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QuickCost 5.0
A Space Project Cost Model

Joe Hamaker PhD, CPP, CCA

The Millennium Group International

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A Common Mindset

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- The assertion that most NASA space flight missions can be estimated with reasonable accuracy quickly and simply is not understood by many managers
  - "My project isn't like those others*"
    - Which is to be interpreted as ….
      - My project won't have any problems that our team from Lake Wobegon cannot handle
      - We will undoubtedly deliver under cost and in less time than we have estimated—just give us the money and stay out of our way
    - Alternate assertion: A good estimate is only possible build up from the details

*"Look on my works, ye mighty, and despair!"
from *Ozymandias* by Percy Byshe Shelley

QuickCost 5.0 Overview

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- QuickCost is dedicated to the proposition that acceptable estimating accuracy is obtainable working at the top levels of the project WBS (quickly)
- Originally, and through Version 4.0, QuickCost estimated automated spacecraft science missions ("SMD type missions")
- Versions 5.0 adds 4 additional models…

Major focus of this briefing →

1. Satellite (Spacecraft Bus + Instruments) QuickCost Model
2. Satellite Trade Studies Model (A More Detailed Version of the Satellite QuickCost Model)
3. Space Module and Transfer Vehicle QuickCost Model
4. An X-Vehicle QuickCost Model
5. A Liquid Rocket Engine Cost Model

QuickCost 5.0 Excel Worksheets

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Tab Guide	
Worksheet Tab	**Worksheet Content**
Satellite DB	This is the database of 131 historical automated satellites/spacecraft missions
Satellite Model	This is the main automated satellite cost model
Satellite Trades Model	A version of the automated satellite model with more independent variables for technical trade studies
Module & Transfer Vehicle DB	This is the database of modules and transfer vehicles
Module & Transfer Vehicle Mode	This is the module (cargo and human) and transfer vehicle (propulsive) cost model
X Vehicle DB	This is the database of X vehicles (aircraft, rockets, combined cycle)
X Vehicle Model	This is the X Vehicle cost model
Liquid Rocket Engine DB	This is the database of liquid rocket engines
Liquid Rocket Engine Model	This is the liquid rocket engine cost model
Model Stats	Statistics associated with the various models
Outliers	An analysis of outliers in the satellite database
IV Table	Definition of independent variables
Rule of 166	Heuristic used where DDT&E/TFU and/or bus/instruments break where not available
QC Versions	A history of QuickCost versions

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QuickCost 5.0 Overview

- Uses statistically validated cost estimating relationships (CERs) and schedule estimating relationships (SERs)
  - Derived using OLS regression analysis
- Based on databases of historical missions
- Provides prediction intervals on cost estimates allowing the user to specify desired level of confidence (70% confidence level is the default)
- Satellite model provides time-phased estimates of
- Spacecraft and instrument cost
- Ground systems cost
- Launch services cost
- MO&DA cost
- Project schedule span
- Project office staffing

	Spacecraft	Ground Systems	Launch Services	MO&DA
Satellite Model	✓	✓	✓	✓
Satellite Trades Model	✓	✓	✓	✓
Modules and Transfer Vehicle Model	✓	✓	✓	✓
X-Vehicle Model	✓	✓	X	X
Liquid Rocket Engine Model	Engine DDT&E and TFU Only			

Satellite Cost Model Independent Variables (Chart 1 of 2)

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- Satellite cost model uses 8 independent variables which should be readily available (or capable of being estimated) early in concept definition
  - Where's it going?
    - *Destination* (Earth 0rbital =0, Planetary=1)
  - When are we starting design?
    - *ATP* (4 digit calendar year – *1960)*
  - How long are we operating?
    - *LifeMonths* (months)
  - What is the relative complexity of the instrument suite?
    - *InstComp* (0 to 100th percentile)

Satellite Cost Model Independent Variables (Chart 2 of 2)

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- What is its expected mass?
  - *TotalDryMass* (kg)
- What is its expected total power (LEO solar flux equivalent)?
  - *Power* (in watts) for total spacecraft and instruments
    - In cost estimating, power must be normalized to some constant solar flux (e.g. flux at Mars is ~half LEO)
    - In QuickCost all power specifications are in terms of LEO equivalent (e.g. if 500 watts is needed at Mars, we have to build and pay for an array that is more like 1000 watts here on earth)
- What is the heritage of the bus?
  - *BusNew*
    - 20% of totally off-the-shelf
    - 60% average
    - 100% all new
    - 130% (or more) for all new and pushing state-of-the-art
- What is the heritage of the total instrument suite (weighted average of all instruments)?
  - *InstNew*
    - Same scale as bus (but instruments typically have less heritage (high higher new design factors)

QuickCost 5.0 Satellite Model
Major Groundrules and Assumptions

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- Quickcost 5.0 satellite database is in 2004 dollars
  - Model output in any year dollars specified
- Model embedded cost…
  - Contractor fee fee
    - Embedded in CADRe costs and added as 10% for other sources such as NAFCOM database)
  - Government civil service and infrastructure ("full cost")
    - Non JPL pre FY2004 cost converted to full cost with 1.17 factor
    - Post FY2004 cost assumed to be full cost
  - Reserve corresponding to the user specified confidence level
- Ground systems cost separately estimated
  - Reflects database average of new versus modification cost
- Launch services based separately estimated
- MO&DA cost separately estimated
  - MO&DA includes facility maintenance and upgrades post launch
  - MO&DA facilities prior to launch included in ground systems development

QuickCost 5.0 Satellite Model Major Groundrules and Assumptions

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- Projects with multiple identical spacecraft (e.g. GRACE, MER, Viking)
  - The cost and technical data was set down in the QuickCost database for only one spacecraft (i.e. the mass is for one spacecraft, the power is for one spacecraft, the data rate is per spacecraft etc.)
  - For many parameters, the number of spacecraft is immaterial (e.g. pointing accuracy)
  - The QuickCost cost data for missions with multiple spacecraft reflect full DDT&E but has been adjusted to reflect only one recurring spacecraft production cost
  - Projects which were a constellation (e.g. GPS and other military fleets) were treated similarly—cost and technical data is for one DDT&E and production unit
  - Thus, QuickCost yields DDT&E and first unit production cost—if more production units are being specified, it is up to the user to manipulate the production cost data appropriately
- For projects with multiple elements such as crew stages, entry and descent stages, landers, rovers, reentry capsules, etc. (e.g. Cassini, Deep Impact, Genesis, Mars Pathfinder, MER, Phoenix,, Pioneer Venus Bus Orbiter, Stardust, Viking, etc.), QuickCost does not separate cost and technical parameters (other than “bus” and “instruments”)
- Spacecraft and instrument mass values exclude any solid propulsion (kick motors etc.)

QuickCost 5.0 Satellite Model
Major Groundrules and Assumptions

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- Some SMD missions have contributions which are not accounted for in the official NASA historical costs
  - Most common example is that of contributed instruments by international partners
  - This is an issue since by and large QuickCost predictive parameters include those contributions (e.g. mass)
  - Where possible, the "value" of those contributions have been added to the NASA cost
    - Cassini is a good example
      - $660M ESA contributions added (Huygens Probe and an ASI spacecraft antenna)
  - However this correction was only imperfectly applied to the entire database due to lack of data on contributions in many cases

QuickCost 5.0 Satellite Database

- 131 projects were identified and researched
  - All automated earth orbital and planetary spacecraft

- Data sources included
  - NASA CADRe (Cost Analysis Data Requirement)
  - NASA Air Force Cost Model (NAFCOM) data base
  - REDSTAR data base
  - NASA Chief Financial Officer library and office files
  - NASA Independent Program Assessment Office
  - Project web sites
  - NASA HQ Science Mission Directorate
  - NASA HQ Library
  - NASA HQ History Office
  - Aerospace Corporation
  - Rand Corporation
  - Author’s files
  - Miscellaneous other sources

Example Projects (Launch Year)

- Cassini (1997)
- Chandra (1999)
- DSCS series (1971-1987)
- Galileo (1989)
- Genesis (2001)
- GP-B (2004)
- Hubble (1990)
- Magellan (1989)
- Mars Pathfinder (1996)
- Mars Exploration Rovers (2003)
- Messenger (2004)
- OSO-8 (1975)
- TRMM (1997)
- Viking (1975)

QuickCost 5.0 Satellite Model Database Upgrades Since QuickCost 4.0

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- Seven new missions added to the satellite model database bring the total number of missions to 131
  - GOES I/8 through GOES M/12
    - Normalized to DDT&E + one unit
  - IBEX
  - Landsat-7
  - LCROSS
  - NOAA-N
  - TRACE
  - WIRE
- In addition, 30 existing missions were revised based on the CADRe database
  - 27 missions which had launch CADRes
  - 3 missions which had CDR CADRes

Map of CADRe Data Line Items To QuickCost 5.0 Satellite Model Database

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- QuickCost database ***Bus DDT&E and TFU Cost*** includes CADRe line items….
  - "Flight Systems Spacecraft" (Phase B through Phase C/D)
  - ALSO "Project Management", "Systems Engineering", "Safety and Mission Assurance"
- QuickCost database ***Instruments DDT&E and TFU Cost*** includes CADRe line items….
  - "Payloads" (Phase B through Phase C/D)
  - ALSO "Science/Technology" (Phase B through Phase C/D)
- QuickCost database ***Ground Systems Acquisition*** Cost includes CADRe line items…
  - "Mission Operations System" (Phase B through Phase C/D)
  - "Ground Data System" (Phase B through Phase C/D)
- QuickCost ***Launch Vehicle*** Services maps directly to CADRe "Launch Vehicle Services" (Phase B through Phase C/D)
- QuickCost database ***Total Acquisition Cost*** is the sum of the above costs (bus + instruments + ground + launch)
- QuickCost ***MO&DA Costs*** includes CADRe "Phase E"
  - This is generally booked against the "Mission Operations System" and "Ground Data System" in CADRe and includes the Phase E costs after launch
  - Note that in the QuickCost database this MO&DA cost is entered in a column to the right of all other costs which are after they have been converted from RY$ to 2004$ and that MO&DA is left in RY$ and also a calculation is shown converting it to an annual amount over the number of years that MO&DA ran
  - Why? Because QuickCost only makes use of the annual MO&DA amount and in terms of a percent of DDT&E for QuickCost CER purposes

QuickCost 5.0 Satellite Cost Model

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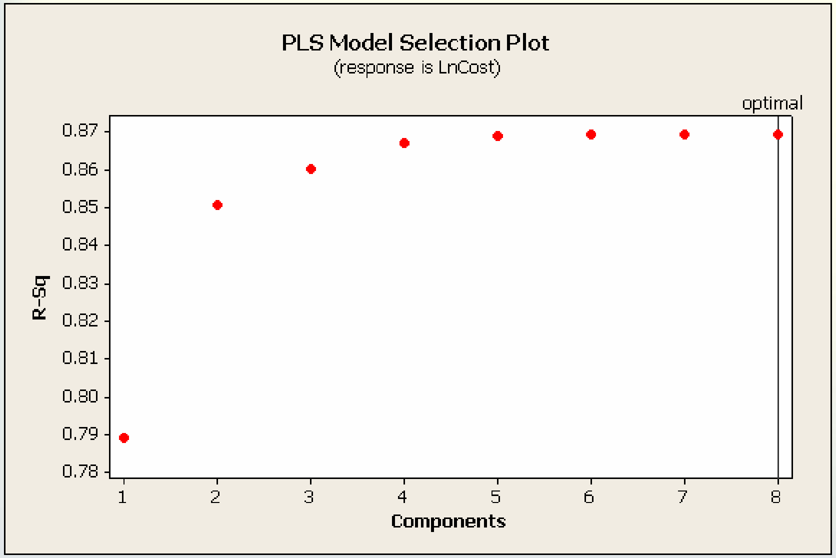
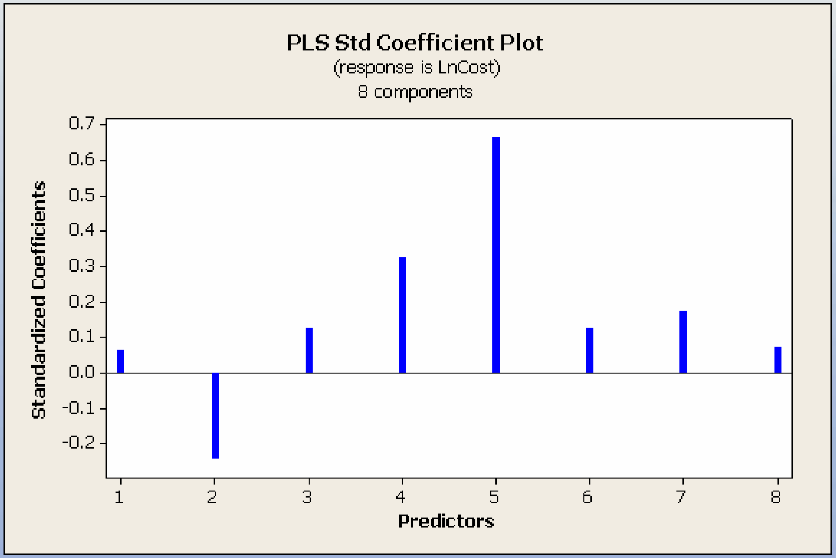
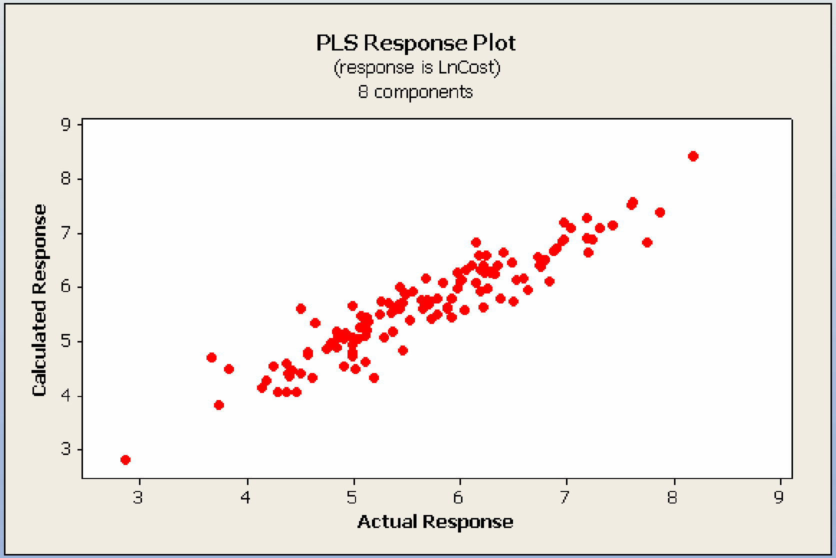


LnCost = - 1.17 + 0.135 Destination - 0.0179 ATP + 0.170 LnLifeMonths + 1.09 InstrComp% + 0.682 LnTotDryMass + 0.118 LnPower + 0.926 BusNew + 0.462 InstrNew

Predictor	Coef	SE	T	P	VIF
Constant	-1.171	0.313	-3.740	0.000	
Destination	0.135	0.087	1.550	0.124	1.525
ATP	-0.018	0.003	-6.500	0.000	1.311
LnLifeMonths	0.170	0.052	3.260	0.001	1.376
InstrComp%	1.085	0.146	7.420	0.000	1.787
LnTotDryMass	0.682	0.055	12.450	0.000	2.662
LnPower	0.118	0.051	2.330	0.022	2.696
BusNew	0.926	0.207	4.480	0.000	1.439
InstrNew	0.463	0.248	1.860	0.065	1.425
S	0.365				
R-Sq	86.90%				
R-Sq(adj)	86.10%				





Residual Plots For Satellite Cost Model

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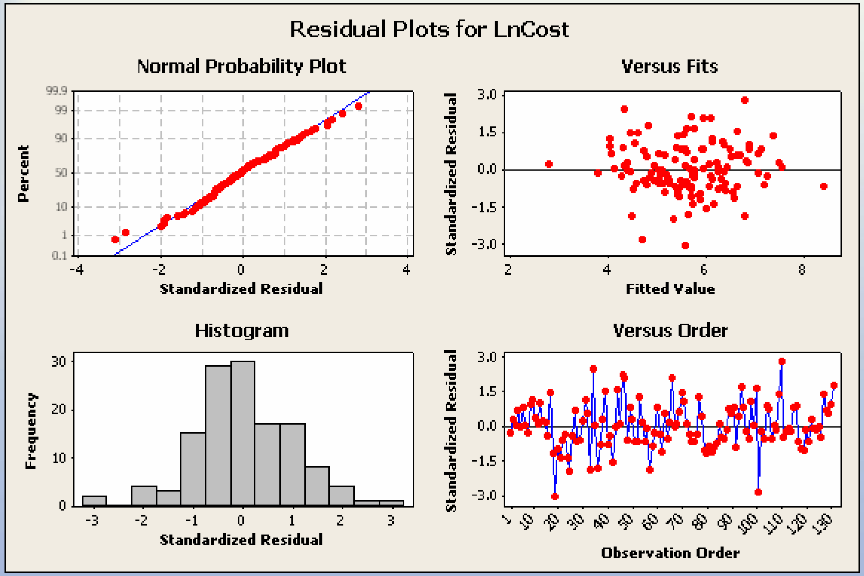
LnCost = - 1.17 + 0.135 Destination - 0.0179 ATP + 0.170 LnLifeMonths + 1.09 InstrComp% + 0.682 LnTotDryMass + 0.118 LnPower + 0.926 BusNew + 0.462 InstrNew



- Acceptable residual plots for baseline model
  - Normally distributed errors
  - Errors uniformly distributed across range of data
  - No order error patterns (data is not ordered in any event)

Don't Know Power?

Then Use This

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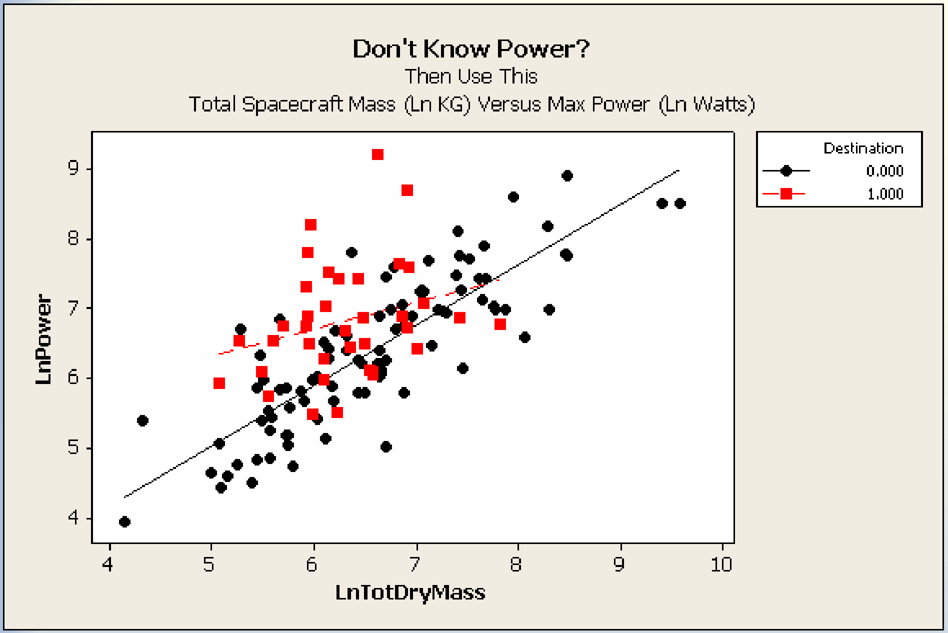

- If power is not known, use the relationship below to estimate power as a function of mass (don't forget to convert to watts with e^x)
  - In terms of total spacecraft mass (Ln KG) and…
  - Destination
    - Earth orbital = 0
    - Planetary = 1

LnPower = 1.03 + 0.818 LnTotDryMass + 0.639 Destination

Predictor	Coef	SE Coef	T	P	VIF
Constant	1.0273	0.4190	2.45	0.016	
LnTotDryMass	0.81788	0.06261	13.06	0.000	1.019
Destination	0.6392	0.1318	4.85	0.000	1.019

S = 0.672864   R-Sq = 58.5%   R-Sq(adj) = 57.8%

- In a real hurry? Then use….
  - Median earth orbital value of 600 watts
  - Median planetary value of 850 watts
  - Or adjust from there

Note: Planetary missions have higher power values than earth orbital missions in the QuickCost database because power is tabulated in terms of LEO equivalent power (i.e. for a given array size, Mars power is ~ 50% LEO power—therefore arrays for outer planet missions have to be "oversized"). Outer planet missions dominate.

QuickCost 5.0 Satellite Model Launch Services Cost

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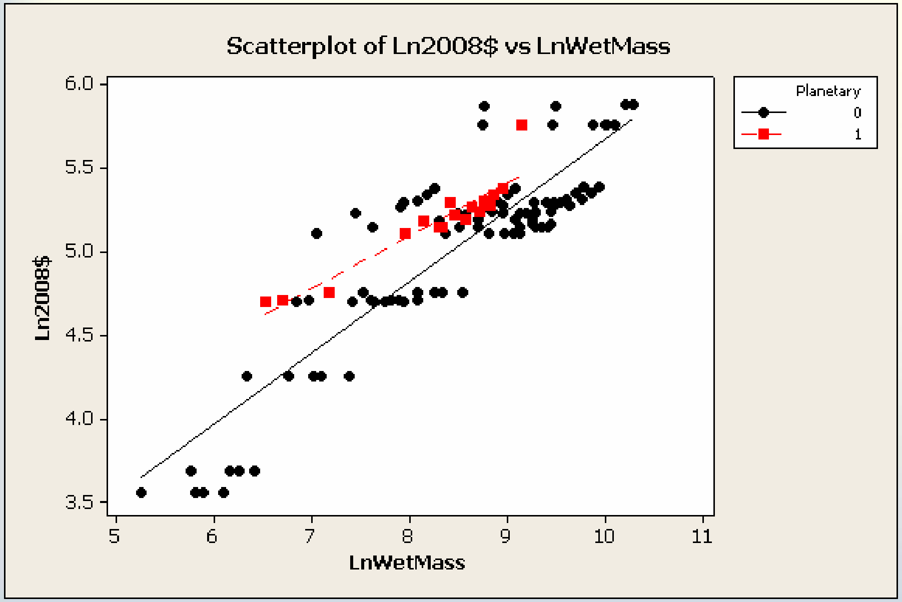

Ln2008$ = 1.48 + 0.419 LnWetMass + 0.243 Planetary

Predictor	Coef	SE Coef	T	P	VIF
Constant	1.478	0.185	7.980	0.000	
LnWetMass	0.419	0.022	19.290	0.000	1.004
Planetary	0.243	0.067	3.650	0.000	1.004
S	0.251				
R-Sq	78.40%				
R-Sq(adj)	78.00%				

- More accurate launch services estimates can be obtained by using the ELV Pricing model developed for the IPAO by SAIC (Hamaker) in 2009.

Note: In the QuickCost speadsheet model the CER automatically increases the spacecraft dry mass to wet mass by 1.3 for earth orbital and 1.6 for planetary missions and adds an additional 10% for a payload adapter/ASE (and converts CER to 2004$).

WBS Element & Spacecraft Breakdowns

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NASA WBS Elements	All CADRe	Launch (33/50)
1.0 Project Management	5.5%	6.1%
2.0 Systems Engineering	2.9%	3.3%
3.0 Safety and Mission Assurance	1.5%	1.7%
4.0 Science/Technology	5.4%	6.2%
5.0 Payload	18.1%	18.2%
6.0 Spacecraft(s)	29.3%	32.5%
7.0 Mission Operations System	6.0%	6.8%
8.0 Launch Vehicle/Services	15.3%	15.2%
9.0 Ground System(s)	4.0%	4.8%
10.0 Systems Integration and Testing	3.5%	4.0%
11.0 Education & Public Outreach	0.6%	0.6%
Reserves	7.8%	0.5%

Flight System \ Spacecraft	Cost %	Mass %
Management	10.4%	N/A
Systems Engineering	4.7%	N/A
Product Assurance	4.1%	N/A
Structures & Mechanism Total	9.8%	40.1%
Thermal Control	2.1%	6.4%
Electrical Power & Distribution	15.9%	25.1%
GN&C	11.5%	8.6%
Propulsion	6.5%	8.1%
Communications	6.0%	3.9%
C&DH	11.5%	5.2%
Software	6.3%	N/A
I&T	10.4%	N/A

Percentage breakout of QuickCost 5.0 satellite model estimated cost is only accurate if the mission heritage is near the median or mean heritage

So How Good Is Quickcost 5.0?

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- The QuickCost satellite model replicates the cost of its own data base within…
  - 3% total mean residual error
    - But this "enjoys" positive and negative error cancelling
    - Might be considered the average error for an estimate of a portfolio of missions
  - 29% absolute value mean residual error
    - Might be considered the average individual mission error
  - 24% absolute value 80% trimmed mean residual error
    - Excludes outliers
    - Might be considered the average individual mission error 80% of the time
- All this is, of course, with perfect knowledge of the technical inputs
  - Ah, there's the rub
    - Sometime we cost estimators aren't given realistic inputs
    - Knowing realistic inputs from bogus inputs is job security indeed!