquisition partnerships for dedicated nano-launcher developments followed by acquisition of commercial services (firm fixed price, “anchor tenant”, etc.)

“To seek and encourage, to the maximum extent possible, the fullest commercial use of space.”

-National Aeronautics and Space Act; also NASA Strategic Plan, 2014

“[That phrase] *in the law that created NASA…gives NASA an often overlooked mission*”

-Remarks by the NASA Administrator Gen Charles Bolden, National Association of Investment Companies Washington DC, October 20, 2009

- Define appropriate who (AES, STMD, Exploration, Science, LSP, etc.)
- Define applicability of acquisition/investment approach
  - Define capability maturity of (1) potential partners, (2) non-government markets/business cases , and (3) NASA anchor needs
- Define advantage to NASA non-recurring investment other than costs
  - Convenience, options for science, responsiveness, ISS-cargo, etc.
  - May be necessary to kick-start the *initial* private sector business cases (IRR, multiples, and other business measures to attract capital, etc.)

Backup

Notes for cost/kg chart

- SpaceX - secondary payload "PPOD" to LEO $200,000-$325,000 (=$67,000-$108,000/kg; from Aug. 2012, 26th Annual AIAA USU, Conference on Small Satellites)
- NanoRacks - "Commercial payloads start at $60,000 per 1U" (from http://nanoracks.com/resources/faq/); +volume discounts, to 50kg.
- SpaceX – secondary payload, ESPA-class satellite weighing up to 180 kilograms would cost $4–5 million for LEO, from August 2012, 26th Annual AIAA USU, Conference on Small Satellites (=$22,000 to $28,000/kg)
- Multiple: Spaceflight Services – 3U $295,000, 6U $545,000, 12U $995,000, 50kg $1,750,000, 100kg $3,950,000, 200kg $5,950,000, 300kg $7,950,000 (from http://spaceflightservices.com/pricing-plans/)

- Generation Orbit - **In development** – data point of 30kg @ $2.5M (=$83,333/kg); assorted configurations; –albeit to **425km**, 30 deg., meaning performance to 200km would be more than 30kg (and cost/kg less than shown). i.e.,
- Firefly - **In development** – 400kg for $9M, as advertised @ http://www.fireflyspace.com/ (=$22,500/kg)
- Rocket Lab – **In development** – 110kg for $4.9M, as advertised @ http://www.rocketlabusa.com/ (=$44,545/kg) –albeit to **500km**, implying performance to 200km would be more than 110kg (and cost/kg less than shown). i.e.,
- Launcher One – I**n development** – 225kg as advertised @ http://www.virgingalactic.com/launcherOne/ for a price "below $10 million" per http://www.newspacejournal.com/2012/07/11/virgin-galactic-relaunches-its-smallsat-launch-business/ (=$44,444/kg)

- Swiss Space Systems (S3) – In development – a reusable spaceplane, air-launched, for 250kg payloads as advertised at http://www.s-3.ch/en/mission-goals "for $10.5 million" per http://www.parabolicarc.com/2013/03/13/swiss-space-systems-announces-smallsat-launch-system/ (=$42,000/kg)

- US DoD DARPA, ALASA project – In development – "The contract is for DARPA's Airborne Launch Assist Space Access (ALASA) program, which is intended to field a system to launch satellites weighing up to 45 kilograms into low Earth orbit for $1 million each." (=$22,222/kg). http://www.spacenews.com/article/military-space/39967darpa-picks-boeing-to-demonstrate-airborne-launcher-concept

- Specific ULA vehicle values are specific launches from most recent data. See original source data at: http://science.ksc.nasa.gov/shuttle/nexgen/Nexgen_Downloads/Space_Biz_Cost_Comparisons_Tool/
- "ULA ALL-as System" is an average of total costs paid by customers. This is about the same value as would be obtained using specific data for 2012 or 2013, including all revenue to ULA for launches, from DoD (both ELS and ELC budgets), NASA payments for specific launches, and commercial customers, at the launch rate both of those years (11). In practice NASA pays less, DoD more, due to ELC payments by DoD to ULA.
- Shuttle has had crew costs removed using a Soyuz rate (820 at $70M ea.). It is in FY10 dollars. **Adjustment pending to remove NASA FTE from Shuttle, leaving only procurement costs as with the other data points.**
- SLS value indicated does not include an Earth Departure Stage / Upper Stage or Orion. 70mt version at average rate of 1 a year (or equivalent, two one year, skipping a year, etc.)

Fixed, Variable and Marginal Costs – Observations on the Space Shuttle

- Space Shuttle "Zero Base" study

Big jumps -the additional recurring, fixed cost of maintaining and operating additional, fixed, flight or ground assets, including labor, required to maintain this production/flight rate

29-Jun-91

ZERO BASE OPERATIONS COST STUDY
ALL PROJECTS
SHUTTLE OPERATIONS COSTS -- FY 94 IN RY $

PROJECT	FLIGHT RATE ($) 1	2	3	4	5	6	7	8	9	1[illegible]
LAUNCH OPERATIONS	318.9	344.5	367.1	479.6	512.5	540.3	636.8	675.5	689.5	702.[illegible]
EXTERNAL TANK	389.3	389.3	389.3	389.3	405.5	422.6	441.0	46[illegible].6	477.1	493.[illegible]
REDESIGNED SOLID ROCKET MOTOR	281.2	2[illegible]1.2	299.5	319.1	354.7	3[illegible]0.1	411.7	437.3	456.8	476.[illegible]
MISSION OPERATIONS	249.1	259.2	2[illegible]8.0	274.4	287.5	297.2	312.5	320.6	327.9	333.[illegible]
ORBITER	145.2	148.0	152.0	169.3	178.2	183.7	197.7	20[illegible].9	207.0	210.[illegible]
LOGISTICS	119.5	126.0	133.9	142.9	149.[illegible]	161.1	177.2	190.2	203.4	209.[illegible]
SOLID ROCKET BOOSTER	111.0	114.0	123.7	132.6	14[illegible].4	150.7	164.[illegible]	172.6	184.0	193.[illegible]
SPACE SHUTTLE MAIN ENGINE	91.6	91.6	91.6	107.4	112.6	117.9	126.1	131.3	138.3	143.[illegible]
SPACE SHUTTLE PROGRAM OFFICE	140.3	142.0	145.4	151.1	158.2	166.8	173.9	180.6	187.3	193.[illegible]
OTHER										
– ENGINEERING	76.9	77.2	78.2	80.2	84.[illegible]	87.7	88.4	91.1	92.1	92.[illegible]
– FLIGHT CREW OPERATIONS	43.4	43.4	43.4	48.9	48.9	51.9	52.6	60.6	60.6	60.[illegible]
– PAYLOAD OPERATIONS	14.2	14.3	25.2	29.9	32.2	38.2	38.9	39.6	42.3	43.[illegible]
– PROPULSION SYSTEMS INTEGRATION	24.8	25.6	26.0	27.7	27.7	28.6	29.6	29.6	29.6	29.[illegible]
– SPACE AND LIFE SCIENCES	18.7	20.7	20.7	20.7	20.7	22.7	22.9	22.9	22.9	24.[illegible]
TOTAL FOR PROJECTS REVIEWED	2024.1	2077.0	2184.0	2373.1	2516.6	2649.5	2873.7	3014.4	3118.8	3205.[illegible]

Small jumps -variable costs of using the existing capability

Spaceflight Services Pricing

See: http://spaceflightservices.com/pricing-plans/