NASA Instrument Cost Model

Impact of Mission Class on Cost

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What is NICM?

- NASA Instrument Cost Model
  - Probabilistic Cost Estimates for Space Flight Instruments
  - Used by all NASA Centers
    - And any organization proposing instruments for NASA Instruments
    - And proposal evaluators
  - Version I Released in 2007
  - Version VII Rev 2 Released 2016

What is NICM?

- NICM also:
  - Estimates schedule
  - Estimates cost and schedule phase breakdowns
  - Supports JCL
  - Contains an normalized instrument database (for civil servants)

Yes – you can get a copy of NICM

- RSVP for only training at:

Joseph.J.Mrozinski@jpl.nasa.gov

Just kidding, you'll never remember that

NICM@jpl.nasa.gov

Today's Story: Mission Class

- Once upon a time… (2007):
  - Version I of NICM was released, and lived (mostly) in the kingdom of Class B missions.
  - For many ages, NICM prospered in this land (NICM I – NICM V)…
  - …Until the denizens of Class C Missions revolted!
  - NICM VI was bestowed upon the land of Class C Missions (2014), and everybody* lived happily ever after.
  - Or so we thought…

*Everybody = C Class Missions/University Built/High Inheritance

Today's Story: Mission Class

- In order for EVERYBODY to be happy, NICM needs to be able to help out Class D missions as well.
- And it's Mike's job to make everybody happy =)

Overview

Mission Class, intuitively, is a reasonable cost driver as it scopes work through design and implementation

NICM-E showed that Mission Class, along with university-built and high inheritance, plays a role in driving cost.

How does Mission Class impact Cost by itself, after the effects of mass and power are removed?

Overview

- The NICM Team has made a preliminary analysis of the impact of Mission Class on Instrument cost for 76 optical instruments flying on 42 NASA space missions.
- Presented here are results of this analysis to-date, focusing on top-level observations.
- **Discussion is encouraged!**

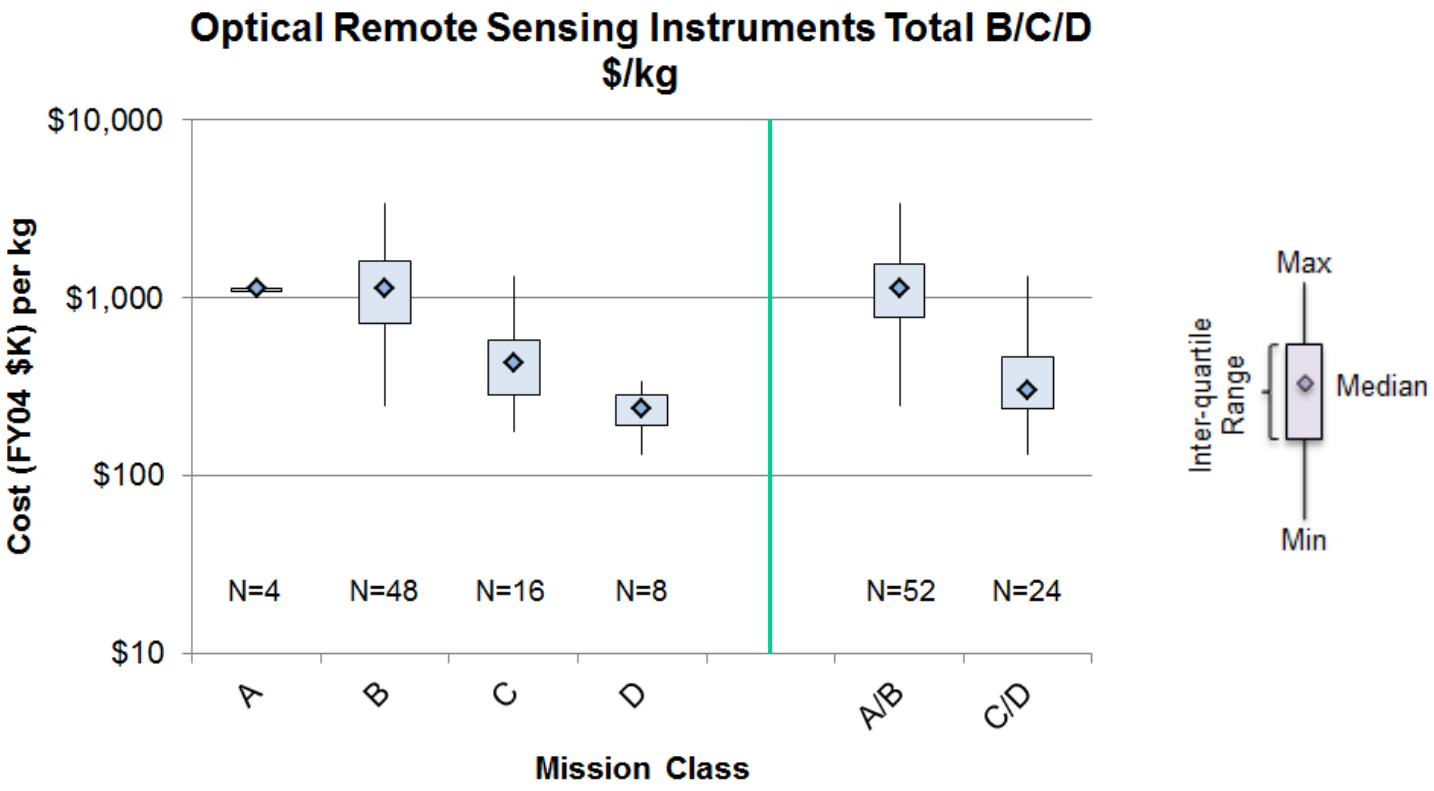
Analysis Plan

- Focus on the largest homogenous group of NICM data, optical instruments.
- Assess categorical groupings for NICM's current Mass/Power models
- Explore preliminary CERs.

Normalized Data Used in this Analysis

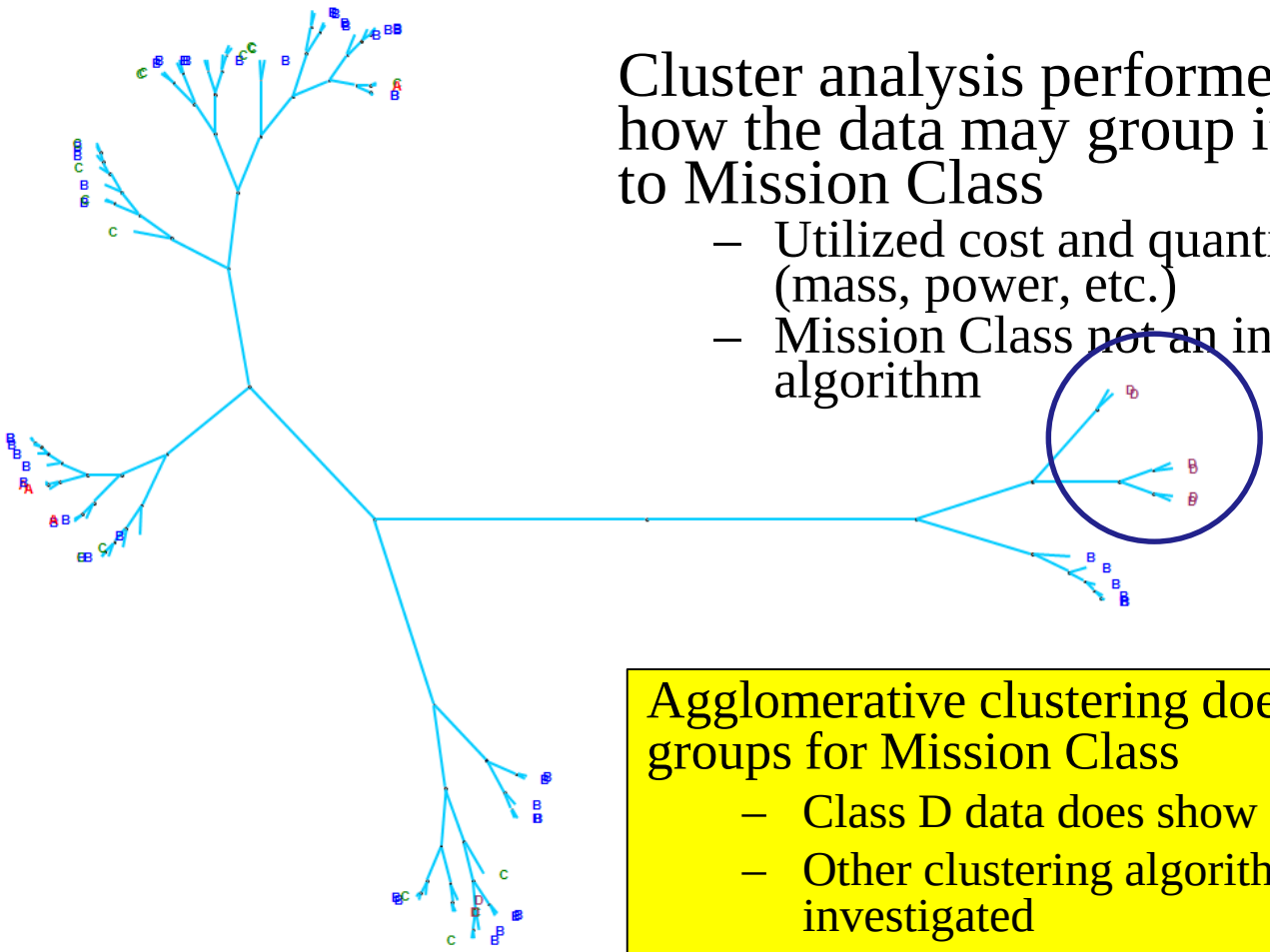
Mission Class	Instrument (Mission) *Earth Orbiting = Blue; Planetary = Black	Count
Class A	CIRS, ISS, UVIS, VIMS (all Cassini)	4
Class B	ACIS (Chandra), ACRIM II (UARS), ACRIM III (ACRIMSAT), AIA (SDO), AIRS (Aqua), ALICE (Rosetta), APS-Glory (Glory), CERES (TRMM), CFI (CONTOUR), CRISM (MRO), CRISP (CONTOUR), CTX (MRO), DLRE (LRO), EVE (SDO), HIRDLS (Aura), HiRISE (MRO), HMI (SDO), HRC (Chandra), HRI (Deep Impact), IRAC (Spitzer), IRS (Spitzer), ITS (Deep Impact), JunoCam (Juno), LAC (EO-1), LOLA (LRO), LORRI (New Horizons), LROC (LRO), M3 (Chandrayaan 1), MARCI (MRO), MASCS (MESSENGER), MCS (MRO), MDIS (MESSENGER), MICAS (Deep Space 1), MIPS (Spitzer), MISR (Terra), MLA (MESSENGER), MOC (Mars Observer), MODIS (Terra), MOLA (Mars Observer), MRI (Deep Impact), OLI (LDCM), ONC (MRO), PHOTO (Kepler), PMIRR (Mars Observer), TES (Aura), TES_MO (Mars Observer), TOMS (EP - Earth Probe Satellite), UVS (Juno)	48
Class C	CHIPS, CIPS (AIM), FUV (IMAGE), GALEX, GSPEC-OCO (OCO), GUVI (TIMED), IRIS, MSI (NEAR), NavCam (Stardust), NIS (NEAR), NLR (NEAR), SABER (TIMED), SOFIE (AIM), THEMIS (Mars Odyssey), TRACE, WISE	16
Class D	MIR, NIR, NSP, TLP, VIS, VSP (all LCROSS), NuStar, RHESSI	8
Total		**76**

Data Exploration: Cost-per-kg Mission Class



Tapering down of the cost-per-kg is evident as Mission Class moves from A/B to C to D.

Data Exploration: Cluster Analysis - Mission Class



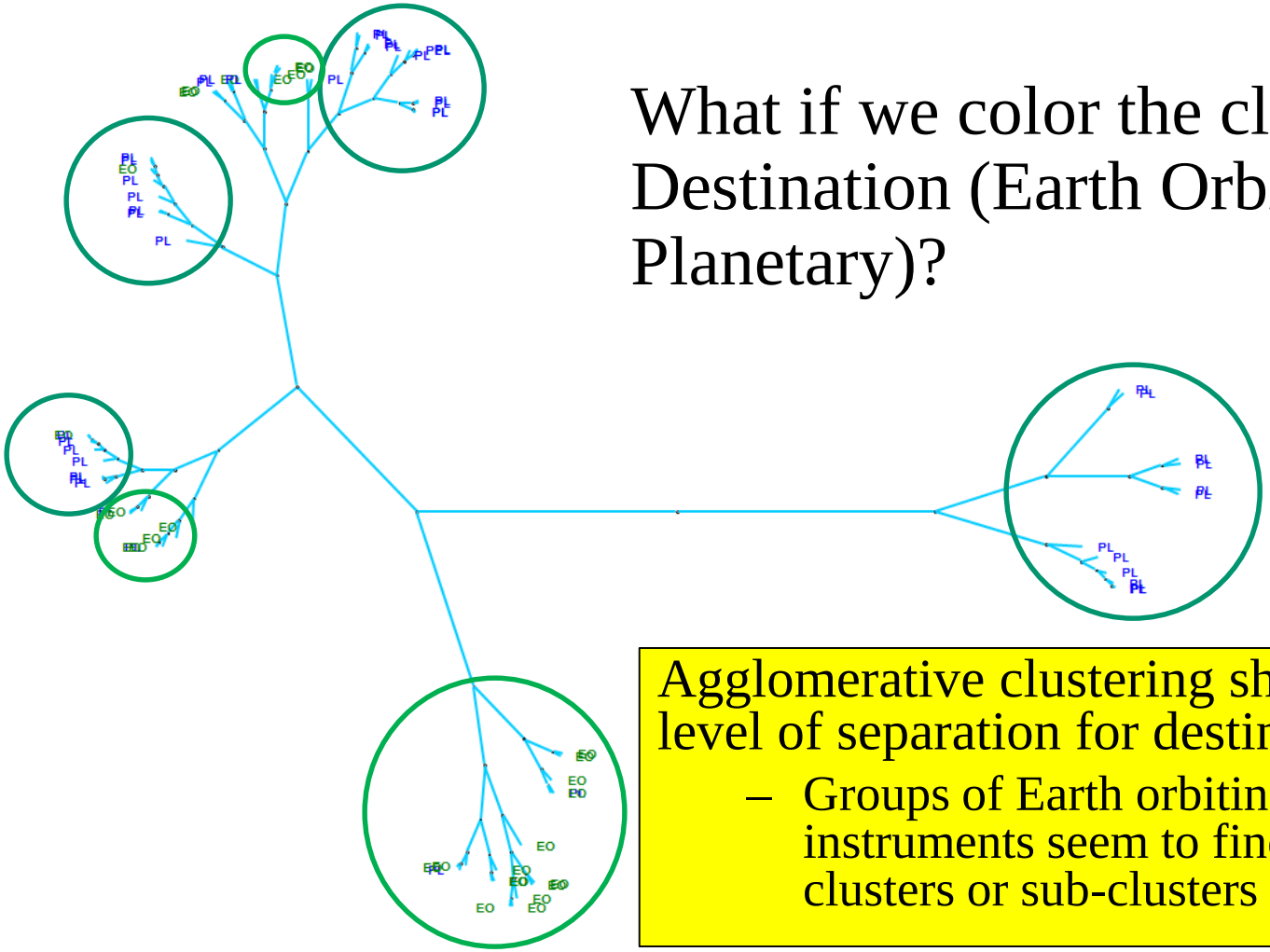
Cluster analysis performed to visualize how the data may group itself according to Mission Class

- Utilized cost and quantitative cost drivers (mass, power, etc.)
- Mission Class not an input to cluster algorithm

Agglomerative clustering does not show distinct groups for Mission Class

- Class D data does show some separation
- Other clustering algorithms will also be investigated
- **Does not** mean that Mission Class is not a useful or significant parameter for a model.

Data Exploration: Cluster Analysis - How about Destination?

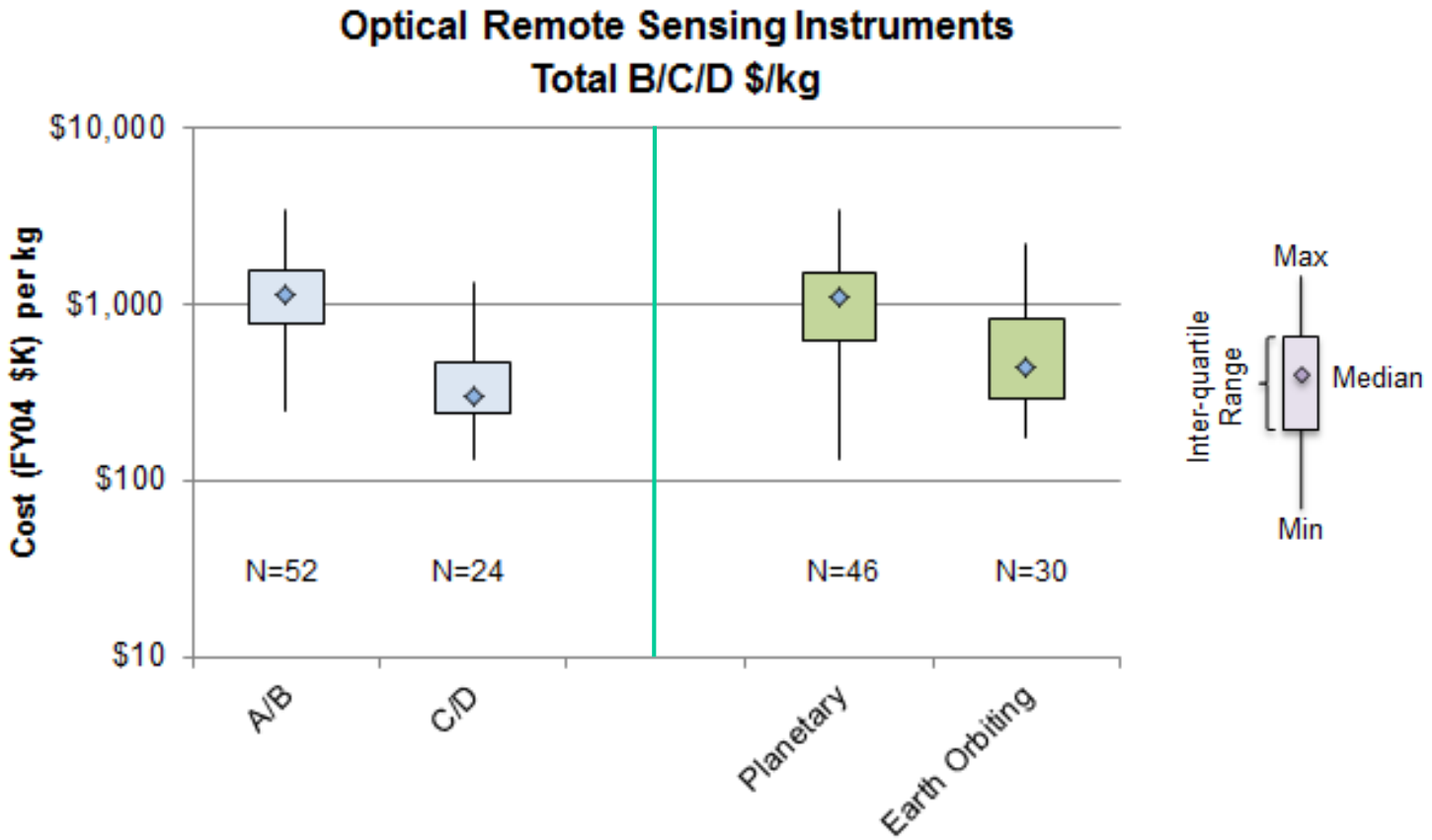


What if we color the clusters by Destination (Earth Orbiting or Planetary)?

Agglomerative clustering shows a moderate level of separation for destination.

- Groups of Earth orbiting and Planetary instruments seem to find their own clusters or sub-clusters

Data Exploration: Cost/kg - Mission Class vs. Destination

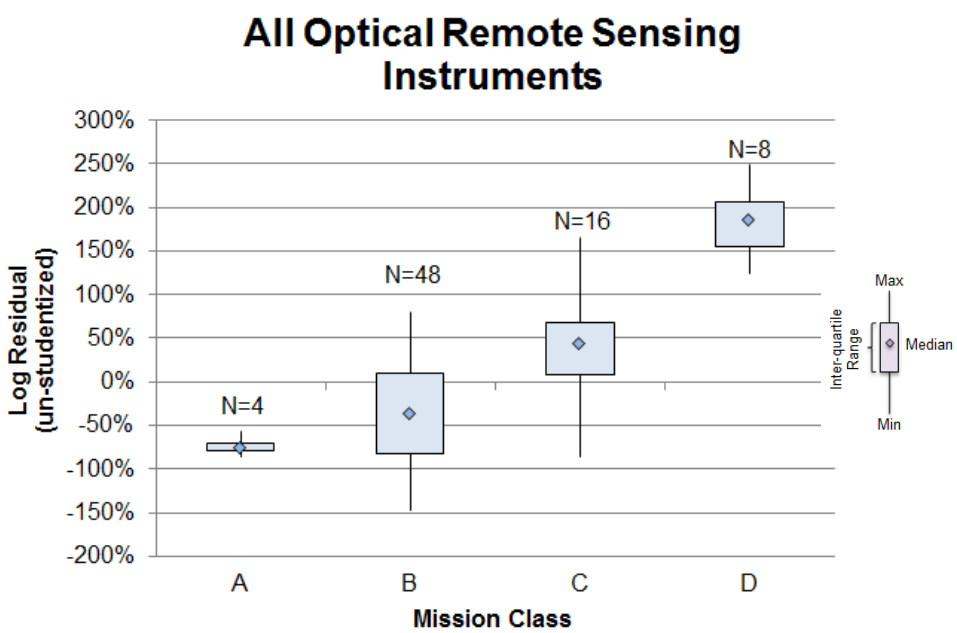


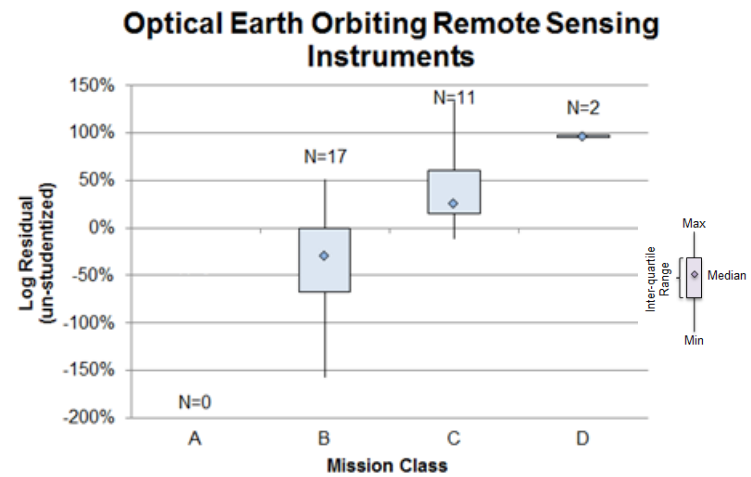
Grouping data according to Mission Class vs Destination results in similar changes in cost-per-kg; this is slightly more apparent when grouped by Mission Class.

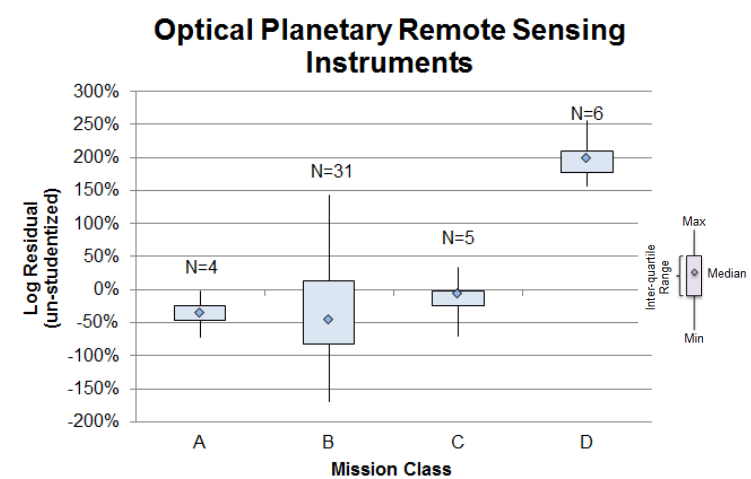
Model Evaluation – Mission Class

Place the log-log model Cost ≈ $\alpha \text{Mass}^{\beta}$ Pwr^{γ} on the data and assess residuals

- Class D instruments have high leverage in the model and show significant lack of fit with other optical instruments
- Some trend evident in residuals even if data is separated by destination first.







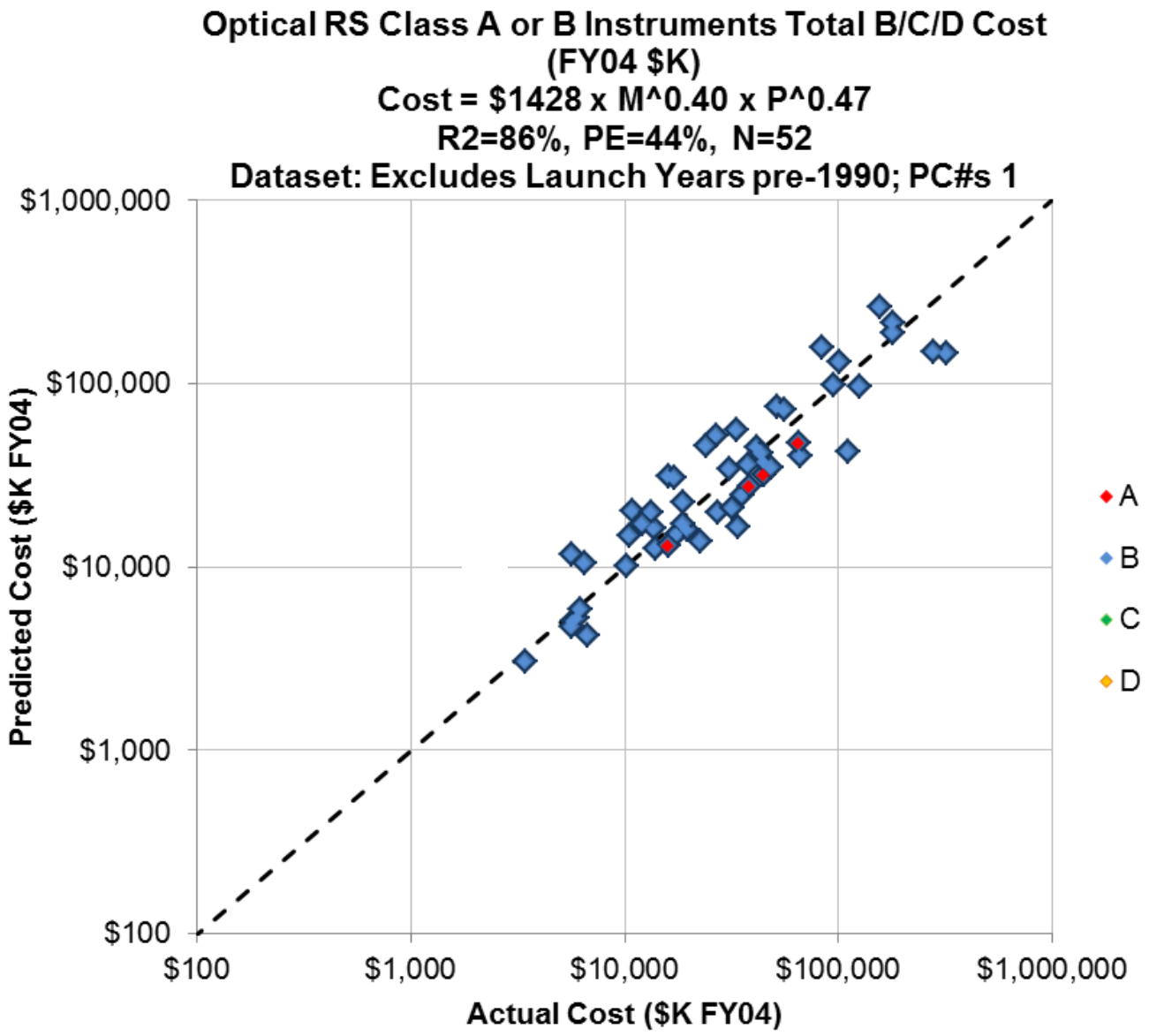
Analysis Summary

Method	Mission Class	Destination
Clustering (Agglomerative)	Little evidence for split by Mission Class, except for Class D instruments	Moderate evidence for split by Destination (Earth Orbiting / Planetary)
Dollar-per-kg	Visible $/kg trend downward from Mission Class A/B to C/D	Visible $/kg decrease from Planetary to Earth Orbiting
Model 1-way AnCoVa (in progress)	*Mission Class is a significant discriminator ($p<0.001$)*	*Destination is a borderline significant discriminator ($0.05<p<0.1$)*
Method	**No Grouping by Destination**	**Group Data by Destination**
Model Residuals	Moderate to Strong visible trend in residuals for Mission Class	Some trend visible in residuals for Mission Class (more for Earth Orbiting instruments).
Model 2-way AnCoVa	TBD: Will be testing both nested and un-nested models as well as interactions	

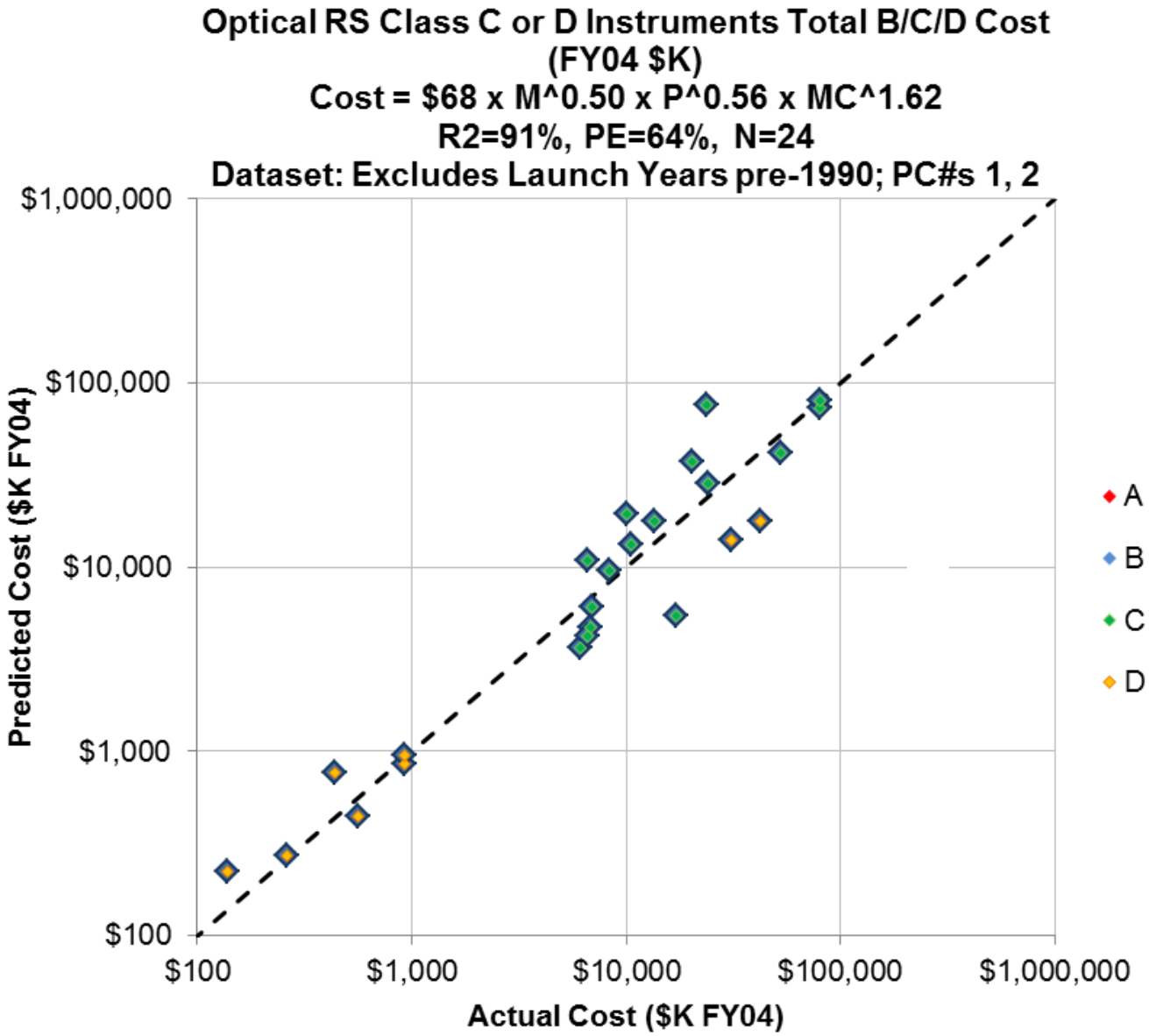
Analysis Results To-date

- Significant mean-shift between Mission Classes
  - Mean-shift for Mission Class is more significant than that for Destination in a 1-way analysis of covariance
  - Still need to test for Interactions to see how they may be impacting results
    - This will be done with two-way AnCoVa models.
- Potential models to be studied include:
  - Group data by Destination, then fit a model using Mission Class, Mass and Power
  - Group data by Mission Class A/B and Mission Class C/D, regressed on Mass and Power

Preliminary CERs -- Mission Classes A and B



Preliminary CERs -- Mission Classes C and D



Next Steps

- Collect more data

Thank you!

- Questions?

Backup

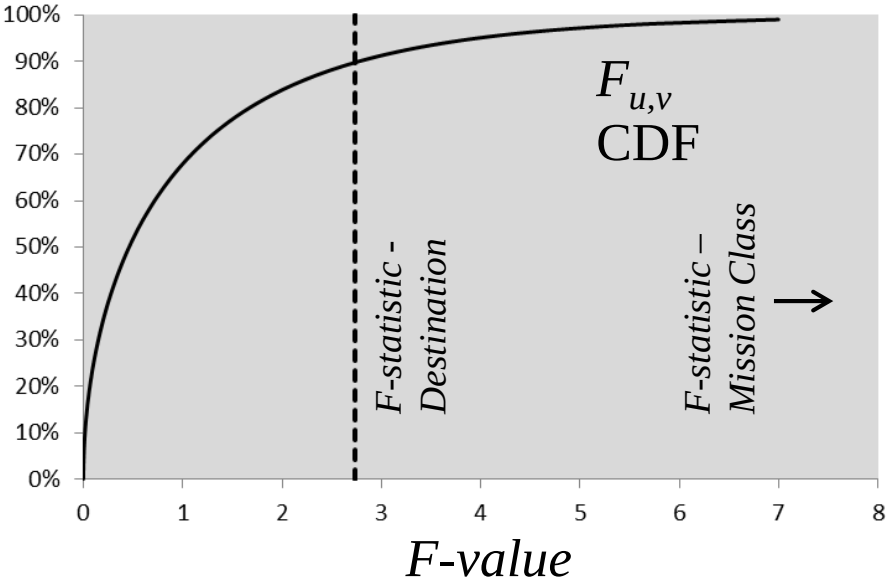
Model Evaluation – Analysis of Covariance (AnCoVa)

- What are questions we would like to answer?
  - Is there a significant shift in instrument cost due to Mission Class?
  - Is Mission Class a more significant factor than Destination (Earth Orbiting or Planetary)?
  - How does Destination affect our perception of cost when we look at Mission Class?
- We will use these questions to guide our development of hypotheses to be tested.

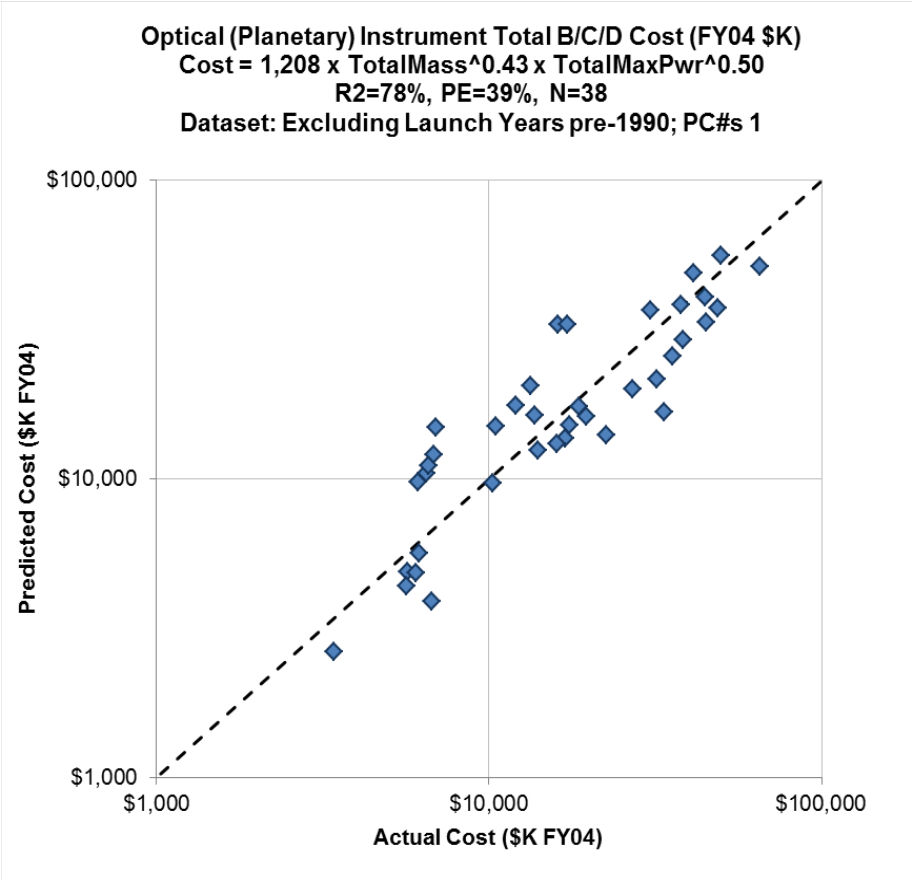
1-way AnCoVa Results

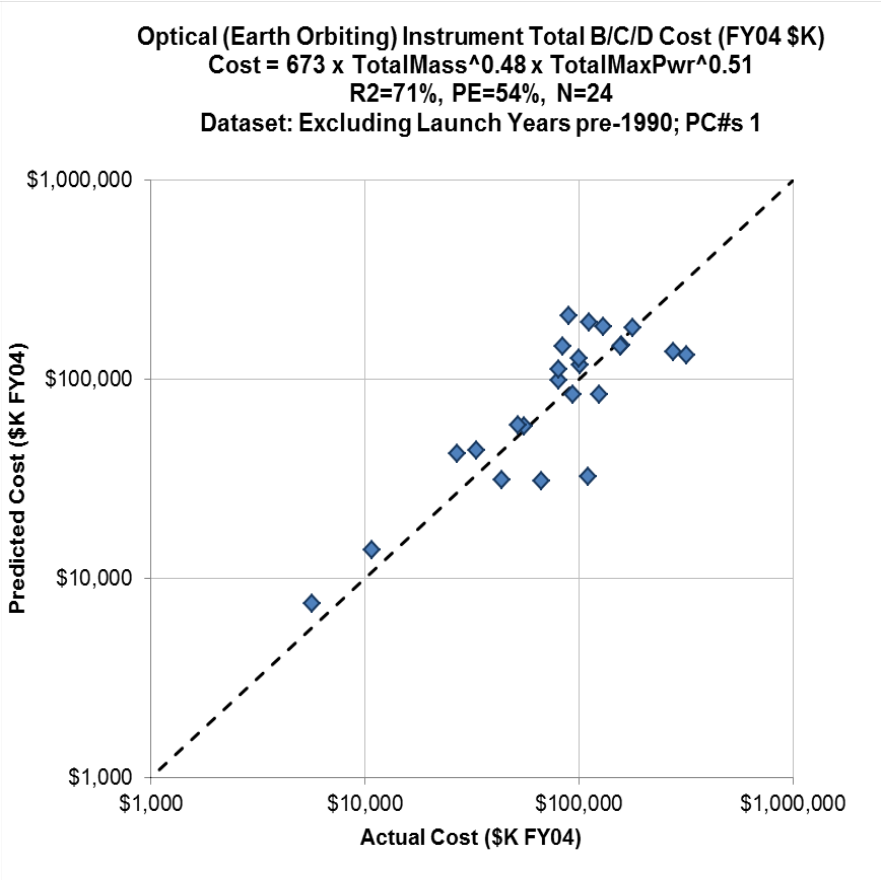
- Significant mean-shift between Mission Classes
  - Null Hypothesis H_0: The scaler shift between Class A&B is the same as Class C&D
  - Null hypothesis rejected (p-value << 0.001)
- Mean-shift for Mission Class is more significant than that for Destination
  - Null Hypothesis H_0: The scaler shift between Earth Orbiting instruments is the same as Planetary instruments
  - Null hypothesis not rejected (p-value = 0.10)

- 2-way tests for nested models and interactions currently underway
  - Interactions and the order in which we group the data may have a significant impact on analysis results

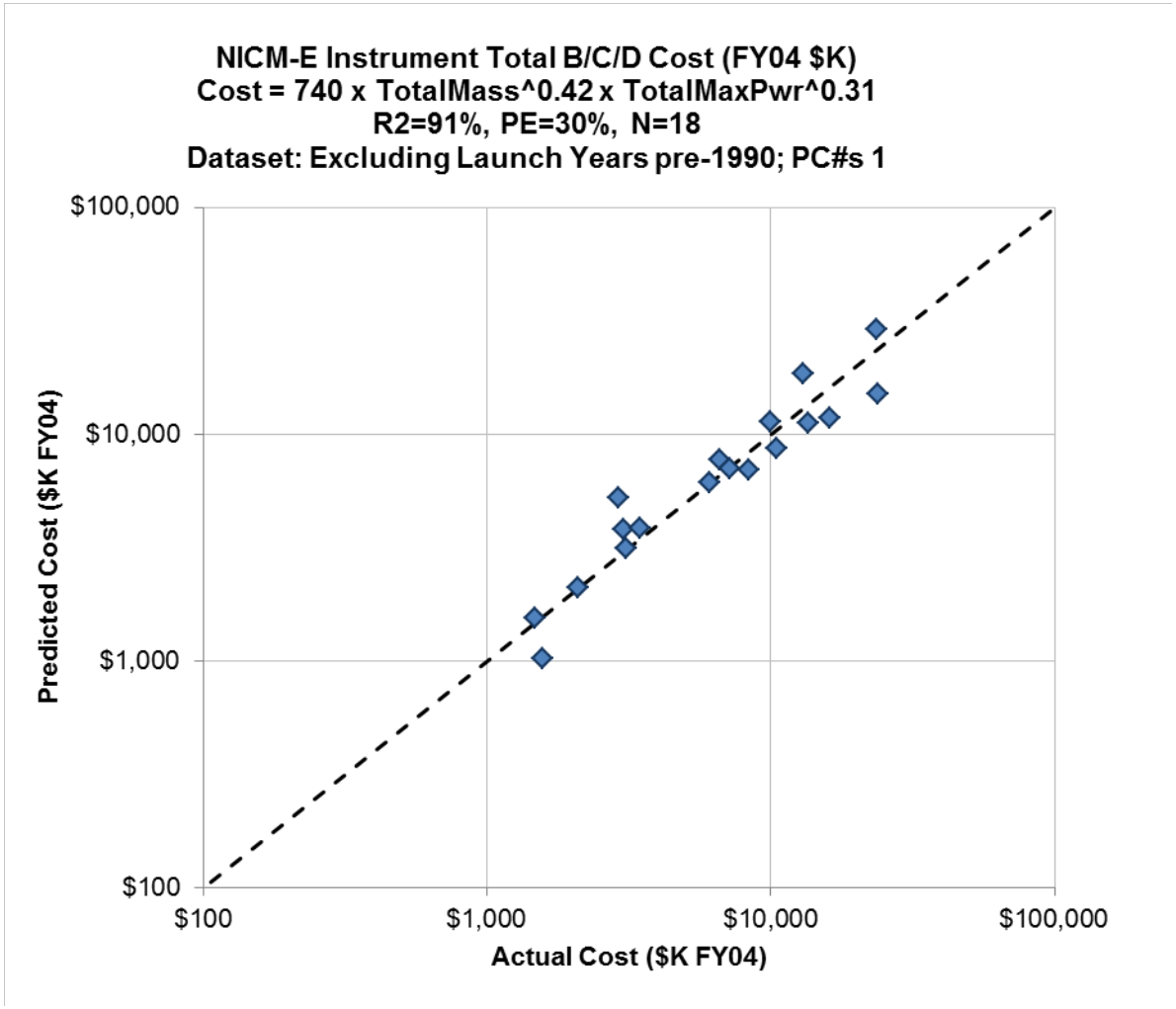


Current Optical RS CERs





Current NICM-E CER



Mission Class Defined

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan)	High priority	High priority	Medium priority	Low priority
National significance	Very high	High	Medium	Low to medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission)	Long, > 5 years	Medium, 2-5 years	Short, < 2 years	Short, < 2 years
Cost	High	High to medium	Medium to low	Low
Launch Constraints	Critical	Medium	Few	Few to none
In-Flight Maintenance	N/A	Not feasible or difficult	Maybe feasible	May be feasible and planned
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Examples	HST, Cassini, JIMO, JWST	MER, MRO, Discovery payloads, ISS Facility Class Payloads, Attached ISS payloads	ESSP, Explorer Payloads, MIDEX, ISS complex subrack payloads	SPARTAN, GAS Can, technology demonstrators, simple ISS, express middeck and subrack payloads, SMEX

Source: NPR 8705.4, Appendix B.

References

- Shayle R. Searle, *Linear Models for Unbalanced Data*, New York: Wiley Interscience, 2006.