DODCAS 2003

A Comparative Analysis of the Cost Estimating Error Risk Associated with Flyaway Costs Versus Individual Components of Aircraft

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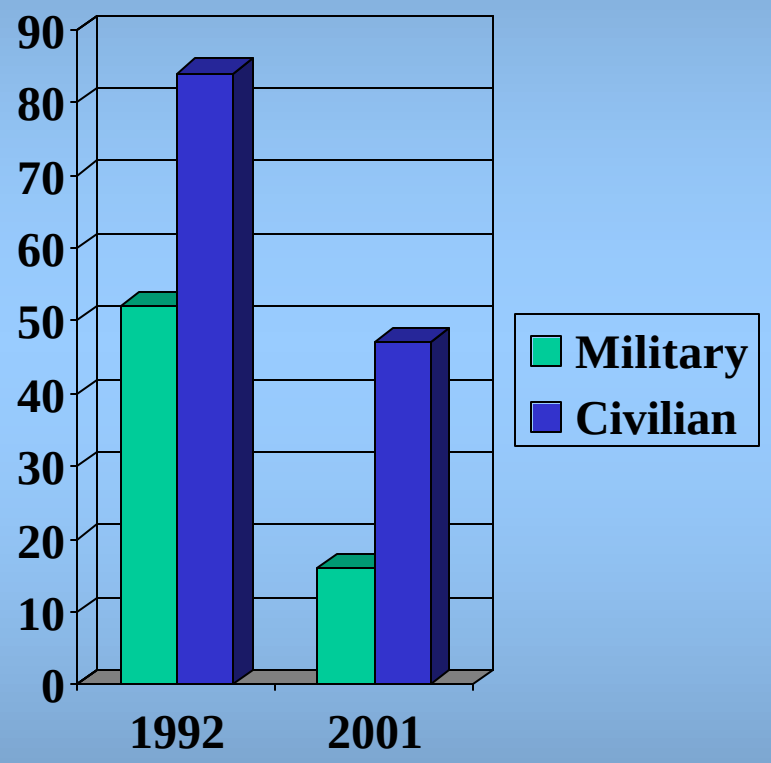
Expectations

- Things to Take Away
  - Conceptual Study
  - Understanding of WBS Estimating Error Level Differences
  - Resource Allocation
- What is Not Provided
  - CER’s to Estimate Next Generation Aircraft

Overview

- Background
- Methodology
- Analysis
- Results

Acquisition Environment for Cost Analysts



- Manpower Reductions
  - Aeronautical System Center (ASC) Cost Authorizations
  - 69% Reduction in Military Slots
  - 44% Reduction in Civilian Slots
- Time

Research Objectives

- Which aircraft components have the most cost estimation error risk, and what is that risk?
- What is the cost estimation error risk associated with estimating at the flyaway cost level?
- Is there a statistically significant difference is estimating at the component level versus the flyaway level?
- Given a constrained resource environment, where should a cost analyst focus their attention when developing an aircraft cost estimate?

Previous Research

- Large, Campbell, and Cates (1976)
  - Multiple Regression to Derive Aircraft Airframe CERs
  - Airframe Unit Weight and Speed were Main Cost Drivers

- Hess and Romanoff (1987)
  - Updated Large, Campbell, and Cates Study
  - Found Total Airframe vs. Airframe Components CERs Virtually Equivalent in Accuracy
  - Attempted to Establish Equations for Homogeneous Sets
    - Fighters, Bombers, Attack
  - Technology Index

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Data Collection

- Two Primary Sources
  - Delta Research Corporation Database
    - Collected from Contractor Cost Data Reports, SPO's
    - Normalized, Consistent Format
  - System Program Offices
    - C-17
- Recurring Only
- Two Categories
  - Fighters
    - F-15, F-16, F-18, B-1
  - Inter-theatre Airlift
    - C-5, C-17, C-141, C-130

Data Breakdown

- Breakdown by WBS Level
  - WBS 1 versus WBS 2 Comparison
  - Military Handbook 881
- Terminology Differences
  - Aircraft System = Flyaway
  - Basic Airframe = Air Vehicle
  - Other Air Vehicle = Common Elements + Other

Level 1	Level 2
Aircraft System	Air Vehicle
Common Elements	SE/PM
	System Test and Evaluation
	Training
	Data
	PSE
	Common Support Equipment

Data Limitation

- Data Points are Primarily Pre 1987
  - F-22, JSF
- WBS Level Breakdown
  - Do we estimate at Level 1?
  - Should Level 2 be Broken Down into More Parts?
  - Breakout of Data by Delta Research Corp.

Methodology

- Develop CERs (for Both Categories)
  - Flyaway
  - Basic Airframe
  - Other Air Vehicle
  - Multiple Regression
  - Item of Interest: Standard Error
- Monte Carlo Simulation
  - Bootstrap Technique
  - Pair and Difference Data
- Analyze Resulting Distribution
  - Mean
  - 95% Confidence Interval Contain Zero?

Regression Model: Independent Variables

Dimensions (Feet)	Weights (lbs)	Engines	Performance	Fuel	Quantity
Wing Span	Airframe Unit Weight	Number of Engines	Takeoff Weight	Max Fuel Internal	Lot Number
Wing Area (sq ft)	Empty Weight	Max Static Thrust Sea Level	Takeoff Run S.L. (ft)	Max Fuel External	Lot Quantity
Length	Max Gross Takeoff Weight		Max Speed S.L.		Cum. Quantity
Height					
Tread					
Wheelbase					

Multiple Regression

- Continuous Dependent Variable
- Multi-Collinearity
  - Visual Plot
  - Variance Inflation Factor
- Analysis of Variance Table
  - Overall Model Predictive Capability
- Parameter Estimates
  - Significance of Independent Variables
- Cook's Distance Influence
- Outliers
- Normality
  - Plot of Studentized Residuals
  - Shapiro-Wilk
- Constant Variance
  - Residual by Predicted Plot
  - Breusch-Pagan
- Independence
  - Time Series Analysis
- Summary of Fit
  - R^2
  - Adjusted R^2

Monte Carlo Simulation

- Residuals from Regression Equations
  - Normal $(0, s^2)$ Distribution
- Bootstrap Technique
  - Sample the Sample or "Resampling"
  - Same Size Resample Drawn Repeatedly
  - Value of a Statistic Computed for Each Individual Resample
  - Bootstrap Statistic Approximated by Taking an Average

Original process

Population $\rightarrow (x_1, x_2, \ldots, x_n) \rightarrow \bar{x}$

Resampling process

BS Sample 1: $(x_3, x_7, \ldots, x_2) \rightarrow \bar{x}_1^*$

BS Sample 2: $(x_8, x_1, \ldots, x_1) \rightarrow \bar{x}_2^*$

....

BS Sample B: $(x_4, x_9, \ldots, x_{11}) \rightarrow \bar{x}_B^*$

Bootstrap with Regression

- Fixed X Residual Resampling
  - Two Step Process
    - Fit a Regression Model
    - Generate Bootstrap Data
    - Y* = (Fit) + (BS sample of OLS residuals)
  - Number of Samples
    - 200 Bootstrap Samples
    - 1000 Iterations within Each Bootstrap Sample
- Pair and Difference Data
  - Looking at Resultant Standard Error
  - Pair and Difference
  - Resultant Distribution
    - Mean and 95% Confidence Interval

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Fighter Category

Basic Airframe

- Independent Variables
  - a = 0.10

Term		Estimate	Std Error	t Ratio	Prob>|t|
Intercept		3.3941178	0.136297	24.90	<.0001
Category[1]		-0.709052	0.153275	-4.63	<.0001
Category[2]		-0.534294	0.139719	-3.82	0.0005
Category[3]		-1.451749	0.130112	-11.16	<.0001
Category[4]		-0.891017	0.321027	-2.78	0.0085
Category[5]		-0.25603	0.137962	-1.86	0.0713
Category[6]		2.0370961	0.339241	6.00	<.0001
Cum Qty		-0.000796	0.000243	-3.28	0.0022

RSquare	0.903714
RSquare Adj	0.885978
Root Mean Square Error	0.36799
Mean of Response	2.517431
Observations (or Sum Wgts)	46

Other Air Vehicle

- Model has Fewer Data Points

RSquared	0.658488
RSquared Adj	0.590185
Root Mean Square Error	0.395943
Mean of Response	1.443977
Observations (or Sum Wgts)	31

Term		Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept		2.1343389	0.161211	13.24	<.0001	.
Category[1]		-0.315531	0.164369	-1.92	0.0664	1.4120392
Category[3]		-0.395569	0.134653	-2.94	0.0070	1.0894043
Category[4]		0.5669808	0.345178	1.64	0.1130	3.7755367
Category[5]		-0.376998	0.157462	-2.39	0.0245	1.5713612
Cum Qty		-0.001152	0.000277	-4.16	0.0003	3.4467635

Flyaway Model

- Final Model for Fighter Category

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	37.202530	5.31465	44.7988
Error	38	4.508085	0.11863	Prob > F
C. Total	45	41.710615		<.0001

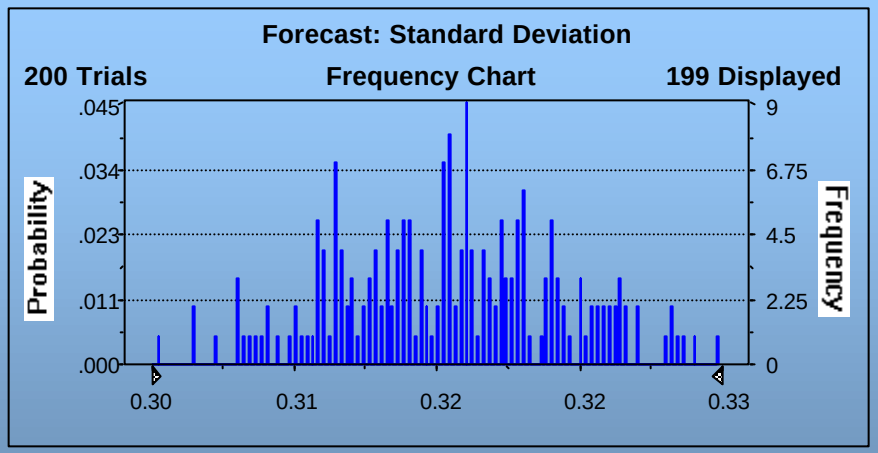
RSquare	0.89192
RSquare Adj	0.87201
Root Mean Square Error	0.344433
Mean of Response	2.859426
Observations (or Sum Wgts)	46

Term		Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept		3.7395676	0.127571	29.31	<.0001	.
Category[1]		-0.697189	0.143462	-4.86	<.0001	1.6745295
Category[2]		-0.431093	0.130774	-3.30	0.0021	1.9085175
Category[3]		-1.221545	0.121782	-10.03	<.0001	1.402332
Category[4]		-0.548961	0.300476	-1.83	0.0756	4.5662778
Category[5]		-0.36779	0.12913	-2.85	0.0071	1.7722244
Category[6]		1.7433997	0.317524	5.49	<.0001	3.3255161
Cum Qty		-0.000895	0.000227	-3.94	0.0003	3.8783792

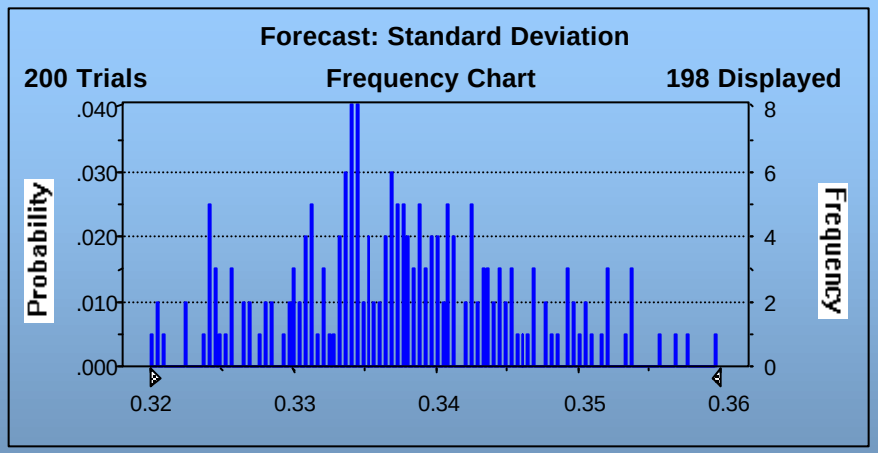
Bootstrap: Residuals

- Flyaway and Basic Airframe
  - Residual Inputs from Regression Equations
- 200 Bootstrap Samples
  - 1000 Iterations within each Sample

Flyaway

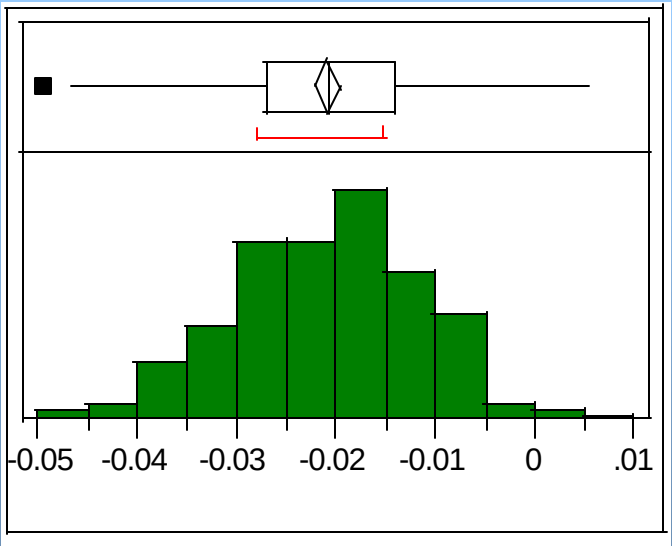


Basic Airframe



Comparison of Flyaway vs. Basic Airframe

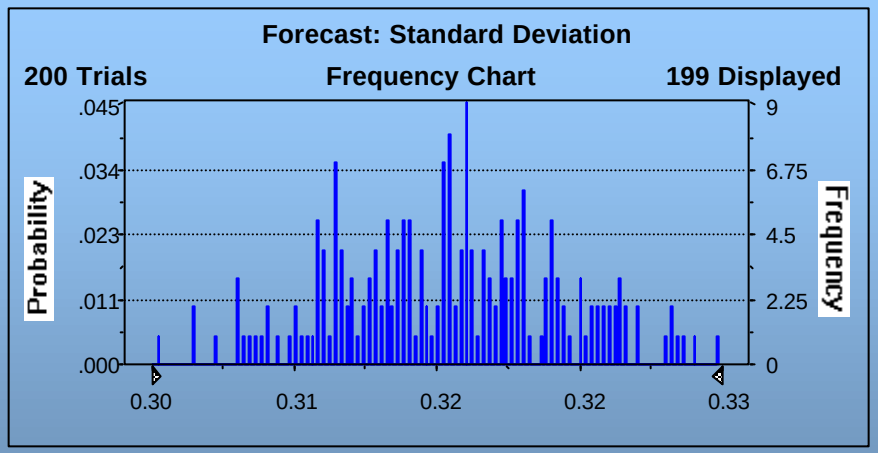
- Data is Paired and Differenced
- Resulting Distribution
  - Mean = -0.0208
  - 95% C.I. (-0.0195, -0.0222)
- Practical vs. Statistical Significance



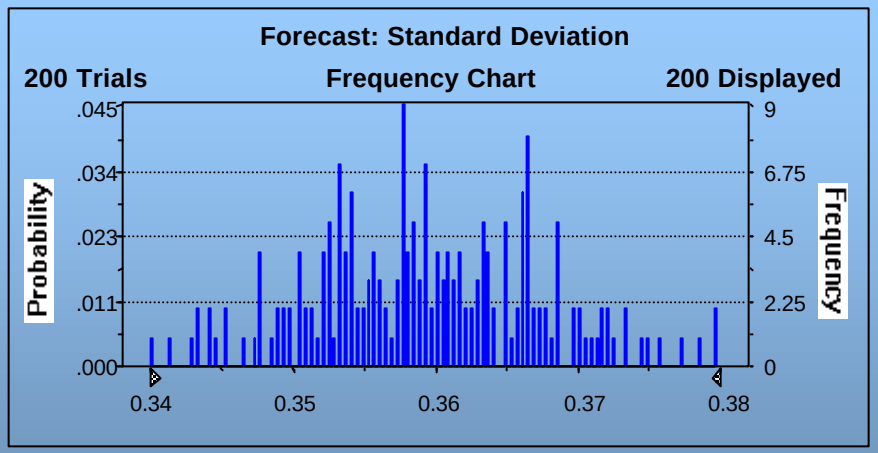
Bootstrap: Residuals

- Flyaway and Other Air Vehicle
  - Residual Inputs from Regression Equations
- 200 Bootstrap Samples
  - 1000 Iterations within each Sample

Flyaway

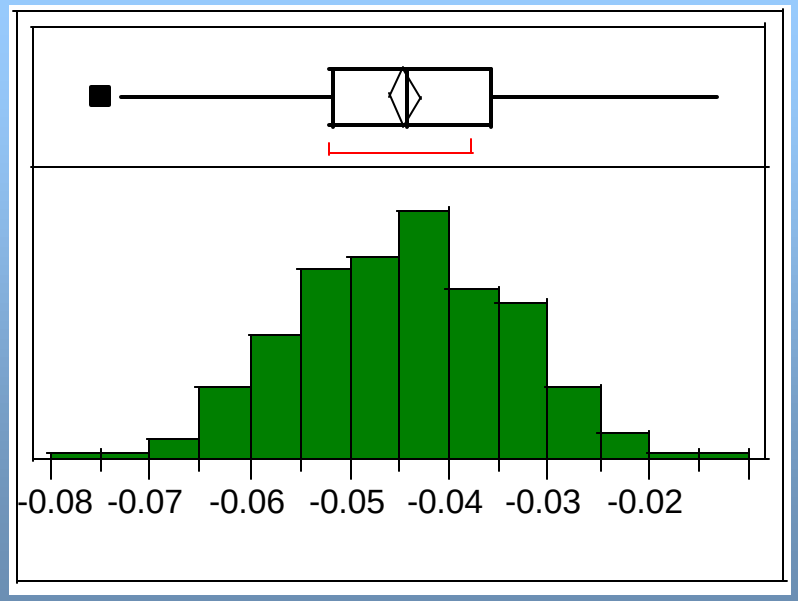


Other Air Vehicle



Comparison of Flyaway vs. Other Air Vehicle

- Data is Paired and Differenced
- Resulting Distribution
  - Mean = -0.0445
  - 95% C.I. (-0.0429, -0.046)
- Practical vs. Statistical Significance



Inter-theatre Airlift Category

Basic Airframe

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	21.000082	5.25002	85.4912
Error	19	1.166792	0.06141	Prob > F
C. Total	23	22.166874		<.0001

RSquared	0.947363
RSquared Adj	0.936282
Root Mean Square Error	0.247811
Mean of Response	3.7751
Observations (or Sum Wgts)	24

Term		Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept		4.5174542	0.079756	56.64	<.0001	.
Category[1]		0.8095095	0.101365	7.99	<.0001	2.5655289
Category[2]		0.7282849	0.145753	5.00	<.0001	3.4449211
Category[3]		-1.436094	0.107786	-13.32	<.0001	2.577618
Cum Qty		-0.017515	0.001677	-10.44	<.0001	1.1791086

Other Air Vehicle

- Cum Quantity Parameter Estimate not Significant
  - Raw Data Analysis (Learning Curve Effect)

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	8.895078	2.96503	34.0974
Error	17	1.478279	0.08696	Prob > F
C. Total	20	10.373357		<.0001

RSquare	0.857493
RSquare Adj	0.832344
Root Mean Square Error	0.294886
Mean of Response	2.706801
Observations (or Sum Wgts)	21

Term		Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept		2.6529963	0.10428	25.44	<.0001	.
Category[1]		-1.019602	0.116718	-8.74	<.0001	2.3723415
Category[2]		0.5212374	0.157098	3.32	0.0041	2.5948719
Cum Qty		-0.002204	0.002069	-1.07	0.3017	1.146707

Flyaway Cost

- All Parameter Estimates are Significant

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	35.224151	8.80604	187.4490
Error	21	0.986545	0.04698	Prob > F
C. Total	25	36.210695		<.0001

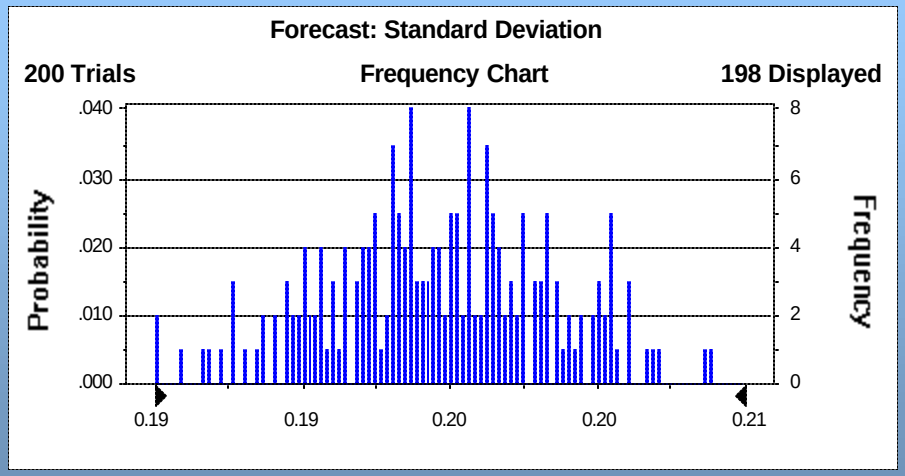
RSquare	0.972755
RSquare Adj	0.967566
Root Mean Square Error	0.216745
Mean of Response	4.598784
Observations (or Sum Wgts)	26

Term		Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept		4.7262224	0.06626	71.33	<.0001	.
Category[1]		0.3233277	0.086936	3.72	0.0013	2.5555149
Category[2]		0.6178742	0.126029	4.90	<.0001	3.5370266
Category[3]		-1.867154	0.089858	-20.78	<.0001	2.7301896
Cum Qty		-0.008976	0.001117	-8.03	<.0001	1.1097917

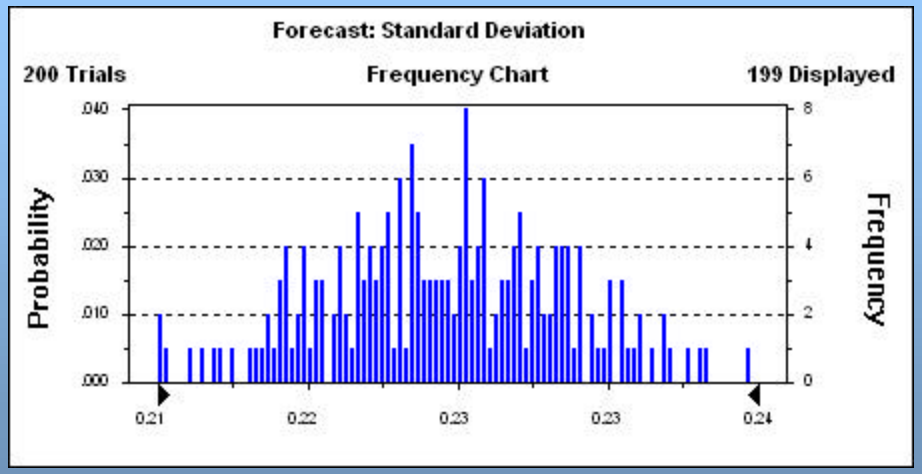
Bootstrap Residuals

- Flyaway and Basic Airframe
  - Residual Inputs from Regression Equations
- 200 Bootstrap Samples
  - 1000 Iterations within each Sample

Flyaway

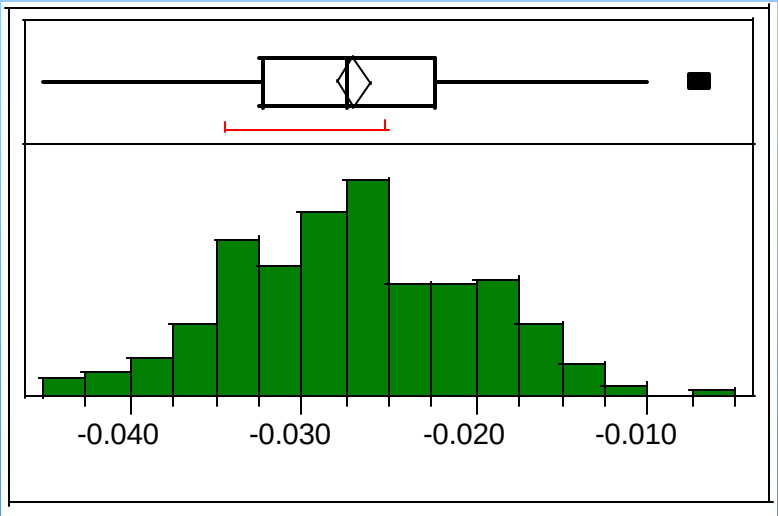


Basic Airframe



Comparison of Flyaway vs. Basic Airframe

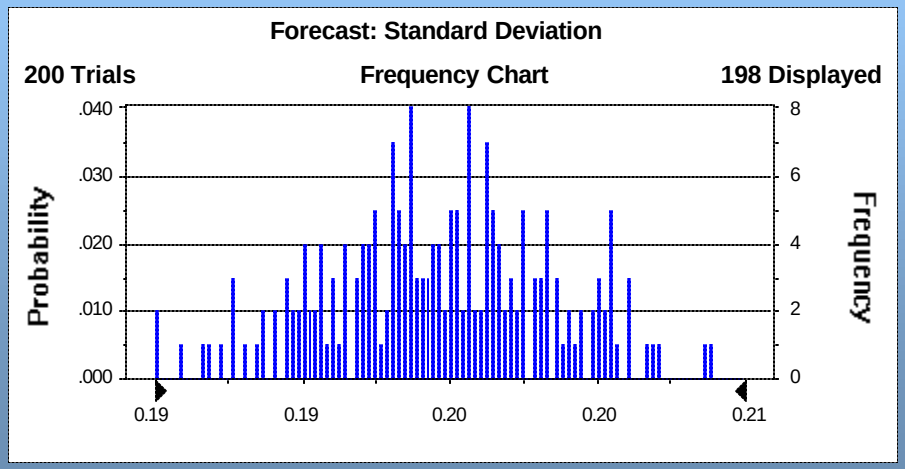
- Data is Paired and Differenced
- Resulting Distribution
  - Mean = -0.027
  - 95% C.I. (-0.026,-0.028)
- Practical vs. Statistical Significance



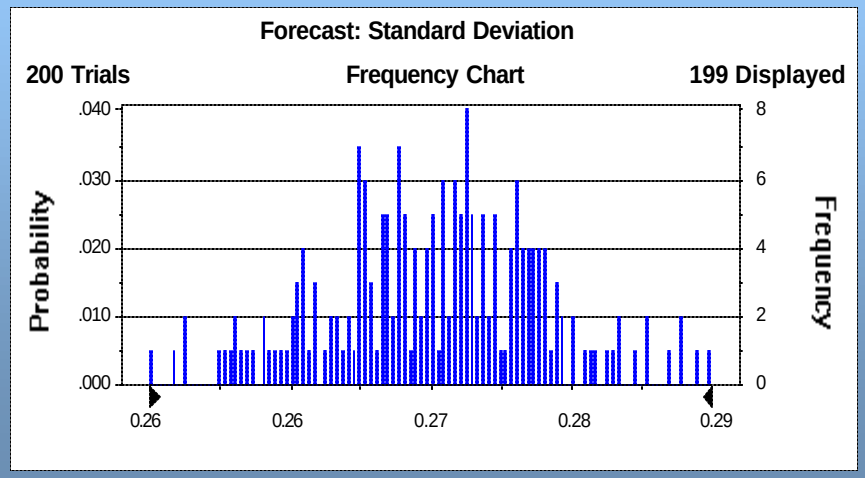
Bootstrap Residuals

- Flyaway and Other Air Vehicle
  - Residual Inputs from Regression Equations
- 200 Bootstrap Samples
  - 1000 Iterations within each Sample

Flyaway

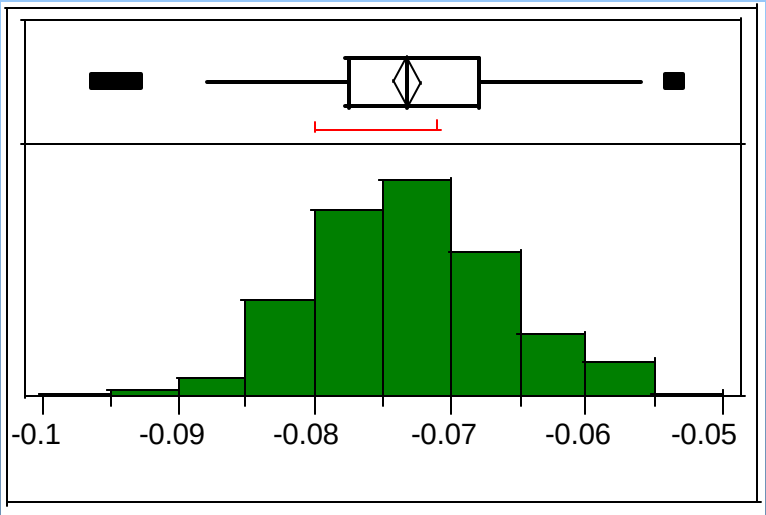


Other Air Vehicle



Comparison of Flyaway vs. Other Air Vehicle

- Data is Paired and Differenced
- Resulting Distribution
  - Mean = -0.0732
  - 95% C.I. (-0.0722,-0.0742)
- Practical vs. Statistical Significance



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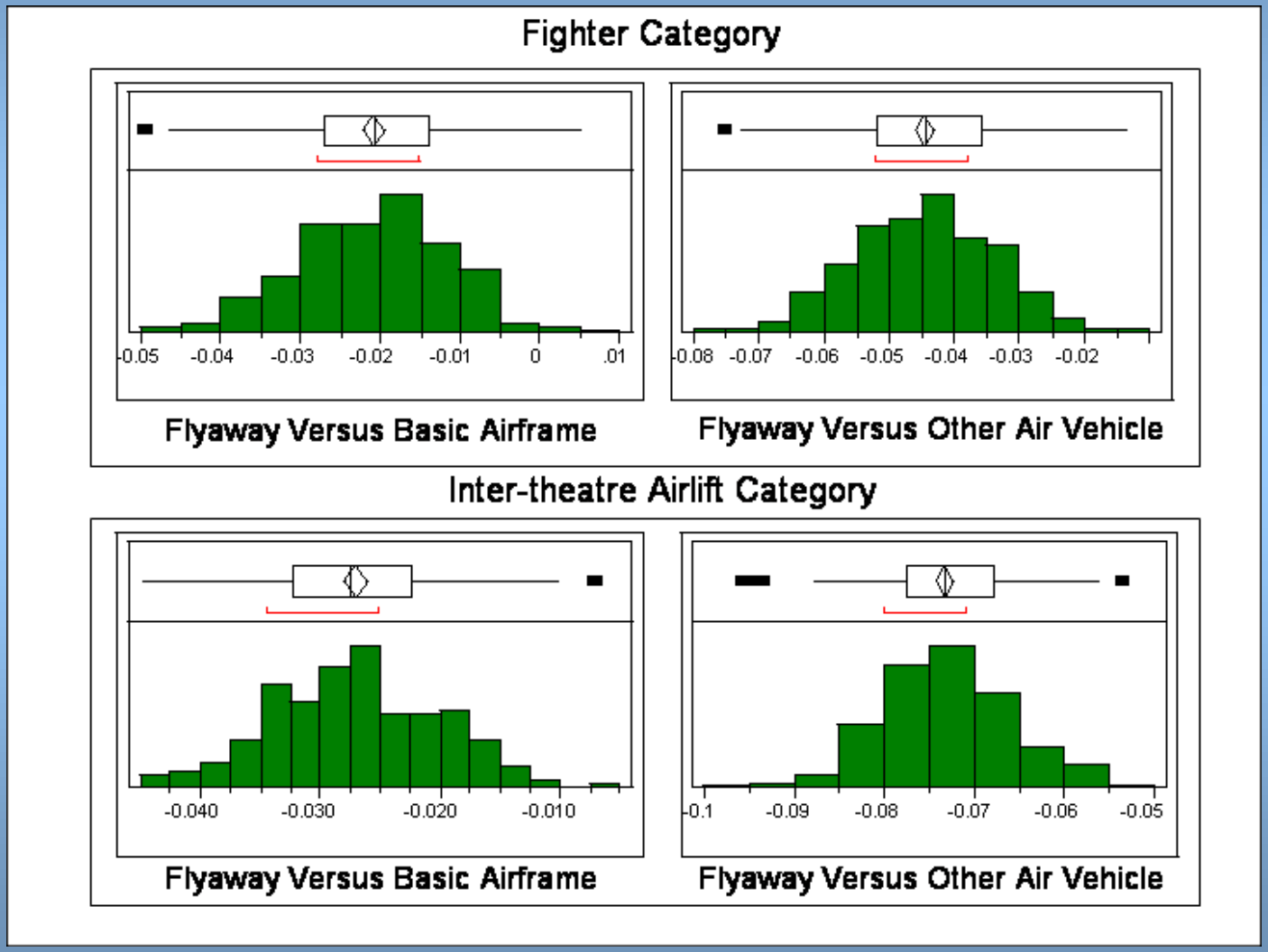
Summary of Distributions for Analysis



Fighter Category Conclusions

- There is a Statistically Significant Difference in the Estimation Error at the Differing WBS Levels
- The Other Air Vehicle Component has more Estimation Error Risk than Basic Airframe
  - PM's Should Allocate More Resources to this Area
- WBS Level 1 Error Risk is Less than WBS Level 2
  - Details Cloud the Bigger Picture
  - Negative and Positive Canceling out Affect

Inter-theatre Aircraft Category Conclusions

- There is a Statistically Significant Difference in the Estimation Error at the Differing WBS Levels
  - This Difference is Larger than the Fighter Category
- The Other Air Vehicle Component has more Estimation Error Risk than Basic Airframe
  - PM's Should Allocate More Resources to this Area
- WBS Level 1 Error Risk is Less than WBS Level 2
  - Details Cloud the Bigger Picture
  - Negative and Positive Canceling out Affect

Practical vs. Statistical Significance

- In Practical Terms there is Virtually no Difference
- Dollar Amount Example

Category	Fighter	Inter-theatre Airlift
Flyaway vs. Basic Airframe	$44,137.60	$68,682.90
Flyaway vs. Other Air Vehicle	$124,097.40	$157,584.96

Questions???

Preliminary Modeling Problem

- Duplicity in Independent Variables: Bias
- Two Potential Solutions
  - Estimate at Specific Quantity (100)
  - Use Category as Dummy Variables

A/C	Lot #	Lot Qty.	Avg. Lot Cost	Wing Span	Wing Area (Sq Ft)	Length	Height	Tread	Wheel-base
F-16	1	8	23.66	32.8	300	49.4	16.4	7.8	13.1
F-16	2	55	7.84	32.8	300	49.4	16.4	7.8	13.1
F-16	3	105	9.02	32.8	300	49.4	16.4	7.8	13.1
F-16	4	145	713	32.8	300	49.4	16.4	7.8	13.1
F-16	5	75	6.74	32.8	300	49.4	16.4	7.8	13.1
F-16	6	348	7.44	32.8	300	49.4	16.4	7.8	13.1
F-16	7	175	5.28	32.8	300	49.4	16.4	7.8	13.1
F-16	8	180	5.23	32.8	300	49.4	16.4	7.8	13.1
F-16	9	160	5.11	32.8	300	49.4	16.4	7.8	13.1
F-16	10	120	6.68	32.8	300	49.4	16.4	7.8	13.1
F-16	11	144	5.85	32.8	300	49.4	16.4	7.8	13.1
F-16	12	150	6.26	32.8	300	49.4	16.4	7.8	13.1