

Real Data, Real Uncertainty

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- CRUAMM Purpose
- CRUAMM Process
- Illustrative Result
- CRUAMM Final Report



The Purpose of CRUAMM

- If you are provided a method without uncertainty information, rather than guess or using one of the AFCAA CRUH defaults, locate the method and its input in CRUAMM for a representative uncertainty distribution
- You can also use CRUAMM to cross check the uncertainty you derive from your data or your other sources
- CRUAMM does not supplant existing best practices
 - If you have the data to build a CER, use it to develop the prediction interval for use in your model
 - If you are provided a CER complete with uncertainty information, use them in your model



Expressing Uncertainty

Given:

Cost Element Point Estimate = Your Methodology

Its uncertainty can then be expressed:

Cost Element _{Uncertainty} = *f*(Your Methodology, Distribution Shape, Distribution Parameters)

With CRUAMM, its uncertainty can then be expressed:

Cost Element _{Uncertainty} = Your Methodology * Unitized Distribution



Orders of Dispersion

First Order

- Amount of spread in a single parameter of a dataset
- Example: cost elements, cost drivers
- Second Order
 - Amount of spread in a factor relationship
 - Example: Non Recurring as a factor of T1

Third Order

- Amount of spread in a the error term of a best fit equation
- Example: Confidence interval of a CER derived from regression

Fourth Order

- Prediction interval from a statistically derived CER
- Example: CER prediction interval for a given independent variable

CRUAMM



Distribution Fit Process

Collect and normalize the data

- Sort sample data in ascending order
- Assign a cumulative percentile using the NIST¹ formula (different than Excel) but apply a "correction for continuity" ² (0.5*ObsFreq+NumObsBelow)/ObsCount
- Use the sample descriptive statistics to provide a starting point for fit parameters

Assess the difference between the sample and fit using either:

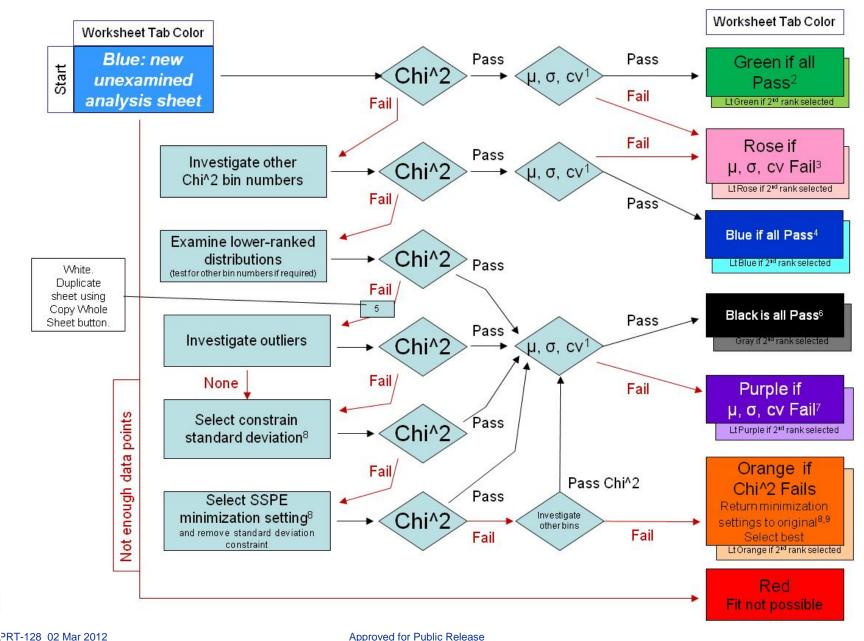
- Sum squared error (SSE) highly influenced by very large sample points (as compared to mean)
- Sum squared percent error (SSPE) highly influenced by fitted points close to zero (divide by zero)
- Use *Excel Solver or ACEIT CO\$TAT to find the fit parameters that minimize SSE or SSPE
 - Set optional constraints such as: Low>0, Low<LowestSamplePoint, High>HighestSamplePoint
- Rank the fits using standard error of the estimate (SEE) or standard percent error (SPE)
 - This is a preferred method to rank the fits (rather than SSE or SSPE directly) because it accounts for the degrees of freedom
 - Accounts for number of parameters required to uniquely define a distribution
 - > 2 for Normal, lognormal, 3 for Triangular, 4 for Beta
 - Many tools do not account for the number of parameters as they are designed to address fits on hundreds or thousands of data points. The difference between 1000, 997 and 995 degrees of freedom (on 1000 data points) has no impact on SEE but for 10 data points, the difference between 10, 7 and 5 degrees of freedom can be dramatic.
- Use a Goodness-of-Fit test (Chi^2) to determine significance of the fit
 - Minimum SSE or SSPE alone does not necessarily mean the fit is meaningful
 - Other tests (K-S, AD) cannot be applied to every distribution. Only Chi^2 provides a p-value for any distribution

1. NIST= National Institute of Standards and Technology

 From "Reliability and Information Functions for Percentile Ranks" Kim May and W. Alan Nicewander, Journal of Educational Measurement, Vol. 31, No. 4 (Winter, 1994), pp. 313-325



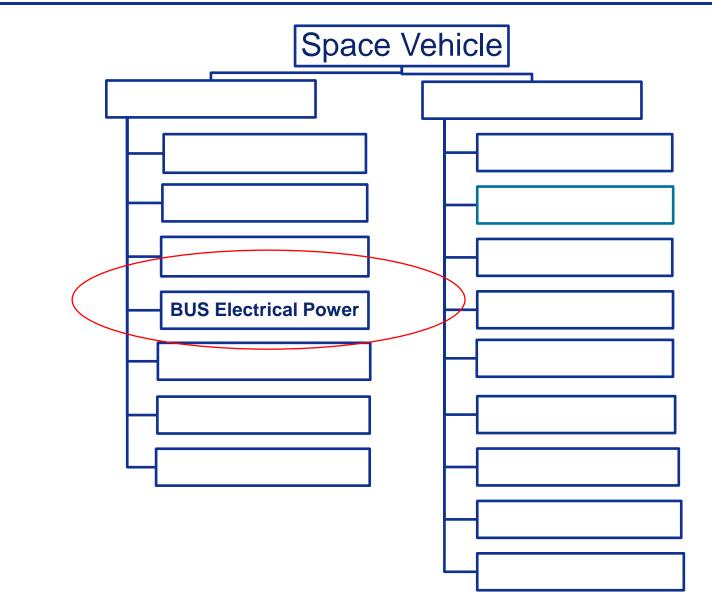
Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com **CRUAMM Results are Based on a Consistent Process for Evaluating Distribution Fits**



Illustrative Results for One Subsystem

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Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Analyst Wants to Use the FireSat CER for EPS, but needs Uncertainty Guidance

Use CRUAMM to identify representative uncertainty for:

• the Electrical Power Subsystem CER

• the EPS CER independent variable (EPS Weight)

WBS Description	Unique ID	CER	Point Estimate	Forecast (PE * Uncert)	Distribution	Uncert ainty	Min	Max or Std Dev
Satellite			\$298,647	\$298,647		Mean or Mode		
Payload	RDPayload		\$168,462	\$168,462				
IR Sensor		356851 * PayloadDiam^0.562	\$168,462	\$168,462	Triangular	1	0.071	1.9640
Spacecraft Bus	RDSpBus		\$15,096	\$15,096				
Structure		157 * StrWgt^0.83	\$2,787	\$2,787	Triangular	1	0	1.9528
Thermal		394 * ThermWgt^0.635	\$1,331	\$1,331	Triangular		Û	1 9528
Electrical Power System (EPS)		62.7 * EPSWgt	\$2,865	\$2,855		1		
Telemetry Tracking & Command (TT&C) and								
Command & Data Handling (C&DH)		545 * TTCWgt^0.761	\$2,344	\$2,344	Lognormal	1		0.2941
Attitude Determination & Control Sys		464 * ADCSWgt^0.867	\$5,769	\$5,769	Lognormal	1		0.4231
Int & Assy		989 + 0.215 * (RDPayload\$ + RDSpBus)	\$40,454	\$40,454	Normal	1		0.3544
Program Level Costs		1.963 * (RDPayload\$ + RDSpBus) ^0.841	\$52,451	\$52,451	Lognormal	1		0.4609
Ground Support Equip (GSE)		9.262 * (RDPayload\$ + RDSpBus) ^0.642	\$22,184	\$22,184	Triangular	1	0	3.1204

Input Variable	Unique ID	CER	Point Estimate	Forecast	Distribution	Uncert ainty	Min	Max or Std Dev
Payload Sensor diameter (m)	PayloadDiam		0.263	0.263	Lognormal	1		0.3000
Structure weight (kg)	StrWgt		32.000	32.000	Lognormal	1		0.5019
Thermal weight (kg)	ThermWgt		6.800	6.800	Triangular	1	0.261	2.7028
EPS weight (kg)	EPSWgt		45.700	45.70		1		
TT&D/DH weight (kg)	TTCWgt		6.800	6.800	Normai			0.1893
ADCS weight (kg)	ADCSWgt		18.300	18.300	Normal	1		0.3103
Spacecraft + Payload Weight (kg)	SpPyWgt		140.000	140.000	Lognormal	1		0.2307



Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Sample **CRUAMM Public Domain Table**

The "unitized" results are intended for public domain and are intended for use in "your" model uncertainty scales with "your" point estimate

			The Point Estimate is:	
Parameter	Filter	Mean	Median	Mode
T1 CER ¹	None	Lognormal (1.0000, 0.4512)	Lognormal (1.0971, 0.4950)	Lognormal (1.3204, 0.5958)
T1 CER ³	None	Triangular (0.1552, 0.7265, 2.1183)	Triangular (0.1635, 0.7651, 2.2308)	Triangular (0.2137, 1.0000, 2.9158)
NR CER ³	None	Triangular (0.5206, 0.7584, 1.7210)	Triangular (0.5418, 0.7892, 1.7911)	Triangular (0.6865, 1.0000, 2.2694)
Weight	None	Triangular (0.5568, 0.6370, 1.8062)	Triangular (0.5850, 0.6692, 1.8975	Triangular (0.8742, 1.0000, 2.8357)
Growth ²	>50% New	Triangular (0.5853, 0.7180, 1.6967)	Triangular (0.6092, 0.7474, 1.7662)	Triangular (0.8151, 1.0000, 2.3631)
	<50% New	Triangular (0.5043, 0.6168, 1.8789)	Triangular (0.5316, 0.6502, 1.9805)	Triangular (0.8176, 1.0000, 3.0461)
T1 / Weight ³	Commercial	Triangular (0.3442, 0.6256, 2.0302)	Triangular (0.3649, 0.6631, 2.1520)	Triangular (0.5503, 1.0000, 3.2454)
	Government	Lognormal (1.0000, 0.7077)	Lognormal (1.2251, 0.8670)	Lognormal (1.8387, 1.3013)
NRE /	New	Triangular (0.0283, 0.1925, 2.7792)	Triangular (0.0316, 0.2155, 3.1103)	Triangular (0.1468, 1.0000, 14.4348)
Weight ³	Modified	Lognormal (1.0000, 0.9282)	Lognormal (1.3644, 1.2663)	Lognormal (2.5397, 2.3573)
NRE / T1 ³	New	Triangular (0.0000, 0.1905, 2.8095)	Triangular (0.0000, 0.2136, 3.1495)	Triangular (0.0000, 1.0000, 14.7445)
	Modified	Lognormal (1.0000, 1.3844)	Lognormal (1.7078, 2.3642)	Lognormal (4.9806, 6.8950)

These footnotes identify the data source for each fit on this particular chart:



2 - CRUAMM - NRO 3 – CRUAMM - USCM

See Previous Chart for Filter Information

For this example, the CER produces the mean and the weight input is assumed to be the mode.

WBS:	Electrical Power	Cost Driver:	T1 CER (\$K)					
CER:	220.0 + Bus Electrical Power V	er Weight*13.0 + CCL * 6000.0 CCL = 0; If Commercial CCL = 1; If Government						
Dist Form:	Actual/Predicted							
Best Fit	Lognormal (Mean =1.1388, Std D)ev = 0.6722)						
Dependent	753 – 4087 6\$K	Independent	94 – 1969 lbs					

Cost Risk and Uncertainty Analysis Data Report										
Commodity	Space	Dispersion	Third							
WBS	Residuals	Units								
Element	EPS	Data Comment	EPS T1 = 220 + EPS Weight(lbs) * 13 + CCL * 9000							
Sub-Element	T1 Rec	Phase								
Category	EPSRecT1Residuals	Comment								
Filter and Fit Settings	Filter= NONE: , Fit = SSE on Value, Percentile =	= CoC, Using: CO\$TAT Engine								
Fit Constraints	raints Force Min => 0: Nor TRI Beta Force Include Sample Min/Max: TRI Beta									
Recommended Fit	Recommended Fit Lognormal (Mean = 1.14, Std Dev = 0.67)									

Dataset Statistics and Fitted Distributions

Sar	nple		Sample	Lognormal	Normal	Triangular	Beta	100% -	
an be used to de	efine a CDF directly	Mean	1.1408	1.1388	1.1760	1.4015	1.1320		and the second sec
Percentile	Value	StdDev	0.6413	0.6722	0.5055	0.8972	0.6526	90% -	
0%	0.2623	CV	0.562	0.590	0.430	0.640	0.576	6 50%	
5%	0.4677	Min	0.2701			0.0000	0.2701	80% -	
10%	0.5174	Mode		0.7272	1.1760	0.2701	0.6171	80% -	
15%	0.6067	Max	3.9345			3.9345	17.2398		
20%	0.6529	Data Count	50			Alpha	1.605	70% -	
25%	0.7129					Beta	30.000		
30%	0.7658		Rank	1	3	4 2		60% -	
35%	0.8204	Standard Er	ror of Estimate	0.0945	0.2744	0.4729	0.1341		
40%	0.8993		SEE / Fit Mean	8.3%	23.3%	33.7%	11.8%	5 0% -	
45%	0.9642	Chi ² Fit test	t 9 Bins, Sig 0.05	Good (63%)	Good (27%)	Poor (0%)	Good (21%)	0	
50%	1.0493	16			Ur		Sample	40% -	
55%	1.1147	14		~~ <u>`</u>	Po		 Lognormal (1) Normal (3) 	10,0	
60%	1.1475	12					Triangular (4)	30% -	Sample
65%	1.1692	ت 10 ا					Beta (2)	30% =	Lognormal (1
70%	1.3436	10							Normal (3)
75%	1.3760	Fred						20% -	Triangular (4)
80%	1.4403		/ /						• Beta (2)
85%	1.6569	4						10% -	
90%	1.8824	2							
95%	2.3306	0+	+ + +					0% -	
100%	3.9345	0.27	0.64 1.00	1.37 1.74 2 Values mark the bi	.10 2.47 2.84	4 3.20 3.57	3.93 4.30		0.00 0.50 1.00 1.50 2.00 2.50 3.00 3.50 4.00



All examples use fictitious data

CRUAMM Commodity Appendix

		Cos	st Risk and Und	certainty Analysis	Data Report			
	Commodity	Space		Dispersion		Third		
	WBS	Residuals		Units				
	Element	EPS		Data Comment		EPS T1 = 220 + EPS	Weight(lbs) * 13 + CCL * 9	000
	Sub-Element	T1 Rec EPSRecT1Residuals		Phase Comment				
	Category Filter and Fit Settings	Filter= NONE: , Fit = SSE on Value, Percentile :	= CoC Using: CO\$					
Not intervale of fear	Fit Constraints	Force Min => 0: Nor TRI Beta Force Include S						
Not intended for	Recommended Fit	Lognormal (Mean = 1.14, Std Dev = 0.67)						
	Dataset Statistics and Fitted D	istributions						
nublic domain		1	Normal	Triangular Beta	1			
public domain.	Sample Can be used to define a CDF directly	Sample Lognormal Mean 1.1408 1.138		······g·····	1320		and a second	*
•	Percentile Value	StdDev 0.6413 0.672			6526 90%		1300	
	0% 0.2623	CV 0.562 0.59			0.576		4	
	5% 0.4677	Min 0.2701			2701 80%		7 /	
	10% 0.5174	Mode 0.727	2 1.1760		6171	3/		
	15% 0.6067 20% 0.6529	Max 3.9345 Data Count 50			2398 .605 ^{70%}			
	20% 0.6529 25% 0.7129	Data Count 50			.605	s 1		
	30% 0.7658	Rank 1	3	4 2	60%			
	35% 0.8204	Standard Error of Estimate 0.0945	0.2744	0.4729 0.134		ह {/		
	40% 0.8993	SEE / Fit Mean 8.3%	23.3%	33.7% 11.8%		 }:/		
	45% 0.9642	Chi^2 Fit test 9 Bins, Sig 0.05 Good (63%)	Good (27%)	Poor (0%) Good (2	1%) Ŭ	<u> </u>		
	50% 1.0493	16		orm is a	40%			
CRUAMM appendix	<u>55% 1.1147</u> 60% 1.1475	14	Poor	Normal (3)			Г	Sample
	65% 1.1475			Triangular Beta (2)	.) 30%			Lognormal (1)
	70% 1.3436				_	<u></u>		Normal (3)
contains data points.	75% 1.3760		•		20%			Triangular (4)
	80% 1.4403							-Beta (2)
	85% 1.6569				10%		L	
	90% 1.8824							
	95% 2.3306				0% 🖻			
	95% 2.3306	Values mark the	bin upper bound		0%	0.50 1.00 1.5	0 2.00 2.50 3.00	3.50 4.00
	95% 2.330b	Values mark the	bin upper bound			0 0.50 1.00 1.5	0 2.00 2.50 3.00	3.50 4.00
	Dataset		bin upper bound			0.50 1.00 1.5	0 2.00 2.50 3.00	3.50 4.00
	11000 IO	Space CERs Faux Data Update	bin upper bound			0.50 1.00 1.5	0 2.00 2.50 3.00	3.50 4.00
	Dataset Source	Space CERs Faux Data	bin upper bound		0.00		2.00 2.50 3.00	3.50 4.00
	Dataset Source Dataset Comments	Space CERs Faux Data Update	bin upper bound	Min Max	0.00	Units	2.00 2.50 3.00	3.50 4.00
	Dataset Source Dataset Comments CER 1st Va	Space CERs Faux Data Update	bin upper bound	753.000 408	0.00 0.00 4.000 0.838	3 Units 0.000		3.50 4.00
	Dataset Source Dataset Comments	Space CERs Faux Data Update	bin upper bound	753.000 408	0.00	3 Units 0.000		3.50 4.00
	Dataset Source Dataset Comments CER 1st Va CER 2nd Va Observation	Space CERs Faux Data Update EPST1 Wt PSRecT1Residual EPST1 Wt	Observation	753.000 408 94.154 19 RecT1Residu EPST	0.00 0.00 0.838 0.846 0.622 wt	3 Units 0.000	2.00 2.50 3.00	
	Dataset Source Dataset Comments CER 1st Va CER 2nt Va CER 2nt Va Project Name 1	Space CERs Faux Data Update r EPST1 /Wt PSRecT1Residuat 0.2701 1,719.0000 472.6923	Observation Project Name 26	753.000 408 94.154 19 SRecT1Residu EPST 1.6569 4,75	0.00 CV 4.000 0.838 9.846 0.622 Wt 0000 203.6923	Units 0.000 0.000		
	Dataset Source Dataset Comments CER 1st Va CER 2nd Va Deservation Project Name 1 Project Name 2	Space CERs Faux Data Update EPST1 Wt 9SRecT1Residual 0.2701 1,719,0000 259.4615	Observation Project Name 26 Project Name 27	753.000 408 94.154 19 RecT1Resid EPST 1.6569 4,75 1.1752 3,71	CV 4.000 0.836 9.846 0.622 0000 203.6923 0000 225.923	Units 0.000 0.000		
	Source Dataset CER 1st Va CER 2nd Va Project Name 1 Project Name 2 Project Name 3	Space CERs Faux Data Update EPST1 Wt 29SRecT1Residual EPST1 0.5035 1,809,0000 259.4615 1.1339 31,849,0000 1,451.3077	Observation Project Name 26 Project Name 27 Project Name 28	753.000 408 94.154 19 RecT1Resid EPST 1.6569 4.75 1.1752 3.71 2.3306 6,56	CV 4.000 0.836 9.846 0.622 0000 203.6922 0000 225.923 0000 29.9625	Units 0.000 0.000 0bservation		
	Dataset Source Dataset Comments CER 1st Va CER 2nd Va Project Name 1 Project Name 2 Project Name 3 Project Name 4	Space CERs Faux Data Update F EPST1 Wt SprecT1Residual EPST1 0.2701 1,719.0000 472.6923 0.5035 1,809.0000 1,451.3077 1,7411 0.864.0000 1,7411	Observation Project Name 26 Project Name 27 Project Name 28 Project Name 29	753.000 408 94.154 19 RecT1Resid EPST 1.6569 4.75 1.1752 3.71 2.3306 6.56 0.8902 2.91	4.000 0.8380 9.846 0.025 0000 225.923 0000 225.923 0000 199.692	Units 0.000 0.000 Observation		
	Source Dataset CER 1st Va CER 2nd Va Project Name 1 Project Name 2 Project Name 3	Space CERs Faux Data Update EPST1 Wt 0.2701 1,719,0000 472,6923 0.5038 1,809,0000 1,1339 31,849,0000 1,451,3077 1,7411 40,864,0000 1,993,0000	Observation Project Name 26 Project Name 27 Project Name 28	753.000 408 94.154 19 RecT1Resid EPST 1.6569 4.75 1.1752 3.71 2.3306 6,56	CV 4.000 0.838 9.846 0.622 0000 203.6923 0000 225.9233 0000 199.6923 0000 1,132.6154	Units 0.000 0.000 0bservation		
	Dataset Source Dataset CER 1st Va CER 2nd Va Project Name 1 Project Name 2 Project Name 3 Project Name 4 Project Name 5	Space CERs Faux Data Update EPST1 Wt 0.2701 1,719.0000 472.6923 0.5036 1,809.0000 1,339 31,849.0000 1,451.3077 1,7411 40,864.0000 1,993.0000	Observation Project Name 26 Project Name 27 Project Name 29 Project Name 30	753.000 408 94.154 19 RecT1Residt EPST 1.6569 4,75 1.1752 3,71 2.3306 6,56 0.9802 2,91 0.9642 23,000	0.00 CV 4.000 0.838 8.46 0.622 0000 203.6923 0000 225.9233 0000 234.6354 0000 134.6354 0000 14.132.6155	Units 0.000 0.000 0.000 0bservation 0		
	Dataset Source Dataset Comments CER 1st Va CER 2nd Va Project Name 1 Project Name 2 Project Name 3 Project Name 6 Project Name 7 Project Name 8	Space CERs Faux Data Update EPST1 Wt 0.2701 1,719.0000 472.6923 0.5035 1,809.0000 259.4615 1.1339 31,849.0000 1,451.3077 1,7411 40,844.0000 0.9265 0.4677 4,273.0000 0.4855 1.324.0000 339.7692	Observation Project Name 26 Project Name 27 Project Name 27 Project Name 30 Project Name 31 Project Name 32 Project Name 32	753.000 408 94.154 19 RecT1Resid EPST 1.6569 4,755 1.1752 3,711 2.3306 6,56 0.8902 2,91 0.9642 23,008 1.0694 10,53 1.0976 9,266 1.0292 13,339	CV 4.000 0.339 0.000 203.6922 0000 223.6922 0000 223.6922 0000 234.6154 0000 1,132.6154 0000 1,132.6154 0000 740.7692 0000 632.6923	Units 0.000 0bservation		
	Dataset Source Dataset Comments CER 1st Va CER 2nd Va Project Name 1 Project Name 2 Project Name 3 Project Name 6 Project Name 7 Project Name 8 Project Name 9	Space CERs Faux Data Update ************************************	Observation Project Name 26 Project Name 27 Project Name 29 Project Name 30 Project Name 31 Project Name 33 Project Name 34	753.000 408 94.154 19 SRecT1Residt EPST 1.6569 4,75 1.1752 3,711 2.3306 6,66 0.8902 2,91 0.9642 23,08 1.0694 10,653 1.0976 9,266 1.0292 13,39 0.7764 8,88	0.00 0.03	3 Units 0.000 0.000 Observation		
	Outraset Source Dataset Comments CER 1st VacCER 2nd Va Observation Project Name 1 Project Name 4 Project Name 5 Project Name 6 Project Name 8 Project Name 9 Project Name 10	Space CERs Faux Data Update EPST1 Wt PSRecTiResidual EPST1 Wt 2958ecTiResidual EPST1 1,719.0000 472,6923 0,5035 1,809.0000 1,4513 31,849.0000 0,9266 4,259.0000 0,9266 4,259.0000 0,9265 1,232.0000 0,4877 4,273.000 0,4877 4,273.000 0,2855 1,324.0000 0,9704 6,532.0000 0,6667 8,253.0000 0,02845 1,029.4615	Observation Project Name 26 Project Name 27 Project Name 28 Project Name 29 Project Name 30 Project Name 31 Project Name 32 Project Name 33	753.000 408 94.154 19 RecT1Resid EPST 1.6569 4,75 1.1752 3,71 2.3306 6,56 0.9802 2,91 0.9642 23,08 1.0694 10,53 1.076 9,26 1.0292 13,39 0.7764 8,889 0.8204 9,39	CV 4.000 0.838 9.846 0.622 0000 225.923 0000 225.923 0000 195.6923 0000 242.5923 0000 243.6923 0000 243.6923 0000 98.4461 0000 98.4461 0000 863.4613 0000 863.4613 0000 863.4613 0000 863.4231	3 Units 0.000 0.000 Observation		
	Dataset Source Dataset Comments CER 1st Va CER 2nd Va Project Name 1 Project Name 2 Project Name 3 Project Name 5 Project Name 6 Project Name 8 Project Name 9 Project Name 10	Space CERs Faux Data Update ************************************	Observation Project Name 26 Project Name 27 Project Name 28 Project Name 29 Project Name 30 Project Name 31 Project Name 31 Project Name 33 Project Name 35 Project Name 36	753.000 408 94.154 19 RecT1Resid. EPST 1.6569 4,755 1.1752 3,711 2.3306 6,565 0.8902 2,91 1.0694 10,53 1.0694 10,53 1.0976 9,266 0.7764 8,88 0.8204 9,39 1.1495 12,27	0.00 0.03 0.03 0.03 0.03 0.03 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.02 0.00 0.132 0.02 0.00 0.132 0.00 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.132 0.0 0.0 0.0 0.0 0.1 0.0 0.0 0.1 0.0 0 0.0 0.0 0.0 0.0 0.0 0 0.0 0	3 Units 0.000 0.000 Observation		
	Outcaset Source Dataset Comments CER 1st Va CER 2nd Va Observation Project Name 1 Project Name 2 Project Name 3 Project Name 6 Project Name 7 Project Name 8 Project Name 9 Project Name 10 Project Name 11	Space CERs Faux Data Update F EPST1 Wt 2PSRecT1Residual EPST1 Wt 2000 0.5035 1.7410 0.864 0.4974 1.7411 0.864 0.9864 0.4677 4.273.0000 0.9865 0.4677 4.273.0000 0.9864 0.6067 0.723 0.9046 0.533.0000 0.92461 0.9046 0.533.0000 0.9346 0.9046 0.538.6923	Observation Project Name 26 Project Name 27 Project Name 29 Project Name 30 Project Name 31 Project Name 32 Project Name 34 Project Name 34 Project Name 35 Project Name 36 Project Name 37	753.000 408 94.154 19 SRecT1Reside EPST 1.1752 3,711 2.3306 6,666 0.8902 2,919 1.0694 10,533 1.0696 1,053 1.06976 9,269 1.0292 13,39 0.0776 8,888 0.8204 9,39 1.1495 12,277 0.813 15,444	Wt 0000 225-923 0000 225-923 0000 225-923 0000 225-923 0000 23-846-15 0000 243-6154 0000 632-6923 0000 632-6923 0000 63-4615 0000 863-4615 0000 863-39231 0000 844-3030 0000 844-3302	3 Units 0.000 0.000 0bservation		
	Dataset Source Dataset Comments CER 1st Va CER 2nd Va Observation Project Name 1 Project Name 4 Project Name 5 Project Name 6 Project Name 8 Project Name 10 Project Name 11 Project Name 12 Project Name 13	Space CERs Faux Data Update EPST1 Wt PSRecTiResidual EPST1 Wt 0.2701 1,719.0000 472.6923 0.5035 1,809.0000 259.4615 1.1339 31,849.0000 1,451.3077 1.7411 40.844.0000 1,096.138 1.4974 25,500.0000 1,293.0000 0.2656 1,324.0000 393.7692 0.9704 6,532.0000 1029.4615 0.7123 5,901.0000 620.3446 0.9084 6,538.0000 536.6923 0.6269 5,626.0000 673.3846	Observation Project Name 26 Project Name 27 Project Name 27 Project Name 29 Project Name 30 Project Name 30 Project Name 33 Project Name 34 Project Name 35 Project Name 36 Project Name 37 Project Name 38	753.000 408 94.154 19 SRecT1Reside EPST 1.6569 4,75 1.1752 3,71 2.3306 6,56 0.9642 23,00 1.0694 10,53 1.0976 9,26 1.0292 13,39 0.7764 8,88 0.8202 9,39 1.1495 12,27 0.8113 15,44 1.1454 11,44	CV 4.000 0.838 9.846 0.622 0000 203.6923 0000 203.6923 0000 203.6923 0000 203.6923 0000 203.6923 0000 203.6923 0000 23.6325 0000 1,132.6154 0000 984.4615 0000 863.4615 0000 863.46323 0000 864.5388 0000 804.5388 0000 754.8662 0000 754.8662	Units 0.000 0.000 0bservation		
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All examples use fictitious data

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Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop RUAWIN To Define Uncertainty

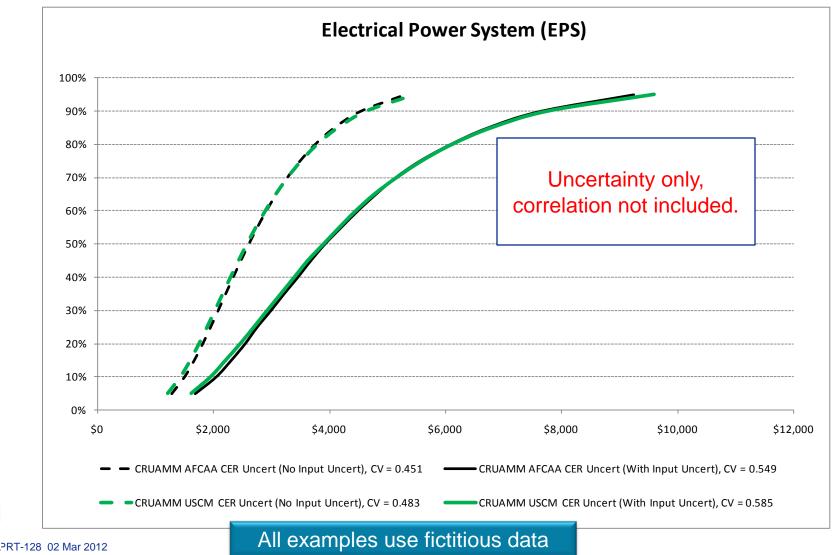
- Notional model, no correlation applied (functional only), not representative of a properly correlated result
- CRUAMM used to identify representative uncertainty for:
 - the Electrical Power Subsystem CER
 - the EPS CER independent variable (EPS Weight)

WBS Description	Unique ID	CER	Point Estimate	Forecast (PE * Uncert)	Distribution	Uncert ainty	Min	Max or Std Dev
Satellite			\$298,647	\$298,647				
Payload	RDPayload		\$168,462	\$168,462				
IR Sensor		356851 * PayloadDiam^0.562	\$168,462	\$168,462	Triangular	1	0.071	1.9640
Spacecraft Bus	RDSpBus		\$15,096	\$15,096				
Structure		157 * StrWgt^0.83	\$2,787	\$2,787	Triangular	1	0	1.9528
Thermal		394 * ThermWgt^0.635	\$1,331	\$1,331	Triongular		0	1.0528
Electrical Power System (EPS)		62.7 * EPSWgt	\$2,865	\$2,865				0.4512
Telemetry Tracking & Command (TT&C) and								
Command & Data Handling (C&DH)		545 * TTCWgt^0.761	\$2,344	\$2,344	Lognormal	1		0.2941
Attitude Determination & Control Sys		464 * ADCSWgt^0.867	\$5,769	\$5,769	Lognormal	1		0.4231
Int & Assy		989 + 0.215 * (RDPayload\$ + RDSpBus)	\$40,454	\$40,454	Normal	1		0.3544
Program Level Costs		1.963 * (RDPayload\$ + RDSpBus) ^0.841	\$52,451	\$52,451	Lognormal	1		0.4609
Ground Support Equip (GSE)		9.262 * (RDPayload\$ + RDSpBus) ^0.642	\$22,184	\$22,184	Triangular	1	0	3.1204

Input Variable	Unique ID	CER	Point Estimate	Forecast	Distribution	Uncert ainty	Min	Max or Std Dev
Payload Sensor diameter (m)	PayloadDiam		0.263	0.263	Lognormal	1		0.3000
Structure weight (kg)	StrWgt		32.000	32.000	Lognormal	1		0.5019
Thermal weight (kg)	ThermWgt		6.800	6.800	Triangular	1	0.261	2 7028
EPS weight (kg)	EPSWgt		45.700	45.700	Triangular	1	0.8742	2.8357
T&D/DH weight (kg)	TTCWgt		6.800	6.800	Normai			0.1893
ADCS weight (kg)	ADCSWgt		18.300	18.300	Normal	1		0.3103
ADCS weight (kg) Spacegraft + Payload Weight (kg)	SpPyWat		140.000	140.000	Lognormal	1		0.2307
					-			

Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Compare Spacecraft Bus EPS FireSat CER Uncertainty Derived from Fitting AFCAA or USCM CER Residuals

- Dotted lines are result using CER uncertainty only
- Solid lines are result using CER plus Input uncertainty

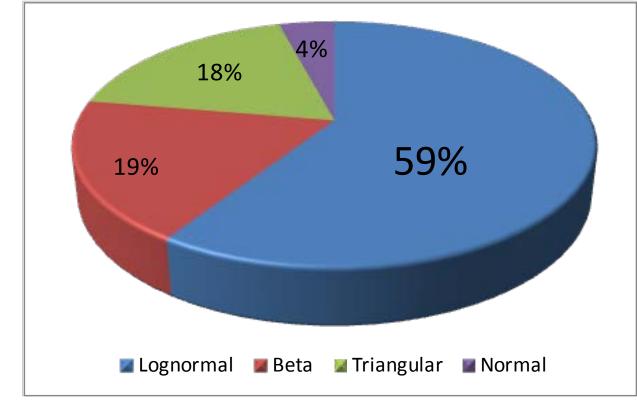


Over 1400 fitted distributions

- Lognormal Dominates
- Normal is Notably Rare

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"Regardless ... the uncertainty ... may be modeled with a lognormal distribution." Air Force Handbook for Cost Uncertainty and Risk Analysis July 2007



CRUAMM Final Report

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DISTRIBUTION LIMITATION: This document was prepared for and submitted to the <u>Air Force Cos</u> <u>Azency (Wilson Rosa)</u> under Contract No. <u>GS 35F 5115H FA701406-A-0015 0006</u> . Further distribut document is subject to any distribution restrictions set forth in the Contract and consent of the Government (Official.	5.1 CRUAMM Missiles Work Breakdown Structure
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Sample CRUAMM Public Domain Document Table (Listed by Commodity and WBS Element)

- Results for a single WBS element from a specific commodity
- Colors identify different orders of dispersion (Orange= 1st, Yellow= 2nd, Green= 3rd)
- Green typically has the lowest CV and are associated with CER residuals
- Orange typically has the highest CV and are associated with raw data

		I	Numerator	D	enominator	Sample	Fitted		My Point Estimate is the:	
Dataset	Count	Label	Range	Label	Range	cv	CV	Mean	Median	Mode
Metrics from CER Dataset										
NR CER, All	11	NR	2477.38 - 11424.26	Weight	86.96 - 621.13	0.271	0.259	Triangular (0.5206, 0.7584, 1.7210)	Triangular (0.5418, 0.7892, 1.7911)	Triangular (0.6865, 1.0000, 2.2694)
NR Cost per Lb, NR CER Datapoints, All	12	NR	2477.38 - 11424.26	Weight	86.96 - 621.13	0.463	0.445	Triangular (0.0709, 0.7294, 2.1997)	Triangular (0.0746, 0.7680, 2.3160)	Triangular (0.0972, 1.0000, 3.0157)
NR Typical Cost, NR CER Datapoints, All	12					0.486		Triangular (0.2965, 0.3942, 2.3093)	Triangular (0.3215, 0.4275, 2.5040)	Triangular (0.7521, 1.0000, 5.8576)
T1 CER, All	44	NR	0 - 20222.18	Weight	10.92 - 621.13	0.421	0.412	Triangular (0.1552, 0.7265, 2.1183)	Triangular (0.1635, 0.7651, 2.2308)	Triangular (0.2137, 1.0000, 2.9158)
T1 Cost per Lb, Commercial	10	T1	1839.7 - 13567.79	Weight	66.9 - 525.5	0.387	0.369	Triangular (0.3442, 0.6256, 2.0302)	Triangular (0.3649, 0.6631, 2.1520)	Triangular (0.5503, 1.0000, 3.2454)
T1 Cost per Lb, Government	34	T1	319.1 - 17861.82	Weight	10.92 - 621.13	0.673	0.708	Lognormal (1.0000, 0.7077)	Lognormal (1.2251, 0.8670)	Lognormal (1.8387, 1.3013)
T1 Typical Cost, Commercial	10					0.642	0.717	Lognormal (1.0000, 0.7168)	Lognormal (1.2304, 0.8819)	Lognormal (1.8625, 1.3350)
T1 Typical Cost, Government	34					1.065	1.011	Lognormal (1.0000, 1.0110)	Lognormal (1.4220, 1.4376)	Lognormal (2.8754, 2.9070)
Metrics from Entire Dataset										
NR to T1 Ratio, New Design	20	NR	184.22 - 20222.18	T1	319.1 - 17450.68	0.707	0.641	Triangular (0.0000, 0.1905, 2.8095)	Triangular (0.0000, 0.2136, 3.1495)	Triangular (0.0000, 1.0000, 14.7445)
NR to T1 Ratio, Modified Design	17	NR	138.54 - 7416.68	T1	765.54 - 17861.82	1.060	1.384	Lognormal (1.0000, 1.3844)	Lognormal (1.7078, 2.3642)	Lognormal (4.9806, 6.8950)
NR Cost per Lb, New Design	20	NR	184.22 - 20222.18	Weight	10.92 - 621.13	0.647	0.630	Triangular (0.0283, 0.1925, 2.7792)	Triangular (0.0316, 0.2155, 3.1103)	Triangular (0.1468, 1.0000, 14.4348)
NR Cost per Lb, Modified Design	17	NR	138.54 - 7416.68	Weight	33.35 - 596.76	0.849	0.928	Lognormal (1.0000, 0.9282)	Lognormal (1.3644, 1.2663)	Lognormal (2.5397, 2.3573)
T1 Cost per Lb, New Design	20	T1	319.1 - 17450.68	Weight	10.92 - 621.13	0.752	0.818	Lognormal (1.0000, 0.8182)	Lognormal (1.2921, 1.0572)	Lognormal (2.1571, 1.7650)
T1 Cost per Lb, Modified Design	17	T1	765.54 - 17861.82	Weight	33.35 - 596.76	0.464	0.452	Triangular (0.3180, 0.4049, 2.2772)	Triangular (0.3445, 0.4387, 2.4674)	Triangular (0.7853, 1.0000, 5.6243)
NR Cost per Lb, All	45	NR	1.24 - 20222.18	Weight	10.92 - 621.13	1.062	1.055	Beta (0.0003, 5.4745, 0.5514, 2.4678)	Beta (0.0004, 8.8015, 0.5514, 2.4678)	Beta (, , 0.5514, 2.4678)
T1 Cost per Lb, All	50	T1	34.88 - 17861.82	Weight	10.92 - 621.13	0.622	0.638	Lognormal (1.0000, 0.6376)	Lognormal (1.1860, 0.7562)	Lognormal (1.6681, 1.0636)
NR Typical Cost, New Design	20					0.985	0.995	Lognormal (1.0000, 0.9950)	Lognormal (1.4107, 1.4036)	Lognormal (2.8072, 2.7931)
NR Typical Cost, Modified Design	17					1.089	1.264	Lognormal (1.0000, 1.2639)	Lognormal (1.6117, 2.0370)	Lognormal (4.1863, 5.2911)
Recurring Typical Cost, New Design	20					1.003	0.937	Beta (0.0527, 3.5826, 0.4797, 1.3079)	Beta (0.0776, 5.2727, 0.4797, 1.3079)	Beta (, , 0.4797, 1.3079)
Recurring Typical Cost, Modified Design	17					1.023	1.213	Lognormal (1.0000, 1.2127)	Lognormal (1.5719, 1.9063)	Lognormal (3.8836, 4.7098)
T1 Typical Cost, Modified Design	20					1.121	1.085	Lognormal (1.0000, 1.0855)	Lognormal (1.4759, 1.6021)	Lognormal (3.2150, 3.4899)
T1 Typical Cost, Modified Design	17					1.002	1.183	Lognormal (1.0000, 1.1832)	Lognormal (1.5491, 1.8329)	Lognormal (3.7177, 4.3986)
NR Typical Cost, All	43					1.189	1.205	Beta (0.0005, 4.5342, 0.3160, 1.1173)	Beta (0.0011, 10.2913, 0.3160, 1.1173)	Beta (, , 0.3160, 1.1173)
Recurring Typical Cost, All	51					1.017	1.028	Beta (0.0029, 4.2807, 0.4890, 1.6092)	Beta (0.0047, 6.8080, 0.4890, 1.6092)	Beta (, , 0.4890, 1.6092)
T1 Typical Cost, All	51					1.080	1.104	Lognormal (1.0000, 1.1044)	Lognormal (1.4899, 1.6454)	Lognormal (3.3071, 3.6524)
Cost Driver Metrics from CER Dataset										
Weight, NR CER Datapoints, All	12					0.735	0.732	Beta (0.3092, 2.2084, 0.2024, 0.3540)	Beta (0.4636, 3.3113, 0.2024, 0.3540)	Beta (, , 0.2024, 0.3540)
Weight, T1 CER Datapoints, Commercial	10					0.375	0.358	Normal (1.0000, 0.3585)	Normal (1.0000, 0.3585)	Normal (1.0000, 0.3585)
Weight, T1 CER Datapoints, Government	34					0.780	0.692	Triangular (0.0000, 0.0429, 2.9571)	Triangular (0.0000, 0.0487, 3.3544)	Triangular (0.0000, 1.0000, 68.9146)
Cost Driver Metrics from Entire Dataset										
Weight, All	50					0.684	0.670	Triangular (0.0000, 0.1062, 2.8938)	Triangular (0.0000, 0.1199, 3.2677)	Triangular (0.0000, 1.0000, 27.2524)



Benefits of the CRUAMM Project

Tools to systematically store normalized data and perform fits

- Underlying math and assumptions are "open" for scrutiny and validation
- Every algorithm is supported by authoritative references
- Validated to generate results very close to other commercial tools
- Standard process to elicit consistent fit analysis across a variety of analysts
 - In particular, the analysis flow chart is a critical and compelling product from this effort
- Over 2000 fits provides a rich source of data to analyze for trends
 - One example was the dominance of lognormal across all fits
 - Should examine subsets of the data for trends (e.g., T1 or weight)

CRUAMM Provides a Source of Real Uncertainty Derived from Real Data

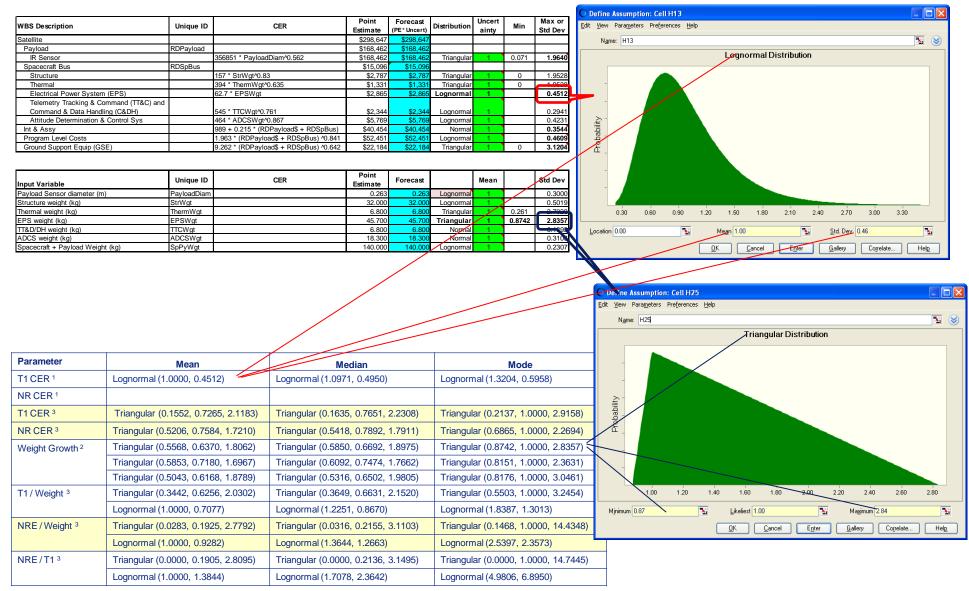


FireSat Spacecraft Bus Backup

PRT-128 02 Mar 2012

Approved for Public Release

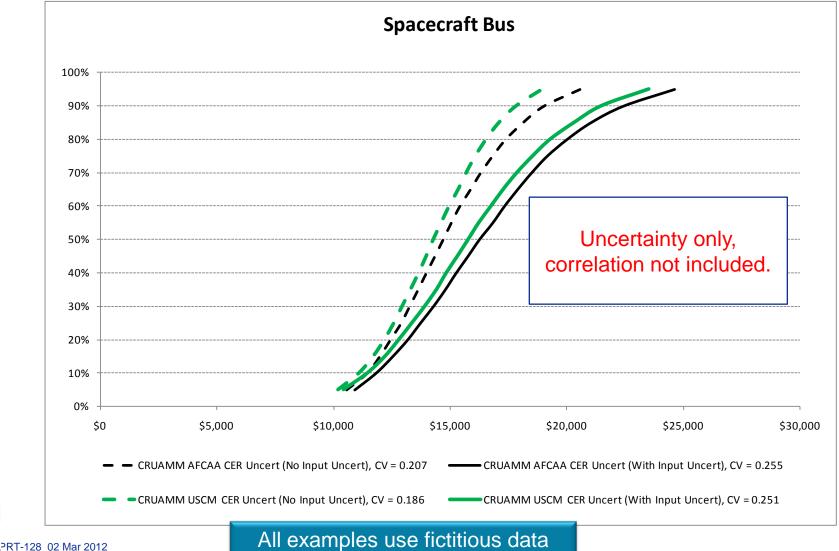
Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Detail of Assigning CRUAMM Unitized Results Into a Crystal Ball Model





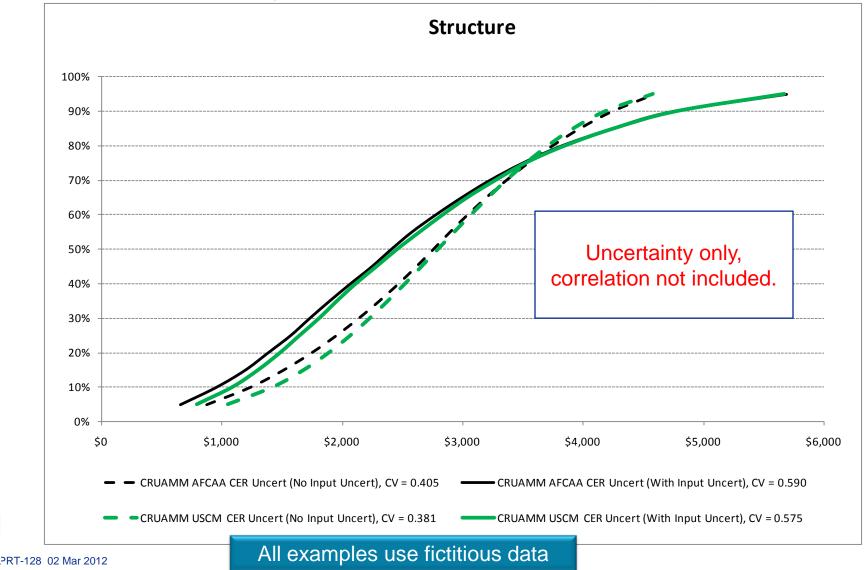
Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Compare Spacecraft Bus AFCAA and USCM Uncertainty Results

- Dotted lines are result using CER uncertainty only
- Solid lines are result using CER plus Input uncertainty



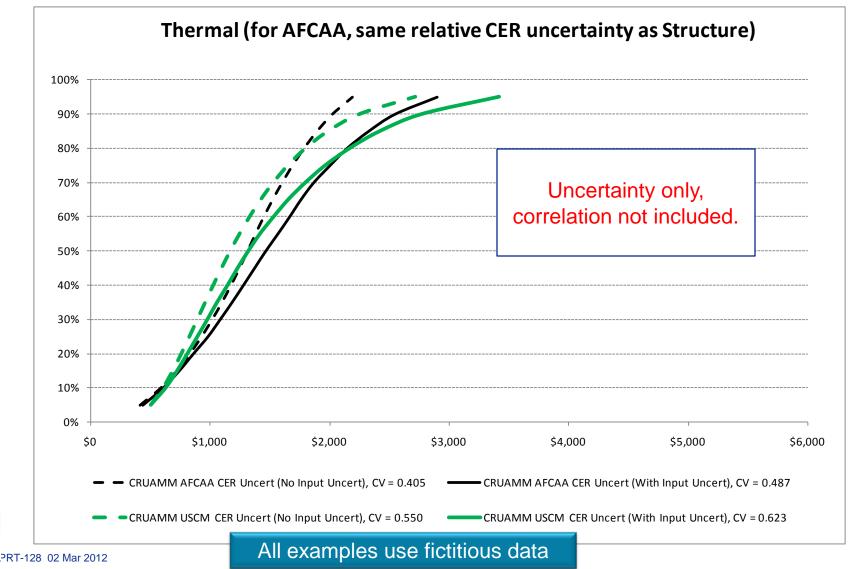
Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Compare Spacecraft Bus Structure AFCAA and USCM Uncertainty Results

- Dotted lines are result using CER uncertainty only
- Solid lines are result using CER plus the same Input uncertainty



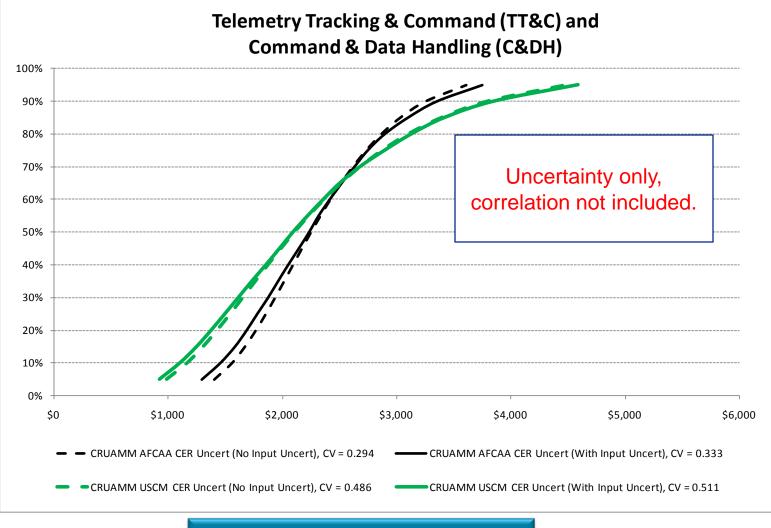
Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Compare Spacecraft Bus Thermal AFCAA and USCM Uncertainty Results

- Dotted lines are result using CER uncertainty only
- Solid lines are result using CER plus the same Input uncertainty



Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Compare Spacecraft Bus TT&C AFCAA and USCM Uncertainty Results

- Dotted lines are result using CER uncertainty only
- Solid lines are result using CER plus the same Input uncertainty

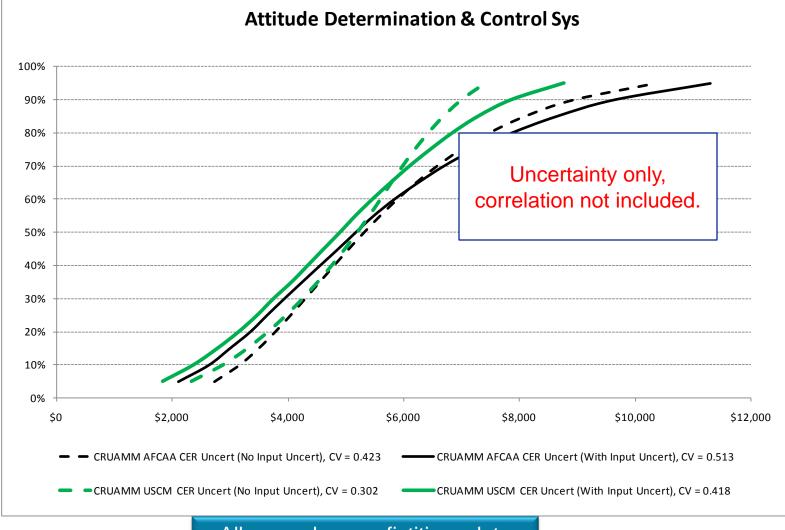


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All examples use fictitious data

Presented at the 2012 SCEA/ISPA Joint Annual Conference and Training Workshop - www.iceaaonline.com Compare Spacecraft Bus ADC AFCAA and USCM Uncertainty Results

- Dotted lines are result using CER uncertainty only
- Solid lines are result using CER plus the same Input uncertainty



All examples use fictitious data

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