This Is Not Your Father's Old Spacecraft

An Examination Into Using Modern Data To Inform Manned Spacecraft Cost Estimates

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Introduction

- **NASA's tools and practices for cost estimation of manned space vehicles are informed by only a handful of data points**
  - None of which are recent and none of which includes the costs of new technologies and commercial/new ways of doing business
- **However, we now have some new data in both our traditional and commercial manned space developments**
- **This presentation will evaluate how this new data informs our body of knowledge and identify new areas for additional analysis**

EFT-1 Cost Actuals

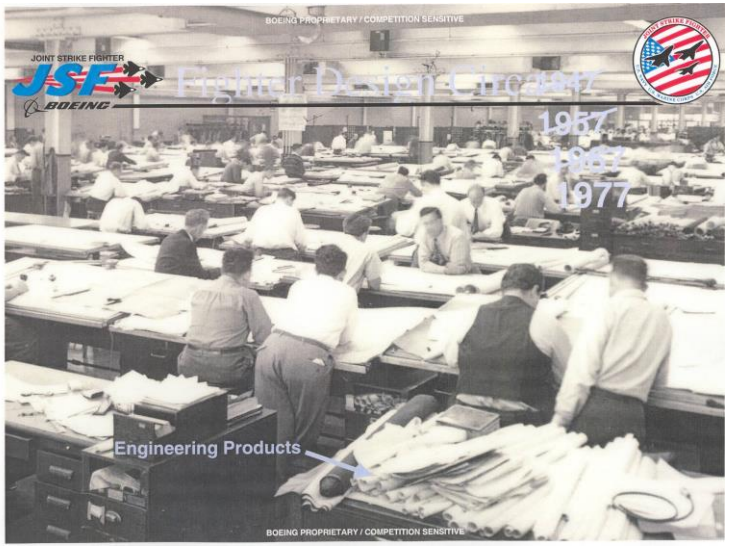
- **Cost data from the recent EFT-1 launch has enabled us to begin evaluating our cost estimation platforms with new manned space data and how well our subject matter expert inputs perform**
- **A detailed PRICE-H estimate done for KDP-B compares reasonably well against EFT-1 actuals (within 10% to 20%)**
  - Need to update for actual hardware content, weight before doing model calibration
- **A detailed SEER-H estimate done for EFT-1 Structures and Mechanisms also compares favorably against actuals**
  - Preliminary top-level modeling on some other subsystems match well against actuals
- **Finally, we examined costs for *flight-like* hardware matched PCEC modeling**
  - Structures, Thermal

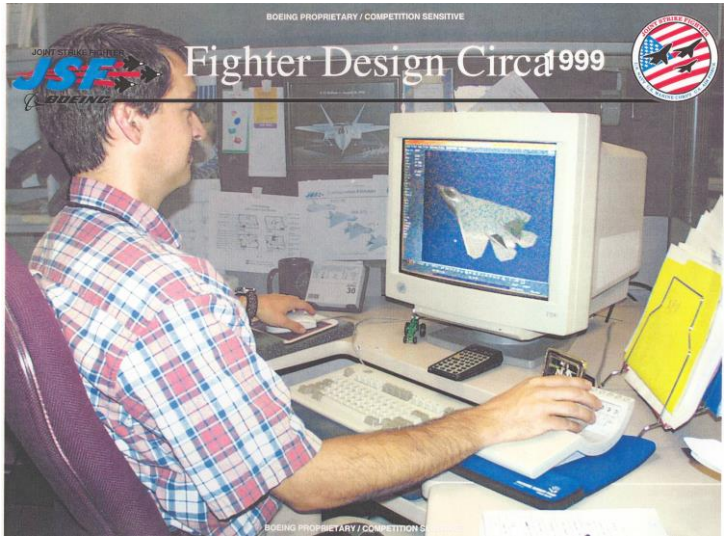
Not Bad For Estimates Based On Old Data

- **Our estimation efforts have been well-informed by inputs from the technical community**
  - Including those pesky subjective variables
  - Weight is **not** an objective input (see "Your Cost Model Is No Good", 2011 Cost Symposium)
  - Sanity checks from data gleaned from CADRe/ONCE
- **While far from perfect, we have crafted a set of models that work fairly well in practice (if not in theory)**
- **EFT-1 data provides a general validation of our cost estimation methods and models**
  - Can use the data to calibrate and refine our CERs (or "adjustment factors")
  - Highlighted areas for improvement (avionics)

But Why Does Old Data Provide A Good Estimate?

- **There has been a good deal of skepticism concerning our modern cost estimates for manned spacecraft**
  - Criticism has been that old data, particularly from the Apollo Program, don't incorporate enough in the way of modern design and manufacturing techniques
  - Expectation that we should be doing better





But Why Does Old Data Provide A Good Estimate?

- **Design hours were supposed to have been reduced by modern computing versus slide rules and hand drafted designs**
  - The reality is that much of the effort in the design phase is spent elsewhere
  - Support for NASA's formal systems such as systems engineering and configuration management, to name a few, remain much as they have in the olden days
- **It has long been noted that the material itself only constitutes a small fraction of the cost of a NASA spacecraft development**
  - Historically around 10% of the total cost
  - While modernization can reduce the costs associated with hardware builds, this impact is dampened by the small contribution to the total cost
  - How much of the overhead burden creeps in and offsets savings from technology?

The Importance Of The Business Model

- **Because most of our modeling inputs are informed by technical parameters and subject matter input, it is easy to overlook the fact that our cost data and CERs are very heavily influenced by our business model**

- ***How* you build is as critical as what you build**
  - Critical to understanding how to calibrate our models to commercial developments, new ways of doing business

- **EFT-1 data has allowed us to validate the assumptions for those parameters that reflect this business model (e.g., conventional ways of doing NASA developments)**
  - NAFCOM/PCEC Engineering Management, Manufacturing Methods

Modeling NASA's Commercial Crew Development

- **Studies into commercial space modeling and insights from study principals have been invaluable in helping to inform how to calibrate our models to commercial ways of doing business**
  - Falcon 9, Surrey Satellite models done in NAFCOM and helped inform model settings
- **In addition, Program Integration Teams (PITs) embedded in commercial partner developments and subject matter experts (SMEs) have helped shape modeling inputs**
  - Business as well as technical parameters
- **Subject matter input was also relied upon to estimate costs for non-vehicle costs for the Commercial Crew Transport Capability (CCtCap) contract**
  - Mission operations
  - Ground operations
  - Launch vehicle services

Disclaimer

- **All information presented today draws solely from publicly available information, no procurement or program sensitive data presented**

- **Hardware based on Orbital Space Plane (OSP) vehicle concepts**
  - Similar vehicle, concept of operations as Commercial Crew
  - No commercial partner hardware data or specific subsystem parameters have been used

- **Contract value data from GAO's decision on the CCtCap protest was used for calibration**
  - http://www.gao.gov/assets/670/667979.pdf

Commercial Modeling is Less a Specific Set of Rules…

… And More What You'd Call Guidelines

PCEC Model Settings for Commercial Modeling

- **PCEC (version 1.1.1) was used for Commercial Crew model calibration, in order to put results in context with other commercial modeling done in NAFCOM**

- **Major business settings in PCEC that drive cost**
  - Manufacturing Methods (lean manufacturing)
  - Engineering Management (less formal systems, fewer requirements changes)
  - System Integration (includes Program Management, Systems Engineering)

- **Major technical settings in PCEC**
  - New Design (less complex, more use of heritage systems)
  - Weight

Manufacturing Methods

		Vertical Integration	Less Formal Systems	Fewer Personnel
(1) Max. Mfg Techniques	Commercial Providers	↕	↕	↕
(2) Sig. Mfg Techniques				
(3) Mod. Mfg Techniques	NASA Average			
(4) Min. Mfg Techniques				
(5) Limited Mfg Techniques		Horizontal Integration	High Systems Heirarchy	More Personnel

Engineering Management

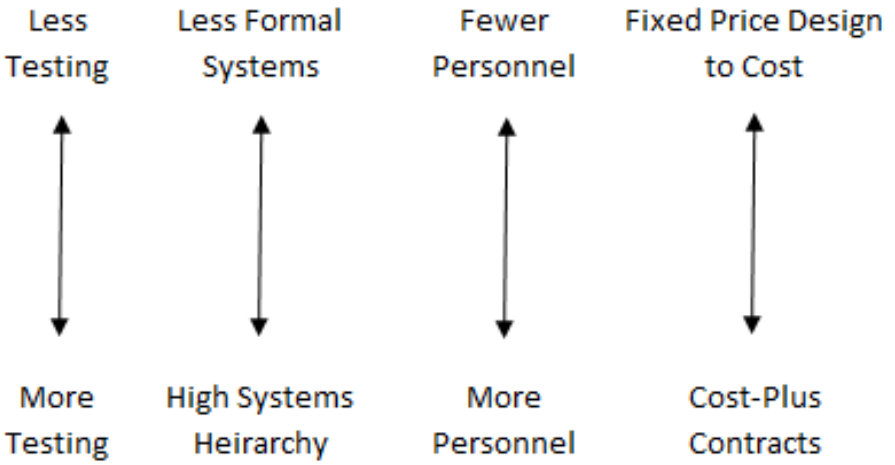
(1) Min Design Changes — Commercial Providers

(2) Few Design Changes

(3) Mod Design Changes — NASA Average

(4) Significant Req. Changes

(5) Major Req. Changes



System Integration

- **PCEC includes Program Management and System Engineering within the System Integration wraps**
- **Consistent with a leaner management structure, these efforts are considerably less in commercial developments**
- **Reducing these efforts drops System Integration to 24% of hardware costs (versus an average 30% for traditional development)**

New Design

(1) Existing "flight proven" design requiring no mods (5%)	
(2) Existing design requiring minor mods that do not require re-qual (15%)	
(3) Existing design requiring minor mods that require re-qual (25%)	Standard bus, spiral designs
(4) Existing design with about half of components requiring mods that require re-qual (43%)	NASA, High Heritage/Low Complexity (Faster/Better/Cheaper)
(5) Existing design with greater than half of components requiring mods (64%)	NASA, High Heritage/Low Complexity (Faster/Better/Cheaper)
(6) New design. Subsystem model or prototype validated in relevant environ (79%)	Commercial Providers
(7) New design. Components validated in relevant environ not yet integrated as a sub (91%)	NASA, Low Heritage/High Complexity
(8) New design. Components validated in lab environ or relevant environment (100%)	NASA, Low Heritage/High Complexity

Other Considerations

- **No conversation of commercial modeling is complete without considering the unique business model of SpaceX**
  - High degree of vertical integration, nearly all hardware built in-house
- **SpaceX is said to employ strategy for a myriad of reasons other than cost**
  - Control (quality, schedule)
  - Bad experience with vendor-supplied parts
  - Doing things in-house allows for re-engineering as needed
- **Our data indicates that vertical integration could cut costs by 20% to 30% versus subcontracted work**
- **Lower labor costs**

Summary of Model Settings for Commercial Crew

- **Manufacturing Methods – 1 (vs 3 for average NASA)**
- **Engineering Management – 1 (vs 3 for average NASA)**
- **System Integration - 24% (vs 30% for most NASA manned)**
- **New Design – 6 (vs 8 for most NASA manned)**
- **Weight – Roughly 70% of NASA OSP concept**
- **Additional calibration needed for SpaceX unique business model**

Bonus Content – PCEC Comparisons

- **Somewhat of a mixed bag**
- **PCEC v1.1.1 performed better on EFT-1 structures**
  - "Data rich" CER that better supports multivariate estimates
  - PCEC v2.0 adjustment factors out of family relative to historical analogs
- **PCEC v2.0 performed better on EFT-1 thermal**
  - Virtually matched many aspects of the Apollo heatshield
  - https://vimeo.com/67660646
- **Need to be able to explain ***why***

Thoughts For Additional Analysis

- **Enhance our business modeling**
  - Have a good handle on traditional, commercial ways of doing business in PCEC v1.1.1, extend knowledge to SEER and PRICE platforms
  - Need to further quantify the international partnership model, cost of multi-center development
- **Explore use of ONCE/CADRe data in manned space modeling**
  - Avionics
  - Research multiplier for man-rating (deltas between manned versus unmanned platforms seem “fixed” and are not the same from model to model)
- **Better understanding of historical manned space data**
  - How as well as what…and why
  - Employ analogies where appropriate, get better insights into this data
- **Undertake effort to collect additional manned space data**

Questions/Comments

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BACKUP

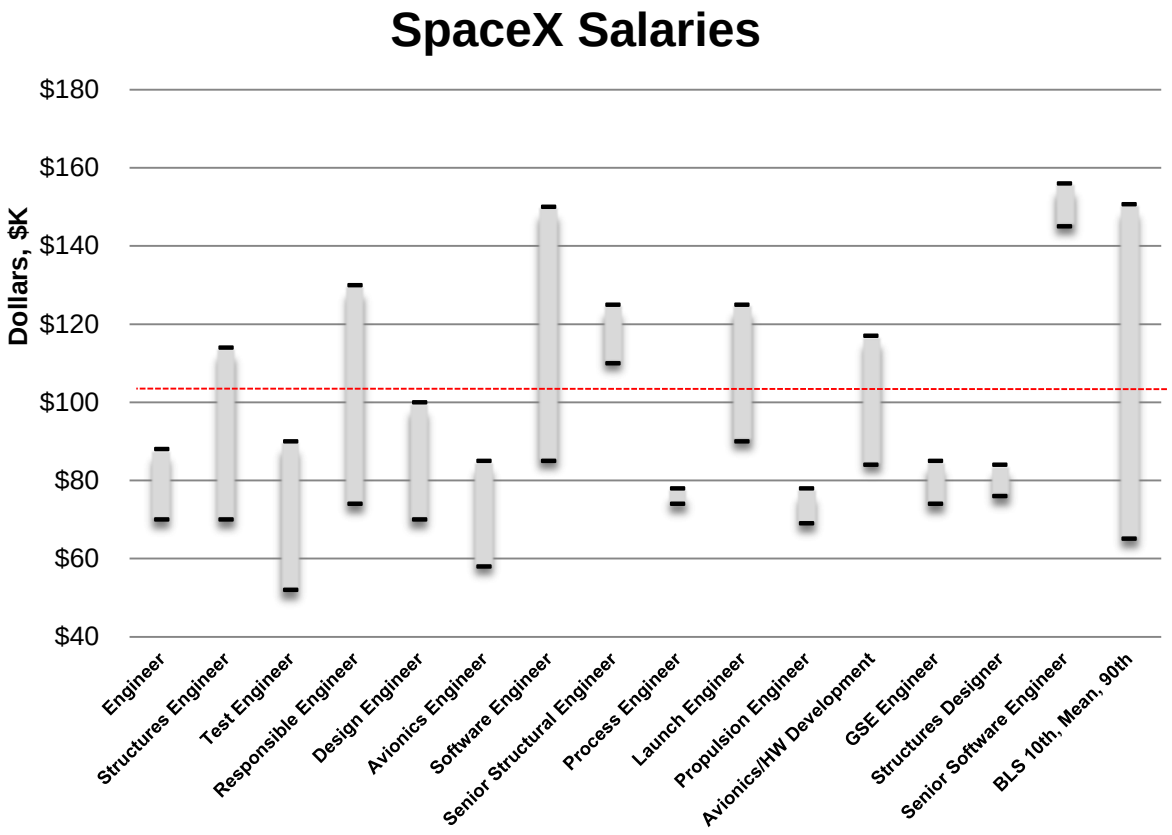
Body of Knowledge on Commercial Modeling

- **The National Reconnaissance Office (NRO) has developed model calibrations for commercial-like acquisition**
  - Based on a large number of data points, regression analysis
- **Aerospace study on Surrey Satellite Technology Limited**
  - Calibration of NAFCOM, Aerospace Small Satellite Cost Model based on a sampling of Surrey spacecraft actuals
- **Falcon 9**
  - Calibration of NAFCOM (performed by Mahmoud Naderi) against Falcon 9 actuals
  - Internal Commercial Crew Program (CCP) modeling of Falcon 9, calibrated against actuals and updated for Falcon 9 v1.1

Labor

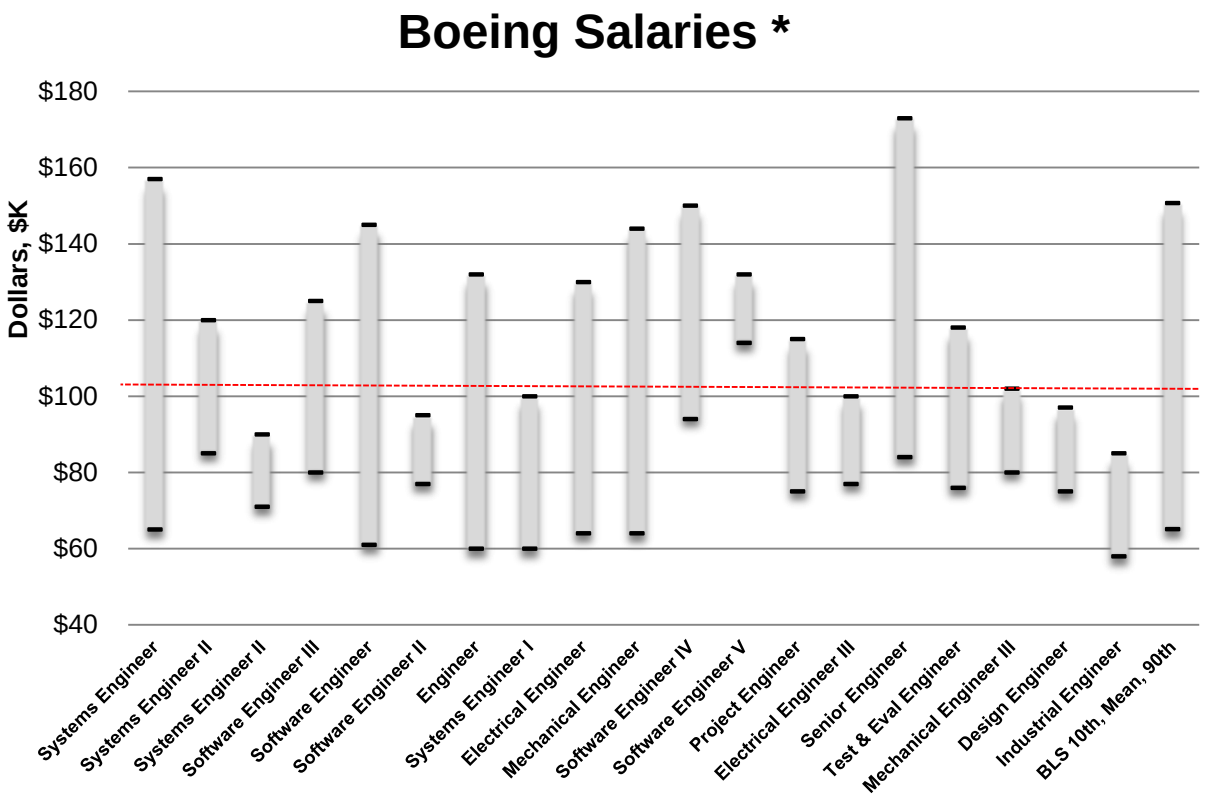
- **Labor costs are considerably less for commercial providers**
- **U.S. commercial developments have demonstrated considerably lower labor costs than traditional labor developments**
  - Salaries range from 10th to 25th percentile of aerospace salaries (based on Bureau of Labor Statistics)
  - Observed labor mix (junior vs senior personnel)
- **Other**
  - Surrey, about 75% of U.S. aerospace salaries
  - India (Mars Orbiter Mission), about 12% of U.S. aerospace salaries

Labor – Commercial Crew Partners



Source: GlassDoor, Bureau of Labor Statistics (red line is mean of BLS data for aerospace salaries)

Labor – Traditional Aerospace



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*** Boeing salaries not specific to commercial development**