Is It Time for Ship Design to Align with Model-Based Systems Engineering?

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1. Introduction - Complexity in Modern Ships

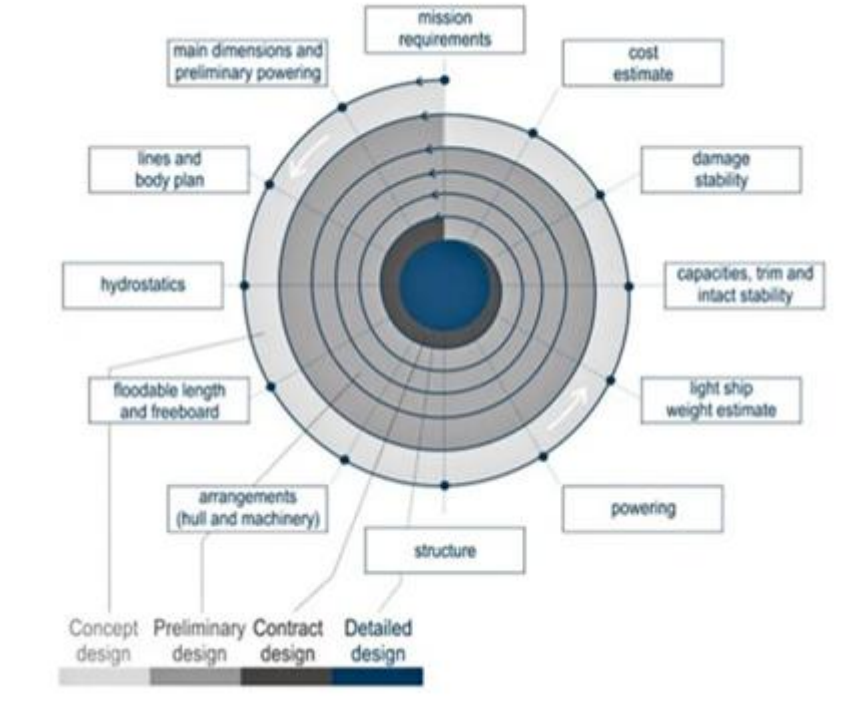
- Ships are becoming increasingly complex and software intensive to meet global threats and warfighter needs
  - Parts count of many millions with diverse interoperability considerations for high tech systems
  - Growth in signals generated by control systems – zero in 1980's to 30,000 in DDG-1000
- Technology can be costly and plagued by requirements changes
  - E.g. USS Zumwalt (DDG-1000) Advanced Warship
    - Of 32 planned, only 3 were built at double the original estimated cost
- Ship programs can suffer from repeated delays due to immature technologies, installation priority shifts, and operational testing
  - Material Development Decision (MDD) to Initial Operating Capability (IOC) is over 15 years, which enables time for obsolescence and technology growth gaps

1.1 Digital Transformation Solution

- Department of the Navy has recognized the need for solutions to manage ship design complexity.
  - The DoN Digital Engineering Transformation Strategy is based on similar DoD guidance
  - Proposes common, composable, interactive, model-based systems to store and exchange data, models, and information
- To best align modern ship design with the digital age, an integrative design solution is needed to help increase cross-functional communication, identify interfaces, and ensure all requirements are satisfied.
- Systems Engineering (SE) using models (diagrams) can help reduce the risk of design complexity
  - Model-Based Systems Engineering is Systems Engineering with ***diagrams*** *rather than* ***documents***

2. Navy Ship Design – Past and Present

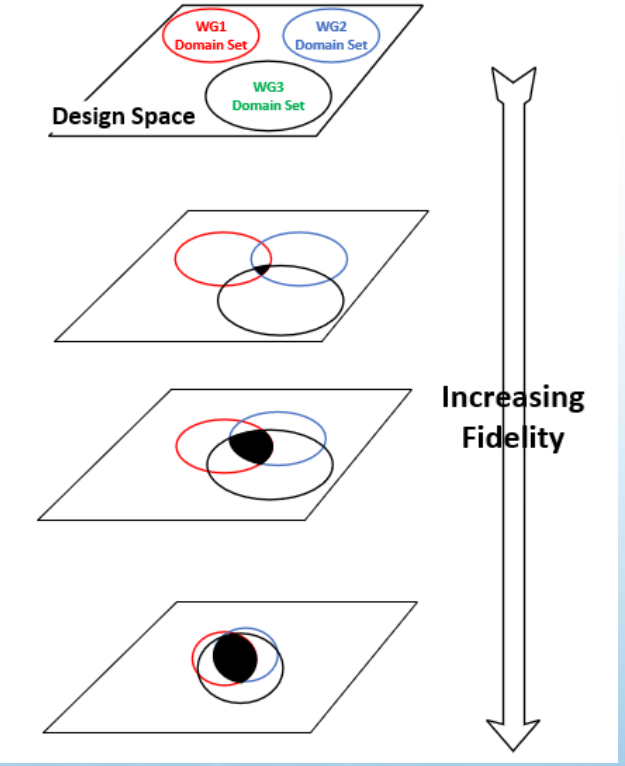
Traditional Ship Design Spiral



Iterative design. Maturation of the design proceeds from the outer ring to the inner through four main phases of development

Set Based Design (SBD)

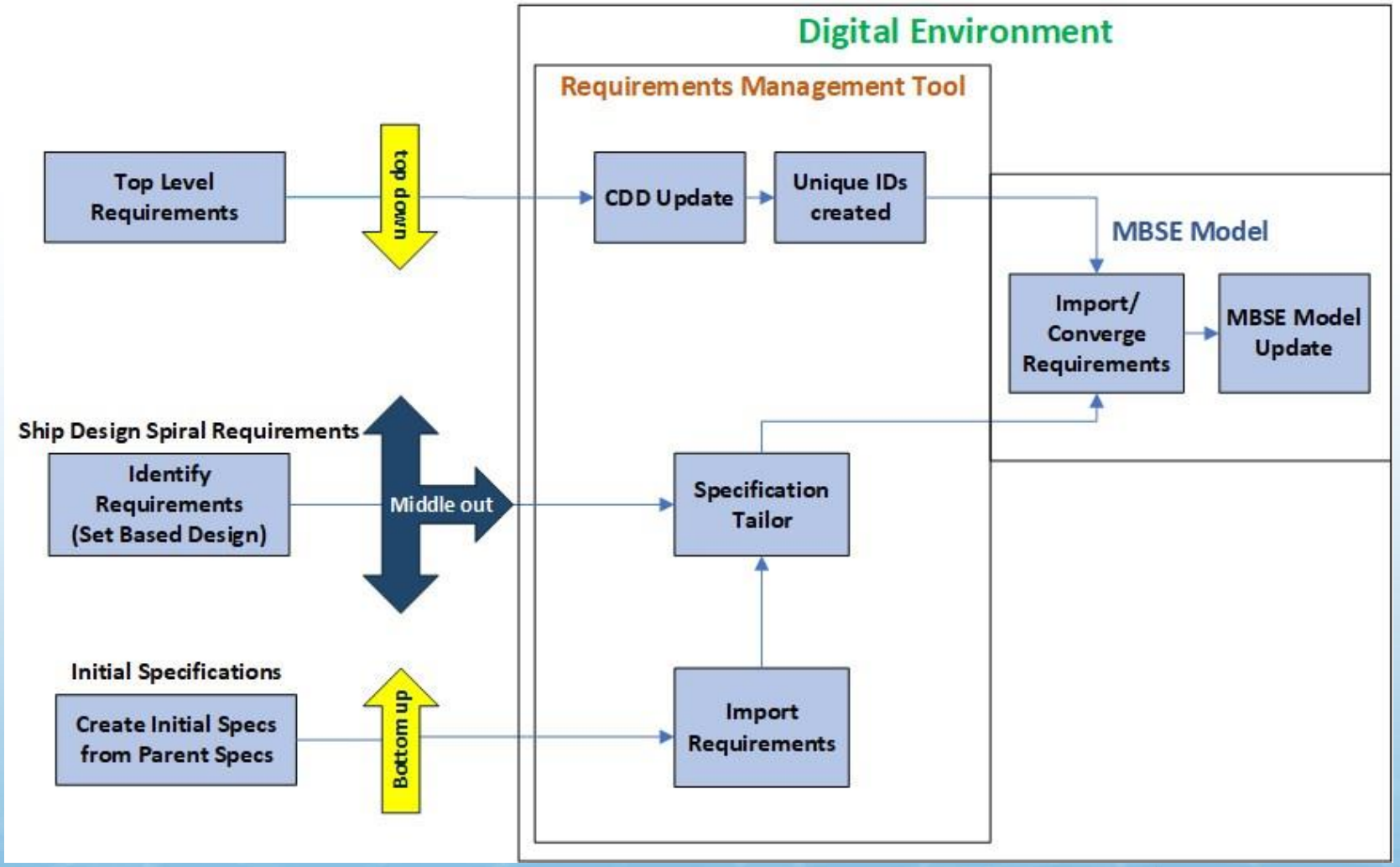
- SBD used increasingly in ship design (e.g. DDG(X) program) to improve quality and responsiveness
- Explores wide range of design alternatives
- Select best solution based on pre-determined criteria
- Eliminates non-optimum solutions vice picking one and modifying it



3. Confluence of a Modern Solution

- Do we need SE in Ship Design?
  - To quote a senior naval architect, ``the spiral is understood, but how do we design so that we don't miss requirements?‘’
  - SE is a holistic and interconnected appraisal of the system and its requirements. It helps inform the ship design and keep it accountable to the user's needs
- Systems Engineering (SE)
  - Analysis of the system to ensure that what the user wants (e.g. CDD) is what the user gets
  - Build it correctly (requirements verification), and build the right thing (design validation)
- SE Aligns with the Ship Spiral and SBD
  - Ship design spiral's initial phase is ``mission requirements”, in SE, Requirements Analysis is genesis of the Design process – agile and iterative
  - SE builds knowledge in parallel while connecting “silos of design” back to user needs

3.1 Top Down and Bottom Up Analysis



- **BOTTOM** - Ship design often starts with parent spec requirements derived from similar class ships, determines "how does the system meet requirements"
- **MIDDLE** - SBD identifies "knowledge gaps" in CDD or initial specifications
- **TOP** – SE looks at top level requirements first to determine "what does the system need to do"

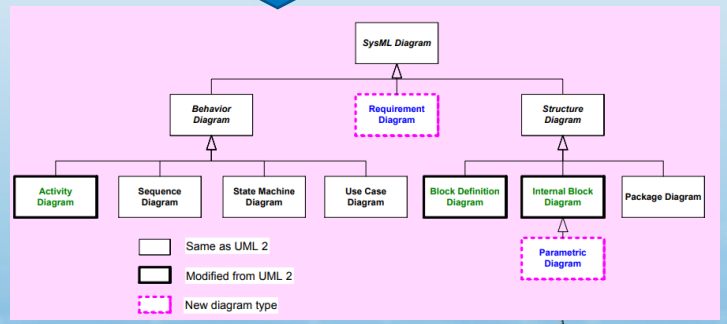
4.1 Paradigm Shift to MBSE

- Because it can be difficult to assess relationships between requirements and design, SE practitioners are increasingly looking to MBSE methodologies.
- What is Model-Based Systems Engineering (MBSE)?
  - The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the concept design phase and continuing throughout development and later life cycle phases (INCOSE)

*In other words: It is Systems Engineering with **diagrams** rather than **documents***

Change from Document-centric to Model-centric

Requirements Specifications
Interface Definitions
System Architecture
System Functionality
Trade-off Analysis
Test Specifications
Etc.



4.2 MBSE Precedence in Industry

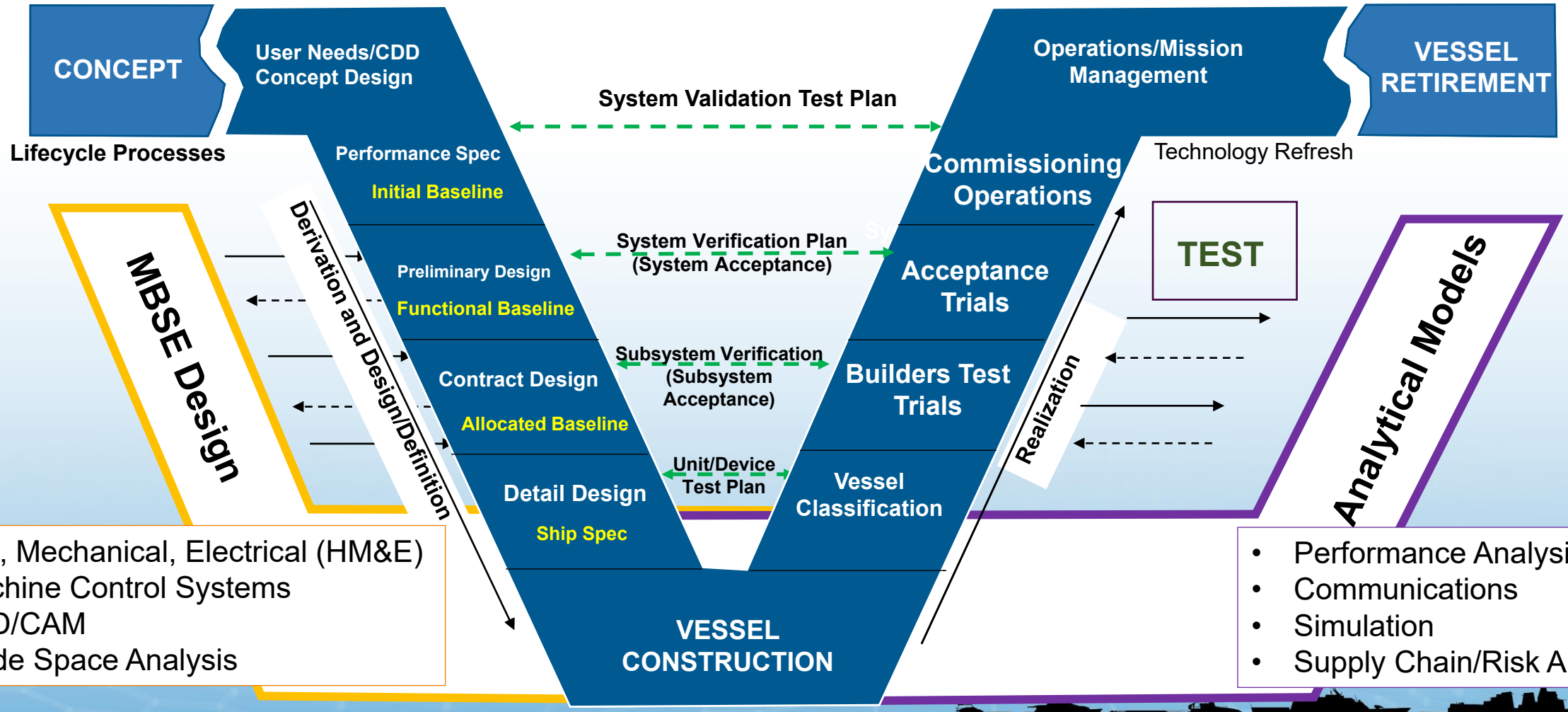
- Submarine Warfare Federated Tactical Systems (SWFTS) program conducted a study, determined a positive Return on Investment (ROI) from converting to MBSE.
  - SWFTS Systems Engineering Team transitioned to MBSE for all work

- NASA has been investigating the use of MBSE since 2009
  - Applied MBSE to:
    - Advance Air Mobility projects (includes unmanned aerial systems)
    - Power Propulsion Element (a Gateway/Artemis system)
    - Lunar Surface Architecture projects

4.3 MBSE Features and Advantages

- **MBSE modeling languages demand precision.**
  - This yields clear and precise requirements, which are more readily verified and tested
- **Stakeholders can be "in the loop"**
  - in the collaborative modeling environment, as SE artifacts are developed, vetted, and approved
- **All documents can be auto-generated from the project repository**
  - not hand-crafted, using templates stored in the MBSE modeling environment
- **MBSE offers a "Authoritative Source of Truth"**
  - establishes a visually traceable and scalable systems model to reduce risk and gain efficiency to help ensure that all requirements are necessary and validated.

4.3 Ship Design MBSE "V"



- Hull, Mechanical, Electrical (HM&E)
- Machine Control Systems
- CAD/CAM
- Trade Space Analysis

- Performance Analysis
- Communications
- Simulation
- Supply Chain/Risk Analysis

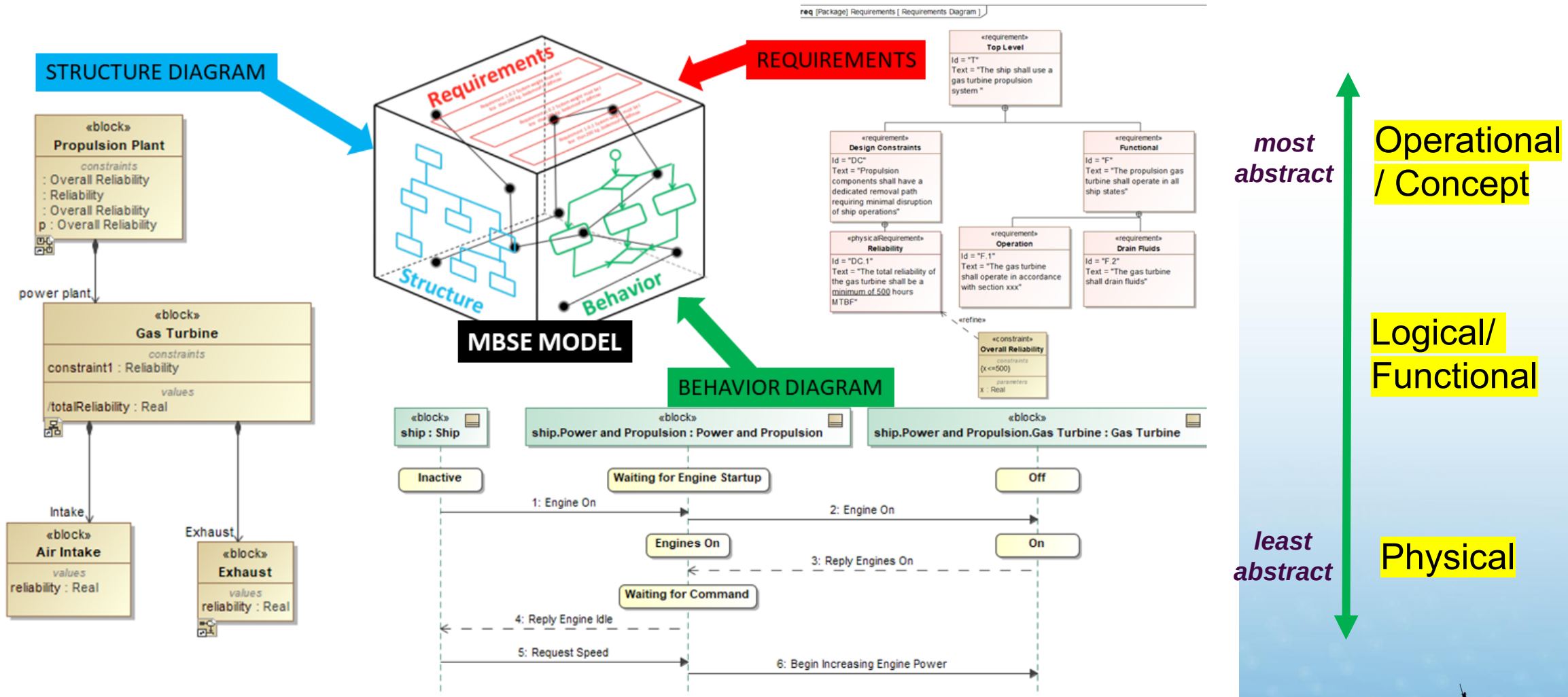
4.4 How to get started in MBSE

- Modeling Language: Vocabulary, Grammar, Syntax e.g.
  - **UML** (Unified Modeling Language) – helps software developers visualize and construct new software systems
  - **SysML** (Systems Modeling Language) – general purpose system modeling language
  - **OPL** (Object-Process Language) - visual and verbal modality language
- Modeling Methodology: A collection of processes and methods for applying systems engineering in a model-based context, includes frameworks. Provides well-structured model with minimal risk of rework. e.g.
  - **MagicGrid® -** aligned 100% with SysML and with IEEE 15288
  - **OOSEM** (Object-Oriented Systems Engineering Method) - object-oriented techniques, a model-based design approach, and traditional top-down SE practices
  - **Harmony-SE** - scenario driven, agile approach to systems and software development centered around requirements and architecture
- Modeling Tool: for creating, reviewing, managing and exercising system models e.g.
  - **Cameo Systems Modeler** – from NoMagic
  - **Rhapsody** – from IBM
  - **Enterprise Architect** – from Sparx

4.5 Architecting the MBSE Ship System

- A representation of the system can be referred to as the system architecture
- Forms the basis of the MBSE Model, used to clarify:
  - Structure, interfaces, and internal and external relationships
  - Behaviors exhibited by the entity and its elements, both internally and externally
  - Global rules to which the entity and its elements must conform to meet allocated requirements
- Provides SBD linkages to static and dynamic elements of design
- Typically defined by operational concept, logical, and physical breakdowns

4.5 Architecting the MBSE Ship System



most abstract

Operational / Concept

Logical/ Functional

least abstract

Physical

4.6 Overcoming MBSE Challenges

- Cultural Change
  - Shift in organizational culture, as well as new tools and skill sets
- Trust
  - Akin to evolving from drafting board to CAD
  - Metrics that quantify MBSE ROI are not prevalent
- Vernacular Differences
  - E.g. MBSE architecture ≠ physical architecture
  - Ship design cycles ≠ SE Technical review milestones
  - Verification and validation are not used interchangeably in SE
- Program Management must recognize that:
  - The potential value of MBSE is realized over an entire program, not just one phase
  - Success depends on full involvement in and commitment to the MBSE team, process and goals.

5. Summary

- The ship acquisition process requires a disciplined application of Systems Engineering best-practices
  - Requirements, architecture, traceability, verification and validation
- Increasing complexity of ships requires an integrated digital approach to Systems Engineering
  - Model-Based Systems Engineering satisfies this need
    - Provides for an integrated, digital, graphical representation of the ship requirements, architecture, verification and validation, and traceability
- MBSE provides an Authoritative Source of Truth
  - Robust digital environment
  - Reduces the chances of overlooking implications of changes and decisions

Back-Up

- Acknowledgement and future work
  - The contents of this presentation are based on a journal paper entitled “Aligning Ship Design and Model-Based Systems Engineering Methodologies”
  - The paper was written in collaboration with Colorado State University
    - Based on a body of research in preparation for a Systems Engineering PhD preliminary exam
    - Will be published in the NEJ post-TSS