Naval Center for Cost Analysis (NCCA)

Unmanned Aerial Vehicle Systems Database and Parametric Model Research

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Outline of Presentation

- Objective
- Data collection
- UAV database
- Cost Estimating Relationship
  - Development
  - Procurement
  - O&S
- Summary
- Next steps

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Objective

- Collect cost, technical and programmatic data for Army, Navy and Air Force UAS programs
- Develop Cost Estimating Relationships (CERs) for development, production and O&S cost elements
- Publish UAS data books and handbook w/ CERs

DoD Tri-service collaborative effort
Sponsored by NCCA and ODASA-CE
Data support from AFCAA, NAVAIR, ASC, and AMCOM

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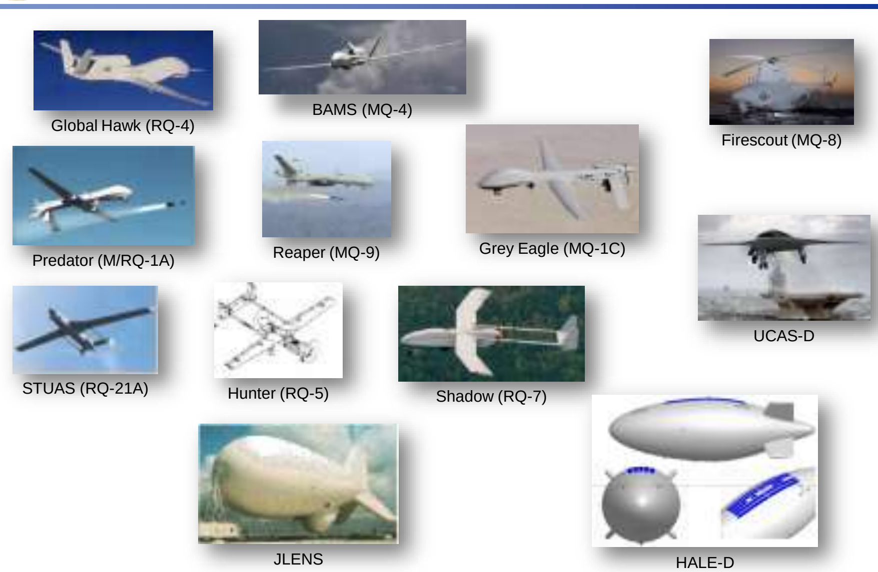
UAS Programs in Scope



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Data Collection

- Data was collected for Unmanned Aerial Systems (UAS) that includes UAV, Ground Control Systems (GCS) and Payloads
- Data collection efforts included trips to NAVAIR, prime contractors
  - Data sources such as CSDRs, CPRs, contractor internal accounting documents, Electronic Document Archive (EDA), Aviation Cost IPT forum, fact sheets, interviews with SMEs and program offices in Navy, Army, and Air Force
- Payload data was collected from CARDs, ACDB database and C4ISR program offices with support from ODASA-CE
- Operating and Support (O&S) cost and technical data was collected from AFTOC (cost) and AFCAP (technical & programmatic) databases
  - Global Hawk, Predator and Reaper have actuals

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Data Collection

- Acquisition cost data was collected and mapped using MIL-HDBK 881-A WBS
  - Many programs in the study were developed and produced before 2005 under 881-A
  - Airframe and Propulsion cost data was available to the WBS third level, other data only supported at the second level
- O&S cost data mapped using 2007 CAIG O&S Guide structure:
  - 1.0 Unit Level Manpower
  - 2.0 Unit Operations
  - 3.0 Maintenance
  - 4.0 Sustaining Support
  - 5.0 Continuing System Improvements
  - 6.0 Indirect Support

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Data Collection

- Technical and programmatic data sources included:
  - CARDs
  - Technical requirements Documents (TRDs)
  - Test and Evaluation Master Plans (TEMPs)
  - Integrated Master Schedules (IMSs)
  - SARs
  - Defense Acquisition Executive Summaries (DAESs)
  - Program Office Briefings
  - International Helicopter Society (IHS)
  - JANE'S Defense & Security Intelligence & Analysis
  - Payload data fact sheets from contractors

Data organized into summary spreadsheets and Data Books for each program

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Data Books

UAV Program	Data Book
Navy/AF High Priority	
Global Hawk (RQ-4)	Data book-N01--GH-RQ-4
Predator-A (MQ-1)	Data book-N02-Predator-MQ-1
VTUAV (Fire Scout) (MQ-8)	Data book-N03-VTUAV-MQ-8
BAMS (MQ-4)	Data book-N04-BAMS-MQ-4
Navy/AF Secondary	
Reaper (Predator-B) (MQ-9)	Data book-N05-Reaper-MQ-9
Hunter (RQ-5)	Data book-N06-Hunter-RQ-5
Shadow (RQ-7)	Data book-N07-Shadow-RQ-7
UCAS-D (X-47B)	Data book-N08-UCAS-D-X-47B
STUAS (RQ-21A)	Data book-N09-STUAS-RQ-21A
Army High Priority	
HALE-D	Data book-A01-HALE-D
JLENS	Data book-A02-JLENS
Army Secondary	
Gray Eagle (MQ-1C)	Data book-A03-GE-MQ-1C
Hummingbird (A160) (YMQ-18)	Data book-A04-Hummingbird-A160

- Data books created by program
  - Folders:
    - I._SARs & DAES
    - II._CARD
    - III._Technical
    - IV._Schedule
    - V._Budget
    - VI._Cost
    - VII._Miscellaneous

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Data Collection

- Technical and Programmatic data was collected as follows:

Weight Data (lbs)	Geometry/Structure	Propulsion Characteristics	Performance Characteristics
Total Weight/Max Take-off	Fuselage Length	Propulsion Type	Speed – Loiter
Air Vehicle Empty Weight	Wingspan	Propulsion Model	Service Ceiling
Air Vehicle Empty Weight	Hull Volume	Propulsion Thrust	Speed – Cruise
Air Vehicle Empty Weight	Fuselage Diameter	Propulsion Horsepower	Speed - Top ("Dash Speed")
Mission Payload Weight	Airframe Material Type	Propulsion Manufacturer	Service Ceiling
	Airframe Manufacturer		Mission Altitude
			Radius of Action (Range)
			Time on Stations
			Max Endurance from T/O to Landing
			Take-off/Launch Type
			Recovery/Landing

Payload Data
Total Weight
Electronics Unit Weight
Turret Weight
Gimbal Weight
Altitude
EO Resolution
IR Resolution
Tracking
First Year of Production
Power Requirement
Laser Rangefinder/Designator
LOS Stabilization

Programmatic Data
Contract start and end dates
Quantities

Summary of Cost Data Collection

Program	Development	Production	O&S	Payload
Navy/AF High Priority				
Global Hawk (RQ-4)	X	X	X	X
Predator-A (MQ-1)	X	X	X	X
VTUAV (Fire Scout) (MQ-8)	X	X	Estimates	X
BAMS (MQ-4)	X		Estimates	X
Navy/AF Secondary				
Reaper (Predator-B) (MQ-9)		X	X	
Hunter (RQ-5)		X		X
Shadow (RQ-7)	X	X		
UCAS-D (X-47B)	X			
STUAS (RQ-21A)	X			
Navy/AF Tertiary				
Avenger (Predator-C)	Excluded for lack of data			
J-UCAS (X-45)	Excluded for lack of data			
K-MAX	Excluded for lack of data			
Army High Priority				
LEMV	Excluded for lack of data			
HALE-D	X			
JLENS	X		Estimates	X
Army Secondary				
Grey Eagle (MQ-1C)	X	X	Estimates	X
Hummingbird (A160) (YMQ-18)	X			
Army Tertiary				
Global Observer	Excluded for lack of data			

- UAS Vehicle Data set includes:
  - 11 Development
  - 7 Production
  - 3 O&S Programs
- Payload Data set includes:
  - 2 Development
  - 7 Production programs

Data Analysis

- Cost data was mapped to 881-A WBS
- Service specific OSD inflation indices were utilized to normalize the cost data to FY13$
- Unit Theory Cost Improvement Curve analysis was performed on the development and production air vehicle lot data
- Rate Curves were evaluated, but were not statistically significant
- CERs were developed using regression statistics for development, production and O&S phases

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Cost Improvement Curve Analysis

Air Vehicle Production

	Programs					
Statistics	**UAS #1**	**UAS #2**	**UAS #3**	**UAS #4**	**UAS #5**	**UAS #6**
Unit Curve Slope	91.7%	98.4%	110.4%	86.4%	111.6%	87.7%
R Square	88.6%	15.0%	44.9%	100%	61.8%	89.6%
Adjusted R Square	82.9%		17.4%		23.5%	87.5%
Standard Error	0.051	0.062	0.229		0.169	0.071
Observations	4	3	4	2	3	7
F	15.58	0.16	1.63		1.61	43.05
Significance F	0.059	0.755	0.330		0.424	0.001

Program	Confidence Interval (CI) for cost improvement
UAS #1	75% CI for the exponent translates to a slope between 88.6% and 95.0%
UAS #2	75% CI for the exponent translates to a slope between 89.4% and 108.3%
UAS #3	75% CI for the exponent translates to a slope between 97.5% and 125.1%
UAS #4	N/A
UAS #5	75% CI for the exponent translates to a slope between 90.6% and 137.4%
UAS #6	75% CI for the exponent translates to a slope between 85.5% and 90.0%

UAV programs often receive continuous in-line improvements

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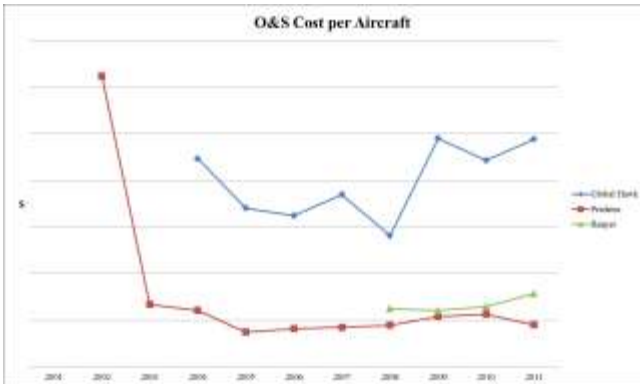
O&S



This figure shows the total O&S cost per aircraft for the available data. Note the spike in Global Hawk beginning in 2009. Analysis at the next lower level indicates the unit costs are driven by continuing system improvements and maintenance costs.

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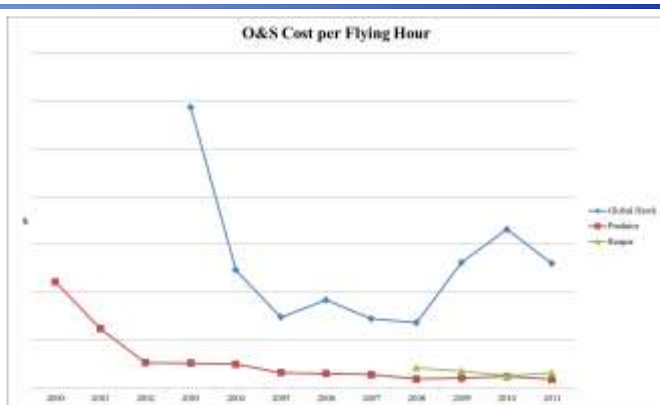
O&S



This figure shows O&S costs per flying hour for the available data.

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CER Summary

UAS System WBS Structure	CER
Total Development	No Recommendation
1.0 Air Vehicle	*First Lot Air Vehicle Recurring Unit Cost = f(Maximum Take Off Weight)*
	First Lot Air Vehicle Recurring Unit Cost = f(Service Ceiling)
1.1 Airframe	*First Lot Air Frame Recurring Unit Cost = f(Payload)*
1.2 Propulsion	*First Lot Propulsion Recurring Unit Cost = f(Engine Weight)*
2.0 Payload	*First Lot Payload Average Unit Cost = f(Weight, whether Radar or not)*
3.0 Ground/Host Segment	
3.1 Ground Control Station	No Recommendation
4.0 UAV System Integration, Assembly, Test and Checkout	Air Vehicle, Payload, and Ground/Host Segment CERs Include this element.

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CER Summary

UAS System WBS Structure	CER
5.0 System Engineering/Program Management	
Development	*Total SEPM cost = f(Total Hardware $)*
Production	*Total SEPM cost = f(Total Hardware $)*
6.0 Test & Evaluation	
Development	*Development System Test and Evaluation = f(Total Hardware $)*
Production	*Production System Test and Evaluation = f(Total Hardware $)*
7.0 Training	
Development Training	*Total Training Costs as a % of Total Recurring Hardware $ Mean , Median, Standard Deviation*
Production Training	No Recommendation
8.0 Data	
Development Data	*Total Data = f(Total Recurring Hardware $)*
Production Data	*Total Production Data = f(Total Recurring Hardware $)*

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CER Summary

UAS System WBS Structure	CER
9.0 Peculiar Support Equipment	
Development Tooling	*Non-recurring Tooling Costs as a % of Total Recurring Hardware $* *Mean , Median, Standard Deviation also provided*
Production Tooling	*Non-recurring Tooling Costs as a % of Total Recurring Hardware $* *Mean , Median, Standard Deviation also provided*
10.0 Common Support Equipment	*Total Common Support Equipment Costs as a % of Total Recurring Hardware $* *Mean , Median, Standard Deviation also provided*
11.0 Operational/Site Activation	*Total Operational/Site Activation Costs as a % of Total Recurring Hardware $* *Mean , Median, Standard Deviation also provided*
12.0 Industrial Facilities	No Recommendation
13.0 Initial Spares and Repair Parts	*Total Initial Spares and Repair Parts Cost as a % of Total Recurring Hardware $* *Mean , Median, Standard Deviation also provided*

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O&S CERs

CAIG O&S CES Structure	CER
1.0 Unit-Level Manpower	*Unit Level Manpower Cost = f(Civilian, Officer, Enlisted Headcounts)*
	Unit Level Manpower Cost = f(Total Aircraft Inventory)
2.0 Unit Operations	*Unit Operations Cost = f(Operating Hours)*
	Operating Hours = f(TAI)
3.0 Maintenance	*Maintenance Unit Cost in = f(MTOW , Age, TAI)*
4.0 Sustaining Support	*Sustaining Support Cost = f(Total Hours)*
5.0 Continuing System Improvements	No Recommendation
6.0 Indirect Support	*Indirect Support Costs = f(Number of Systems)*

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CER Example

Air Vehicle

Program	Development	MTOW (lbs)	Rotary	Air Vehicle Recurring Unit Cost (FY13$K)
BAMS MQ-4C	1	32,250	0	
Fire Scout MQ-8B	1	3,150	1	
Gray Eagle MQ-1C	1	3,283	0	
Predator RQ-1A	1	2,120	0	
Shadow RQ-7A	1	350	0	
Fire Scout MQ-8B	0	3,150	1	
Global Hawk RQ-4B (Block 20)	0	31,456	0	
Global Hawk RQ-4A (Block 10)	0	26,700	0	
Hunter RQ-5	0	1,620	0	
Pioneer RQ-2B	0	447	0	
Predator RQ-1A	0	2,120	0	
Reaper MQ-9A	0	10,500	0	

12 data points

Development = Dummy variable denoting manufacturing phase
0 = Production
1 = Development
MTOW = Maximum Takeoff Weight in pounds
Rotary = Dummy Variable denoting rotary wing aircraft
0 = Fixed Wing
1 = Rotary Wing
Air Vehicle Recurring Unit Cost = Recurring cost for the applicable development or production contract as identified in the cost report.

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CER Example

Air Vehicle

#	Equation	R^2 adj %	n	t-value > 90%	MAD (%) (unit)	CV (%) (unit)	3 < 30%	SE (unit)	Comments
1	*f*(MTOW, Dev, Rotary)	97	12	Y	17	19	10	6087	All Data points
2	*f*(MTOW, Dev, Rotary)	96	11	N	18	25	9	6634	Less BAMS
3	*f*(MTOW, Dev, Rotary)	96	11	Y	18	25	9	6196	Less BAMS
4	*f*(MTOW)	92	12	N	41	24	6	4204	All Data points
5	*f*(MTOW)	89	11	N	50	30	5	4319	Less BAMS
6	*f*(MTOW)	94	11	N	28	30	7	5137	Less BAMS
7	*f*(MTOW)	99.8	11	Y	28	29	8	4464	Less BAMS

- Equations 1 through 3 are log-linear and include dummy variables to adjust for a program in development and whether the platform is rotary or not. Good statistics were observed in Equation 1.
- With Equation 1, 10 of the 12 observations were predicted within 30% of the actual values. The remaining 2 data points were within 60%.
- Equations 2 and 3 remove the BAMS data point due to it being less than 50% complete. Equation 3 is the same function form as Equation 2 without the intercept.
- The limitations with models in Equations 1 through 3 may be in regard to rotary wing UAVs: the model only has one program in the dataset representing rotary wing, Fire Scout, and was removed
- Equations 4 through 7 analyzed a MTOW relationship only.
- Equations 4 and 5 are linear.
- Equations 5 through 7 removed BAMS.
- Equations 6 and 7 are log-log relationships.
- Equation 7 removes the intercept due to being insignificant.

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CER Example

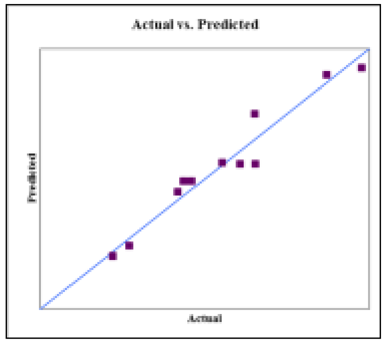
Air Vehicle (cont)

CER Summary:

Equation 7
Y = *f*(MTOW)

Variables:	
Y	= First Lot Air Vehicle Recurring Unit Cost
MTOW	= Maximum Takeoff Weight in pounds
Statistics:	
	Adjusted R^2 = 99.8
	SE = 0.350 (4464 unit space)
	Df = 10
	t(MTOW Coefficient) = 77.489
Data Ranges:	
	350 <= MTOW <= 31,456
80% Prediction Interval (2,500) = +65%, -39%	

Below is the plot of the estimates using the CER versus the actuals.



Complete data set, data plots, and CERs are now available

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Summary

- Data books with metadata for priority programs is complete
- UAS Database and Handbook have been published
- O&S historical actuals was limited to Air Force programs
  - Any use of the CERs for analysis should be limited to similar platforms in terms of size, mission type, support concept

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From Here…

- Combine UAS and manned aircraft into single data sets—many key subsystems are similar in higher end of MTOW scale
- Understand historical anomalies in certain programs
- UAS programs are growing and need to ensure the database and analysis is frequently updated to account for new data and technologies

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