NASA Productivity Study

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Bob Bitten, Aerospace Corp
Joe Hamaker, SAIC
Henry Hertzfeld, GWU

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Topics

- **Overview---Tom Coonce**
- **Genesis of Study--------------------------------------Tom Coonce**
- **Productivity and Inflation---------------------------Joe Hamaker**
- **Terminology---Henry Hertzfeld**
- **NASA Productivity Trend Analysis---------------Joe Hamaker**
- **Organizational Comparative Analysis-----------Bob Bitten**
- **Review of Workshop Results----------------------Tom Coonce**
- **Actionable Ideas--------------------------------------Tom Coonce**

- **Other material developed as part of this study but not briefed today (to be addressed in journal paper being prepared)**
  - **Review of Previous Space Industry Efficiency/Productivity Lessons Learned**
    - **by Bob Bitten, Aerospace**
  - **A Brief Summary of Efficiency and Productivity in Academic Literature**
    - **by Henry Hertzfeld, GWU**

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Genesis of This Study

- **Comments from the Administrator**
  - "I start with the hypothesis that aerospace work is not significantly different in kind from other defense and hi-tech work. The OMB has separate deflators for these two categories, but in fact they do not differ greatly. The NASA New Start index does.
  - We assign this difference to the cost of labor. But all of my experience leads me to conclude that our labor market is, to a high order of accuracy, interchangeable with that of the defense and high-tech sectors. Such interchange occurs constantly, as I have observed it.
  - People do not become intrinsically less productive because they move from R&D or defense to the narrower sector of aerospace. Thus, my hypothesis is that if we are paying significantly higher labor costs leading to an NNSI which is measurably different from the OMB defense and R&D deflators, we are observing and measuring a real difference in productivity; i.e., more $$ per unit of product for "aerospace" stuff.
  - If, per my claim, the people are fungible, and the nature of the hardware is similar, then the difference may logically be ascribed to process. Aerospace "process" sucks up money that, in related sectors, goes into product. That is my conclusion.
  - My hypothesis depends upon postulates which I've stated above. They may or may not be correct, or even if correct in themselves, they may be incomplete. My goal is to obtain data which can be used to support, or falsify, my hypothesis.
  - Either way, the result should be useful. In fact, I think it would be an important, publishable research result. Ultimately, it could influence policy."

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Genesis of Study (Recap)

- **NASA Administrator hypothesized that NASA must be less productive than the rest of the economy because NASA's New Start Index is typically higher than the OMB-prescribed deflator and higher than DoD, NOAA, and NRO**
  - NASA work not that different than DoD, NOAA, and NRO
  - Draw from the same labor pool
  - Concludes that NASA gets less output for a given input
  - Can't differentiate the signal from the noise
- **The fact that NASA future projections of its prices are higher than OMB and OSD *could* indicate that NASA is less efficient than other organizations which have lower inflation projections.**
- **NASA Administrator wants to know if this is true and if so, why and what can be done about it**

Considerations Concerning Productivity and Inflation

- **First some background….**
  - NASA generally uses one of two methods for accounting for inflation in its cost estimates
    - Prior to contractor selection, the NASA New Start Inflation Index is used
      - This index is based on forecasted price changes by the econometric firm, Global Insights, for a market basket of goods and services that is believed to be representative of NASA work
    - After contractor selection (usually around KDP B (SDR) for most projects), NASA budget submissions generally reflect the forward pricing rates of the selected contractors (i.e. the NASA new start index is no longer needed)
  - Historically, both the NASA index and contractor forward pricing rates have tended to be higher than an index that the OMB uses to inflate the top line in the President's Budget for NASA budget
    - Historically, the delta between the OMB index and NASA rates has been on the order of 1-2%
      - This can actually be billions of dollars over time due to compounding

Considerations Concerning Productivity and Inflation (Continued)

- **Background continued….**
  - Cold comfort but the NRO and DOD cost estimating inflation indices agree with the NASA/Global Insight index very closely
    - NRO also uses Global Insight data
    - The DOD index basis is less transparent but ends up with similar rates (and most programs use this method)
    - And this agreement shouldn't be surprising since we use the same contractors and materials
  - To further confound the issue, it should be remembered that the OMB President's Budget (PB) is almost always changed by Congress
    - Whose appropriated amounts do not explicitly adjust for inflation in any transparent way
  - So to a very large extent, the debate on inflation indices becomes overtaken by events by the time Congress provides NASA its actual budget
  - But assuming that the OMB PB is a starting point for Congress, "high" inflation rates in NASA (and its sister organizations) remains problematic

Considerations Concerning Productivity and Inflation (Continued)

- **Setting aside the debate on inflation rates, inflation and productivity are related, but are different and independent economic forces**
- **The effects of inflation and productivity can be described metaphorically…**
  - *Inflation is like a jet stream headwind* which negatively affects the fuel economy of an airliner
    - The headwind is beyond the control of the airliner but the effects can't be ignored
    - Likewise, the cost of engineering labor, exotic materials, etc. are largely beyond the control of the buying agency but can't be ignored
      - Or suppressed as the OMB would have it
  - *Productivity is like the aircraft design* which also affects the fuel economy of the airliner
    - The cleverness of the design of the airliner affects fuel economy
    - Likewise, the cleverness of NASA engineering and management affects NASA productivity
      - However, this study shows that some productivity factors are in NASA's control and some are not

Considerations Concerning Productivity and Inflation (Continued)

- **Inflation and productivity are connected in economics like the jet stream and the aircraft design are connected**
  - The observed fuel economy of the airliner is determined by *both* the effects of the jet stream headwind and the efficiency of the aircraft design
- **Thus the initial "ruminations" on inflation and productivity which began this study were well founded**
- **Likewise, the overall cost of NASA products is influenced by inflation and productivity**
  - To the extent that NASA is cleverly productive, the negative effects of inflation can be overcome
  - Our study shows that productivity in NASA is actually growing by something like 3% per year holding performance specifications constant
  - But we must remember that NASA is constantly demanding higher performance specifications of its products
  - Analogously, if an airliner wants to go faster, fuel economy will suffer even though the aircraft designers were very clever
    - All else is <u>not</u> being held equal—the airliner wants to go faster

Considerations Concerning Productivity and Inflation (Concluded)

- **In some economic sectors, Moore's Law type productivity improvements are sufficient to overcome inflation and constantly increasing performance demands**
  - Computers are ever faster, have more memory and storage, more capable software, and are designed by scarce/expensive computer science labor
  - Yet computer prices drop
- **In NASA, the 3% productivity gain is approximately equal to its 3% inflation loss**
- **The remaining independent variable/degree of freedom is finding ways to increase NASA's 3% productivity metric**
  - *This is the focus of the balance of this study*

Overview

Examine NASA productivity

Analyze existing data from past projects
- Historical trends over time
- Cost/Schedule/Complexity comparison to other organizations

Elicit external input via a Workshop

Capsule Findings:
- NASA is no less efficient than other equivalent Government Agencies
- NASA is less efficient than Commercial

Actionable Ideas

Terminology Review

- **In economics *productivity* refers to measuring the amount of output per unit of input from the production process**
  - Measuring productivity in an R&D organization is slightly different
- **The term, productivity, can be used in many different ways**
  - Firm level inputs/outputs, Economy-wide inputs/outputs, Cost savings, Methods improvement, Work-effort measurement, Program evaluation
- **Efficiency**
  - Maximizing outputs with given inputs or minimizing input for a given output
- **Effectiveness**
  - Degree to which public objectives are met
- **This study:**
  - Productivity, efficiency, and "bang-for-the buck" are used interchangeably
  - Effectiveness, although very important, is not the focus of this analysis

NASA Productivity Trends

Joe Hamaker, SAIC

Analysis of NASA Productivity Trends

- **The BLS uses "hedonic regression" when developing inflation indices to account for performance changes in products over time**
  - Classic example: personal computers
    - Statistically controls for improvements in processing speed, RAM, HD capacity, software capability, etc.
  - This provides the BLS with a tool to examine the underlying cost trends of computers while controlling for changes in capability

- **In the case of NASA, we used spacecraft performance metrics**
  - Mass, power, data rate, design life….
    - Only included performance variables which could survive t-test for statistical significance
  - Provides a tool for examining science spacecraft cost trends over time holding performance constant

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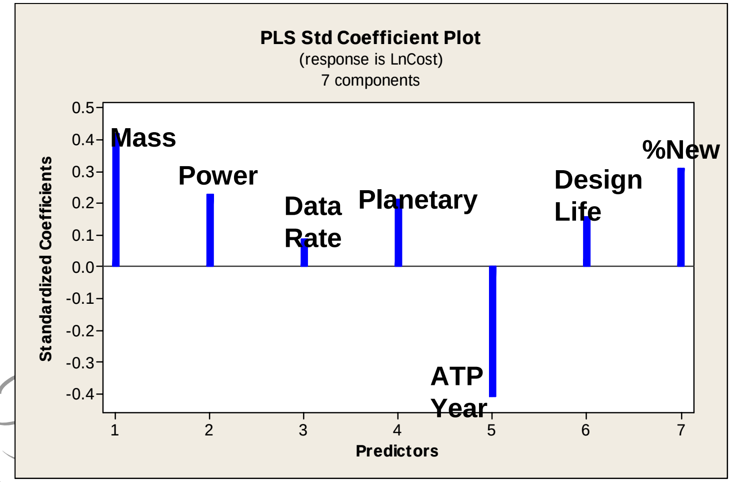
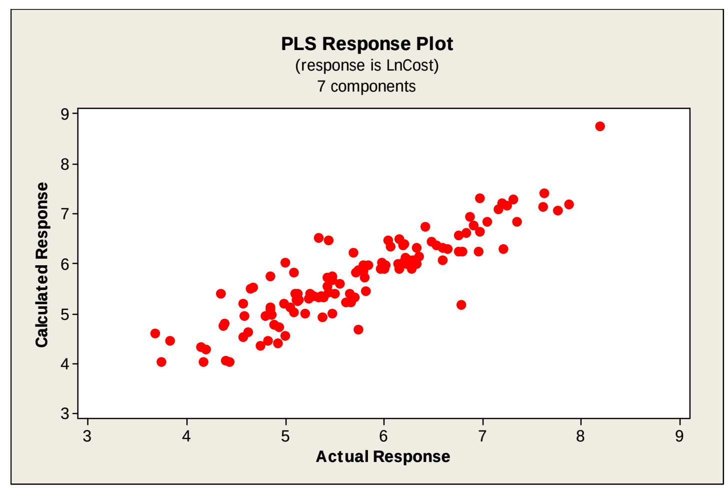
Regressing Cost Against Productivity Metrics

The regression equation is
LnCost = 1.53 + 0.427 LnDryMass + 0.224 LnPower
+ 0.0257 LnData + 0.443 Planetary - 0.0305 Year-1960
+ 0.243 LnLife + 1.21 LnNew

Predictor	Coef	SE Coef	T	P
Constant	1.5282	0.3827	3.99	0.000
LnDryMass	0.42719	0.07040	6.07	0.000
LnPower	0.22392	0.06961	3.22	0.002
LnData	0.02567	0.01656	1.55	0.124
Planetary	0.4432	0.1076	4.12	0.000
Year-1960	-0.030471	0.004047	-7.53	0.000
LnLife	0.24309	0.07844	3.10	0.002
LnNew	1.2129	0.1848	6.56	0.000

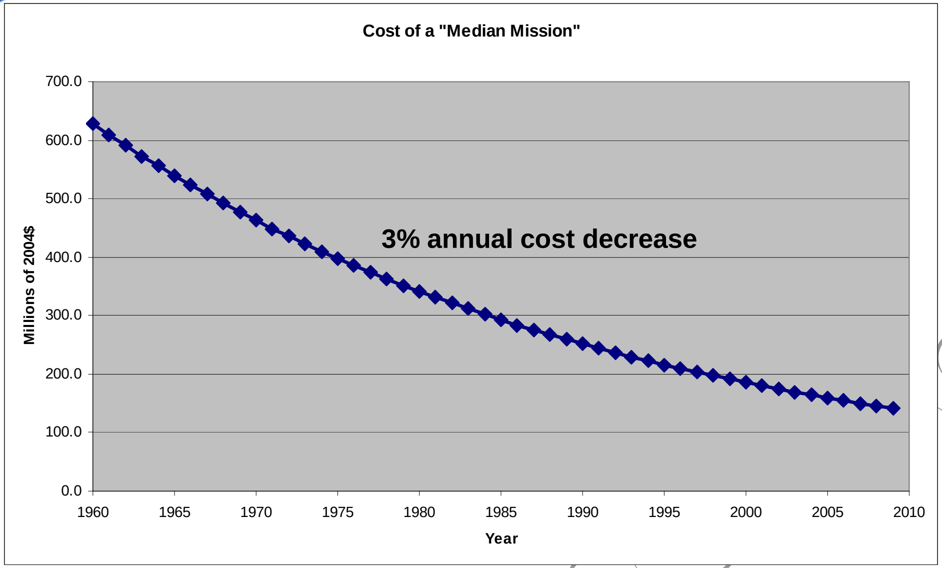
S = 0.448407 R-Sq = 79.6% R-Sq(adj) = 78.3%





(“Planetary” and “% New” variables for statistical controls to improve fit)

Cost Decrease Over Time Holding Other Regression Variables Constant



Mass (kg)	640
Power (watts)	645
Date Rate (kbps)	768
Earth Orbital=0, Planetary =1	0.294
ATP Year	1987
Design life (months)	36
Percent New	68%

- **“Median Mission” represents a mission of median mass, power, data rate, earth orbital vs planetary, design life and percent new**
  - All held constant
  - In constant dollars (inflation effects removed)
- **ATP Year allowed to vary over range of data in the model**
- **Annual percent cost decrease averages about 3%**
  - This result is consistent with many other studies of NASA cost efficiency improvements
  - A similar analysis by the NRO of their data resulted in a 1.38% annual decrease

Comparative Economic Efficiency Analyses

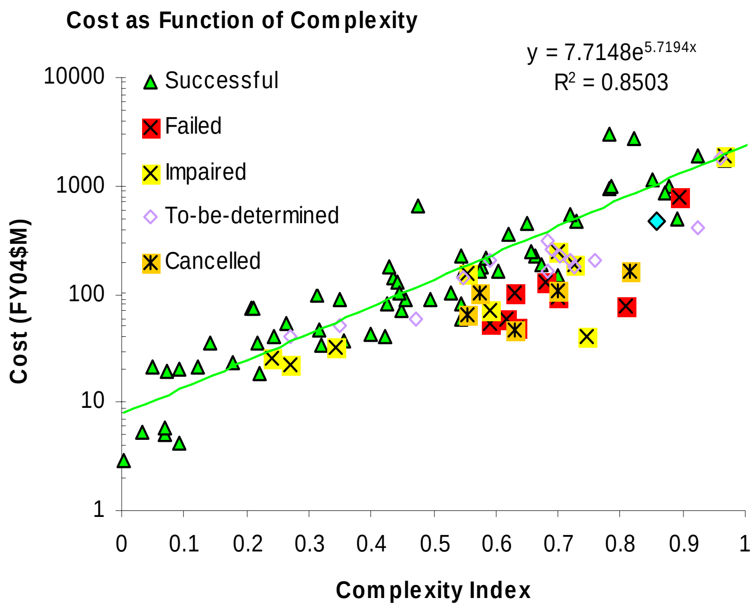
Bob Bitten, Aerospace

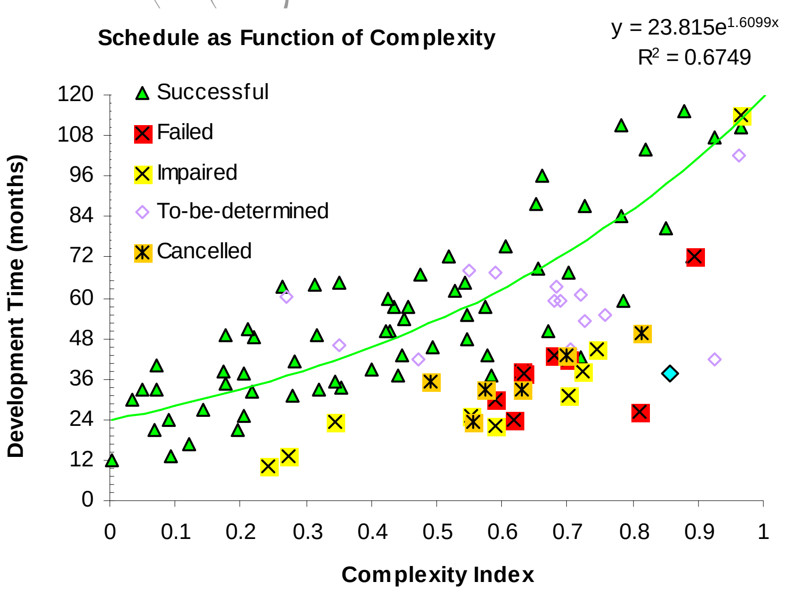
Complexity Analysis Overview

- **Purpose**
  - Compare NASA "Efficiency" to other agencies
- **Approach**
  - Compare NASA to DoD and Commercial acquisitions for ***missions of similar content*** (e.g. imaging systems)
  - Compare NASA and ESA science missions
- **Analysis**
  - Compare missions of similar content across agencies with normalizing metric
    - Utilize Complexity Based Risk Assessment (CoBRA) approach to assess "dollar per complexity" metric
    - Comparing CoBRA regressions vs. cost for varying organizations should provide insight into relative efficiencies

CoBRA Background

- Developed by Dr. David Bearden to assess the relative complexity of space systems vs. development cost and schedule
- Hypothesizes that *Complexity Index* could be derived using a broad set of parameters to arrive at a top-level representation of overall system capability
- Complexity Index based on performance, mass, power and technology choices is used to determine relative ranking of system compared to over 120 other satellites
- Complexity Index shows good correlation between complexity, cost and schedule





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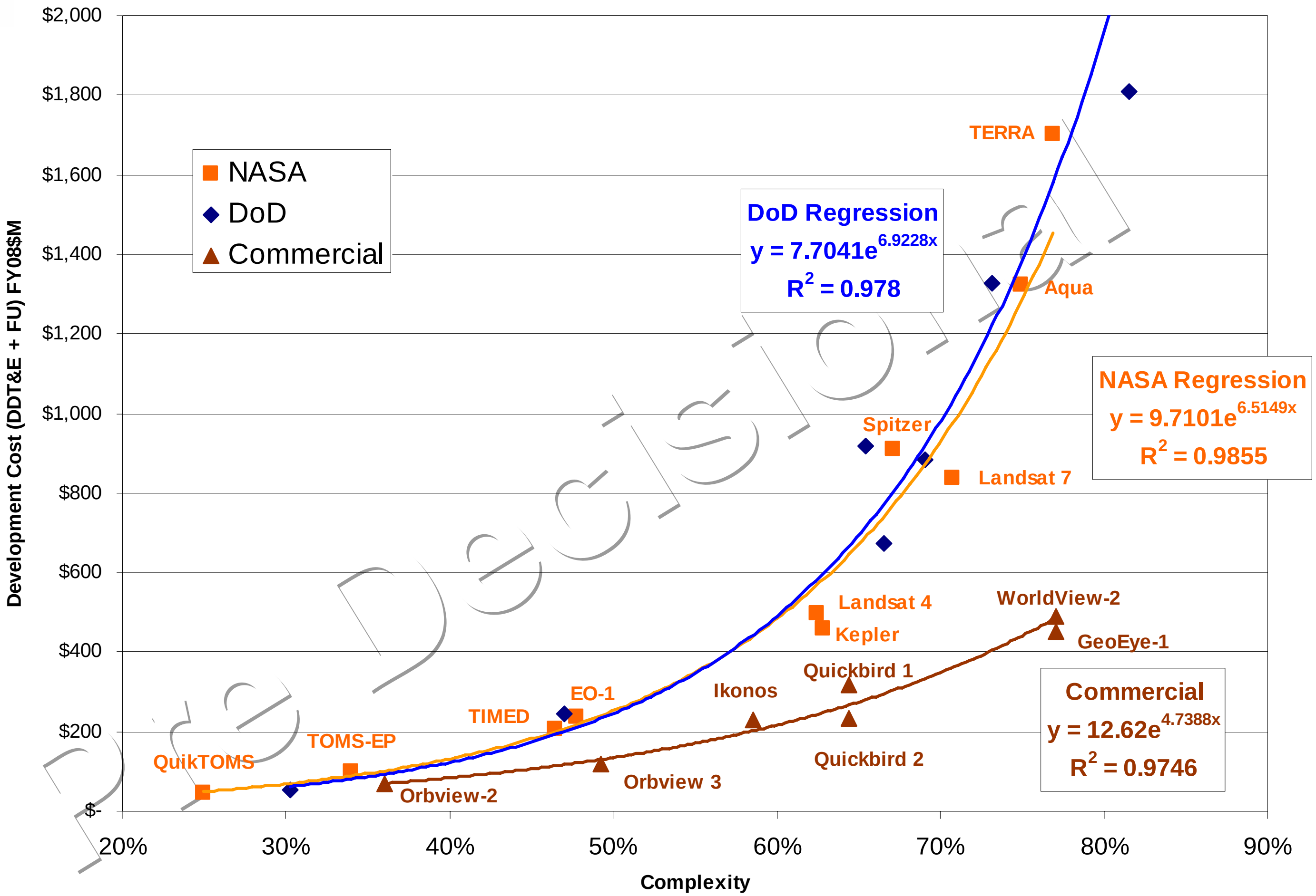
Relative Cost vs. Complexity of Imaging Systems



DoD & NASA Efficiencies are Similar but Much Less Than Commercial

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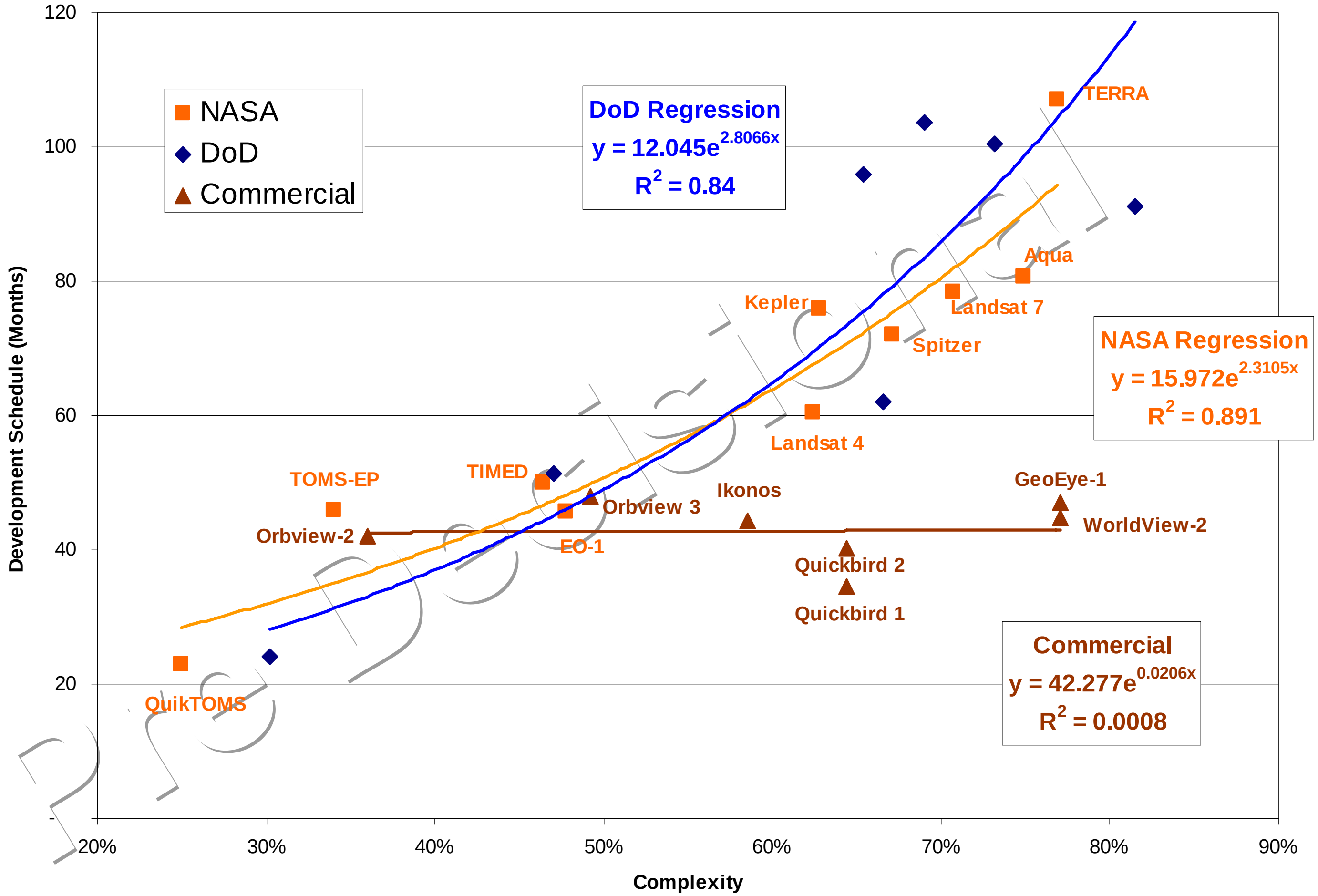
Relative Schedule vs. Complexity of Imaging Systems



Schedule Increases with Complexity Except for Commercial Systems

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Commercial Evolutionary Approach Helps Limit Risk While Allowing for an Increase in Complexity

Uses same Payload & Bus provider

Long term Commitment & partnership

0.6 m	0.6 m	1.1 m	Aperture (m)
BCP 2000	BCP 5000	BCP 5000	Bus Platform

QuickBird, WorldView 1 vs. WorldView 2 Evolutionary Approach

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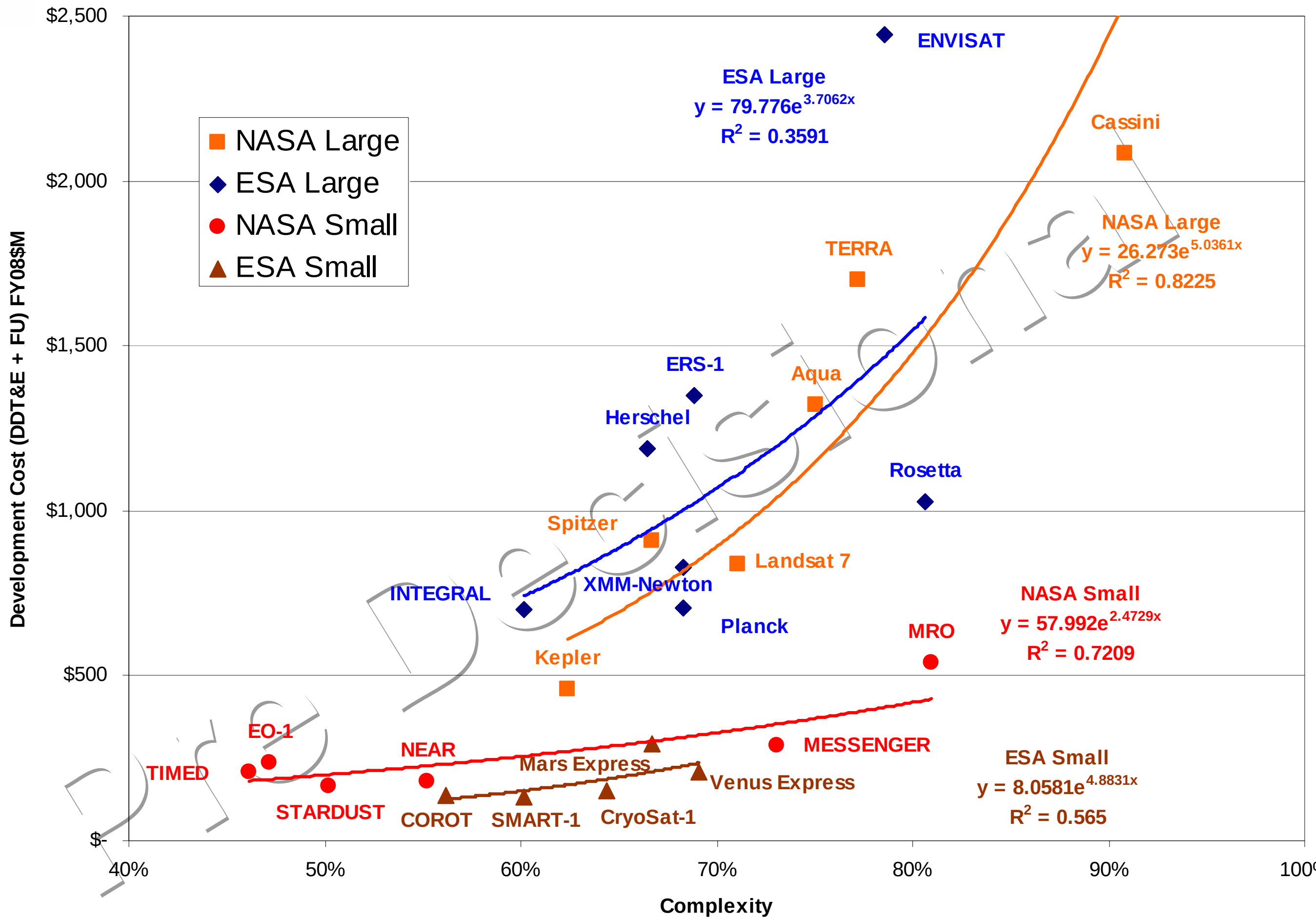
Relative Cost vs. Complexity of NASA & ESA Missions



NASA & ESA Comparable, although ESA Smaller Missions are More Efficient

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Constrained Use of Mars Express Spacecraft Benefited Venus Express Mission

Mars Express

Complexity = 67%
Cost = $295M

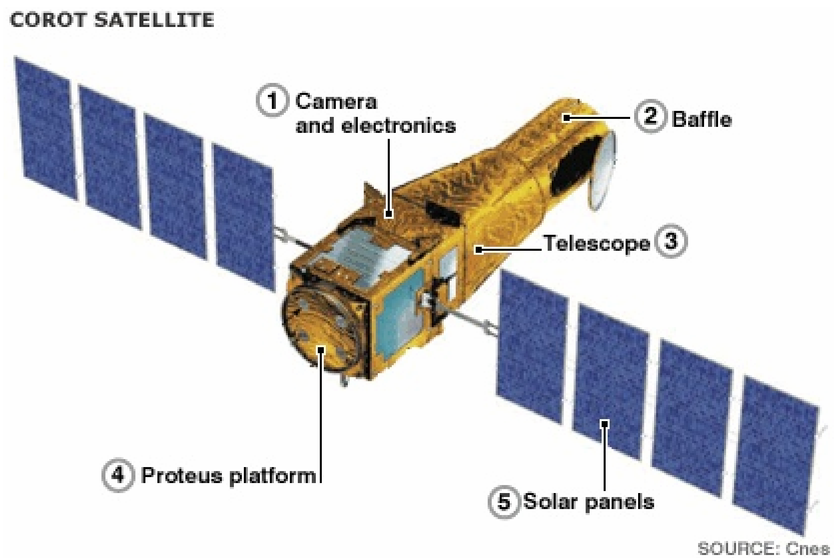
Venus Express

Complexity = 69%
Cost = $210M

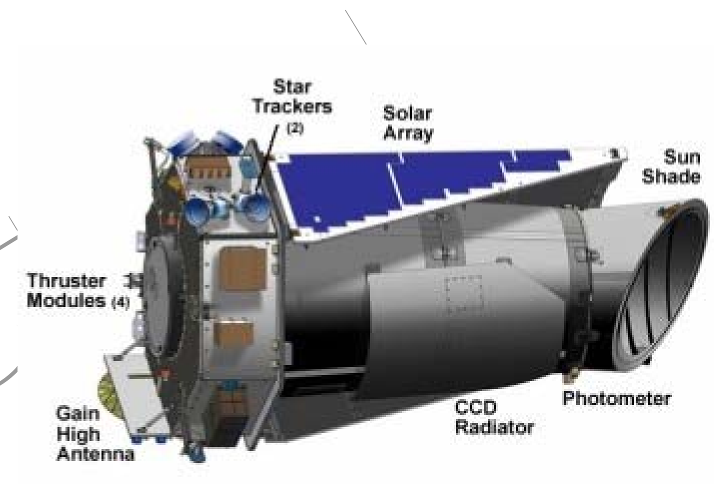
Venus Express Resulted in a Greater Complexity at Less Cost than Mars Express

Different Approaches Provide for Addressing Science Requirements at Different Levels of Complexity

CNES/ESA CoRoT



NASA Kepler



COROT started with existing Proteus bus and simple telescope
Aperture Size = 27 cm
Development Cost = $137M

Kepler approached similar science (Stellar Photometry) with completely new development effort
Aperture Size = 80 cm
Development Cost = 3.5 x COROT

Differing Approaches Led to Significantly Different Development Costs

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CoBRA Analysis Summary

- **Relative Efficiency of different missions compared using CoBRA complexity index**
- **For imaging systems, NASA and DoD show little difference in efficiency although commercial systems tend to provide systems of similar complexity at a lesser cost**
  - Working with common busses and common payload suppliers in evolutionary mode may provide cost savings as mission capability and complexity increases
- **For science missions, NASA and ESA are similar for large missions, although ESA tends to provide smaller missions at less cost than NASA**
  - Different acquisition approaches may provide savings relative to NASA

Workshop Results

Tom Coonce, NASA

Workshop

- **A one day workshop was conducted at GWU on 20 November**
  - To solicit inputs from across NASA, other government organizations, industry, SETA/FFRDCs and academia
- **20 invited participants attended (next chart)**
  - Purposefully eclectic group
    - Managers, executives, analysts…
  - Major primes (Ball, Boeing, LM, NG,)
  - Government (DOC, JPL, NRO)
  - Commercial (Intelsat , SES America)
  - NASA project management (Counts, Barrowman)
  - FFRDC/SETA (Aerospace, MCR)

Workshop Participants

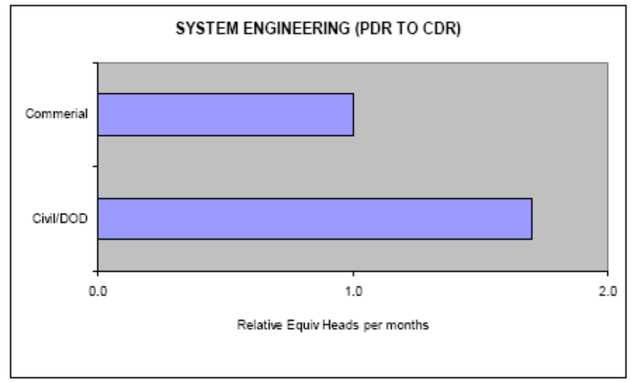
Order	Name	Organization
1	Dick Janda	Lockheed-Martin
2	Steve Burrin	Aerospace Corporation
3	Maureen Heath	Northrop Grumman
4	Dave Bearden	Aerospace Corporation
5	Ken Nash	Boeing
6	Debra Emmons	Aerospace Corporation
7	Gerry Janson	Intelsat
8	Jim Good	Ball Aerospace
9	Gary Anderson	Department of Commerce
10	Ken Lee	Intelsat
11	Kevin Bell	Aerospace Corporation
12	Eric Burgess	National Reconnaissance Office
13	Steve Price	Lockheed-Martin
14	Fred Doumani	Jet Propulsion Laboratory
15	Carson Agnew	Independent Consultant
16	Win Cadwell	SES America
17	Steve Book	MCR
18	Jim Barrowman	Former NASA Project Manager
19	Parker Counts	Former NASA Project Manager

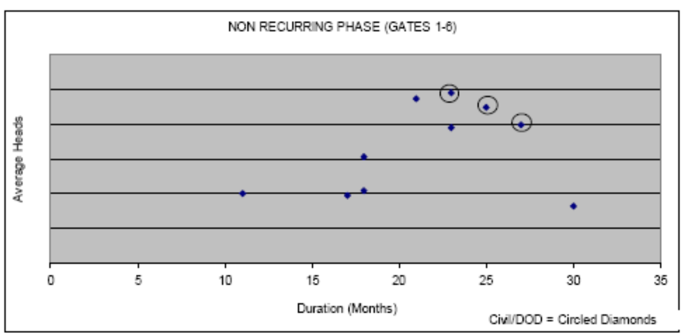
Boeing Efficiency Assessment
DoD = NASA < Commercial

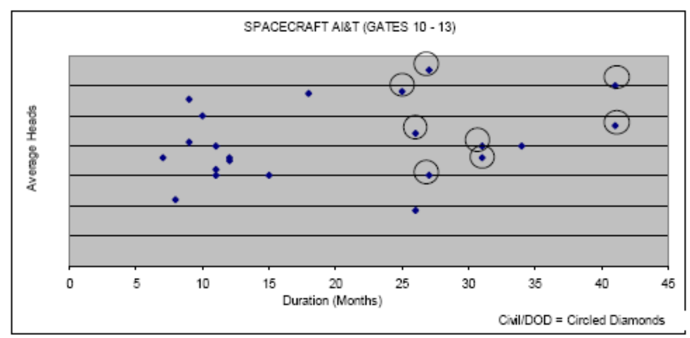
Productivity Measures

Integrated Defense Systems | Space and Intelligence Systems

- **Civil/DOD relative to Commercial Programs of comparable scope, typically require greater resources and time**
  - Larger system engineering teams
  - NRE and Spacecraft AI&T phases have longer durations and require larger program teams







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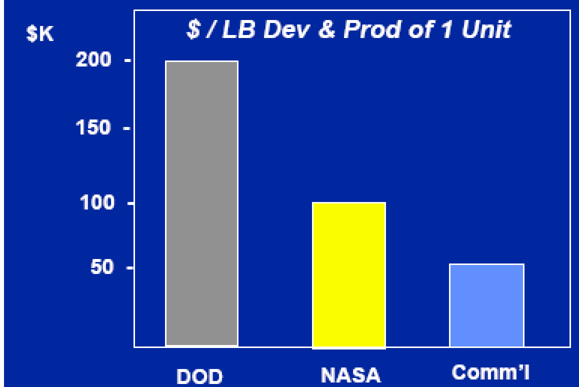
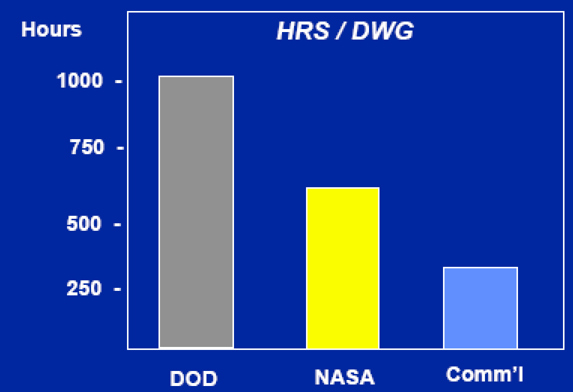
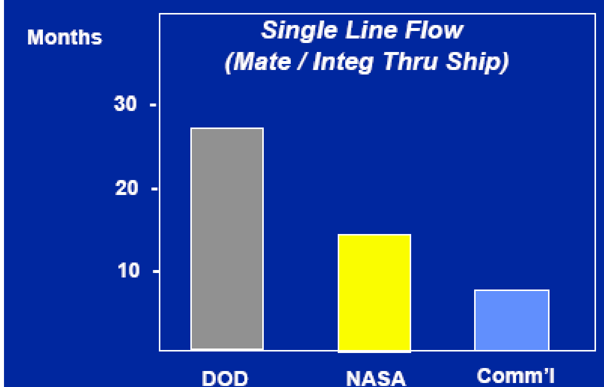
Lockheed Martin Efficiency Assessment
DoD < NASA < Commercial

LM SATELLITES







Satellite Types:

DOD – Large (5-9K Lbs.)
Complex Single Mission Satellites

NASA – Small (1-2K Lbs.)
Complex Planetary Science Satellites

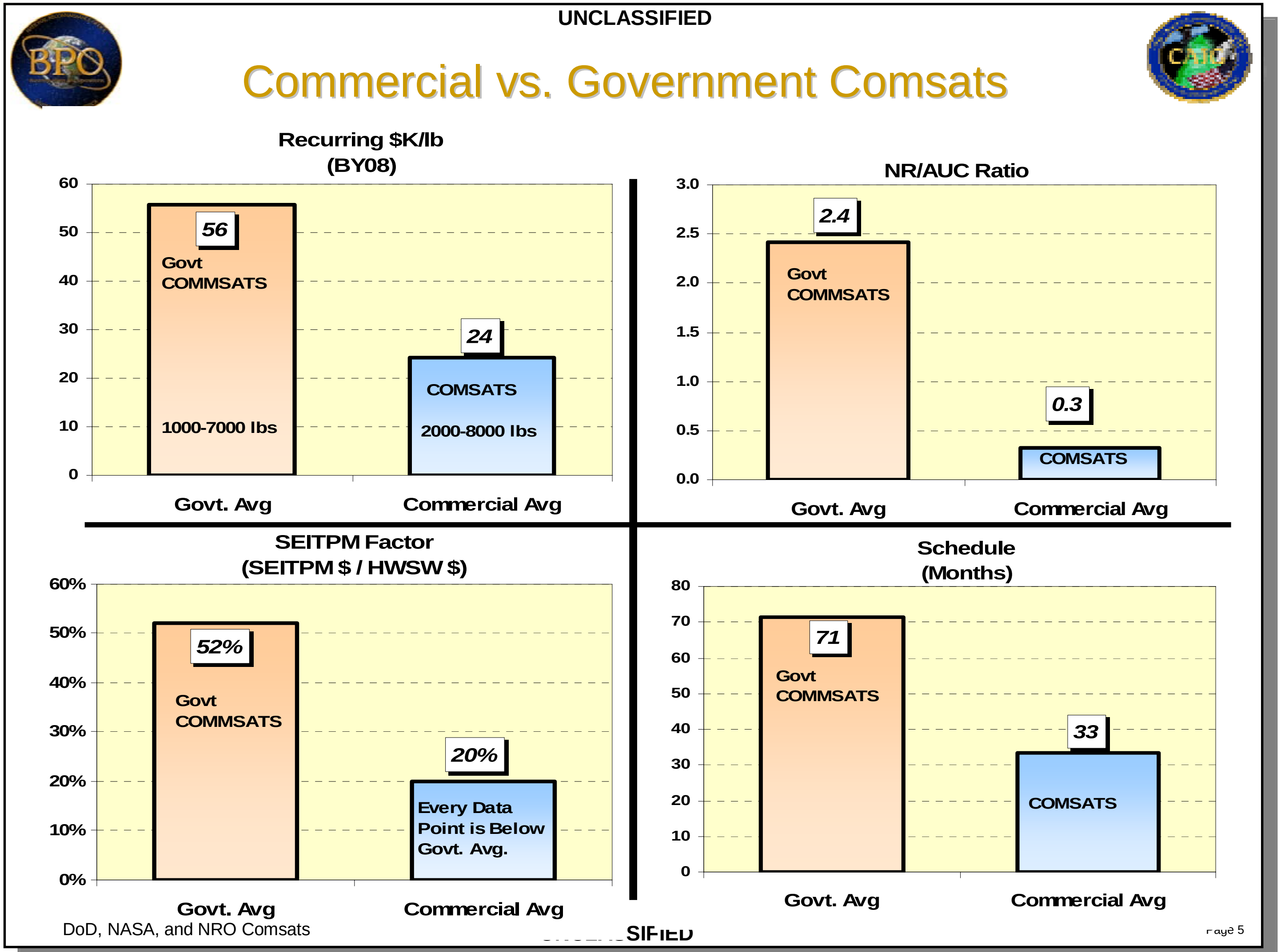
Commercial – Medium (2-6K Lbs.)
Communication Satellites Configured from Commercial Business

Ball Efficiency Assessment
DoD Classified < NASA < Commercial

Comparison of NASA Program Productivity to other Agencies and Markets

- Based on Ball experience, productivity generally tends to rank (best to worst) -
  - Pure Commercial
    - Radarsat I, QuickBird, WorldView
  - Pseudo Commercial
    - USG, FAR Part 12 Commercial procurement
    - NASA Rapid Spacecraft Development Office (RSDO)
    - QuikSCAT, ICESat, NPP, Glory Cloud Cameras
  - Performance Based Cost Plus Contracts
    - NPOESS Ozone Mapping and Profiler Suite (OMPS)
  - Cost Plus Award Fee Contracts
    - JWST
  - DoD Classified

NRO Efficiency Assessment
DoD/NRO < Commercial



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NRO Efficiency Study

- **Since 1970s, U.S. commercial space industry hailed as a model of success**
  - Said to have lower cost, shorter schedules and less cost and schedule growth
  - Results were mixed
  - Commercial-like projects have been more expensive than pure commercial
- **NRO wanted to understand why and to more accurately estimate the cost of "commercial-like" projects by developing an adjustment factor to an existing estimating model**
- **Differences driven by technical and acquisition complexity**

Technical Complexity	Acquisition Complexity
•Performance, SWAP, new technologies, heritage, etc. •Defined, measured, & modeled by existing cost methods	•Oversight, contracting, reporting, etc. •Varies among commercial <u>and</u> Gov't programs •Need to define, quantify, and incorporate in cost models

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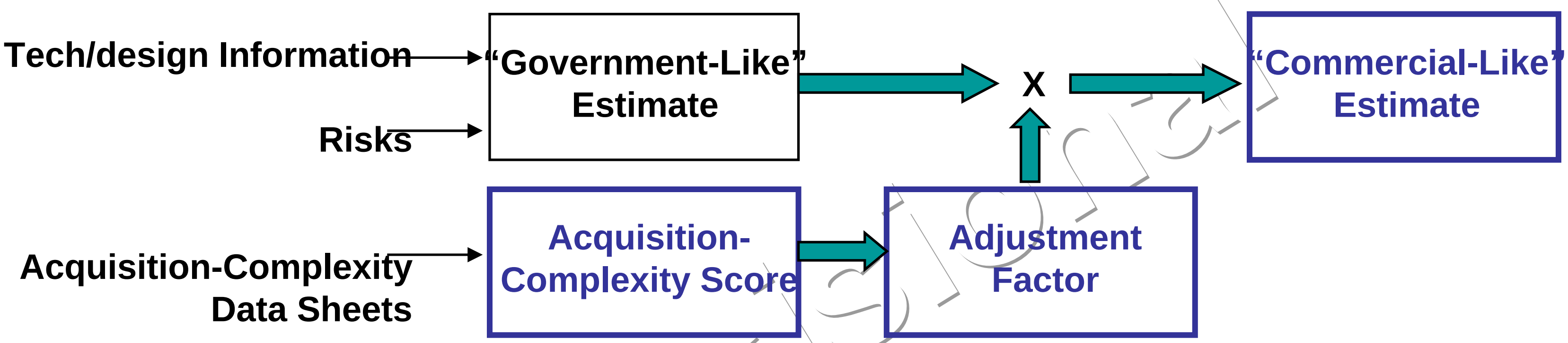
NRO Study: Estimating Commercial-Like Spacecraft

- **Goal:**
  - Defensible basis for estimating commercial-like acquisitions
- **Approach:**
  - Focus on quantifying acquisition complexity
  - Leave technical complexity to other studies
- **Data collection:**
  - Earned access to cost, technical, and acquisition complexity data on over 60 comsats & imagers
  - Conducted program reviews with contractor personnel (Lockheed Martin, Boeing, Space Systems/Loral, General Dynamics, Orbital Sciences, Ball Aerospace)
- **Methods development:**
  - Develop and test method to quantify acquisition complexity
  - Combine with traditional government models to estimate cost

Estimating Commercial-Like Projects



AC Score is converted to an adjustment factor to be applied to the satellite cost estimate:

Adjustment = a + b × [AC Score]

Commercial-like Estimate = [Gov't-like Estimate] × Adjustment

Constants a, b, and weights, w_i are found by regression

- **Minimize percent error between adjusted (commercial-like) estimates and actuals**
- **Constrain to zero average error**

High AC Score can result in adjustment factors equal or greater than 1.0

Acquisition Complexity

Traditional Government

Factors That Drive Acquisition Complexity Up Or Down:

- ❑ Type Of Contract
- ❑ Scope Of Contract (Launch Interface, Ground Interface, Etc.)
- ❑ Industrial Base
- ❑ Technology And Manufacturing Maturity
- ❑ Requirements Stability
- ❑ Amount Of Development Hardware & Obsolescence
- ❑ Vehicle Test Requirements
- ❑ EMI/EMC Requirements
- ❑ Parts, Materials, Processes (PMP)
- ❑ Documentation Delivered (CDRLs)
- ❑ Outside Oversight (Aerospace, SETAs, System Integrators, Etc.)
- ❑ Subcontractor Management/Auditing/Reporting Requirements
- ❑ Program/Design Reviews
- ❑ Number Of Customer On-Site Reps
- ❑ Number Of Customer Personnel Dedicated To Program (Off Site)

Hands-Off Commercial

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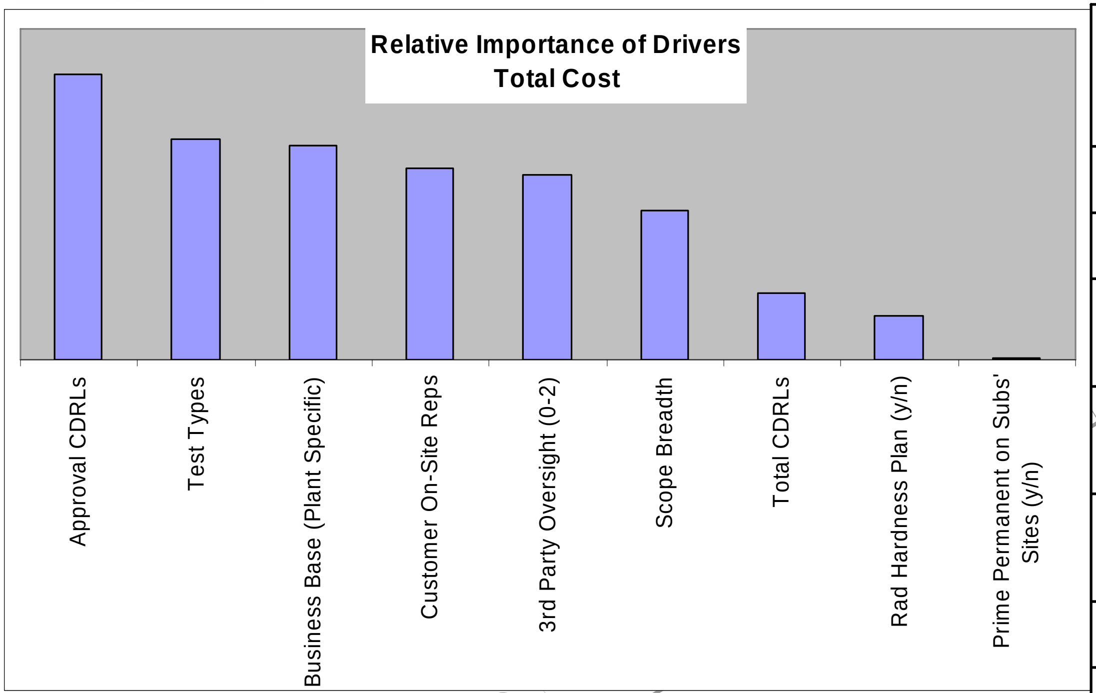
NRO Study Results



Parameter x_i	Weight (W_i)	x_{min}	x_{max}
# Approval CDRLs	2.59	0	75
Types of Testing	2.00	6	10
Plant Business Base at ATP	1.94	46	3
# Customer On-Site Reps	1.74	0	35
3rd Party Oversight Types	1.67	0	2
Scope Breadth	1.35	0	9
Total # CDRLs	0.61	15	175
Rad Hardness Assurance Plan (y/n)	0.40	0	1
Prime Presence Permanent on Subcontractors' Sites (y/n)	0.02	0	1

$$Adj = 0.129 + 0.719 \times (\text{AC Score}) \times 0.951^{NoMPL}$$

NoMPL = 1 if data point does not include a payload (IMINT)

(Stratifier allows us to include IMINT systems in model)

NRO Efficiency Study Takeaway Points

- **Aside from technical complexity, the following acquisition practices have a measurable impact on the cost of NRO, NASA, and DoD commercial-like acquisitions (in order of importance):**
  - **Number of Contract Data Requirements (CDRLs) that require government approval**
  - **Number of required tests**
  - **The business base of the supplier (the lower it is, the higher the cost)**
  - **The number of on-site customer representatives (no regard for decision authority)**
  - **The number of third-party overseers (SETA contractors)**
  - **Scope of the work (the broader the scope, the more it costs)**
  - **The total number of CDRL**

Workshop Summary of Why Commercial Projects are More Efficient

	Categories	Commercial	Government
	Development Trend	Evolutionary	Revolutionary
	Production	Standardization and re-use of building blocks. Build multiple units	Unique designs. Build One-Off's
★	Requirement Definition	Well understood before project start	Not well understood at project start
★	Requirement Stability	Stable	Unstable
	Stakeholders	Single customer/stakeholder	Many stakeholders
★	Performance Specification	Specifies only performance requirements	Specifies performance requirements and "how - tos"
	Design Incentive	Profit driven	Science driven
★	Design Approach	Buses viewed as product line and are a known entity	Instruments changes, especially after PDR, drives the bus

★ Actionable

Workshop Summary of Why Commercial Projects are More Efficient

Categories	Commercial	Government
★ Cost/Schedule BOE	Based on known similar historical data (buy mode)	Cost and schedule estimates are optimistic (sell mode)
Funding Stability	Stable	Potential annual changes (e.g. CR's)
★ Portfolio Management	If a project gets into trouble, it typically gets cancelled	Projects allowed to continue and usually cause collateral damage to the portfolio (very inefficient)
★? Procurement Process	Streamlined	Long and complicated
★? Contract Type	Incentives for early delivery and late delivery penalties (skin in game)	Cost plus type contracts
★ Oversight / Reporting	Minimal oversight of subcontractors	Extensive oversight of primes and subcontractors
★ Test Philosophy	Deletes non-valued added processes (profit driven)	Tend to avoid seeking waivers. Success valued on success of mission, not cost/schedule overruns

★ Actionable

SAIC From Science to Solutions

AEROSPACE Assuring Space Mission Success

THE GEORGE WASHINGTON UNIVERSITY WASHINGTON DC

Workshop Summary of Why NASA is Less Efficient

- **In AO process, NASA rewards the bidder who has the most promising scientific content, without adequate consideration of cost risk**
  - Selecting medium/high risk missions often causes most collateral damage to the portfolio when they overrun
  - NASA requirements often push design beyond State-of-the-Art
    - Could leverage existing industrial capabilities instead

- **NASA invests too little in Phases A and B to reduce uncertainty**
  - Less than 1% in Phase A

- **NASA, with it's 10 Centers, has higher overhead than other Agencies and Commercial entities**

★ **Actionable**

Some Actionable Ideas for Consideration

- **Give more credence to NASA independent non-advocate assessments**
  - Budget to ICE (similar to DoD and NRO reforms)
  - Minimizes portfolio collateral damage
- **Improve AO process to select SMD missions with lowest risk with acceptable Category 1 science return**
- **Solidify requirements and design by KDP-C, for example:**
  - Tighten-up standards for PDR gate: Invest more resources in Phase A/B
  - Develop instruments through CDR prior to committing to spacecraft bus
  - For contracted projects, specify performance versus "how-tos"
- **Tailor oversight/reporting to minimum acceptable levels**
  - Train PMs to eliminate non-value added DRs/CDRLs
  - Use empowered in-situ government insight at contractor facilities in lieu of formal reports where possible
- **Use Incentive/FFP type contracts after CDR where development risk is low, to minimize:**
  - Cost/Schedule growth
  - Oversight/Reporting