Abstract

- Model-Based Systems Engineering (MBSE) can enhance the coordinated/efficient definition, architecture, design, verification, validation and modification of an integrated system beginning early in a program lifecycle. MBSE inherently encourages a thorough understanding of customer needs, promotes the efficient development of system requirements, behaviors, functions, and architecture (both physical and functional structure), and thereby enables integrated analyses of the system. Among its many benefits, MBSE improves communication throughout the team, as the system model can be viewed from many different perspectives – from the project, mission, or segment (e.g. vehicle) levels, or from within domains, for instance. The definition and use of emerging formal methods of MBSE is often misinterpreted and scoped with wide variability. Northrop Grumman Innovation Systems viewpoints from Space Systems Group (SSG) in Dulles, VA; Propulsion Systems Division (PSD) in Promontory, UT; and Launch Vehicles Division (LVD) in Chandler, AZ contribute to articulate:

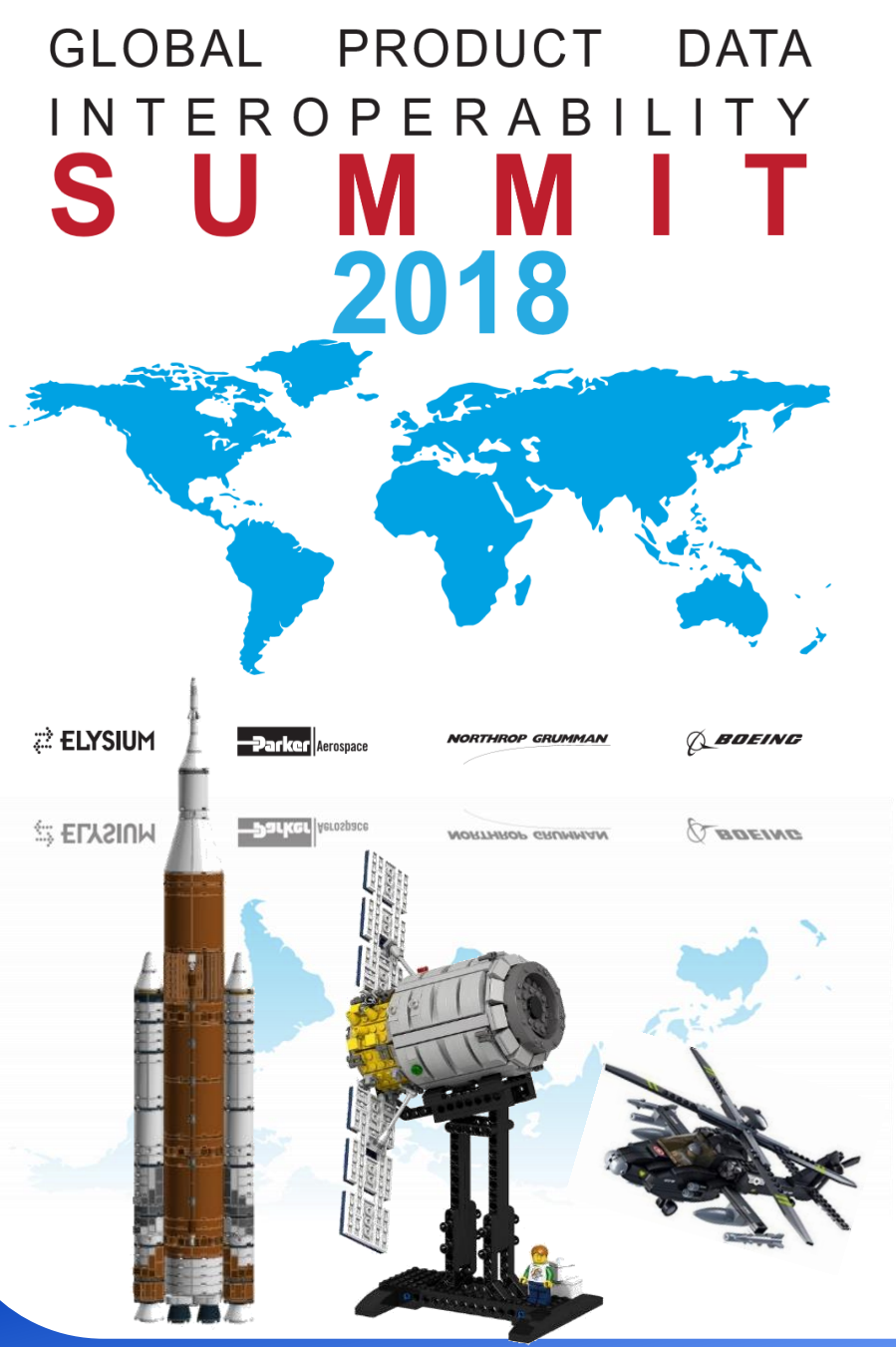
    - What is MBSE?
    - Where is this MBSE trend leading?
    - What is the value of MBSE to Northrop Grumman Innovation Systems?
    - Why we believe our customers are investing in this subject?
    - What are the next steps to further mature MBSE at Northrop Grumman Innovation Systems?

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

MBSE at Northrop Grumman Innovation Systems (NGIS)

Paul Nelson

Teamcenter (ePIC) PUB001327



BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

Paul Nelson Bio

- Paul leads technical strategy for Integrated Digital Product Development and Services (IDPDS) as chief technical strategist at Northrop Grumman. He is promoting the proper processes and tools to significantly reduce development time and costs while meeting all customer requirements. Paul has BS and MS degrees in mechanical engineering. He is INCOSE CSEP certified, holds a graduate certificate in Systems Engineering, and is CM2-Professional certified.
- Paul joined Northrop Grumman via the Orbital ATK acquisition in June 2018 and moved into Enterprise Services 8/20/2018.
- At Northrop Grumman Innovation Systems (formerly Orbital ATK) Paul served as technical fellow for the Product Lifecycle Management (PLM) discipline in the IS sector's Propulsion Systems division and helped to technically lead the Innovation Systems sector's PLM Center of Excellence.

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

Outline

- Who is NGIS?
- What is MBSE?
- Where is this MBSE trend leading?
- What is the value of MBSE?
- MBSE Next Steps at NGIS

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

Who is NGIS?

Leading Developer and Manufacturer of Innovative, Reliable & Affordable Products for Government & Commercial Customers

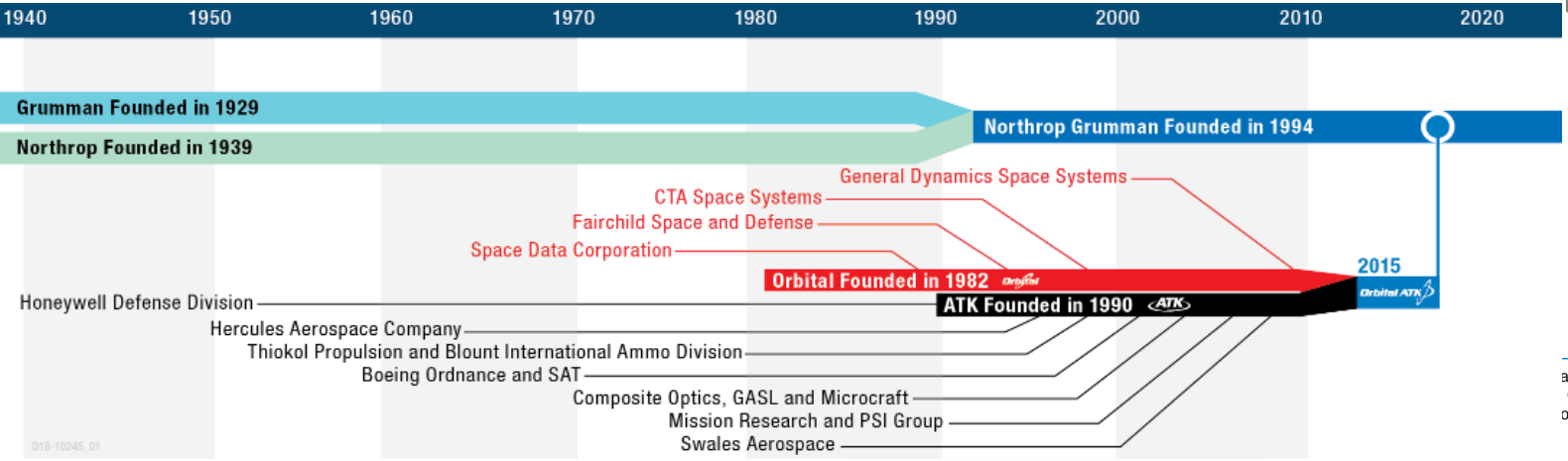
- SSG: Satellites, Space Components & Technical Services
- DSG: Missile Products, Armament Systems, Defense Electronic Systems, & Small Caliber Systems
- FSG: Launch Vehicles, Rocket Propulsion Systems & Aerospace Structures

Key Statistics

- Approximately 15,000 Employees (incl. 5,000 Engineers & Scientists)
- Approximately $5.0 Billion in Revenues

Sector Headquarters in Dulles, VA

- Major Locations in Alabama, Arizona, California, Florida, Maryland, Minnesota, Mississippi, Missouri, Texas, Utah, Virginia, West Virginia



Space Systems Group (SSG)

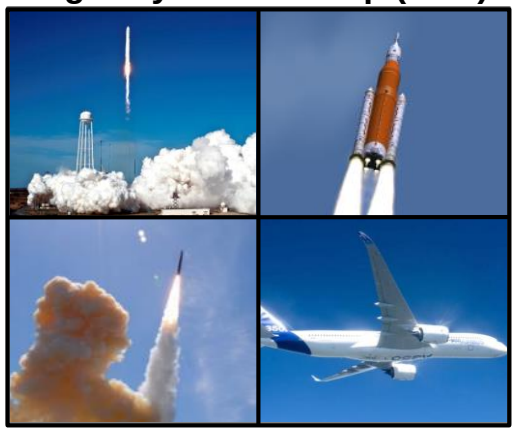
Defense Systems Group (DSG)

Flight Systems Group (FSG)

a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
op Grumman Corporation. All rights reserved.

NGIS Structure

Flight Systems Group (FSG)



- Workforce ~ 5,800 people
- Divisions
  - Aerospace Structures
  - Launch Vehicles
  - Propulsion Systems
- Major Locations in:
  - Alabama, Arizona, KSC, Mississippi, Ohio, Utah & Virginia

Defense Systems Group (DSG)

- Workforce ~ 5,300 people
- Divisions
  - Armament Systems
  - Defense Electronics
  - Missile Products
  - Small Caliber Systems
- Major Locations in:
  - Arizona, California, Maryland, Minnesota, Missouri, Texas, Virginia, West Virginia

Space Systems Group (SSG)

- Workforce ~ 3,000 people
- Divisions
  - Advanced Programs
  - Satellite Systems
  - Space Components
  - Technical Services
- Major Locations in:
  - Arizona, California, Maryland, Texas, Utah & Virginia

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

What is MBSE?

- MBSE – Model-Based Systems Engineering
  - Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases." 1 INCOSE SE Vision 2020 (INCOSE-TP-2004-004-02, Sep 2007)
  - NGIS definition "MBSE is the formalized application of modeling principles, methods, languages, and tools to govern the specification, design, evaluation and support of a system throughout its entire lifecycle"
  - Goals of MBSE:
    - Provide a clear, concise and valid view of the system of interest
    - Improve quality of requirements and design to reduce downstream defects
    - Improve communications among the development team
    - Improve efficiency and productivity of the systems engineering efforts
    - Orchestrate the product development plan with a system-driven blueprint
    - Streamline interactions between engineering functions with a system centric approach
    - Faster, better, cheaper program delivery with increased confidence

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

What is MBSE?
Three MBSE Perspectives

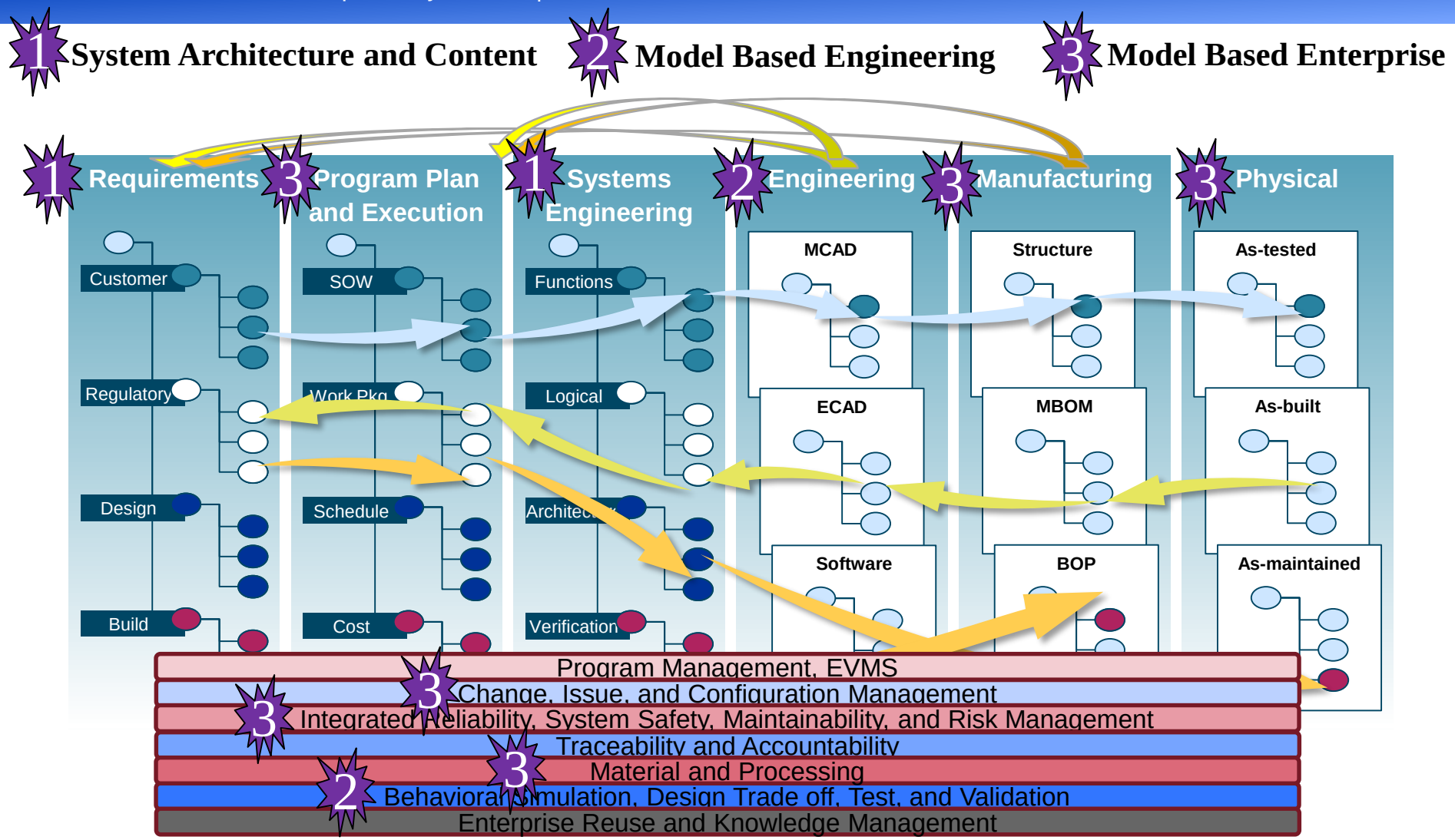
Three Complementary Views/Levels in MBSE Strategy/Practice:

1. System Architecture and Content - $
   - Comprised of a modeling language (SysML), modeling method, and modeling tool
   - Scoped to preliminary design and system model / definition (ConOps, architecture, requirements, verification, etc.)
2. Multidisciplinary Model-Based Engineering and Model Integration - $$
   - Broader discipline level simulation (e.g., ballistic, structural, thermal, multi-physics, etc.) integration with the system model (i.e., Level #1 plus domain analyses)
   - Scoped to all of core engineering (mechanical, electrical, software, analysis)
3. Holistic Model-Based Enterprise or Digital Engineering Ecosystem - $$$
   - Broad brush holistic vision approach (includes program cost/schedule integrations, manufacturing integrations, integration of MBSE system model/data with other PLM data such as EBOM, etc.).
   - Scope on the end to end value chain (both internal and external)

$ - cost to implement and integrate, but also $ value potential

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

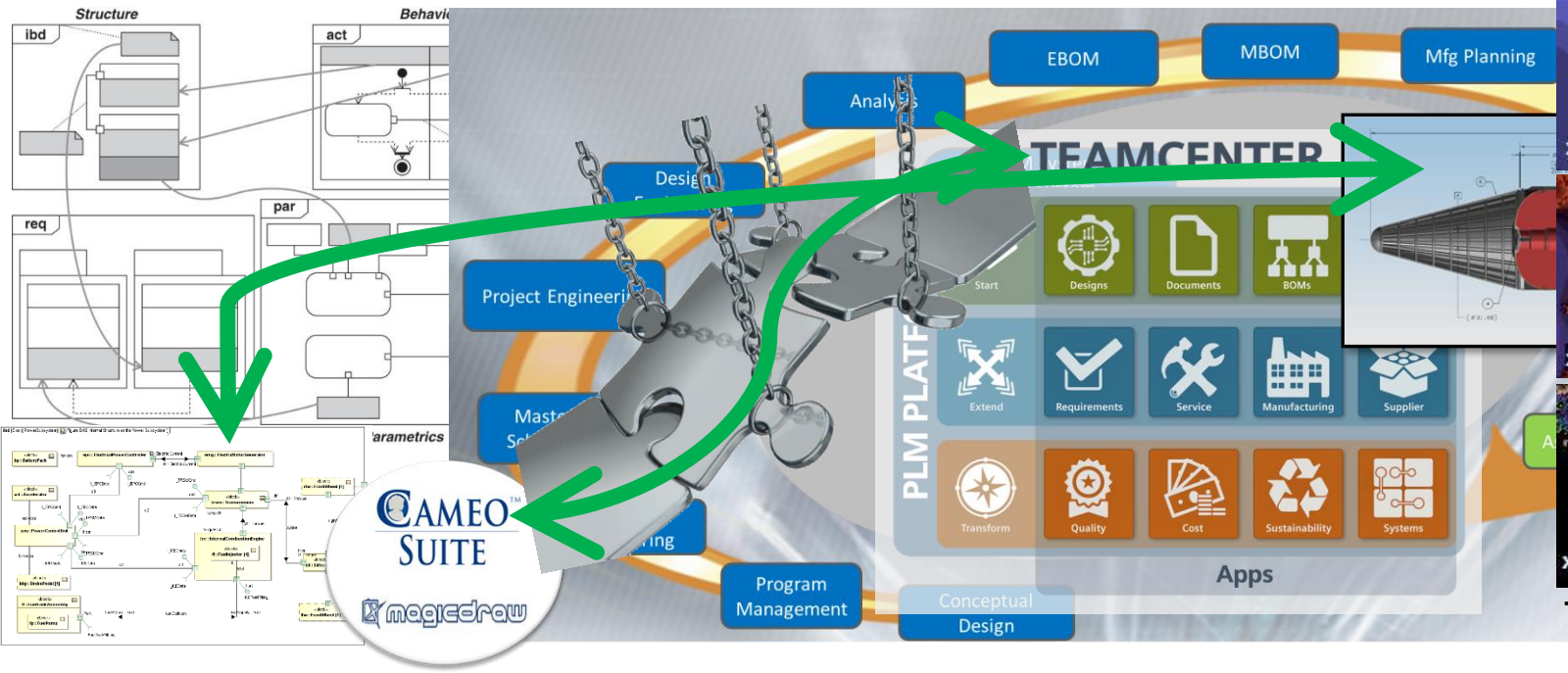
3 MBSE Perspectives

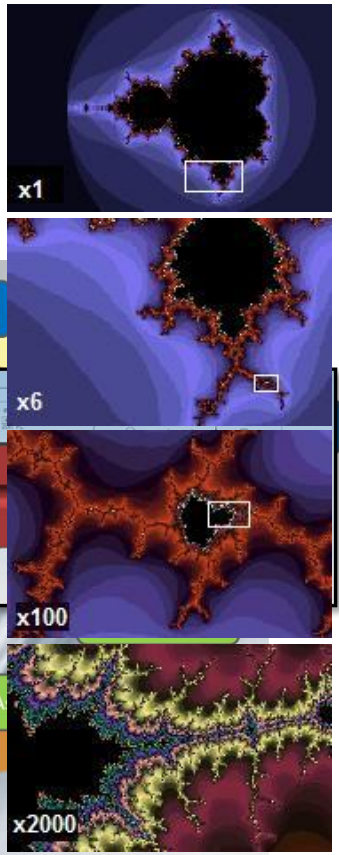


BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

MBSE and PLM Working Together

- Standalone SysML / MBSE information silos miss the mark
- Need information to flow between systems engineering and the rest of the organization; the MBSE and PLM integration enables this flow





The Mandelbrot set

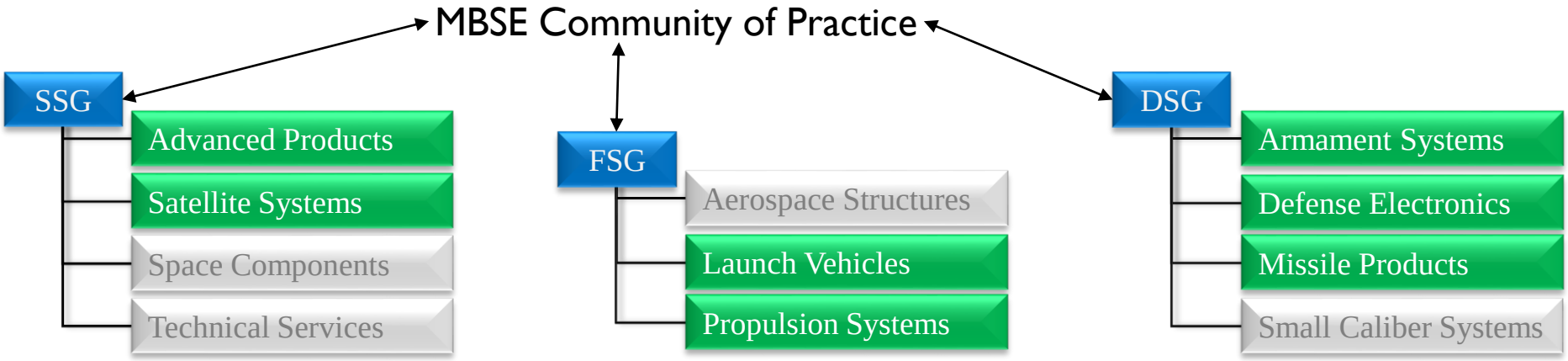
BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

MBSE Trends

- The 'big picture' objectives of MBSE include:
  - Overcoming document-centric process risk and shortfalls (design escapes, late findings on interface errors, referencing obsolete products, recreating existing data products, lack of captured engineering rationale, etc.)
  - Integrating requirements, verification, and operations with a system's actual behavioral, functional, and structural design to improve procedural development, V&V efficiency and rigor, and the evaluation of design trades/changes
  - Making use of digital engineering products for more efficient transition from system formulation through operation
  - Making use of digital engineering products for more efficient reuse
  - Improving the translation of contracting organization's objectives and requirements to vendor solutions
  - Improving the efficiency and rigor of design solution reviews

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

MBSE at NGIS

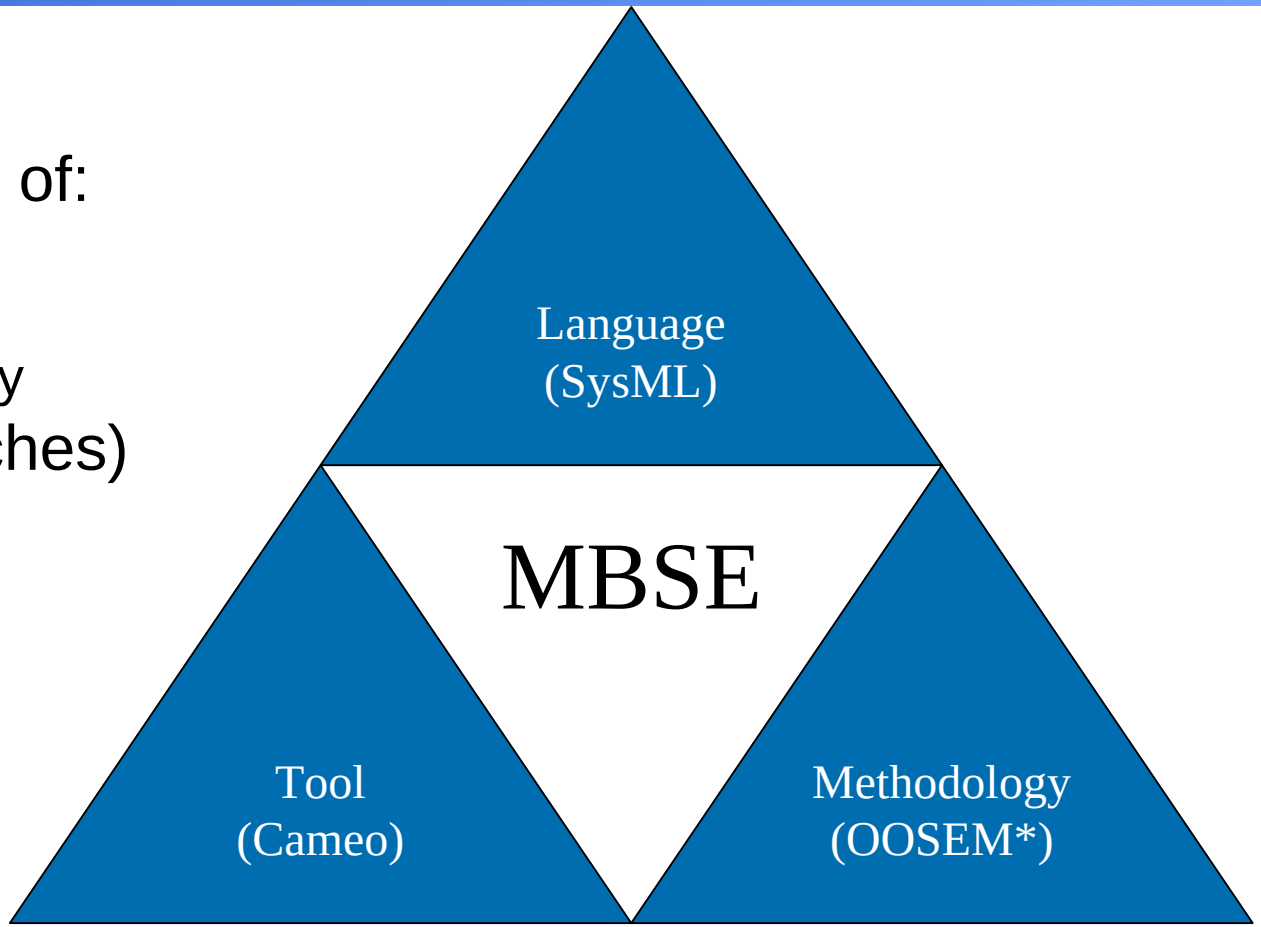


- 7 of 11 divisions within NGIS are investing in MBSE efforts (not all using SysML)
- A Community of Practice (CoP) has been established to exchange best practices
- Strongest MBSE divisions are those doing system-level integration work
- Common themes across business groups:
  - Develop MBSE capabilities by exercising it on active programs – in all lifecycle phases
  - Mature descriptive modeling for concept dev phase to capture new business (new USG contract reqts)
  - Developing & nurturing common approaches/ontologies are critical to fully realize the Digital Enterprise
  - Leveraging MDAO & SE expertise to bridge descriptive & analytical models is a vital need on many pgms
  - Architect for reusability of components & design patterns to slash cycle time

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

MBSE Adoption at NGIS

- MBSE consists of:
  - A language
  - A tool
  - A methodology
- (NGIS Approaches)



* OOSEM: Object oriented systems engineering method

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

Conclusions and Recommendations
Major MBSE Benefits

- **Promotes Reuse of More Than Just Hardware/Software Components**
  - System models will support ability to reuse product architectures, design patterns, analysis methodologies, test approaches, processes, …
  - Model elements embody hard-earned technical expertise
  - System models will help us to pursue *mass customization*, allowing rapid (& inexpensive) development of new capabilities

- **Leverages Power of Machines to Query Our Designs**
  - Tailored model views enable users to quickly obtain needed insight
  - System models based on formal ontologies enable rapid/formal queries of the design to ensure standardization, find errors, notice changes…
    - Examples: 1) Quickly find suspect reqt verifications; 2) Rapid impact assessment of reqt change; …

- **Proves Out Effectiveness of Design Before "Bending Metal"**
  - Rapid/thorough design evaluation enables more concepts to be explored & hence more innovative solutions for potential customers
  - System model can be executed, allowing validation of system behavior
  - Proving out the design early/often (as it matures) saves money & time!

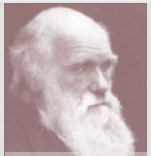
BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.

Next Steps

Forward Strategy

Practice MBSE!

> " It's not the strongest of the species that survive, nor the most intelligent, but the ones most adaptable to change"



Charles Darwin
(1809 – 1882)

Educate

Plant seeds of disruption across the NGIS sector

Start Small

Stay small & low key to avoid the organizational antibodies that fight change

Enable Innovation

Provide access to tools and support the early adopters

Solve Real Problems

Program Managers will ask for MBSE when they see it working

Assimilate & Adapt

Resistance is futile! Add successful approaches into the functional collective & be prepared to restructure when needed

BOEING is a trademark of Boeing Management Company
Copyright © 2018 Boeing. All rights reserved.
Copyright © 2018 Northrop Grumman Corporation. All rights reserved.