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NASA Air Force Cost Model (NAFCOM): Capabilities and Results

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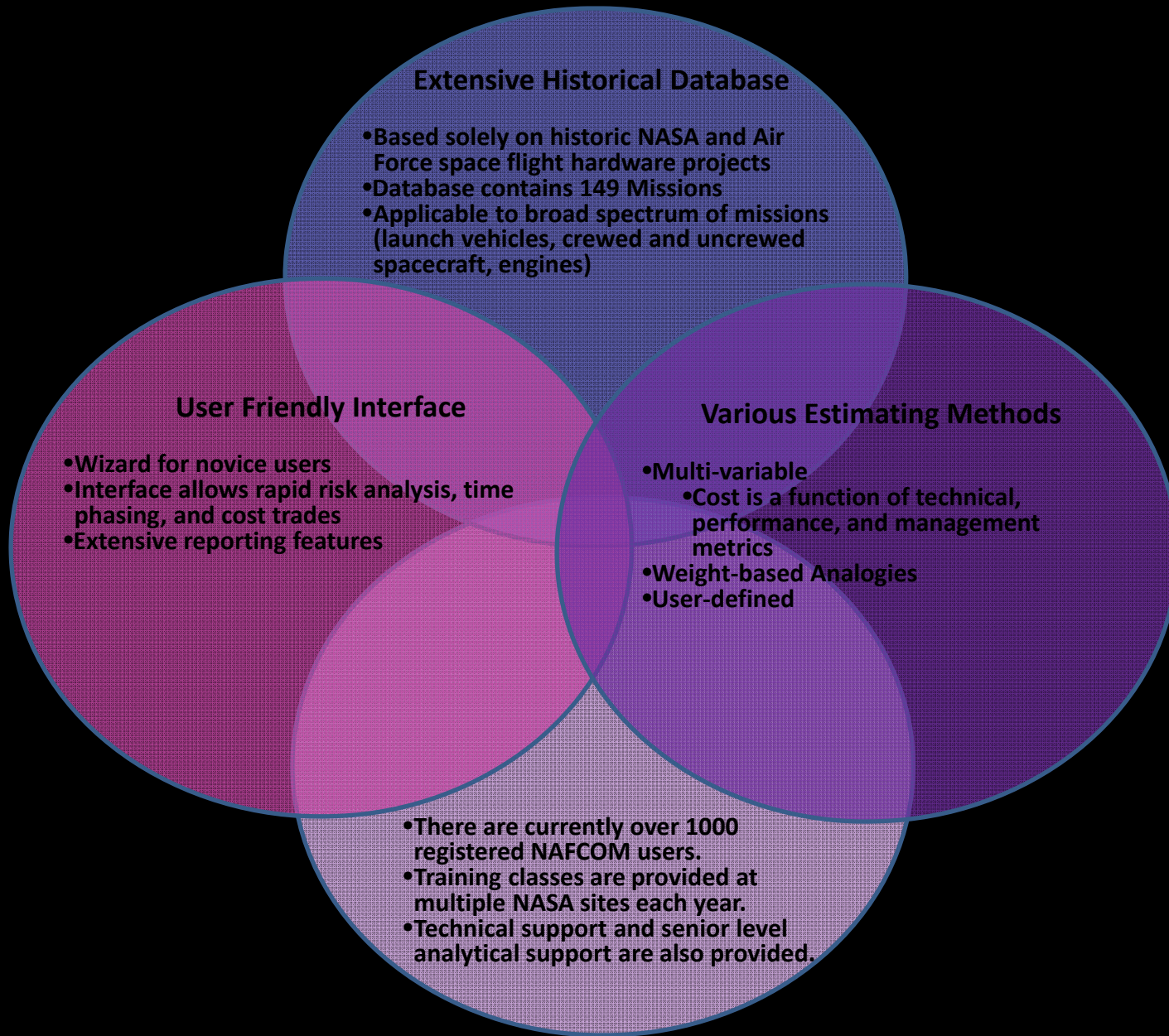
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NAFCOM Description

- NAFCOM is a parametric estimating tool for space hardware.
- Uses cost estimating relationships (CERs) which correlate historical costs to mission characteristics to predict new project costs
- It is based on historical NASA and Air Force space projects.
- It is intended to be used in the very early phases of a development project.
- NAFCOM can be used at the subsystem or component levels and estimates development and production costs.
- NAFCOM is applicable to various types of missions (crewed spacecraft, uncrewed spacecraft, and launch vehicles)
- There are two versions of the model: a government version that is restricted and a contractor releasable version

NAFCOM11



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

1999

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

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

2007

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

2008

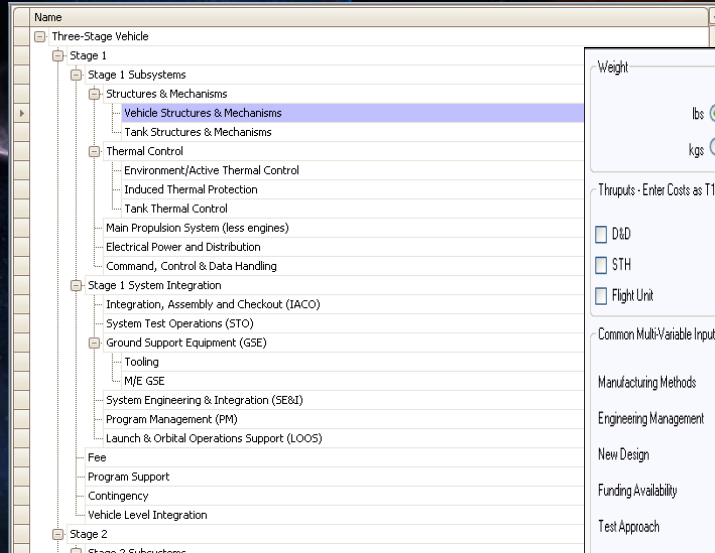
- 17 New Component Level multi-variable CERs
- New statistics integrated into database
- Historical Schedule Data integrated into toolbar
- Converted to .NET Platform and SQL Databases
 - New interface for risk analysis outputs
- Database contains 135 data points

Screenshots

NAFCOM v2011

NAFCOM11

New Estimate Open Estimate
NOOGLE Open Search



Weight

Most Likely DB Avg

lbs 17000 76,059.0

kgs 100 34,572.3

Thruputs - Enter Costs as T1 Values in FY 2006 \$ Millions

Most Likely

D&D 0

STH 0

Flight Unit 0

Common Multi-Variable Inputs

Most Likely DB Avg

Manufacturing Methods (3) Mod. Mfg Techniques 3

Engineering Management (5) Major Req. Changes 4

New Design (8) New design, Components 1

Funding Availability (3) Funding is Constrained - D 3

Test Approach (3) Maximum Testing, Qualific... 3

(3) Extensive Major Interfaces 3

(2) One Study Contract - Betw... 2

Mission	Selected	NoInSS	KnownInheritance	Subsystem Type	Level	New Des
Centaur-D	<input checked="" type="checkbox"/>	0	Centaur-D: Stru...	Structural/Mech...	Group	0.6
ACTS	<input type="checkbox"/>	0	ACTS: Spacecra...	Structural/Mech...	Group	0.7
AE-3	<input type="checkbox"/>	0	AE-3: All of the ...	Structural/Mech...	Group	0.6
AEM-HCMM	<input type="checkbox"/>	0	AEM-HCMM: Th...	Structural/Mech...	Group	0.4
ALEXIS	<input type="checkbox"/>	0		Structural/Mech...	Group	0.1
AMPTE-CCE	<input type="checkbox"/>	0	AMPTE-CCE: Th...	Structural/Mech...	Group	0.5
Apollo CSM	<input type="checkbox"/>	0	Apollo CSM: Hea...	Structural/Mech...	Group	1.0
Apollo LM	<input type="checkbox"/>	0	Apollo LM: The f...	Structural/Mech...	Group	1.0
Aqua	<input type="checkbox"/>	0	Aqua: Truss and...	Structural/Mech...	Group	0.4
ATS-1	<input type="checkbox"/>	0	ATS-1: The maj...	Structural/Mech...	Group	1.0
ATS-2	<input type="checkbox"/>	0	ATS-2: The maj...	Structural/Mech...	Group	1.0
ATS-5	<input type="checkbox"/>	0	ATS-5: The maj...	Structural/Mech...	Group	0.9
ATS-6	<input type="checkbox"/>	0	ATS-6: Structur...	Structural/Mech...	Group	0.8
Cassini	<input type="checkbox"/>	0		Structural/Mech...	Group	0.9
Centaur-G Pri...	<input type="checkbox"/>	0	Centaur-G Prime...	Structural/Mech...	Group	0.9
Chandra	<input type="checkbox"/>	0		Structural/Mech...	Group	0.9
CloudSat	<input type="checkbox"/>	0	ICESat	Structural/Mech...	Group	0.1
COBE	<input type="checkbox"/>	0	Structure simil...	Structural/Mech...	Group	0.6

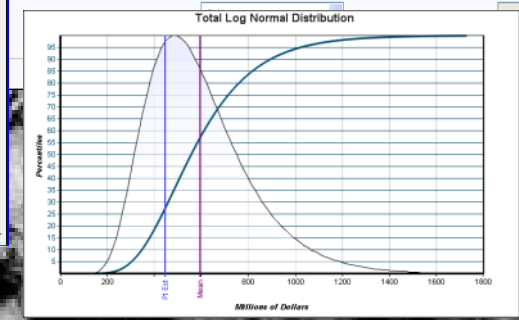
Specific Inputs

Most Likely DB Avg

(2) No 1

(1) Yes 1

1



Spitzer

MISSION OVERVIEW

Spitzer is the third in NASA's Great Observatories program, following the Hubble Space Telescope and the Chandra X-ray Observatory. It is a space-based infrared telescope that will observe the universe in the infrared spectrum. The telescope is named after Lyman Spitzer, a physicist who first proposed the concept of a space-based infrared telescope in 1946.

MISSION OBJECTIVES

Spitzer will observe the universe in the infrared spectrum, which allows it to see through dust clouds and observe the formation of stars and planets. It will also study the evolution of galaxies and the structure of the universe.



New Features

- 14 New Missions were added to NAFCOM 11's Historical Database bringing the mission total to 149:
 - CloudSat
 - ECLS (OGS, WRS)
 - IBEX
 - LCROSS
 - MAP
 - Messenger
 - MRO
 - New Horizon
 - RHESSI
 - SLWT
 - Spitzer
 - STEREO
 - TRMM

New Features

- New Multi-variable CER – **Composite Structures**
- Historical weight units are now sensitive to global selection.
- Users now have the ability to thruptut costs in any fiscal year.
- While in the multi-variable CER methodology the missions that were utilized to create the active CER will be bolded in the on-screen dataview. This gives users immediate access to which historical datapoints were used in the CER creation.

The screenshot displays the MARCOM Contractor v2011 interface. The left pane shows a project tree with 'Structure & Mechanisms' selected. The main pane shows a table with columns: Mission, Selected, WBS Item, Non-SS, Known/Inherit, Subsystem Type, and Level. The 'Mission' column contains entries like 'Galeville Orbiter', 'Apollo CSM', 'Galeville Probe', 'STARBUST SRC', and 'X-34'. The 'Selected' column has checkboxes, and the 'WBS Item' column has values like 'Thermal Control ...'. The 'Mission' column is bolded for the first four entries.

The right pane shows various input controls. The 'Thruptut' dropdown menu is highlighted with a red circle and set to 'Most Likely'. The 'Thruptut Fiscal Year' dropdown menu is also highlighted with a red circle and set to '2011'. The 'Composite Structures Specific Inputs' section is highlighted with a red circle and contains several dropdown menus: 'Significant Deployable?' (No), 'Structure Type' (Primary Structure), 'Faster, Better, Cheaper?' (Yes), and 'Composite Type' (Polymer Matrix).

At the bottom, a summary bar shows: DDTBE Cost: 464, Flight Unit Cost: 646, Production Cost: 646. Total Cost: 284.0. Fiscal Year: 2011. Records Returned: 5.

New Features

- Real Year Time Phasing
- Two new templates have been added: Earth Orbiting and Planetary.
- Total mission weight, cost and developing organization have been added to the historical schedule database.

The screenshot displays the NAF-COM v2011 software interface. The main window shows a hierarchical tree of systems under 'Crewed Vehicle'. The 'Electrical Power and Distribution' system is highlighted, and a table below it shows data for various years. A red circle highlights the 'Real Year' column and the 'Flight Line' row.

Real Year	Total (Bk)	2010	2011	2012	2013	2014
Electrical Power and Distribution						
DDTIE	0.1	2.4	5.0	0.7	0.0	0.0
Flight Line	0.9	0.0	0.0	0.4	0.1	0.0

At the bottom of the window, the following costs are displayed: DDTIE Cost: 2,958.1; Flight Unit Cost: 477.6; Production Cost: 477.6; Total Cost: 4,913.3.

The screenshot shows the 'NAF-COM 11 Template Wizard' dialog box. It features a 'Select a Template Type:' dropdown menu with the following options: Earth Orbiting Spacecraft Template, Planetary Spacecraft Template, Uncrewed Spacecraft Template, Crewed Spacecraft Template, and Launch Vehicle Stage Template. The 'Continue' button is visible below the dropdown.

New Features

- The NAFCOM historical database has undergone an extensive review. All historical technical data has been verified and updated if necessary.
- A new visual prompt has been incorporated to remind user's that costs do not change when making database selections when using the multi-variable CER methodology
- A new "Quick Entry" tool has been integrated into the NAFCOM toolbar. This tool will provide the user quick access to major technical fields in one screen.
- The F1 help has been improved.
- The latest NASA and Air Force inflation indices have been incorporated.

NAFCOM Quick Entry Form - NOTE: Your estimate WILL reflect the changes you make on this form!

Elements	Weight (lbs)	STH Qty	% of Flt Unit	Mfg Meth/DD Cmplx	Eng Mgmt/DD Inher	New
▶ Crewed Vehicle						
System 1						
System 1 Subsystems						
Structures & Mechanisms	1,288.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New
Vehicle Structures & Mechanisms	644.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New
Tank Structures & Mechanisms	644.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New
Thermal Control	400.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New
Environment/Active Thermal Control	100.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New
Induced Thermal Protection	200.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New
Tank Thermal Control	100.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New
Main Propulsion System (less engines)	500.0	1	130	(3) Mod. Mfg Techniques	(5) Distributed Design Team	(8) New
Composite Structures	155.6	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(5) Limi
Electrical Power and Distribution	100.0	1	130	(3) Mod. Mfg Techniques	(5) Distributed Design Team	(8) New
Command, Control & Data Handling	100.0	1	130	(3) Mod. Mfg Techniques	(5) Distributed Design Team	(8) New
System 2						
System 2 Subsystems						
Structures & Mechanisms	1,288.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New
Vehicle Structures & Mechanisms	644.0	1	130	(2) Sig. Mfg Techniques	(2) Few Design Changes	(8) New

OK

NAFCOM Access

- Please contact Julie McAfee (mcafeej@saic.com) for information on obtaining the NAFCOM model.
- NAFCOM website:
<https://nafcom-government.saic.com>



NAFCOM Benchmarking Activity

Intent & Guidelines

- Purpose of this exercise was to create benchmark estimates of selected missions in their final state to compare against historical actuals
- Several guidelines placed on this activity
 - Keep estimates at subsystem level, no thruputs
 - Initial focus of only Launch Vehicle projects expanded to include Earth Orbiting and Planetary
 - Don't “doctor” the outcomes—level playing field

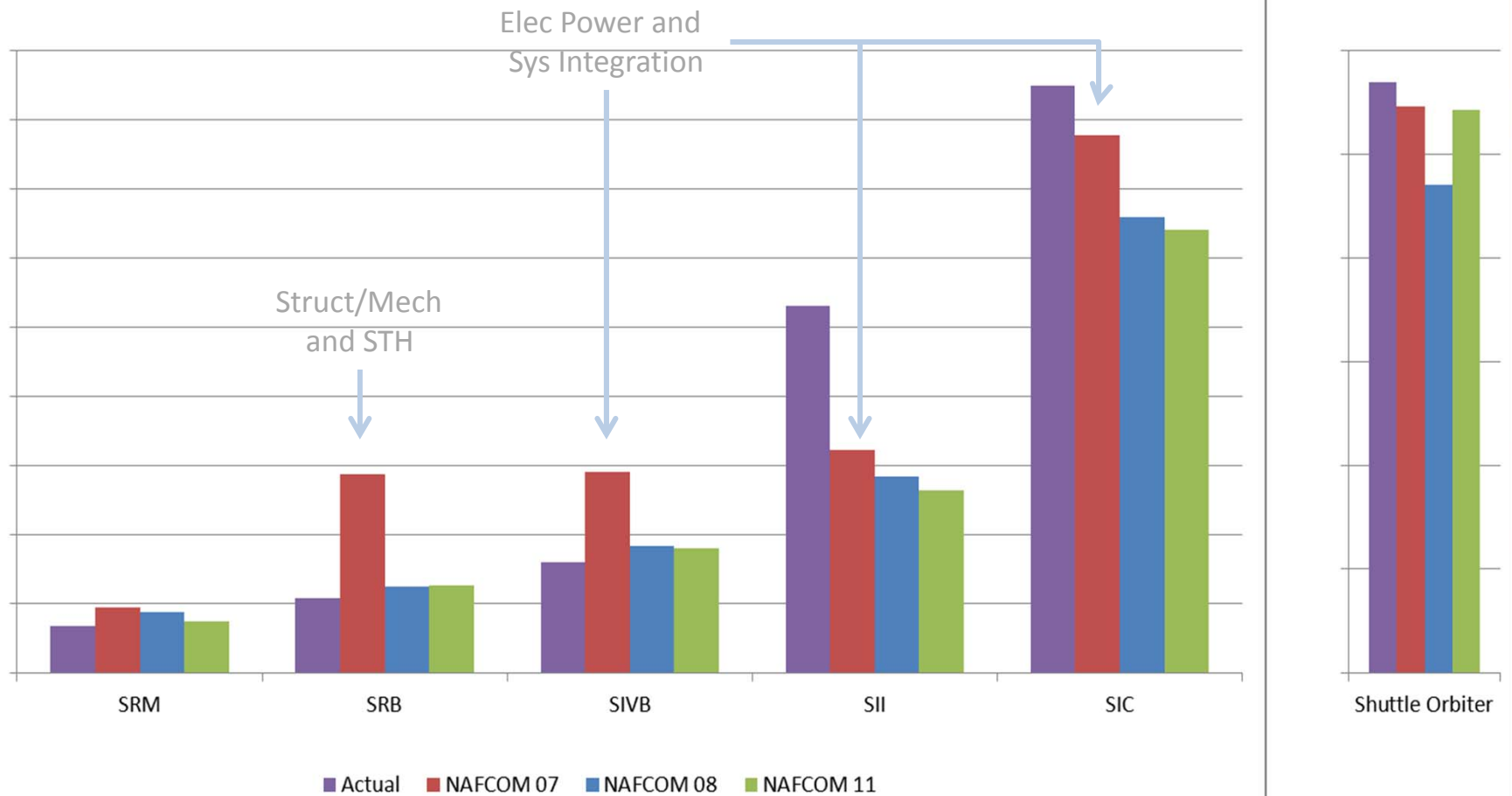
Methodology

- Extract historical subsystem data and actual costs from NAFCOM database for identified missions
- Model these missions in NAFCOM07 to estimate subsystem costs
 - Deflate to FY06 as common denominator
- Model same missions in NAFCOM08 and 11 with identical technical inputs (NAFCOM file converter)
- Collect all subsystem data in summary database
- Aggregate cost to system level & report results

Selected Mission Set

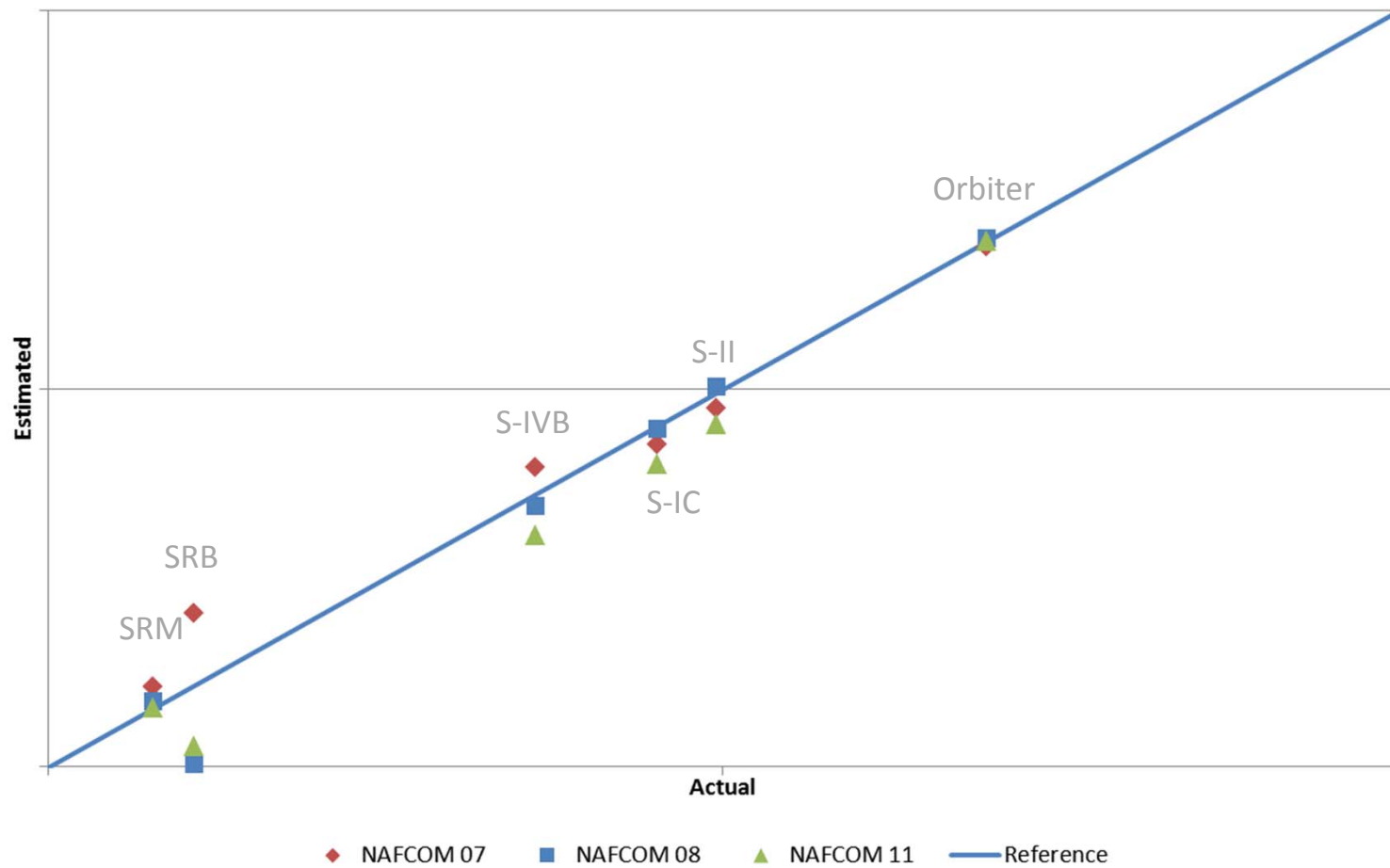
- Launch Vehicles (focus of this presentation)
 - SRM, SRB, S-IVB, S-IC, S-II, Shuttle Orbiter
- Science Missions (results in backup)
 - Aqua, Chandra, DART, IBEX, STEREO, CONTOUR, Deep Impact, Genesis, LCROSS, MRO

Comparison to Actual—LV DDT&E

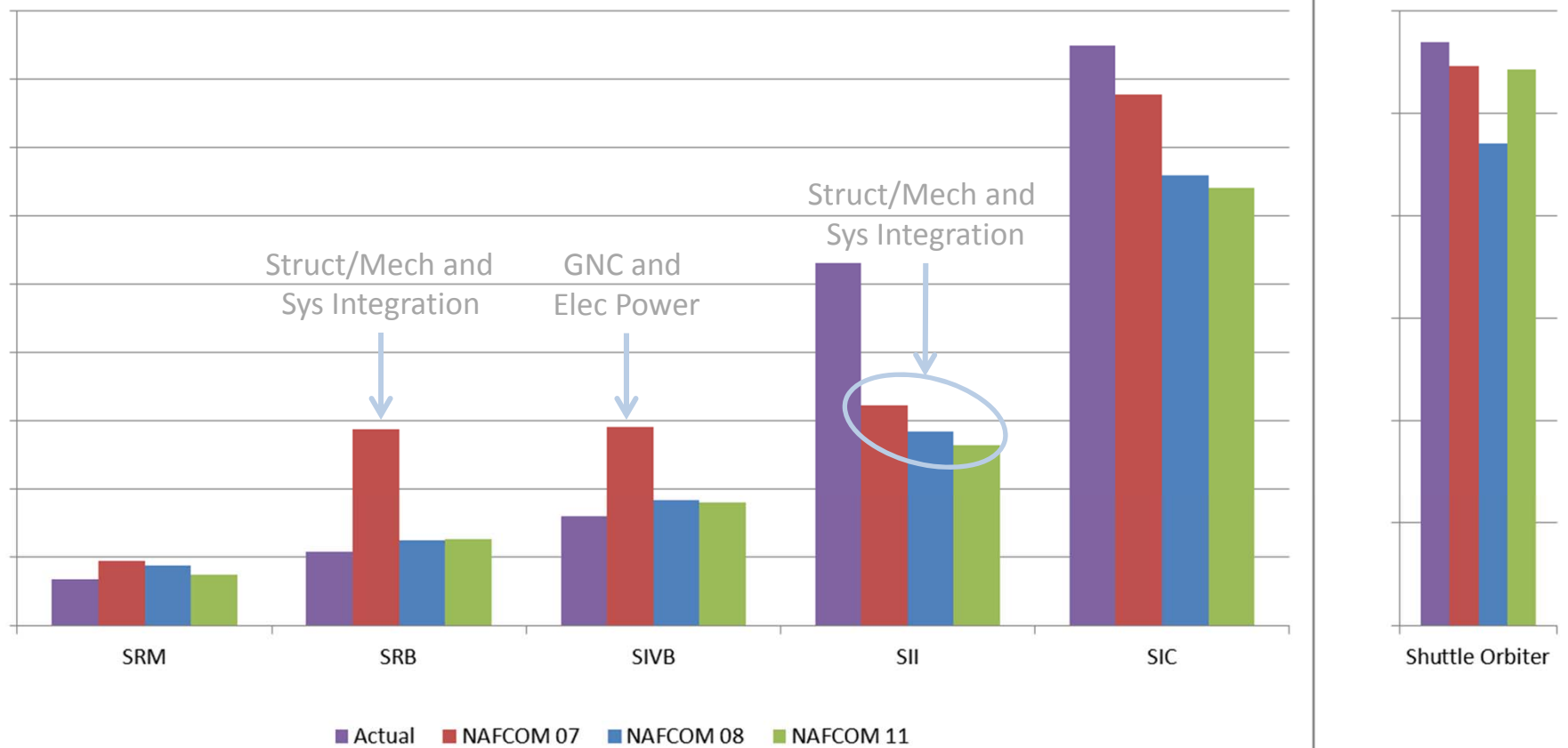


Log-Log Scatterplot—LV DDT&E

NAFCOM Launch Vehicle Benchmarking - DDT&E Cost

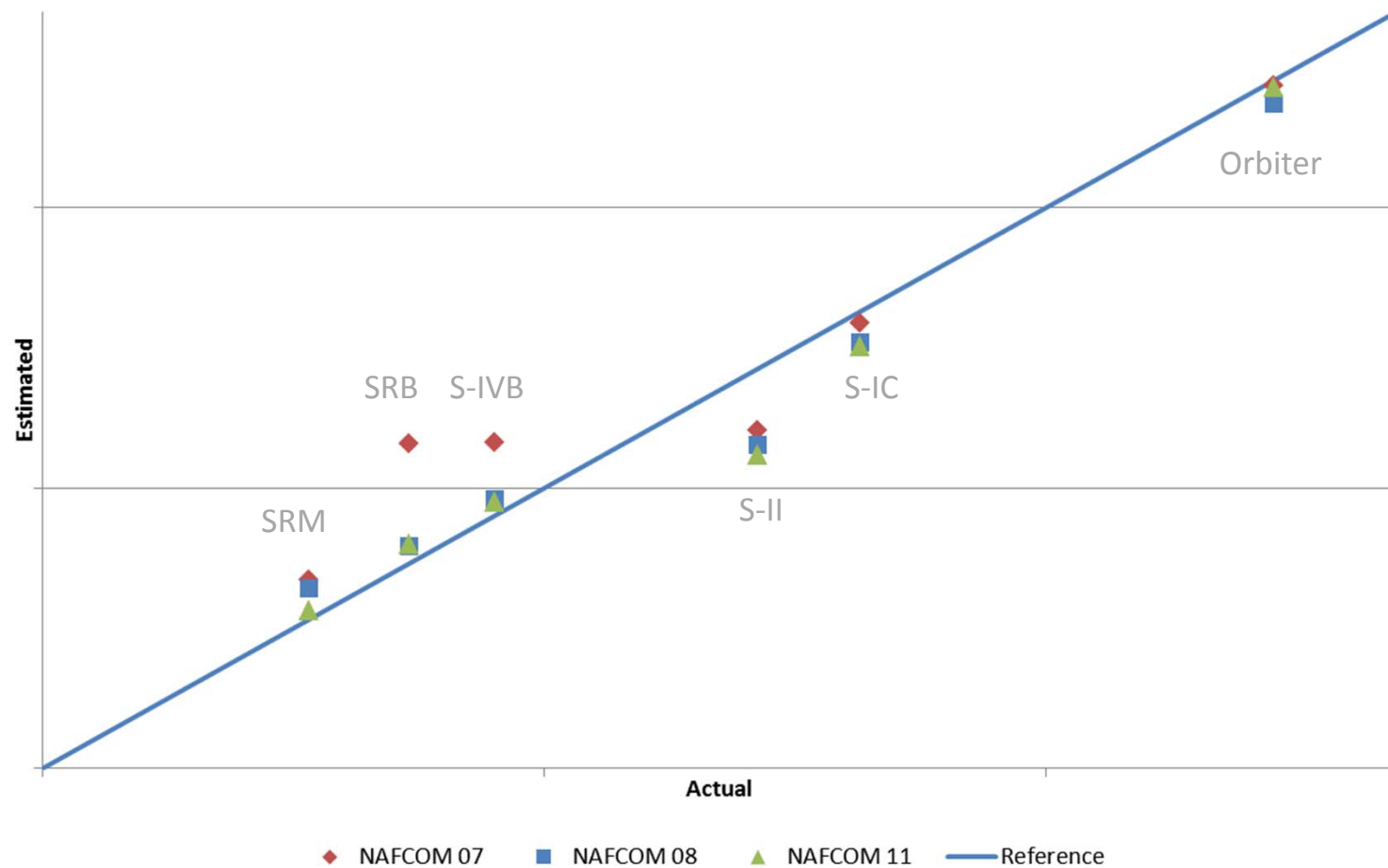


Comparison to Actual—LV TFU



Log-Log Scatterplot—LV TFU

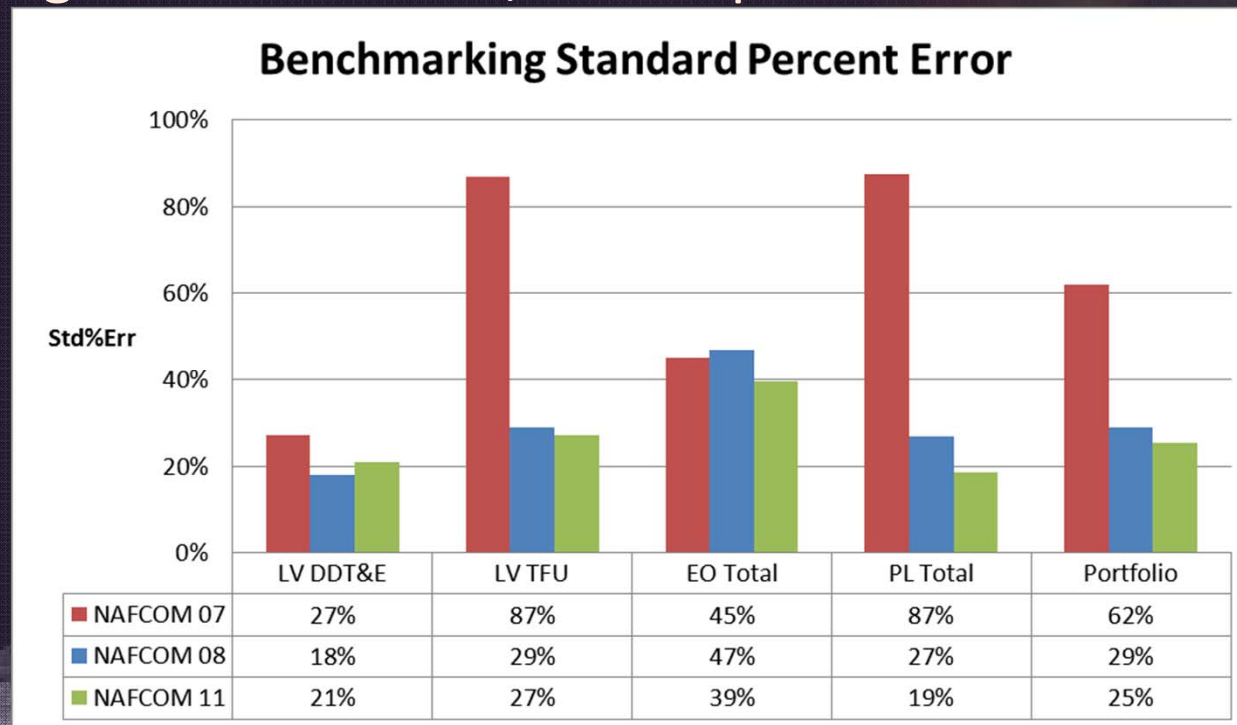
NAFCOM Launch Vehicle Benchmarking - Flight Unit Cost



Scorecard

- Standard Percent Error of sample set can be calculated as square root of sum of squares of percent error divided by degrees of freedom, or in equation form:

$$Std\%Err = \sqrt{\frac{\left(\frac{Act - Est}{Act}\right)^2}{dof}}$$



- Trend shows reduced error with latest NAFCOM releases

Benchmarking Results

- Benchmarking activity highlights general improvement in estimating tools
 - Helped with additional data points and CER improvements
- Relatively consistent outcomes across mission classes in NAFCOM 11

NAFCOM And Commercial Projects

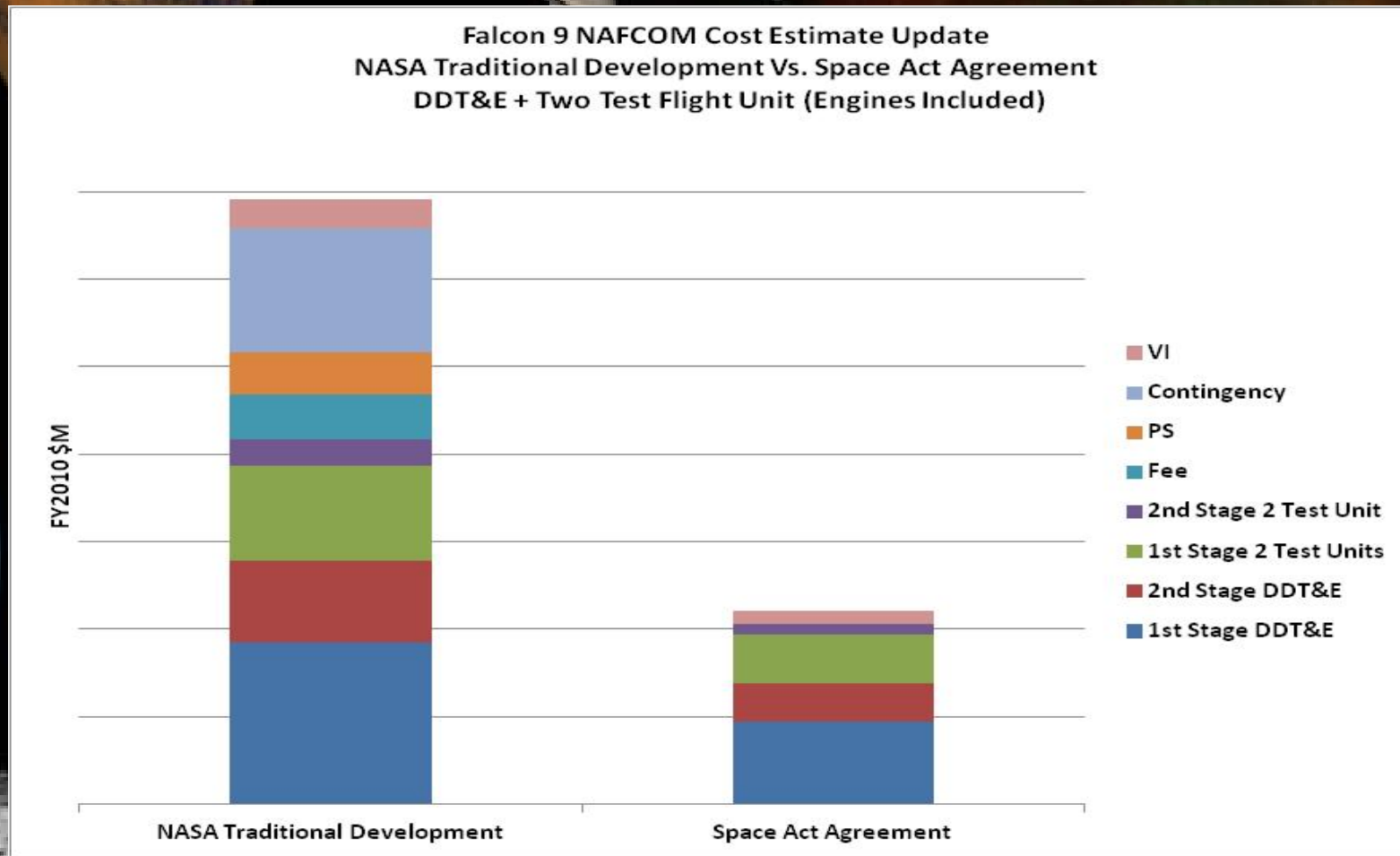
- NAFCOM database does not currently contain any commercial projects data
- NAFCOM database does contain X-projects data
- NAFCOM technical inputs provide a wide range of settings which when used properly, can capture various development environments
- NAFCOM recently used to capture/estimate a commercial launch vehicle development cost

NAFCOM Estimate of SpaceX Falcon 9

- NASA HQ developed two cost estimates using Falcon 9 technical information:
 - A commercial approach (SpaceX Space Act Agreement/ Firm Fixed Price like acquisition)
 - A traditional NASA development approach (cost plus fee acquisition)
- NAFCOM technical inputs settings were adjusted to represent the different approach in each estimate
- Commercial approach result within 13% of the Space Act Agreement
- NASA environment estimate nearly three times higher

Falcon 9 NAFCOM Cost Estimate results

Falcon 9 NAFCOM Cost Estimate Update
NASA Traditional Development Vs. Space Act Agreement
DDT&E + Two Test Flight Unit (Engines Included)



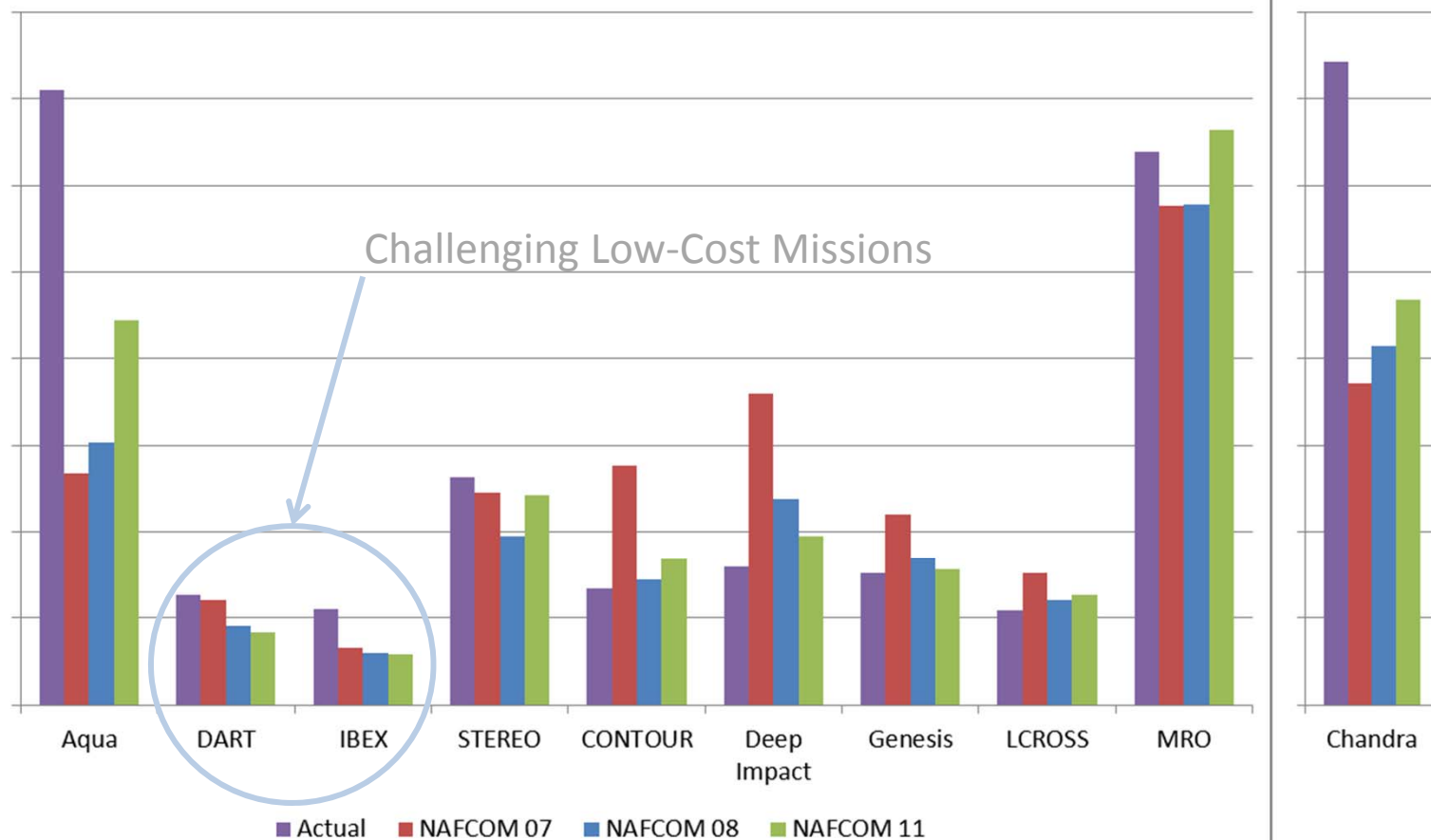


BACKUP

Science Missions

- Less concern on separating DDT&E from production for one-off missions
- This analysis combines both to assess total hardware cost
- Note: instruments, launch vehicle/services, and Phase E (operations) excluded
 - Spacecraft bus only estimated with multi-variable CERs

Comparisons to Actual



Log-Log Scatterplot

NAFCOM EO & PL Benchmarking - Total Bus Cost

