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Sandia National Laboratories

Systematic Literature Review: How is Model-based Systems Engineering Justified?

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November 9, 2016

SAND2016-11485 PE

U.S. DEPARTMENT OF ENERGY NNSA

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MBSE Study Introduction

What is the value of MBSE to Sandia?

- Principle Investigator: Ed Carroll
  - Retired Naval Aviator
  - 25 years in software / systems engineering
  - 15 years in systems analytics and data management
- Four questions were outlined for the MBSE study:
  - What does it look like? (Industry standards, guidelines, and manuals)
  - What can we learn from others? (Literature review & external visits)
  - What are we currently doing? (SMEs and MGRs, & pilot projects)
  - What is the path forward? (based on conclusions from above)
- Pilots:
  - 4 pilot projects, including: small, large, complex, hardware, software
- External Visits
  - Lockheed Martin, JPL, Huntington Ingalls, USAF, US Navy, DOD, & DOE

Definitions - MBE vs. MBSE

- Model-Based ***Enterprise*** – the tools, models, and infrastructure used to share design information across the enterprise that develops and supports the system
- Model-Based ***Engineering*** -- Integrated use of models to define the system technical baseline across the full life cycle, across all disciplines, across all program members [models are the authoritative definition of the system]
- Model-Based ***Systems Engineering*** – a specialized type of descriptive modeling used to create and analyze systems engineering information across the life cycle [the model is the authoritative definition for all systems engineering information]

Agenda

- Introduction – What is the value of MBSE to Sandia?
  - Gathering metrics about MBSE
- What is Systems Engineering?
  - Industry description (iterative processes)
  - What is driving us toward MBSE?
- What is Model-based Systems Engineering?
  - Conclusions and Key Findings from my Systematic Literature Review
    - An MBSE approach provides significant advantage
    - Systems engineering improves engineering efficiency
    - MBSE Prevents Defects and Rework
    - Systems engineering needs to drive engineering processes
    - Skilled system engineers are needed
    - Prerequisites and Commitments

Metrics Being Gathered

- Gathered from existing processes:
  - SME and MGR use characteristics and opinions
  - Defect rates
    - Failure mode analysis – tracing, mistake proofing
    - Halt Hass, Fagen Inspections, CONOPS reviews
    - Interaction points, degree of completion, consistency
    - Compare to COQUALMO defect predictions
  - Level of Effort (cost and schedule)
    - compare manhours to $$ and schedule overage
  - Informal Assessment of SE Capability

gathered as a bi-product of project work already being conducted

What are the Key SE Standards?

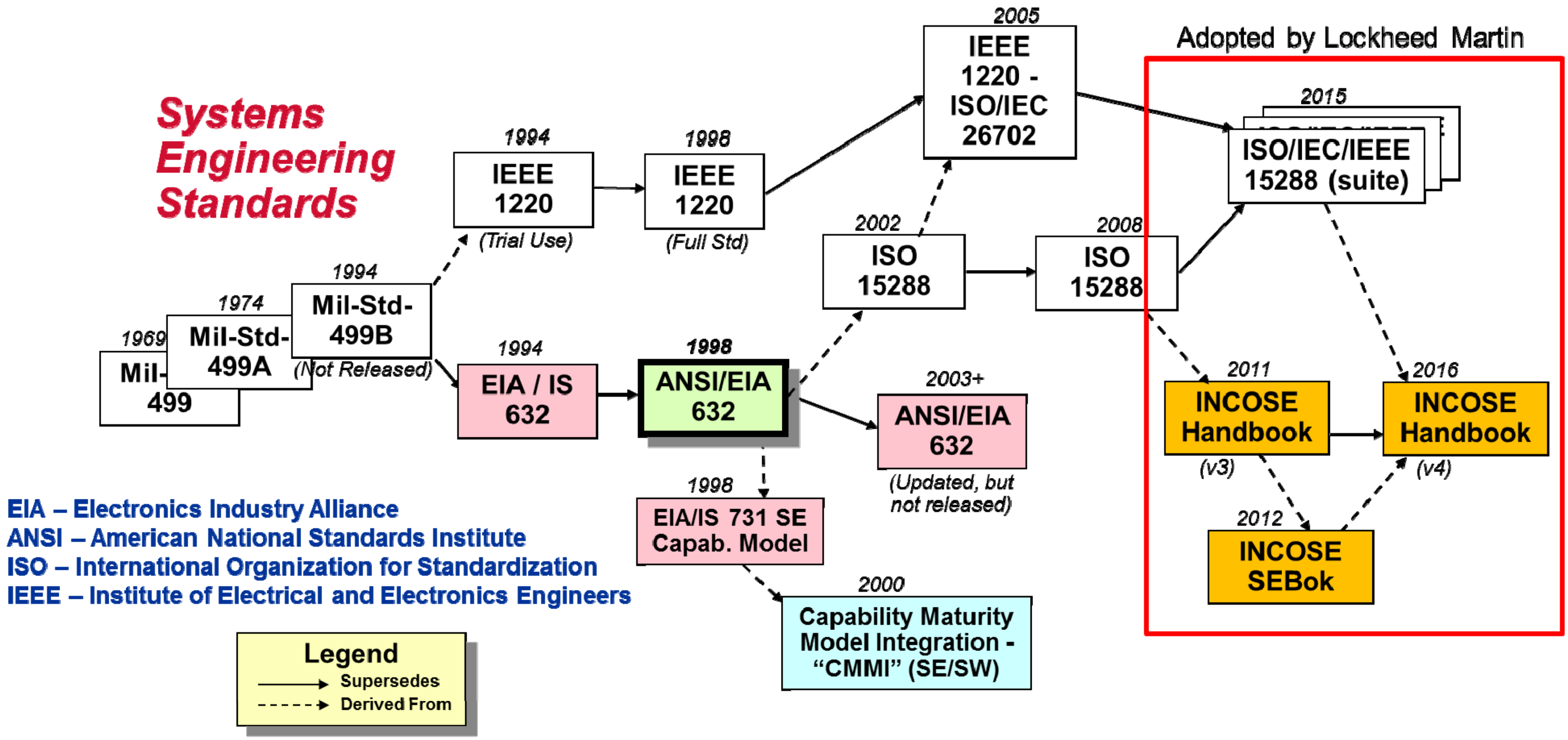
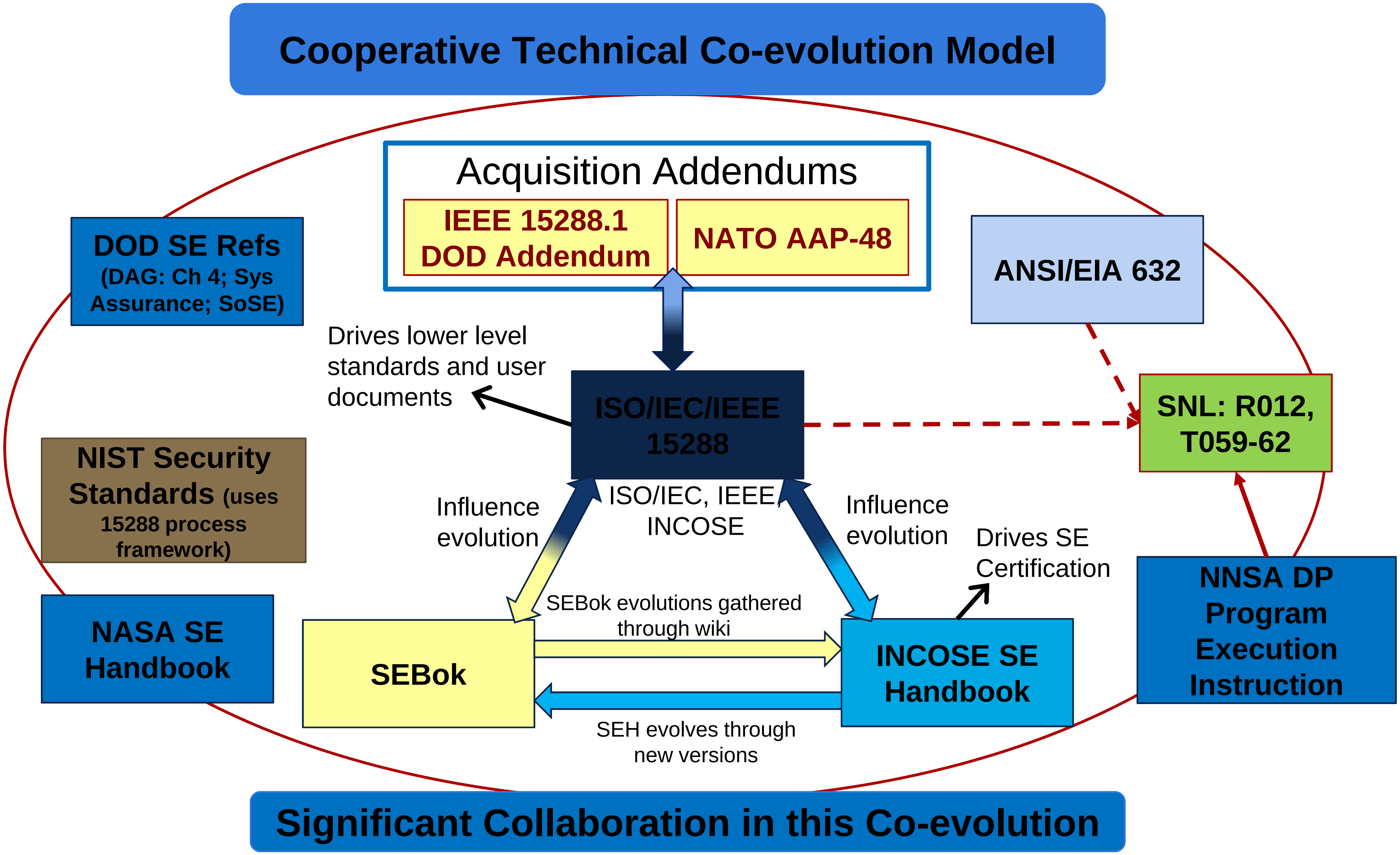


Figure 1: © Garry Roedler 2016 , adapted with permission

The applicable standards

The industry standards have converged into ISO/IEC/IEEE 15288



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The industry standard processes

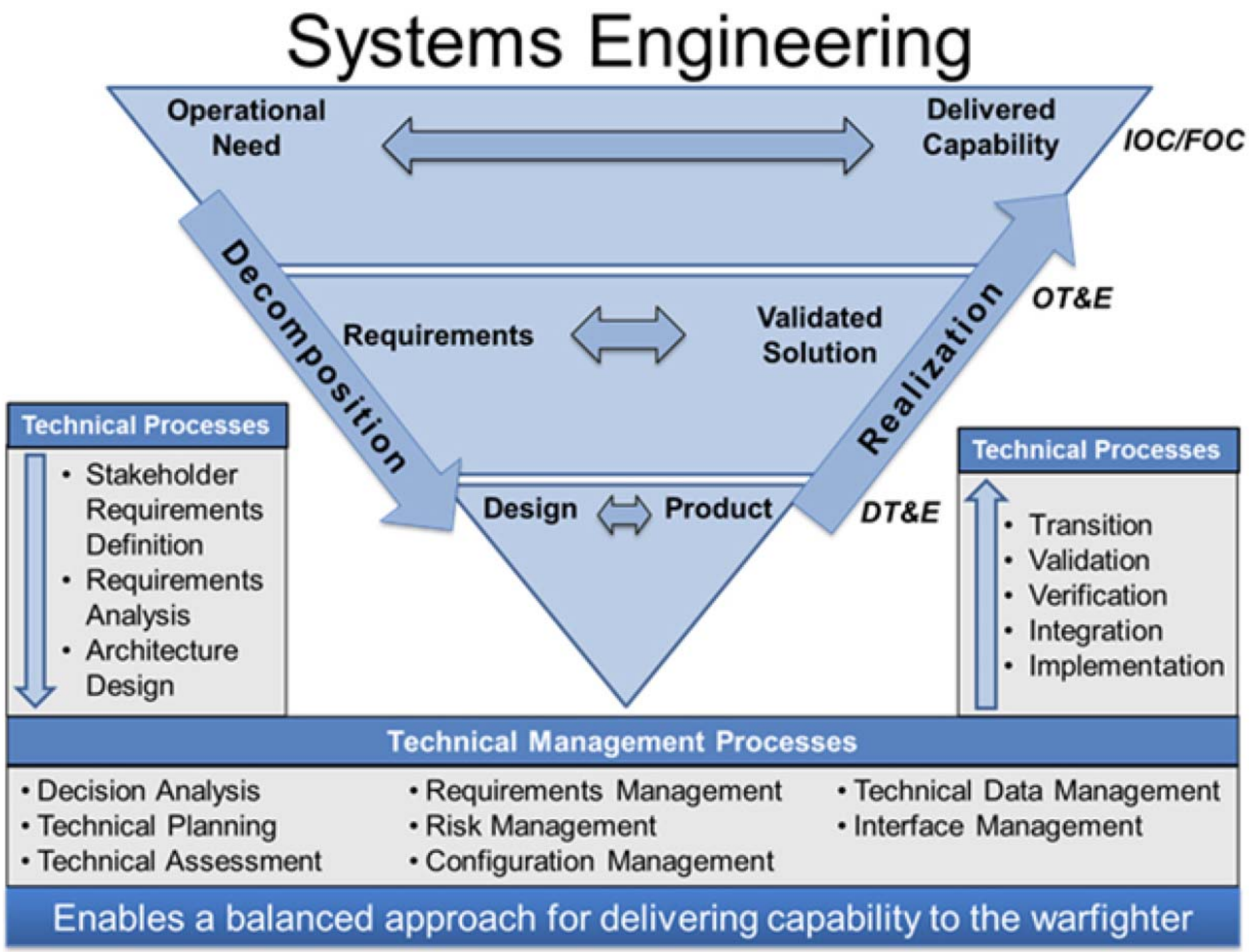
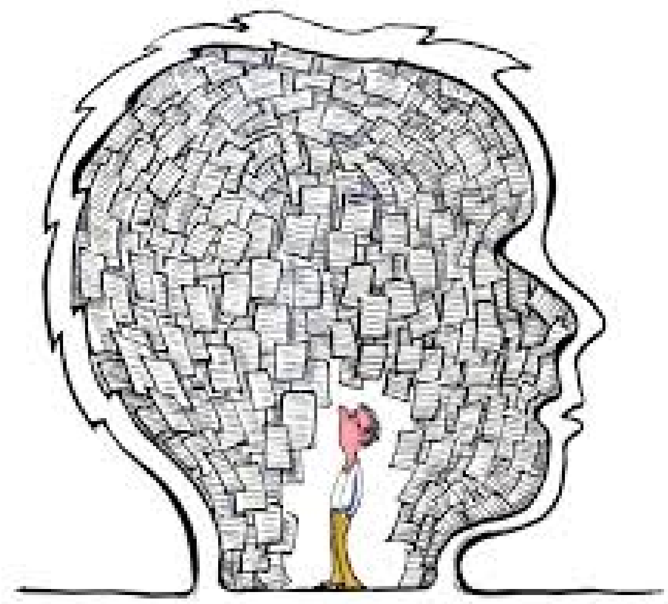
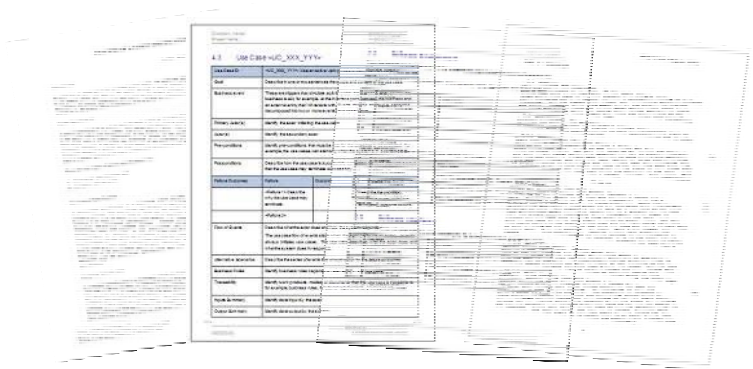


Figure 3: © the Defense Acquisition University

Why MBSE?



How do I navigate this???



- Complex system example:
- Heavily document-based approach
- over 6000 parts per system
  - Customer docs:
    - Text: 327 pages, over 750 mined requirements
    - Physical: 396 mined requirements
  - These led to system and major component requirements documents:
    - 832 pages of functional requirements
    - 232 pages of interface requirements
  - Documents do not address
    - Subordinate components
    - Environments
    - Dev Test plan
    - Qual plan
    - Maintenance/Ops Plan
    - Standards and Best Practices
    - Any production related requirements

Figure 4

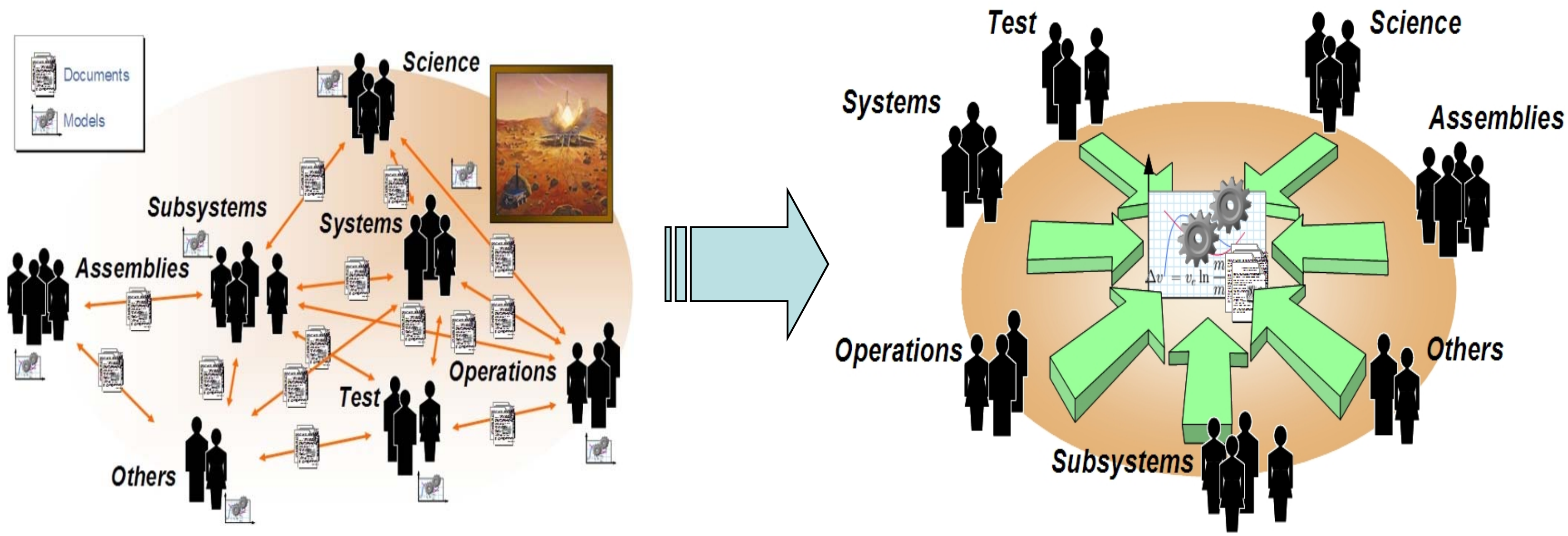
What is driving the industry to MBSE?

- Systems are getting more complex
- Customers want to reduce cost / schedule
- Customers want guaranteed reliability

Others have said "how can we not use an MBSE approach?" - Consider SNL's agile, adaptable, affordable initiative

- Modeling is prevalent in all engineering disciplines
  - Electrical, mechanical, physics-simulation, software
  - Data shows a positive ROI for using models to solve the problems of complexity, cost, and reliability
- DOD is mandating models in contracts
  - ie., The Ground Based Strategic Deterrent SOW (section 3.2.3)
  - Nunn-McCurdy breach on the GPS III program – due to inadequate systems engineering at program inception, the Air Force said in a press statement.
- Additive Manufacturing requires models

What Would MBSE Look Like …
In Current Practice to Future Practice



Today: Standalone models related through documents

Future: Shared system model with multiple views, and connected to discipline models

INCOSE
International Council on Systems Engineering

MBSE Workshop

Figure 5: © INCOSE, adapted with permission 2014

What SE Processes does MBSE overlay?

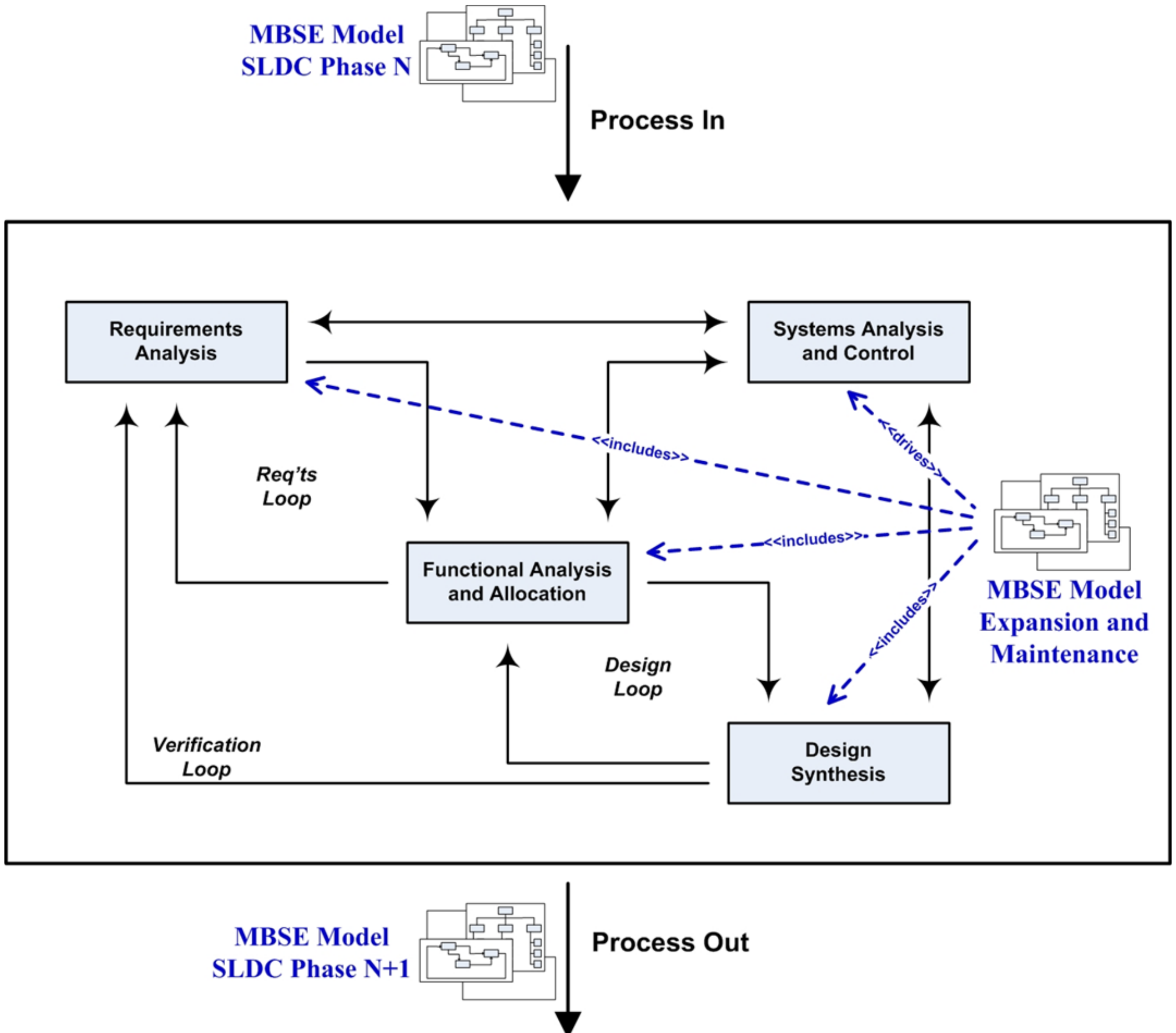
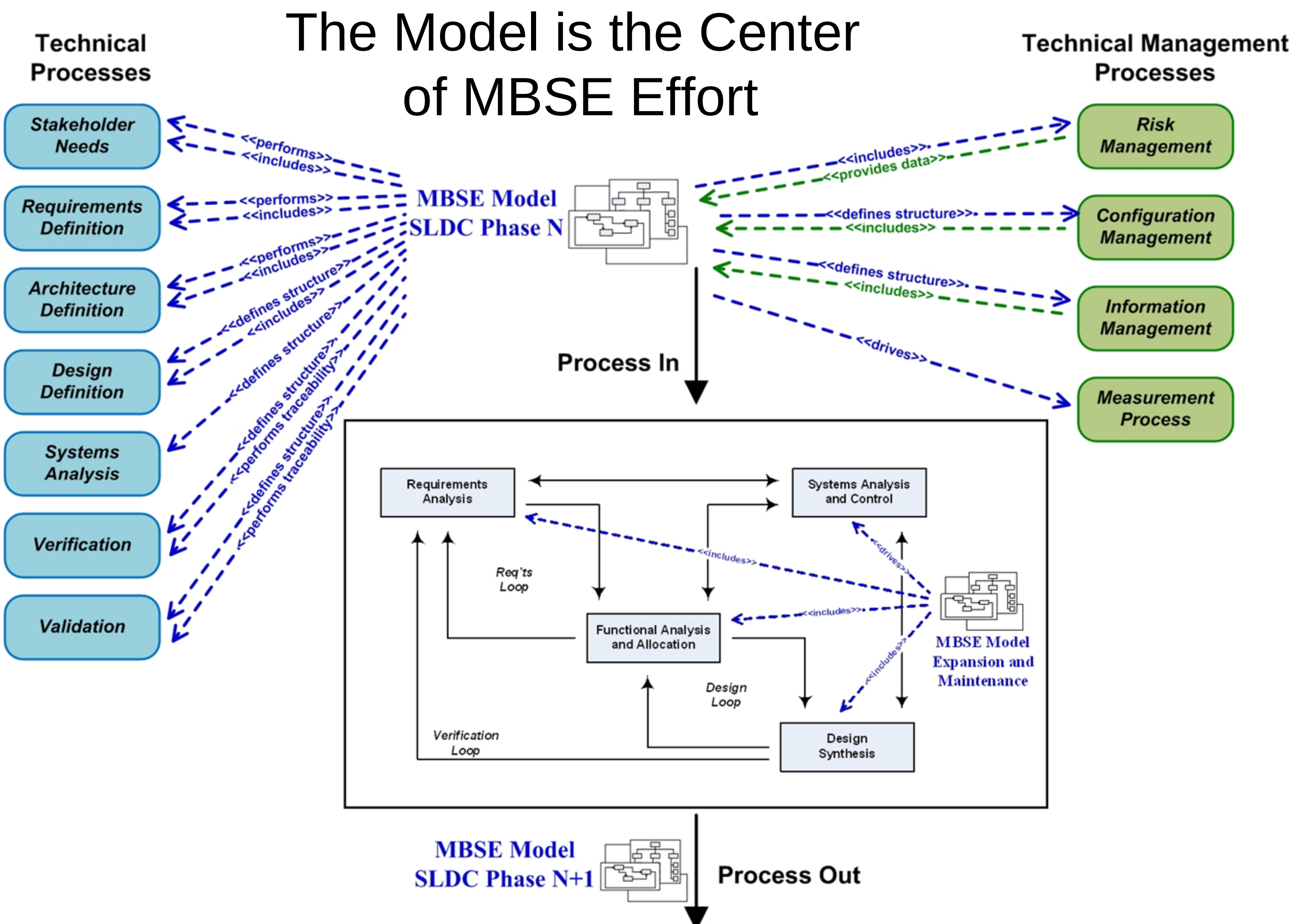


Figure 6: © Copyright ROI Training, Inc. 2016, adapted with permission

What is Different When Using MBSE?



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Overlaying MBSE to SE Foundation

Figure 8: © INCOSE, with permission 2012

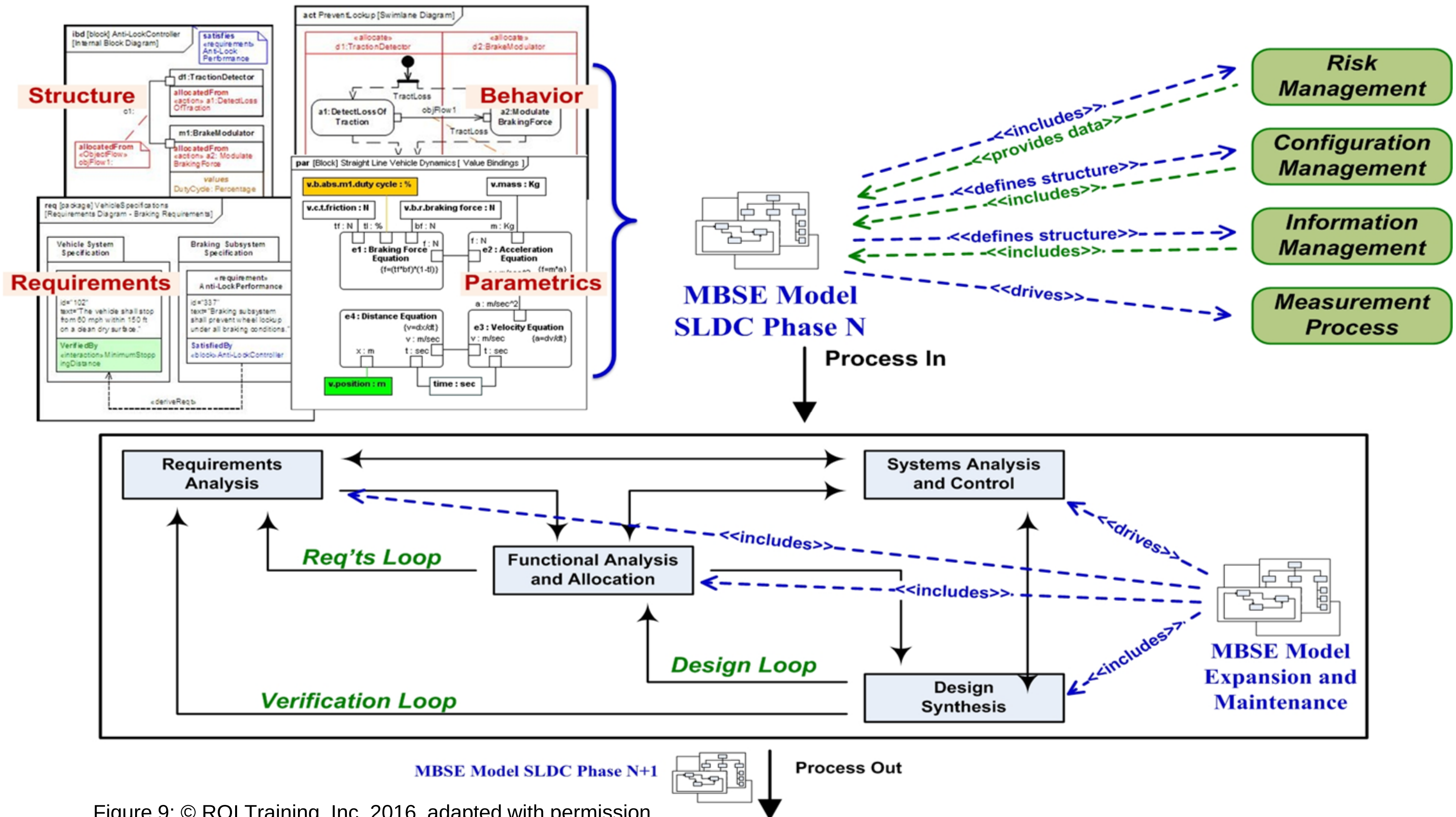
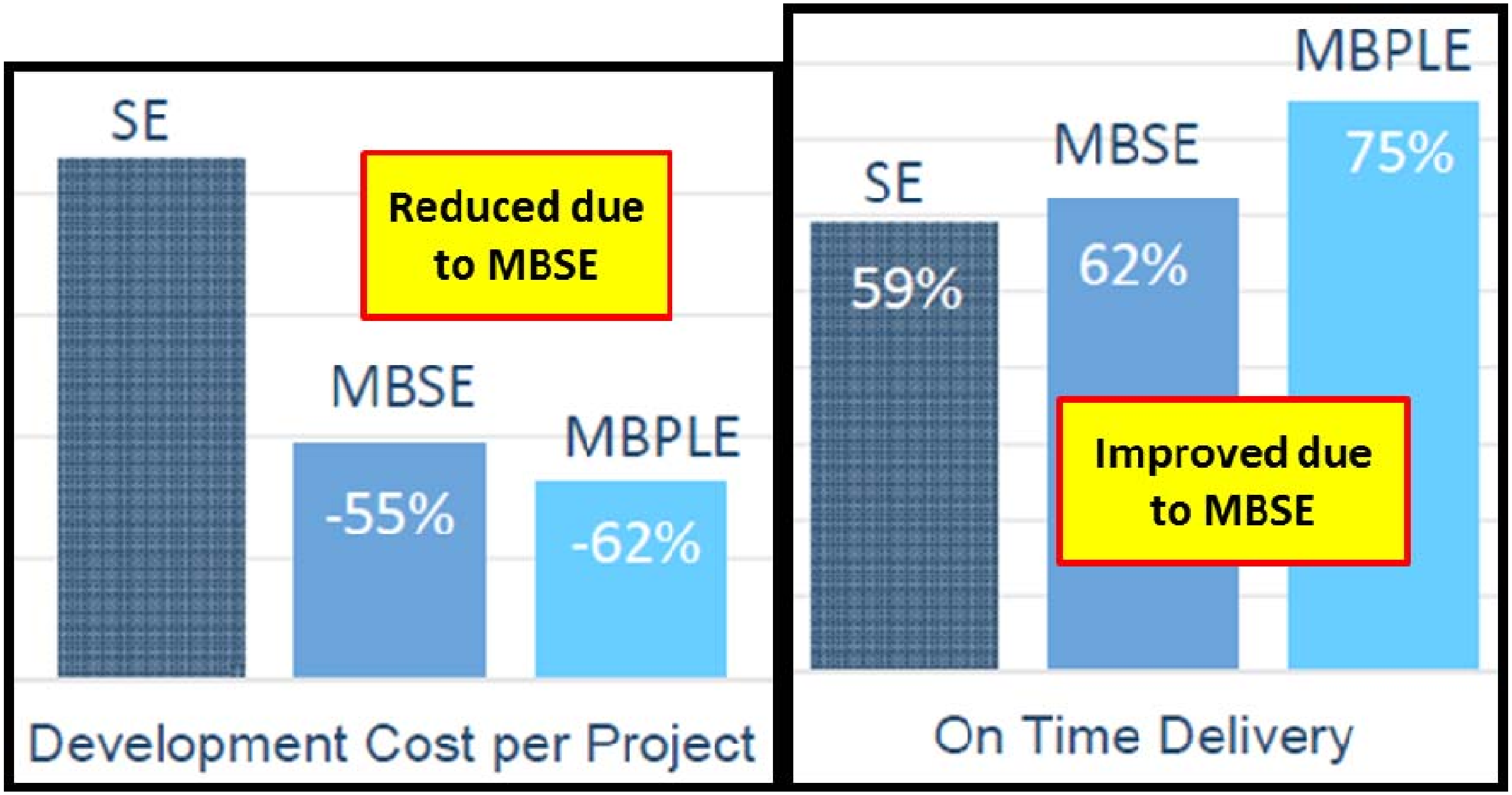


Figure 9: © ROI Training, Inc. 2016, adapted with permission

Findings and Conclusions from Lit Rev

- 67 case studies justified by claiming benefits of:
  - Completeness, consistency, and improved communications
  - Or highlighted contributions to test and evaluation, V&V, concept exploration, design reuse and systems margin analyses
- 21 case studies justified with quantified results of:
  - Cost and schedule improvement
  - Finding defects and preventing rework
- Case studies were from:
  - (67) 8 countries, 10 defense, 33 space, 5 non-defense, 6 commercial
  - (21) 4 countries, 12 defense, 5 space, 4 commercial, 6 used MBSE to develop complex weapon systems

MBSE Provides Significant Advantage



MBSE is an extension of Systems Engineering,
And model-based product line engineering is an extension of MBSE

Figure 11: © PTC inc. 2014, adapted with permission

SE Improves Engineering Efficiency

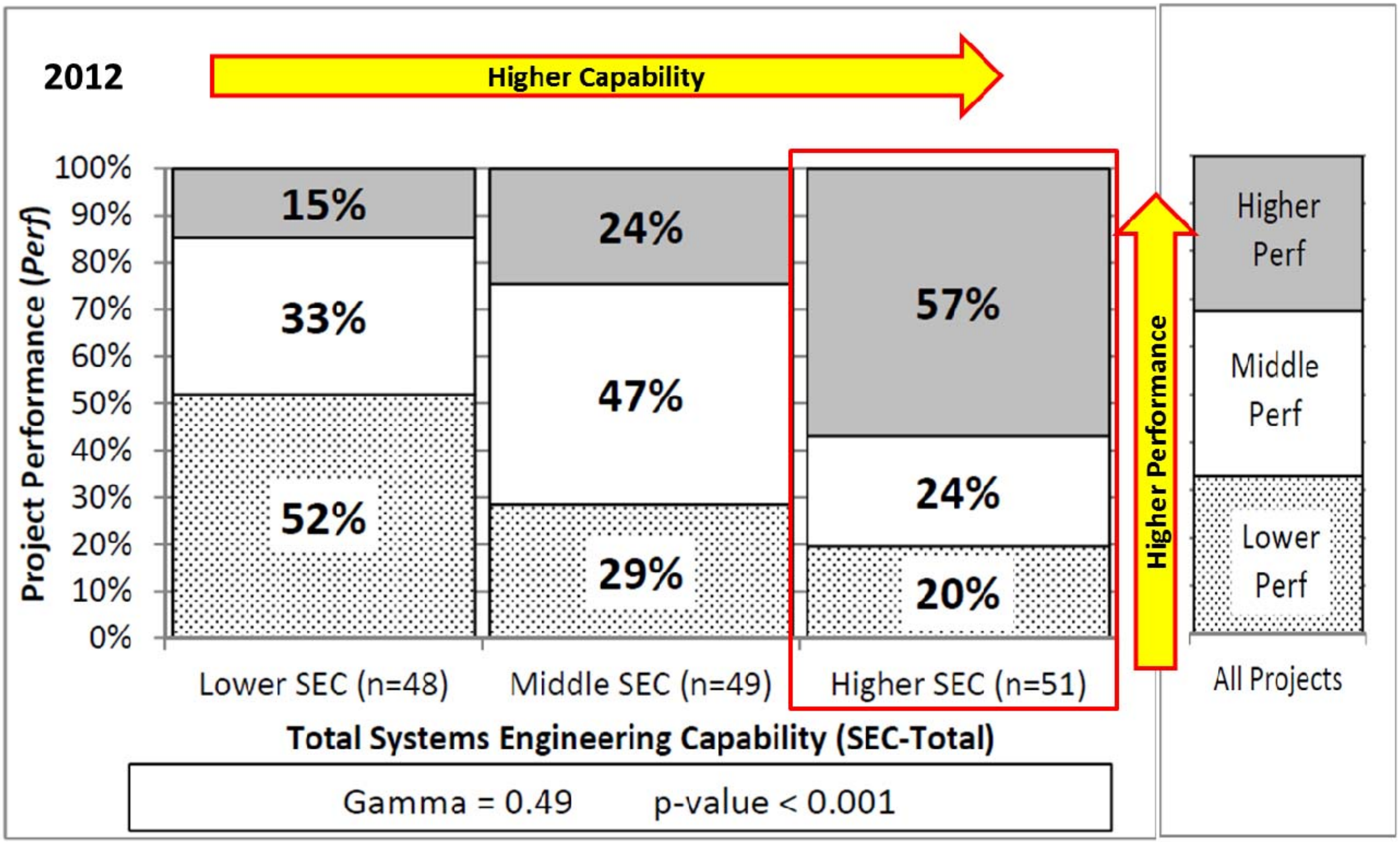


Figure 12: © Carnegie Mellon University 2012, adapted with permission

MBSE Prevents Defects and Rework

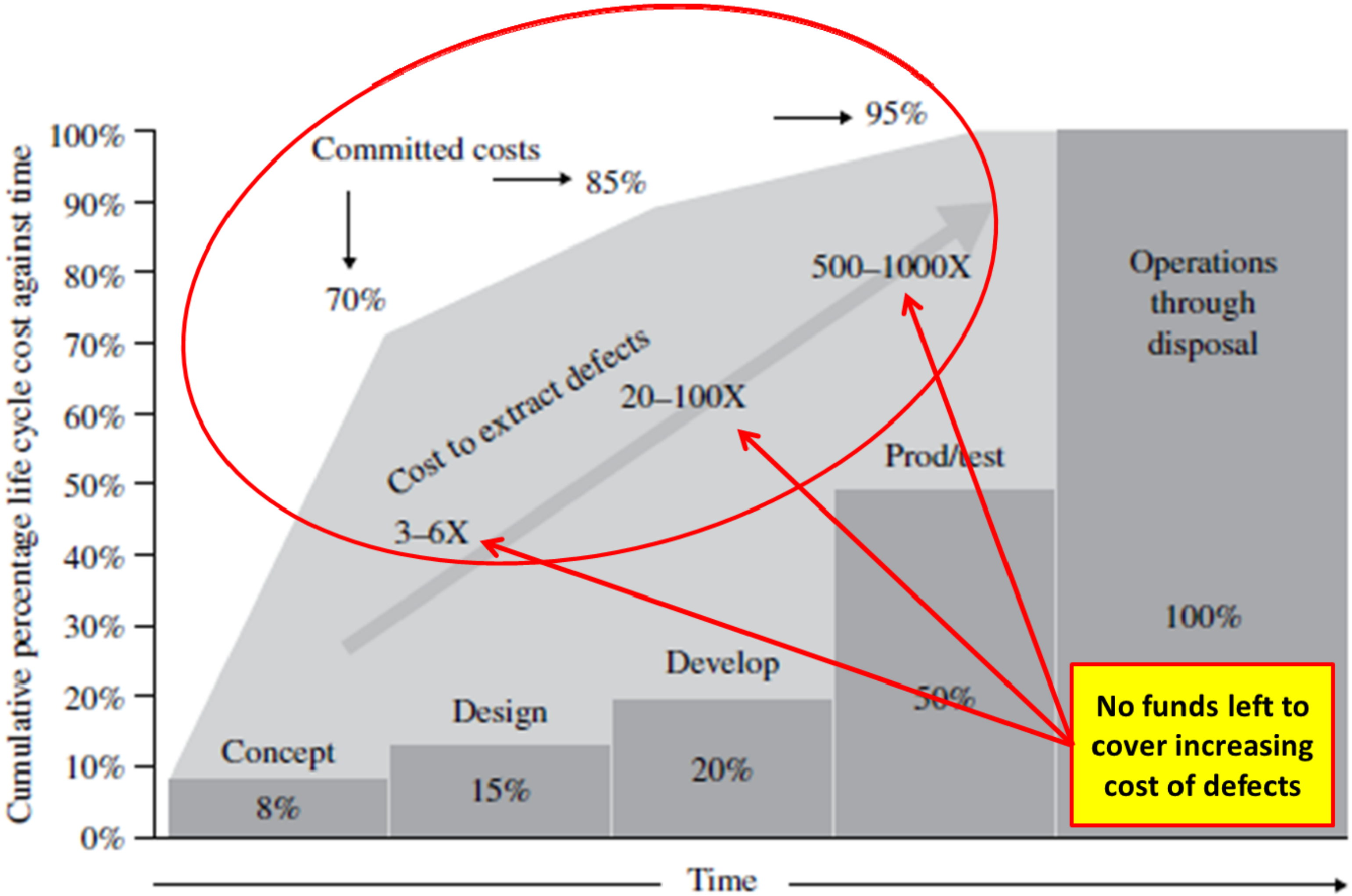
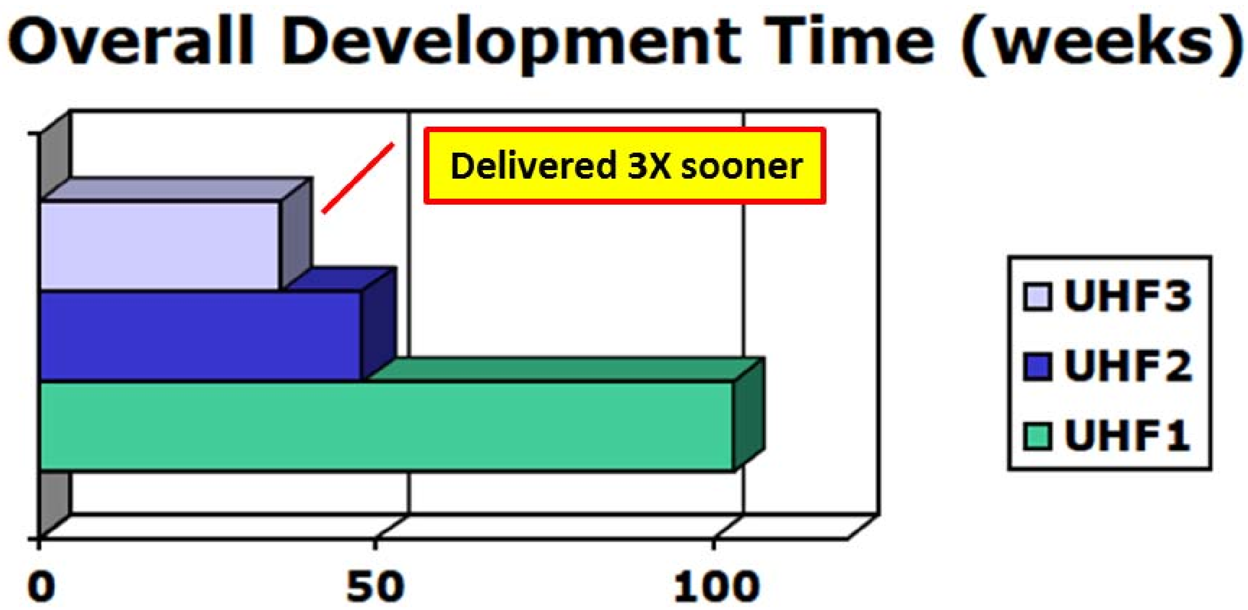


Figure 13: © Raytheon Company 2011, *Defense AT&L*

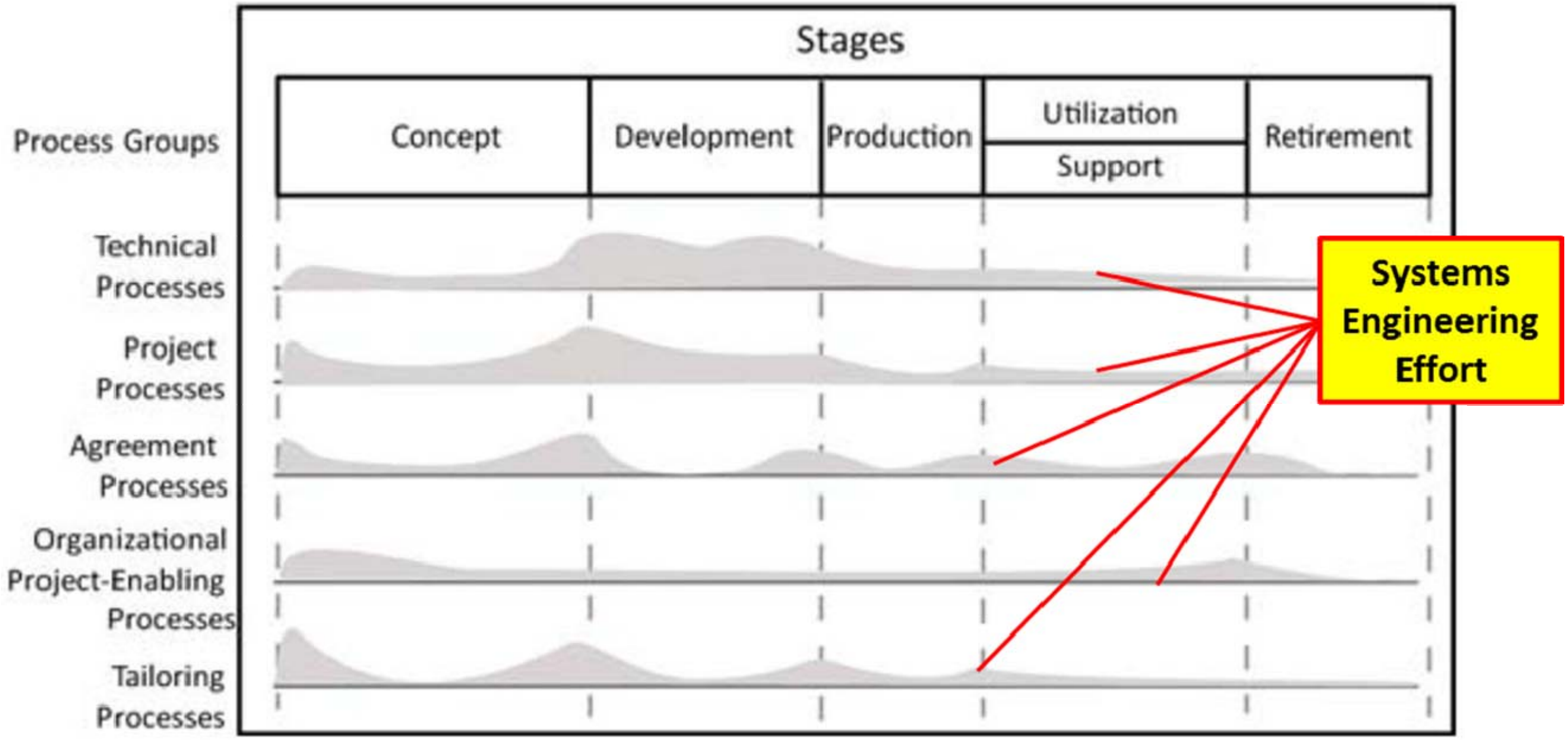
SEs Need to Drive Engineering Processes



- To effect delivery, SEs must drive their processes
  - First change the model, then change the system
  - High access to systems management, who pays attention

Figure 14: © The Boeing Company 1995 , adapted with permission

Skilled SEs are Needed to Drive Engineering Processes



- Delivery times are not effected by data entry clerks
- Systems Engineers must be well trained engineers
  - MBSE employs new techniques, tools, and processes

Figure 15: © INCOSE adapted with permission 2012

The data shows an optimal SE staffing at 12-17% of total

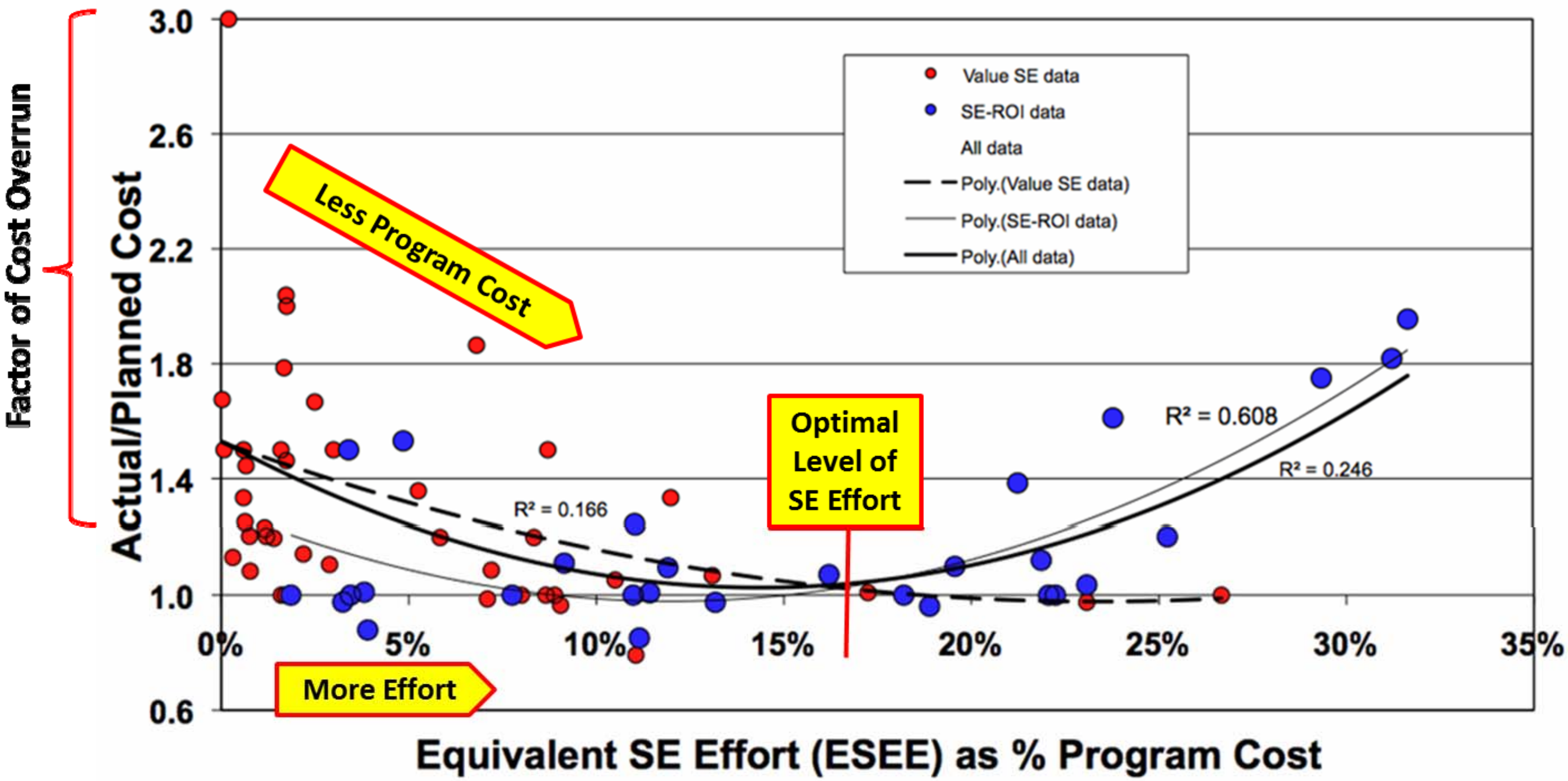


Figure 16: © Eric Honour 2013, adapted with permission

Adding MBSE to the SE Foundation?

- Good SE = Good Program Performance
- Good SE → begets → Good MBSE
- Good MBSE = Good program Performance

- The model becomes the center of information
  - For Communication – across team and across program
  - For Technical Process Performance
  - For Technical Management Processes

MBSE Provides Significant Advantage

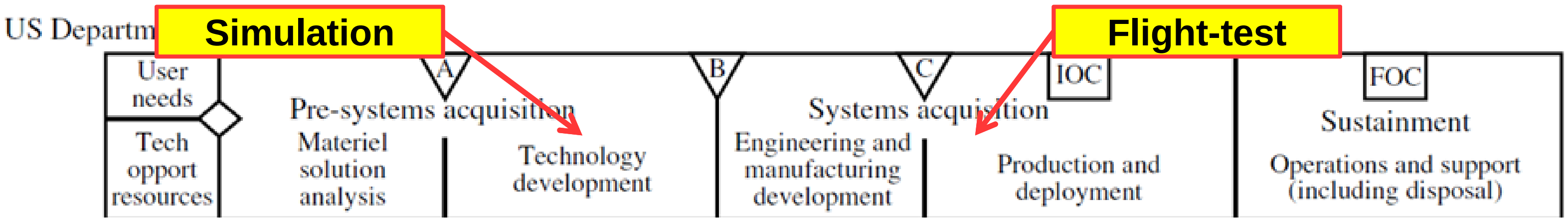


Figure 17: © *INCOSE* 2014, adapted with permission

Figure 18: © by-sa 2.0 Tim Felce – Gripen – RIAT 2010

MBSE Avoids Rework

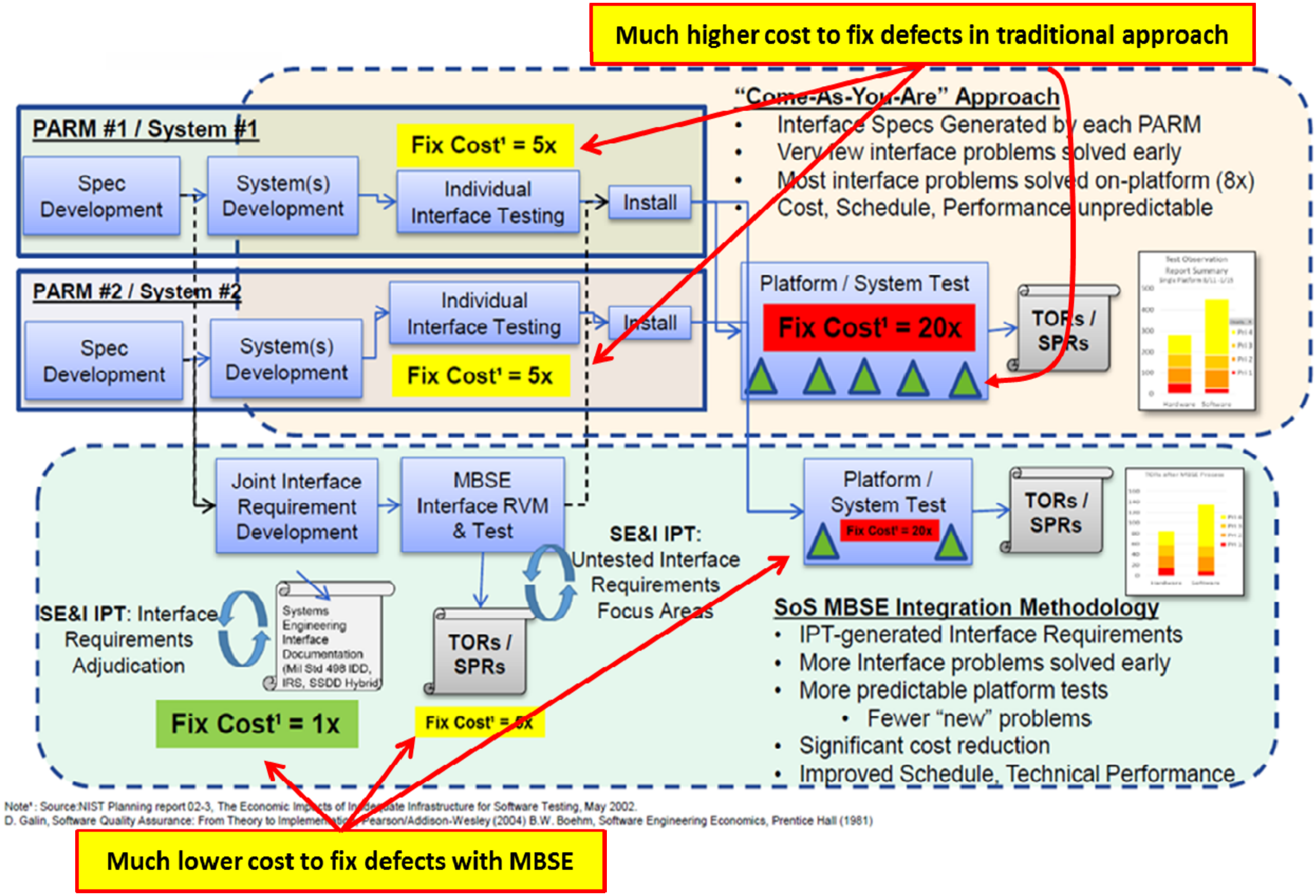


Figure 19: © Lockheed Martin Corporation 2015, adapted with permission

MBSE Avoids Rework

	System f0 Phase	Success Probability [probOfSuccess]	Failure Probability [1 - probOfSuccess]
No change to design	Baseline	0.6	0.4
Without MBSE	Update 1	0.73	0.27
With MBSE	Update 2	0.93	0.07

From 73 % chance of success to 93 % chance of success

Figure 20: © Rafael Mareni Perez 2014, adapted with permission

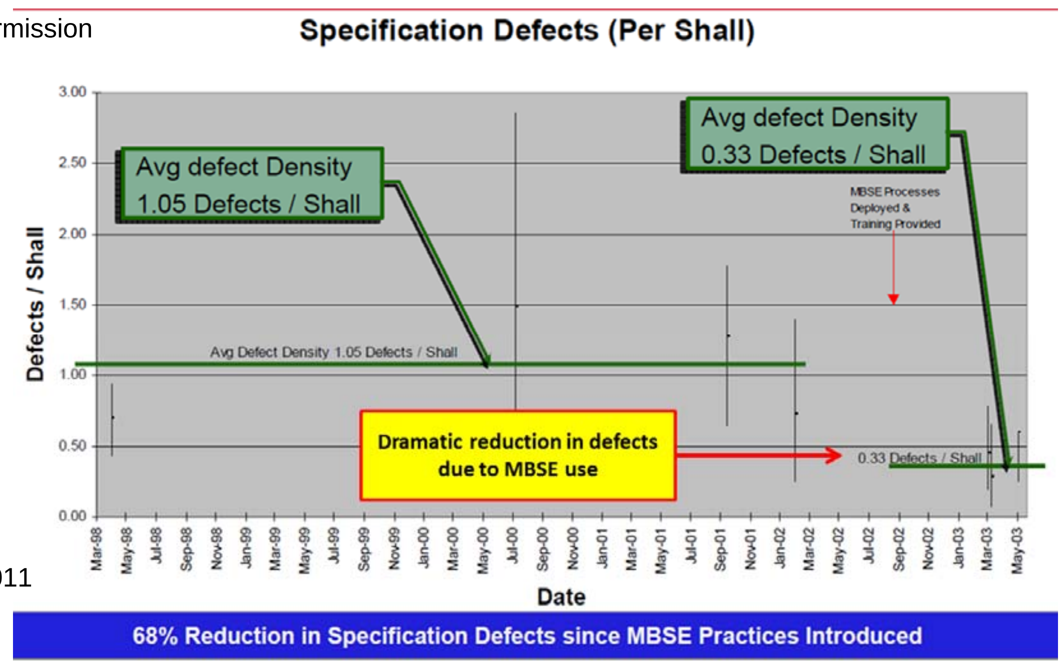


Figure 21: © Raytheon Company 2011 (DAT&L)

What are the keys to effectiveness?

- From our Systematic Literature Review of the industry, the following findings were reported as keys for effectiveness:
  - Engage Systems Engineers as engineering process leaders
  - Diligently perform defined (iterative) processes
  - Systems Engineering effort is highest early in the project
  - The optimal SE staffing is up to 12-17% of total program staffing

Engage System Engineers as technical leaders of these processes

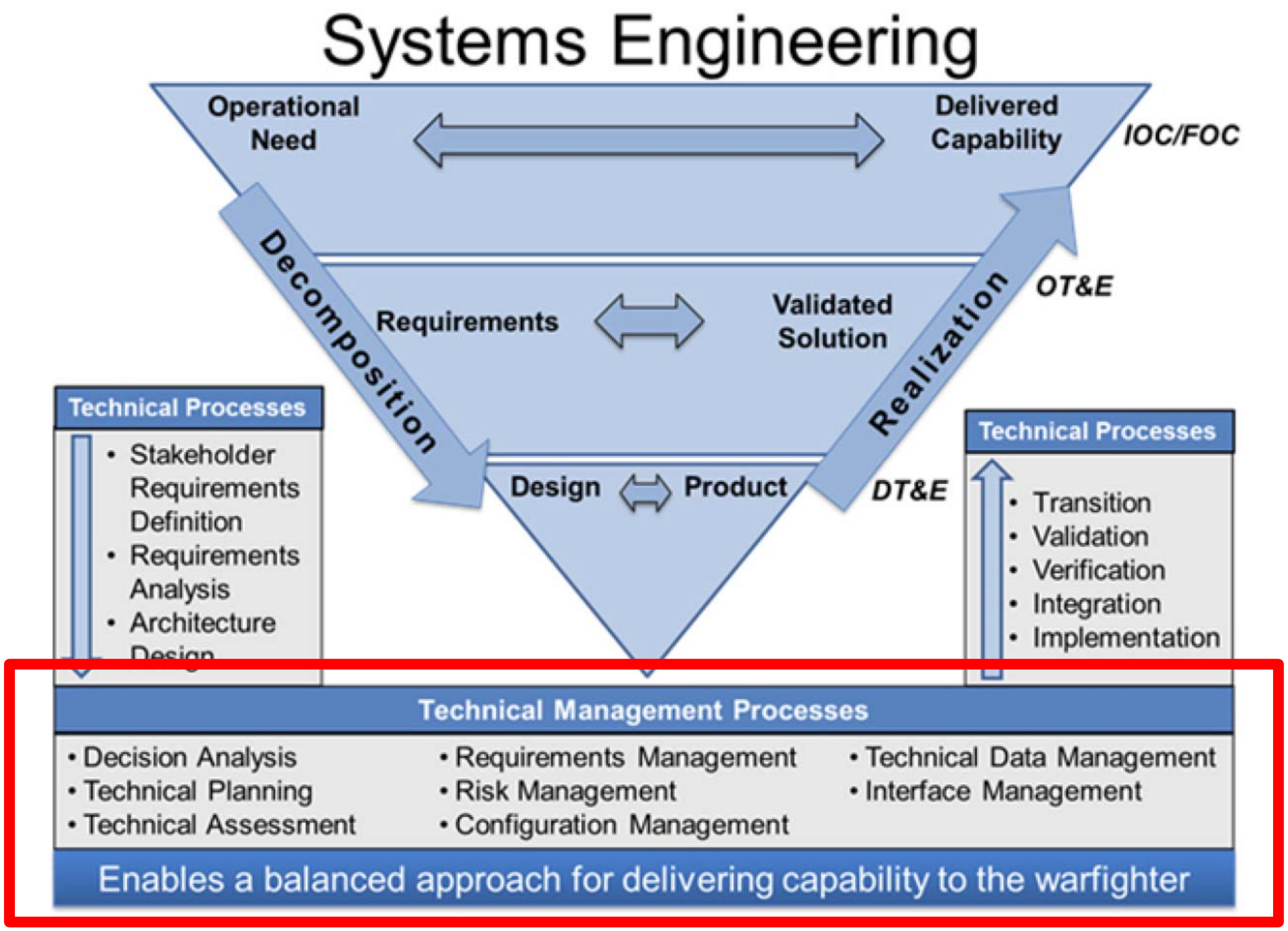


Figure 22: © the Defense Acquisition University

Key Processes – Iterate through feedback

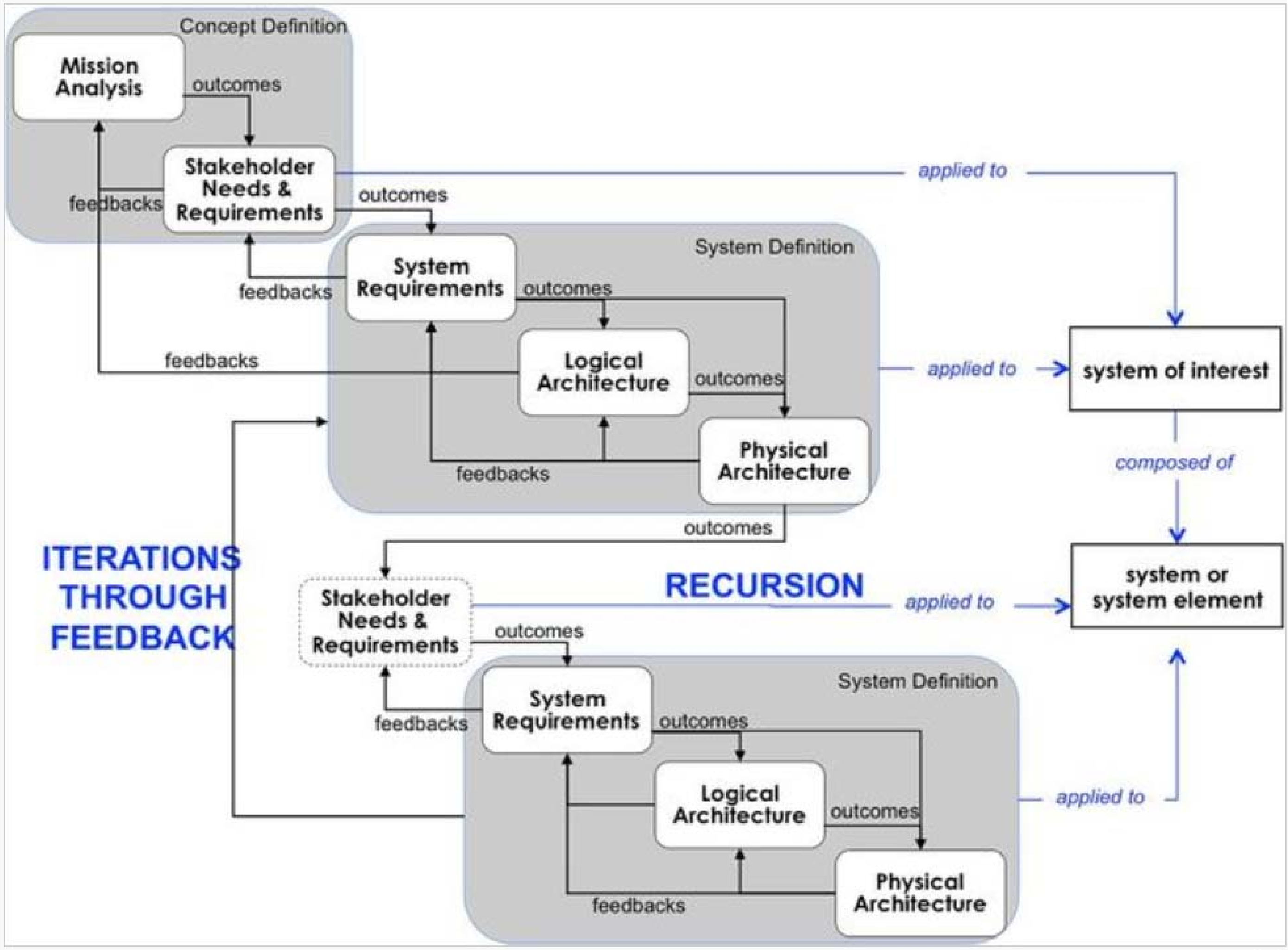


Figure 23 **Figure 4. Recursion of Processes on Layers (Faisandier 2012).** Permission Granted by Sinergy'Com. All other rights are reserved by the copyright owner.

SE Effort is highest early in project

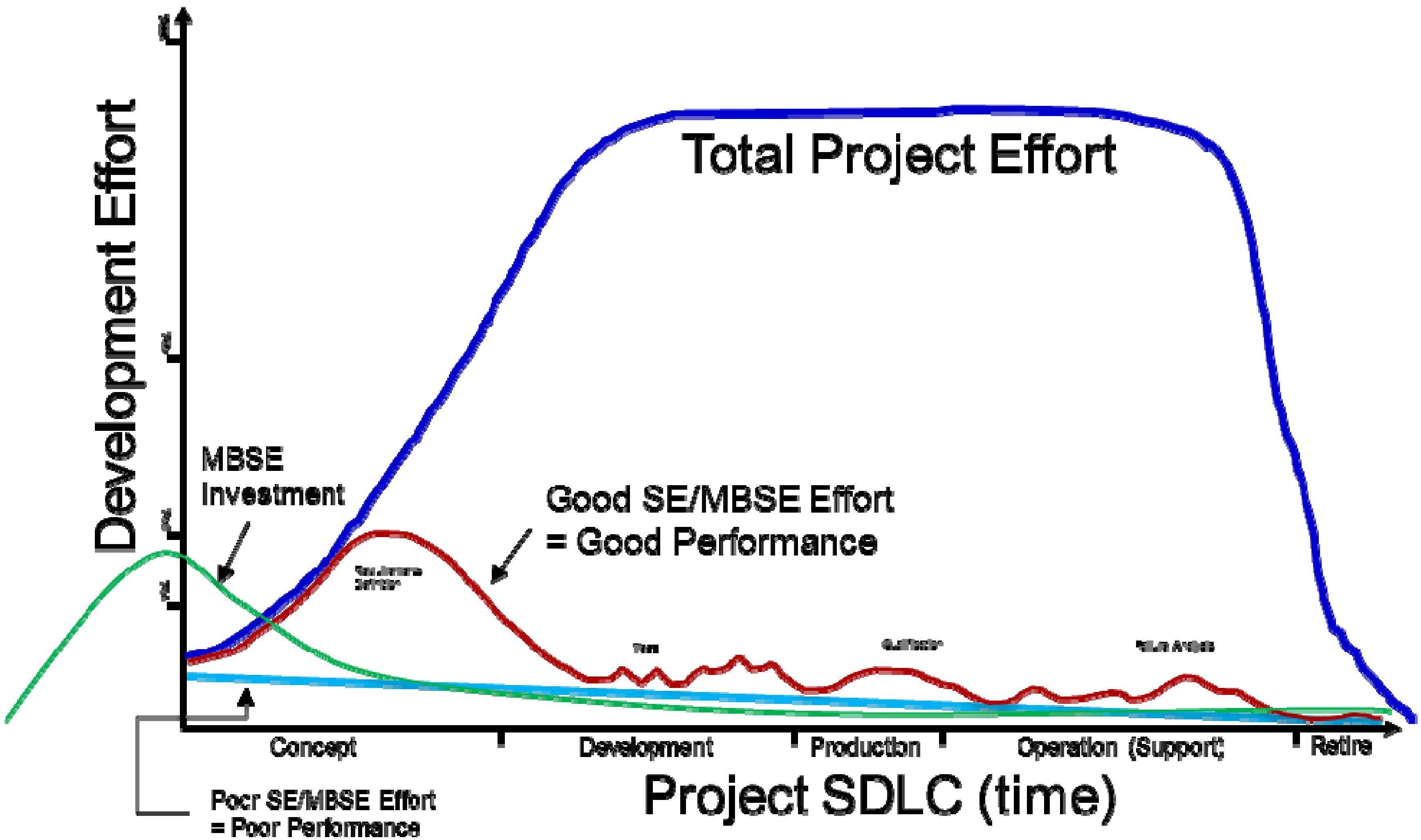


Figure 24

Prerequisites

- Well documented SE processes that spans the SDLC
- Trained systems engineers
- Access to training in the SE processes at SNL
- Defined processes for model management throughout the SDLC
- Invest in full scale MBSE tools

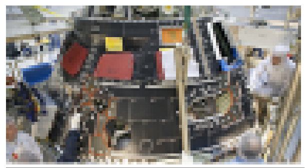
Commitments

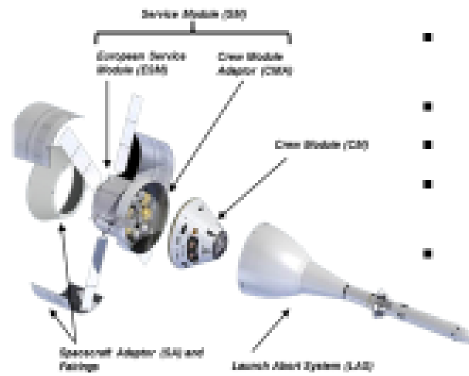
- Initiate modeling with appropriate staffing levels at the beginning of a program
- Configuration manage the model “change the model first, then the design”
- Provide continuous resources to maintain the models throughout the SDLC
- Provide MBSE resources and models to support qualification
- Provide appropriate computing infrastructure throughout SDLC

Orion - Human Space Flight

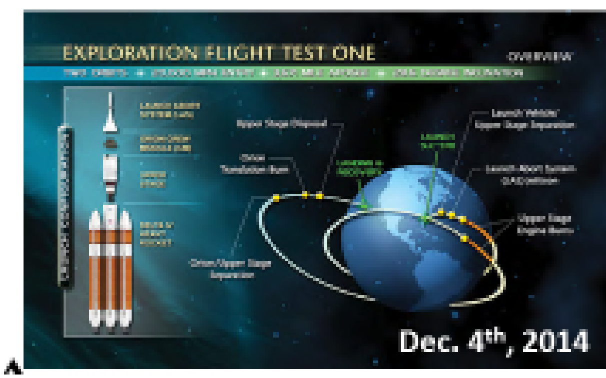
"Orion was designed from inception to fly multiple, deep-space missions. The spacecraft is an incredibly robust, technically advanced vehicle capable of safely transporting humans to asteroids, Lagrange Points and other deep space destinations that will put us on an affordable and sustainable path to Mars."

Lockheed Martin Space Systems
Denver, CO
100% system reliability required
Model-centric customer (NASA)
Core MBSE Team





- NASA's human space exploration vehicle (CEV / Orion / MPCV)
- LM is prime contractor (2006 award)
- First orbital test flight Dec 4th, 2014
- Uncrewed test to DRO Lunar orbit (2018)
- First Crewed flight, Lunar orbit, 2021



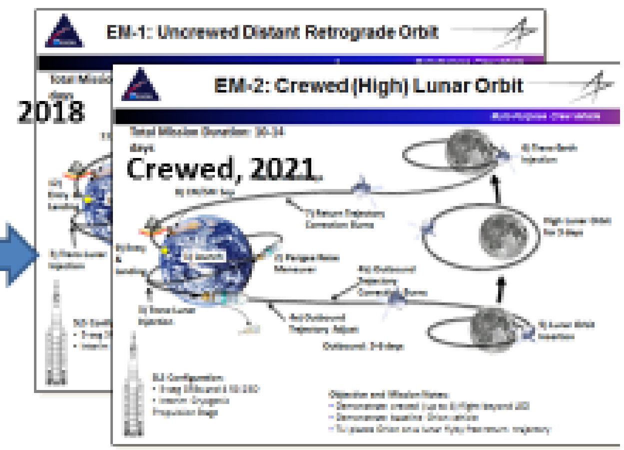


Figure 25: © NASA Photo

Europa Exploration Mission

"This effort entails a highly complex integration of extensive modifications and numerous subsystems which must seamlessly interface with each other in order to meet the NASA 'no fail' mission."

JPL
Pasadena, CA
Model-driven customer (NASA)
100% digital design and documentation

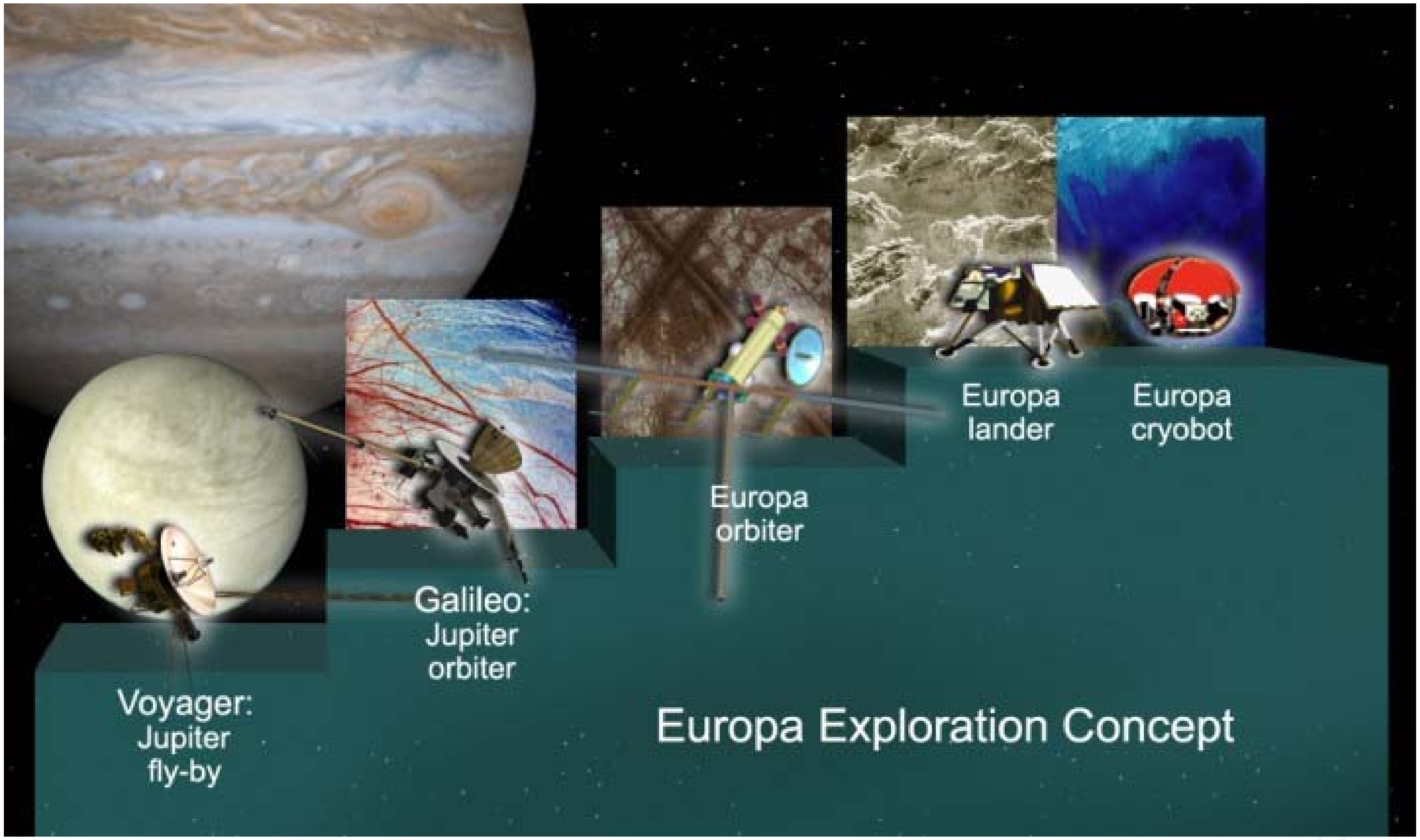


Figure 26: NASA/JPL photo

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