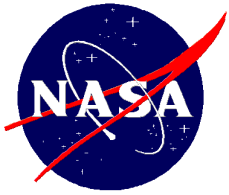


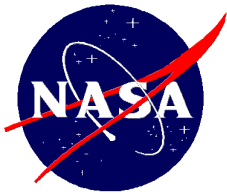
Risk Analysis in the NASA/Air Force Cost Model

Christian Smart, Ph.D., CCEA



NAFCOM Description

- NAFCOM is a **parametric** estimating tool for space hardware.
- Uses **cost estimating relationships (CERs)** which correlate historical costs to mission characteristics to predict new project costs
- It is based on **historical** NASA and Air Force **space projects**
- It is intended to be used in the **very early phases** of a development project.
- NAFCOM can be used at the **subsystem or component** levels and estimates **development and production** costs.
- NAFCOM is applicable to various types of missions (**manned spacecraft, unmanned spacecraft, and launch vehicles**).
- There are two versions of the model: a **government version** that is restricted and a **contractor releasable version**.



NAFCOM Evolution

- Since 1990, nine versions of NAFCOM have been developed and distributed across NASA and other government agencies.



NASCOM Books

1990

- NASCOM database in hardcopy only
- Estimators hand-entered data into spreadsheets
- Database contained 65 data points



NASCOM Automated DB

1992

- Allowed online searches and copying of data
- Cost estimates developed in spreadsheets with CERs created by individuals
- Database contained 70 data points



NASCOM Ver. 3.0 NASCOM Ver. 4.0

1994

- Fully functional cost model with user defined WBS and data access
- CERs built automatically within NASCOM using "1st Pound" method
- Database contained 91 data points



NAFCOM96

1996

- Combined NASA and Air Force data
- Enhanced search and filtering of data
- Standardized WBS elements created
- Database contained 102 data points



NAFCOM99

1998

- First non-weight based CERs for five subsystems (Complexity Generators)
- Government and contractor versions distributed
- Database contained 114 data points



NAFCOM Versions 2002 & 2004

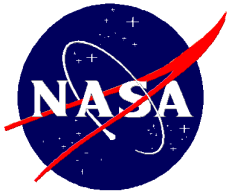
2002

- Total re-write of all NAFCOM program code
- Complexity Generators for all subsystems
- Major user interface improvements
- Database contains 122 data points

2004

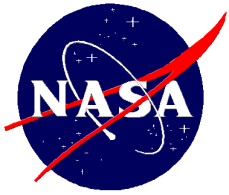
- Cost Risk Analysis Module
- CER Improvements
- SOCM
- Component level Complexity Generator





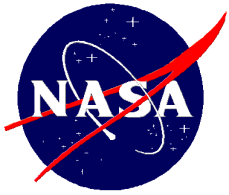
Rationale

- Previously the NASA/Air Force Cost Model (NAFCOM) provided a point estimate as opposed to a probabilistic range estimate requiring external third party risk tools
- The addition of a probabilistic cost risk analysis module in NAFCOM v2004:
 - Integrates a comprehensive risk capability into NAFCOM including technical risk, cost equation uncertainty, and correlation
 - Provides a seamless and simple interface for accomplishing complete risk analysis of NAFCOM estimates



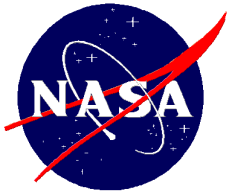
Development

- Experts in the risk field, including representatives from MCR, Aerospace, NASA, IPAO, and Mitre participated in the methodology development.
- Dr. Steve Book and Erik Burgess of MCR worked directly with SAIC and NASA to ensure that the best possible approaches were considered for integration into NAFCOM and to consult on the methodology implementation.



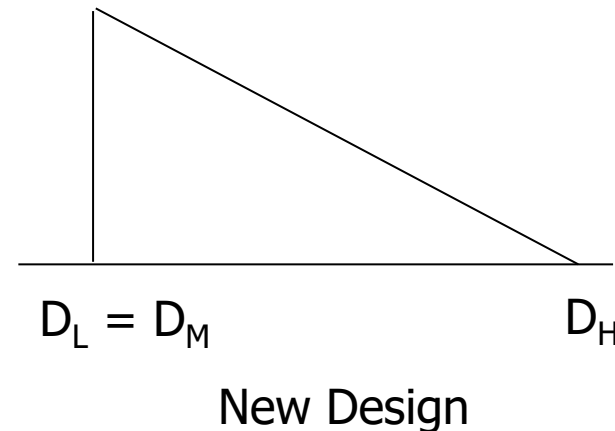
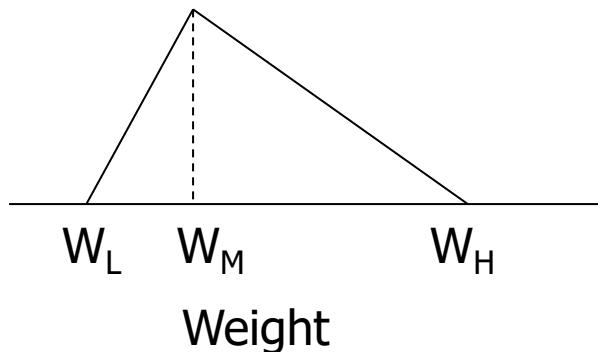
Model Selection

- Choice between Analytic approach (similar to FRISK) or Monte Carlo-based sampling approach
- We chose an analytic method because we wanted a method that:
 - Is computationally as simple as possible while still providing accurate estimates
 - Calculates the correct top-level means and standard deviations
 - Is faster than Monte Carlo
 - Allows full access to the correlation matrix
 - User can set individual inter- and intra-subsystem correlations to any desired value in the range $(-1,1)$, unlike PRICE, SEER, and others



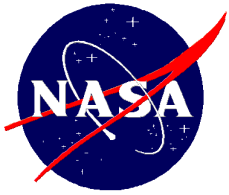
Technical Risk – Step 1

- For each WBS element (D&D and flight unit cost):
 - For each CER input*, define a triangular distribution using minimum value, most likely value, and maximum value



Note: NAFCOM multivariate CERs estimate cost at the subsystem or component level and have the general form:

$$\text{Cost} = C * \text{Weight}^V * \text{New Design}^W * \text{Technical}^X * \text{Management}^Y * \text{Class}^Z$$



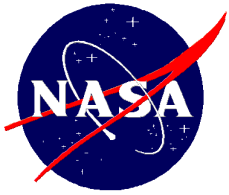
Technical Risk – Step 2

- Use appropriate CER to estimate costs for three cases: all complexity generators set to minimum (optimistic) values, all set to most likely, and all set to maximum (pessimistic) values

$$\textit{Low Cost} = a \cdot W_L^{b_1} \cdot D_L^{b_2}$$

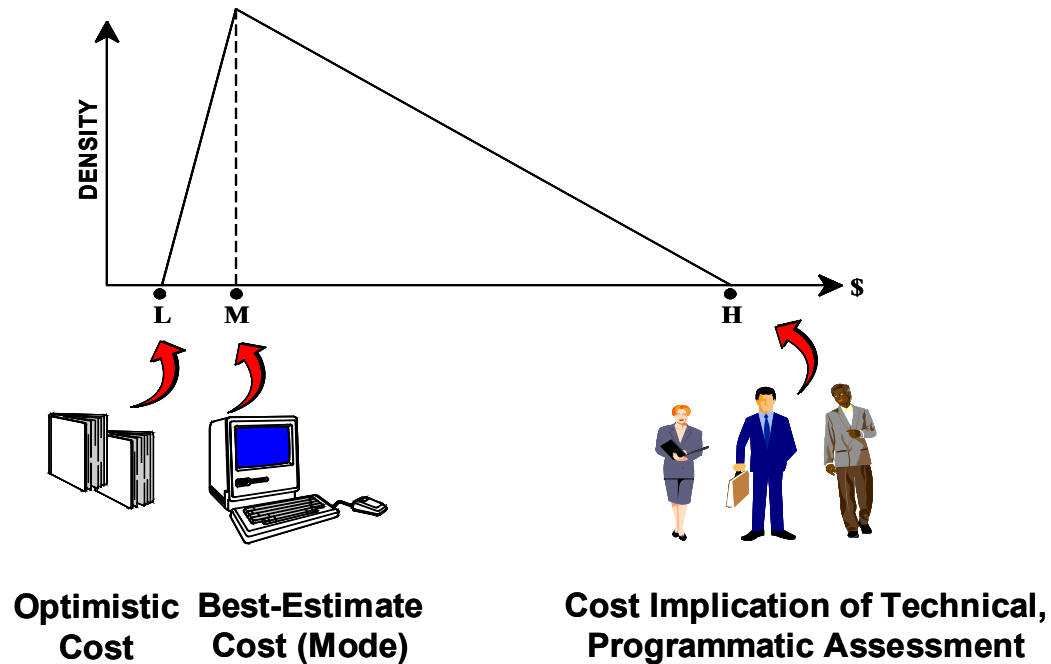
$$\textit{Most Likely Cost} = a \cdot W_M^{b_1} \cdot D_M^{b_2}$$

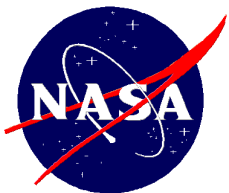
$$\textit{High Cost} = a \cdot W_H^{b_1} \cdot D_H^{b_2}$$



Technical Risk – Step 3

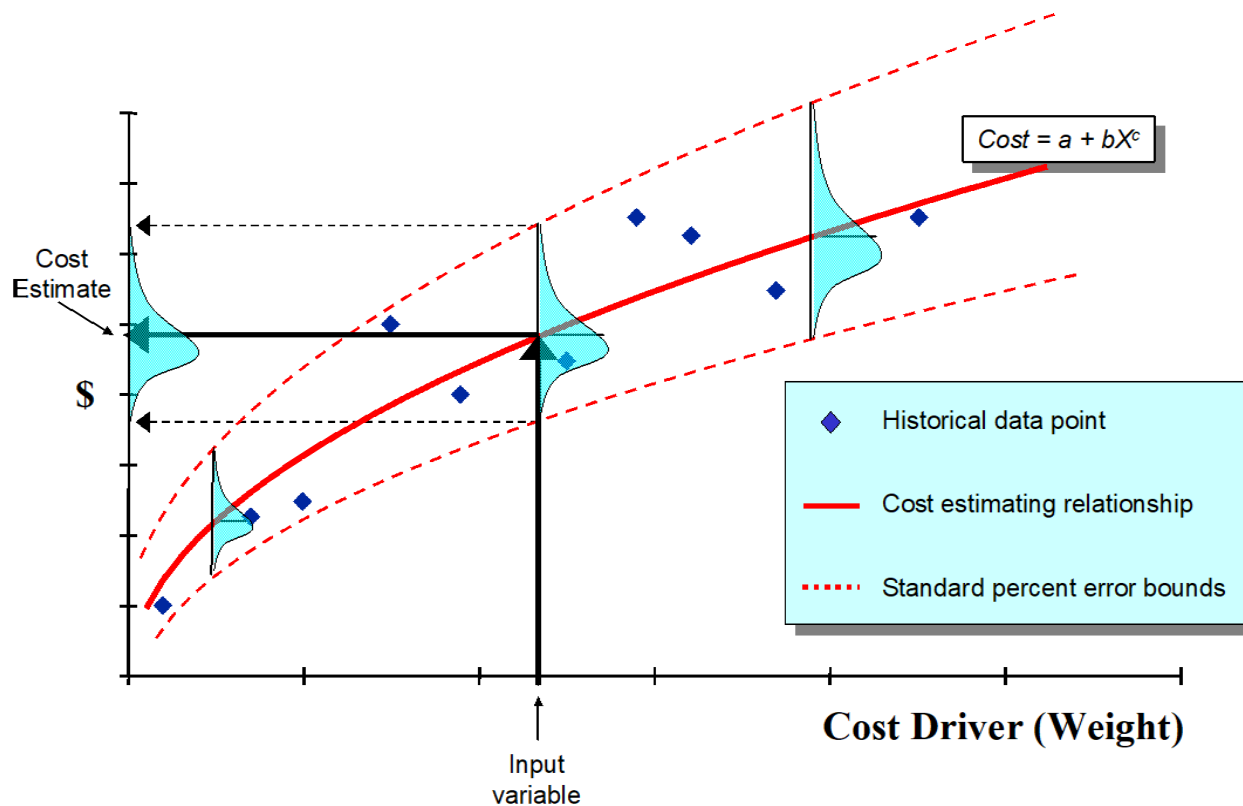
- Define a triangular distribution about each estimate with the minimum, most likely, and maximum values

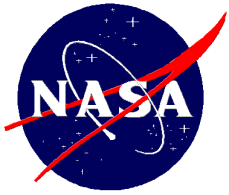




CER Risk

- NAFCOM CER errors are lognormally distributed:





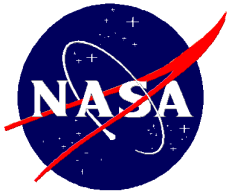
CER Risk

- NAFCOM CERs follow a multiplicative error model:

$$Y = aX^b \varepsilon$$

where ε represents the error between the estimated cost $\hat{Y} = aX^b$ and the actual cost Y

- The error distribution of the CER is lognormal with median = 1 and standard deviation equal to the standard error of the CER

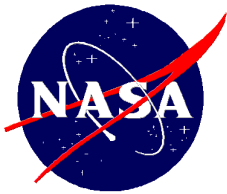


CER Risk

- For each WBS element (D&D and flight unit cost):
 - Define a lognormal distribution using the median and standard error for the CERs
 - Fit a lognormal distribution to the first two moments (mean, standard deviation) of the technical risk triangular distribution defined on the previous page
 - Multiply the lognormal distribution of the CER error and the lognormal distribution defined in the preceding step – this product is a lognormal distribution
 - Calculate the DDT&E risk distribution mean and variance for each hardware element using the formula:

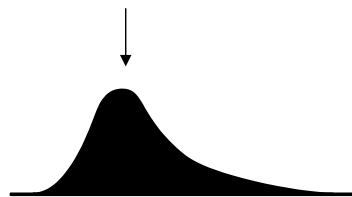
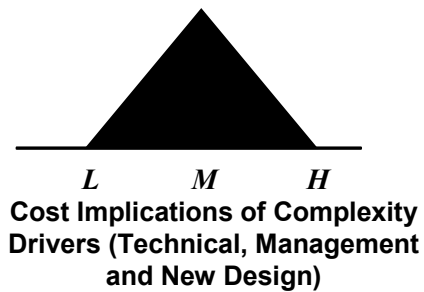
$$\mu = \mu_{D\&D} + (\%Flt Unit) * \mu_{Flt Unit}$$

$$\sigma^2 = \sigma_{D\&D}^2 + (\%Flt Unit)^2 \sigma_{Flt Unit}^2 + 0.2 * (\%Flt Unit) * \sigma_{D\&D} \sigma_{Flt Unit}$$



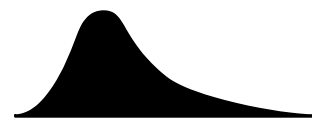
Combining CER and Technical Risk

At Estimating Level



P_1, Q_1

X



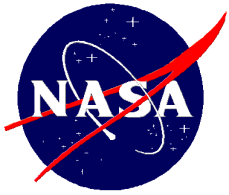
$P_2 = 0, Q_2 = \text{S.E.}$

Distribution of Estimating Error



$$\mu = e^{P_1 + 0.5(Q_1^2 + Q_2^2)}$$

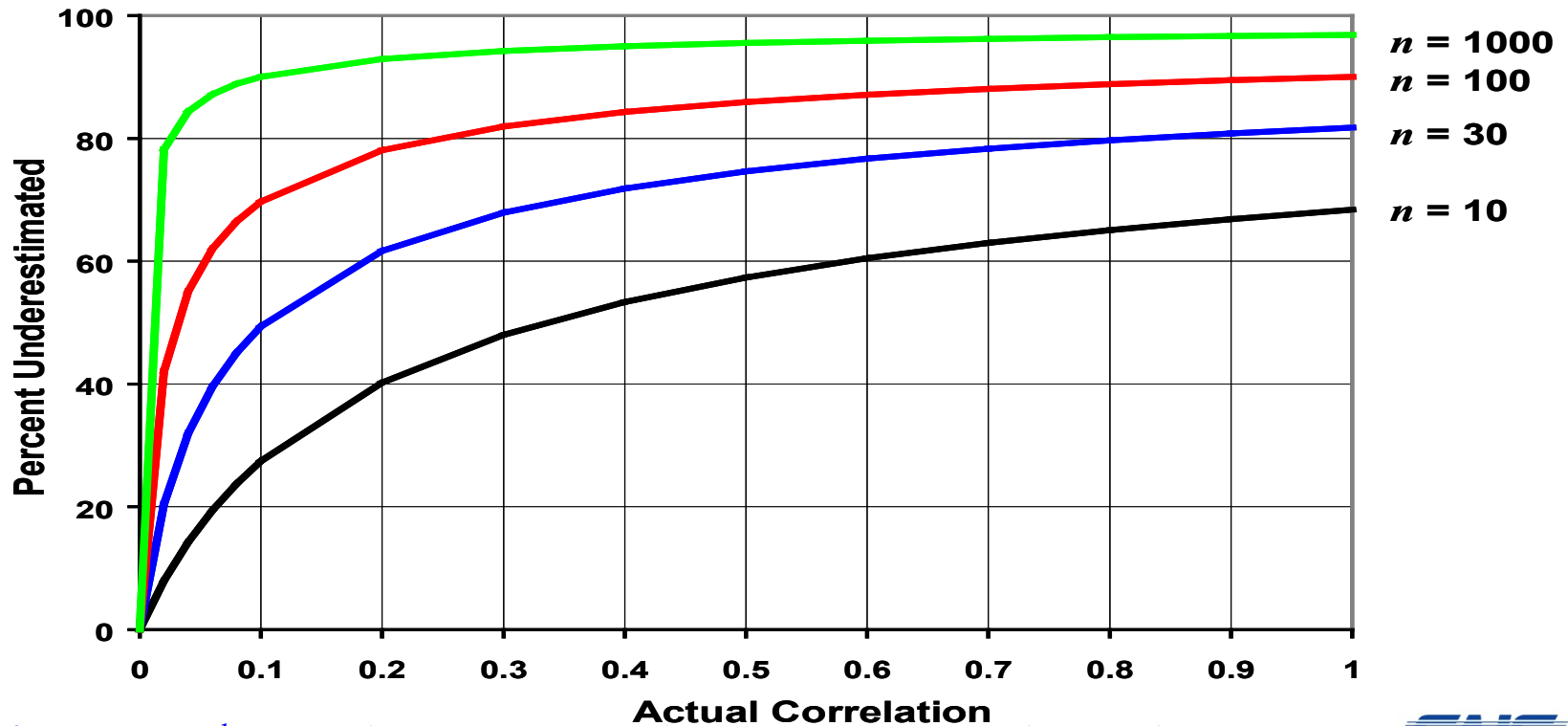
$$\sigma^2 = e^{2P_1 + Q_1^2 + Q_2^2} (e^{Q_1^2 + Q_2^2} - 1)$$



Correlation

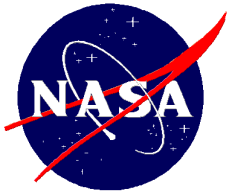
Maximum Possible Underestimation of Total-Cost Sigma

Percent that Total-Cost Sigma is underestimated when correlation assumed to be 0 instead of ρ given n WBS elements



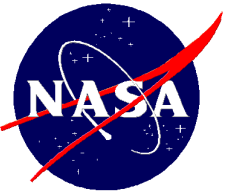
Reference: 32nd Annual DOD Cost Analysis Symposium Advanced Training Session, "Why Correlation Matters in Cost Estimating," Stephen A. Book



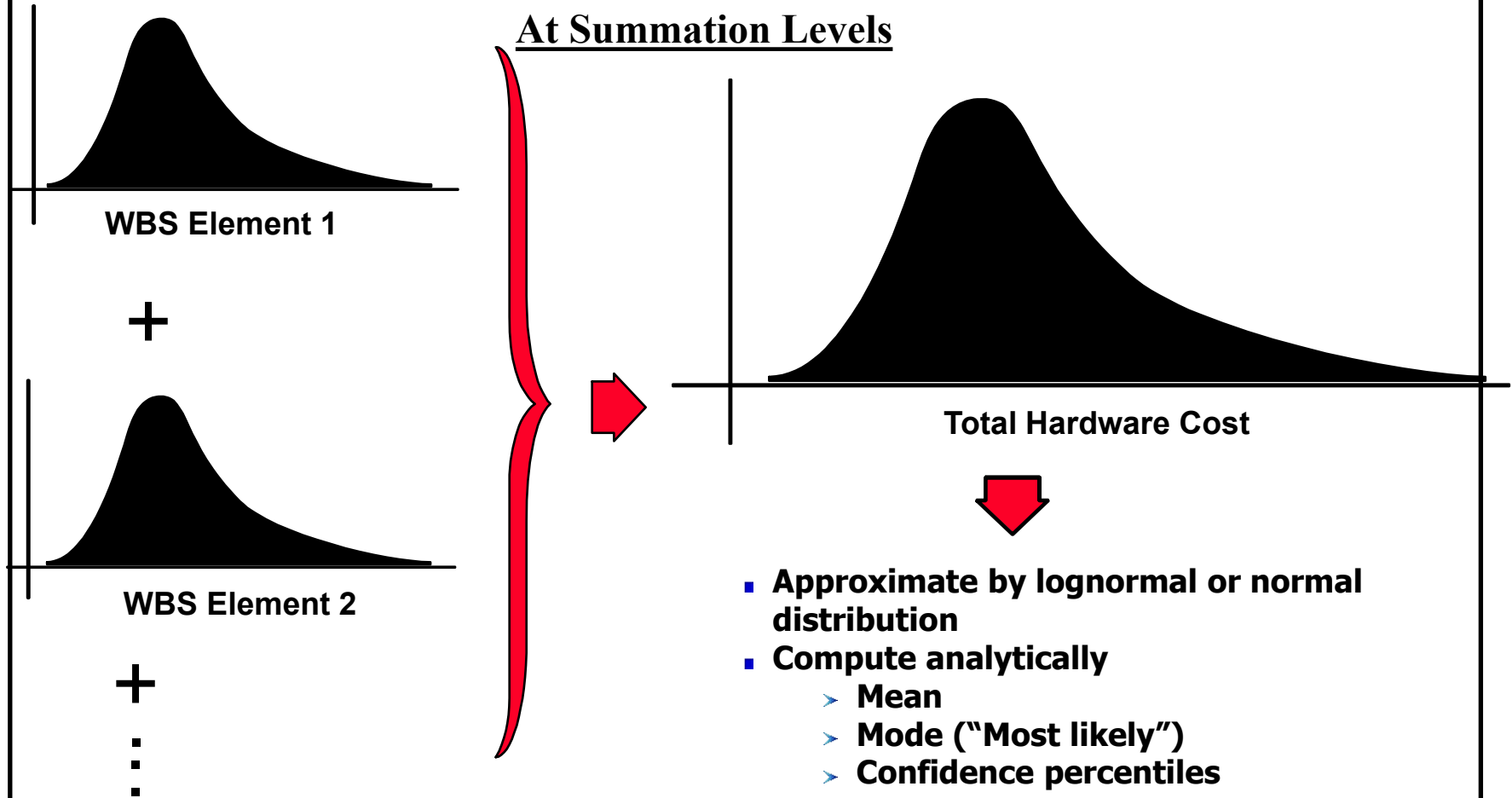


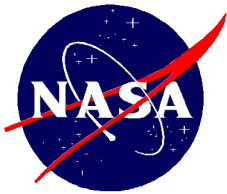
Correlation in NAFCOM

- Set default values of the correlation matrix:
 - 0.2 for inter-subsystem and inter-system correlations
 - 0.5 for intra-subsystem correlations
- The user can set any of the correlations to any value between -1 and 1 he/she desires



Summing Means and Variances





Summing Means and Variances

Separately for DDT&E and flight unit cost, sum the mean and variance for all WBS items taking correlations (ρ_{ij}) into account

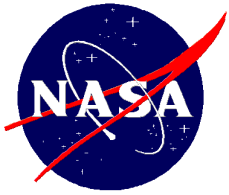
X_1, X_2, \dots, X_n are costs of WBS elements
(considered as random variables)

$$\text{Total (Hardware) Cost} = \sum_{k=1}^n X_k = X_1 + X_2 + \dots + X_n$$

$$\text{Mean of Total (Hardware) Cost} = E\left(\sum_{k=1}^n X_k\right) = \sum_{k=1}^n E(X_k) = \sum_{k=1}^n \mu_k$$

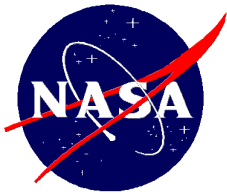
Variance of Total (Hardware) Cost =

$$\text{Var}\left(\sum_{k=1}^n X_k\right) = \sum_{k=1}^n \sigma_k^2 + 2 \sum_{j=2}^n \sum_{i=1}^{j-1} \rho_{ij} \sigma_i \sigma_j$$



Total Cost Distributions

- Fit a lognormal or normal distribution (chosen by the user) to the top level mean and variance
- Add the means and variances (including correlation) for the DDT&E and flight unit distributions to obtain a total cost distribution
- Outputs are the mean, median, mode, standard deviation, 5th, 10th, 15th, ..., 95th percentiles for DDT&E, flight unit, and total cost distributions



Model Interface

- Users can elect to run NAFCOM in Risk On or Risk Off mode via toolbar

File View WBS Help About Insert Subsystem

Elements

- Two-Stage Vehicle
 - Stage 1
 - Stage 1 Subsystems
 - Structures & Mechanisms
 - Vehicle Structures & Mechanisms
 - Tank Structures & Mechanisms
 - Thermal Control
 - Environment/Active Thermal Control
 - Induced Thermal Protection
 - Tank Thermal Control
 - Main Propulsion System (less engines)
 - Electrical Power and Distribution
 - Command, Control & Data Handling
 - Stage 1 System Integration
 - Integration, Assembly and Checkout (IACO)
 - System Test Operations (STO)
 - Ground Support Equipment (GSE)
 - Tooling
 - M/E GSE
 - System Engineering & Integration (SE&I)
 - Business Management (BM)

DataView

Mission	Sel...	WBS Item	Weight	Launch Year
Shuttle Orbiter	<input checked="" type="checkbox"/>	Thermal Control Subsystem	24900.0	1981
Apollo CSM	<input type="checkbox"/>	Thermal Control Subsystem	1553.3	1968
Apollo LM	<input type="checkbox"/>	Thermal Control Subsystem	142.1	1968
Gemini	<input type="checkbox"/>	Thermal Control Subsystem	114.0	1965
Lunar Rover	<input type="checkbox"/>	Thermal Control Subsystem	20.6	1971
Skylab Airlock	<input type="checkbox"/>	Thermal Control Subsystem	532.0	1973
Skylab OWS	<input type="checkbox"/>	Thermal Control Subsystem	3345.0	1973
Spacelab	<input type="checkbox"/>	Thermal Control Subsystem	985.0	1983

Weight

Most Likely: 1300.0 lbs, DB Avg: 24900.0 lbs

569.7 kgs, 11294.6 kgs

Thruputs (Enter costs as FY values in FY 2004 in Millions)

D&D, STH, Flight Unit

Design Life: 240.0 Months, 240 Months

Manufacturing Methods: (3) Mod. Mfg Techniques, 3

Engineering Management: (4) Significant Req. Changes, 5

New Design: (8) New Design, 8

Funding Availability: (3) Funding is Constrained - Delay, 3

Test Approach: (3) Maximum Testing, Qualification, 3

Integration Complexity: (3) Extensive Major Interfaces Inv, 3

Pre-Development Study: (2) One Study Contract - Between, 2

External Cryogenic Storage Tank: (2) No, 2

Louvers / Heaters: (1) No Louvers / No Heaters, 1

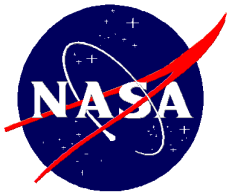
Special Materials / Special Configuration: (1) Yes, 1

45.6 D&D Cost, 2.5 STH Cost, 48.0 DDT&E Cost, 1.9 Flight Unit Cost, 1.9 Production Cost, 49.9 Total Cost

Major Inputs: Other Inputs, CER Methodology, Funding Profile

Total DDTE 8,023.6 Total Flight Unit 1,400.6 Total Production 1,400.6 Vehicle Total 9,424.4 Total Weight (lbs) 224,900.0 FY2004





Model Interface

- NAFCOM's Risk On Mode provides capability to define triangular distributions for all cost driver inputs and for cost thruputs
- These distributions are combined with CER errors to produce distributions for nonrecurring and recurring cost for each subsystem

File View WBS Help About Insert Subsystem

Elements

- Two-Stage Vehicle
 - Stage 1
 - Stage 1 Subsystems
 - Structures & Mechanisms
 - Vehicle Structures & Mechanisms
 - Tank Structures & Mechanisms
 - Thermal Control
 - Environment/Active Thermal Control
 - Induced Thermal Protection
 - Tank Thermal Control
 - Main Propulsion System (less engines)
 - Electrical Power and Distribution
 - Command, Control & Data Handling
 - Stage 1 System Integration
 - Integration, Assembly and Checkout (IACO)
 - System Test Operations (STO)
 - Ground Support Equipment (GSE)
 - Tooling
 - ME GSE
 - System Engineering & Integration (SE&I)
 - System Management (SM)

Data View

Mission	Sel...	WBS Item
Shuttle Orbiter (includes Landing Gear)	<input checked="" type="checkbox"/>	Structural/Mechanical Group
Apollo LM	<input type="checkbox"/>	Structural/Mechanical Group
Apollo CSM	<input type="checkbox"/>	Structural/Mechanical Group
Gemini	<input type="checkbox"/>	Structural/Mechanical Group
Lunar Rover	<input type="checkbox"/>	Structural/Mechanical Group
Skylab Airlock	<input type="checkbox"/>	Structural/Mechanical Group
Skylab OWS	<input type="checkbox"/>	Structural/Mechanical Group
Spacelab	<input type="checkbox"/>	Structural/Mechanical Group

Copy 8 Records Returned

Total DDTE 8,532.0 Total Flight Unit 1,430.3 Total Production 1,430.3 Vehicle Total 9,962.3 Total Weight (lbs) 224,900.0 FY2004

Weight

	Low	Most Likely	High	DB Avg	
<input checked="" type="radio"/>	20500.0	20500.0	20500.0	82505.0	lbs
<input type="radio"/>	9298.8	9298.8	9298.8	37424.3	kgs

Thruputs (Enter costs as FY values in FY 2004\$ in millions)

	Low	Most Likely	High	DB Avg
<input type="checkbox"/> D&D				
<input type="checkbox"/> STH				
<input type="checkbox"/> Flight Unit				
Structural Efficiency	54.0	54.0	54.0	54

Manufacturing Methods

	Low	Most Likely	High	DB Avg
(3) Mod. Mfg Techniques	(3) Mod. Mfg Techniques	(3) Mod. Mfg Techniques	(3) Mod. Mfg Techniques	3
(4) Significant Req. Changes	(4) Significant Req. Changes	(4) Significant Req. Changes	(4) Significant Req. Changes	5
(8) New Design	(8) New Design	(8) New Design	(8) New Design	8

Funding Availability

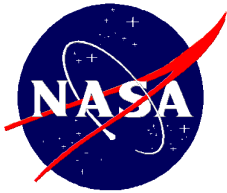
	Low	Most Likely	High	DB Avg
(3) Funding is Constrained - Delay	(3) Funding is Constrained - Delay	(3) Funding is Constrained - Delay	(3) Funding is Constrained - Delay	3
(3) Maximum Testing, Qualificatio	(3) Maximum Testing, Qualificatio	(3) Maximum Testing, Qualificatio	(3) Maximum Testing, Qualificatio	3
(3) Extensive Major Interfaces Inv	(3) Extensive Major Interfaces Inv	(3) Extensive Major Interfaces Inv	(3) Extensive Major Interfaces Inv	3
(2) One Study Contract - Between	(2) One Study Contract - Between	(2) One Study Contract - Between	(2) One Study Contract - Between	2
Deployed	(3) Multiple Deployed Structures			3
Large Inert Structure?	(2) No			2

303.0 55.4 358.4 42.6 42.6 401.0

D&D Cost STH Cost DDT&E Cost Flight Unit Cost Production Cost Total Cost

Major Inputs Other Inputs CER Methodology Funding Profile

Help



Model Interface

- The final result is uncertainty distributions for DDT&E, Flight Unit, Production and Total Cost.
- Result data includes summary statistics, probability densities, and cumulative distributions for each major estimating element (i.e. stage, bus)

The screenshot displays the Model Interface software. The main window shows a hierarchical tree of elements for a Two-Stage Vehicle. A 'Cost Report' window is open, showing a normal distribution graph for 'Total Costs - Normal Distribution'. The graph has a red shaded area under the curve, with the x-axis ranging from 2,800 to 2,840. Below the graph are radio buttons for 'Bell Curve' (selected) and 'Cumulative Curve', and a 'Cost Graphs' button.

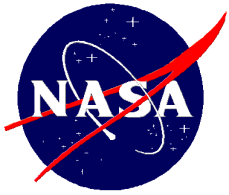
At the top right of the main window, there is a 'Total Subsystem Weight' field with a value of 77,300.0 lbs and a 'Thruput Weights to Zero' button.

A 'Statistics' table is displayed, showing the following data:

Statistics	DDT&E	Flight Unit	Production	Total Costs
Mean	2,394.5	426.0	426.0	2,820.5
Median	2,394.5	426.0	426.0	2,820.5
Mode	2,394.5	426.0	426.0	2,820.5
Standard Deviation	4.0	4.0	4.0	6.4
5th Percentile	2,388.0	419.4	419.4	2,809.9
10th Percentile	2,389.4	420.9	420.9	2,812.3
20th Percentile	2,391.1	422.6	422.6	2,815.1
30th Percentile	2,392.4	423.9	423.9	2,817.1
40th Percentile	2,393.5	425.0	425.0	2,818.8
60th Percentile	2,395.5	427.0	427.0	2,822.1
70th Percentile	2,396.6	428.1	428.1	2,823.8
80th Percentile	2,397.8	429.3	429.3	2,825.8

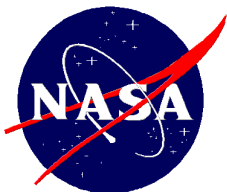
Below the table, there is an 'Export Statistics' button and four input fields with values: 2,394.5 (DDT&E Cost), 426.0 (Flight Unit Cost), 426.0 (Production Cost), and 2,820.5 (Total Cost).

The status bar at the bottom of the window shows: Total DDT&E 8,532.0, Total Flight Unit 1,430.3, Total Production 1,430.3, Vehicle Total 9,962.3, Total Weight (lbs) 224,900.0, FY2004.

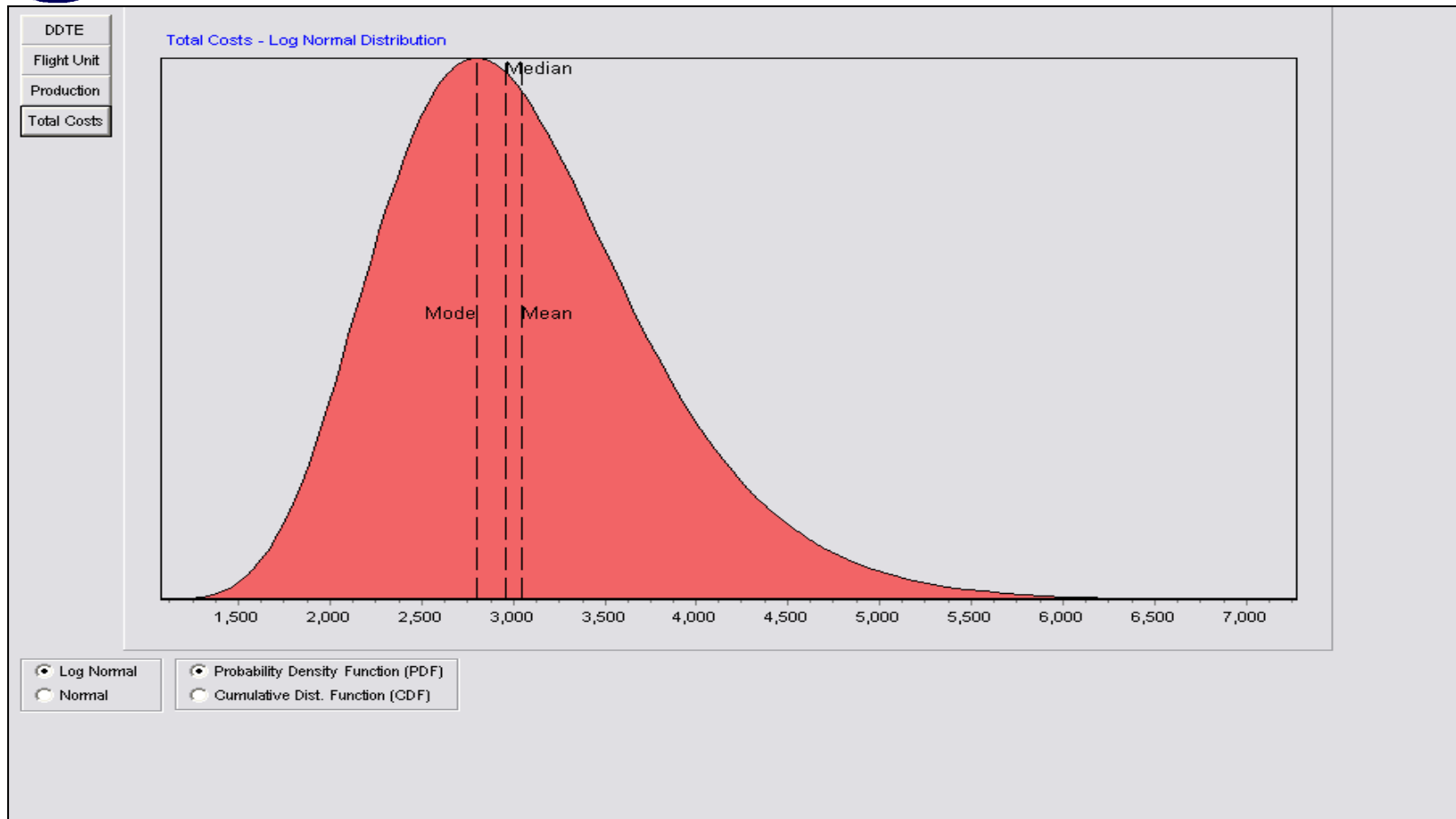


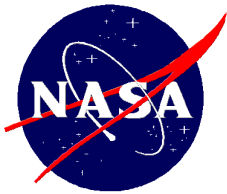
Risk Results Statistics – Example

Risk Results - Vehicle (2004 \$ Millions)	DDTE	FU	Prod	Total
Mean	2374.2	465.2	673.8	3048.0
Median	2293.0	418.6	638.1	2962.2
Mode	2138.9	339.0	572.3	2797.8
Standard Deviation	637.4	225.5	228.5	738.8
5th Percentile	1485.8	196.6	370.9	1999.5
10th Percentile	1635.2	232.3	418.1	2180.8
20th Percentile	1836.4	284.4	483.4	2422.6
30th Percentile	1996.8	329.0	536.7	2613.3
40th Percentile	2144.8	372.6	586.9	2788.2
60th Percentile	2451.5	470.3	693.7	3147.1
70th Percentile	2633.3	532.7	758.6	3357.6
80th Percentile	2863.1	616.3	842.3	3622.1
90th Percentile	3215.5	754.3	973.8	4023.5
95th Percentile	3538.9	891.3	1097.8	4388.4

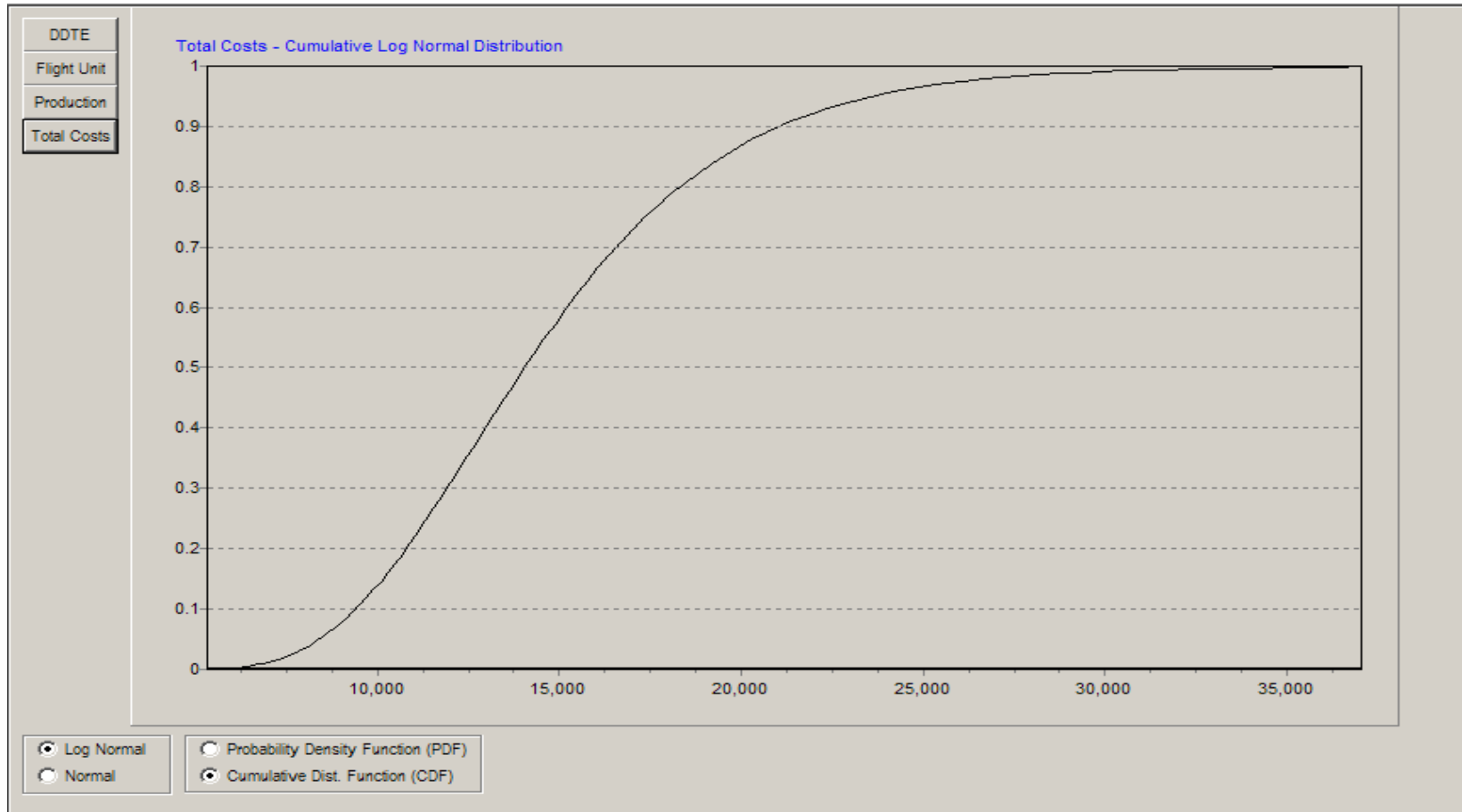


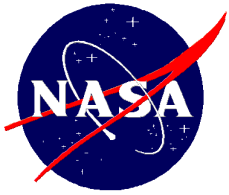
Risk Results PDF – Example





Risk Results CDF – Example





Saving Risk Output - Statistics

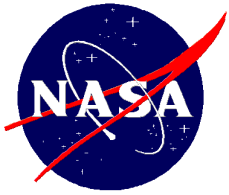
Statistics	DDT&E	Flight Unit	Production	Total Costs
	2,374.2	465.2	673.8	3,048.0
Median	2,293.0	418.6	638.1	2,962.2
Mode	2,138.9	339.0	572.3	2,797.8
Standard Deviation	637.4	225.5	228.5	738.8
5th Percentile	1,485.8	196.6	370.9	1,999.5
10th Percentile	1,635.2	232.3	418.1	2,180.8
20th Percentile	1,836.4	284.4	483.4	2,422.6
30th Percentile	1,996.8	329.0	536.7	2,613.3
40th Percentile	2,144.8	372.6	586.9	2,788.2
60th Percentile	2,451.5	470.3	693.7	3,147.1
70th Percentile	2,633.3	532.7	758.6	3,357.6
80th Percentile	2,863.1	616.3	842.3	3,622.1

Distribution Type
 Log Normal
 Normal

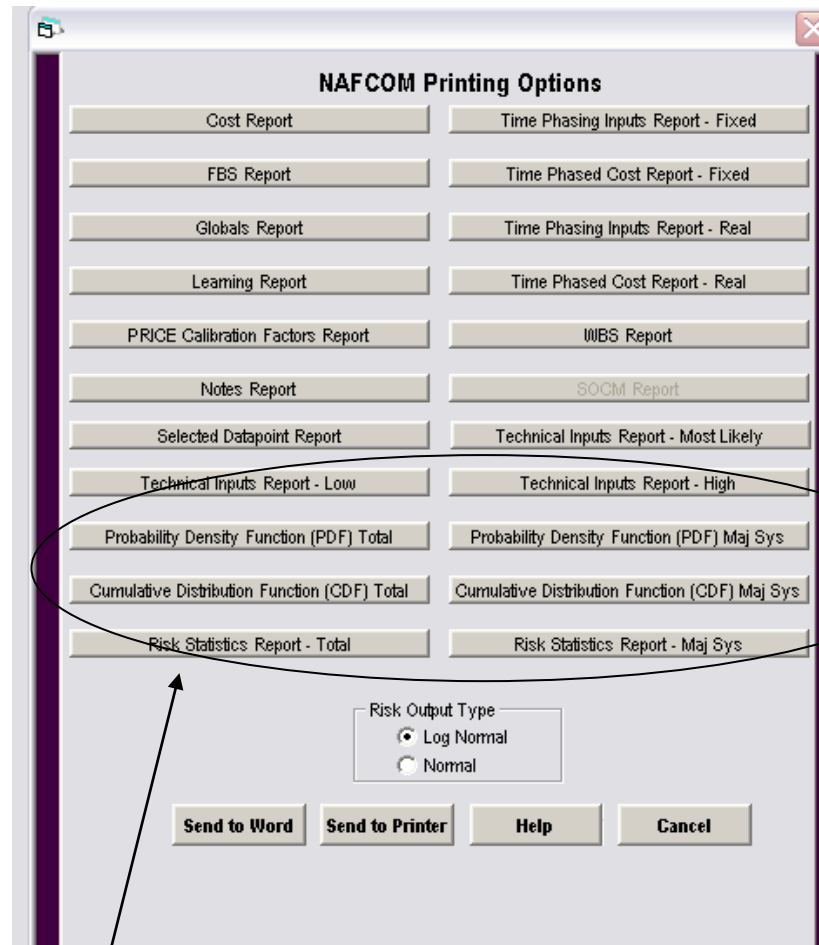
Export Statistics

2,374.2 465.2 673.8 3,048.0
DDT&E Cost Flight Unit Cost Production Cost Total Cost

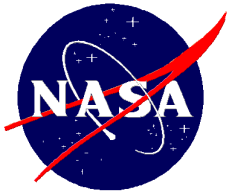
Click "Export Statistics"
To save to Excel



Generating Risk Reports



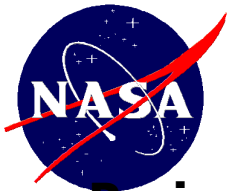
From the File Menu, Choose Printing Options, then one of the Risk Report Options



Risk Allocation to WBS Elements

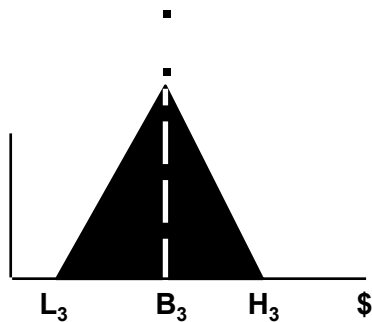
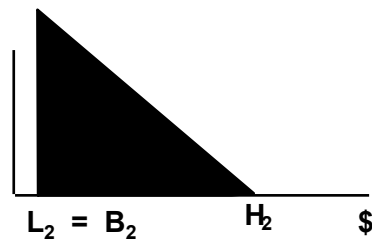
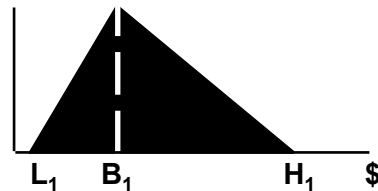
- NAFCOM also provides the ability to determine which elements have the most cost risk associated with them and allocating risk dollars back to those WBS elements.
 - User may select a percentile (70th, 80th or 90th) to be used to determine the amount of risk dollars to be allocated to the WBS elements

Reference: NSA Cost Performance Office Presentation, "Allocating 'Risk Dollars' Back to Individual Cost Elements," by Stephen A. Book, 2003

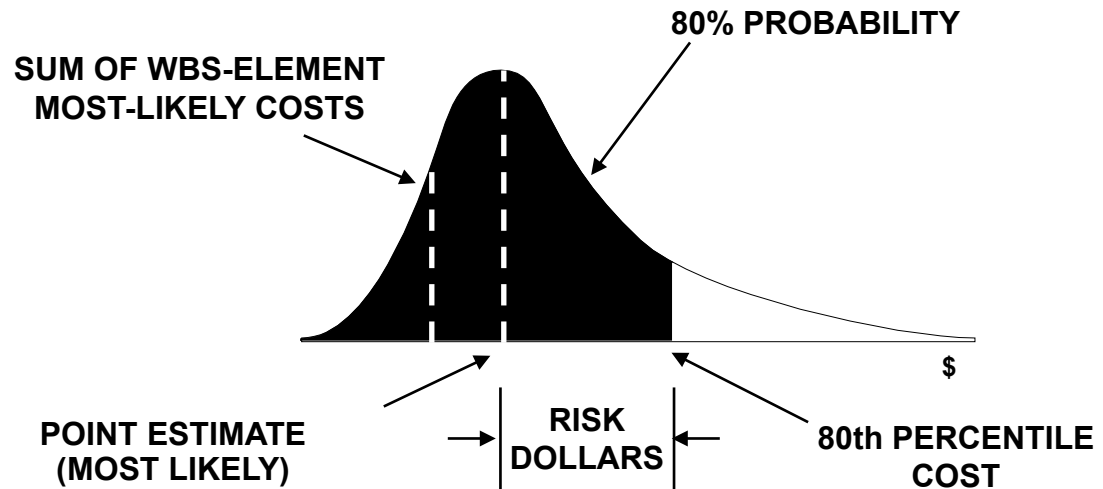


Risk Dollar Computation Procedure

Project-Element Triangular Distributions



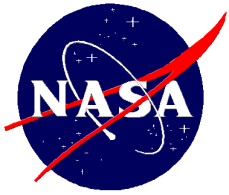
Merge Element Cost Distributions Into Total-Cost Distribution



Note: Addition of risk dollars increases confidence that total appropriation (mean plus risk dollars) is sufficient to fund program.

Reference: NSA Cost Performance Office Presentation, "Allocating 'Risk Dollars' Back to Individual Cost Elements," by Stephen A. Book, 2003





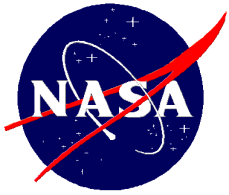
Allocating Risk Dollars Based on "Need"

§ For each WBS element $k = 1, \dots, N$, the risk dollars are calculated as:

$$\text{Risk Dollars}(k) = \frac{\text{ElementNeed}(k)}{\text{Need Base}} * \text{Risk Dollars}$$

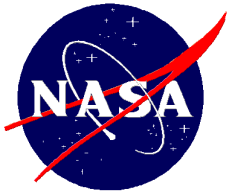
Reference: NSA Cost Performance Office Presentation, "Allocating 'Risk Dollars' Back to Individual Cost Elements," by Stephen A. Book, 2003





Analytic Approximation Vs. Monte Carlo

- While there is no consensus on whether or not Monte Carlo is more accurate than analytic approximation, recent tests by Tecolote, MCR, and SAIC suggest that both methods provide similar results



Comparison of Risk Model Output

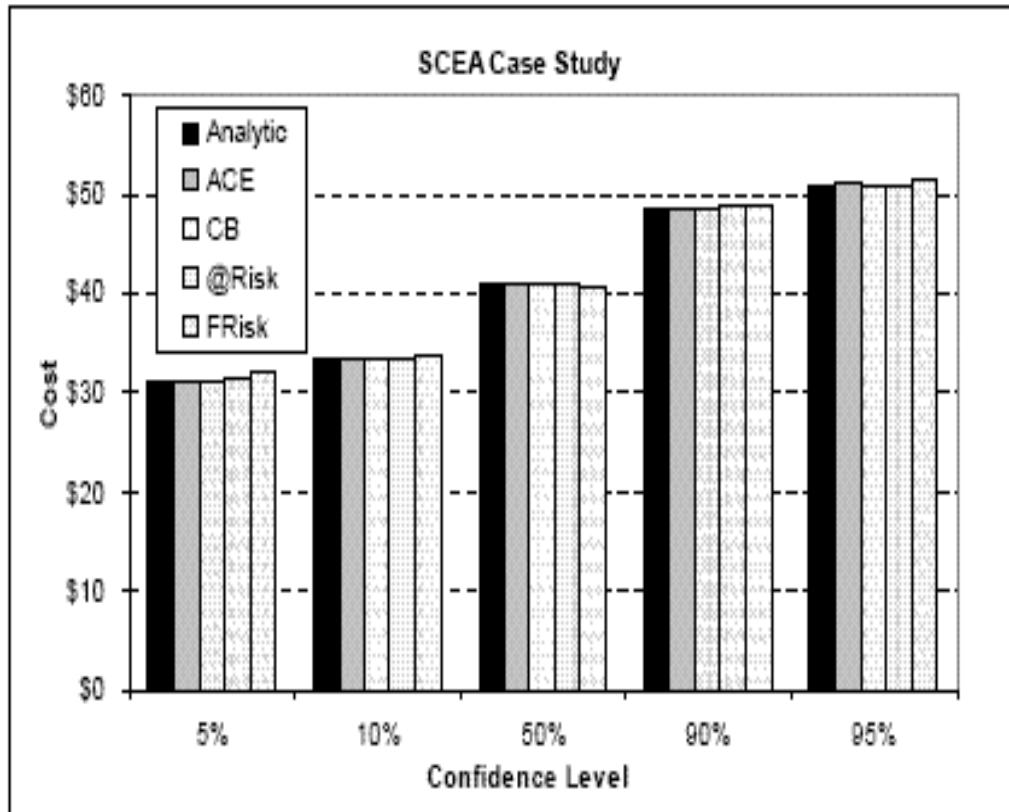
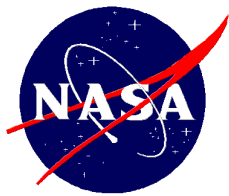


Figure 12: Comparing Risk Simulation Tools Based Upon 10,000 LHC Iterations.

Reference: SCEA Presentation “Cost Risk Analysis ‘For the Masses’”
by Tecolote Research, 2004.



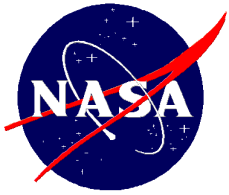


Comparative Risk Model Outputs for 2002 MCR Case Study

Table 6: MCR Case Study

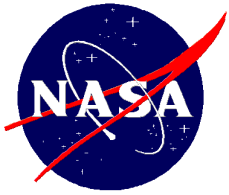
	Sd	5%	10%	50%	90%	95%
ACE	487.2	1,043	1,156	1,708	2,438	2,630
CB	486.1	1,044	1,157	1,704	2,441	2,626
@Risk	489.9	1,039	1,150	1,705	2,448	2,640
Normal	491.8	947	1,126	1,756	2,386	2,565
FRISK	491.8	1,076	1,189	1,691	2,405	2,657
Beta	491.8	994	1,121	1,729	2,431	2,610

Reference: SCEA Presentation "Cost Risk Analysis 'For the Masses'"
by Tecolote Research, 2004.



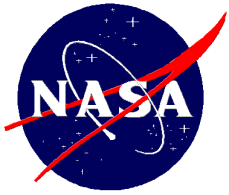
NAFCOM Case Studies

- SAIC worked with Erik Burgess of MCR to compare the NAFCOM analytic approximation algorithm with Monte Carlo simulation
- We compiled four test cases and analyzed each using both Monte Carlo and analytic approximation
- Monte Carlo simulations were performed in @Risk, using 10,000 trials
- @Risk uses rank correlation, so the Monte Carlo results underestimate the standard deviation and thus slightly underestimate the risk



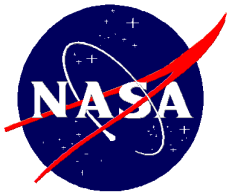
Results Summary

- Comparisons are very favorable
 - Even for the case with the most variance, the differences in means is less than 1%
 - All percentiles are within 12%
- Results for tails are as expected
 - Monte Carlo tails are thinner than NAFCOM
 - Expected because @Risk uses rank correlation
- Nothing significant would be gained from implementing Monte Carlo approach

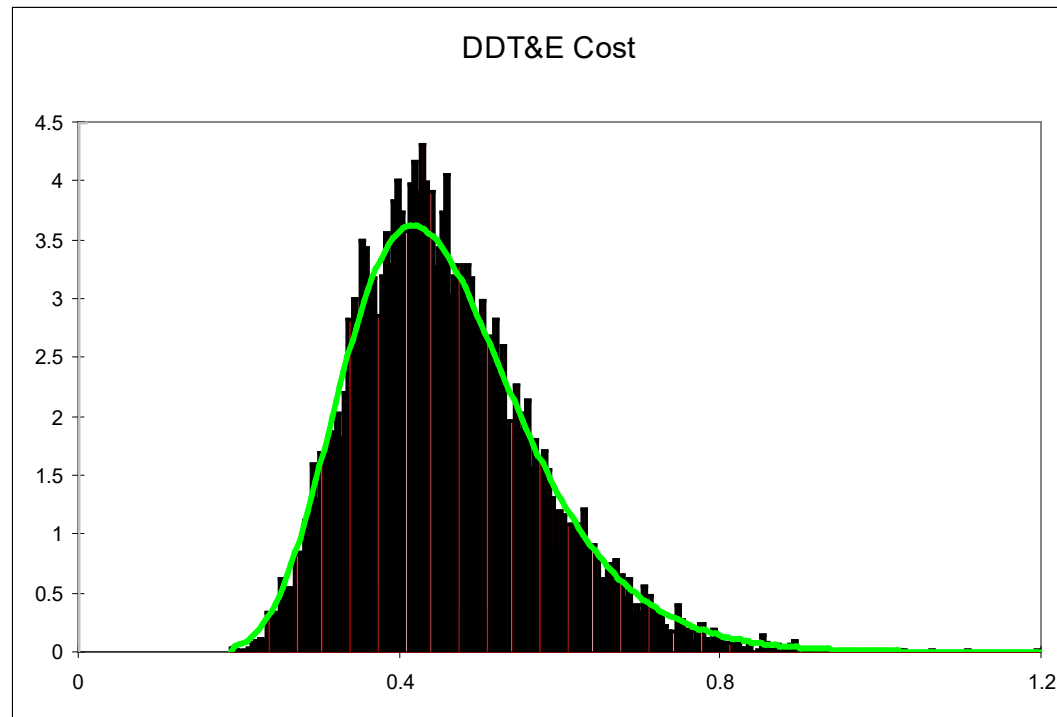


Test Case 1

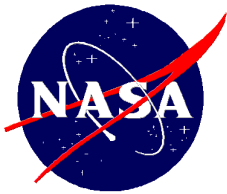
- Single Stage Vehicle
- Hardware Only
- Four Subsystems
 - Structures
 - Thermal Control
 - EPD&C
 - CC&DH



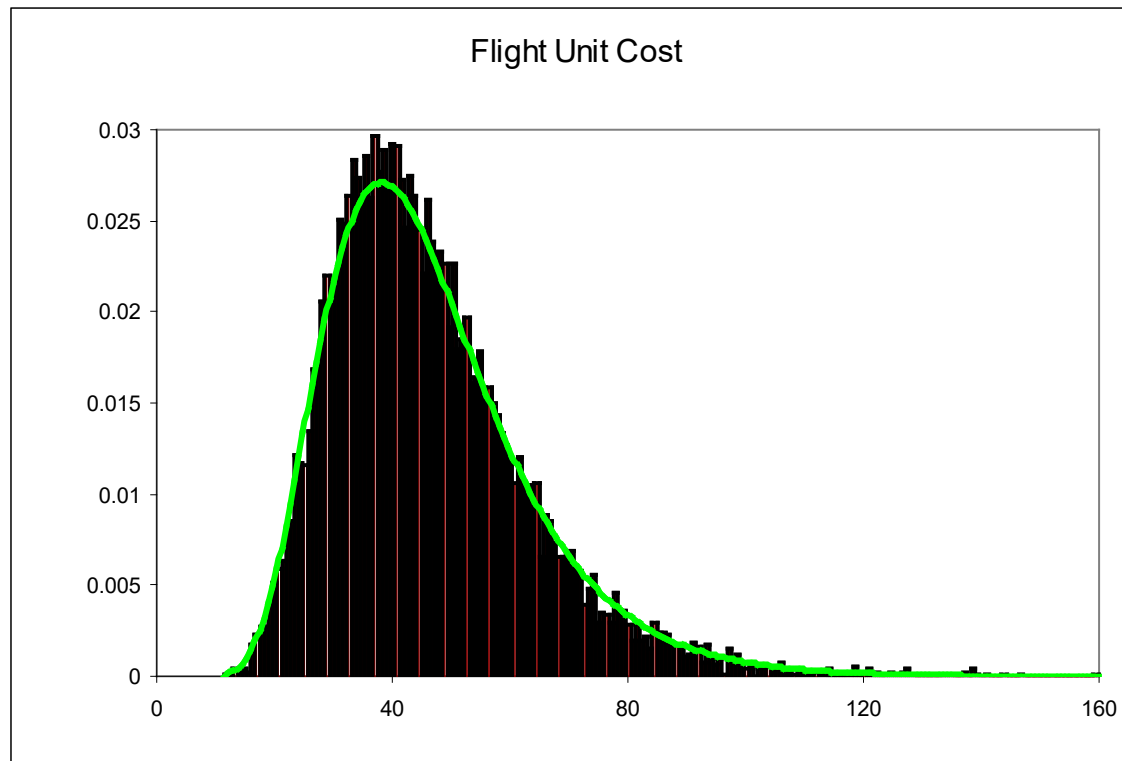
Test Case 1 Overlay Comparison – DDT&E*

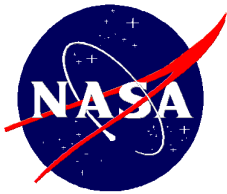


* The green line represents the Lognormal distribution from NAFCOM and the histogram represents the Monte Carlo simulation results.

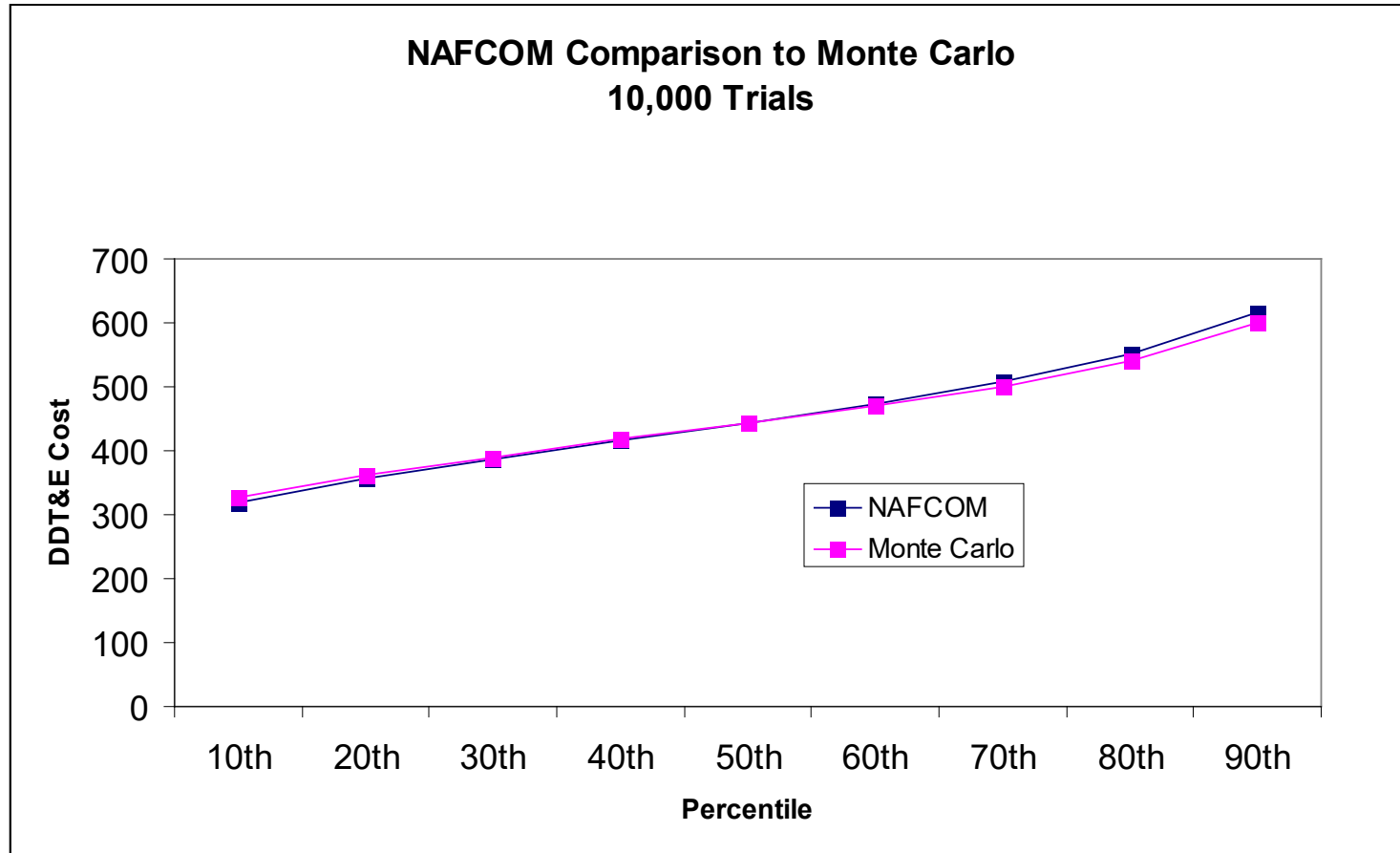


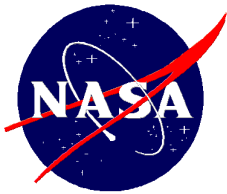
Test Case 1 Overlay Comparison – Flight Unit



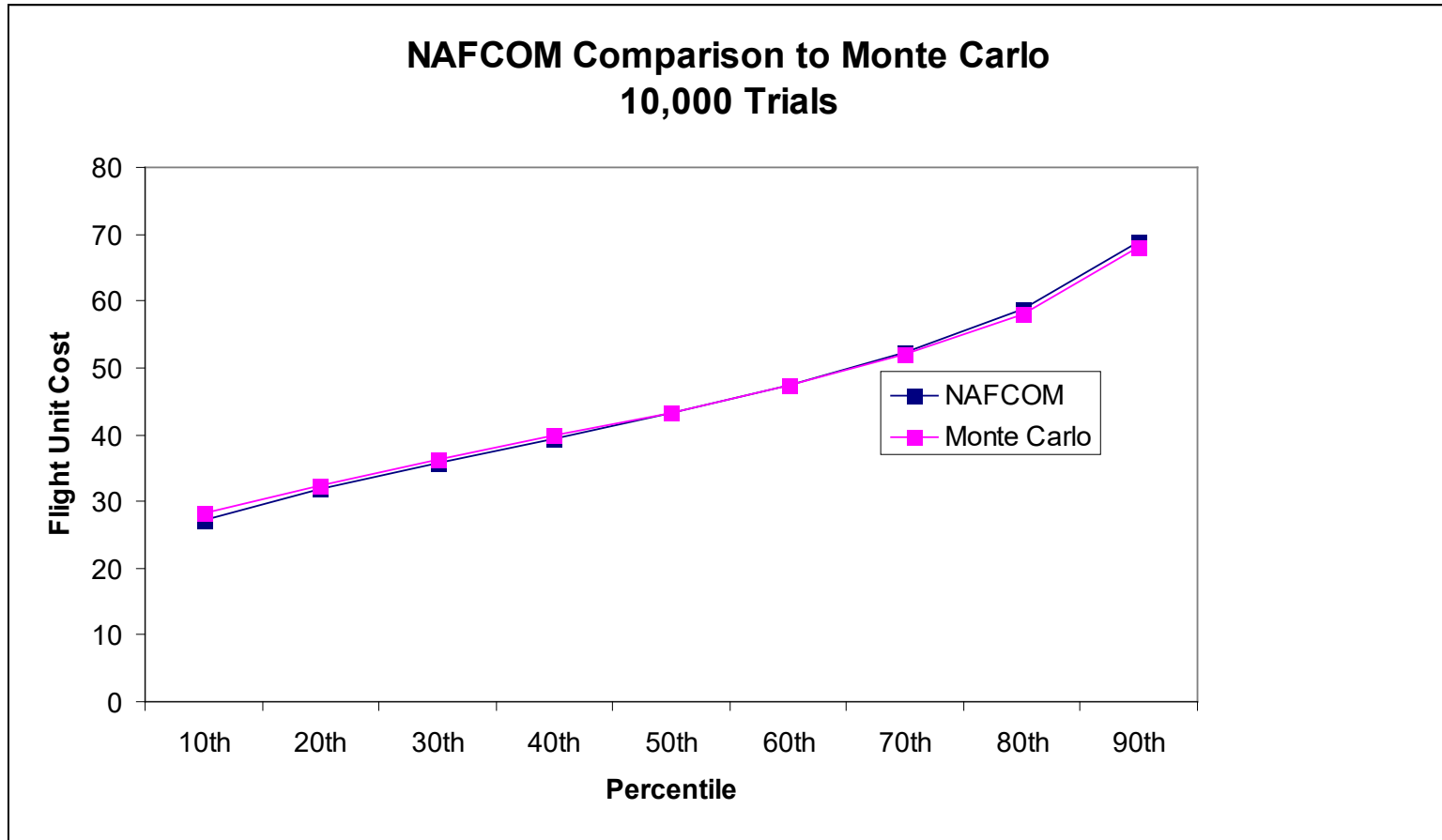


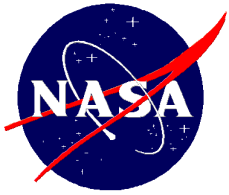
Test Case 1 DDT&E Percentile Comparisons





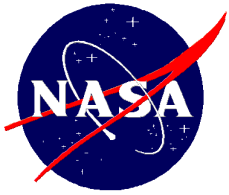
Test Case 1 Flight Unit Percentile Comparisons



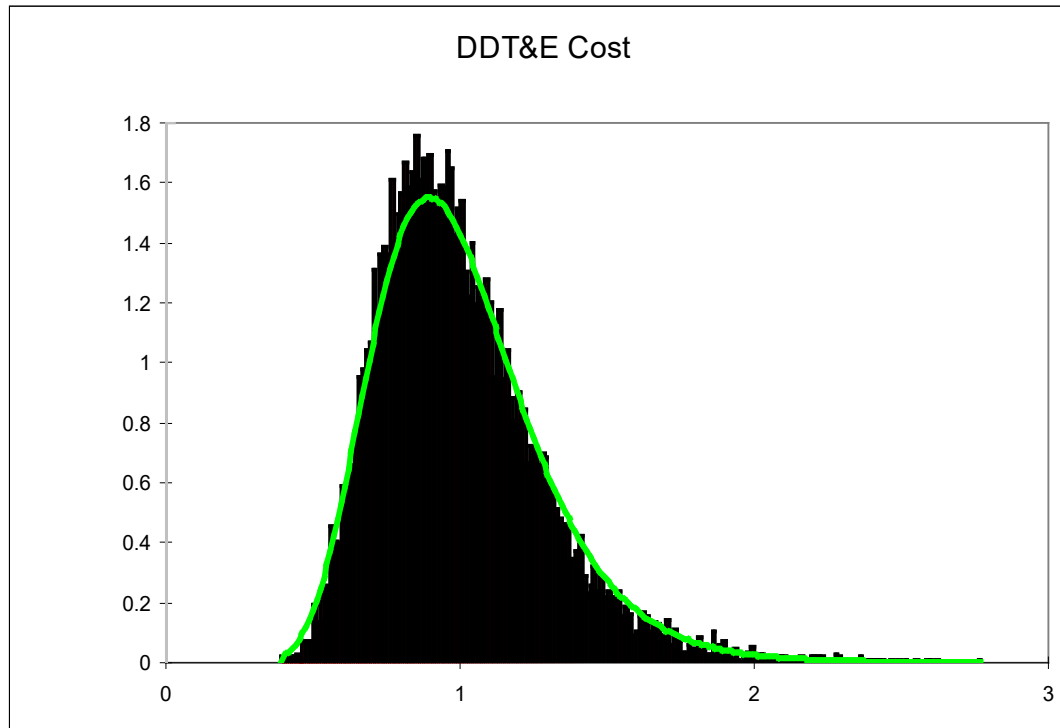


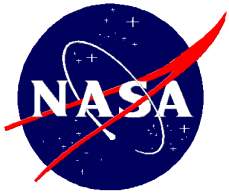
Test Case 2

- Consists of the same hardware subsystems as Test Case 1
- Also includes systems engineering

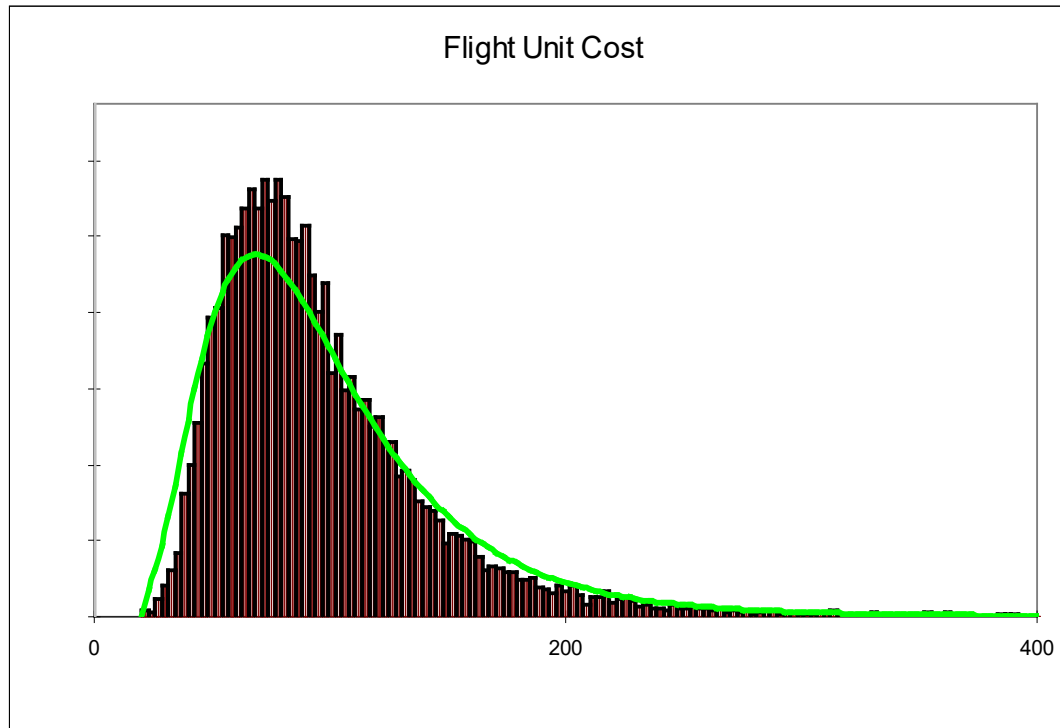


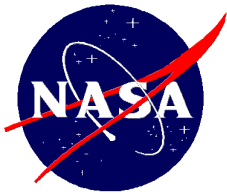
Test Case 2 DDT&E Overlay Comparisons



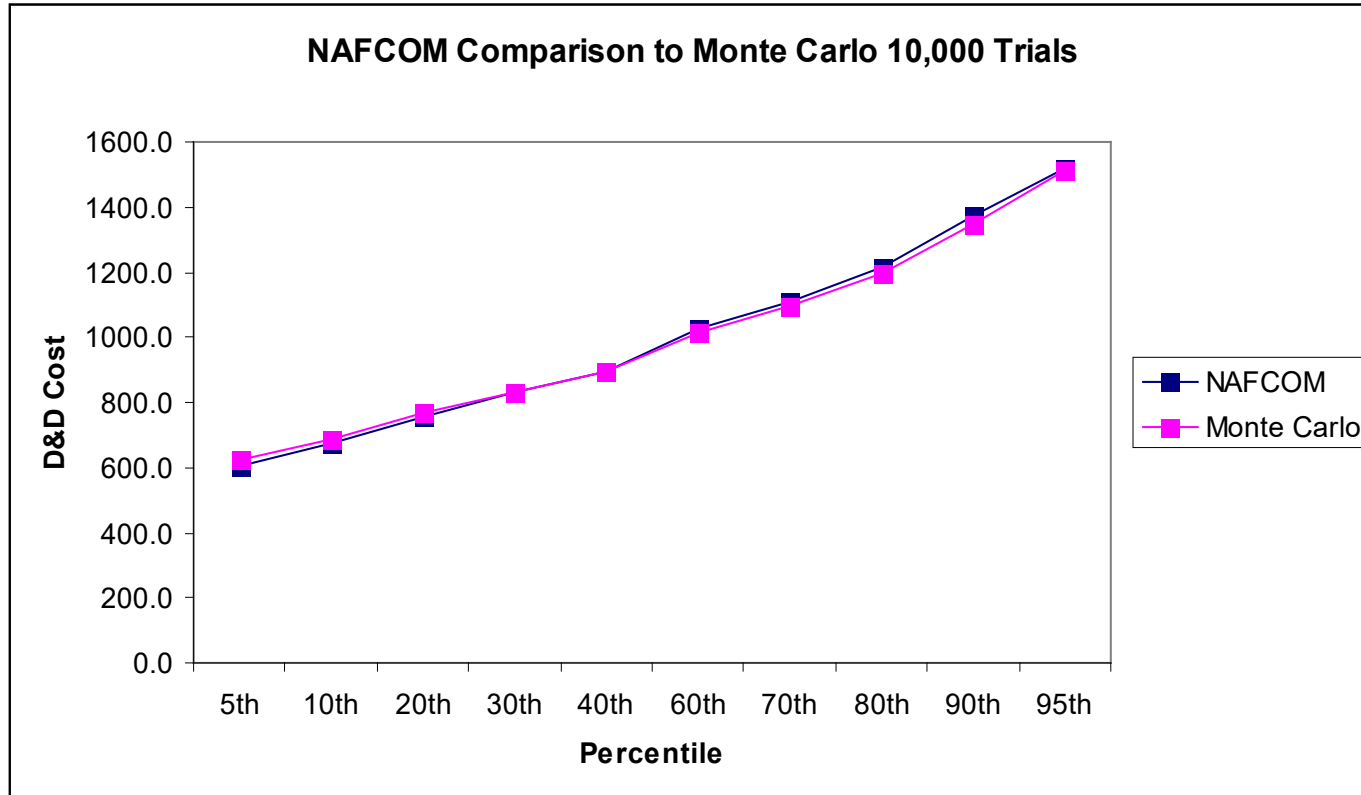


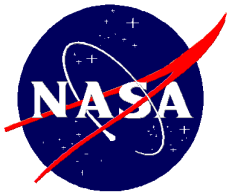
Test Case 2 Flt. Unit Overlay Comparisons



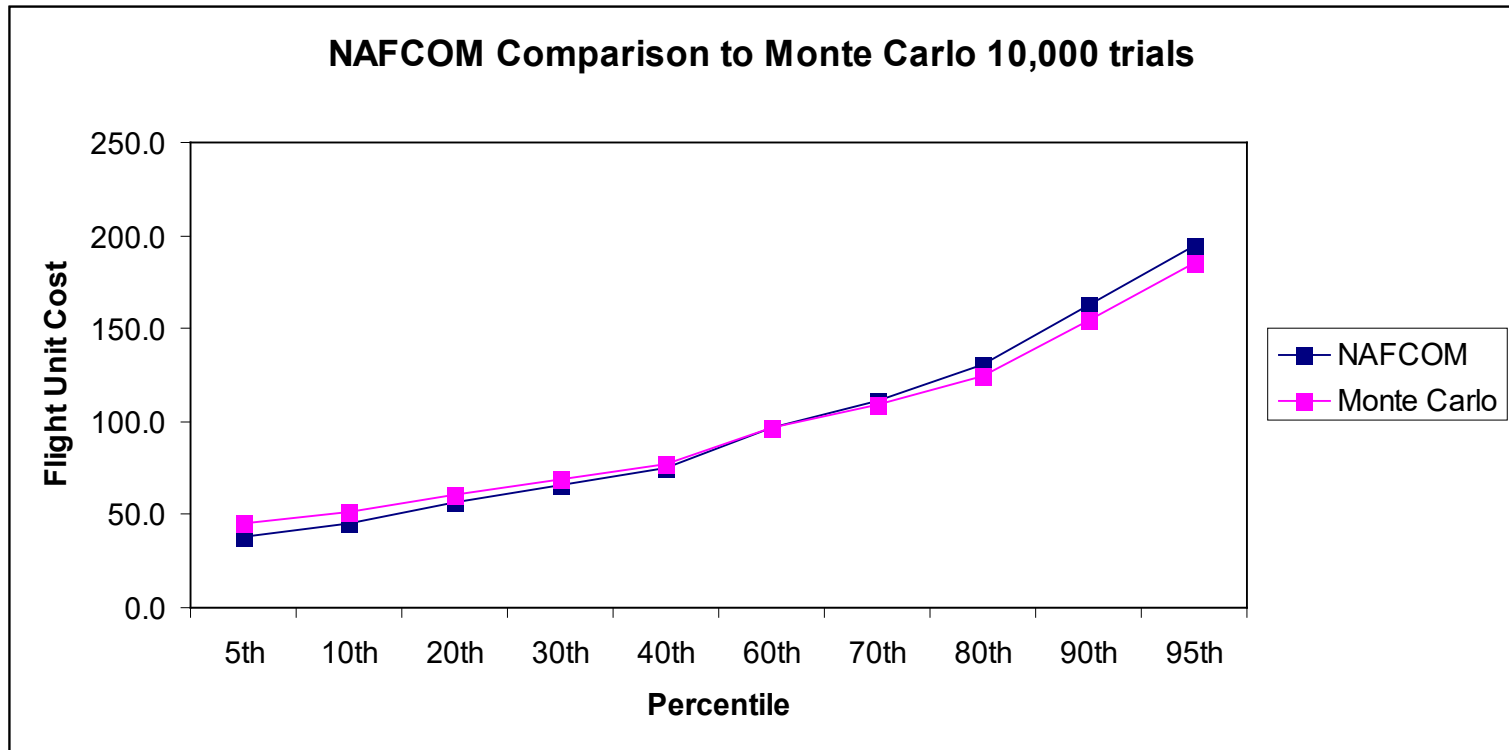


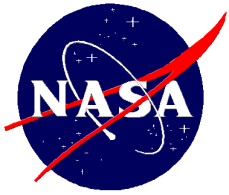
Test Case 2 DDT&E Percentile Comparisons





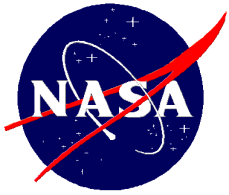
Test Case 2 Flight Unit Percentile Comparisons



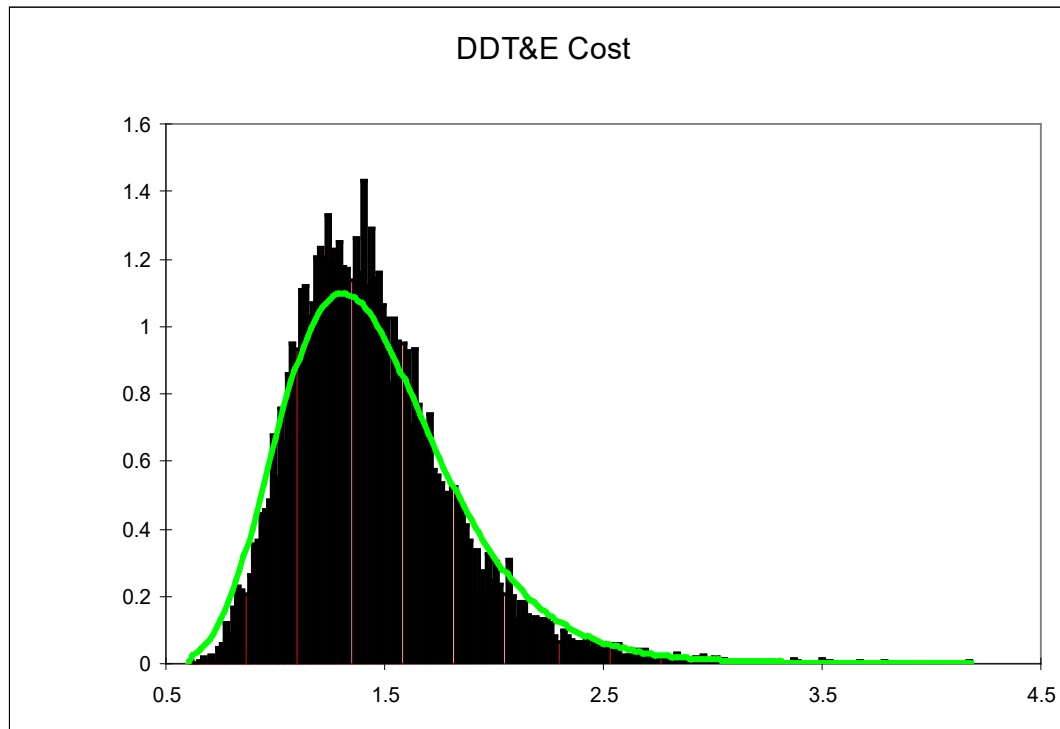


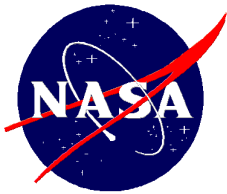
Test Case 3

- Consists of a single stage vehicle, subsystem hardware plus systems engineering.
- The hardware elements include 7 subsystems
 - Structures
 - Thermal control
 - Electric power
 - Command control and data handling
 - Guidance navigation and control
 - Reaction control/auxiliary propulsion
 - Main propulsion (less engines) subsystems.

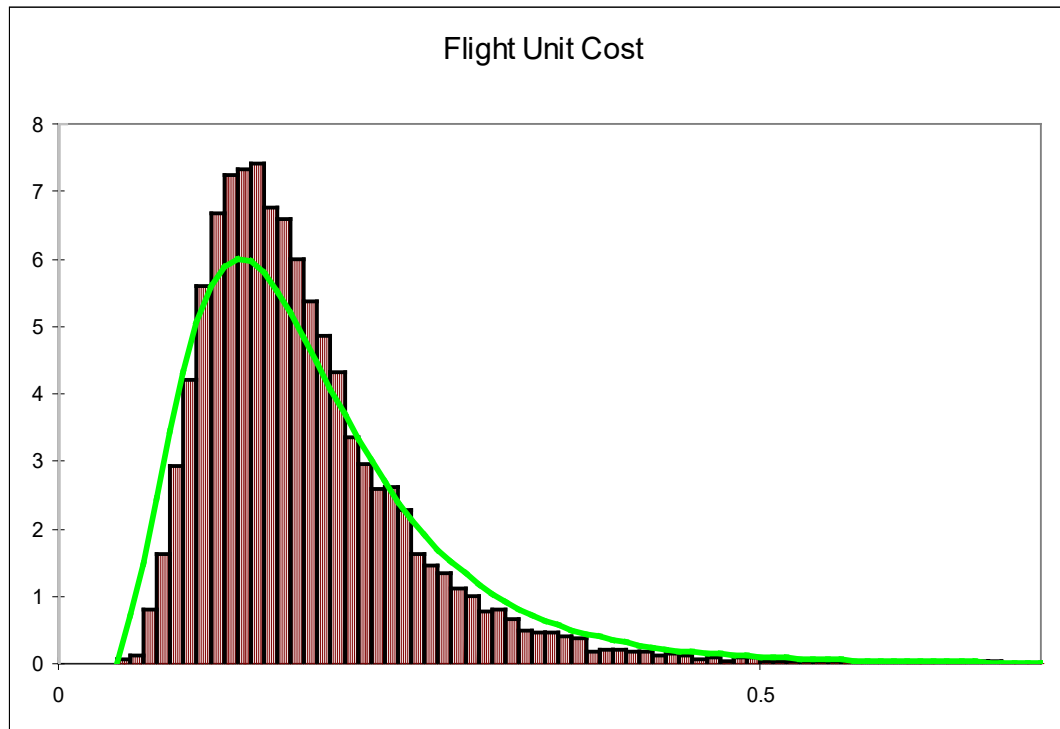


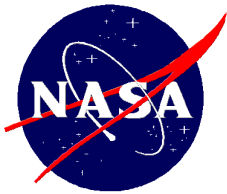
Test Case 3 DDT&E Overlay Comparisons



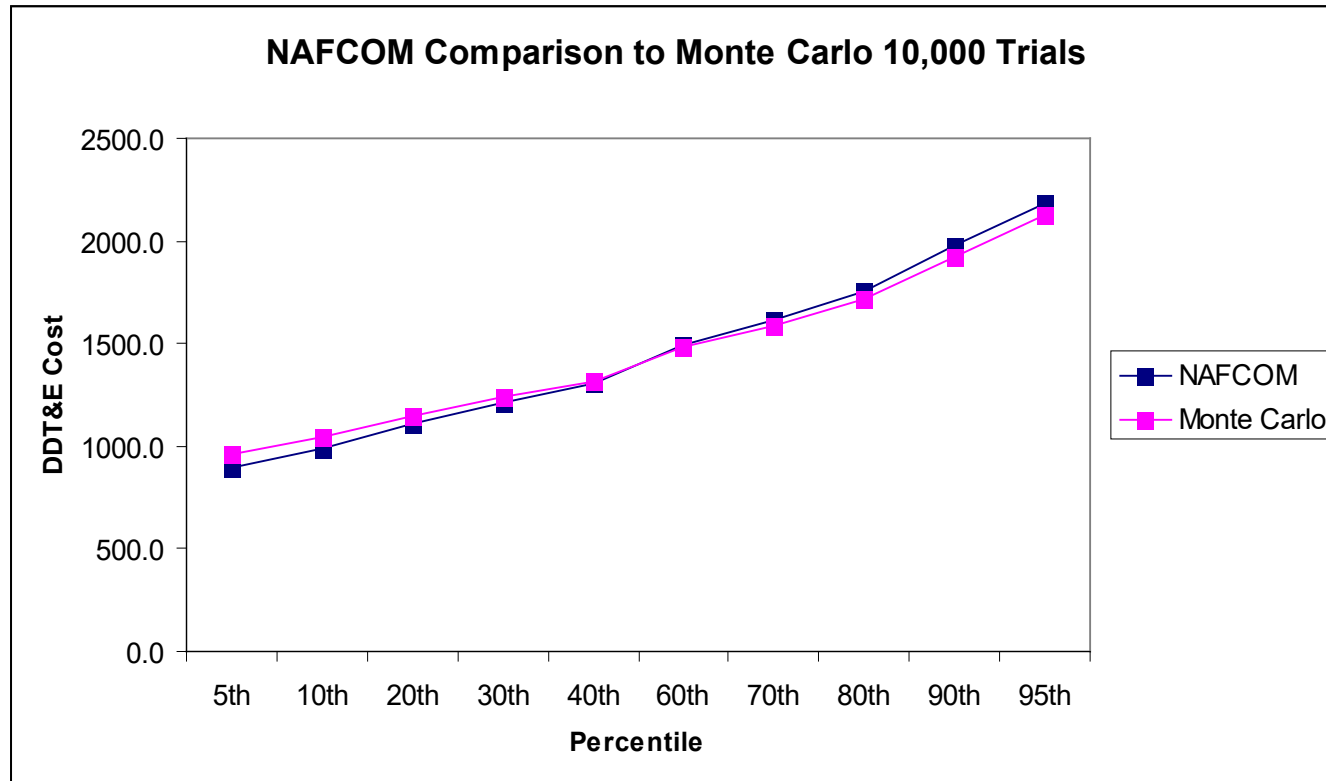


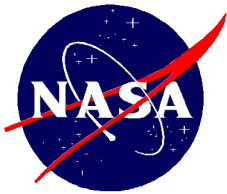
Test Case 3 Flight Unit Overlay Comparisons



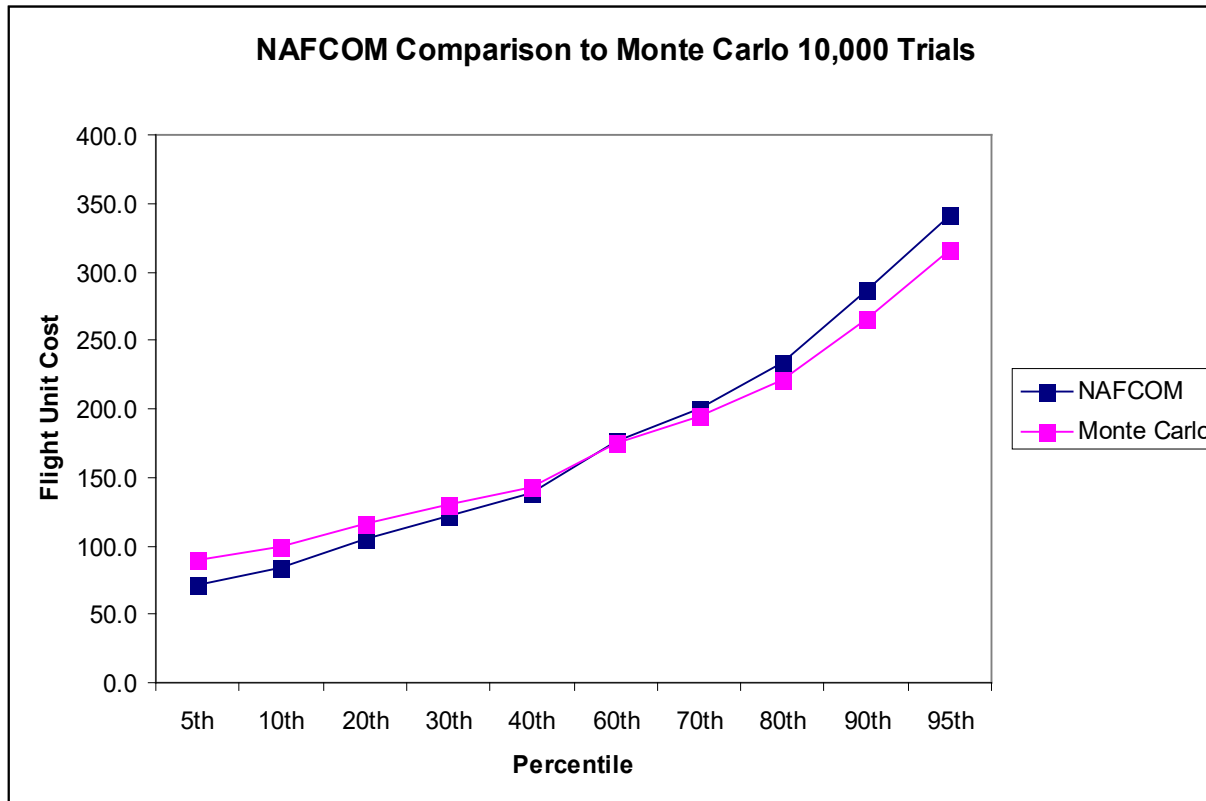


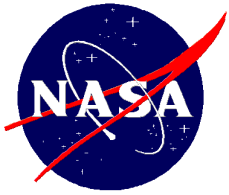
Test Case 3 DDT&E Percentile Comparisons





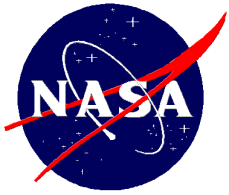
Test Case 3 Flight Unit Percentile Comparisons



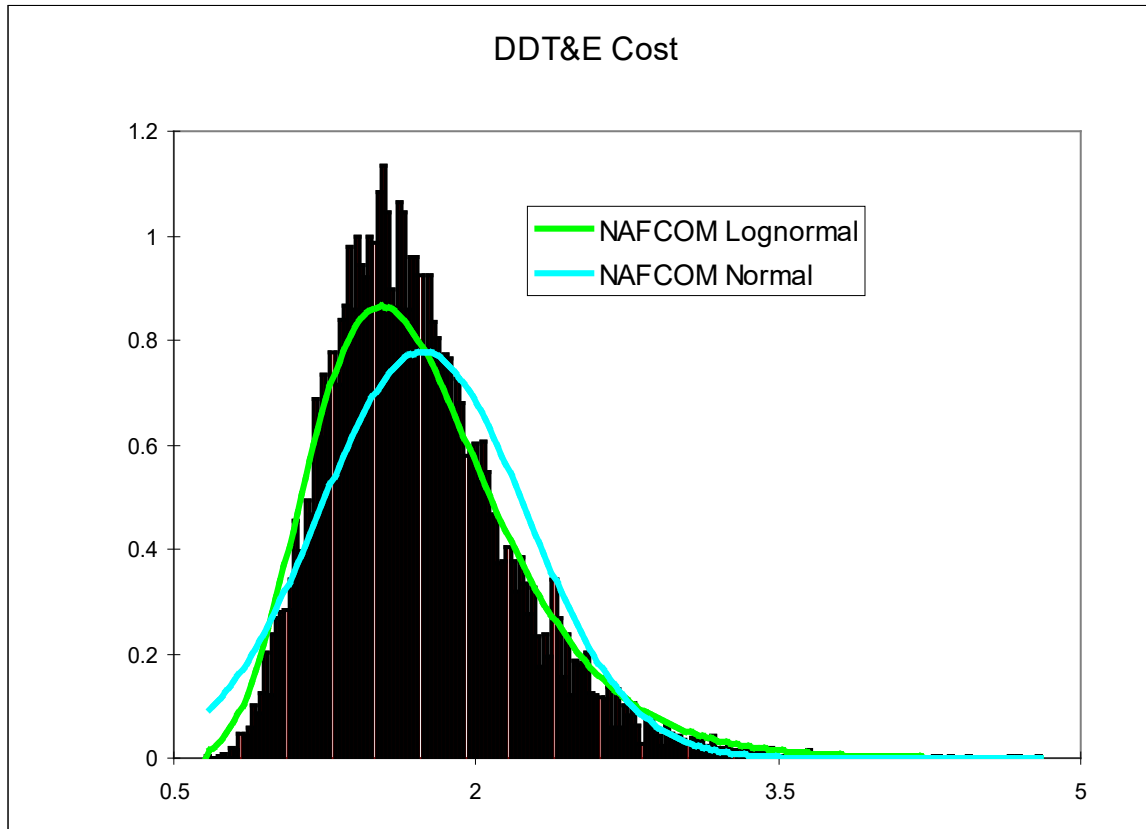


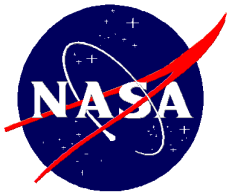
Test Case 4

- Consists of a single stage vehicle, subsystem hardware plus systems engineering
- The hardware elements are the same as for test case 3
- Test case 4 is similar to test case 3
 - The only difference is that the inputs vary more than in test case 3

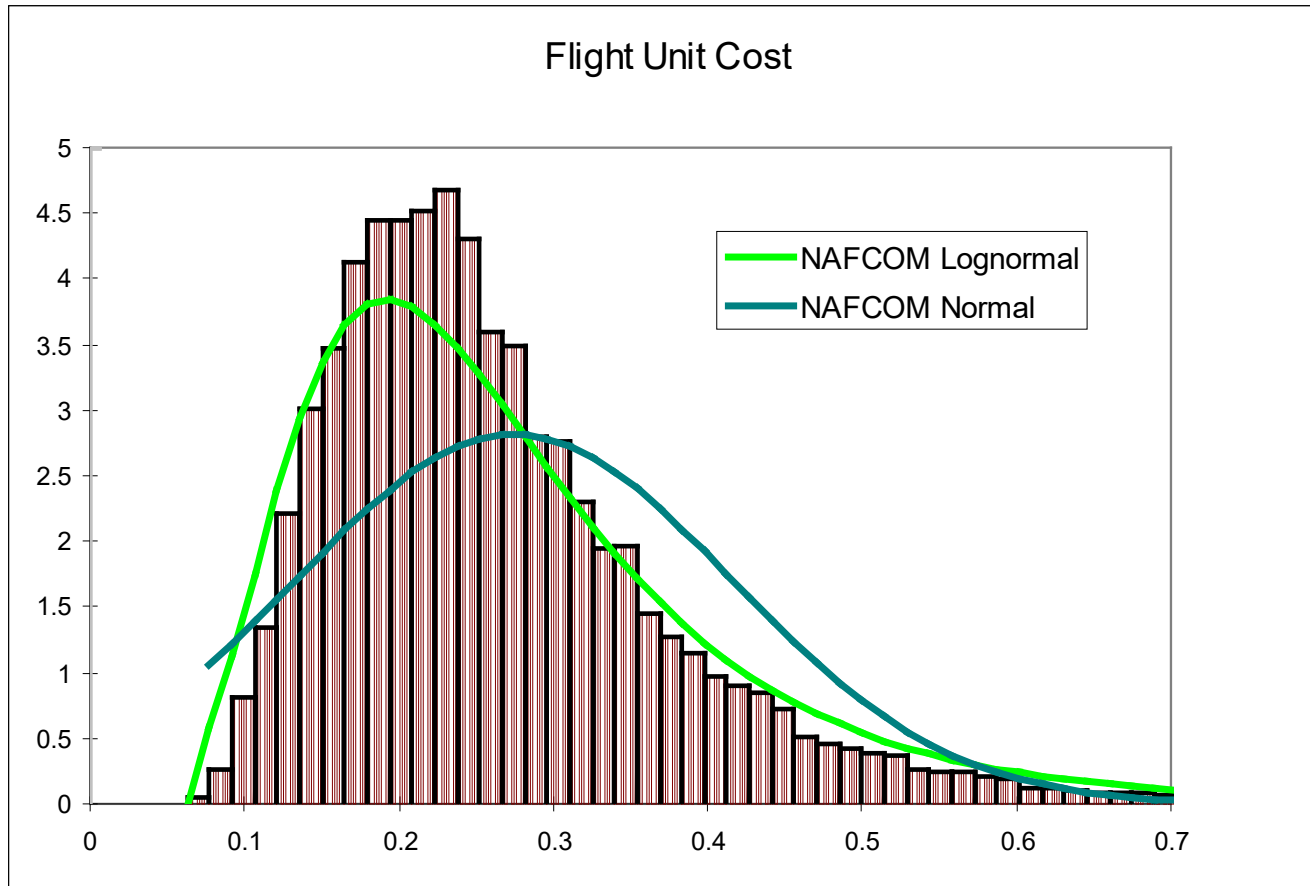


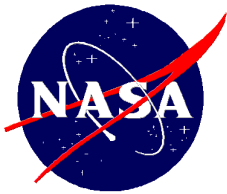
Test Case 4 DDT&E Overlay Comparisons



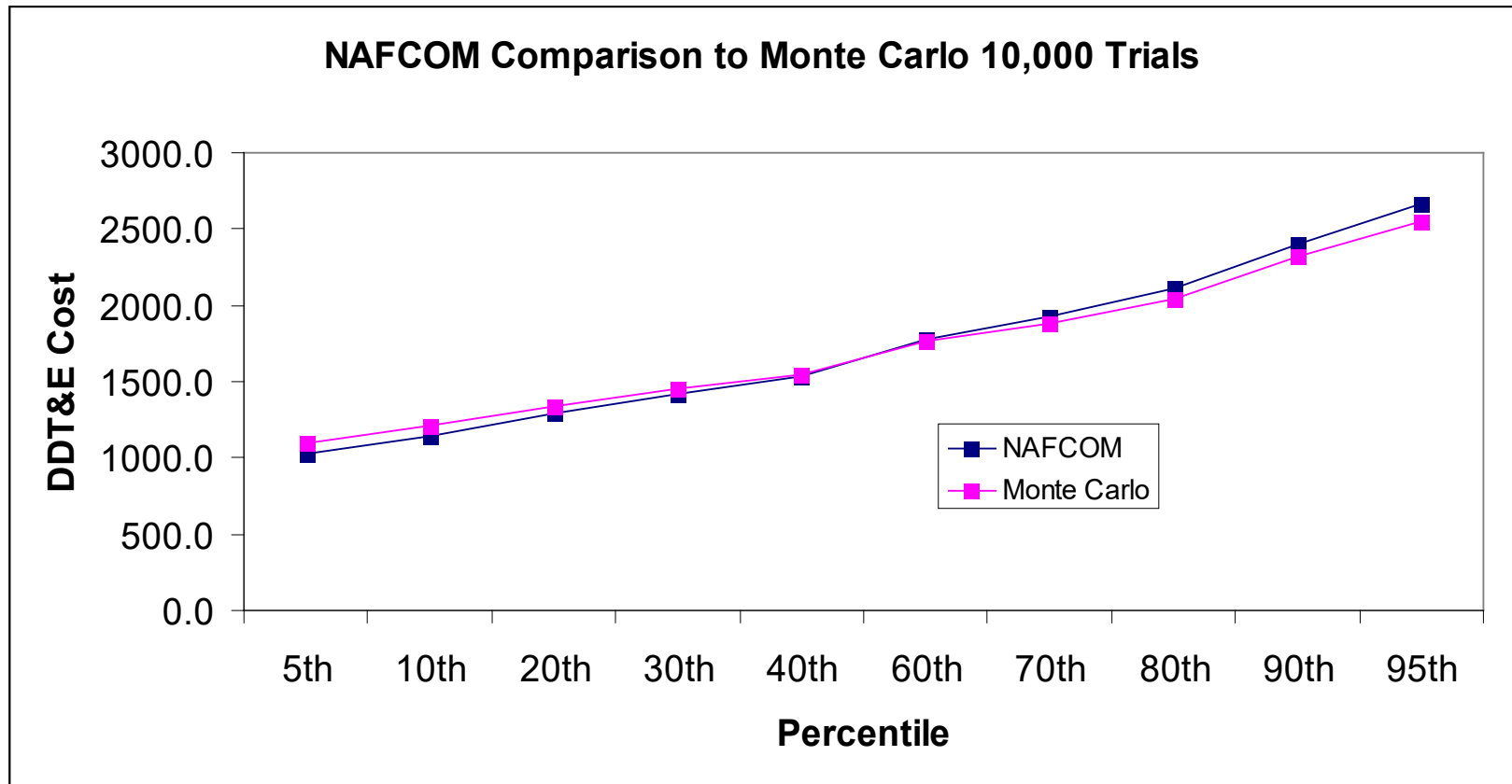


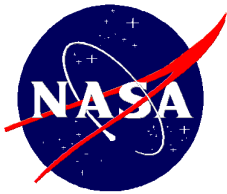
Test Case 4 Flight Unit Overlay Comparisons



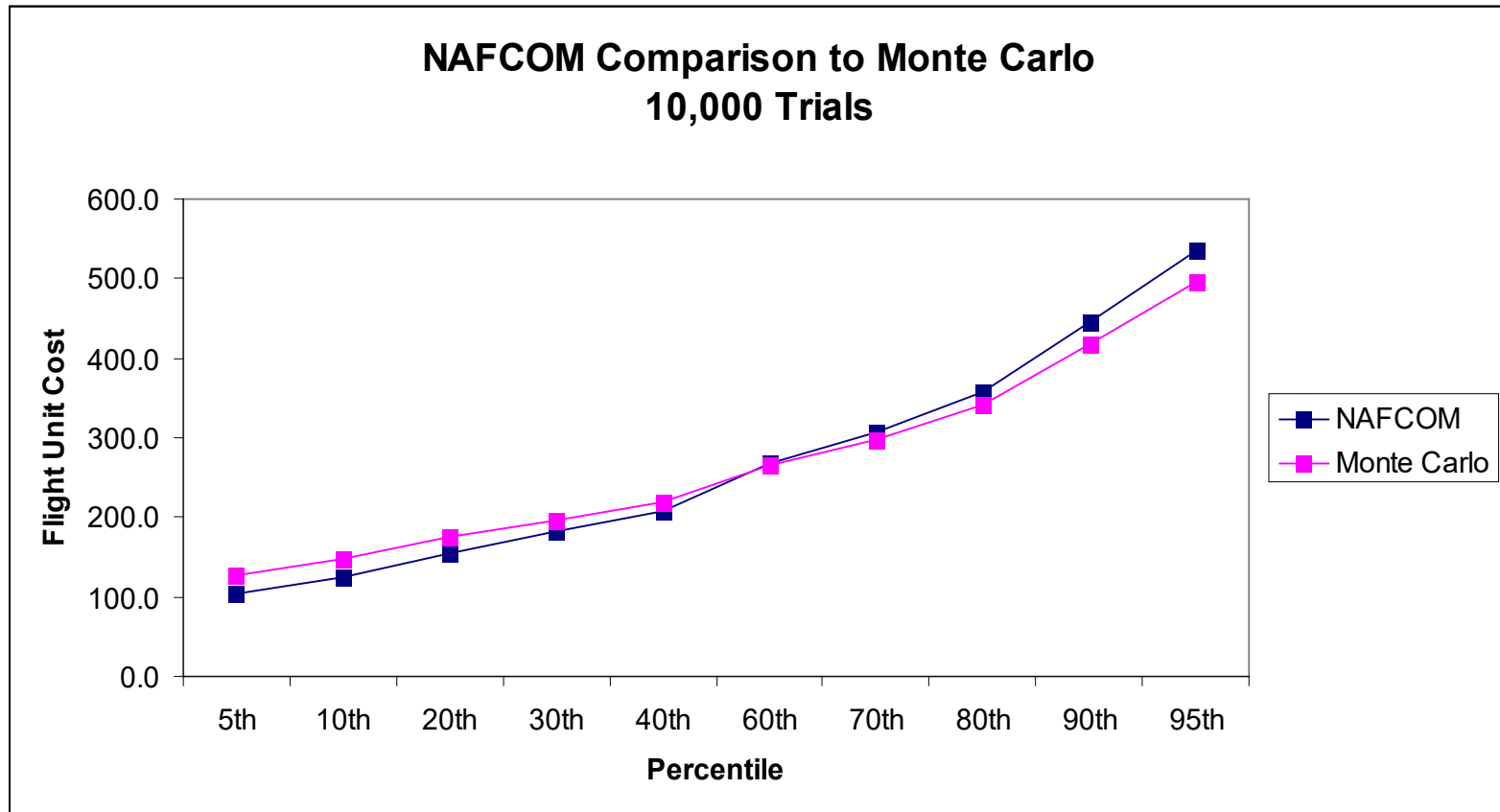


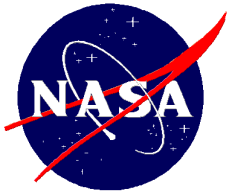
Test Case 4 DDT&E Percentile Comparisons





Test Case 4 Flight Unit Percentile Comparisons





NAFCOM Risk Capabilities

Summary

- Uses well-documented analytical method to calculate risk
- User can input low, most likely, and high values for all NAFCOM complexity generator and conventional CER inputs
- Incorporates both technical and estimating uncertainties
- Incorporates correlation between subsystem costs
- Results displayed to the user are summary statistics, probability densities, and cumulative distributions for DDT&E, Flight Unit, Production, and Total Costs for each major estimating element (i.e. stage, bus, etc.)
- User can select either the Normal distribution or the Lognormal distribution to approximate the final results
- Provides similar results to Monte Carlo simulation