

# NASA Project Cost Estimating Capability: New Analyses for Spacecraft Estimating

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# Overview



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- NASA / Air Force Cost Model (NAFCOM) History
- Project Cost Estimating Capability (PCEC) Introduction
- PCEC Analysis Approach
  - Robotic SC
  - Crewed and Space Transportation Systems
- PCEC Capabilities
- Summary



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## NAFCOM History



# NAFCOM Overview



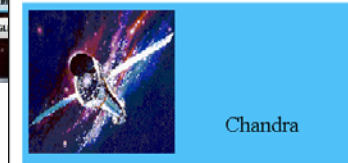
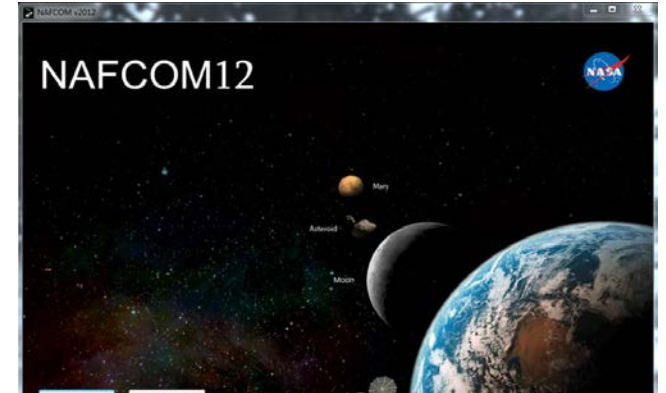
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- **Overview**

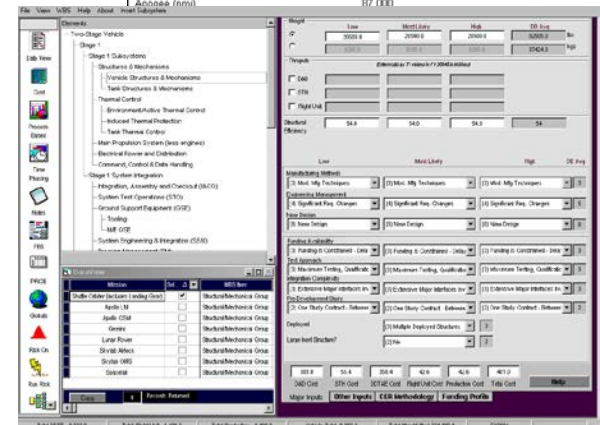
- Parametric cost estimating tool for launch vehicles, robotic spacecraft, human spacecraft, landers, rovers, and other flight hardware systems
- Development began in 1990 with 12 major releases providing increased accuracy, data content, & functionality
- Based on over 155 NASA and U.S. Air Force space flight hardware projects
- Used by over 1000 Government and Contractor employees
- Two cost estimating methodologies are available:
  - Multi-Variable CERs
  - Weight/Analogy based CERs
- Incorporates Liquid Rocket Engine Cost Model (LRECM) and Space Operations Cost Mode (SOCM)
- Allows user input CERs and thruptut costs
- Performs probabilistic risk analysis using FRISK

- **Versions of NAFCOM**

- **Government:** Includes modeling capability and access to all underlying data
- **Contractor:** Includes Government version capability (CERs, etc) but no underlying cost & mass data



MANAGEMENT CENTER: MSFC  
 CONTRACTOR: TRW  
 LAUNCH DATE: July 1999  
 LAUNCH WEIGHT (LBS):  
 SUBSYSTEM DRY WEIGHT (LBS):  
 DESIGN LIFE: 5-10 years  
 LAUNCH VEHICLE: Space Shuttle  
 DESIGN APPROACH: Protoflight  
 ORBIT PARAMETERS:  
 Apocnee (nm): 87,000



July of 1999, is the very regions of the  
 y known as AXAF, the  
 uments and a  
 tra spacecraft carries a  
 e features are: an order  
 for high spectral



# NAFCOM Over the Years



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## NAFCOM Evolution

**1990**

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

**1992**

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

**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

**1996**

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

**2011**

- Thruput \$ in any fiscal year
- Historical weight units sensitive to global selection
- Two new templates (Earth Orbiting and Planetary)
- Historical Database QA
- Multi-Variable CER Mission indicator
- Database contains 149 data points

**1999**

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

**2008**

- 17 New Component Level multi-variable CERs
- New statistics integrated into database
- Historical Schedule Data integrated into toolbar
- Converted to .NET Platform and SQL Databases
- New interface for risk analysis outputs
- Database contains 135 data points

**2002**

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

**2007**

- Calibration Module
- Matrix Consistency Checker
- Ability to send full NAFCOM Cost Report directly to Excel
- Database contains 133 data points

**2004-2006**

- Cost Risk Analysis Module
- CER Improvements
  - SOCM
- Component level multi-variable CER
- Allocation of Risk Dollars by WBS Elements
  - WBS Generator
- Expanded Drag and Drop manipulation
- Dynamic display of Weight Based standard errors





# Why Move Away from NAFCOM?



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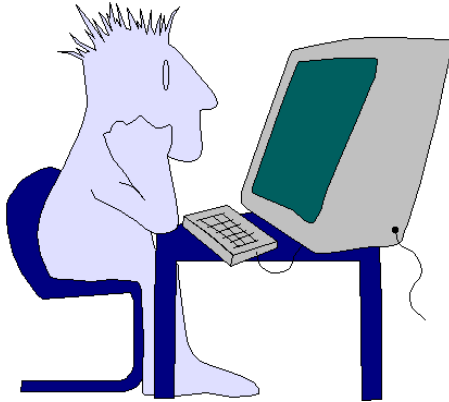
- **CER Issues**
  - Non-Homogeneous data set
  - Input parameters that are statistically insignificant
  - Subjective variables have significant explanatory value
  - Documentation for assigning subjective variables limited
  - Oversubscribed CERs
  - Some CERs yield nonsensical results
- **Software Issues**
  - “Black box” to users
  - Calculation errors
  - Data protection requirements
- **Analysis Issues**
  - Results produced in standalone environment
  - Over-reliance on exercising the model



# Moving to a Data Centric Approach



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## Model Centric

- Focus is on how to use the model
- Model becomes a medium for communication with the technical community
- Model gets all the credit (or blame) for the estimate
- **Estimate becomes an evaluation of the present, rather than a prediction of the future**

## Data Centric

- Focus is on the relationship of the data to the estimating problem
- Analyst must access and know the underlying data
- Puts onus for the quality of the estimate on the estimator
- **Done properly, can lead to value-added solutions**



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## PCEC Introduction





# What is PCEC?



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- PCEC is a new parametric cost model developed and maintained by NASA to replace NAFCOM
  - PCEC development started in late 2013 to begin a new course for space cost estimating, leveraging the historical analyses but expanding them to align with evolving NASA estimating needs
- Goals for PCEC
  - Emphasize good analysis as a critical component of credible cost estimating (model-focused approach vs. data-focused approach)
  - Create an environment that addresses the diverse estimating and analysis requirements across NASA
  - Enable the entire NASA cost community to have ownership and add value to an Agency-wide capability
  - Conduct new normalization and analyses to address the issues identified with NAFCOM
  - Address all elements of the NASA Standard WBS



# PCEC Development Philosophy



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## Tool Development

- Simple, Robust, Transparent
- Focus on Flexibility and Capability versus Ease of Use
- Don't Duplicate Existing Capabilities / Models / Tools
- Leverage Existing Software to the Greatest Extent Possible (e.g., Argo, @Risk, Crystal Ball)
- Expect NASA Cost Analysts to Know how to Use Spreadsheets and other Desktop Applications
- Keep the Data behind the NASA Firewall
- Modular, Open Source Architecture

## Model Development

- Use the Best Data Possible
- Total Transparency in the Analysis of the Data and the Development of the CERs
- No Cherry Picking the Data Points
- Minimize or Eliminate Subjective Inputs
  - Follow a Data Driven Process for the Derivation of Subjective Inputs
  - Allow the User to Follow the same Process for Determining Input Values
- Emphasize Quality of Input Parameters over Quantity
- Expect the User to Develop the Rationale for the Estimate
  - Model Centric to Data Centric
  - Know the Data



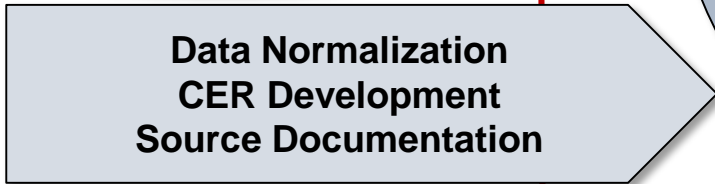
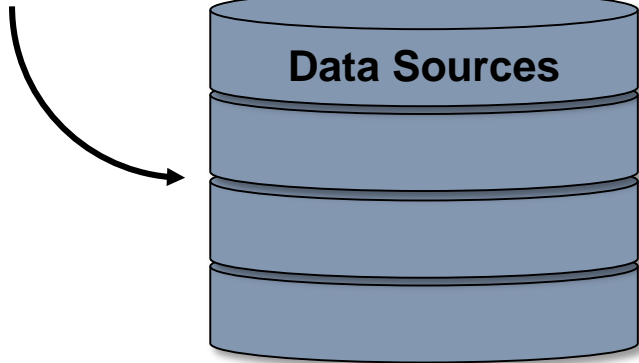
# The PCEC Architecture



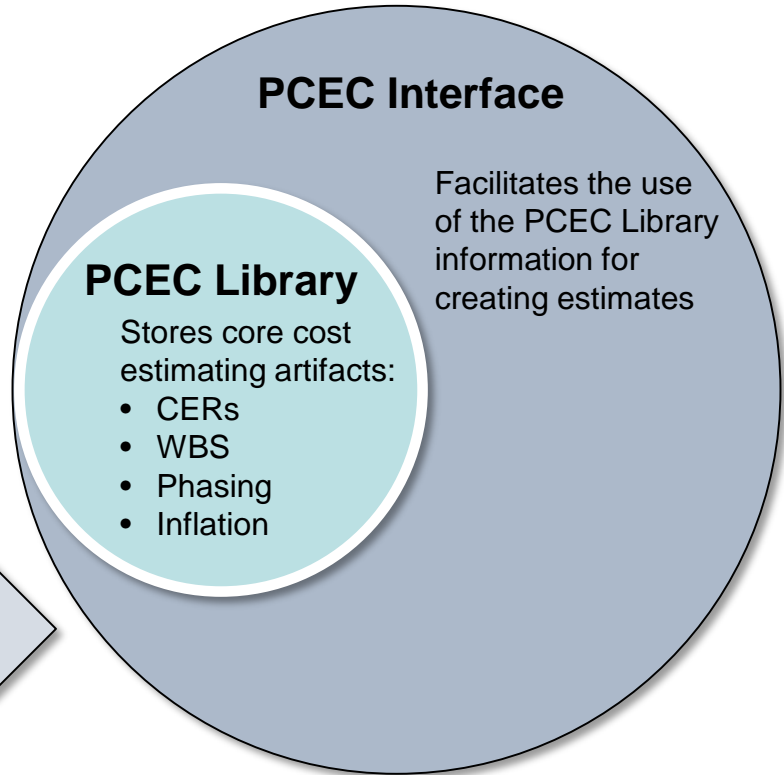
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## Key Elements of the PCEC Architecture

**NASA Historical  
Cost Libraries**



**Accessible with NASA User  
ID and Account Approval**



**Publicly Releasable via NASA  
Software Release Authority Process**

**NASA IT Security Interface**



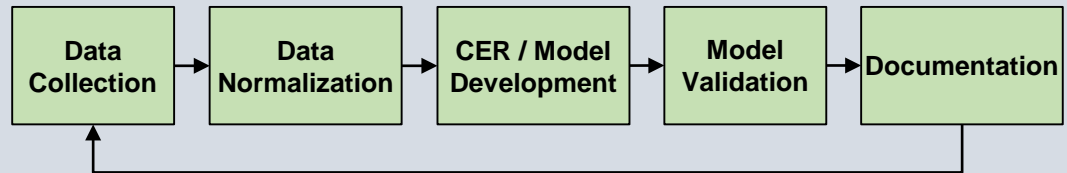
# PCEC Development Primary Activities



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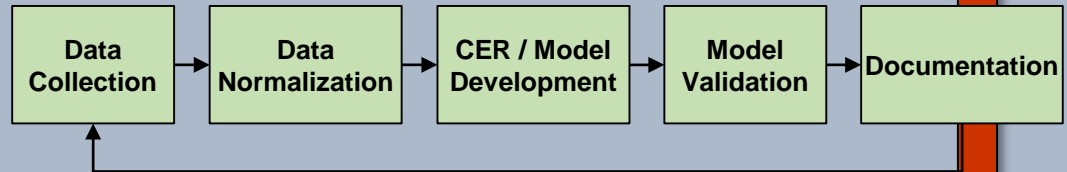
## Robotic Spacecraft (Robotic SC)

- New CERs for estimating cost of subsystems for all types of Robotic Spacecraft
- New model for estimating project, payload, and spacecraft support function costs (e.g., PM, I&T)



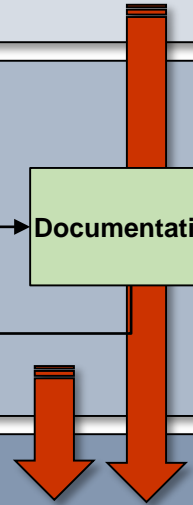
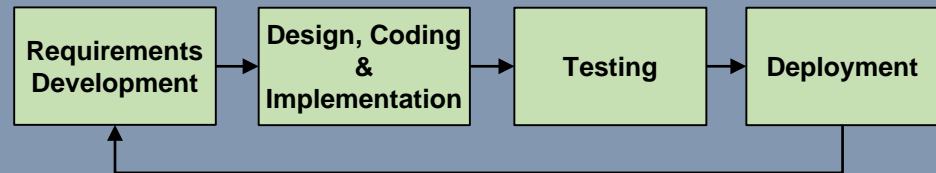
## Crewed & Space Transportation Systems (CASTS)

- New CERs for estimating the cost of subsystems on launch vehicles, crewed space structures, and in-space transportation systems
- New cost-to-cost CERs for support functions



## PCEC Software Development

- Coding of the Routines to Access cost artifacts used to build a complete space cost estimate
- Development of Estimating Templates for different types of methodologies
- Documentation





## Robotic Spacecraft Model



# PCEC Robotic SC Model Objective & Approach



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## Objectives

- Develop a set of cost estimating methodologies tailored for NASA's robotic science missions: Earth Science, Heliophysics, Astrophysics, and Planetary
- Provide full traceability into the data normalization and CER development processes

## Approach

### Data Collection & Normalization

- Collect cost data from NASA Cost Analysis & Data Requirements (CADRe)
- Identify technical & programmatic input candidates
- Develop repeatable 8-step normalization process

### Data Analysis & Model Development

- Explore multiple analysis options to determine most logical modeling approach
- Create, evaluate, and test CERs
  - Spacecraft
  - Support Function
  - Other

### Documentation

- Cost Normalization Workbooks
- Cost Assessment Reports (CARs) summarizing data normalization
- CER Input workbooks
- PCEC CER Calculation Workbooks
- CER Validation analysis



# PCEC Robotic SC Model Data Normalization Process



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**START**  
Raw  
(Unadjusted)  
Project Data

**STEP 1**  
Inflate to  
Common  
Fixed Year \$

**STEP 2**  
Allocate to  
NASA WBS

**STEP 3**  
Account for  
Management,  
Fees, &  
Burdens

**OUTPUT A**  
NASA WBS by Year  
w/o Fees or  
Burdens

**STEP 4**  
Full Cost  
Accounting  
Adjustments

**STEP 5**  
Account for  
Contributions

**OUTPUT B**  
NASA WBS by Year  
w/FCA & Contributions  
but w/o Fees or  
Burdens

**STEP 6**  
Development Profile  
Phasing – Schedule  
& Long Lead Items

**STEP 7**  
Removal of  
Costs for  
Multiple Units

**OUTPUT C**  
NASA WBS by Phase  
(normalized to a  
single protoflight unit)

**STEP 8**  
Removal of  
Costs from  
External  
Impacts

**OUTPUT D**  
NASA WBS by Phase  
w/o External Impacts



# PCEC Robotic SC Model Data Analysis Approach



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- Effort began by defining a set of potential model inputs
  - Multiple information sources were reviewed to generate the initial input candidate list, including mass & performance metrics
  - More than 100 input candidates were identified

## Sample Inputs

- Modeling effort explored three alternatives:
  1. Principal Component Analysis (PCA): Narrow the input data set to key parameters before running regression (~10-20 per subsystem)
  2. Regression using Expert Judgment: Use PCA results and expert judgment to narrow the input data set before running regression
  3. Hybrid Approaches: Use regression to develop the initial CERs, with adjustment factors to refine the CERs using additional inputs

<u>PROJECT/MISSION</u>		<u>FLIGHT SYSTEM</u>	
Mission Risk Class		Flight System Type	
Mission Target/Type		Flight System Mass	
Lead Organization		Flight System Power	
Flight System Lead Organization		Flight System Heritage	
Payload Lead Organization		Flight System Advanced Technology	
Flight System Lead Experience		Flight System New Design	
Payload Lead Experience		Flight System Design Modifications	
# of Key S/C Contractors		Parts Rating	
# of Key Payload Contractors		Payload Mass	
Degree of In-House Scope		Payload Power	
International HW Participation		# of Pavload Elements	
Directe		ht system elements	
Subsyst		ng Environment	
Subsyst		on Environment	
# of Key			
Degree			

<u>THERMAL</u>	
Mass	
Thermal Operating Environment	
Thermal Control Type	
Radiator Material	
Insulation Type	
Power, Heaters (W)	

<u>COMMAND &amp; DATA HANDLING</u>	
Mass	
Board Form Factor	
# of Boards	
Data Storage Capacity	
Onboard FSW, SLOC	
FSW Reuse	
Processor Type	





# PCEC Robotic SC Model Data Analysis Approach (Cont'd)



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- PCA was selected as the initial modeling approach to investigate relevant independent variables, followed by iterative multiple regression to develop specific CERs
- For each Subsystem and Support Function, we iterated through the following general process:
  - Segment & transform the normalized data
  - Run PCA to identify variables explaining most of the variation
  - Conduct multiple regression runs to identify potential CERs using from one to five independent variables
  - Evaluate independent variables, statistics, coefficients
  - Select CER for incorporation into the PCEC Library



# PCEC Robotic SC Model CER Example



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**NOTIONAL**

## Attitude Control Non-Recurring CER

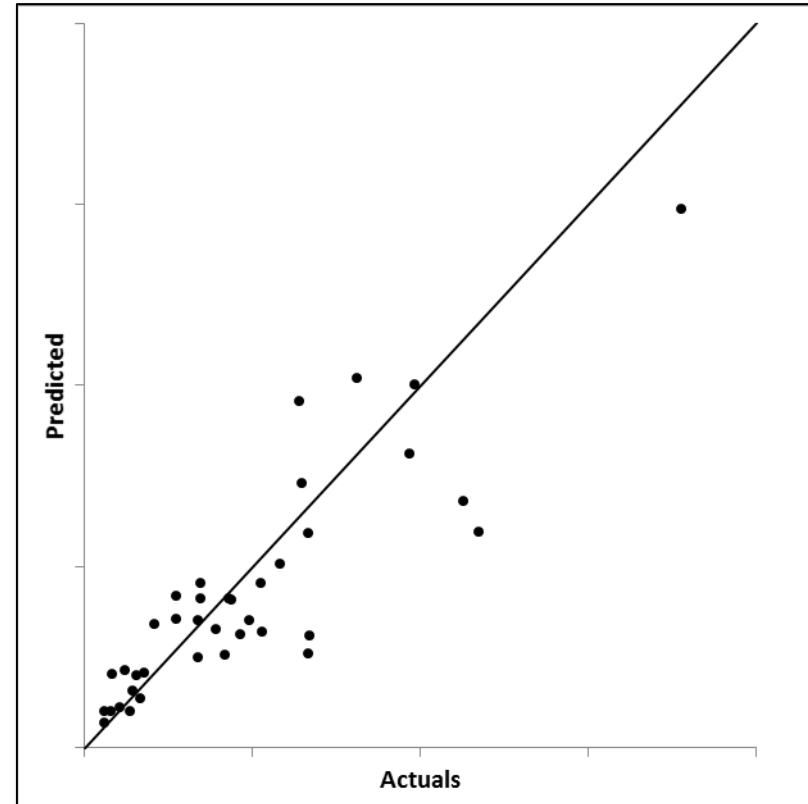
$$\text{Cost} = 0.1 * \text{WeightPerUnitKg}^{0.42} * \text{OpEnvironment}^{0.75} * \text{RadEnvironment}^{0.19} * \text{SubsysDesignTime}^{0.26} * \text{LaunchYearMinus1960}^{1.56}$$

R^2	0.774
Adj R^2	0.740
F-Stat	22.602
F-Stat P-Value	0.000
PING Factor	1.088
SPE	5.49E-02

SSR	22.439
SSE	6.552
SST	28.992
SEE	0.446
Y_Bar	8.151
CV	0.055
Pearson's Co	0.880

Regression DF	5
Residual DF	33
Total DF	38

Variable Name	Cost	WeightPer UnitKg	OpEnvrmt	RadEnvrmt	SubsysDesi gnTime	LYMinus196 0
Min	574.157	0.610	1.000	1.000	3.467	36.000
Max	17776.345	132.567	5.000	400.000	52.100	54.000
Mean	4779.184	38.961	1.872	30.449	24.979	46.179
Median	4172.519	34.240	2.000	15.000	24.200	47.000
SD	3705.472	29.325	0.978	64.842	11.196	4.833





# PCEC Robotic SC Model Summary



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- **Methodologies based on newly-normalized data from 42 recently-launched missions, with most data from CADRe**
- **One set of subsystem-level CERs for estimating Non-recurring and Recurring costs (15 CERs)**
  - All are multi-variable power CERs developed using Ordinary Least Squares (OLS) regression of log-transformed data
  - Derived using PCA and multiple regression
  - Assume a protoflight approach for spacecraft development
  - Estimate Gov't + Prime-costs for development and production
- **Another set of CERs for estimating additional costs at the project, payload, and spacecraft levels (6 CERs)**
  - New CERs that estimate the total PM, SE, MA, and I&T costs; allocations distribute costs to the project, payload, and spacecraft level
  - New CERs to estimate the Mission Operations Systems / Ground Data Systems (MOS/GDS) development costs
  - Developed using a PCA approach



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## Crewed and Space Transportation Systems (CASTS) Model



# PCEC CASTS Model Objectives



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## Objectives

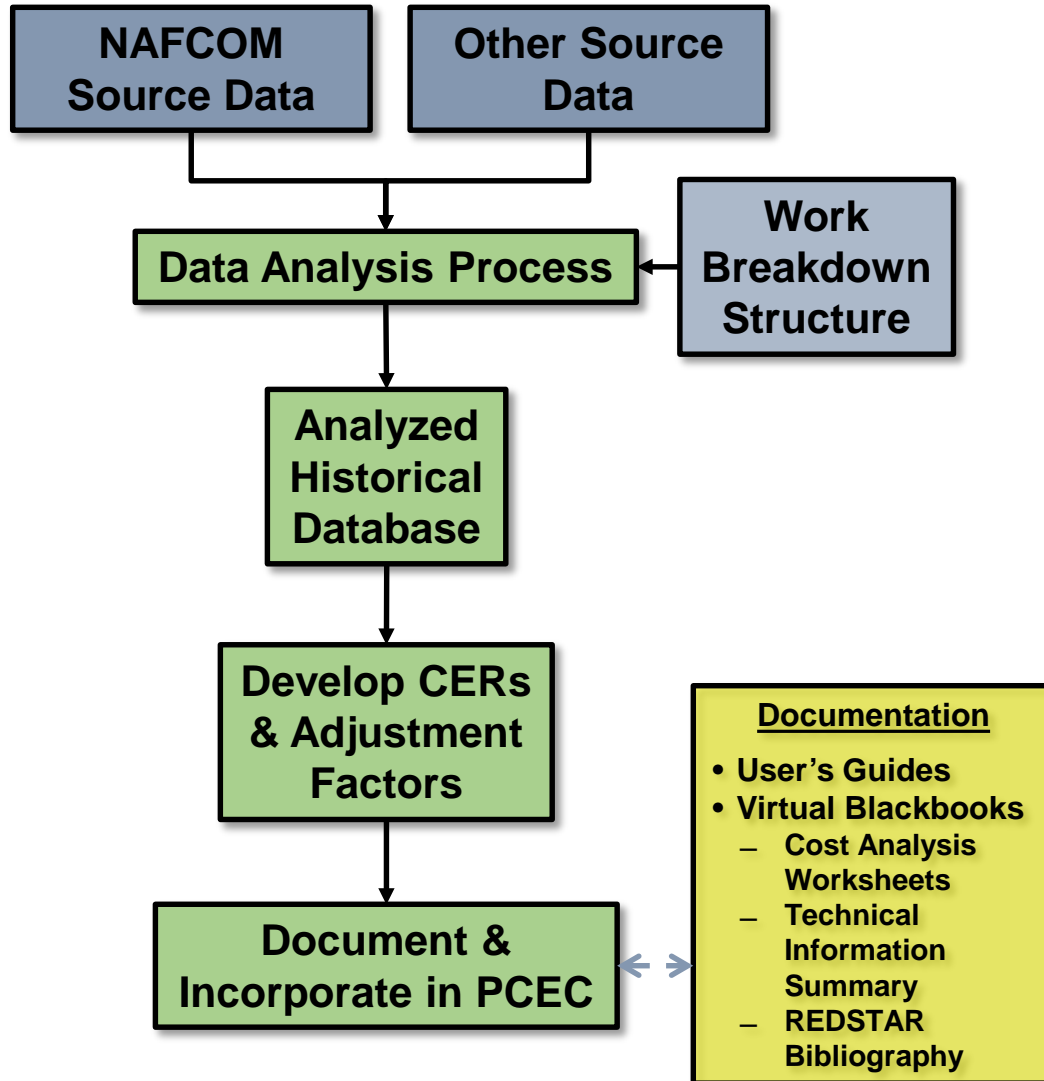
- Develop a new, unique cost model for use in estimating space transportation systems, including crewed systems, earth-to-orbit systems, and in-space transportation systems
- Construct model from a historical database consisting exclusively of transportation/crew systems
- Empower users to create *Credible, Supportable, Defendable* estimates



# PCEC CASTS Model Approach



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1. Develop Overall WBS
2. Identify Source Data
  - NAFCOM-heritage systems: Trace back to original sources; re-evaluate using common definitions/assumptions; fit to CASTS WBS
  - New systems: Understand/analyze source data; evaluate using common definitions/assumptions; fit to CASTS WBS
3. Normalize Source Data
  - Convert to common year & units
  - Separate out elements of cost: Design & Development, First Unit, System Test Hardware, etc.
4. Assign to Appropriate CASTS WBS Elements
5. Develop CASTS CERs
  - Identify potential independent variables
  - Develop CER equations
  - Evaluate CER “goodness”
6. Document Analysis



# PCEC CASTS Model

## Data Normalization & Analysis



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- Model Development Approach
  - Perform iterative multiple regression with a small set of potential independent variables; mass as primary input with additional variables unique to subsystems
  - Create & evaluate CERs in both power and linear forms based on data
- Why this approach? Significant data “clutter”
  - Minimal number data points with multiple potential independent variables (overfitting, potential multi-collinearity)
  - Lack of/dissimilar definitions of technical variables between sources
  - Poor predictive value (P-values  $\gg .05$ )
  - Counter-intuitive results (cost  $\uparrow$  over time, cost  $\downarrow$  increased complexity)
  - Conflicting/countervailing influences between potential variables
- Calculated “adjustment factor” for each data point
  - Ratio of the actual to predicted value for a data point
  - Not a “complexity” factor – says nothing about why value is what it is



# PCEC CASTS Model Example CER



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## Adapters Design & Development CER

$$\text{Cost} = 0.45 * \text{WeightPerUnit}^{0.83}$$

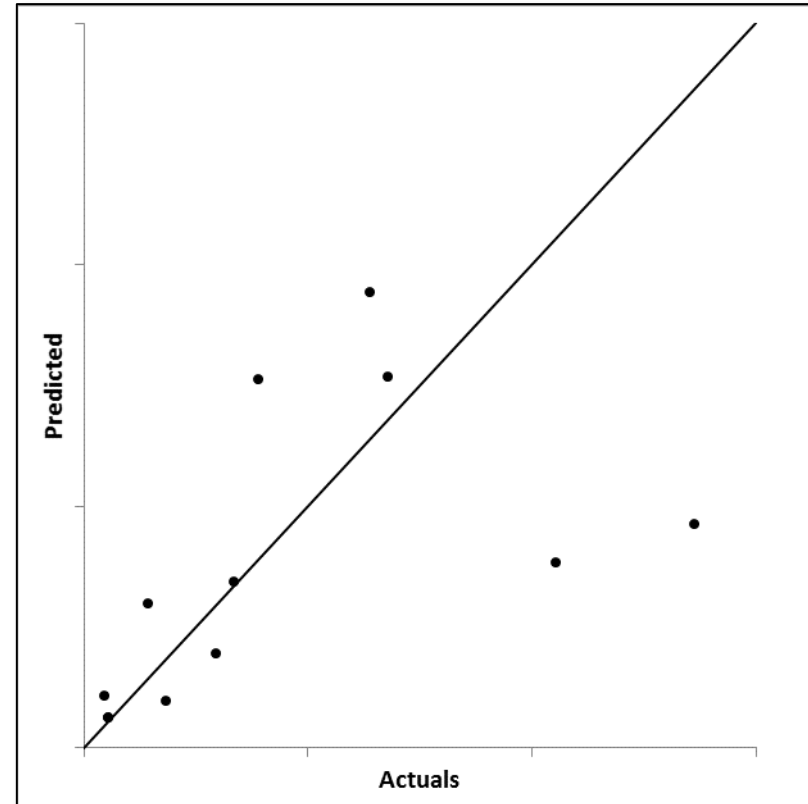
**NOTIONAL**

R^2	0.691
Adj R^2	0.661
F-Stat	22.412
F-Stat P-Value	0.001
PING Factor	1.213
SPE	0.28647763

SSR	10.405
SSE	4.643
SST	15.047
SEE	0.681
Y_Bar	2.554
CV	0.267
Pearson's Co	0.832

Regression DF	1
Residual DF	10
Total DF	11

Variable Name	Cost	WeightPer Unit
Min	2.337	120.000
Max	68.068	5262.000
Mean	21.772	1691.250
Median	15.667	1179.000
SD	21.122	1754.561







# PCEC CASTS Model Summary



**Engineering  
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- **Methodologies based on data from ~34 historical launch vehicle stages, crewed vehicles, and related space transportation systems/subsystems**
- **One set of CERs for estimating subsystem-level costs of Design and Development (D&D) and Flight Unit (43 CERs)**
  - Nearly all are single-variable power CERs (with weight as the independent variable); a small number are linear CERs or multi-variable power CERs
  - Adjustment factors provide an analogous estimating supplement
  - Estimate Prime costs
- **Another set of CERs for estimating supporting costs (e.g., PM, ground support equipment, tooling) at the spacecraft level (8 CERs)**
  - Most are cost-to-cost CERs (use flight system cost as base)
  - Estimate Prime-level costs only; factors used for Program/Project level



## PCEC Capability Overview



# PCEC Interface Overview



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The PCEC Interface...

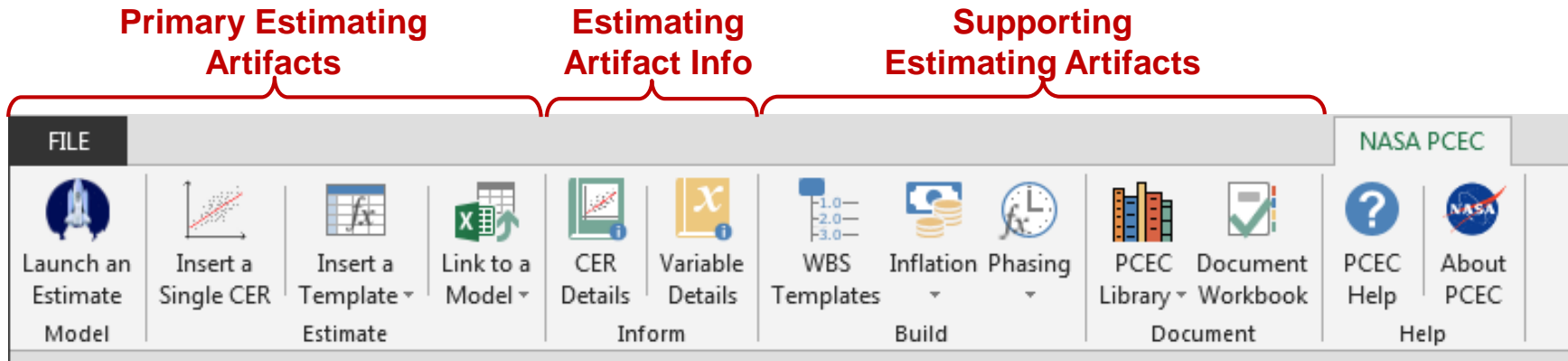
- is an Excel Add-in that appears as its own tab in the Excel Ribbon, with buttons to access capabilities for building an estimate in Excel
- contains a compressed copy of the PCEC Library and associated artifacts needed to build an estimate, including...
  - CERs
  - Statistics about the CERs
  - Other worksheets with WBSs, Inflation, specialized methodologies, etc.
- is compatible with Windows versions of MS Office
  - Excel 2007, 2010, and 2013; Excel 2016 TBD
  - Mac users must use a virtualization program to run Windows
- is completely open: no code passwords, protected sheets, etc.



# PCEC v2.1 Interface Ribbon Overview



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The primary section contains the key elements used to create a cost estimate in an Excel workbook

- The “Launch” feature, which auto-generates a complete estimate from a user-customized WBS
- Ability to insert single CERs into a worksheet
- Ability to insert pre-formatted templates into a workbook that estimate the DDT&E and production costs of a subsystem
- Linking to other NASA-related cost models (e.g., NICM)

The middle section provides access for learning more about the specific estimating artifacts that are available to users

- Information about the CERs: regression statistics, descriptive statistics, missions used
- Definitions and variables, their input units, and lists of valid inputs

The final section contains supporting elements for adding elements to complete an estimate

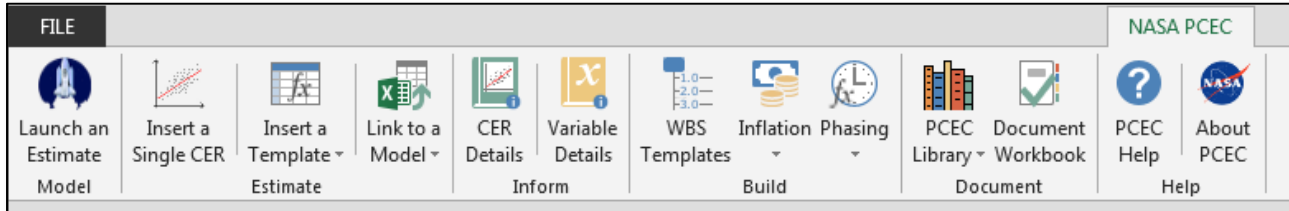
- Starting NASA Standard WBSs
- Inflation worksheets for escalating
- Phasing options for developing a by-year profile for the cost estimate
- Auto-generation of a documentation workbook for all CERs used in an estimate
- Help documents



# PCEC v2.1 Components



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## Robotic Science Missions



- Spacecraft Subsystem CERs
- Support Function CERs
- NASA Instrument Cost Model
- MOS/GDS Development CERs
- Science Team Wrap Factors
- Launch Services ROM Estimator
- PCEC v1 Legacy CERs
- First Pound Cost CERs

## Launch Vehicles/Human Spaceflight Missions



- Crewed and Space Transportation Systems (CASTS) Subsystem CERs
- Cost-to-cost Support Function CERs
- PCEC v1 Legacy CERs
- First Pound Cost CERs
- Wrap Factors

## Estimating Support

- Thruput Templates
- CER Library
- WBS Templates
- Help File
- Inflation Indices
- Cost Phasing

## Outside of PCEC

- Robotic Spacecraft data analysis spreadsheets and cost analysis reports
- CASTS “Virtual Blackbooks”
- CASTS User’s Guide
- Cost Analysis Data Requirements (CADRe) documents & backup data
- Other historical cost and technical data in the REDSTAR Library



# PCEC v2.1 Model Capabilities



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- PCEC v2 is currently best suited for estimating the cost to design, develop, and produce the following types of space systems
  - Spacecraft: Earth Orbiting Satellites, Planetary Probes, Rovers
  - Launch Vehicles: Multi-stage rockets, liquid and solid engines
  - Human Space Flight Systems: Crew Capsules, Orbiters, Habitats
- PCEC v2 CERs are designed to estimate at the subsystem level
  - Historical v1 Legacy CERs can estimate at the lower level but are separate from the Robotic SC and CASTS Models
- PCEC v2 currently does not have the capability to estimate...
  - Cubesats, Balloons, Aircraft
  - Nanosat Launchers, Sounding Rockets
  - Human hardware elements (e.g., space suits)



# PCEC Today



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- PCEC v2.1 is the latest version available (released in Aug 2016), which includes enhancements for estimating more elements across the NASA Standard WBS
- The general public can obtain PCEC (with some export restrictions) via the NASA Software Repository

**PCEC Email Contact:** MSFC-PCEC@mail.nasa.gov

**Application Website:** <https://software.nasa.gov/> , search for PCEC

- Ongoing data analyses and code development will continue to evolve the tool for future releases



# PCEC Summary



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- PCEC replaces NAFCOM as NASA's in-house developed parametric cost estimating tool, accessible by many organizations
- PCEC is not just a software tool but also a set of underlying analytical efforts to provide quality models within the tool
  - New normalizations and CERs for Robotic SC and CASTS that follow a traceable, consistent approach
  - Transparent calculations within the tool
  - Tailorable environment to meet an individual or organization's unique estimating needs
  
- Questions?





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Backup



# PCEC Robotic SC Model Mission Database



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MISSION	Launch Date	Lead Org PM	Lead Org Flt Sys	NASA Program
1 TDRSS K-L	1/23/14	GSFC	Boeing	Space Comm
2 MAVEN	11/18/13	GSFC	LMA	Planetary
3 LADEE	9/6/13	GSFC	ARC	Planetary
4 IRIS	6/27/13	GSFC	LMMS	Astrophysics/SMEX
5 Van Allen Probes	8/30/12	GSFC	APL	Heliophysics/LWS
6 NuSTAR	6/13/12	JPL	OSC	Astrophysics/Explorer
7 MSL	11/26/11	JPL	JPL/LMA	Planetary/Mars Expl
8 GRAIL	9/10/11	JPL	LMA	Planetary/Discovery
9 Juno	8/5/11	JPL	LMA	Planetary/New Frontiers
10 Glory	3/4/11	GSFC	OSC/Swales	Earth Sciences
11 GOES (-P)	3/4/10	GSFC/NOAA	Boeing/SGT	Earth Sciences
12 SDO	2/11/10	GSFC	GSFC	Heliophysics
13 WISE	12/14/09	JPL	BATC	Astrophysics/Explorer
14 LCROSS	6/18/09	ARC	NG	Planetary/Discovery
15 LRO	6/18/09	GSFC	GSFC	Planetary
16 KEPLER	3/6/09	JPL	BATC	Astrophysics/Discovery
17 OCO	2/24/09	JPL	OSC	Earth Science
18 IBEX	10/19/08	SwRI	OSC	Astrophysics/Explorer
19 DAWN	9/27/07	JPL	OSC/JPL	Planetary/Discovery
20 Phoenix	8/4/07	JPL	LMA	Planetary
21 AIM	4/25/07	LASP	OSC	Heliophysics
22 THEMIS	2/17/07	UCB	Swales	Astrophysics/Explorer
23 STEREO	10/26/06	GSFC	APL	Heliophysics
24 CLOUDSAT	4/28/06	GSFC	BATC	Earth Sciences
25 NEW HORIZONS	1/19/06	APL	APL	Planetary/New Frontiers
26 MRO	8/12/05	JPL	LMA	Planetary/Mars Expl
27 DEEP IMPACT	1/12/05	JPL	BATC	Planetary/Discovery
28 Swift	11/20/04	GSFC	Spectrum Astro	Astrophysics/Explorer
29 MESSENGER	8/3/04	APL	APL	Planetary/Discovery
30 Spitzer	8/25/03	JPL	LMA	Astrophysics
31 MER	6/10/03	JPL	JPL	Planetary/Mars Expl
32 GALEX	4/28/03	JPL	OSC	Astrophysics/Explorer
33 RHESSI	2/5/02	UCB	Spectrum Astro	Heliophysics
34 TIMED	12/7/01	APL	APL	Earth Sciences
35 GENESIS	8/8/01	JPL	LMA	Planetary/Discovery
36 Mars Odyssey	7/7/01	JPL	LMA	Planetary/Mars Expl
37 WMAP	6/30/01	GSFC	GSFC	Astrophysics/Explorer
38 WIRE	3/5/99	GSFC	GSFC	Astrophysics/Explorer
39 TRACE	4/2/98	GSFC	GSFC	Astrophysics/Explorer
40 Cassini	10/15/97	JPL	JPL	Planetary/Outer Planets
41 Mars Global Surveyor	11/7/96	JPL	LMA	Planetary/Mars Expl
42 NEAR	2/17/96	APL	APL	Planetary/Discovery
	Group 1	Group 2	Group 3	



# PCEC CASTS Model Mission Database



Engineering  
Cost  
Office

## *Roster of systems currently included in CASTS CER datasets*

### Launch Vehicles

Atlas V Common Core Booster  
Atlas V Centaur  
Apollo Command/Service Module  
Apollo Lunar Module  
Centaur D  
Centaur G' (Shuttle Centaur)  
Centaur G' CISS - ASE  
Shuttle External Tank  
Shuttle Orbiter  
Shuttle Solid Rocket Motor  
Shuttle Solid Rocket Booster  
Saturn V 1st Stage (SIC)  
Saturn V 2nd Stage (SII)  
Saturn V 3rd Stage (SIVB)  
Titan Centaur  
Titan IV 5m Fairing  
Atlas I, II, IIA, IIAS  
Super Lightweight External Tank

### Liquid Engines

F1  
J2  
J2X  
RS27  
RD180  
RL10  
RS68  
SSME

### Solids

Titan IV SRMU  
Athena Castor 120  
Trident D5  
Shuttle RSRM  
Atlas IIAS Castor 4A  
Atlas V SRM  
Ariane V EAP-P230  
Pegasus

### Software

SSME Adv Health Mgt Sys  
Orbiter Cockpit Avionics Upgrade  
Orbiter Primary Avionics Software Sys  
Orbiter Backup Flight Software  
BRAHMS  
DART  
X33  
Centaur G'  
Atlas II  
Atlas V