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OFFICE OF THE DIRECTOR OF NATIONAL INTELLIGENCE

DESIGN LIFE STUDY

International Cost Estimating & Analysis Association

LEADING INTELLIGENCE INTEGRATION

Overall Classification of this briefing is: UNCLASSIFIED

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12 JUNE 2018

Study Purpose

- Performed a study evaluating design life impact on the cost of satellite constellations

- Goals:
  - Determine optimal cost design life for a reference architecture
  - Examine the sensitivity of the results to diminishing future launch vehicle costs
  - Identify potential for technology insertion on satellites due to quicker replenishment

- Approach – analyze how the optimal cost design life varies with:
  - Constellation size
  - Satellite complexity
  - Required development effort
  - Replenishment risk posture

Ground Rules and Assumptions

- Satellite technical performance is equivalent for all options, regardless of design life or other variables

- Architecture costs include space vehicles and launch
  - Excluded costs: Ground, Operations and Maintenance, Impacts to the Communication Architecture, System Integration, Other Government Costs

- Satellites will continue to live much longer than specified design life
  - Contractual design life requirements not changed
  - Change from the current replenishment risk posture

- Did not assess industrial base impacts or mission utility evolution

- Did not address specific vehicle type or architecture

Definitions

Design Life (DL): length of time specified in the contract through which the manufacturer provides a given probability of mission success for a single satellite

Mean Life Estimates (MLEs): expected remaining time that a single satellite will contribute to satisfying mission requirements based on current reliability estimates

Functional Availability (FA): probability of satisfying the functional success criteria for a given mission as a function of time

Functional Success Criteria (FSC): minimum satellite constellation performance required for mission success

Probability of Success at DL (P_s): probability that a single satellite will perform its intended function at design life under stated conditions. P_s for this study is 0.85 at design life.

Trade Space and Reference Architecture

- Trade space
  - Constellation Size (2 – 10)
  - Satellite Size/Complexity (3,000 lb. – 20,000 lb.)
  - New Design in 1st Block (50% - 100%)
  - New Design in Follow-On Blocks (25% - 75%)
  - Reliability and Infant Mortality (Operational, commercial-like, specification (spec.) curves)

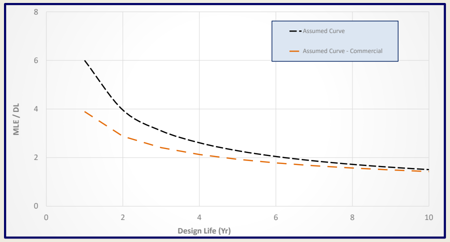
- Reference architecture
  - 5 vehicle constellation
  - 7,500 lb. satellite (dry)
  - 75% New Design in 1st Block
  - 50% New Design in Follow-On Blocks

All options estimated with:

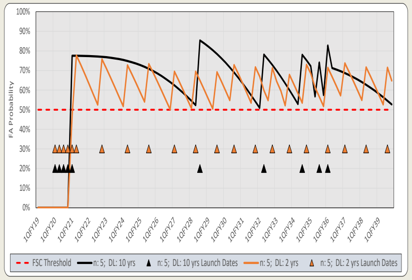
- Design life of: 2, 4, 6, 8, 10 yrs.
- Current and Future Launch Costs

Overview

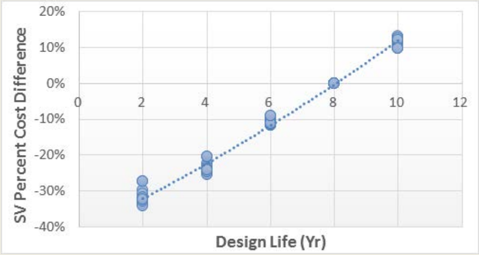
Vehicle Reliability



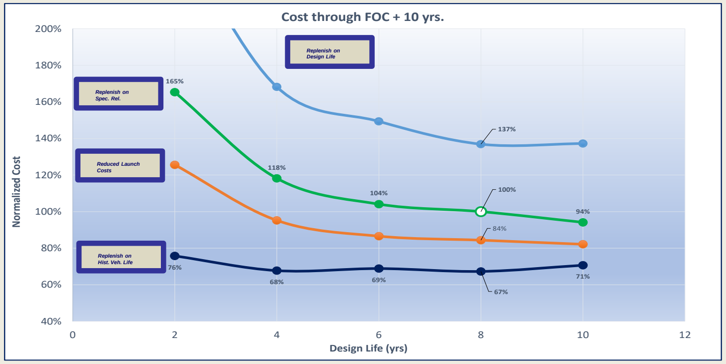
Functional Availability



Space Vehicle Cost

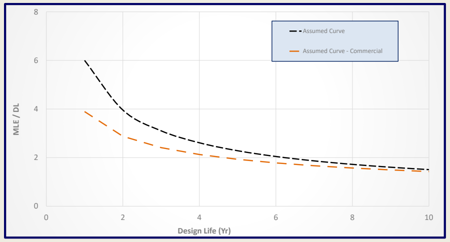


Architecture Cost

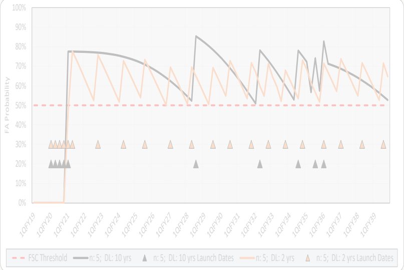


Space Vehicle Reliability

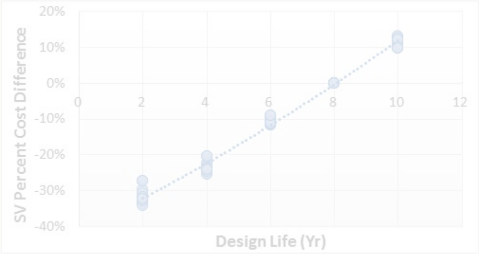
Vehicle Reliability



Functional Availability

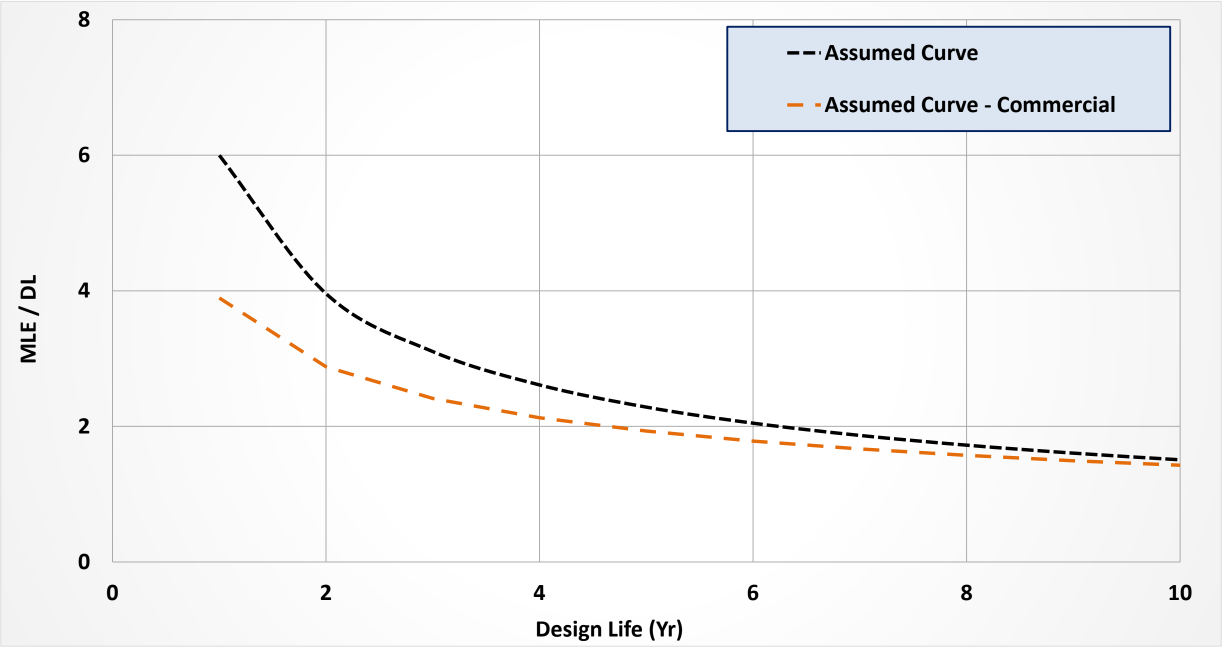


Space Vehicle Cost



Architecture Cost

Space Vehicle: Expected Life vs. Design Life



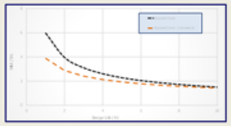
- **Examined ratio of actual satellite life to design life**
  - **Validated by OSD/CAPE study**

- **Historically, vehicles lasted much longer than design life**

- **Low design life vehicles have a much higher ratio of MLE to DL**

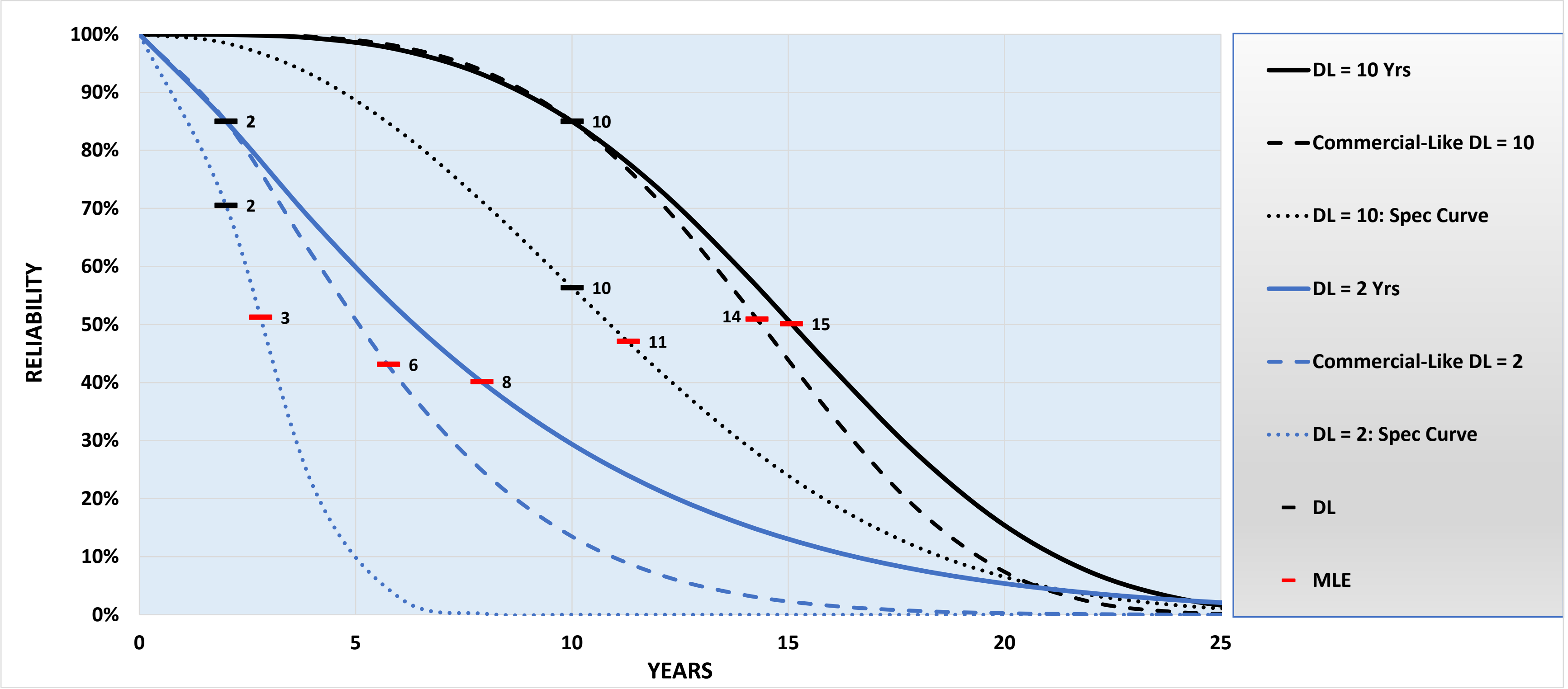
- **On average, commercial-like vehicles have a lower MLE to DL ratio**

Vehicle Reliability



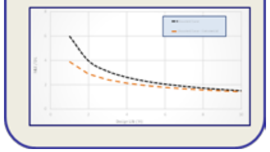
Reliability Curves

Historically-Derived vs. Specification



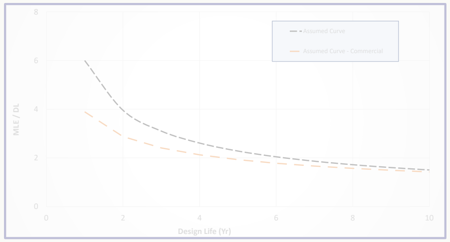
- Reliability curve differences are more pronounced at lower design lives
- Results in large quantity difference to maintain constellation
    - Especially true for satellites with lower design lives

Vehicle Reliability

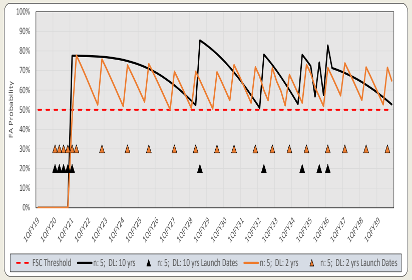


Architecture Functional Availability

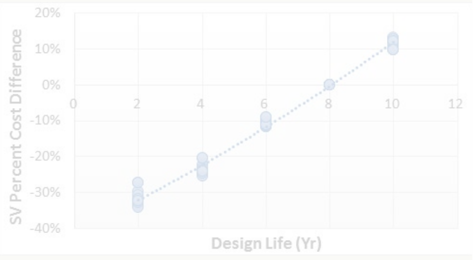
Vehicle Reliability



Functional Availability



Space Vehicle Cost

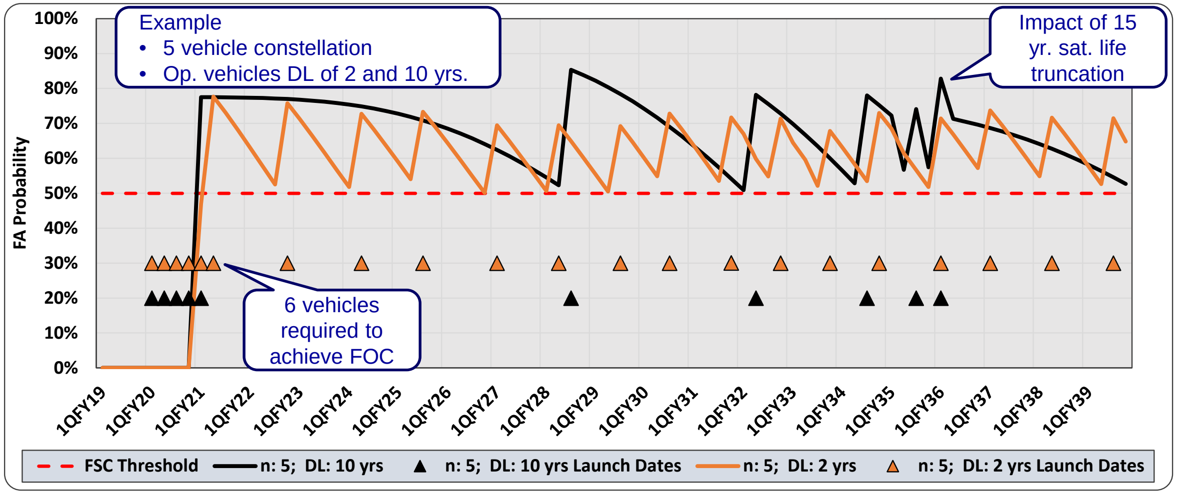


Architecture Cost

Functional Availability (FA) Analysis

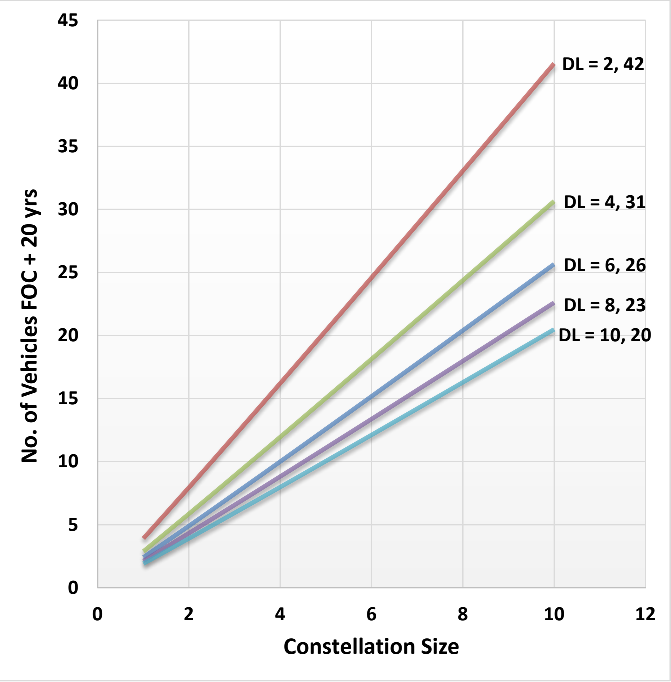
Utilized FA analysis to determine frequency of launches for all combinations of design life

Developed algorithm to predict total number of vehicles required to meet Full Operational Capability (FOC) for a given constellation size

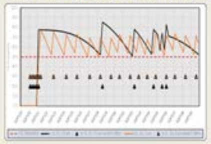

Example
- 5 vehicle constellation
- Op. vehicles DL of 2 and 10 yrs.

Impact of 15 yr. sat. life truncation

6 vehicles required to achieve FOC



Functional Availability

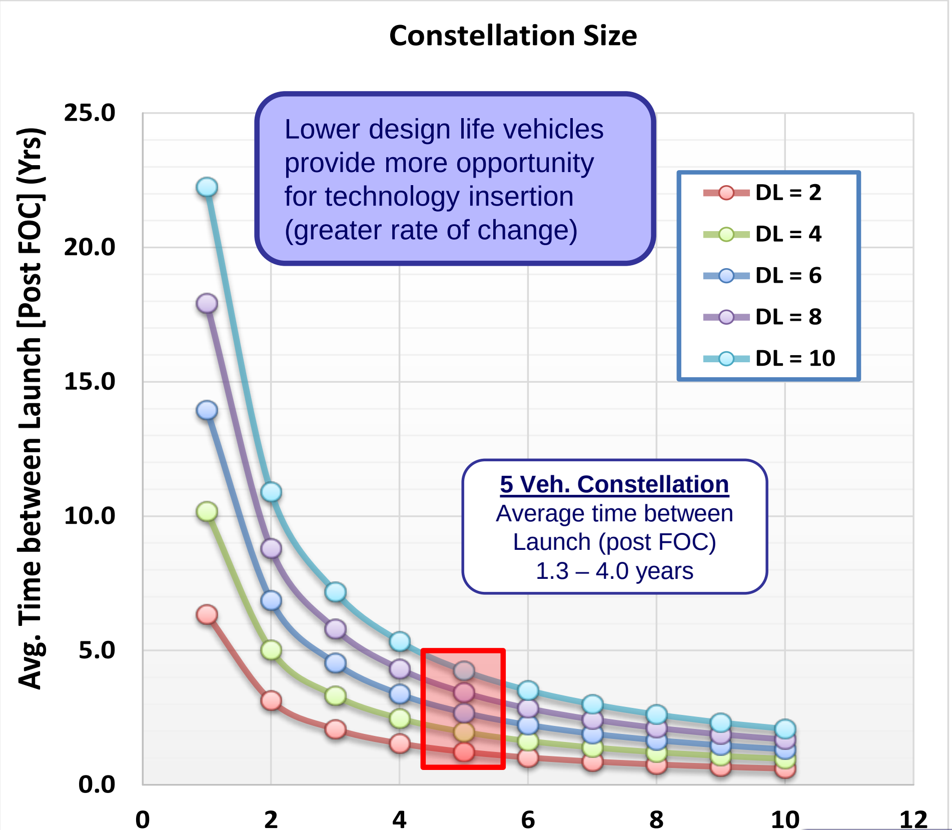


Functional Availability Results

Analysis yielded curves for time between launch

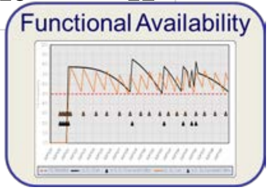
Represents opportunities for technology insertion or resiliency

Costs of technology insertion addressed later in conclusion



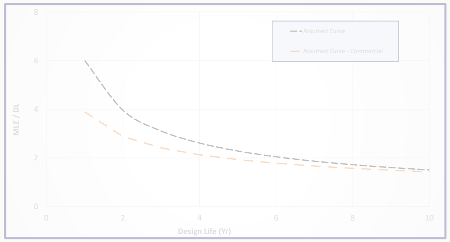
Lower design life vehicles provide more opportunity for technology insertion (greater rate of change)

5 Veh. Constellation
Average time between Launch (post FOC)
1.3 – 4.0 years

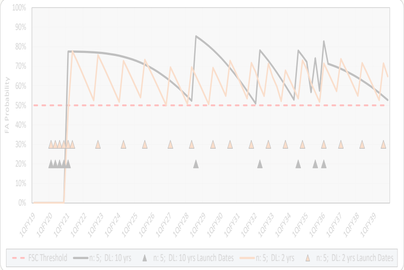


Space Vehicle Cost

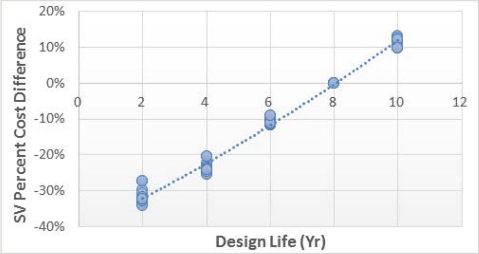
Vehicle Reliability



Functional Availability

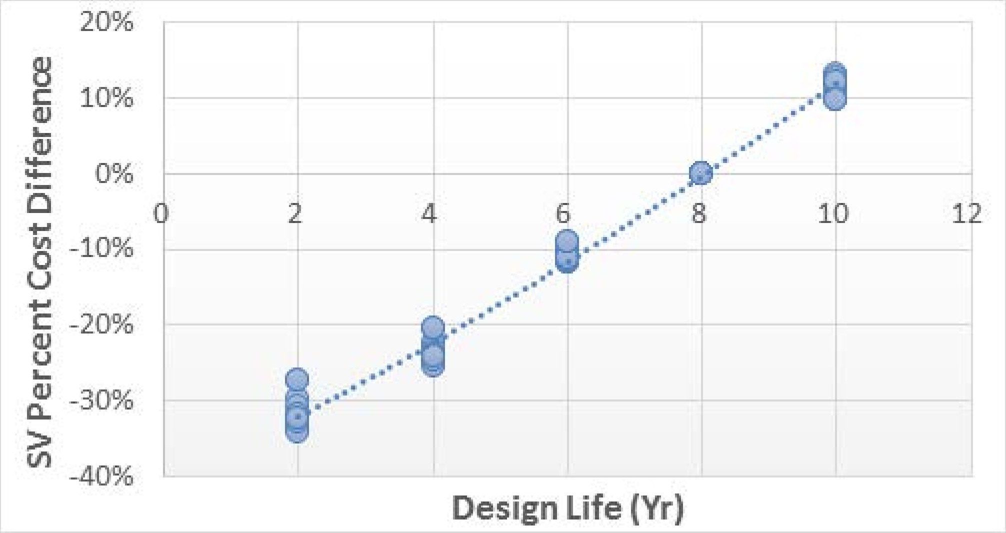


Space Vehicle Cost



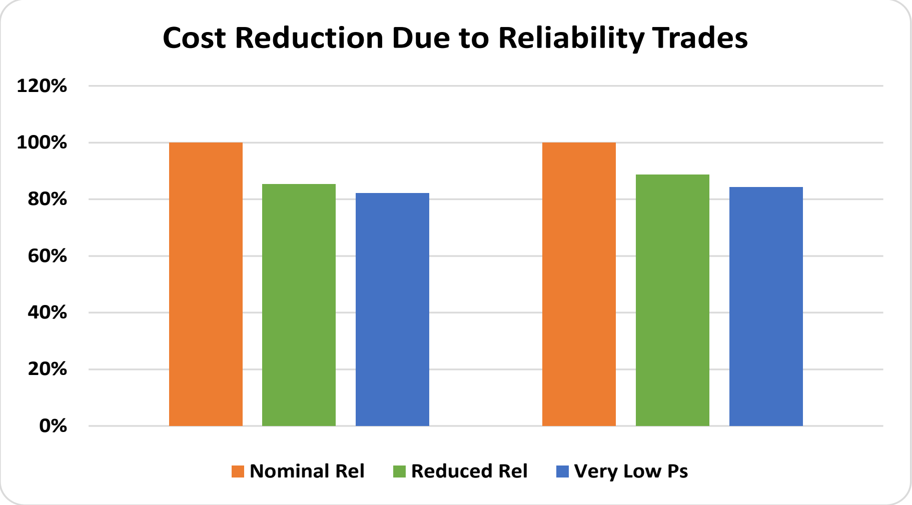
Architecture Cost

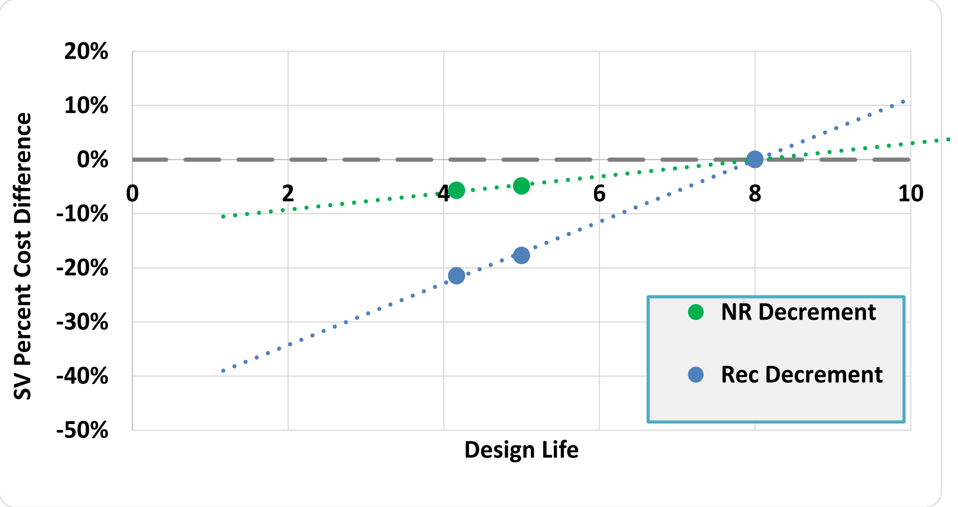
Space Vehicle Cost vs. Design Life



- **Space vehicle costs scaled by design life**
  - Affects Non-recurring and recurring costs
- **Plot shows the net cost difference due to:**
  - Redundancy
  - Space Vehicle Sizing
  - Mission Assurance
  - Integration & Testing
  - Systems Engineering & Program Management

Translating Redundancy to Cost





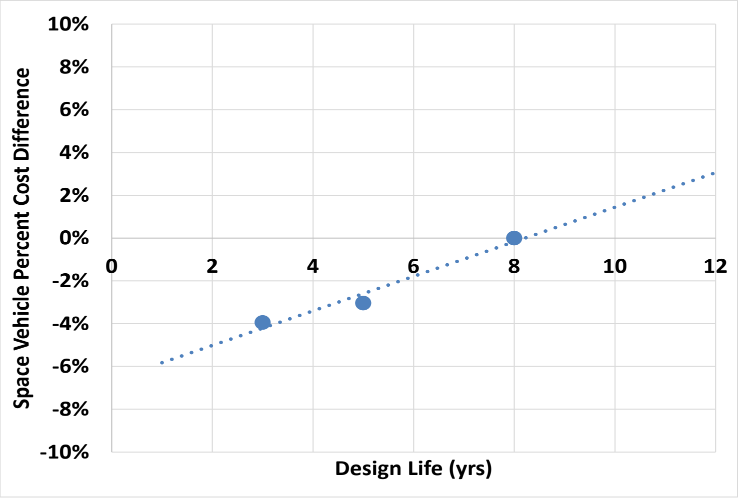
- **Estimated cost of three vehicle redundancy postures for two NRO programs**
- **Performed estimates with redundancy reductions**
- **Redundancy accounted for largest reductions to cost**

- **Adjusted Weibull reliability curves based on adjustments to reliability model for single-string components**

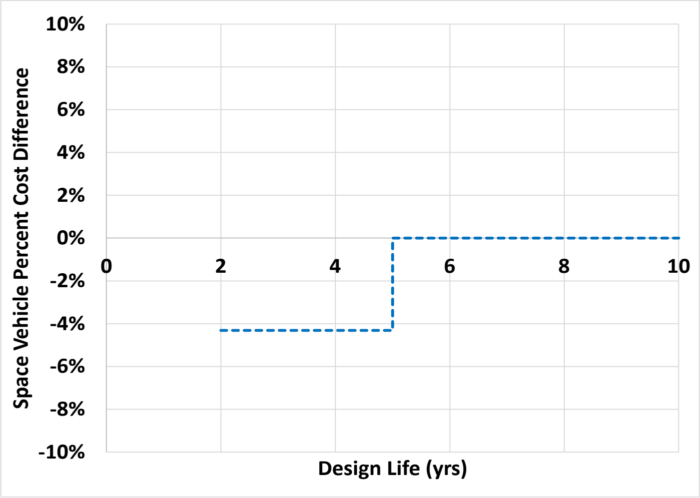
Cost Reductions Due to Design Life

- **Other adjustments to cost included mission assurance and SEITPM**
- **NRO CAAG performed studies on space vehicle testing and mission assurance**
  - **System Engineering, Integration and Test, Program Management (SEITPM):**
    - **I&T adjustment applies to bus and space vehicle levels**
    - **I&T adjustment does not apply to payload**
    - **SEPM scales linearly with box level costs and I&T**
  - **Mission assurance accounts for step increase around 5-year design life**

SEITPM

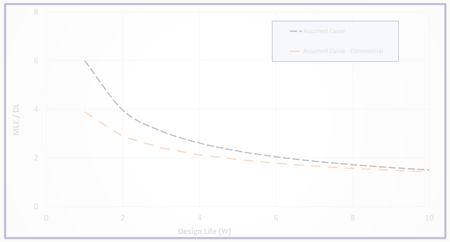


Mission Assurance

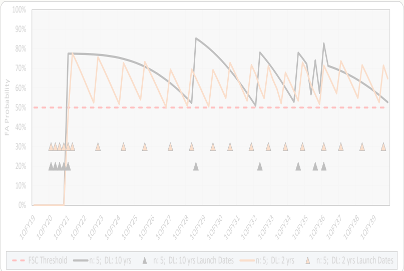


Architecture Cost

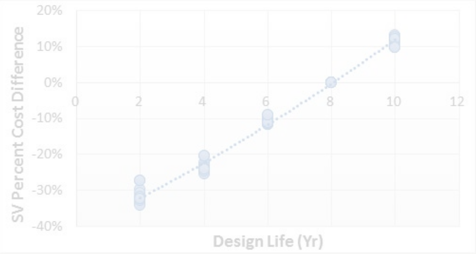
Vehicle Reliability



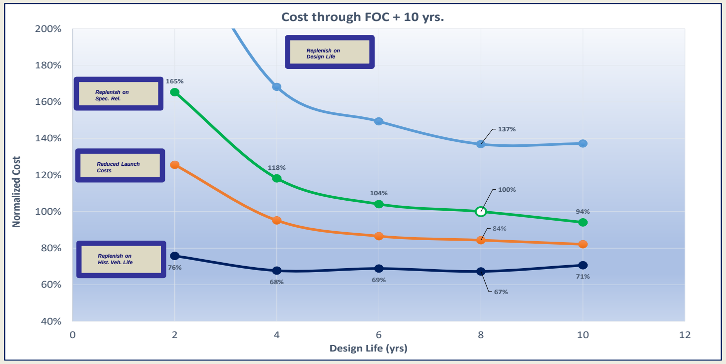
Functional Availability



Space Vehicle Cost



Architecture Cost

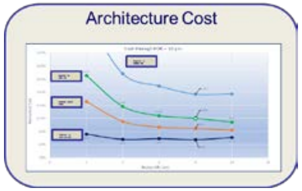


Architecture Cost Estimates

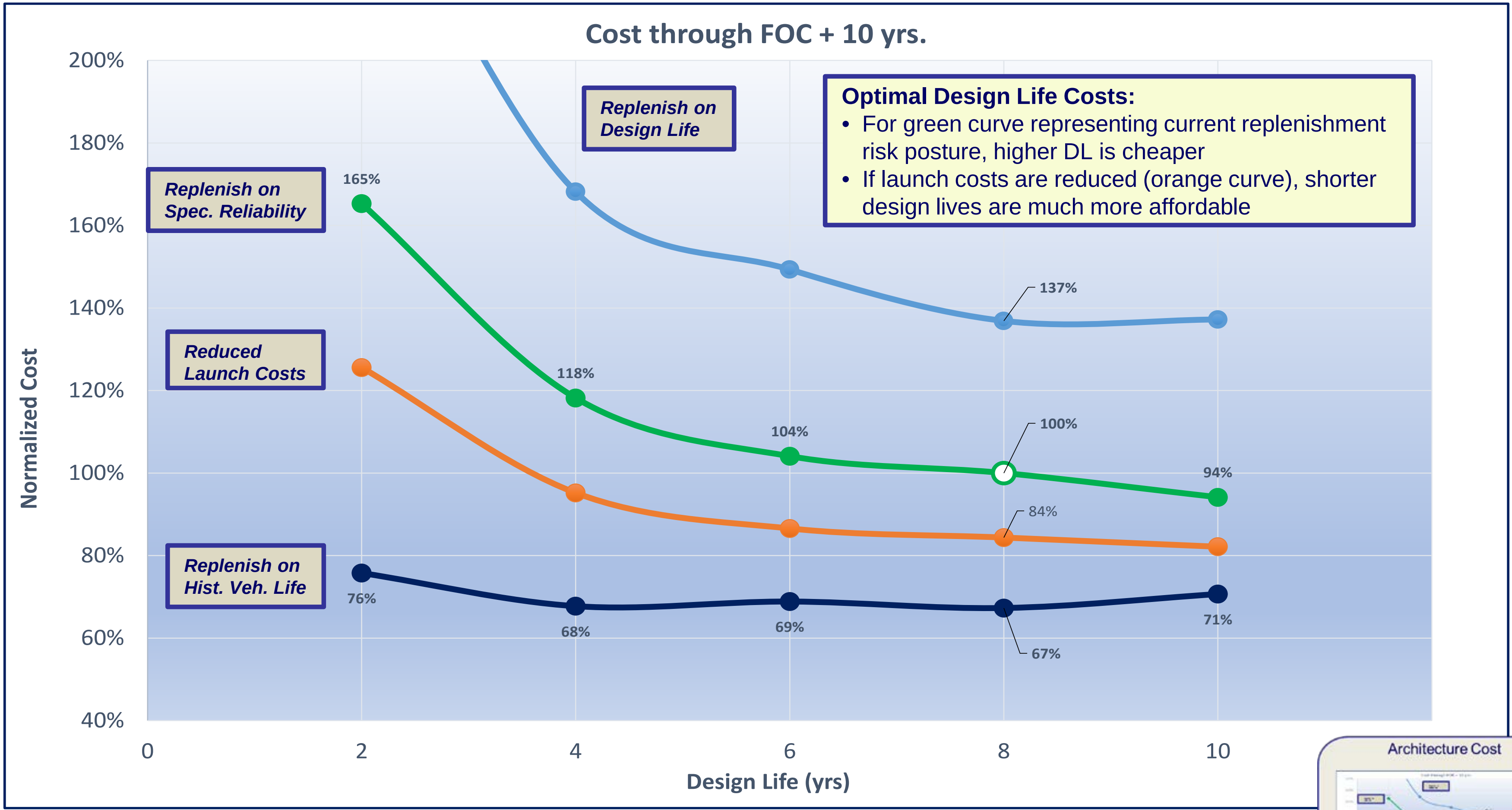
Family	Constellation Size	Reliability Assumptions	SV Wt. (lb.)	BLOCK 1 SV % New Design	BLOCK 2 SV % New Design	BLOCK 3 SV % New Design	BLOCK 4 SV % New Design
2 Veh Const	2	On-orbit data	7,500	75%	50%	50%	50%
3 Veh Const	3	On-orbit data	7,500	75%	50%	50%	50%
4 Veh Const	4	On-orbit data	7,500	75%	50%	50%	50%
Reference Arch	5	On-orbit data	7,500	75%	50%	50%	50%
6 Veh Const	6	On-orbit data	7,500	75%	50%	50%	50%
7 Veh Const	7	On-orbit data	7,500	75%	50%	50%	50%
8 Veh Const	8	On-orbit data	7,500	75%	50%	50%	50%
9 Veh Const	9	On-orbit data	7,500	75%	50%	50%	50%
10 Veh Const	10	On-orbit data	7,500	75%	50%	50%	50%
Spec Curves	5	Spec. Curves	7,500	75%	50%	50%	50%
Big Sat	5	On-orbit data	20,000	75%	50%	50%	50%
Small Sat	5	On-orbit data	3,000	75%	50%	50%	50%
New Design	5	On-orbit data	7,500	100%	50%	50%	50%
Existing Design	5	On-orbit data	7,500	50%	50%	50%	50%
Obsolescence	5	On-orbit data	7,500	75%	25%	25%	25%
Enhancement	5	On-orbit data	7,500	75%	75%	75%	75%
Baseline - 1 Veh	1	On-orbit data	7,500	75%	50%	50%	50%
Big Sat - 1 Veh	1	On-orbit data	20,000	75%	50%	50%	50%
Small Sat - 1 Veh	1	On-orbit data	3,000	75%	50%	50%	50%

Red depicts what changes from the reference architecture

- **Acquisition schedule derived**
  - Block 1: # of vehicles required to achieve FOC
  - Block 2: # of vehicles launched form FOC to FOC+10 yrs
  - Block 3: # of vehicles launched from FOC+10 to FOC+20 yrs
  - Block 4: # of vehicles launched from FOC+20 yrs to FOC+30 yrs
- **Space vehicle costs estimated by block**
  - Number of vehicles required to maintain constellation
  - Complexity / size of the satellite
  - Amount of new development effort
  - Vehicle design life
  - Recurring vehicle costs reset for each block (reset learning)
- **Varied design life (2, 4, 6, 8, 10 year) for each option**
- **Varied launch cost**
- **Ran nearly 300 scenarios to generate curves**

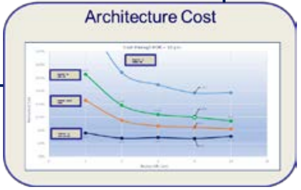


Architecture Costs vs. Design Life

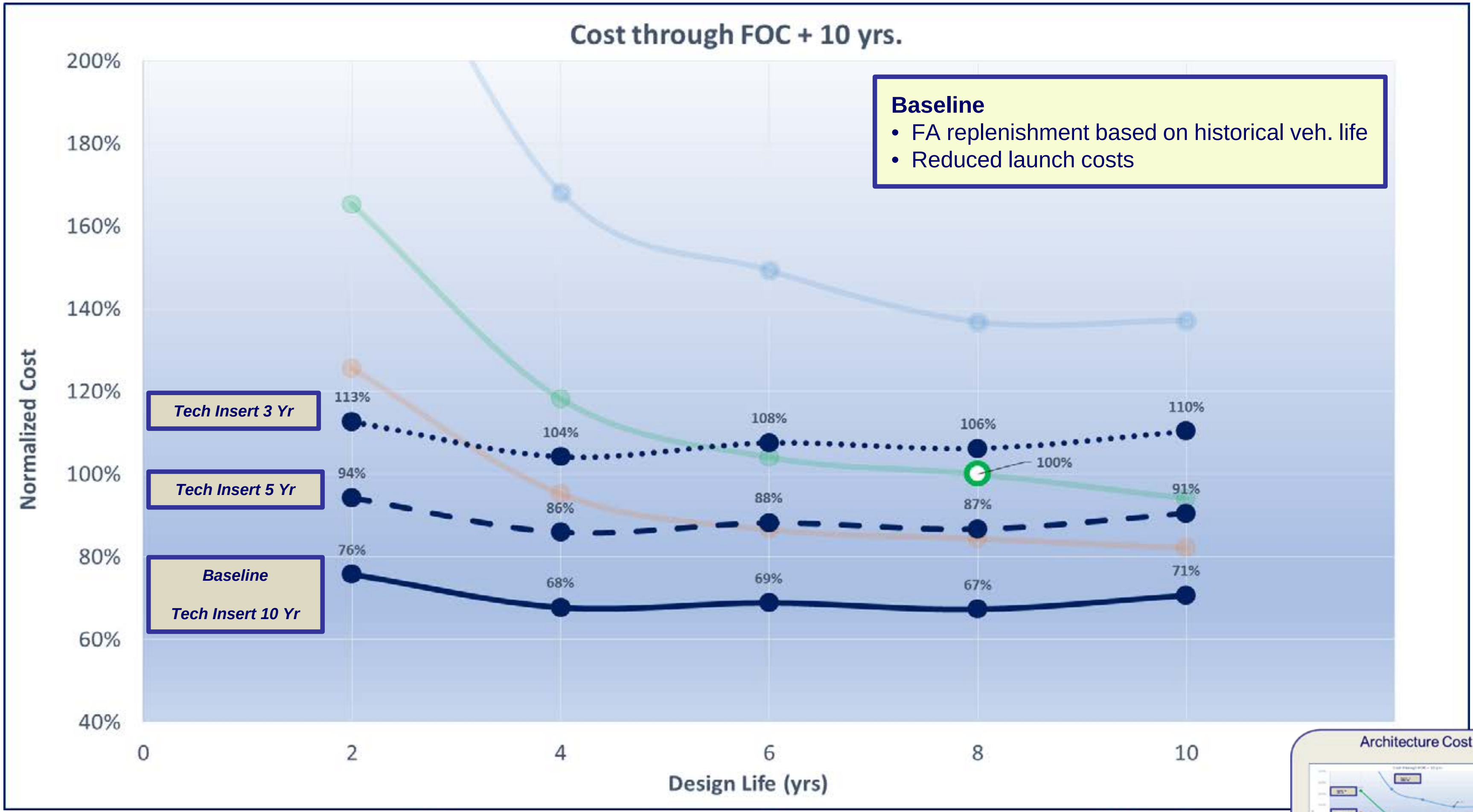


Optimal Design Life Costs:
- For green curve representing current replenishment risk posture, higher DL is cheaper
- If launch costs are reduced (orange curve), shorter design lives are much more affordable

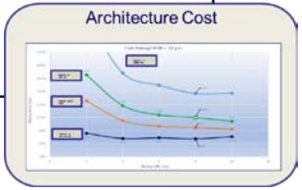
Potential for cost avoidance by adopting a more aggressive replenishment strategy combined with reduced launch costs



Technology Insertion

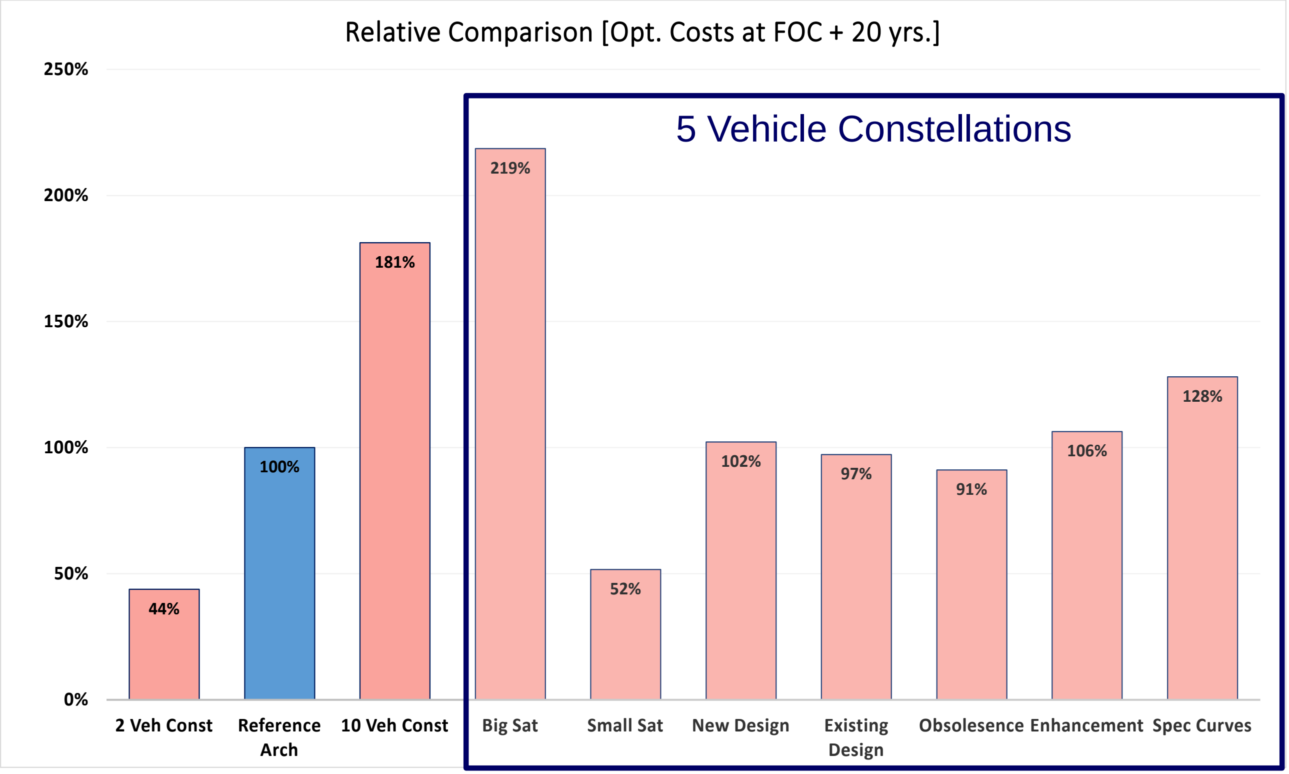


Baseline
- FA replenishment based on historical veh. life
- Reduced launch costs



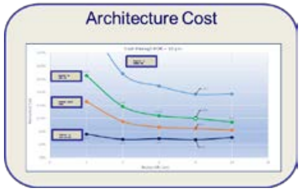
Potential cost avoidance can be applied to technology insertion

Architecture Cost Drivers



Architecture Cost Drivers:

1. Constellation Size
2. Satellite Complexity
3. Required Development Effort
4. Replenishment Risk Posture



Initial Findings and Observations

- **Optimal cost design life decreases with decreasing launch costs**
  - Current Launch Pricing: 6 – 10 yr. DL (cost neutral)
  - Future Launch Pricing: 4 – 8 yr. DL (cost neutral)
- **Acquisition decisions for cost neutral architectures can be based on other factors such as operational concepts, technology insertions, mission utility**
- **Optimal cost design life decreases with increasing on-orbit vehicle life**
- **Replenishment risk posture (specification vs. empirical data) is a significant cost driver**