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NRO CAAG Parametric Model for Spacecraft-to-Launch-Vehicle Integration Cost

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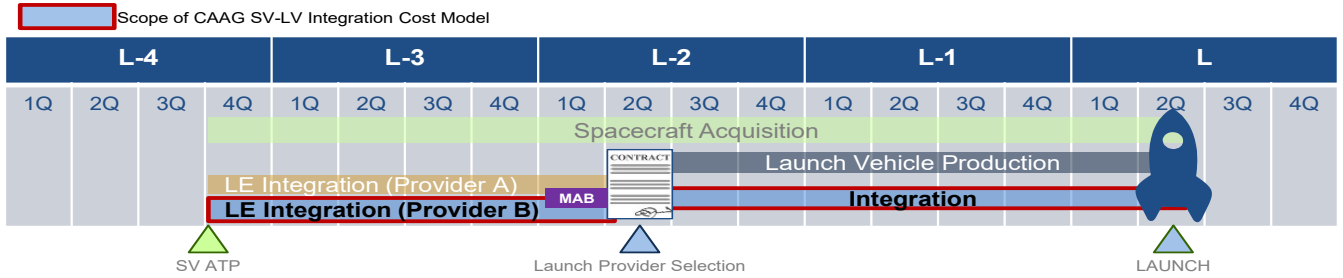
Launch Cost – Not an Afterthought Anymore

- In the past…
  - Few options for National Security Space launch providers
  - Similar costs for a given mass-to-orbit capability

- NSS launch in the 20's
  - Several viable new entrants
  - Launch is more of a commodity, but also more flexibility within the tradespace
    - Disaggregated capabilities
    - Ridesharing
    - Mission life vs. tech insertion capability
    - Multiple launch
    - Etc.
  - Standard launch services still tend to be fixed-price
  - Mission-unique aspects & requirements vary greatly in cost
    - From single-digit $M to over $100M!

Scope of SV-LV Integration Effort

"Integration": Multi-year engineering effort performed by a launch service provider ensuring compatibility between spacecraft and launch vehicle & facilities, enabling mission success



Mission Design & Analysis

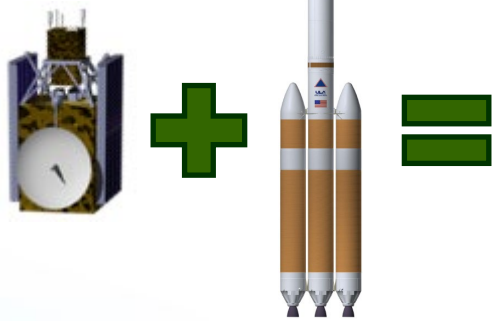
Manage/Validate Launch Base Interfaces & Infrastructure Requirements

Manage/Validate SV-LV Interface Requirements

Mission-Unique HW Design

Coupled Loads Analysis

Launch Rehearsals



Trailblazers

Trajectory Planning

Aerophysics, Thermal, Contamination

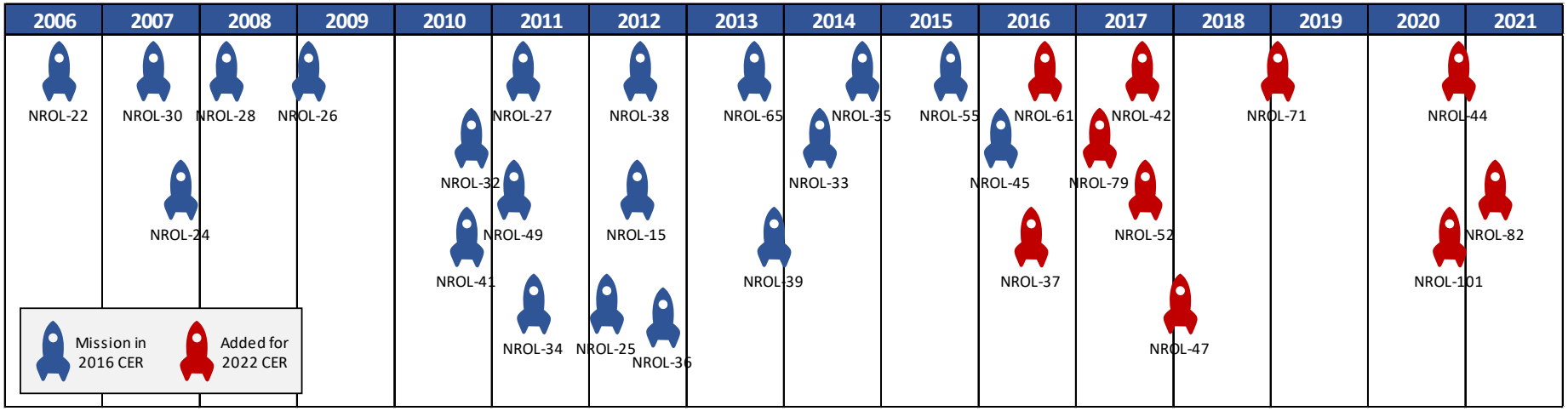
SV-LV Integration Potential Cost Drivers

- SV-to-LV Integration is primarily an engineering effort, cost is therefore driven by complexity of the mission and SV-LV interface
- Quantifiable measures of integration complexity
  - Requirements ("shall" statements) in the Interface Control Document (ICD)
    - ICD identifies all technical requirements the LV and SV must meet to enable matchmate and successful mission
    - Managed by the LV provider
  - Wet Dress Rehearsals, Integrated Crew Exercises, and other launch rehearsals
    - LV provider, SV provider, customer and range support personnel must train to execute mission
    - Mock fuelings, mock anomaly resolution, and other on-console day of launch simulations
  - Mechanical Trailblazers
    - Hardware built to simulate SV
    - Designed to help train ground crews with SV handling, encapsulation, transport, etc.
  - Customer-directed Studies
    - Often mission assurance efforts for upgraded LV hardware or other first-flight items

SV-LV Integration Potential Cost Drivers (2)

- Quantifiable measures of integration complexity (cont'd)
  - Custom-designed Environmental Control Hardware
    - SV components may require cleanroom conditions within the fairing, positive pressure, humidity control, etc.
    - Can require LV provider to design & build specialized environmental management HW
  - Heavy-Lift Launch Vehicle
    - Few launches, few customers
    - Extensive tailoring to specific missions
  - First-time Pairing of SV Design and LV
    - Nonrecurring engineering efforts that can be leveraged for subsequent "clone" launches
    - Increased mission assurance effort to ensure success of first-time attempt
  - First-time Use of LV at Launch Site
    - Often requires infrastructural modifications
    - Additional mission assurance effort associated with unproven infrastructure
  - First Customer Use of LV
    - Drives mission assurance work and studies to ensure success on first attempt

CAAG SV-LV Integration Cost Model Dataset



- Previous update to CAAG Integration CER – 2016
  - Briefed at NRO/Air Force Launch Cost Summit, 2018
- 2022 dataset expanded to include total of 30 missions
  - Mix of Heavy & Medium/Intermediate, Eastern & Western ranges, First-time & recurring
  - Broad ranges represented in integration cost, ICD requirements count, number of WDRs performed, trailblazer activities required

NRO CAAG Integration CER – Functional Form

Stratifiers capture major mission assurance categories

2022 NRO CAAG SV-LV Integration CER

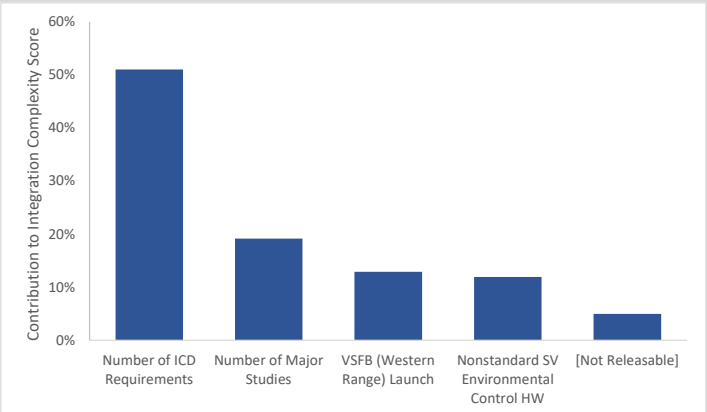
$$\text{Integration Cost (BY00\$K)} = (a \cdot [\text{Score}] + e) \cdot b^{[\text{First SV–LV}]} \cdot c^{[\text{First Customer or Pad Use}]} \cdot d^{[\text{HLV}]}$$

where

$$\text{Int. Complexity Score} = \frac{\sum w_i [\text{Normalized Parameter}]_i}{\sum w_i}, \quad \text{Normalized Parameter} = \frac{\text{Parameter} - \text{Parameter}_{min}}{\text{Parameter}_{max} - \text{Parameter}_{min}}$$

Integration Complexity scoring approach

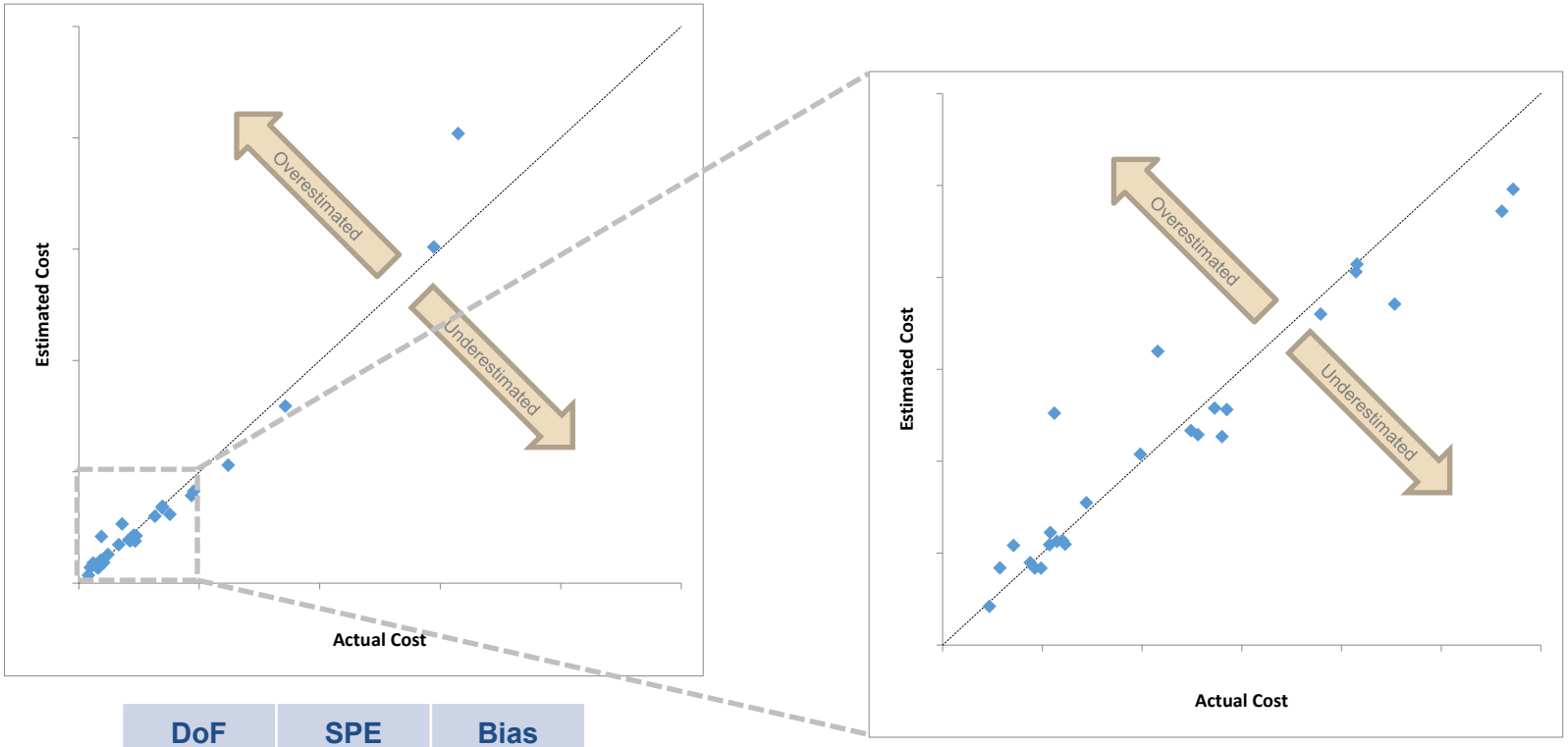
- Mission complexity is scored 0-100%
- Weighted average of percentile rank in the dataset for each statistically significant mission-specific scope driver
- Weightings determined by regression



- Drivers associated with **mission assurance** define ranges of potential cost
  - First-time SV-LV pairing, First customer or launch facility use of LV, Heavy lift
- Drivers associated with **mission-specific scope** determine estimate within range
  - Requirements in ICD, Customer-directed studies, Western range, Mission-unique environmental control

NRO CAAG Integration CER – Goodness of Fit

$$\text{Integration Cost (BY00\$K)} = (a \cdot [\text{Score}] + e) \cdot b^{[\text{First SV–LV}]} \cdot c^{[\text{First Customer or Pad Use}]} \cdot d^{[\text{HLV}]}$$



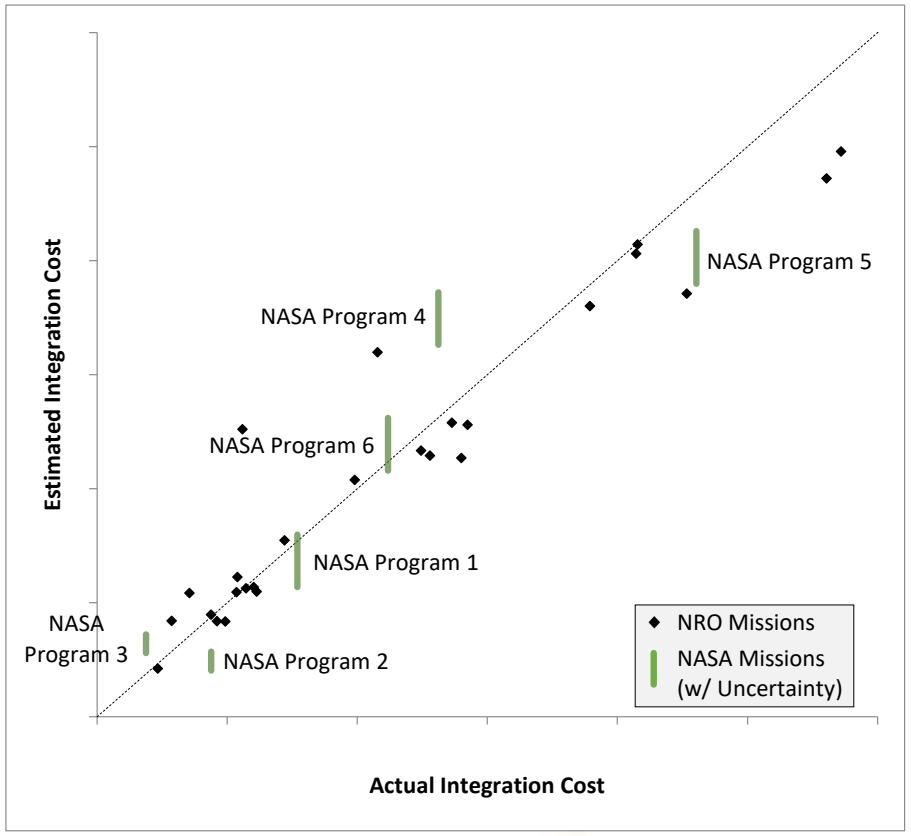
DoF	SPE	Bias
20	22.5%	0%

CER shows good performance across a broad range of integration campaign complexities and costs

NASA-Provided Data

- NASA/LSP provided NRO CAAG data on several recent launch procurements for NASA missions to compare against CAAG models
- Challenging to align integration scope to compare against NRO model!
- Continuing work with NASA to refine data and align scope:
  - Removal of flight HW such as ESPA ring, payload adapter
  - Reduction of payload processing scope cost
  - Removal of LV propellant costs
  - Removal of base & range services costs
  - Collect data on ICD requirements count
- With some margin of error, can assess generally how well CAAG integration model fits NASA historical data

NASA Data in NRO CAAG Integration CER



	Points	SPE	Bias
NRO Data	30	22.5%	0%
NASA Data	6	43.8%	7.5%

- Missing data results in some uncertainty around Integration Complexity scoring for NASA missions
- NASA integration costs appear to be in-family with NRO costs
- NASA integration costs appear to be driven by the same parameters that drive NRO costs

CER appears to be a good predictor of SV-LV integration costs independent of customer

Summary

- Launch cost is an increasingly variable part of enterprise-level trades for US government satellite constellation architectures
- NRO CAAG has developed a parametric cost model for the highest-variability portion of launch cost, SV-to-LV Integration Engineering
- Integration cost is predicted well by two categories of cost drivers:
  - **Mission assurance** drivers related to familiarity and LV provider proven capability with the specific requirements of the mission – First-time SV-LV design pairing, First-time customer use of LV, Heavy-lift LV
  - **Integration complexity** drivers related to the scope of the mission-specific tasks to be performed – ICD requirements, customer-directed studies, mission-unique environmental control equipment, use of western range
- NRO CAAG cost model shows good agreement with NRO and NASA historical data

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