Analysis of Recent NASA Flight Software Costs

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Nicole Krepps

Parametric Cost Analyst

nicole.krepps@jhuapl.edu

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Background

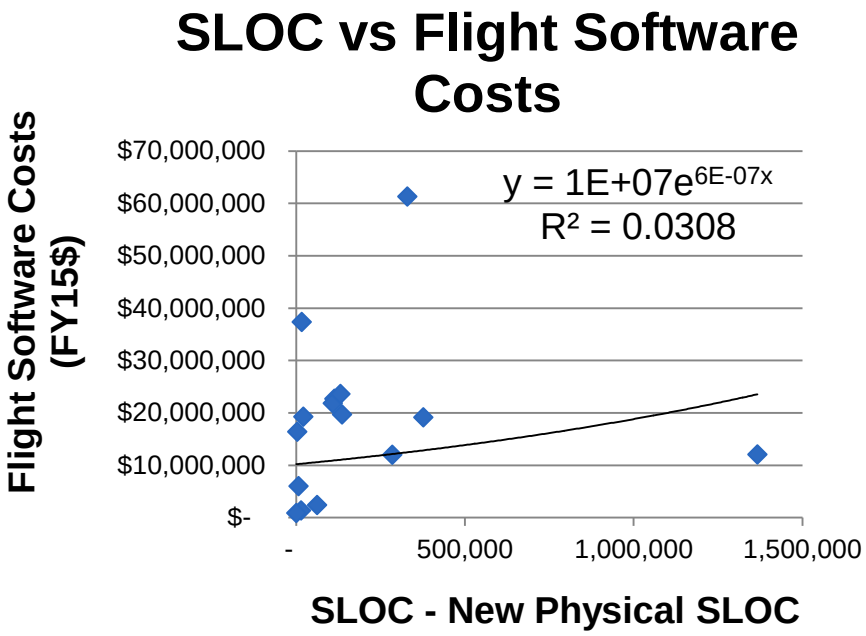
- **There are several parametric tools available to estimate software costs based on**
  - **SLOC**
  - **Team Experience**
  - **Rate**
  - **Reused Code**
  - **Language**

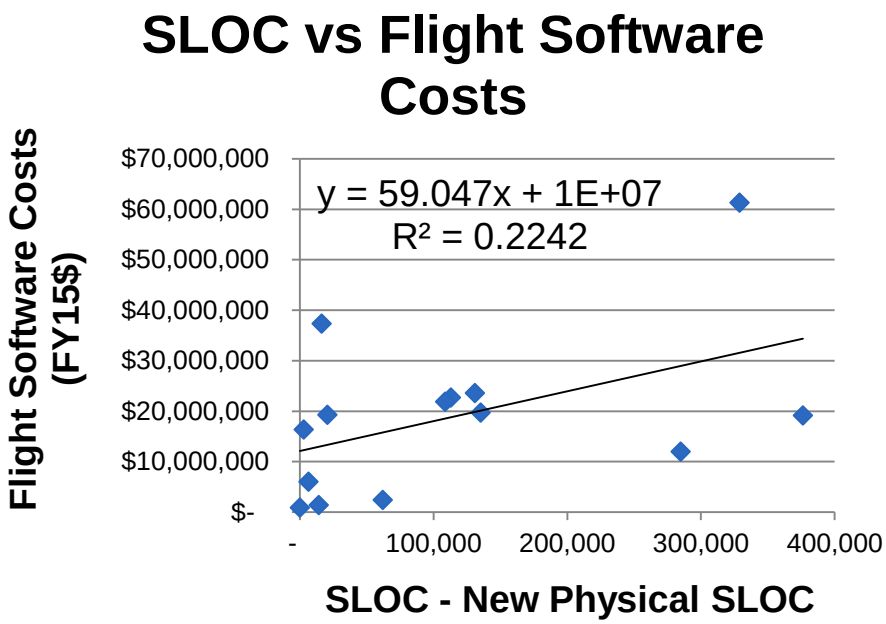
- **Discussion with software engineers prompted further research**
  - **Objective parameters only**
  - **Is SLOC the best predictor?**
  - **Do the number of interfaces affect software costs?**
  - **How does schedule duration affect software costs?**

Assumptions/Methodology

- CADRe software data available from LRD or CADRe Plus parts B and C
- All costs were normalized for FY15$K
- 30 missions used in analysis that are representative of;
  - Class A – Class D
  - GSFC, APL, JPL, ARC
  - Earth Orbiting, Planetary
  - 112kg – 3,899kg
  - 1 and 2 Spacecraft
  - 1 – 10 instruments
  - Launch years 1992 – 2014
- "Diagnostic" single-variable regressions were used to investigate the hypothesized variables: ie SLOC, Schedule, Interfaces

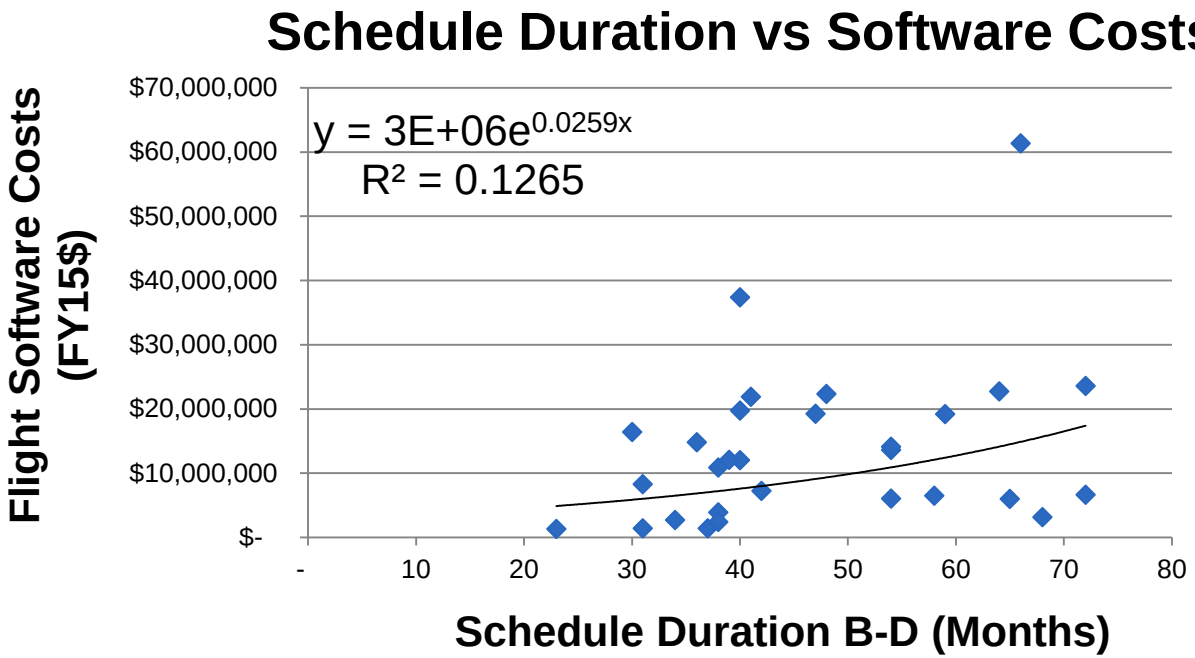
Linear Regression Results: SLOC





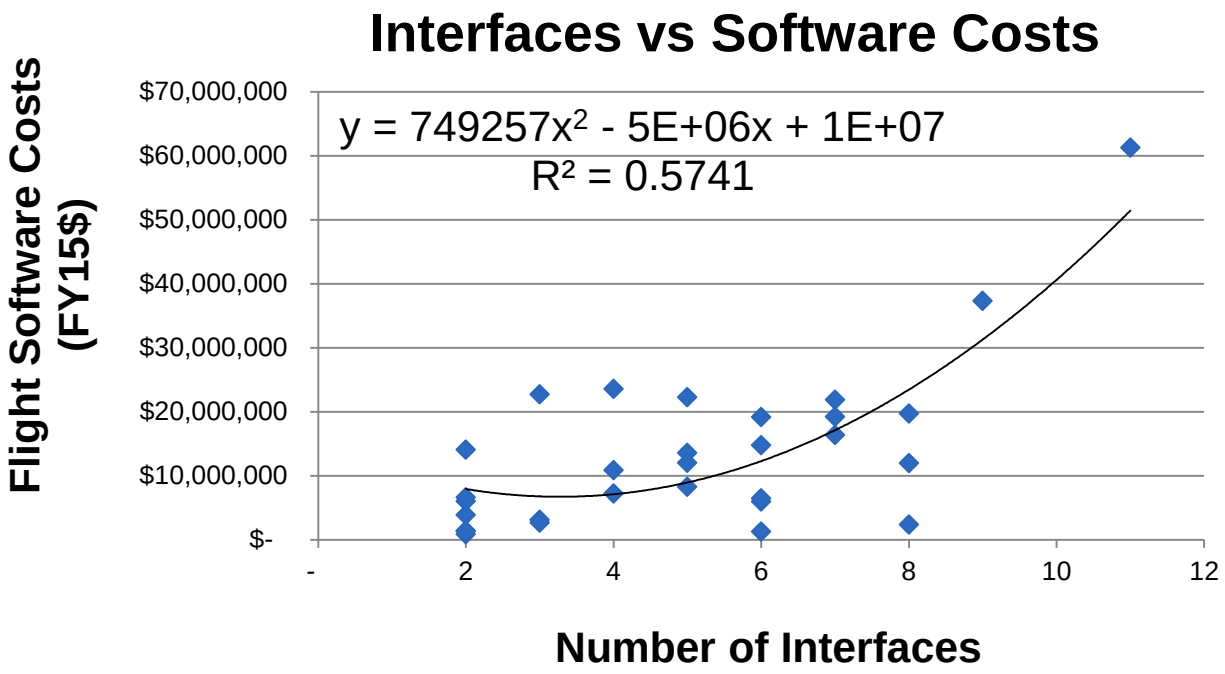
- **SLOC not always available in CADRe**
  - **Analyzed both new physical SLOC and total physical SLOC**
  - **Represents 18 missions**
- **Even after removing the outlier on the left graph the data is not strongly correlated**

Linear Regression Results: Schedule



- **Schedule duration is measured from PDR until 1 month after launch as reported in CADRe part C**
  - **Represents 29 missions**

Linear Regression Results: Number of Interfaces



- **Number of interfaces = number of spacecraft + number of instruments**
  - **ie many different items need to be able to communicate with each other**
- **R squared is higher but there is grouping**

Methodology

- **After initial "diagnosis" multivariate regressions were used to identify statistically significant cost driving parameters**
- **The objective parameters examined were chosen based on availability of data in CADRe**
  - **Schedule Duration (Months):** Phase A-D, Phase B-D, CDR – SIR
  - **Cost (FY15$):** Flight System Costs (excl. FSW), Spacecraft (excl. FSW), Spacecraft Hardware
  - **Launch Year, Institution**
  - **Spacecraft Mass(kg), SLOC, GNC Stabilization, Number of Interfaces**
  - **Destination, Mission Class**

Multivariate Regression Results

Regression Statistics	
Multiple R	89%
R Square	79%
Adjusted R Square	76%
Standard Error	$ 6,161,578
Observations	30

Moderately robust R square with a very significant F-value

ANOVA

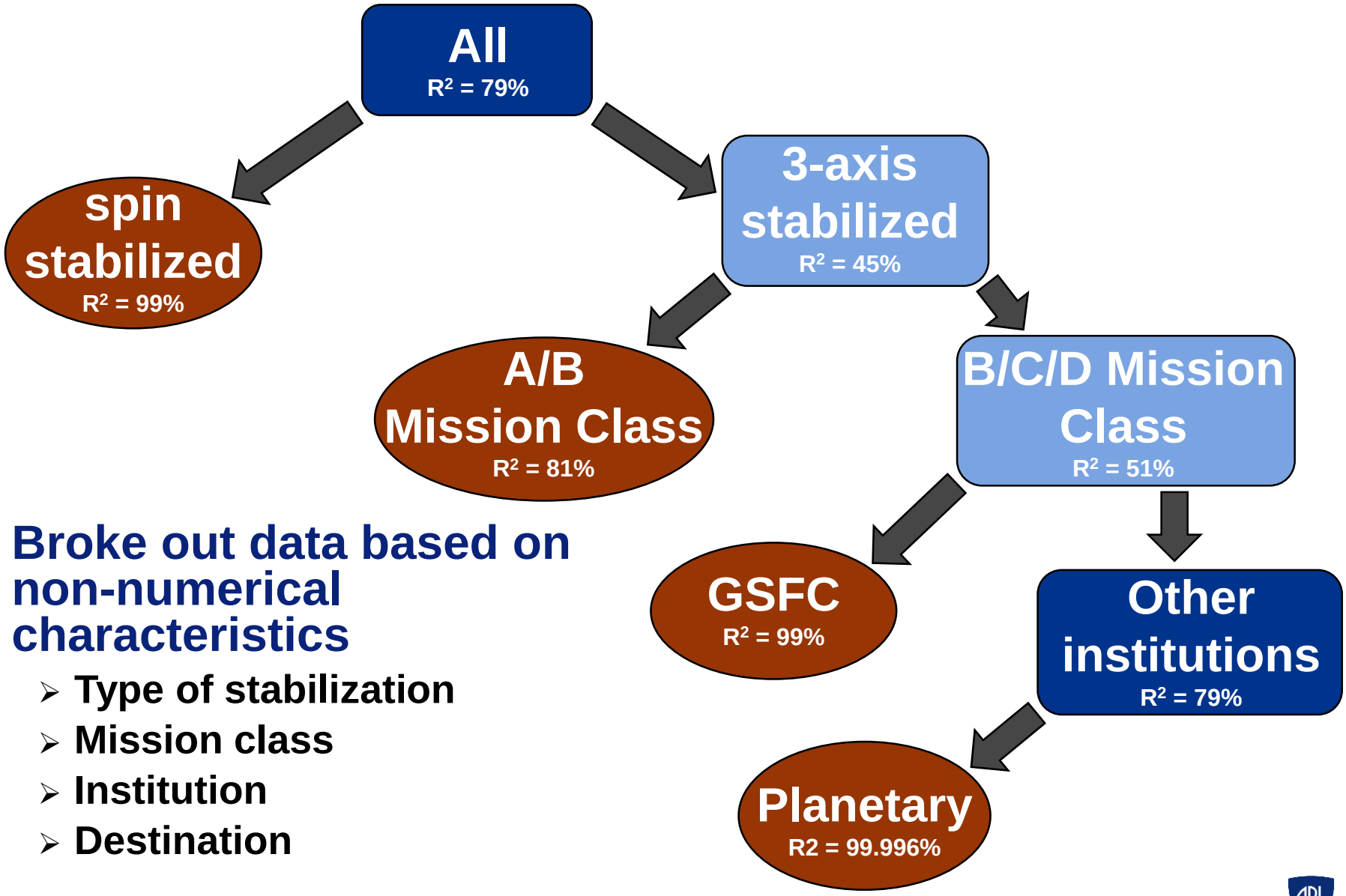
	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	3.6446E+15	1.21487E+15	32.00	0.000000007
Residual	26	9.87091E+14	3.7965E+13		
Total	29	4.63169E+15			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	(774,070,836)	368,392,033	(2.10)	0.0455
Number of Interfaces	1,198,134	582,727	2.06	0.0499
Spacecraft Hardware	0	0	5.86	0.0000
Launch Year	386,797	183,764	2.10	0.0451

Significant p-value for each parameter

- **All 30 data points used in generating the multivariate software CER**
- **Eliminated extra non-significant variables**

Multivariate Regression Results (continued)



- **Broke out data based on non-numerical characteristics**
  - Type of stabilization
  - Mission class
  - Institution
  - Destination

Multivariate Regression Results: General Flight Software

General Flight Software	
R-Squared	79%
Adjusted R-Squared	76%
F-Statistic	0.00000001
Observations	30
Significant Parameters	**P-Value**
Number of Interfaces	0.0499
Spacecraft Hardware Cost	0.0000
Launch Year	0.0451

- $\boldsymbol{Flight\ Software\ Cost\ (FY15\$K)} = -\$774{,}070.84 + (\boldsymbol{Number\ of\ Interfaces} * \$1{,}198.13) + (\boldsymbol{Spacecraft\ Hardware} * 4.7\%) + (\boldsymbol{Launch\ Year} *$

Multivariate Regression Results: Spin Stabilized

Spin Stabilized	
R-Squared	99.2%
Adjusted R-Squared	98.5%
F-Statistic	0.0001
Observations	8
Significant variables	**P-Value**
Number of Interfaces	0.003
Flight System Cost	0.002
Phase B-D Duration	0.025

- $\boldsymbol{Flight\ Software\ Cost\ (FY15\$K)} = \$3{,}104.99 + (\boldsymbol{Number\ of\ Interfaces} * \$3{,}104.99) + (\boldsymbol{Flight\ System\ Cost} * 2.6\%) + (\boldsymbol{Phase\ B-D\ Duration} * -\$408.71)$

Multivariate Regression Results: 3-Axis Stabilization Mission Class A/B

3-Axis Stabilized Mission Class A/B	
R-Squared	81%
Adjusted R-Squared	74%
F-Statistic	0.015
Observations	8
Significant Parameters	**P-Value**
Total Flight System Cost	0.024
Mass	0.006

- $\boldsymbol{Flight\ Software\ Cost\ (FY15\$K)} = \$19{,}962.22 + (\boldsymbol{Flight\ System\ Cost} * -3.6\%) + (\boldsymbol{Mass} * \$8.26)$

Multivariate Regression Results: 3-Axis Stabilized Mission Class B/C GSFC

3-Axis Stabilized Mission Class B/C GSFC	
R-Squared	99%
Adjusted R-Squared	97%
F-Statistic	0.003
Observations	7
Significant variables	**P-Value**
Mass	0.003
Launch Year	0.027
Spacecraft Hardware Cost	0.001

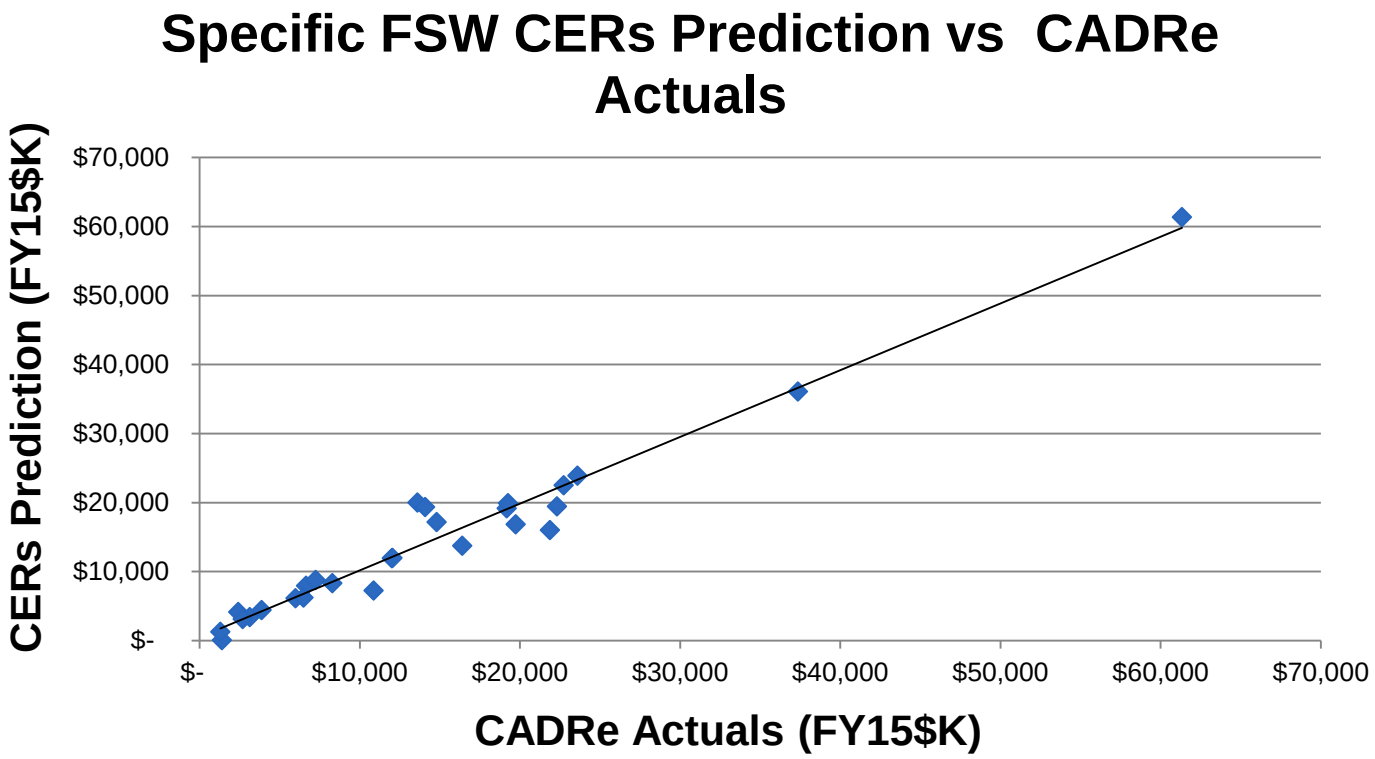
- $\boldsymbol{Flight\ Software\ Cost\ (FY15\$K)} = -\$742{,}531.95 + (\boldsymbol{Mass} * -\$8.82) + (\boldsymbol{Spacecraft\ Hardware} * 17.3\%) + (\boldsymbol{Launch\ Year} * \$371.64)$

Multivariate Regression Results: 3-Axis Stabilized Mission Class B/C/D Other Institutions Planetary

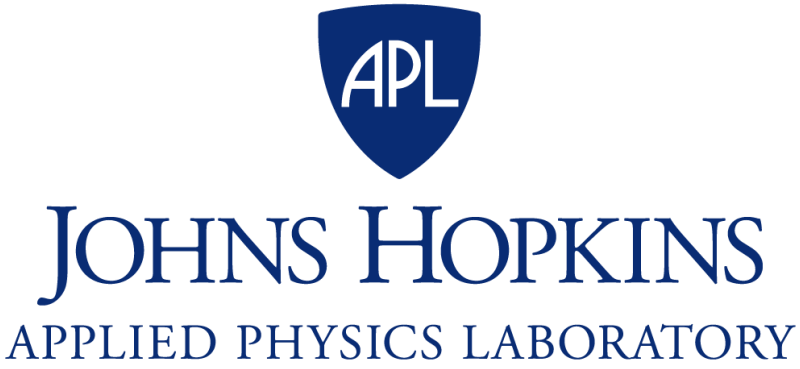
3-Axis Stabilized Mission Class B/C/D Other Institutions Planetary	
R-Squared	99.996%
Adjusted R-Squared	99.987%
F-Statistic	0.007
Observations	4
Significant Parameters	**P-Value**
Phase B-D Duration	0.01
Total Spacecraft Cost	0.02

- $$\boldsymbol{Flight\ Software\ Cost\ (FY15\$K)} = -\$8{,}638.69 + (\boldsymbol{Phase\ B-D\ Duration} * \$601.53) + (\boldsymbol{Spacecraft\ Cost} * -3.3\%)$$

Error Range



- **Average prediction error of 1%**
- **Prediction error standard deviation of 0.277**
- **Represents 27 recent NASA missions**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