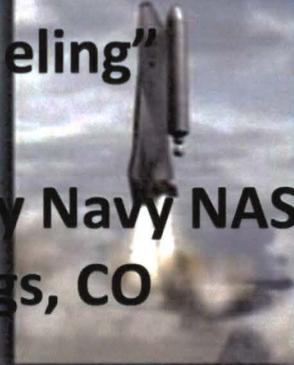




“New Approaches in Reusable Booster System Life Cycle Cost Modeling”

**2013 Joint Army Navy NASA Air Force Conference,
Colorado Springs, CO**

**Edgar Zapata
NASA Kennedy Space Center**





Team

- NASA Kennedy Space Center (KSC)
 - Edgar Zapata, Operations Modeling and Analysis
 - Robert Johnson, KSC Engineering and Technology, NASA and AFRL Collaboration Lead
 - Carey McCleskey, KSC Engineering and Technology
 - Eddie Santiago, Space Systems Engineer
- Air Force Research Laboratory (AFRL)
 - Greg Moster, Integrated Flight/Ground Systems Technical Lead
 - Tom Jacobs, Integrated Flight/Ground Systems Program Lead





Objective

- Assist in maturing the **business case** for the development and operation of a responsive and affordable, Air Force Reusable Booster System (RBS).
- Emphasize tangible, **actionable characteristics** of the whole system, design/technology and organization/industry processes/practices, to inform a potential programs definition and direction.
- Examine **data** within the context of “how” (processes, practices) as well as “what” (the product).



Preliminary Results, Summary Business Case for an RBS

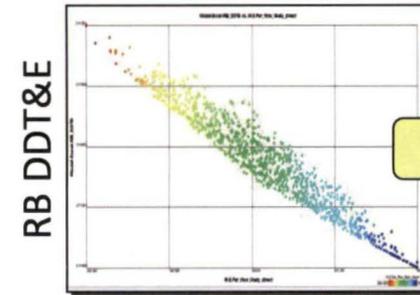
- Identified abundant options along dual paths that support a decision to proceed with a Reusable Booster System program.

Path 1 - Effectiveness:

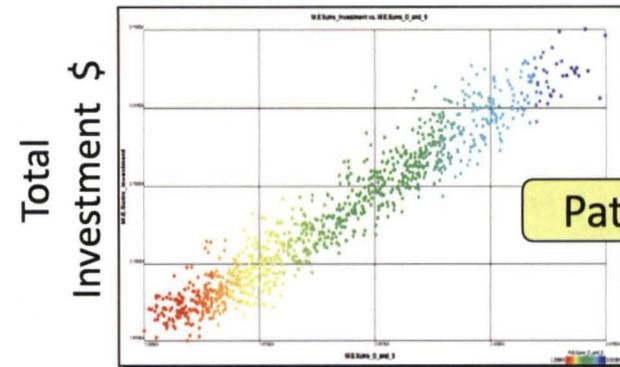
- There are numerous investments paths for design/technology that can achieve significant levels of responsiveness, with low costs per flow, achieving a higher launch rate tempo.

Path 2 – Effectiveness AND Efficiency:

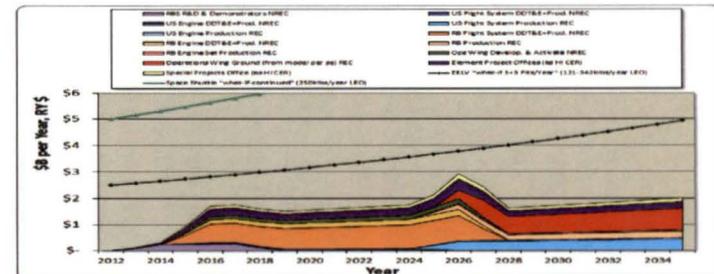
- There are numerous acquisition paths that can achieve significant levels of responsiveness, with low costs per flow, and more affordable up-front investment.



Per flow direct workforce ~ Wing Ops



Total O&S \$ (incl. production)





Approach

- Specifically, explore the design space for an RBS in the 15,000lbm (LEO 28.7deg, 100nm) payload class; avoid a single point design or single point estimate.
- Balance the traditional emphasis on Work Breakdown Structures (“what”, product) with characteristics of the performing organizations (“how”, processes/practices), especially as apply to acquisition and industry counterparts.
- Model with as much input emphasis (as much detail) on the performing organizations capabilities (process, practices) as would traditionally be applied only on the product (design, technology).
 - Generate from first causes, **actionable design/technology** or **process/practices**, any **operational** cost consequences, direct and indirect.
 - Extrapolate the effect of innovative, non-traditional industry business models (**process/practices**) to existing **development and production** cost estimates.



System/Study Scope

Green = Included White = Not Included

Performing Organizations

R&D

R&D and Demonstrators

DDT&E

Reusable Booster Flight System DDT&E +Engine

Upper Stage Flight System DDT&E +Engine

Ops Wing Develop and Activate

Production

Reusable Booster Production +Engine

On-going, replacement, end of life, obsolescence, etc.)

Upper Stage Production +Engine

Ops Wing

RBS Ops Wing Ground

Responsible Organizations

Air Force & Support Personnel

DoD Special Projects Office (SPO) and Support

~akin to a Level 1 Program Function

DoD Element Project Offices and Support

~akin to a Level 2 Project Function

Non-recurring Costs

Design, Development, Test & Engineering (DDT&E) thru 1st unit; establish production capability.

Develop the capability.

Recurring Costs

Production, operations, launches, missions.

Use the capability.

Basing, Support Wings

Payload Development

In-space Operations - Capability Development

In-space Operations

~akin to Mission Ops

Depot Operations

Payloads - Preparation & Integration



Basis of Estimate

Observations and Data – Industry Costs

- Well established that aerospace industry functions farther removed from the products increasingly comprise most of the costs of those products.
 - 1990: “**Overhead** costs were neither visible nor understood, so common practice was to use poorly documented (sometimes proprietary) factors to “**burden**” the labor estimates. The practice has persisted, **even though direct manufacturing labor has nearly disappeared as a cost driver**, and overhead has grown to represent more than half the cost of defense systems, and may rise to represent two-thirds of these costs.[1]
 - 1991: “Experience **at these firms indicates that overhead had grown** from about 38 percent of total business in 1973 to about 49 percent by 1987. Extrapolation of this trend indicates that **overhead** will reach about 54 percent by the year 2000.”[2]
 - 2011: “About three-quarters of the 84 recommendations in the EELV should-cost review are associated with **overhead and indirect costs**”.[\[link\]](#)



Basis of Estimate

Observations and Data – Industry Costs

- Space Shuttle detailed cost data was lacking till the early 1990's (The Zero Base Cost Study, [link](#)) but matured quickly by the mid-90's (The Access to Space Study, RAND study ([link](#)), and numerous others).
 - Data confirmed *program wide* what was already suspected – that the cost of the effort “close-in”, the nearer to the product (the vehicle turnaround, the production, the materials, etc.) was the SMALLEST part of total expenses.
- These previous terms of costs, making up most of the total costs in our industry, have come to be referred to with assorted, ***often inconsistent naming - indirect, overhead, non-touch, systems engineering [1], project, program management, etc.***
- Costs and responsiveness go hand-in-hand, e.g., ***“This process revealed that the largest operability improvement for a new Shuttle-like RLV came from the systems engineering/design process.”***

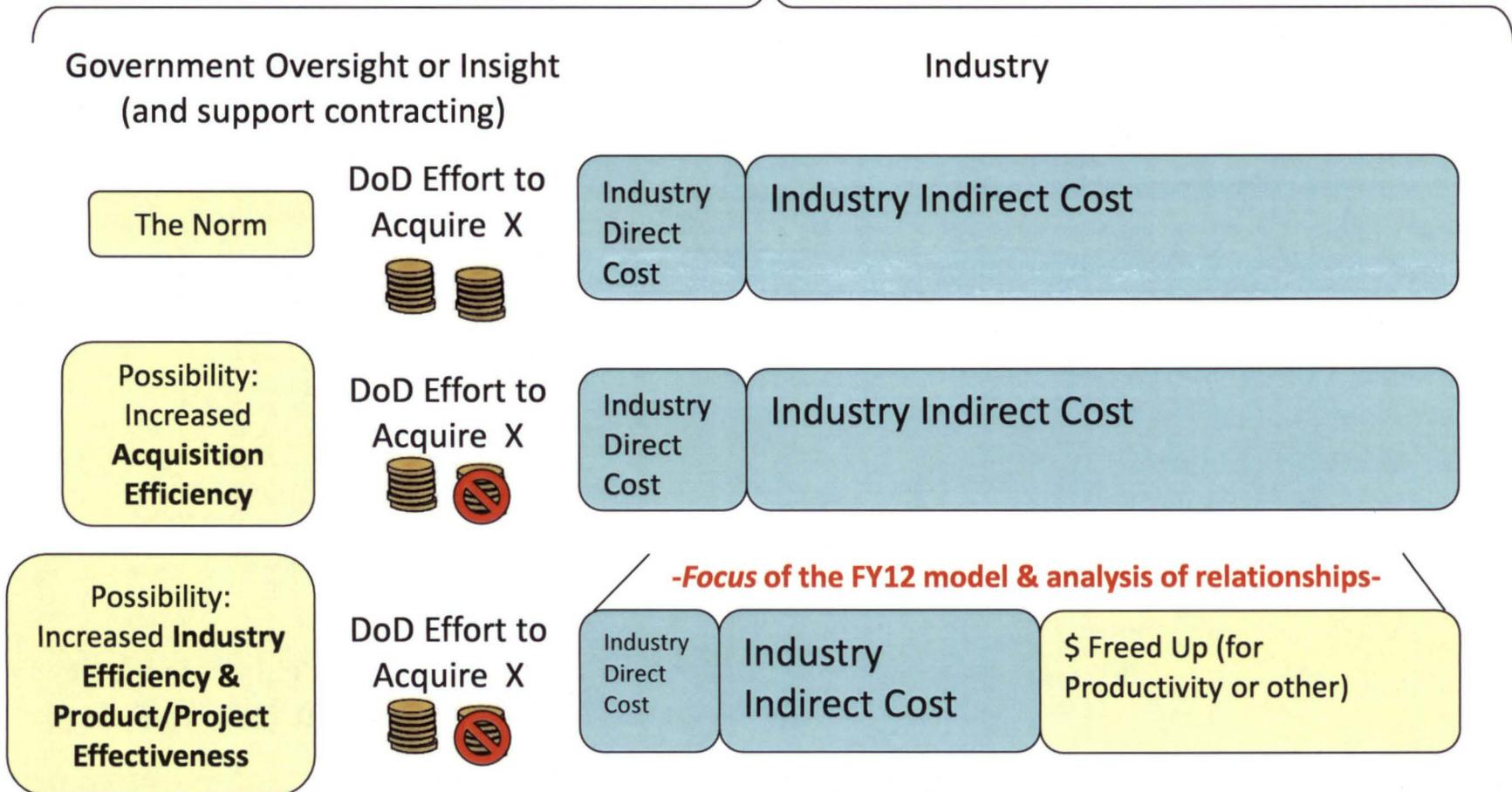
Air Force RBS Analysis of Alternatives, 2005



Basis of Estimate

Cost Estimating Relationships – Government, Industry - Notional

Project X



-No change in Project X or the product/service/quantity acquired-
 -Notional, in a development phase, names/roles may vary, esp. once operational-



Basis of Estimate

Work Breakdown Structure – Detail

- **Government / Acquisition Effort (Responsible Organization, by applicable concept, Oversight or Insight, by phase, R&D, DDT&E, Ops and Support, Production, etc.)**
 - Program view
 - **Program Management (aka "SPO")** : Government, Civil Servants, Blue Suiters and Support Contractors
 - Leadership/Management
 - Systems Engineering and Element Integration
 - Technical Management, Financial, Budgeting, etc.
 - +Overhead, etc. (May or may not be included in cost estimates. Re. GR&A. Captures **generic** facilities, I/T, human resources, payroll, and other administrative and business costs.)
 - Project view
 - **Project Management**: Government, Civil Servants, Blue Suiters and Support Contractors
 - Management
 - Element Engineering and Sub-systems Integration
 - Technical Management, Financial, Budgeting, Procurement, etc.
 - +Overhead, etc. (May or may not be included in cost estimates. Re. GR&A. Captures **generic** facilities, I/T, human resources, payroll, and other administrative and business costs.)
- **Industry Effort (Performing Organization, by applicable concept / contract approach, by phase, R&D, DDT&E, Ops and Support, Production, etc.)**
 - Product view
 - **DIRECT (Design/technology)**
 - MAKE: Technicians, Shop Floor Tasks and Personnel, Unique Facilities, Material and Equipment, Tooling, Production, Integration, Assembly and/or Operation.
 - Processes/practices view
 - **INDIRECT - Support**
 - MAKE: Engineering, including Systems Engineering and Integration, Safety, Quality, Technical Management, Design, Changes in Design, Document Creation (Drawings, Instructions, etc.)
 - **INDIRECT - Business Functions**
 - PLAN: Requirements management and flow-down, program / project interfaces / coordination, rules management, configuration management, documentation, authorization, tracking and scheduling (PLAN the SOURCING, MAKING, etc.)
 - SOURCE: Acquisition, purchase, sub-contracts, supplier management, verification of product, make or engineer, etc.
 - DELIVER: The logistics, validation, delivery scheduling, planning/interfaces, etc.
 - RETURN: Reverse of Deliver and Source functions, identifying anomalies, defects, conditions, disposition, etc.
 - +Overhead, etc. (Always included in cost estimates, as this is built into industry pricing. Captures **generic** facilities, I/T, human resources, payroll, and other administrative and business costs.)

\$1

\$1

\$1

\$1 \$1

\$1

\$1 \$1

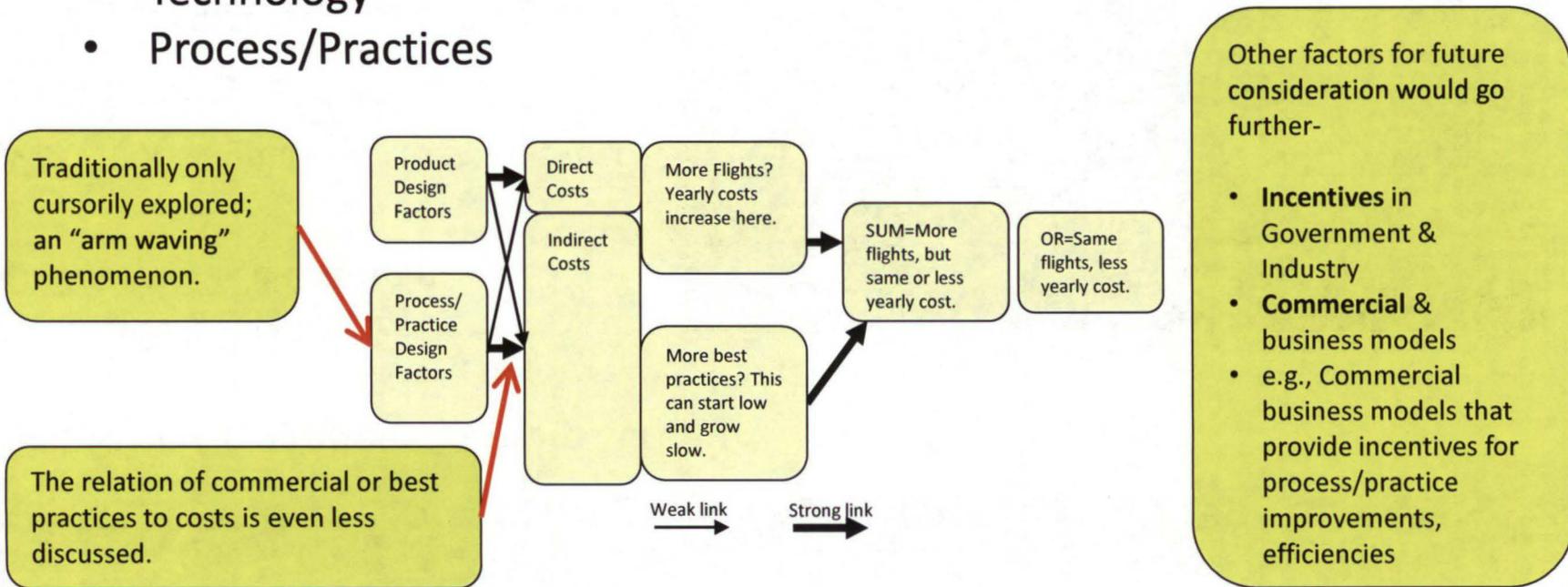
\$1 \$1

An Example Split of \$10 based on Historical Data.



On Modeling of Government or Industry Processes/Practices

- No desire to be overly prescriptive
- No best practices apply always; not a “cook book” model
- Each phase of the business case, and industry considerations, are unique
- The main objective of the model is to contribute to a process where, proceeding into program decisions, *a complete set of actionable factors and their relation to life cycle costs are being realistically characterized.*
 - Technology
 - Process/Practices



- Other factors for future consideration would go further-
- **Incentives in Government & Industry**
 - **Commercial & business models**
 - e.g., Commercial business models that provide incentives for process/practice improvements, efficiencies

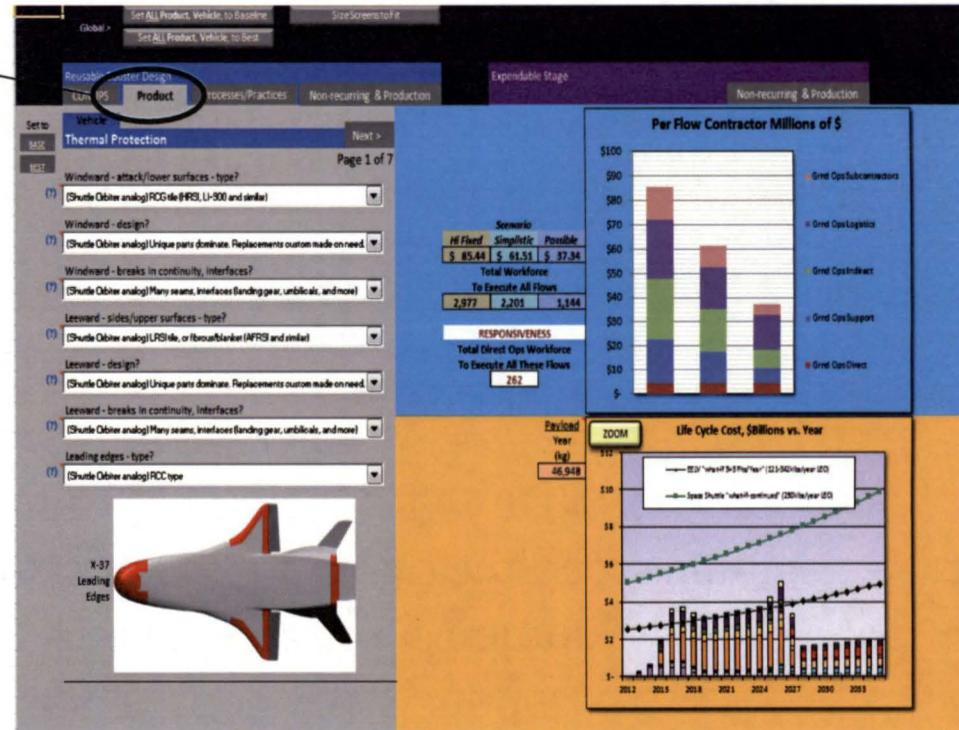


The RBS LCC Model – Sample Screen

- **Product Inputs**
(7 Screens, TPS example)

Most model inputs represent a level of detail that is pre-PDR, high level.

- Some inputs may require more fidelity in system definition.
 - TPS
 - Propulsion (Main + Other)
 - Fluids and Gases
 - Power, Avionics and Health Management
 - Structures
 - Other



Sample screen for illustrative purposes only.
Specific values shown do not represent specific analysis.

- 2 outputs graphs calculate on any change; immediate user feedback.

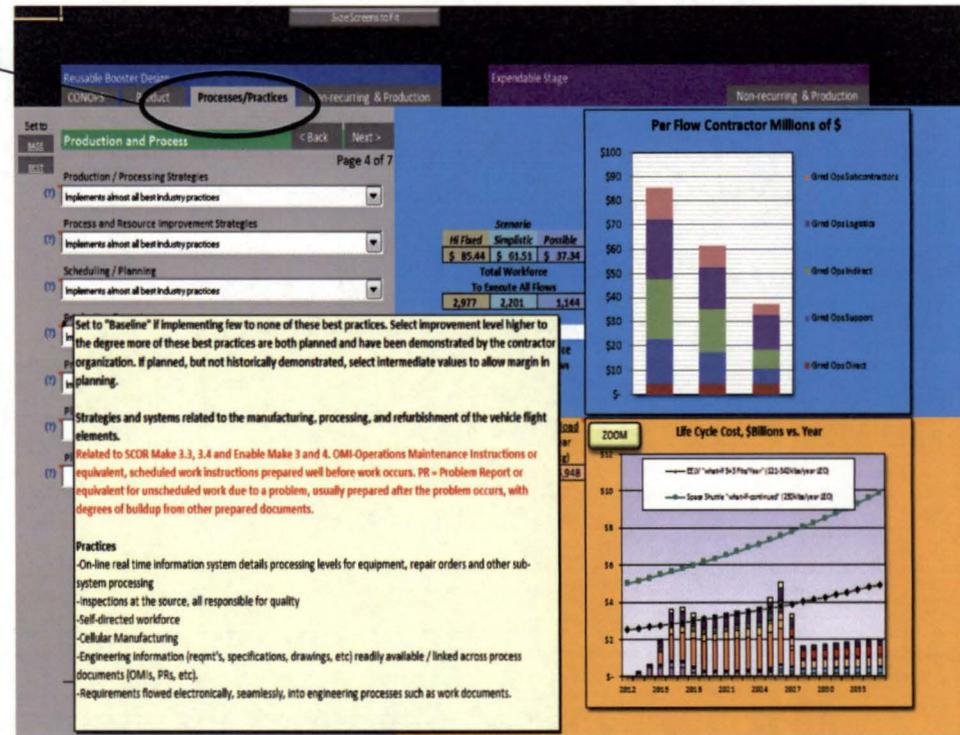


The RBS LCC Model – Sample Screen

- Processes/Practices Inputs (7 Screens, Production example)

Analysts must select inputs descriptive of the expected capability of the performing organization:

- “Best practices” follow a plan, source, make, deliver, return pattern.
- “Agile R&D” and “Agile Product Development”, lead to “Lean Manufacturing/Production” and Advanced Supply Chain Management, segueing into similarly efficient operations.



Sample screen for illustrative purposes only.
Specific values shown do not represent specific analysis.

- Area of the model most likely to evolve significantly in immediate Forward Work – esp. the graphic user interface, and the visibility of input linkages specifically to either early R&D, product development, manufacturing/production, or operations.

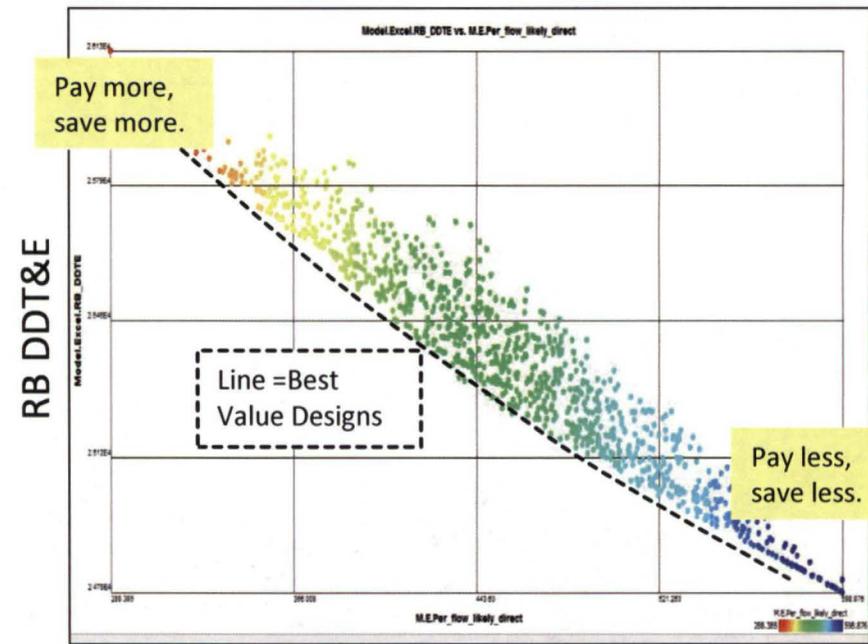


The RBS LCC Model in ModelCenter – Design of Experiments

- **Multi-Objective Genetic Algorithm Optimization**
 - **Seeking Options Improving Responsiveness through Design/Technology**



- NOT a co-relation
- Traditional optimization of product design/technology inputs only (which yield X & Y) reveals the typical decision makers dilemma - pay now or pay later.
- Pro's – Identifies tactical, specific areas for best value R&D, design and technology investment .
 - Identified **\$ spent per O&S saved**.
 - Reduced per flow O&S direct means greater **responsiveness**.
 - **More launches** possible by scaling up an affordable per flow operation.



Per flow direct workforce ~ Wing Ops

- Con's - Understanding these relationships lends only partial insight into an acquisition path seeking significant gains in responsiveness and up-front affordability.

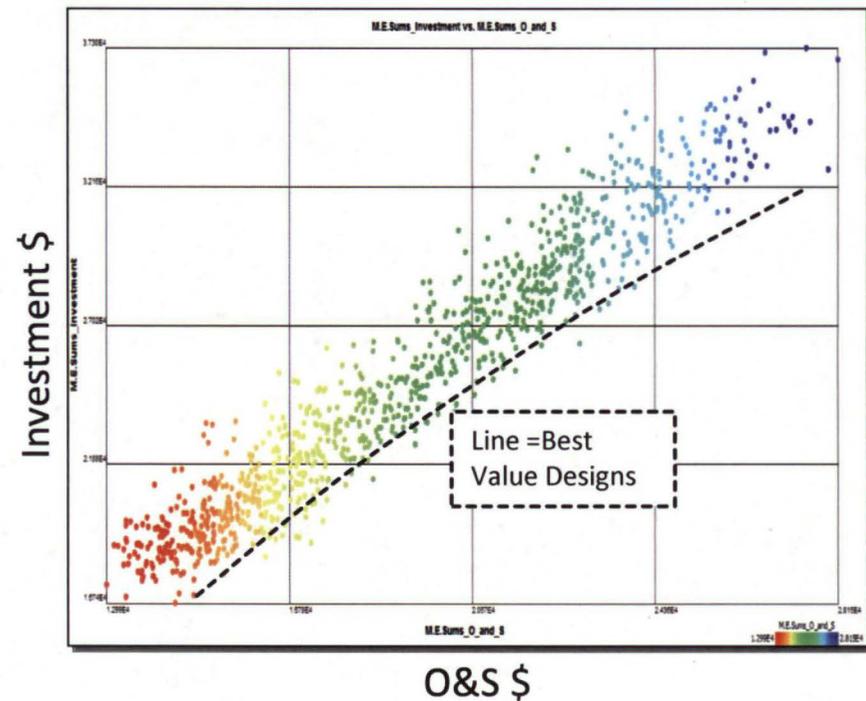


The RBS LCC Model in ModelCenter – Design of Experiments

- **Multi-Objective Genetic Algorithm Optimization**
 - Seeking Options Lowering Both O&S and Investment \$



- NOT a co-relation
- Rather, *seeking* options according to the fitness of meeting certain criteria.
 - *MINIMIZE INVESTMENT SUM*
AND
 - *MINIMIZE O&S SUM* (to 2035).
- INVERTS the decision makers dilemma, locating solutions that best address the competing factors of near and far term costs.
- By definition, includes indirect factors, as processes/practices.



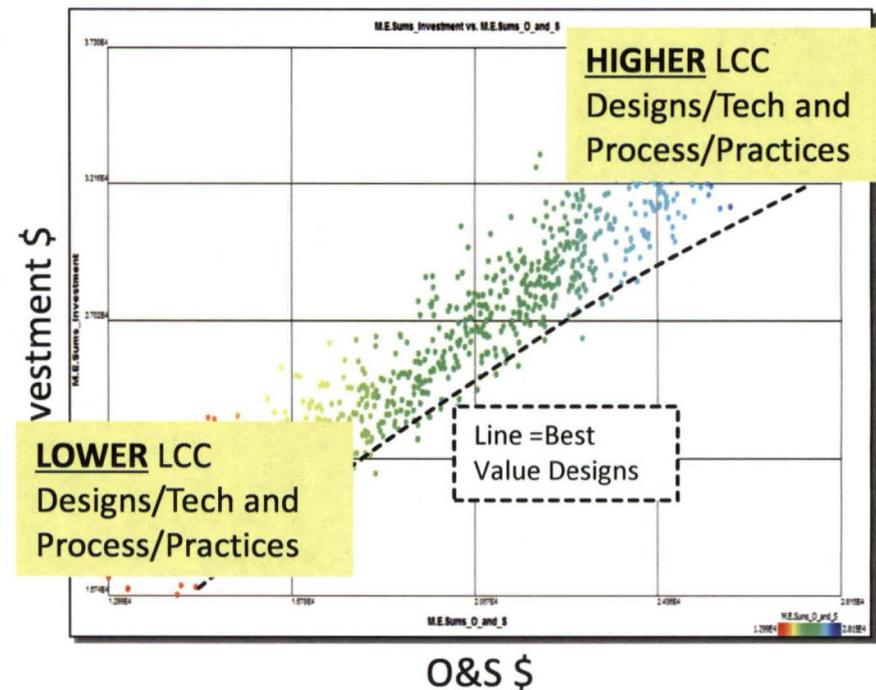
- **Investment:** R&D + DDT&E incl. production capability, flight & ground.
- **O&S:** Wing Ops Ground + Production.
- SPO + PM in each of prior.



The RBS LCC Model in ModelCenter – Design of Experiments

- **Multi-Objective Genetic Algorithm Optimization**
 - Seeking Options Lowering Both O&S and Investment \$

- Design Space made visible - assisting in decision making.
- The question “How can we go from traditional costs, with business as usual, to what products *could* or *should* cost” = “how to go from High LCC to low LCC”?
- This option: Addressing design/technology AND industry process/practices.

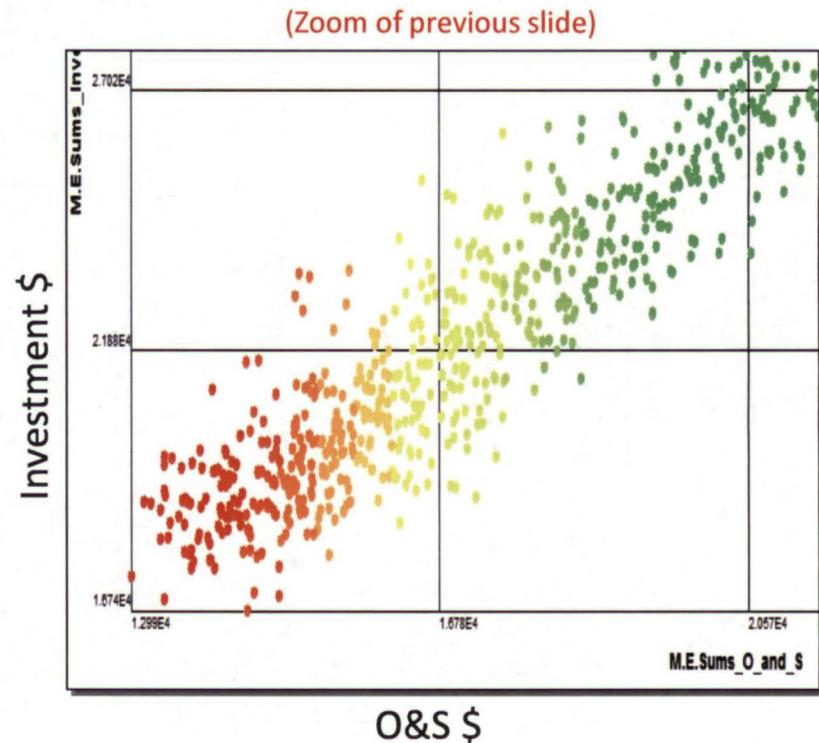


- **Investment:** R&D + DDT&E incl. production capability, flight & ground.
- **O&S:** Wing Ops Ground + Production.
- SPO + PM in each of prior.



Results Discussion

- The analysis and model capability are NOT point-design centric.
- Numerous RBS paths identified for low cost investment AND low cost O&S (including production). *Paths* as characteristics in:
 - Design/technology.
 - Processes/practices.
- Future sync with performance, reliability, etc. has a large design space.
- Slope of ~ 1.3 (Investment/O&S) varies/improves if a longer/complete program life-span considered.

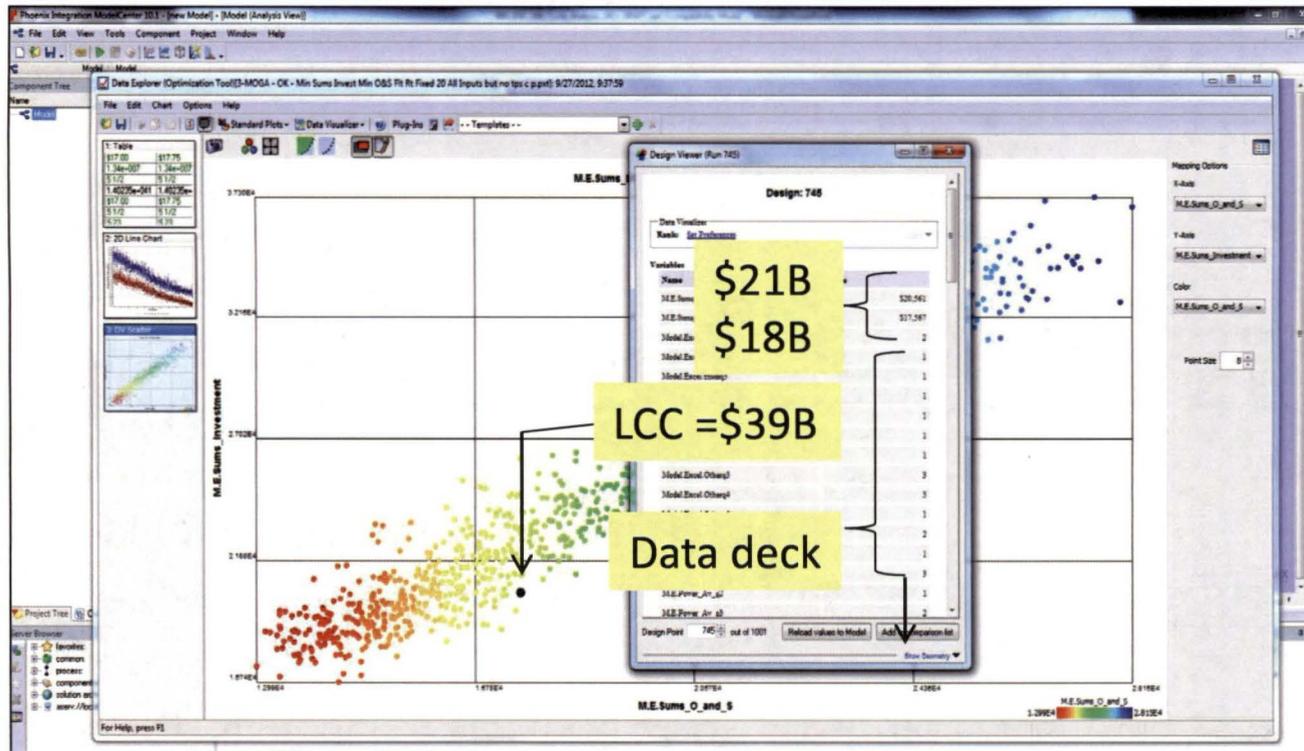


- The lower left quadrant cost options (shown) represent investment ranges of **~\$17B-\$27B**, and O&S ranges (20 flights per year, **thru 2035**, ref. BoE) of **\$13B-\$20B** (real year, inflated dollars). Flights phasing in starting in mid-2020's.



Results Discussion

- Example: A single design points data deck from the prior “seeking” run.

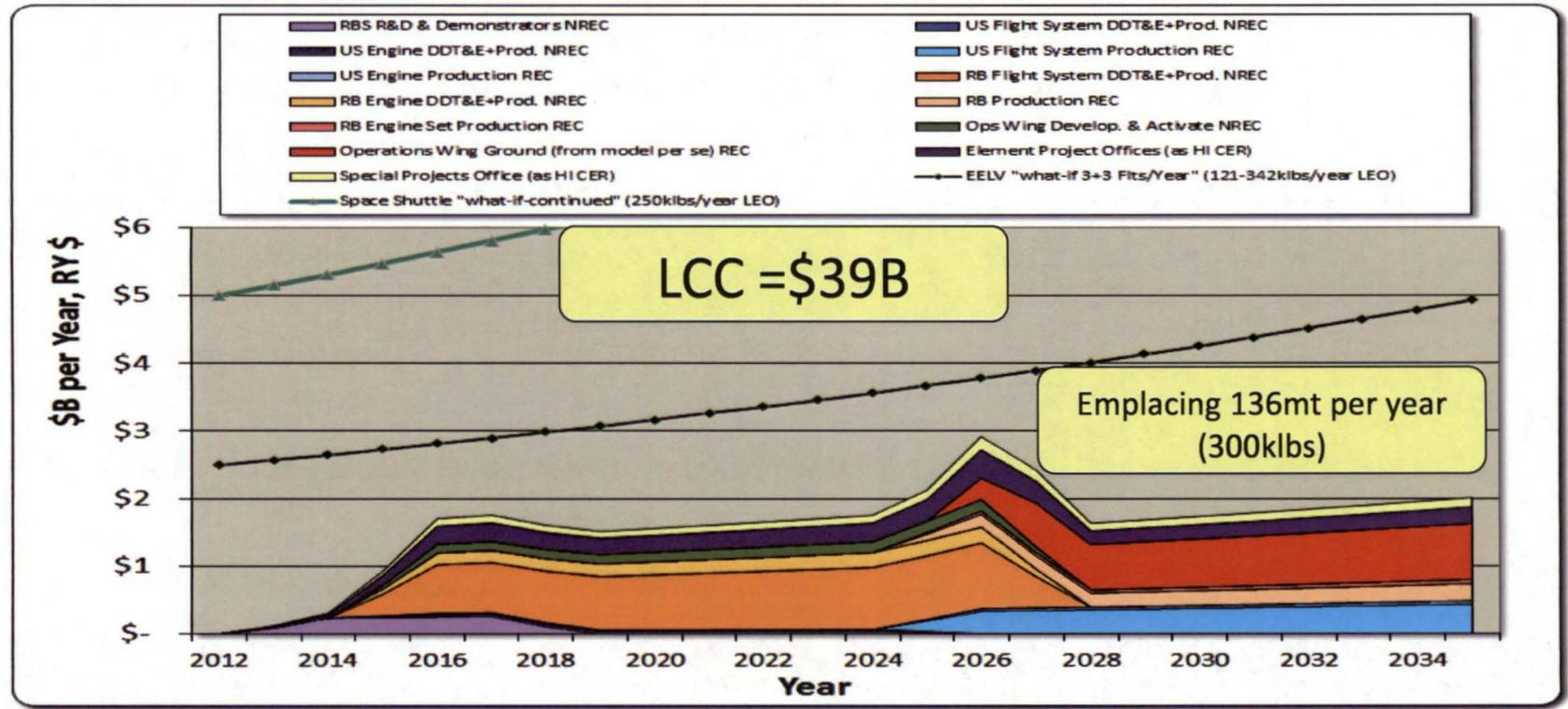


- Ref. BoE. – 23 years, through 2035. Phasing in flights starting mid-2020’s.
- **Investment:** R&D + DDT&E incl. production capability, flight & ground.
- **O&S:** Wing Ops Ground + Production.
- SPO + PM in each of prior.



Results Discussion

- Example: Same as prior, as an LCC sand chart.
- Many similar options in the low-end of both investment and O&S / Production can support a credible business case upon further mission definition.
 - Constraints (performance, other margin) have room to maneuver.
 - Refinements in phasing /scheduling (to eliminate spikes) are possible.





Forward Work, FY 2013

Collecting, addressing feedback on FY 2012 work.

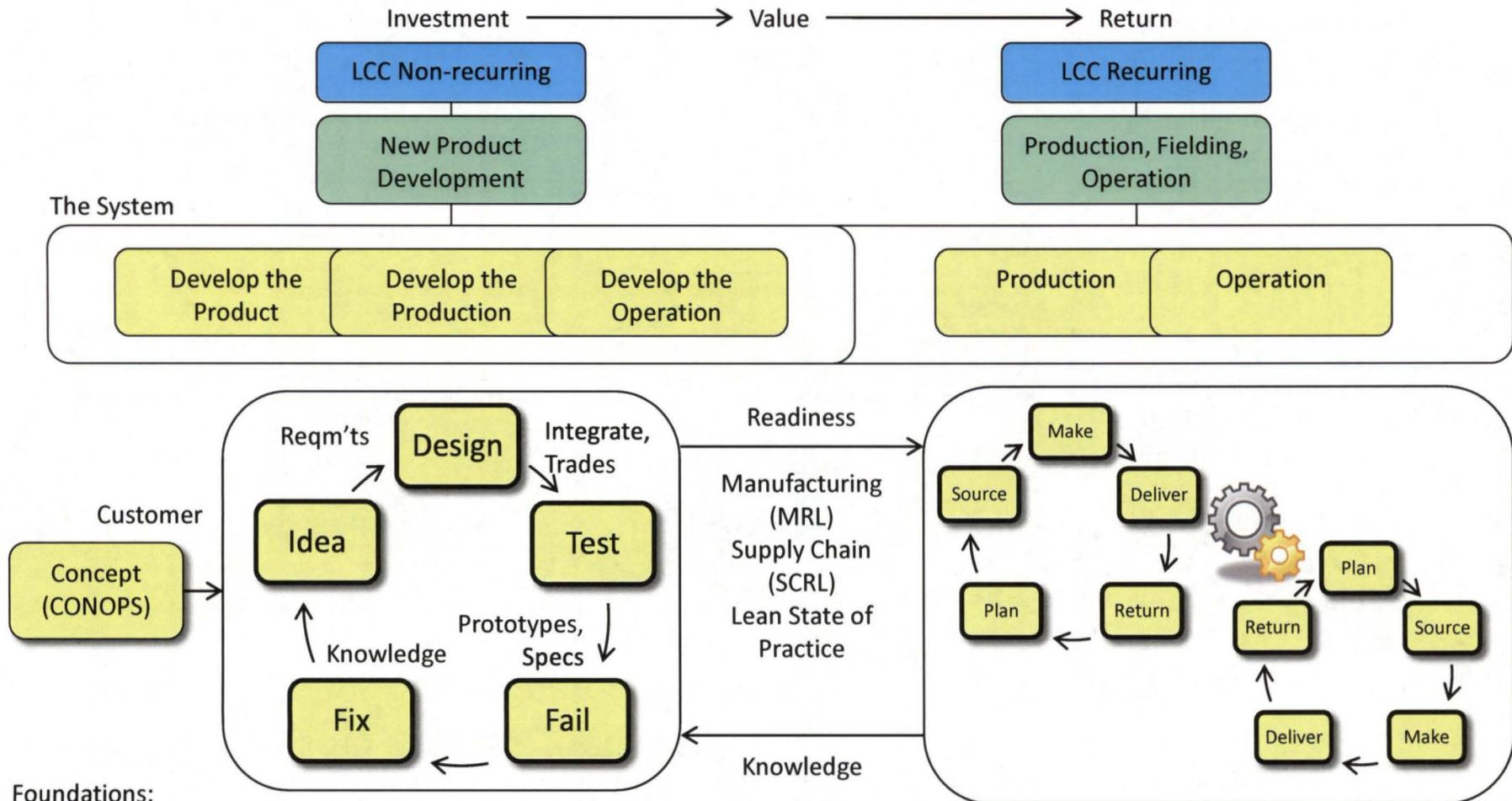
- Especial emphasis on improving the process/practices section of the model.
- Improve the models:
 - User interface.
 - Level of fidelity as appropriate to the analysis phase, pre-acquisition.
 - Transparency of estimating relationships.
 - Ease of being modified by either the developer or new users.
 - Usefulness as a learning tool, independent of an analyst generating results.
- Develop “top-10” lists of:
 - Prioritized technology specifics and directions
 - Prioritized industry process/practice specifics and directions
- Develop prioritized list of further upgrades.

The plan is to distribute the model across the stakeholder community.



RBS LCC Model Process/Practices

Model/Methodology Upgrade in Progress



Foundations:

- DoD Integrated Product & Process Development (IPPD) Handbook, Lean Aerospace Initiative (LAI), Lean Enterprise Model (LEM), ISO 15288 (and many more)

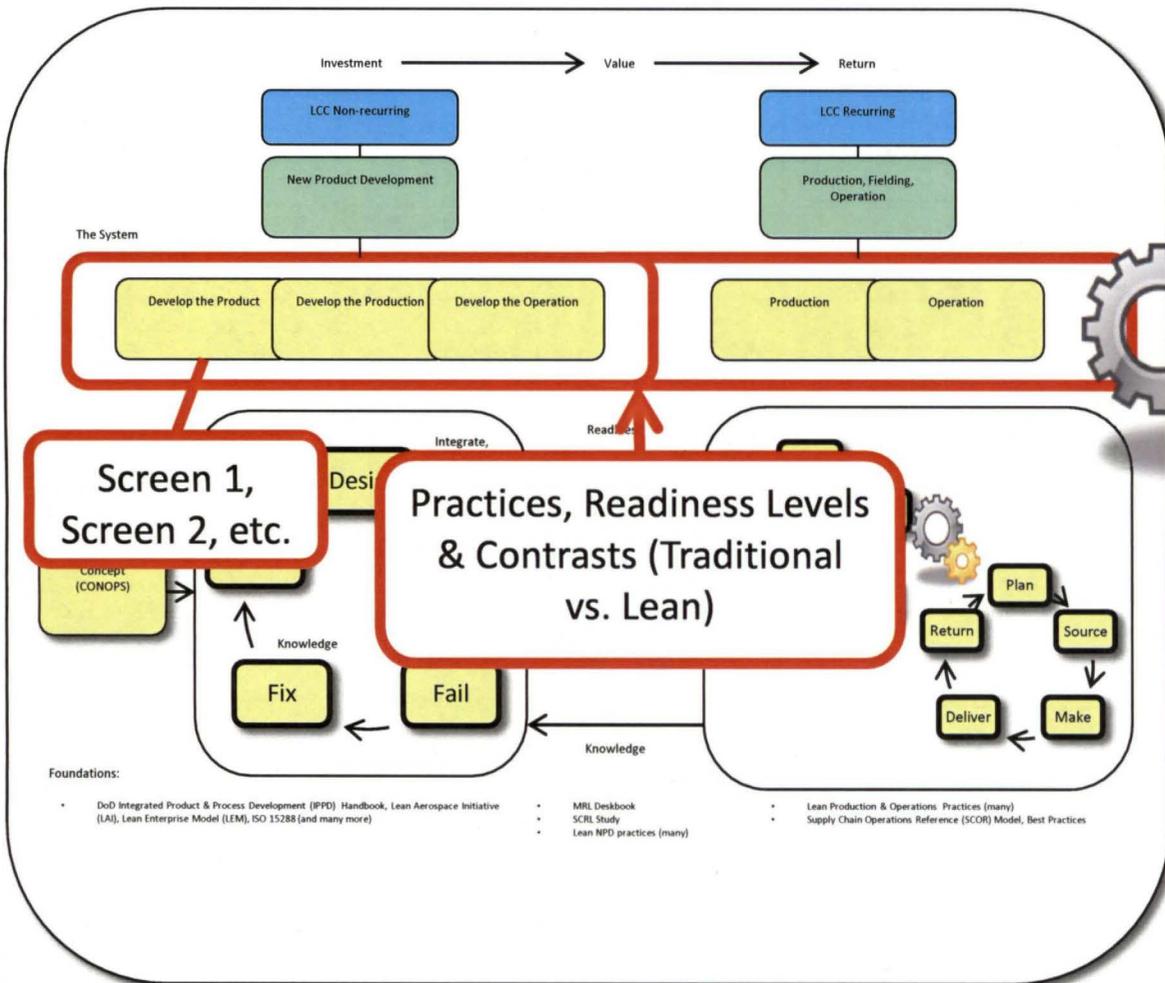
- MRL Deskbook
- SCRL Study
- Lean NPD practices (many)

- Lean Production & Operations Practices (many)
- Supply Chain Operations Reference (SCOR) Model, Best Practices



RBS LCC Model Process/Practices

Model/Methodology Upgrade in Progress - Relationships



Life Cycle Costs

Non-recurring

- RB DDT&E & Prod. Setup
- US DDT&E & Prod. Setup
- Ops Wing DDT&E & Ops Setup

Recurring, Production

Mission Driven -each flight

- Expendable Stage Production

Demand Driven -as desired (flight rate), required (flight rate & life limits) or possible (flight rate & limit of responsiveness)

- Reusable Stage & Engine Production

Recurring, Operations

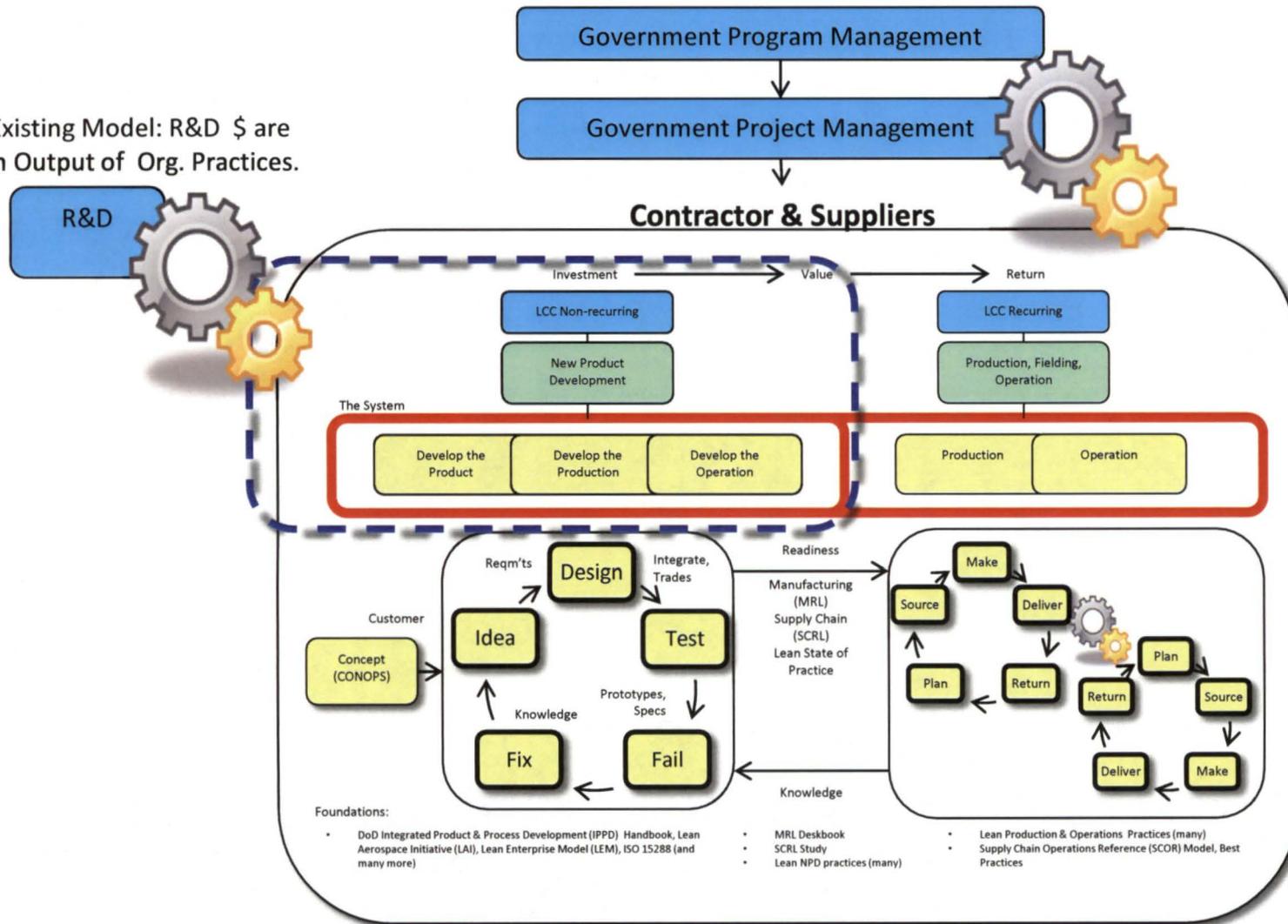
- Direct & Indirect (esp. Indirect)



RBS LCC Model Process/Practices

Model/Methodology Upgrade in Progress - Relationships

Existing Model: R&D \$ are an Output of Org. Practices.





Questions?



Backup



Preliminary Results, Summary Business Case for an RBS

- Recommendations – RBS Program:
 - Integrate this LCC model / analysis capability alongside other RBS programmatic features.
 - Esp. acquisition/business strategies (commercial/financial, contracting/investing, competition, insight/oversight), pathfinder development and demonstrators definition, and technology investment definition.
- Recommendations – LCC Modeling and Analysis:
 - In Planning 2014
 - Integrate this LCC model / analysis capability with other disciplines (performance, reliability, etc.)
 - Address competing levels of systems fidelity in the assorted disciplines across program phases.
 - ✓ In Work 2013
 - Refine the model usability / ease of use, level of fidelity appropriate by phase of analysis and acquisition, and transparency of estimating relationships.
 - ✓ Distribute the model across the stakeholder community.



Basis of Estimate Methodologies – Decision Analysis

- Cost estimating relationships consistent with decision analysis and problem decomposition techniques.
 - Large, complex problem reduced to a more manageable set of relationships.
 - Focus on individual components of the problem factors and their relationships.
 - Avoids pitfalls and biases of tackling complex problems as a whole.
 - Holistic, *after* the sum of detailed, individual factors are normalized.

“Also, the cognitively demanding task of information combination can be performed by model, typically implemented on a computer. Furthermore, the framework is general enough to incorporate information from diverse sources, including both 'hard' data and 'soft' subjective assessments.”

“Decomposition and the Control of Errors in Decision Analytic Models”
Kleinmuntz, Massachusetts Institute of Technology [1]