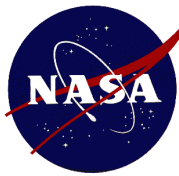


The Efficacy of NASA's JCL Policy

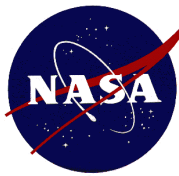
Andy Prince

Manager, Engineering Cost Office
NASA/Marshall Space Flight Center
May 14, 2019



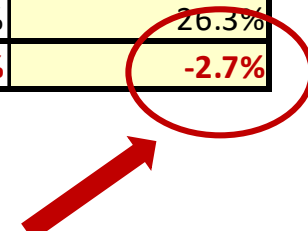
Outline

- **Motivation**
- **JCL Primer**
- **Approach to the Analysis**
- **Data Analysis**
- **Analysis Results**
 - **Descriptive Statistics**
 - **Time Series Analysis**
 - **Statistical Inference Tests**
- **Findings**
- **Conclusions**

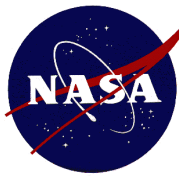


Motivation

Mission	Data			Cost Growth		
	SRR	ABC	Actuals	SRR to ABC	SRR to Actuals	ABC to Actuals
NuSTAR	\$96.2	\$109.9	\$104.0	14.2%	8.1%	-5.4%
Landsat 8	\$382.1	\$587.6	\$395.7	53.8%	3.6%	-32.7%
IRIS	\$86.2	\$140.7	\$156.0	63.3%	81.1%	10.9%
LADEE	\$117.9	\$168.2	\$188.3	42.6%	59.6%	11.9%
MAVEN	\$488.7	\$567.2	\$467.9	16.1%	-4.2%	-17.5%
GPM	\$660.2	\$555.2	\$470.5	-15.9%	-28.7%	-15.3%
OCO-2	\$225.2	\$249.0	\$304.6	10.6%	35.3%	22.3%
SMAP	\$412.0	\$485.7	\$469.9	17.9%	14.0%	-3.2%
MMS	\$741.0	\$857.3	\$962.3	15.7%	29.9%	12.2%
Astro-H	\$30.0	\$44.9	\$51.0	49.9%	70.1%	13.5%
OSIRIS-Rex	\$515.7	\$778.6	\$648.7	51.0%	25.8%	-16.7%
CYGNSS	\$125.0	\$152.8	\$90.1	22.2%	-27.9%	-41.0%
SAGE-III	\$56.8	\$64.6	\$81.6	13.7%	43.7%	26.3%
Average				27.3%	23.9%	-2.7%

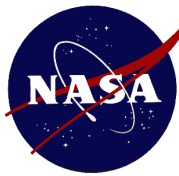


- Data from CADRe and the ONCE Database
- Lack of overall cost growth from ABC to Actuals indicates that JCL might be working (more data and analysis needed to confirm)



Purpose of the Study

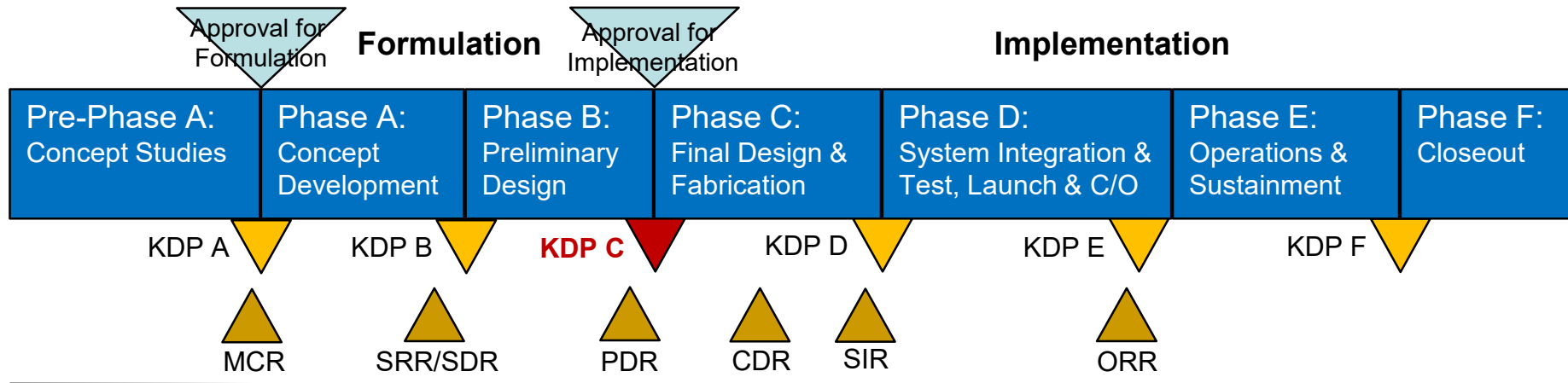
- The **purpose** of the study is to determine if NASA's Joint (Cost Schedule) Confidence Level (JCL) policy is having the effect of improving *project cost estimates*.
- The **method** is to compare the *cost and schedule* growth for NASA space missions approved prior to the implementation of the JCL policy with missions approved (and launched) after the policy was put into effect.



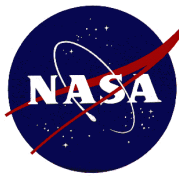
NASA's JCL Policy



Engineering
Cost
Office



- **KDP C** - generate a cost loaded schedule probability calculation that meets cost, schedule and **JCL**.
 - JCL - probabilistic analysis of the coupled cost and/or schedule to measure the likelihood of completing all remaining work including mitigating risks and conducting operations prior to phase
 - Projects will be **budgeted** at the **70% confidence level**
 - At a minimum, **projects** are to be funded at a level that is equivalent to a **confidence level of 50%**, or as approved by the applicable decision authority

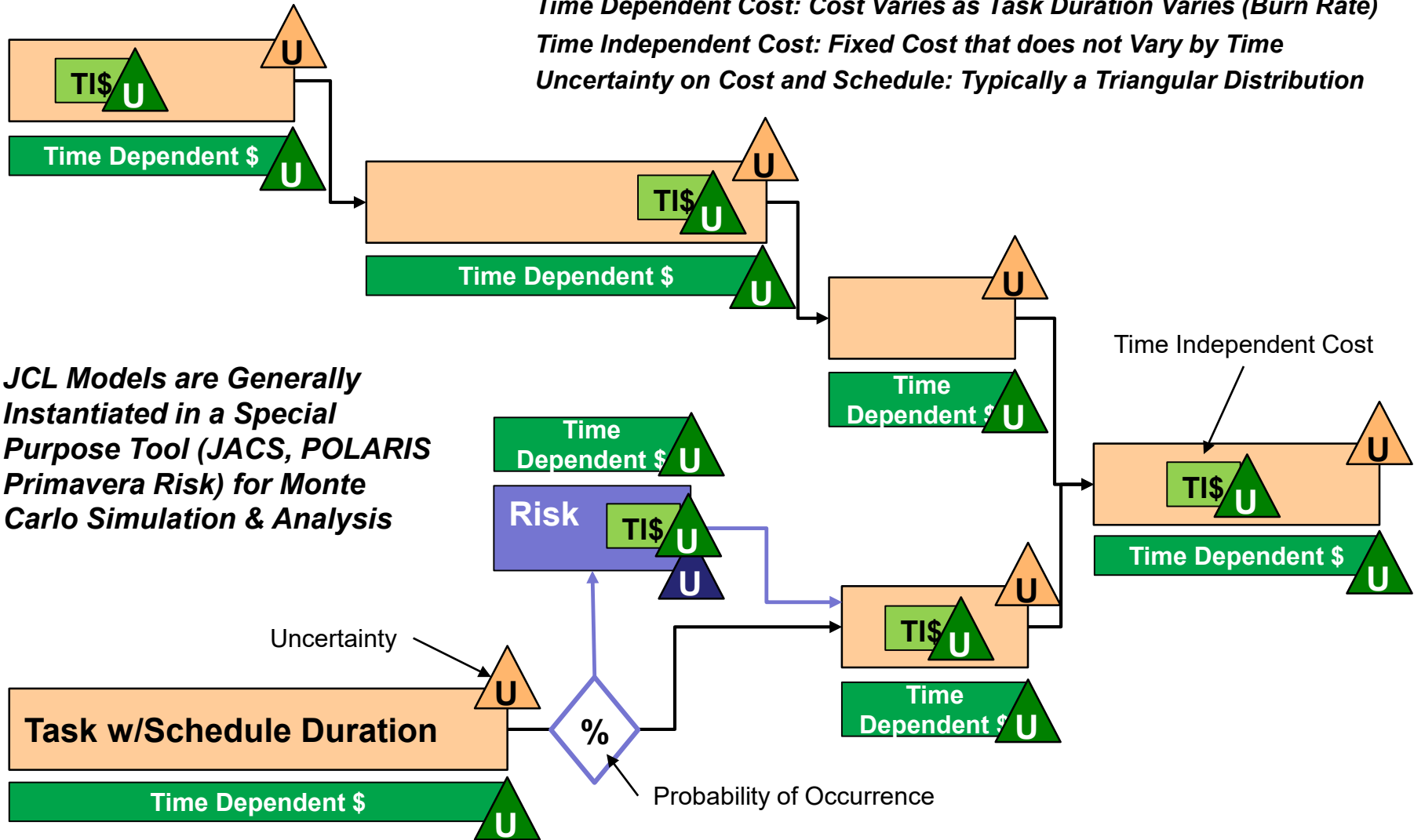


The JCL Model

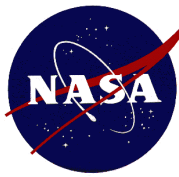
Time Dependent Cost: Cost Varies as Task Duration Varies (Burn Rate)

Time Independent Cost: Fixed Cost that does not Vary by Time

Uncertainty on Cost and Schedule: Typically a Triangular Distribution

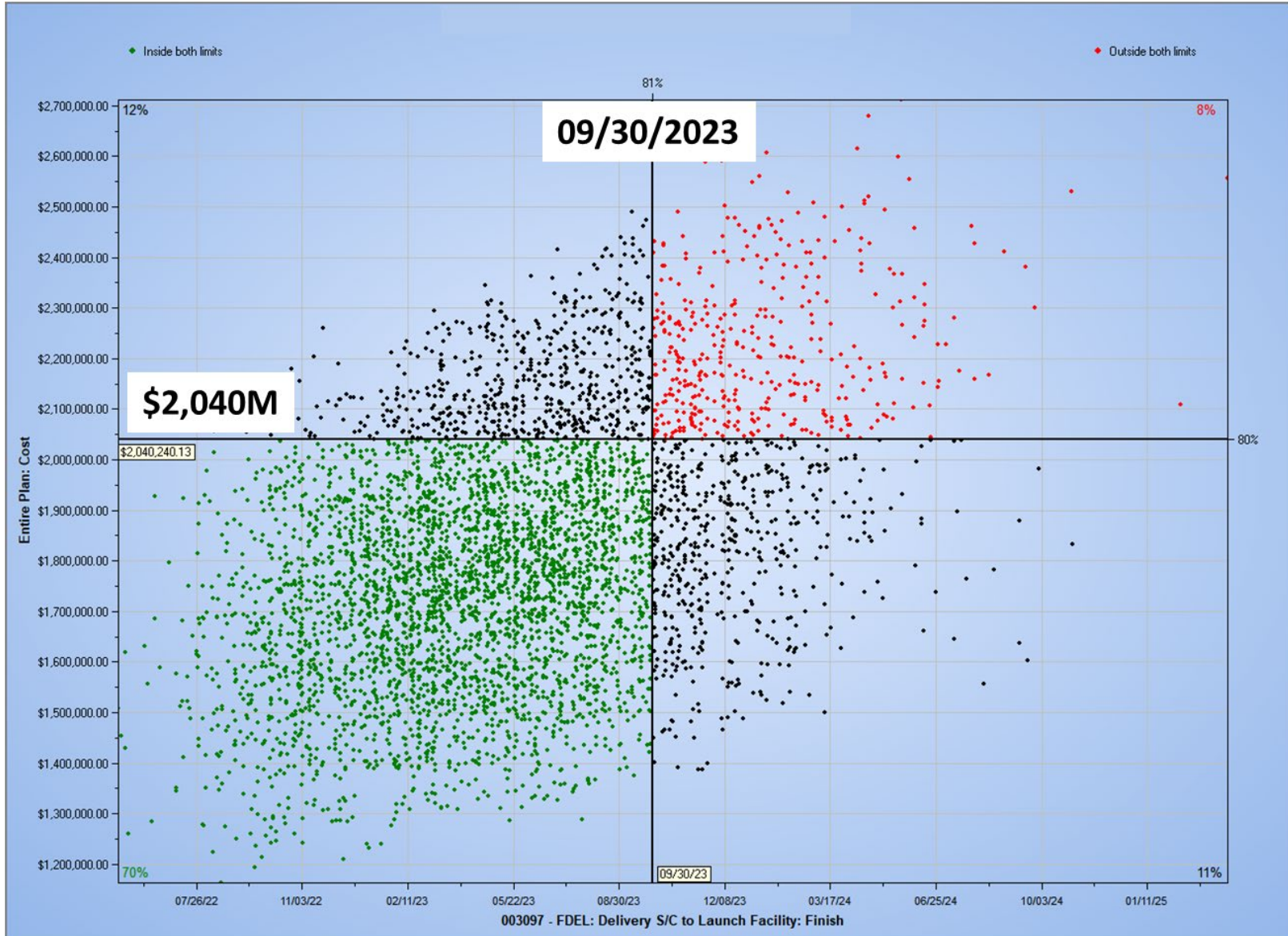


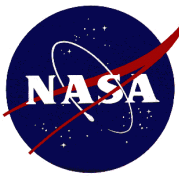
JCL Models are Generally Instantiated in a Special Purpose Tool (JACS, POLARIS Primavera Risk) for Monte Carlo Simulation & Analysis



Example JCL Output

70th Percentile

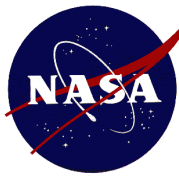




Analysis Approach

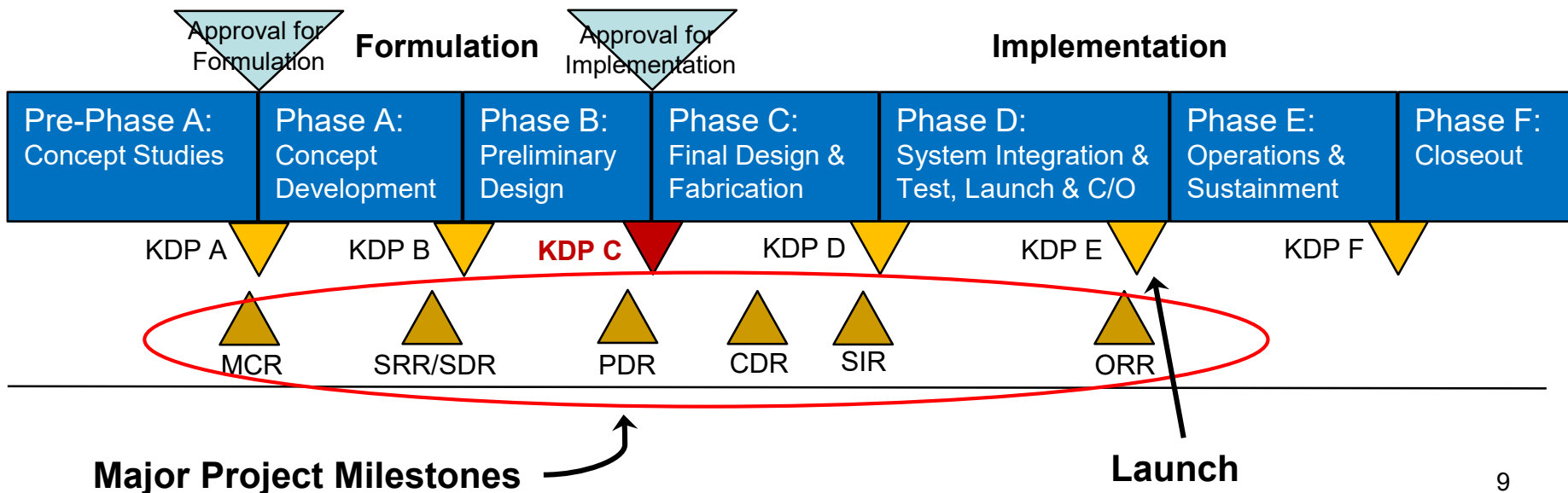
PDR CADRe			LRD CADRe			Data			Phase CD			Phase AB/CD		
Phase AB Cost	Phase CD Cost	PDR Date	Phase CD	LRD Date	LRD Cost	Phase AB Cost	Phase CD Cost	Phase AB/CD Ratio at PDR	Phase AB/CD Ratio at Launch	Phase AB/CD Ratio at Launch	Phase AB/CD Ratio at PDR	Phase AB/CD Ratio at Launch	Phase AB/CD Ratio at PDR	Phase AB/CD Ratio at Launch
\$ 85,732.6	\$ 390,774.9	11/13/1995												
		5/21/1996												
		2/1/1997												
		6/19/1997												
		9/23/1997												
		7/20/1998												
		7/28/1998												
		10/17/1998												
		11/3/1998												
		8/29/2000												
		9/26/2000												
		2/2/2001												
\$ 39,801.0	\$ 167,032.0	2/26/2001												
\$ 34,717.8	\$ 196,730.4	3/6/2001												
\$ 45,241.4	\$ 227,160.4	12/7/2001												
\$ 51,101.0	\$ 361,524.0	7/20/2002												
\$ 22,224.9	\$ 265,727.8	10/24/2002												
\$ 31,681.0	\$ 258,723.6	10/16/2003												
\$ 11,411.4	\$ 76,893.7	11/12/2003												
\$ 17,058.0	\$ 71,738.0	1/15/2004												
		3/9/2004												
\$ 32,688.0	\$ 130,473.4	7/26/2004												
\$ 75,886.3	\$ 240,899.5	10/13/2004												
\$ 44,226.5	\$ 162,922.1	7/19/2005												
\$ 49,671.0	\$ 108,635.0	9/1/2005												
\$ 28,414.0	\$ 195,972.0	9/14/2005												
\$ 20,763.8	\$ 65,318.8	1/17/2006												
\$ 103,189.6	\$ 244,224.1	2/7/2006												
		9/1/2006												
\$ 519,621.0	\$ 711,033.6	6/8/2007												
\$ 179,884.2	\$ 493,582.9	5/13/2008												
\$ 103,956.2	\$ 290,526.7	10/12/2008												
\$ 208,717.1	\$ 563,224.8	11/10/2008												
\$ 28,267.0	\$ 63,188.0	7/1/2009												
\$ 177,759.0	\$ 536,741.5	7/15/2009												
\$ 350,968.9	\$ 355,054.4	7/15/2009												
\$ 36,775.0	\$ 256,509.4	9/24/2009												
\$ 17,547.0	\$ 24,305.0	3/1/2010												
\$ 7,722.4	\$ 92,196.8	5/20/2010												
\$ 60,676.4	\$ 337,559.4	7/10/2010												
\$ 74,942.7	\$ 124,568.9	7/22/2010												
\$ 58,264.2	\$ 157,602.0	8/25/2010												
\$ 15,490.1	\$ 43,052.4	8/2/2011												
\$ 301,193.9	\$ 322,955.1	10/10/2011												
\$ 29,000.0	\$ 55,200.0	5/1/2012												
\$ 118,329.7	\$ 508,403.3	3/4/2013												
\$ 13,911.2	\$ 51,654.4	12/10/2013												
\$ 107,260.7	\$ 237,161.4	1/21/2014												
\$ 16,254.0	\$ 68,840.0	1/22/2014												
\$ 6,815.1	\$ 44,465.4	12/9/2014												

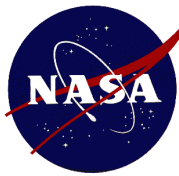
- Collect Data
- Normalize Data
- Develop Homogenous Data Set
- Calculate Descriptive Statistics
- Look at Possible Correlations
- Do Some Time Series Analysis
- Perform t-Tests to Compare JCL and non-JCL Missions
- Summarize Findings



Data Source - CADRe

- **CADRe – Cost Analysis Data Requirements**
- **Three Parts**
 - Part A: Narrative Description
 - Part B: Technical Data & Schedule Milestones
 - Part C: Cost, Schedule, Risk Data
- **CADRes are produced at each major project milestone**
 - The “Launch” CADRe captures the actual development cost





CADRe Versus the ABC

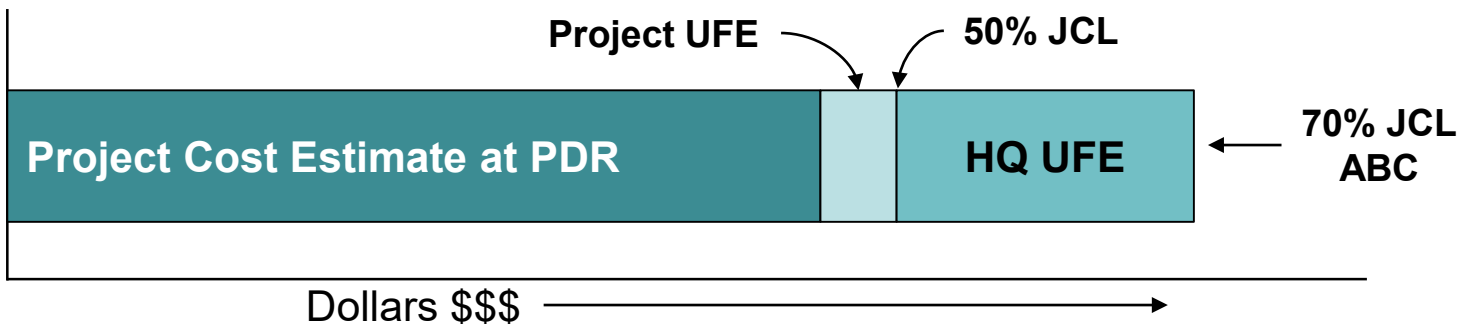


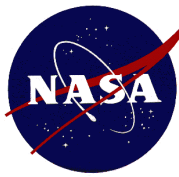
CADRe

- Data Collected by the Cost Community for the Cost Community
- *Captured at Each Project Milestone*
- Intent is to be a “Flight Recorder,” Capturing Actuals and Estimates to Complete

Agency Baseline Commitment (ABC)

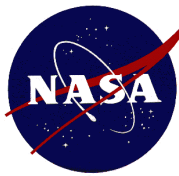
- Commitment made by Senior NASA Leadership
- *Determined at KDP-C Using Results from the JCL*
- Does not Change unless Project is Re-Baselined
- Reported to OMB and Congress





Normalization

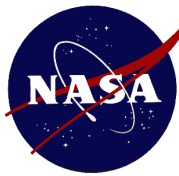
- **Actual year dollars** (no adjustment for inflation)
- Excluded all **launch vehicle** and **post-launch mission operations** cost
- When necessary, **estimated** cost by phase using schedule data
- All data taken from PDR and LRD CADRe's with the following exceptions:
 - Astro-H used PSR CADRe in lieu of LRD CADRe
 - NuSTAR used CSR CADRe in lieu of PDR CADRe
 - OCO-2 used CDR CADRe in lieu of PDR CADRe
 - Phoenix CADRe data augmented with information provided by project manager



Initial Data Set

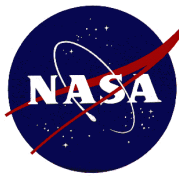
- Started with a Data Set of 65 Missions
- Eliminated **15 Missions** that had Missing or Problematic Data

AIM	Glory	InSight	MAVEN	OCO	STEREO
Astro-H	GOES-P	IRIS	MER	OCO-2	Swift
Aquarius	GOES-R	JASON-3	MESSENGER	Odyssey	TDRSS K-L
CALIPSO	GOLD	JPS-1	MGS	OSIRIS-Rex	THEMIS
CloudSat	GPM	JUNO	MMS	Parker Solar Probe	TIMED
CYGNSS	GPM	JWST	MRO	Phoenix	TRACE
Dawn	GRACE-FO	Kepler	MSL	RHESSI	VAP
Deep Impact	GRAIL	LADEE	NEAR	SAGE-III	WIRE
EO-1	IBEX	Landsat 8	New Horizons	SDO	WISE
GALEX	ICESAT-2	LCROSS	NICER	SMAP	WMAP
Genesis	ICON	LRO	NuSTAR	Spitzer	



Analysis Focus

- Primary Focus was on **Comparing Development (Phase CD) Cost and Schedule Growth** for JCL versus non-JCL Missions
- Discovered during Data Analysis that **Phase AB Cost changed** between the PDR CADRe and LDR CADRe for almost every Mission
 - KDP-C Occurs after PDR
 - PDR CADRes often Developed prior to Actual PDR
 - Different Analyst
 - Better Data
- As a Result, Compared **Phase A-D Cost**
- Also looked at the **Phase AB/CD Ratio**



Analysis Data Set

Remaining Missions Fell into One of Three Groups

General Statistics and Phase AB/CD Ratio at Launch

Complete Data and JCL

Astro-H	MAVEN	OCO-2	SMAP	MMS
CYGNSS	MSL	OSIRIS-Rex	GPM	
GRACE-FO	NuSTAR	SAGE-III	LADEE	

Complete Data but No JCL

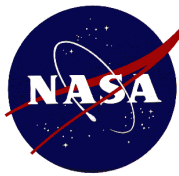
AIM	GRAIL	NICER	THEMIS	IRIS
Aquarius	JASON-3	OCO	WISE	Landsat 8
Dawn	JUNO	Phoenix	CloudSat	LRO
Deep Impact	Kepler	Spitzer	Glory	New Horizons
GOLD	MRO	STEREO	IBEX	VAP

Useful Data and No JCL

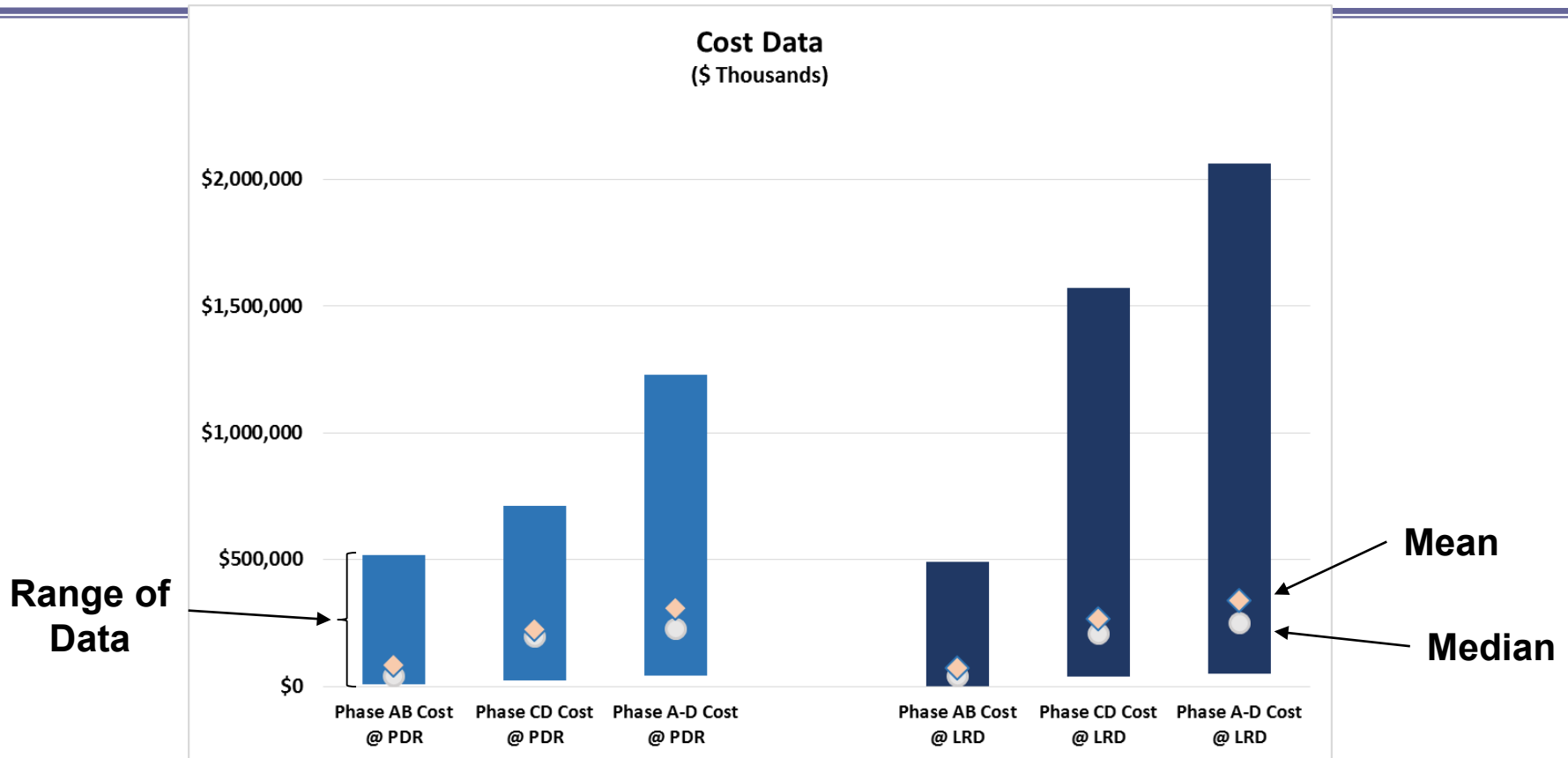
GALEX	Odyssey	TIMED	TRACE
Genesis	SDO	LCROSS	WIRE
MER	Swift	RHESSI	WMAP

Missing PDR Data

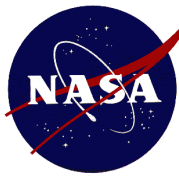
*Cost and Schedule Growth; t-Test for
Equivalence of Means*



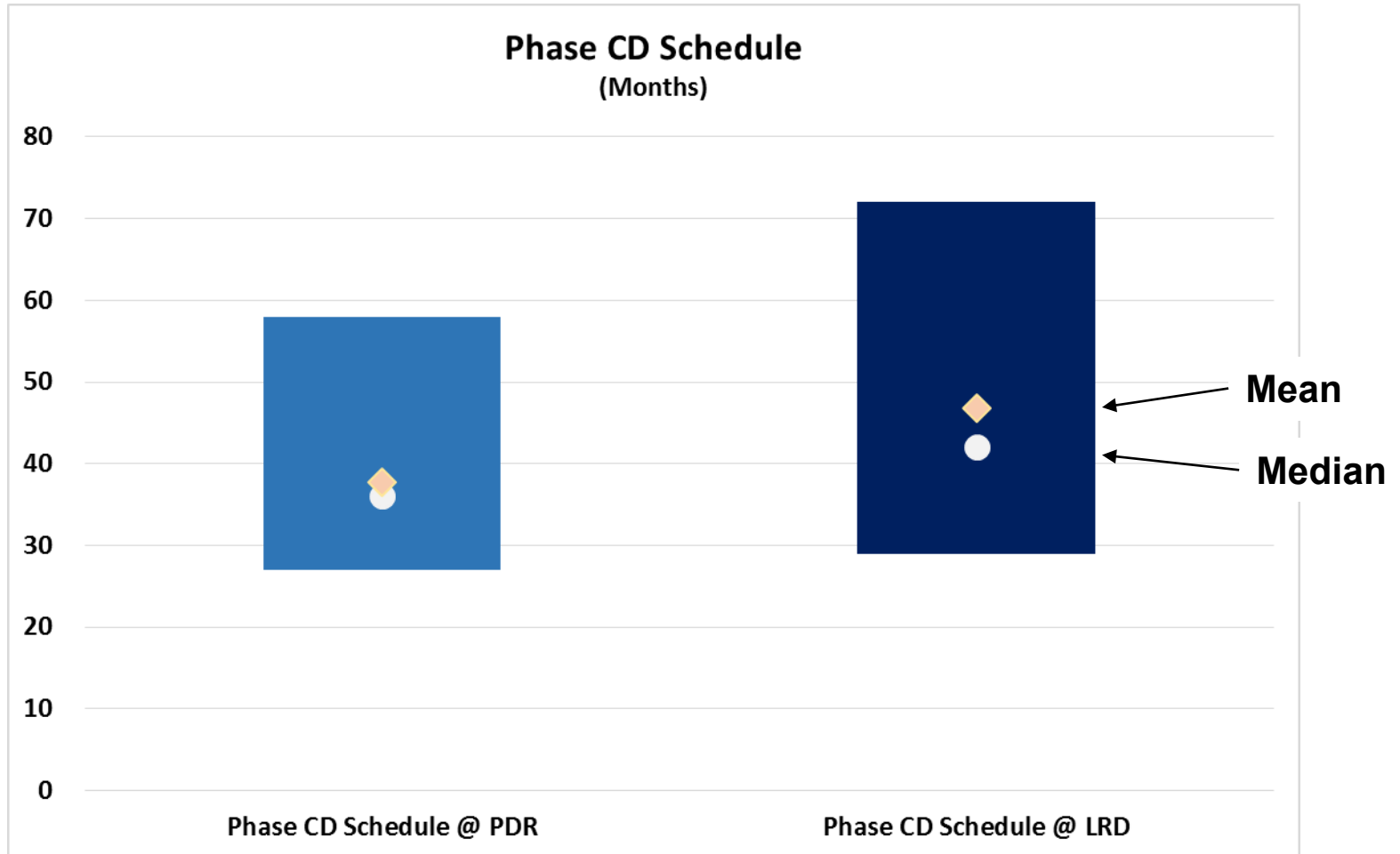
Cost - All Data



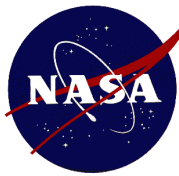
	Minimum	Maximum	Mean	Median
Phase AB Cost @ PDR	\$ 6,815.1	\$ 519,621.0	\$ 82,682.8	\$ 42,013.8
Phase CD Cost @ PDR	\$ 24,305.0	\$ 711,033.6	\$ 225,932.0	\$ 196,351.2
Phase A-D Cost @ PDR	\$ 41,852.0	\$ 1,230,654.6	\$ 308,614.8	\$ 227,917.1
	Minimum	Maximum	Mean	Median
Phase AB Cost @ LRD	\$ 2,205.0	\$ 492,344.1	\$ 71,377.3	\$ 38,788.1
Phase CD Cost @ LRD	\$ 36,573.3	\$ 1,570,570.2	\$ 265,757.3	\$ 206,960.0
Phase A-D Cost @ LRD	\$ 51,400.3	\$ 2,062,914.4	\$ 337,134.6	\$ 251,022.3



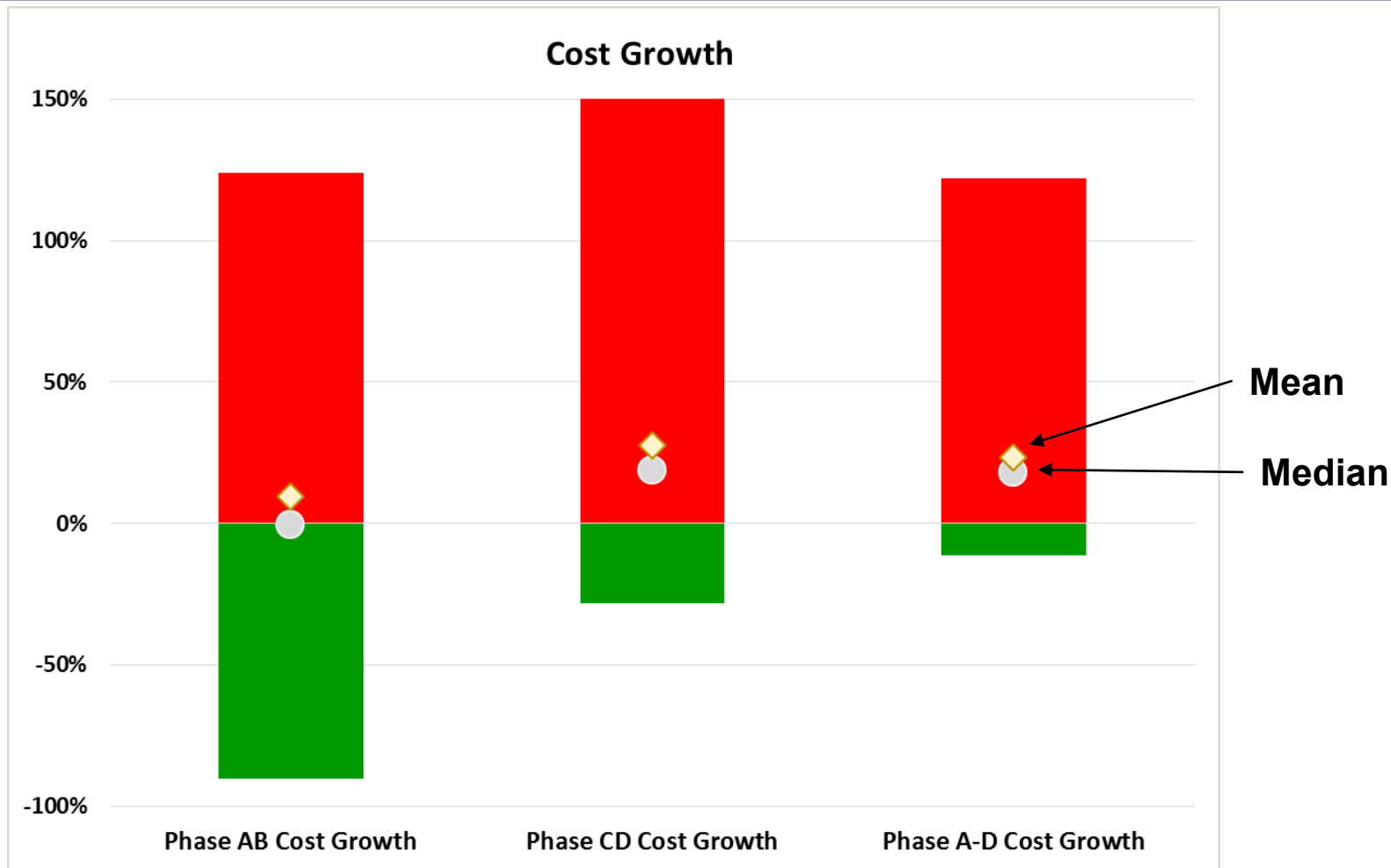
Phase CD Schedule - All Data



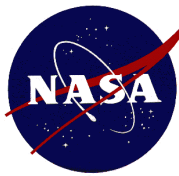
	Minimum	Maximum	Mean	Median
Phase CD Schedule @ PDR	27.0	58.0	37.7	36.0
Phase CD Schedule @ LRD	29.0	72.0	46.8	42.0



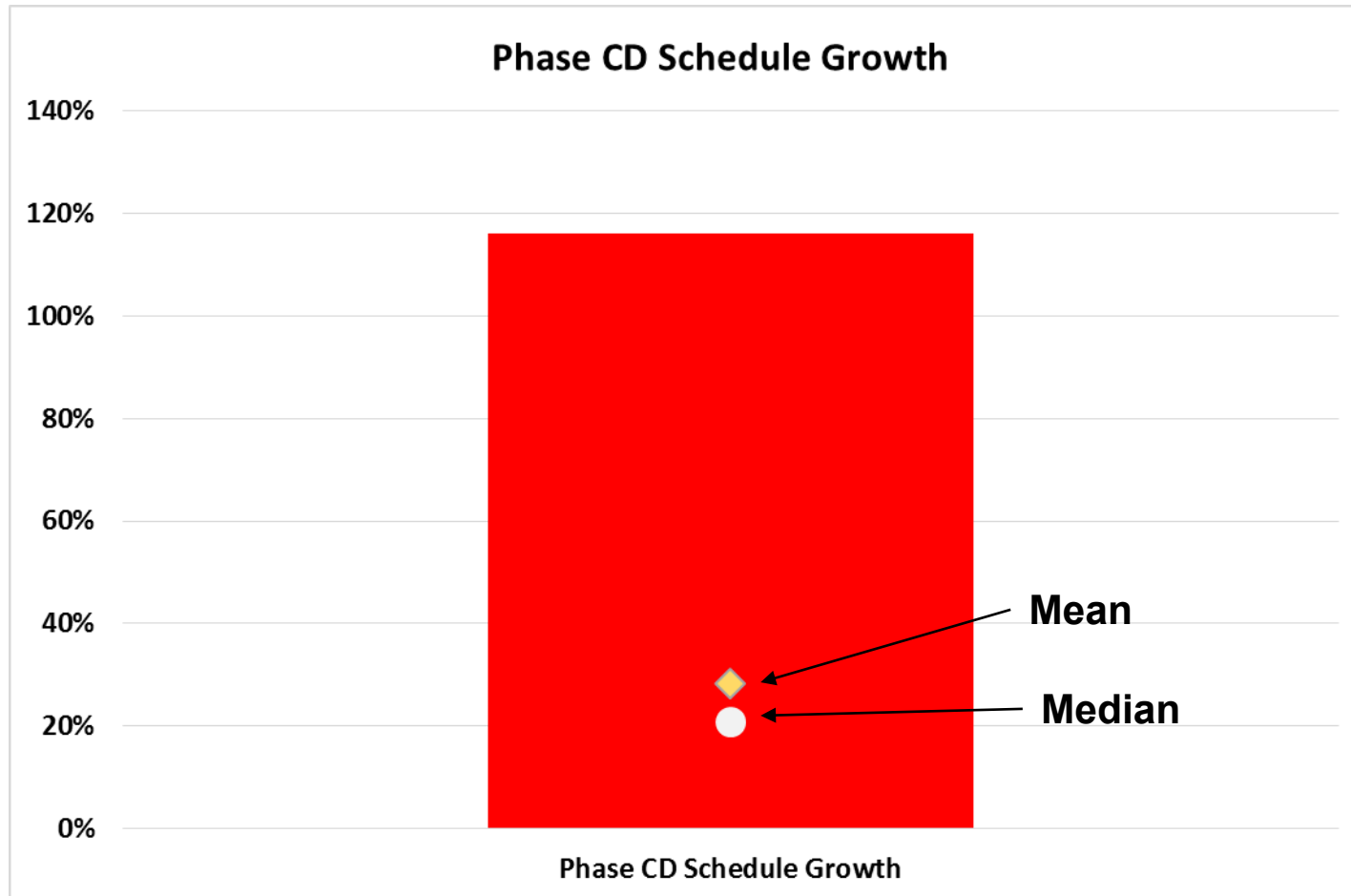
Cost Growth



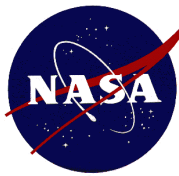
	Minimum	Maximum	Mean	Median
Phase AB Cost Growth	-90.1%	123.8%	9.5%	-0.4%
Phase CD Cost Growth	-28.1%	151.2%	27.6%	19.0%
Phase A-D Cost Growth	-11.1%	121.8%	23.4%	18.0%



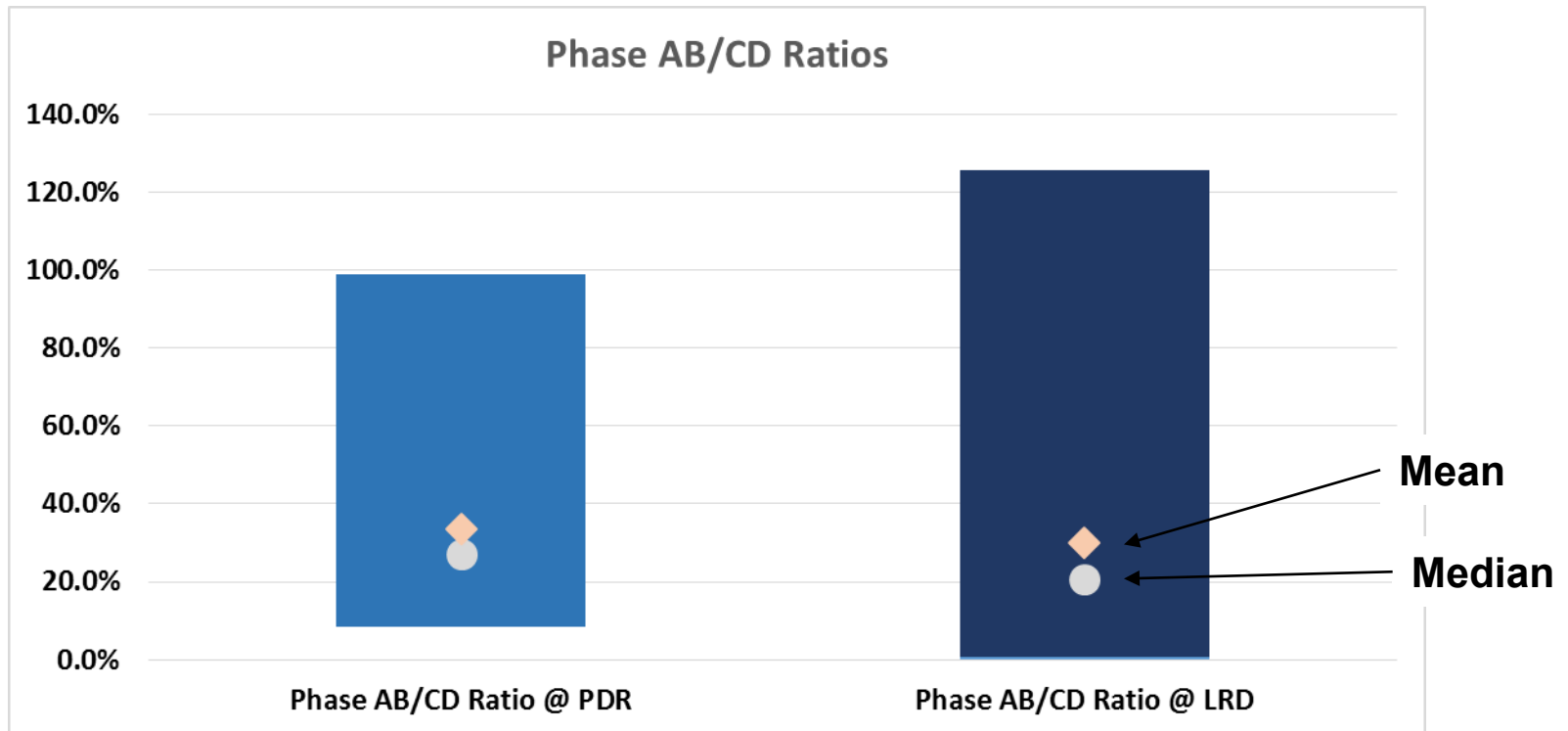
Schedule Growth



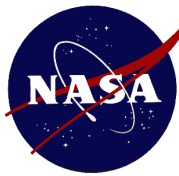
	Minimum	Maximum	Mean	Median
Phase CD Schedule Growth	0.0%	116.1%	28.2%	20.9%



Phase AB/CD Ratio – All Data



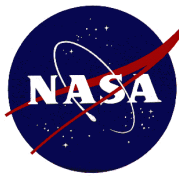
	Minimum	Maximum	Mean	Median
Phase AB/CD Ratio @ PDR	8.4%	98.8%	33.6%	27.0%
Phase AB/CD Ratio @ LRD	0.7%	125.5%	30.1%	20.7%



Correlations

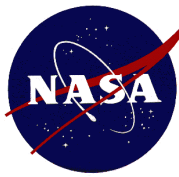
	<i>Planned Phase CD (months)</i>	<i>Actual Phase CD (months)</i>	<i>Phase CD Schedule Growth</i>	<i>Phase AB Cost Growth</i>	<i>Phase CD Cost Growth</i>	<i>Phase ABCD Cost Growth</i>	<i>Phase AB/CD Ratio at PDR</i>	<i>Phase AB/CD Ratio at Launch</i>
Planned Phase CD (months)	1							
Actual Phase CD (months)	0.619	1						
Phase CD Schedule Growth	-0.195	0.637	1					
Phase AB Cost Growth	-0.086	-0.047	-0.016	1				
Phase CD Cost Growth	-0.030	0.550	0.689	-0.201	1			
Phase ABCD Cost Growth	-0.038	0.544	0.678	0.111	0.924	1		
Phase AB/CD Ratio at PDR	0.090	0.151	0.105	0.125	0.107	0.145	1	
Phase AB/CD Ratio at Launch	0.102	-0.046	-0.133	0.503	-0.281	-0.068	0.818	1

- **Some correlations were expected (Phase CD Cost Growth and Phase ABCD Cost Growth)**
- **But others were surprising (Actual Phase CD and Phase CD Cost Growth)**



Time Series Analysis

- Determine if Cost and Schedule Growth are **Changing** over Time
- Grouped Data into **3 Year** Increments
- **Averaged** Cost Growth, Schedule Growth, and Phase AB/CD Ratio for Each Increment
- Plotted Data and Examined for Trends
- Data Limited Analysis to the Years **2001 to 2015**

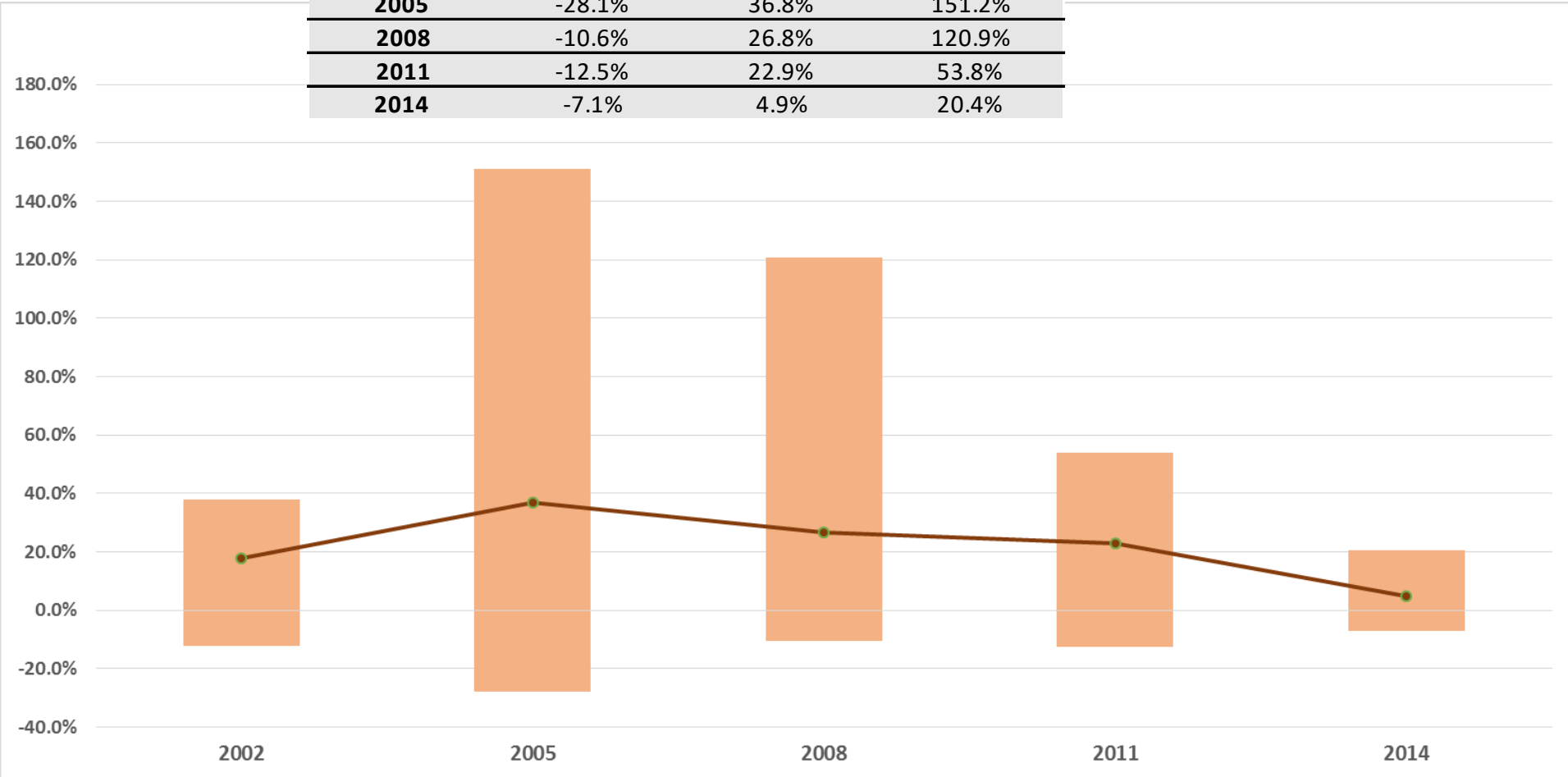


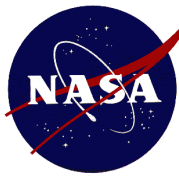
Phase CD Cost Growth Over Time



**Engineering
Cost
Office**

	Phase CD Cost Growth		
	Minimum	Average	Maximum
2002	-12.3%	17.8%	37.9%
2005	-28.1%	36.8%	151.2%
2008	-10.6%	26.8%	120.9%
2011	-12.5%	22.9%	53.8%
2014	-7.1%	4.9%	20.4%



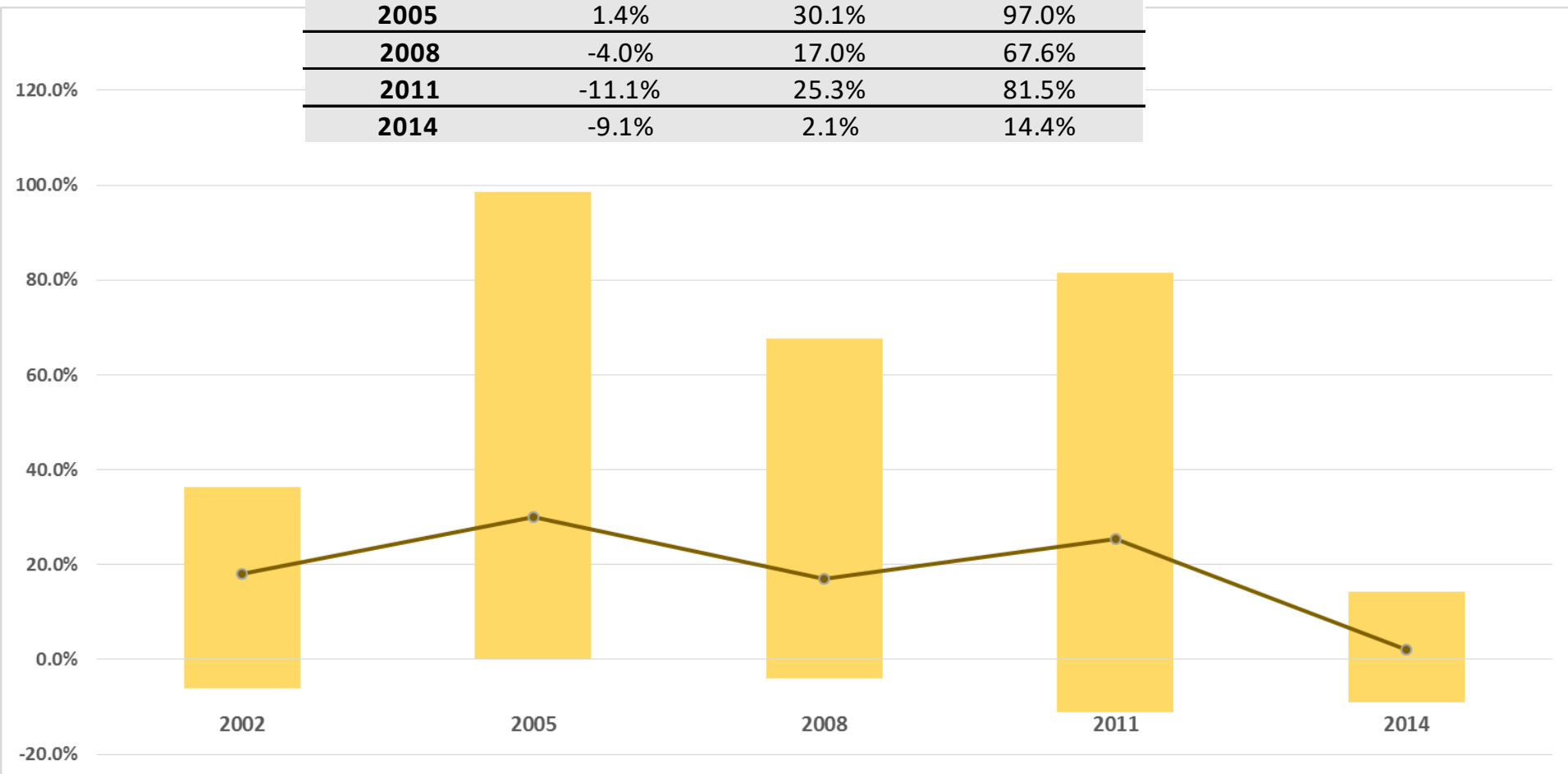


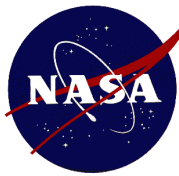
Phase ABCD Cost Growth Over Time



**Engineering
Cost
Office**

	Phase A-D Cost Growth		
	Minimum	Average	Maximum
2002	-6.0%	18.1%	36.4%
2005	1.4%	30.1%	97.0%
2008	-4.0%	17.0%	67.6%
2011	-11.1%	25.3%	81.5%
2014	-9.1%	2.1%	14.4%



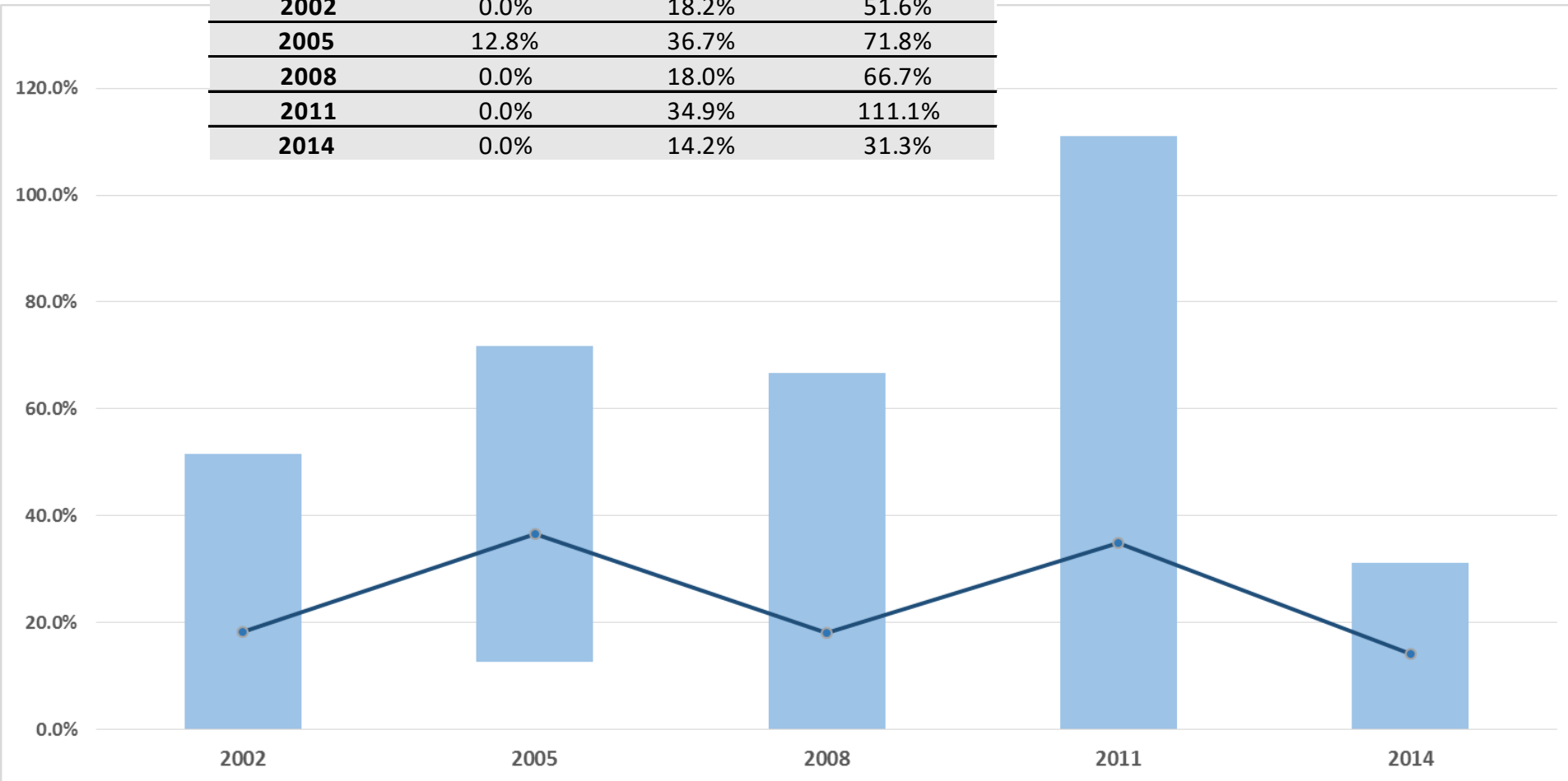


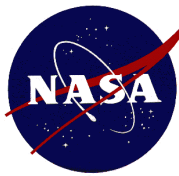
Phase CD Schedule Growth Over Time



**Engineering
Cost
Office**

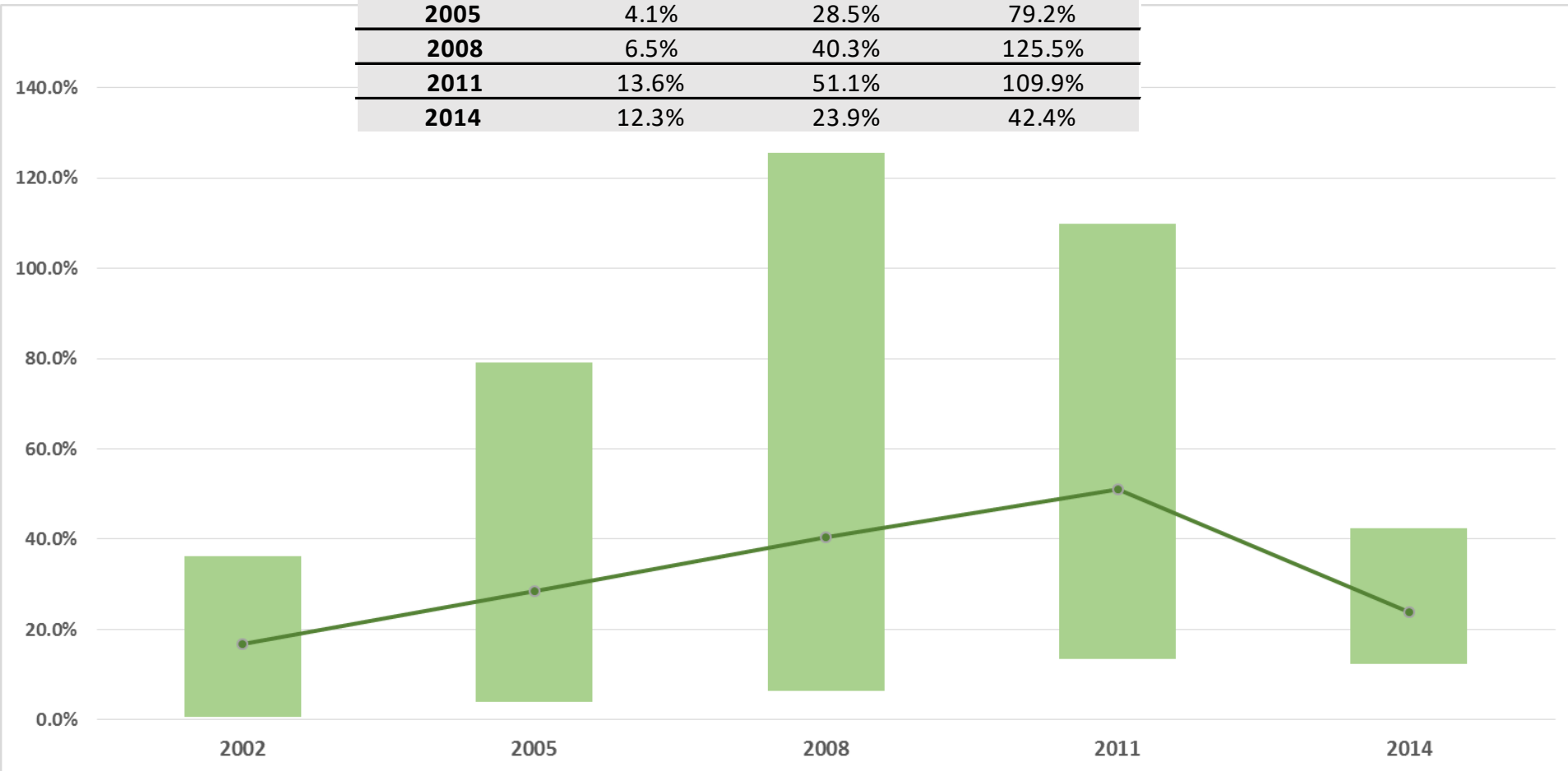
	Phase CD Schedule Growth		
	Minimum	Average	Maximum
2002	0.0%	18.2%	51.6%
2005	12.8%	36.7%	71.8%
2008	0.0%	18.0%	66.7%
2011	0.0%	34.9%	111.1%
2014	0.0%	14.2%	31.3%

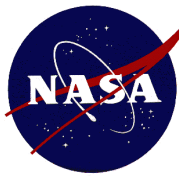




Phase AB/CD Ratio Over Time

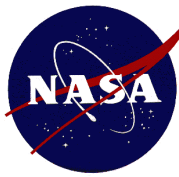
	Phase AB/CD Ratio		
	Minimum	Average	Maximum
2002	0.7%	16.7%	36.2%
2005	4.1%	28.5%	79.2%
2008	6.5%	40.3%	125.5%
2011	13.6%	51.1%	109.9%
2014	12.3%	23.9%	42.4%





Tests for Equivalence of Means

- **Comparing mean (average) cost growth for missions that had a JCL prior to implementation to missions that did not**
- **Hypotheses:**
 - H_0 : Mean JCL Missions = Mean non-JCL Missions
 - H_1 : Mean JCL Missions < Mean non-JCL Missions
- **Used t-Test with both equal and unequal variance assumptions at a 95% confidence level**



t-Test Results

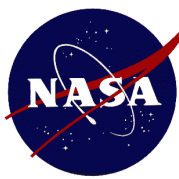
Phase CD Cost Growth			
	Mean	Median	Standard Deviation
JCL	28.0%	20.4%	34.8%
No JCL	27.5%	17.5%	42.7%
Two-Tailed			
	Unequal Variance	Equal Variance	
t Calculated	0.038	0.036	
t Critical Value	1.699	1.688	One-Tail

Phase A-D Cost Growth			
	Mean	Median	Standard Deviation
JCL	21.9%	17.9%	27.0%
No JCL	24.2%	18.0%	30.4%
Two-Tailed			
	Unequal Variance	Equal Variance	
t Calculated	-0.242	-0.233	
t Critical Value	1.703	1.688	One-Tail

Phase CD Schedule Growth			
	Mean	Median	Standard Deviation
JCL	29.1%	18.8%	32.5%
No JCL	27.7%	21.9%	26.9%
Two-Tailed			
	Unequal Variance	Equal Variance	
t Calculated	0.137	0.146	
t Critical Value	1.721	1.688	One-Tail

Phase AB/CD Ratio at Launch			
	Mean	Median	Standard Deviation
JCL	42.7%	31.6%	31.5%
No JCL	27.0%	18.6%	27.1%
Two-Tailed			
	Unequal Variance	Equal Variance	
t Calculated	1.533	1.609	
t Critical Value	1.721	1.688	One-Tail

Bottom Line: Cannot Reject H_0



Reconciliation

- The analysis on the previous charts is at odds with the assessment performed by the NASA Science Mission Directorate
- **Why?** Both the composition of data sets and the measurement baseline are different
 - Differences between PDR and ABC are to be expected

SMD Data

Mission	Original KDP-C Baseline	Actual	Cost Growth: ABC vs Actuals
Astro-H	\$ 44.9	\$ 71.2	58.6%
CYGNSS	\$ 151.1	\$ 127.1	-15.9%
GPM	\$ 555.2	\$ 484.3	-12.8%
IRIS	\$ 140.7	\$ 143.0	1.6%
LADEE	\$ 168.2	\$ 188.2	11.9%
Landsat 8	\$ 583.4	\$ 502.8	-13.8%
MAVEN	\$ 567.2	\$ 472.0	-16.8%
MMS	\$ 857.3	\$ 875.3	2.1%
NuSTAR	\$ 109.9	\$ 116.0	5.6%
OCO-2	\$ 249.0	\$ 320.3	28.6%
OSIRIS-Rex	\$ 778.6	\$ 620.8	-20.3%
SAGE-III	\$ 64.6	\$ 88.2	36.5%
SMAP	\$ 485.7	\$ 454.3	-6.5%

GRACE-FO	\$ 265.0	\$ 249.0	-6.0%
MSL	\$ 711.0	\$ 1,570.6	120.9%

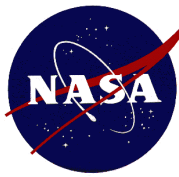
Average w/o GRACE-FO and MSL	4.5%
Average with GRACE-FO and MSL	11.6%

CADRe Data

Mission	PDR Phase CD Cost	LRD Phase CD Cost	Cost Growth: ABC vs Actuals
Astro-H	\$ 24.3	\$ 37.4	53.8%
CYGNSS	\$ 68.8	\$ 82.9	20.4%
GPM	\$ 563.2	\$ 601.4	6.8%
IRIS	\$ 92.2	\$ 127.0	37.7%
LADEE	\$ 124.6	\$ 159.7	28.2%
Landsat-8	\$ 355.1	\$ 317.5	-10.6%
MAVEN	\$ 337.6	\$ 304.9	-9.7%
MMS	\$ 536.7	\$ 783.9	46.1%
NuSTAR	\$ 63.2	\$ 71.8	13.6%
OCO-2	\$ 157.6	\$ 194.7	23.6%
OSIRIS-Rex	\$ 508.4	\$ 472.2	-7.1%
SAGE-III	\$ 55.2	\$ 84.7	53.4%
SMAP	\$ 323.0	\$ 350.7	8.6%

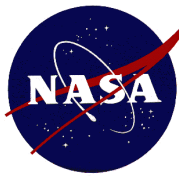
GRACE-FO	\$ 237.2	\$ 249.0	5.0%
MSL	\$ 711.0	\$ 1,570.6	120.9%

Average w/o GRACE-FO and MSL	20.4%
Average with GRACE-FO and MSL	26.0%



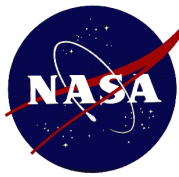
Findings

- **Analysis of CADRe Data Indicates that NASA's JCL Policy *is not* having an Impact on **Project Cost or Schedule Estimates** at PDR**
 - CADRe captures the project's estimate, the ABC is based on the JCL Results
- **There is **Weak** Evidence that NASA's JCL Policy may be Increasing the Amount of Resources being Spent in Formulation (Phase AB)**
- ****Inconsistent** CADRe Formatting and Content Increased the Difficulty of this Analysis**
 - Variation in Phase AB cost is troubling



Conclusions

- While the CADRe evidence does not prove that NASA's JCL policy is improving **project** cost estimates, anecdotal evidence indicates that it is a ***forcing function*** for better project management and executive decision making
- Additional research is needed to reconcile the differences between the SMD and LRD CADRe data



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