U.S. AIR FORCE

CHARACTERIZING THE ACCURACY OF DoD OPERATING AND SUPPORT COST ESTIMATES

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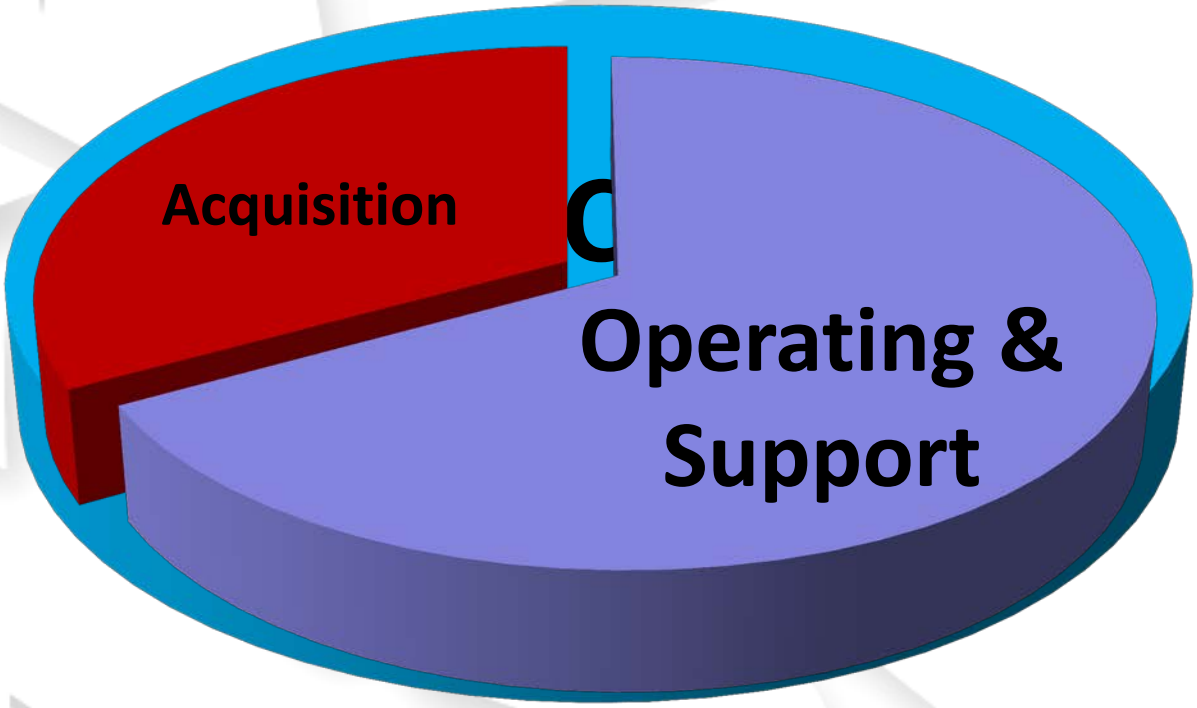
Life Cycle Cost



O&S Costs comprise 60-75% of Life Cycle Costs

DoD Cost Growth Studies (1972-08)

ACQUISITION COST GROWTH

1972: Choice Among Strategies for System Acquisition (RAND)
1972: Should Cost/Will Cost/Must Cost--A Theory on the Cause of Cost Growth (U. S. Army SSO)
1973: Cost Growth in Major Weapon Systems (GAO)
1973: Cost Overruns in Defense Procurement: A Problem of… (Northwestern University)
1974: The Study of Cost Growth of a Major Weapon System (NPGS)
1974: Bias in Initial Coat Estimates: How Low Estimates Can Increase the Cost… (RAND)
1974: A Cost Growth Model for Weapon System Development Programs (AFIT)
1975: A Model to Predict Final Cost Growth in a Weapon System Development Program (AFIT)
1976: Study of Weapon System Cost Growth (OSD)
1976: Statistical Analysis of the Effectiveness of Program Initial Conditions as Predictors… (NPGS)
1977: A General Technique for R&D Cost Forecasting (USAF Academy)
1977: Study of Factors Leading to Changes in Cost Estimates… (George Washington University)
1978: Methodology for Developing Total Risk Assessing Cost Estimates (U. S. Army MRDC)
1978: A Range of Cost Measuring Risk and Uncertainty in Major Programs (GAO)
1978: Financial Status of Major Federal Acquisitions (GAO)
1979: Inaccuracy of DoD Weapons Acquisition Cost Estimates (Committee on Govt Operations)
1979: An Overview of Acquisition Policy Effectiveness in the 1970s (RAND)
1984: On Estimating the Cost Growth of Weapon Systems (IDA)
1984: The Problem of Cost Growth (Management Consulting & Research, Inc.)
1986: Improving the Military Acquisition Process, Lessons from RAND Research (RAND)
1988: Weapons Cost: Analysis of Major Weapon Systems Cost and Quantity Changes (GAO)
1989: Acquiring Major Systems: Cost and Schedule Trends and Acquisition…(IDA)
1991: Estimating Potential Cost Growth of the Most Probable Cost Estimate (AFIT)
1993: Analysis of Weapon System Cost Growth (RAND); Pitfalls in Calculating Cost Growth…(RAND)
1996: The Defense System Cost Performance Database: Cost Growth Analysis Using SARs (RAND)
1999: The Impact of the Packard Commission's Recommendations on Reducing… (Air Force)
2000: Acquisition Trend Metrics in the Department of Defense (DAU)
2003: Estimating Procurement Cost Growth Using Logistic and Multiple Regression (AFIT)
2003: The Relationship Between Cost Growth and Schedule Growth (DAU)
2004: Surveying Cost Growth (OSD/AT&L)
2004: An Analysis of Aircraft Weapon Systems Cost Growth and Implementation… (AFIT)
2006: Historical Cost Growth of Completed Weapon System Programs (RAND)
2007: Is Weapon System Cost Growth Increasing (RAND)
2008: Sources of Weapon System Growth (RAND)

O&S COST GROWTH

None

Agenda

- **Study Motivation**
- **Methodology**
- **Results**
  - Annualized Unit O&S Cost (AUC)
  - Life Cycle Cost (LCC)
  - Total O&S Cost
- **Implications**
- **Validity**
- **Now What?**

Study Motivation

- **Premise: DoD needs to be able to characterize accuracy of O&S/LCC estimates for its programs**
  - Affordability!
- **Greater emphasis from OSD on this topic—**

> *"The strategic intent is to emphasize how O&S cost estimates will actively support key decisions throughout the system life cycle, rather than calling for O&S cost estimates simply for the sake of having an estimate."*

-- FY2010 Annual Report on Cost Assessment Activities, Director CAPE, Feb-2011

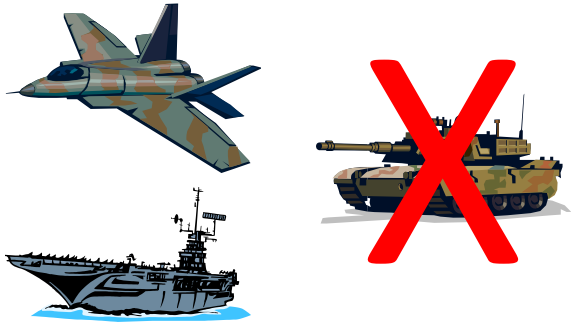
Recent O&S Cost Growth Studies

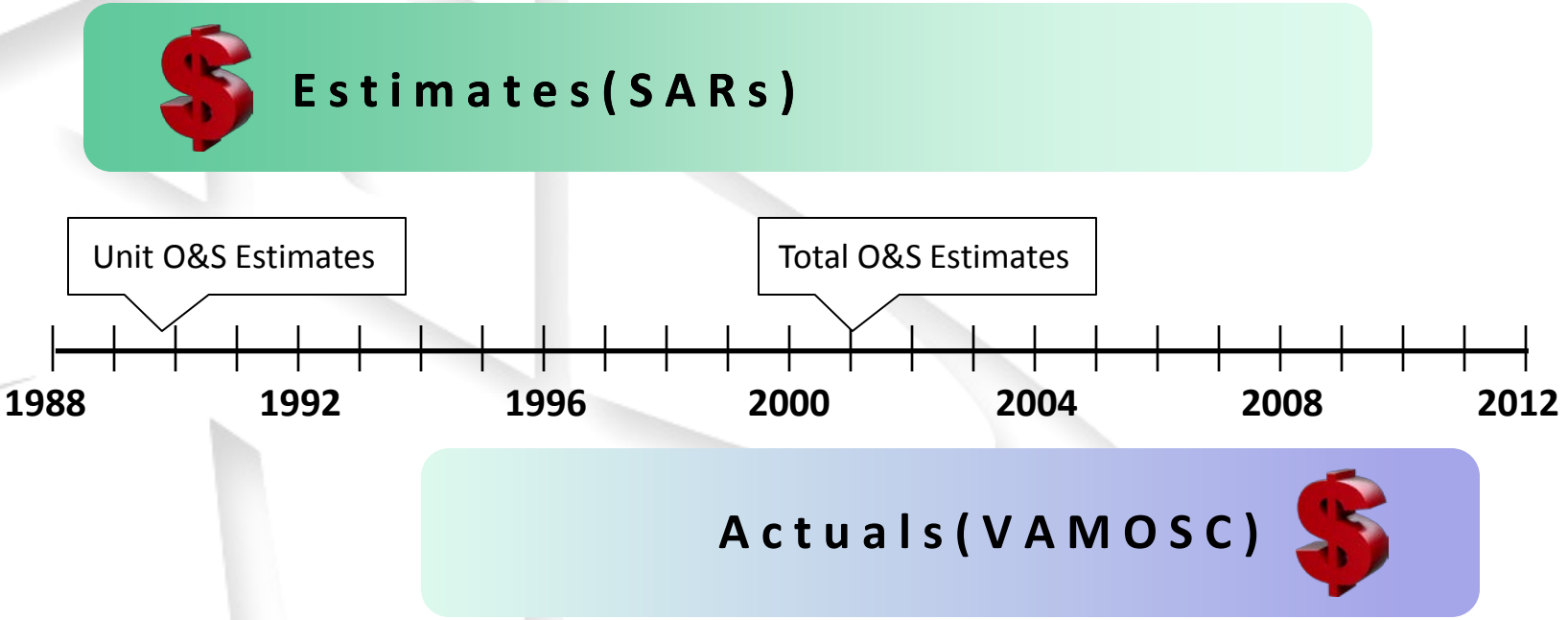
- **And then came WSARA…**
  - 4 O&S "cost growth" studies since 2009

#	Source	Year	# of Systems	Method	Quant. Results?
1	OSD	2009	34	Cost Growth in O&S Actuals	n/a
2	CNA	2009	23	Cost Growth in O&S Estimates	n/a
	CNA	2009	3	**O&S Estimates vs. O&S Actuals**	No
3	IDA	2010	1	Cost Growth in O&S Estimates	n/a
4	GAO	2010	5	Cost Growth in O&S Estimates	n/a
	GAO	2010	2	**O&S Estimates vs. O&S Actuals**	**Yes**

Methodology

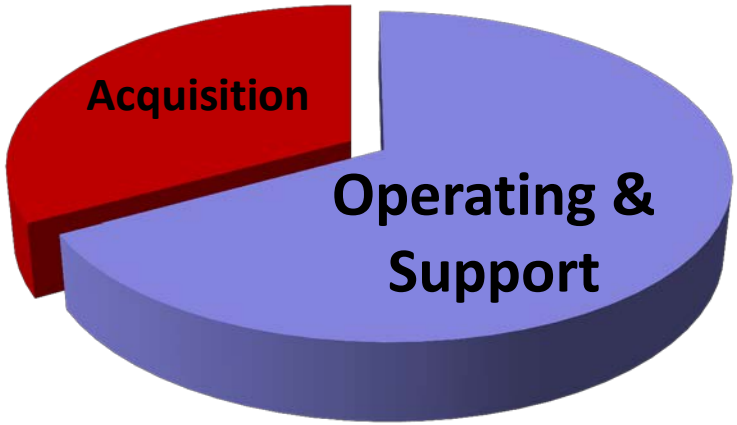
- **Three elements required**
  - Estimates, Actuals, and Elapsed Time
  - Predictions vs. “ground truth”





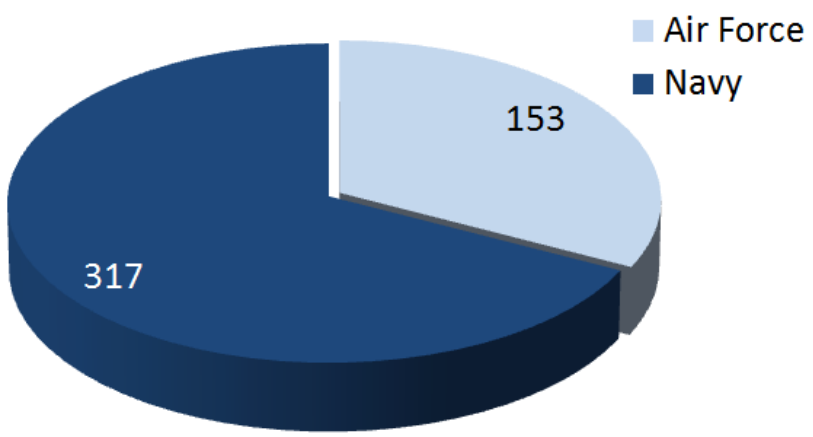
Definitions

- **O&S Cost**
  - Total cost to sustain weapon system after fielding
- **Annual Unit O&S Cost (AUC)**
  - Yearly cost to maintain per unit
- **Life Cycle Cost (LCC)**
  - Total cost to govt spanning all phases of the program's life
  - Essentially LCC = Total Acq Costs + Total O&S Costs

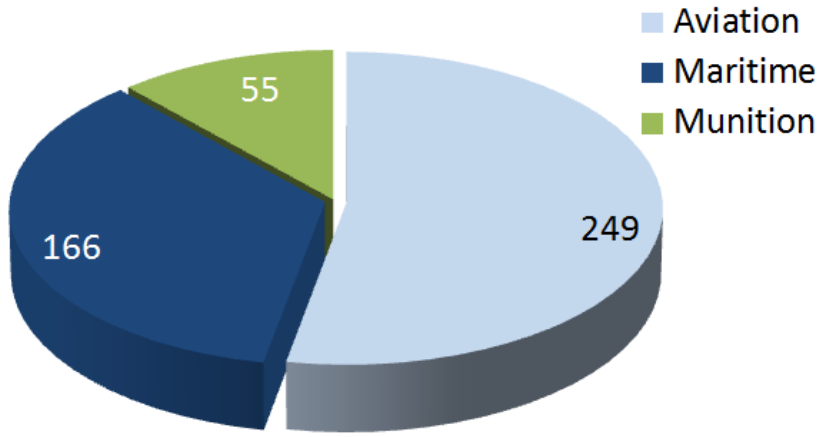


Summary Statistics

- 470 SARs (observations)
- 36 MDAPs (24 Navy, 12 Air Force)
- 53% Aviation, 35% Maritime



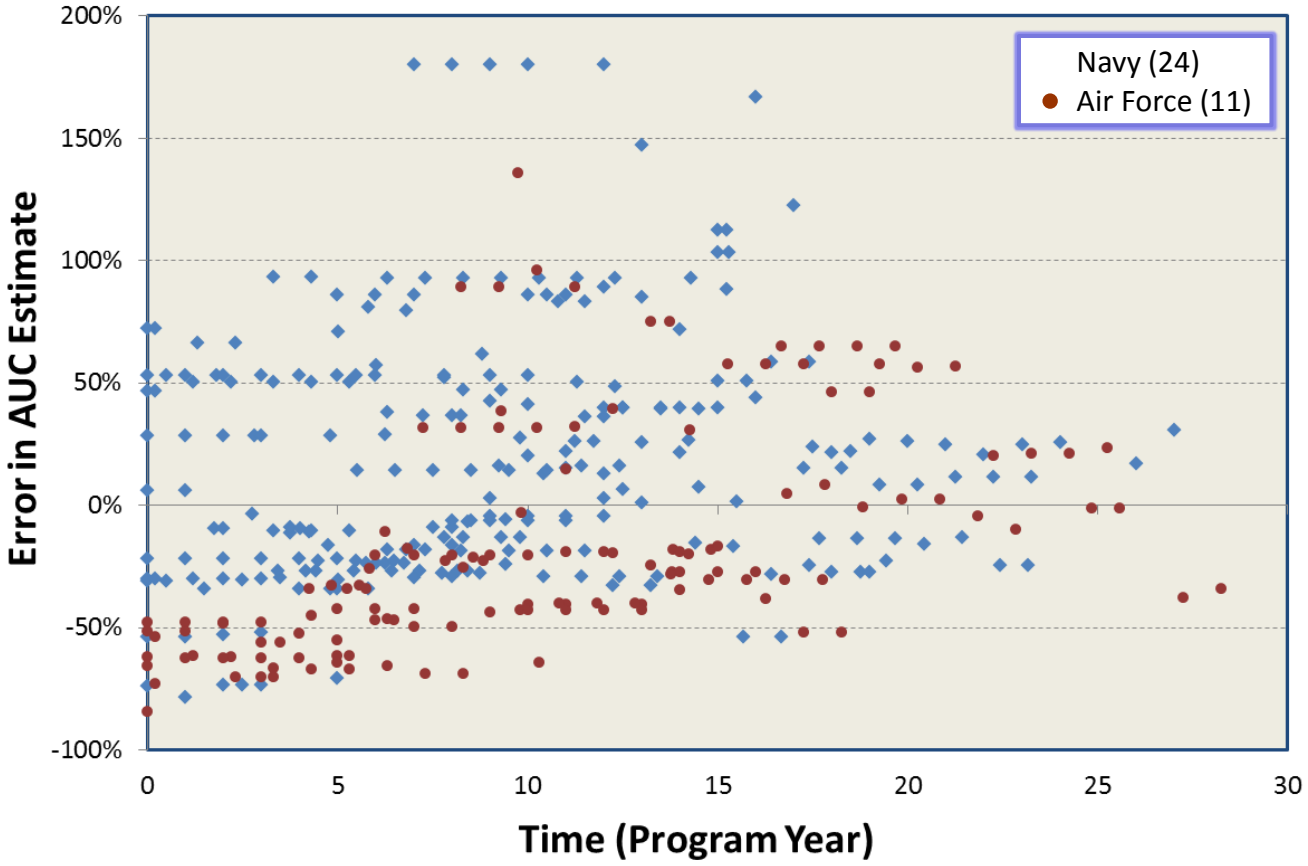
SARs By Service Component



SARs By System Type

AUC Estimate Errors

- **Overall estimate accuracy (392 cases)**
  - 84% of estimates had error >15%; 68% of estimates > 25%



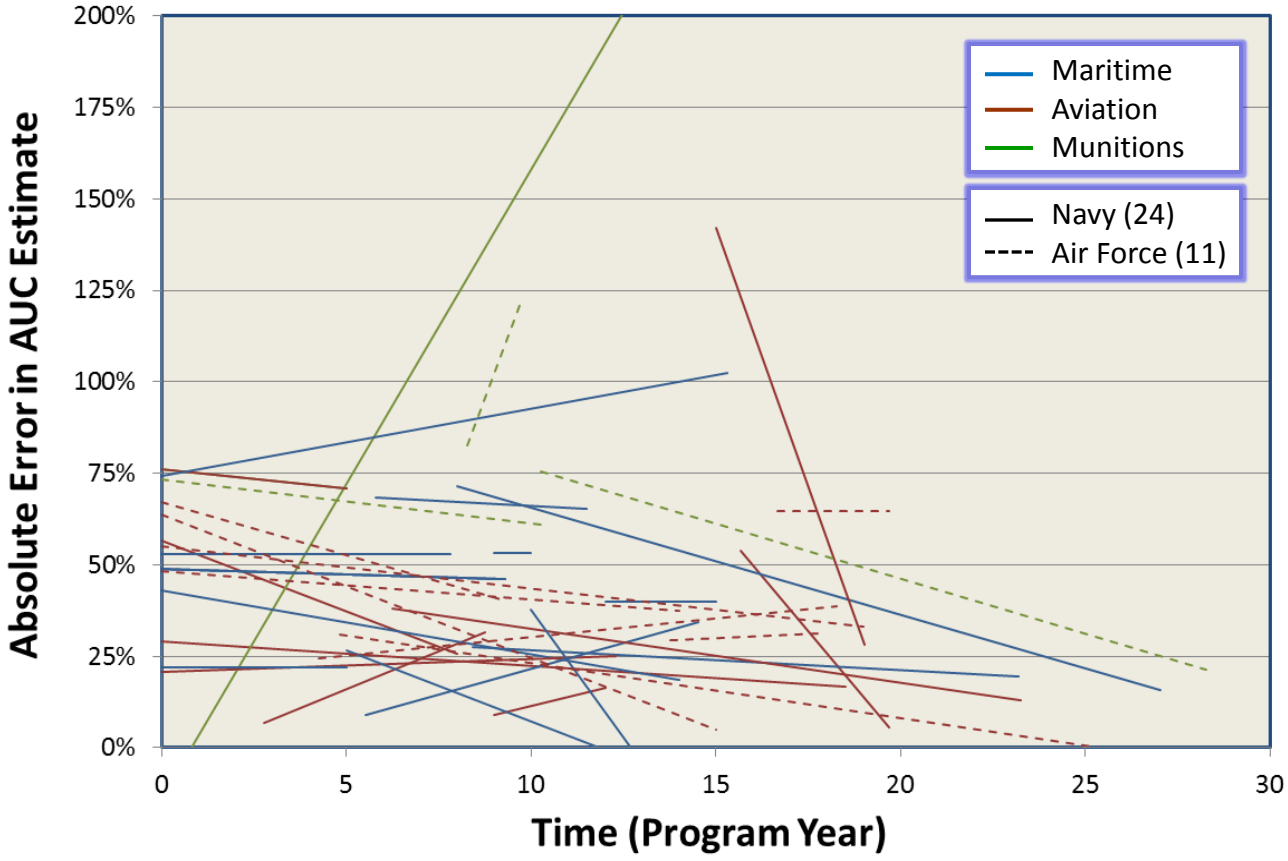
Mean Error	5.6%
Mean Abs. Error	41.2%

Navy Mean Error	18.4%
Navy Mean Abs. Error	40.4%

AF Mean Error	-17.7%
AF Mean Abs. Error	42.5%

AUC Estimate Errors

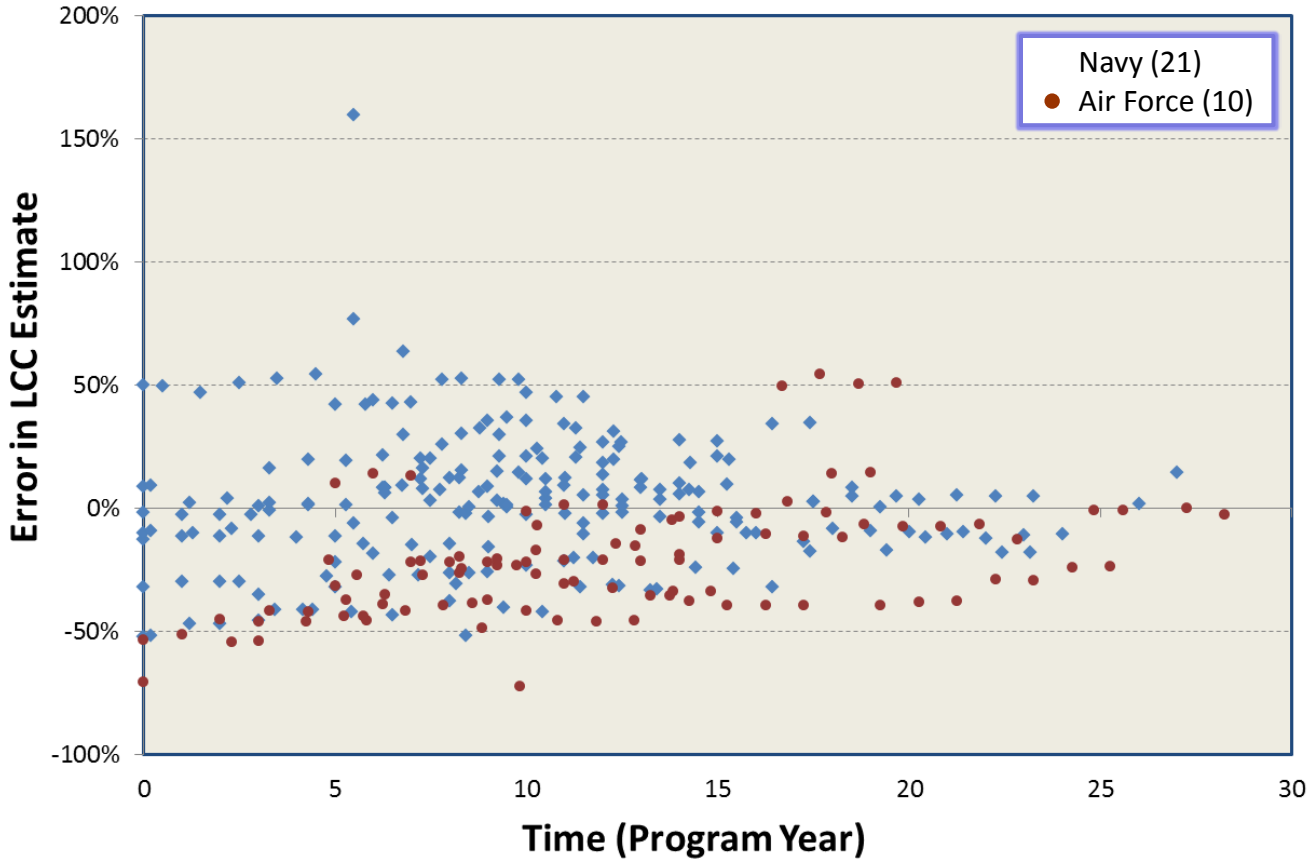
- **Accuracy trends over time (35 programs)**
  - For 15/35 programs, estimate accuracy did not improve over time



Mean Slope of Abs Error	-0.8% / year
Navy Mean Slope of Abs. Error	-1.7% / year
AF Mean Abs. Error	1.3% / year

LCC Estimate Errors

- **Overall estimate accuracy (317 cases)**
  - 56% of estimates had error >15%; 38% of estimates ≤ 25%



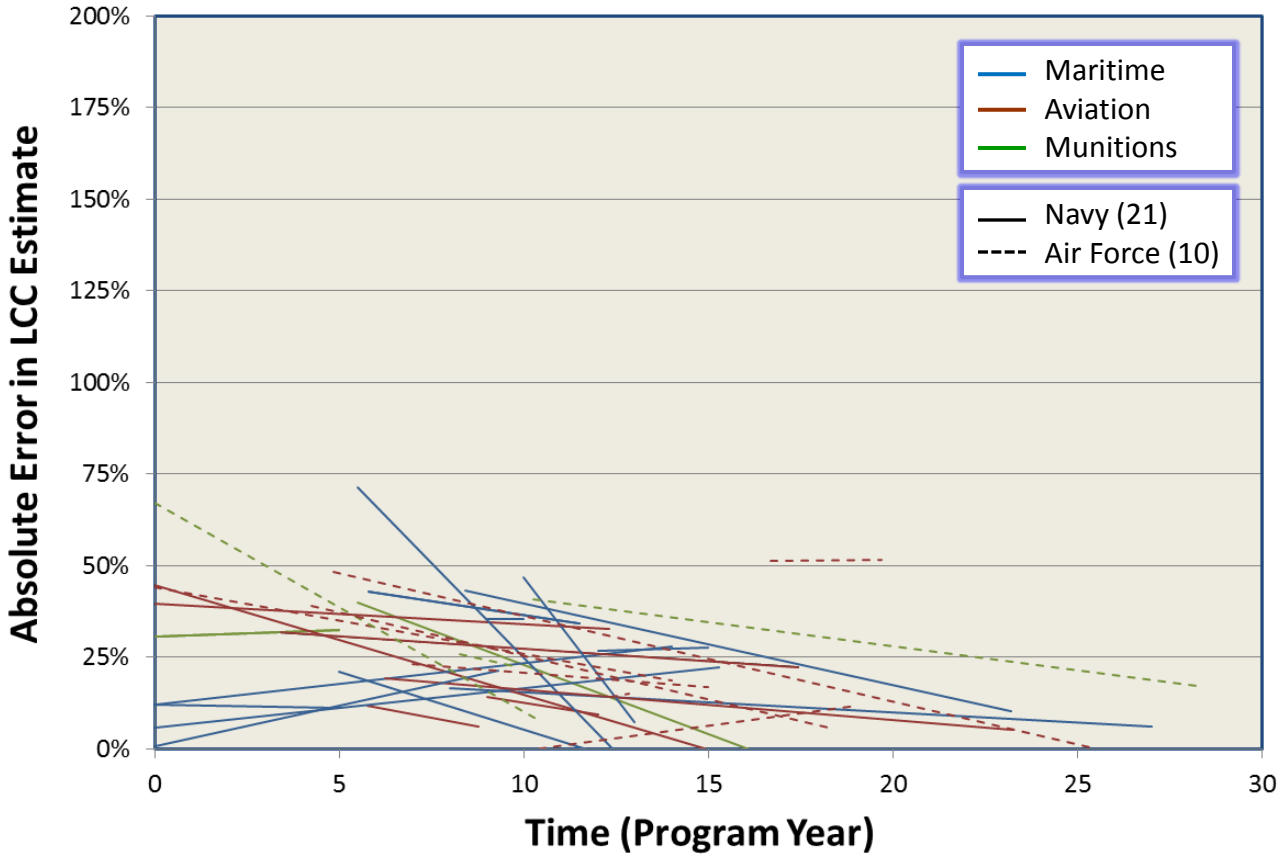
Mean Error	-4.7%
Mean Abs. Error	22.4%

Navy Mean Error	3.2%
Navy Mean Abs. Error	20.2%

AF Mean Error	-21.6%
AF Mean Abs. Error	27.1%

LCC Estimate Errors

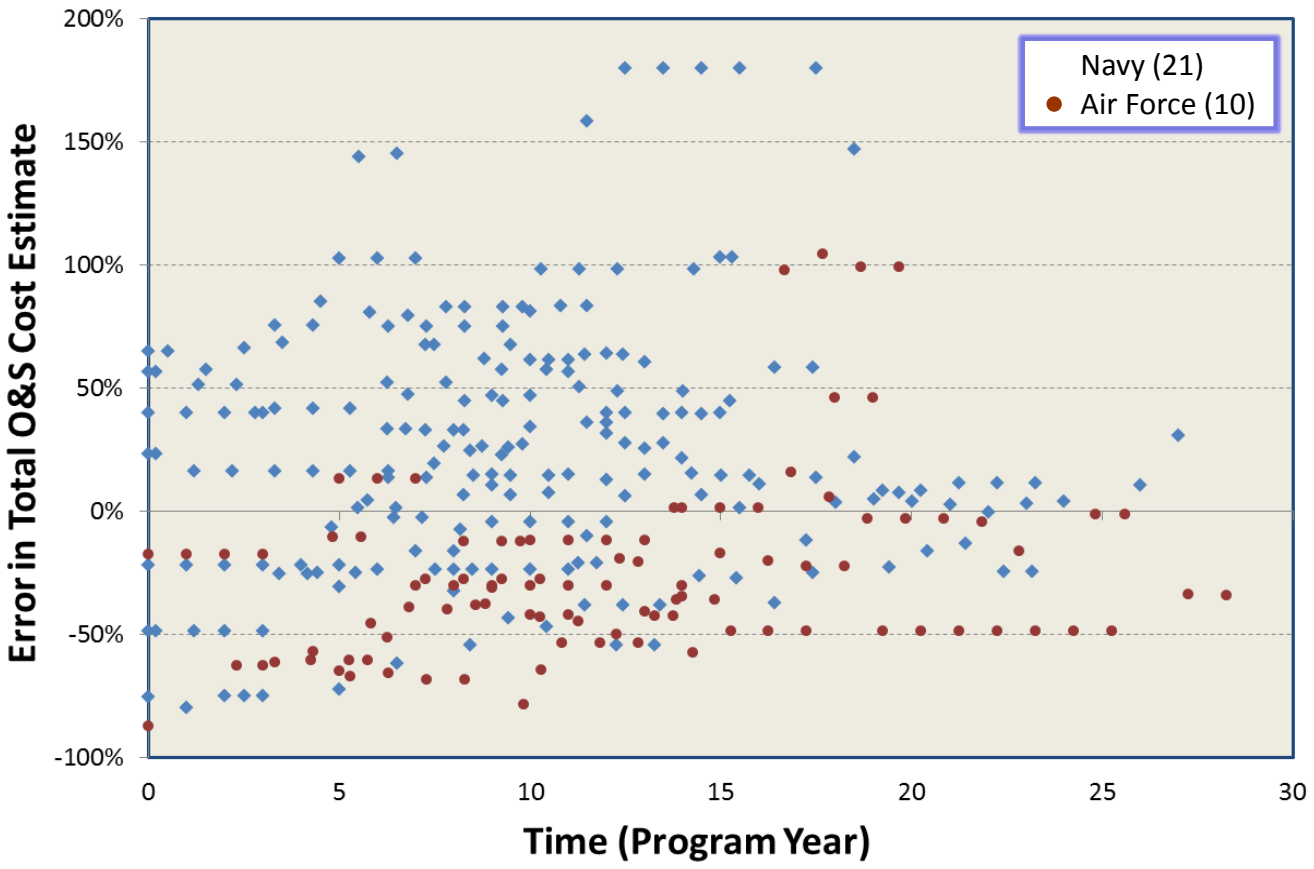
- **Trends Over Time (31 Programs)**
  - For 10/31 programs, estimate accuracy did not improve over time



Mean Slope of Abs Error	-1.7% / year
Navy Mean Slope of Abs. Error	-1.8% / year
AF Mean Abs. Error	-1.3% / year

Total O&S Cost Estimate Errors

- **Overall estimate accuracy (317 cases)**
  - 79% of estimates had error >15%; 62% of estimates ≤ 25%



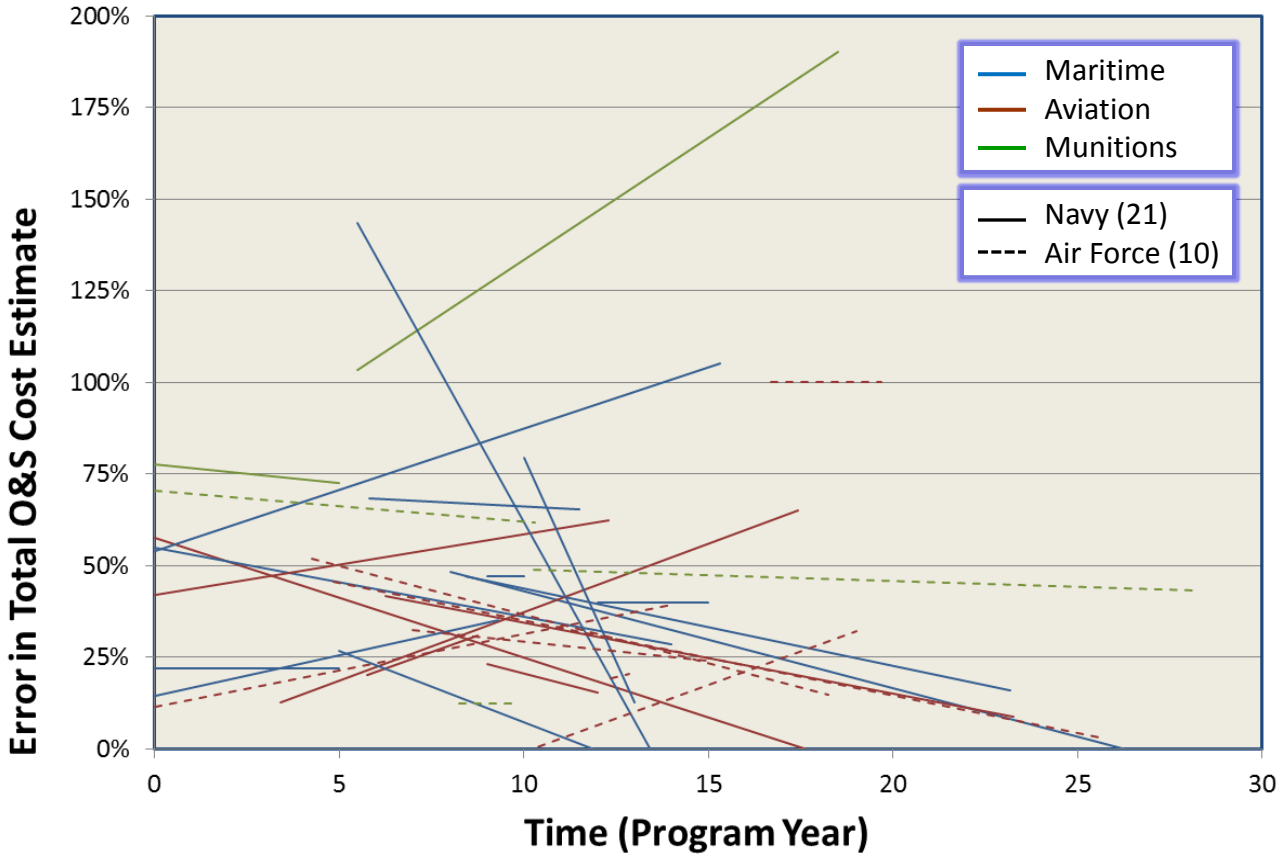
Mean Error	11.1%
Mean Abs. Error	43.1%

Navy Mean Error	28.2%
Navy Mean Abs. Error	46.1%

AF Mean Error	-25.6%
AF Mean Abs. Error	36.6%

Total O&S Cost Estimate Errors

- **Trends Over Time (31 Programs)**
  - For 15/31 programs, estimate accuracy did not improve over time



Mean Slope of Abs Error	-1.2% / year
Navy Mean Slope of Abs. Error	-1.9% / year
AF Mean Abs. Error	0.1% / year

Key Findings

- **Accuracy of O&S-based cost estimates is poor and improves little over time**
  - AUC Estimates
    - Magnitude of mean errors ~40%; reduces ~1% per year on average
  - LCC Estimates
    - Magnitude of mean errors ~20%; reduces ~1.5% per year on average
  - Total O&S Cost Estimates
    - Magnitude of mean errors ~40%; reduces ~1% per year on average
- **O&S cost estimates behave differently than acquisition cost estimates**
  - Consistently greater levels of inaccuracy
  - Do not converge in the time spans of consideration

More Key Findings

- **Error biases extend in both directions**
- **Estimate accuracy and trends vary significantly between the Navy and the Air Force**
- **Many other program elements exhibit significant relationships with estimate accuracy**
  - Type of system
  - Size of acquisition effort
  - Procurement Quantity
  - Cost Variance Trends

Opportunity to improve cost estimating…

Implications

- **Future Studies**
  - Invalidates premise of extant O&S characterization studies
- **Lack of Accuracy Impacts Funding**
  - Underestimating cost creates challenges for entire portfolio
  - Overestimating cost liability creates opportunity loss
- **Lack of Convergence Affects Budgeting Strategy**
  - Decision-makers may be under the (apparently) false impression that later cost estimates are more reliable

More Implications

- **Decision Analysis**
  - AUC frequently used to differentiate competing designs
  - LCC is discriminator between competing programs or comparing cost-effectiveness of modifying vs. initiating a new acquisition
    - Absolute accuracy less important than relative accuracy
    - Relative accuracy appears no better than absolute

Calls into question validity of value decisions based on AUC/LCC estimates

Validity?

Key Question

- **Is it valid to compare O&S cost estimates to actuals?**
  - Assumptions used to construct the estimates are often fundamentally different from what occurred in reality
    - Peacetime vs. war, commodity prices, healthcare costs, quantities, etc.
    - Uncertainty and long time horizon greatly complicate estimate
- **Corollary: Should programs be held accountable for O&S cost estimates?**

Validity?

Response

- **Is it valid to compare O&S cost estimates to actuals?**
  - Acq phase also lengthy and characterized by uncertainty
  - Why demand accuracy/accountability for estimates that apply to acquisition phase but not sustainment?
  - Is goal to have best estimate assuming current baseline is fixed or do we want best estimate in the real world of changing baselines?
- **Should programs be held accountable?**
  - Absolutely!
  - If estimates can't be accurate—
    - Why go to all the effort of building them?
    - Why base key budgetary/programmatic decisions upon them?

Now What?

- **Explore the "why"**
  - Not the fault of cost estimators! Process is flawed
- **Build cost estimating models based on findings here**
- **New model "corrects" original LCC estimates to achieve greatly improved accuracy**
  - "Macro-Stochastic" cost estimating

Summary

- **Importance of O&S cost estimating accuracy**
- **DoD lacks insight into current accuracy levels**
- **O&S cost estimates are very poor and improve little**
- **Patterns exist in estimate accuracy**
- **Opportunities exist to improve estimates**
- **Embrace Uncertainty!**
  - An otherwise “perfect” cost estimate constrained by today’s baseline is bound to be wrong tomorrow
  - Decision makers need an estimate that accounts for uncertainty

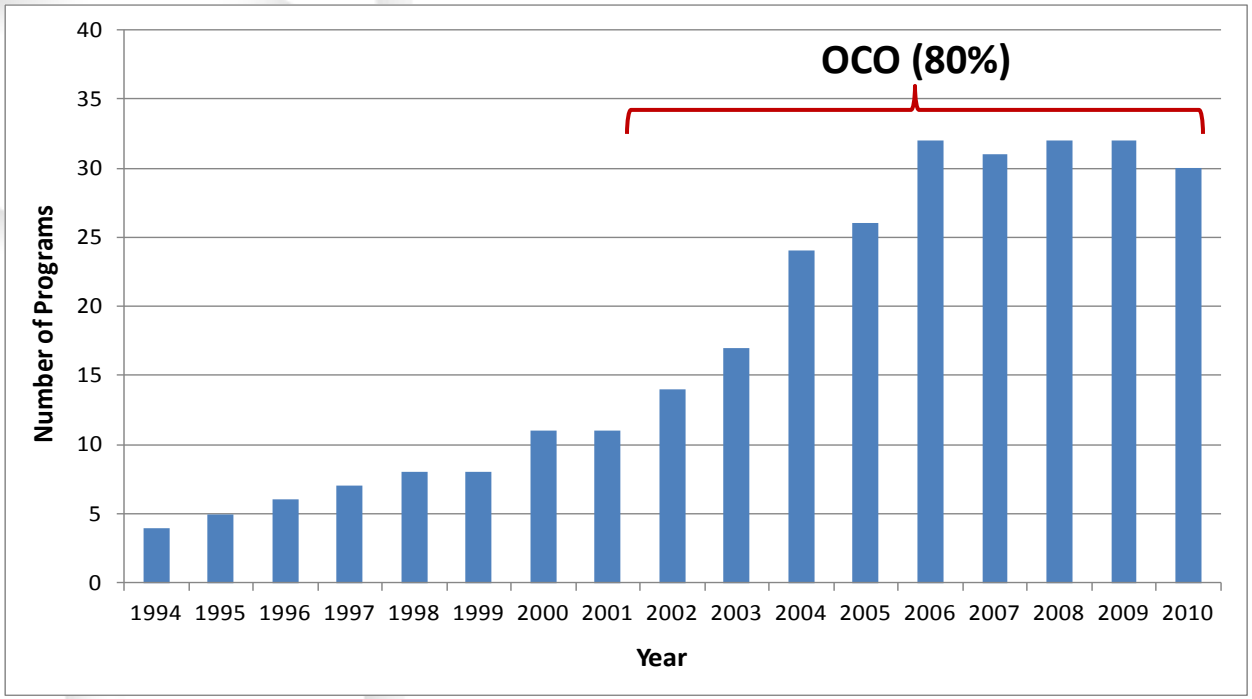
More Information

- **"A Proposed Methodology to Characterize the Accuracy of Life Cycle Cost Estimates for DoD Programs"**
  - *Procedia Computer Science*
- **"Characterizing the Accuracy of DoD Operating and Support Cost Estimates"**
  - *Journal of Public Procurement*
- **"A Macro-Stochastic Model for Improving the Accuracy of DoD Life Cycle Cost Estimates"**
  - *Journal of Cost Analysis and Parametrics*

BACKUPS

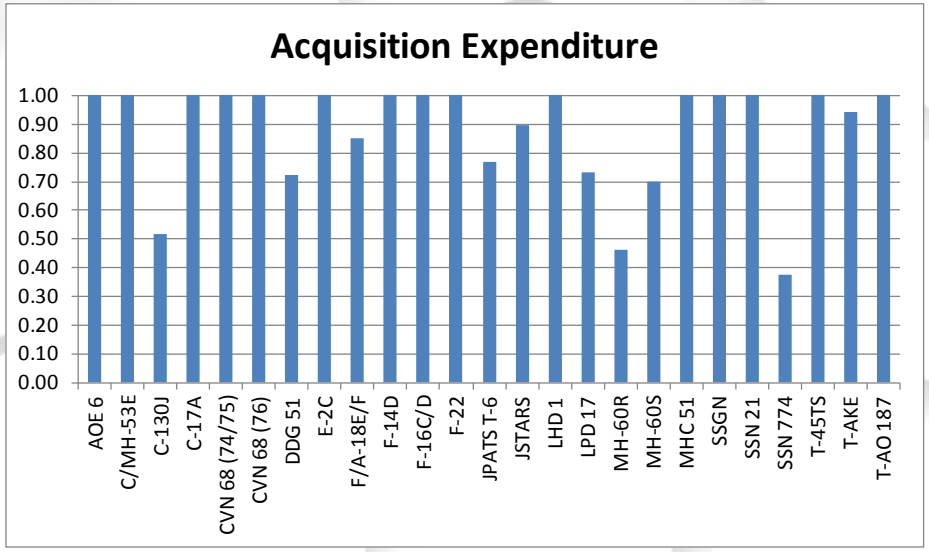
Methodological Concerns

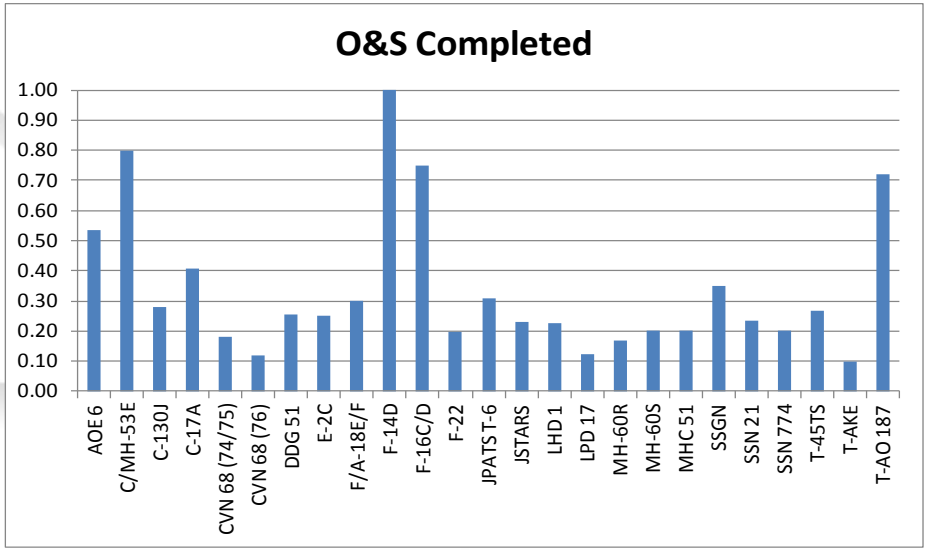
- **Inherent dataset biases**
  - Programs that provided “good” data
  - Programs that “succeed”
  - Phasing of actuals (majority of actual costs incurred during war)



Methodological Concerns

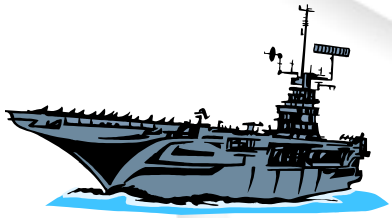
- **Incomplete Data**
  - Must infer LCC from partial lifecycle actuals
  - Op Service Life is held constant
  - No escalation factor applied (i.e., CGAI)
    - May skew results, but not likely to change general findings

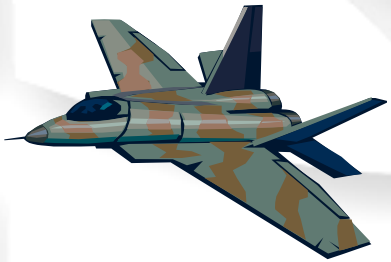




Methodological Concerns

- **Data Integrity**
  - Errors in Prediction: Reliability of SARs
  - Errors in Actuals: Reliability of VAMOSC
- **Scope of Applicability**
  - MDAPs
  - Air Force and Navy programs
- **Precursor paper details full methodology**





Mixed Models

- **Mixed models compensate for correlated errors**
  - Can account for subject observations not independent
  - Allow data to exhibit inherent correlations and non-constant variability that arise from the data hierarchy
  - Some regression parameters are population-specific (fixed-effects)
  - Other parameters are subject-specific (random-effects)

$$y = X\beta + Z\gamma + \varepsilon$$

y = Observed data vector
X = Fixed-Effect Design Matrix
β = Vector of Fixed-Effect Parameter Estimates (same for all subjects)
Z = Random-Effect Design Matrix
γ = Vector of Random-Effect Parameter Estimates (varies by subject)
ε = Vector of Residual Errors