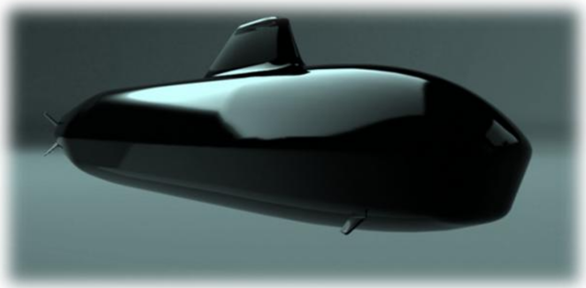
Introducing MBSE to a Submarine Concept Design Team



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Senior Systems Engineer

Contents

- Background
- Recent events
- Current activities
- History behind SE & MBSE in DBT
- Observations and Challenges
- Safety, Risk and Production Considerations

Background

- The Royal Australian Navy (RAN) currently operate the Collins Class conventional (diesel-electric) submarines
- Since 2009, the Australian Department of Defence has formed a Project Office (under project "SEA1000") to acquire a successor to the Collins Class.
- A Defence White Paper was also published by Government in 2009 defining the capabilities required for a future submarine.

<u>Indicative timeline:</u>
2013/2014: First Pass Approval
2017: Second Pass Approval
~2020: Construction commences

Background (cont.)

- The Government is now considering four broad options for the Future Submarines*:
  - An existing submarine design available off-the-shelf, modified only to meet Australia's regulatory requirements (Option 1);
  - An existing off-the-shelf design modified to incorporate Australia's specific requirements, including in relation to combat systems and weapons (Option 2);
  - An evolved design that enhances the capabilities of existing off-the-shelf designs, including the Collins Class (Option 3); and
  - An entirely new developmental submarine (Option 4)

* http://www.minister.defence.gov.au/2012/05/03/prime-minister-minister-for-defence-minister-for-defence-materiel-joint-media-release-next-stage-of-future-submarine-project-announced/

SEA 1000 Option 4

- The Australian Government is currently establishing a Defence and Industry Integrated Project Team (IPT)
- The IPT will develop two costed, scheduled and technically balanced submarine concept designs for this future submarine capability
- The IPT will also:
  - help better inform Australian industry about the requirements of the project,
  - foster growth of local submarine design capability, and
  - determine the capability of progressing with an Australian bespoke design for SEA 1000 Government First Pass consideration

https://www.tenders.gov.au/?event=public.atm.showClosed&ATMUUID=BF67A210-F51D-4ED0-D606515BE5DE6BB2

Introducing Deep Blue Tech

- Deep Blue Tech (DBT)
- A wholly owned subsidiary of ASC
- Based in Adelaide, South Australia
- Operates separately and independently from other ASC activities
- Started in 2007
- Focusses on Australia's Future Submarine

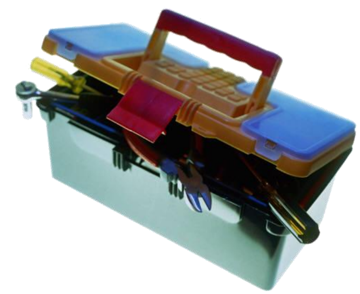
www.deepbluetech.com.au

Deep Blue Tech in a Nutshell

- Since 2007, DBT has been building an in-country submarine concept design capability.
  - Currently ~ 60 personnel
  - An integrated set of tools and processes for developing submarine designs
  - A wide range of skills and levels of experience
    - Naval architects to software engineers and draftspeople
    - Junior engineers to eminent greybeards
  - Established relationships with many potential providers of systems and technology

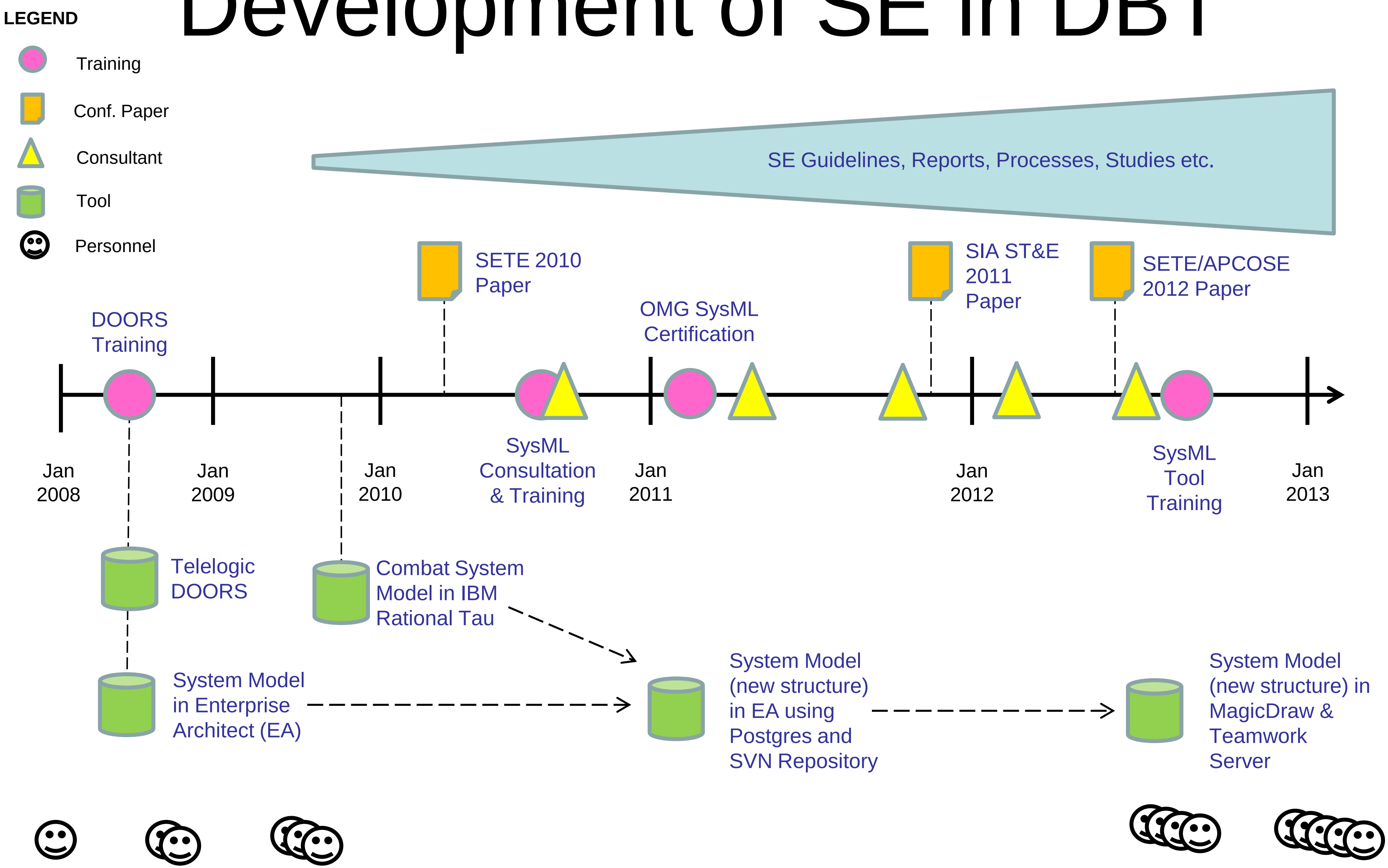
DBT Concept Designs

- Since 2007, each year DBT’s growing team has developed a Submarine Concept
  - 2007/2008: A1 
  - 2009/10: A1.1, A1.2, A2
  - 2010/11: A2, A2.1 
  - 2011/12: A3 



- Each iteration has also developed DBT tools and processes and developed a team with experience in designing submarines.
  - Including SE tool and process development

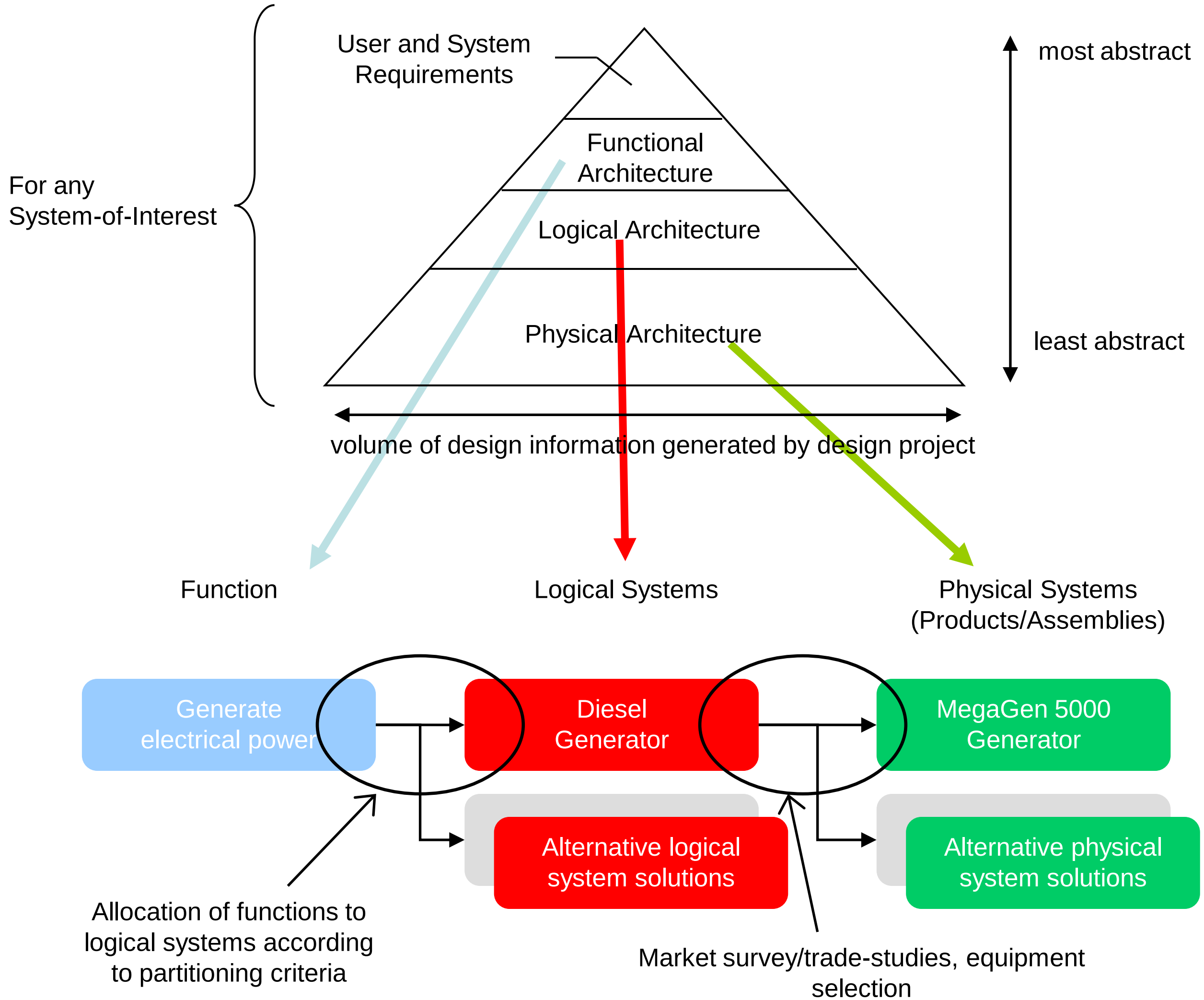
Development of SE in DBT



Early Principles

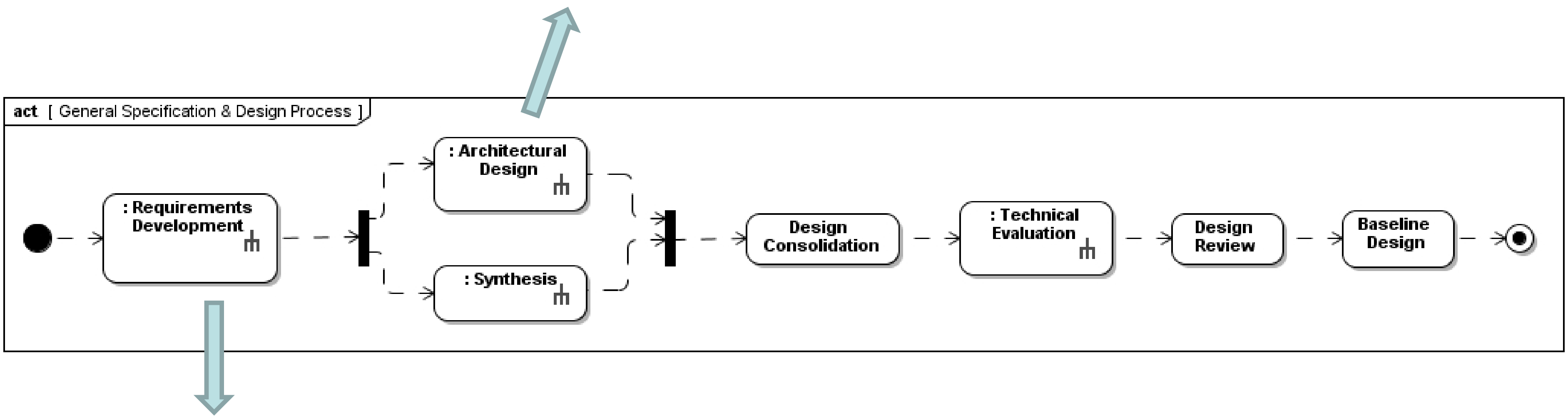
- Model-based approach to SE
- Adoption of SysML
- SE Process Framework
- Traceability
- Levels of Abstraction (functional, logical, physical)
- Inspiration from Object-Oriented Systems Engineering Method (OOSEM)

Levels of Abstraction



Specification & Design Process

Develop Logical & Physical Architecture in System Model



Elicit and Analyse Requirements and Build requirements traceability between DOORS and System Model

System Modelling Tool

- MagicDraw from No Magic, Inc.
- Selected in March 2012 after comprehensive trade study
  - Now deployed in DBT
  - Onsite training for team members held in July 2012
  - Modelling Guideline to help users bridge gap between tool and process
  - Migrated Submarine System Model from superseded tool (Sparx Systems Enterprise Architect)
- Details
  - SysML modelling enabled with SysML plugin
  - Common model available to team through Teamwork Server
  - Interface with DOORS via Datahub plugin
  - Interface with MATLAB/Simulink via ParaMagic plugin
  - Interface with PLM system via hyperlinks

Submarine System Model Organisation

- Data
  - Model Library
  - Operational Domain
    - 1-Requirements
    - 2-Use Cases
    - 3-Behavior
    - 4-Structure
    - 5-Analysis
    - 6-Verification
    - 7-Interfaces
    - 8-Value Types
    - External Systems
    - Submarine System
      - 0-Black-Box Specification
      - 1-Behaviour
      - 2-Structure
      - 3-Analysis
      - 4-I/O Definitions
      - Crew
      - Payloads
      - Submarine
        - 0-Black Box Specification
        - 1-Behavior
        - 2- Structure
        - 3-Analysis
        - 4-I/O Definitions
        - Subsystems
  - Sandbox

Subsystems:

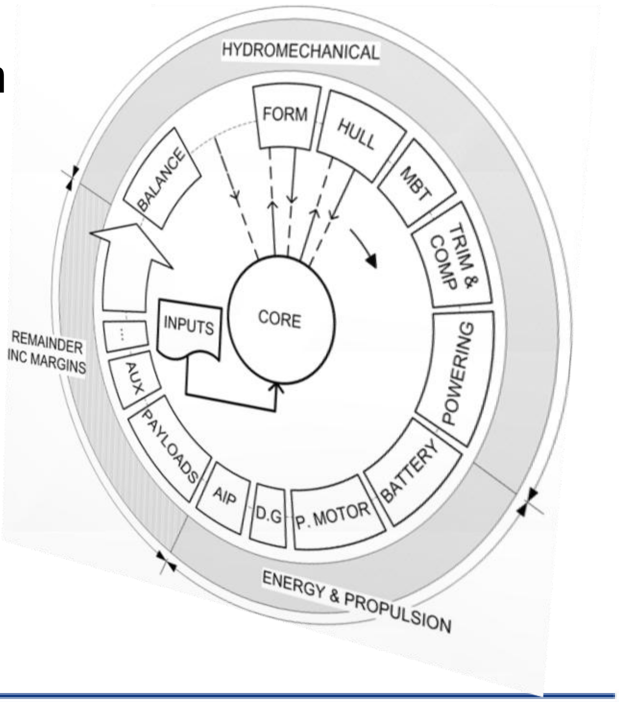
- 00-1.2.1.1 Pressure Hull
- 01-1.2.1.5.1 Anchor System
- 02-1.2.2.1 Air Dependent Propulsion System
- 03-1.2.2.2 Air Independent Propulsion System
- 04-1.2.2.3 Main Battery System
- 05-1.2.2.4 Buffer Battery
- 06-1.2.2.5 Main Propulsion System
- 07-1.2.2.6 Emergency Propulsion System
- 08-1.2.3.1 Power Conversion & Distribution System
- 09-1.2.3.3 Lighting System
- 10-1.2.3.5 Control System (Hardwire and Safety Chains)
- 11-1.2.4.1 Internal Environmental Control System
- 12-1.2.4.2.1 Seawater Cooling System
- 13-1.2.4.2.2 Fresh Water System
- 14-1.2.4.2.3 Demineralised Fresh Water System
- 15-1.2.4.2.4 Tepid Water System
- 16-1.2.4.2.5 Chilled Water System
- 17-1.2.4.3 Refrigeration System
- 18-1.2.4.4 Atmosphere Monitoring System
- 19-1.2.4.6.1 High Pressure Air System
- 20-1.2.4.6.2 Low Pressure Air System
- 21-1.2.4.6.3 Emergency Air Breathing System
- 22-1.2.4.6.4 Built-In Breathing System
- 23-1.2.4.6.5 Divers Air Breathing System
- 24-1.2.4.7 Hydraulic Systems
- 25-1.2.4.8 Potable Water and Sanitary Systems
- 26-1.2.4.9 Fire Protection Systems
- 27-1.2.5.1 Maneuvering Control System
- 28-1.2.5.2.1 Ballast System
- 29-1.2.5.2.2 Weight Compensation System
- 30-1.2.5.2.3 Trim System
- 31-1.2.5.3 Bilge System
- 32-1.2.5.4 Diver Lockout System
- 33-1.2.5.5 Escape System
- 35-1.2.6.3 Weapons Handling & Discharge System
- 36-1.2.6.4.1 Masts
- 37-1.2.6.4.2 Unmanned Vehicles Handling System
- 38-1.2.6.4.3 Submerged Signal Ejector
- 39-1.2.6.4.4 Countermeasure System
- 40-1.2.6.4.5 Maritime Special Operations System
- 41-1.2.6.4.6 Deployable Sensors Handling System
- 42-1.2.7.1 Degaussing System
- 43-1.2.7.3 De-amping System
- 44-1.2.8.1 VISINT Systems
- 45-1.2.8.2 Radar System
- 46-1.2.8.3 SIGINT Systems
- 47-1.2.9.1 Active Sonar System
- 48-1.2.9.2 Passive Sonar System
- 49-1.2.9.3 Self-Noise Monitoring System
- 50-1.2.10 Combat Management System
- 51-1.2.11.1 External Communication System
- 52-1.2.11.2 Internal Communication System
- 53-1.2.12 Navigation System
- 54-1.2.13 Ships Management & Information System

A4

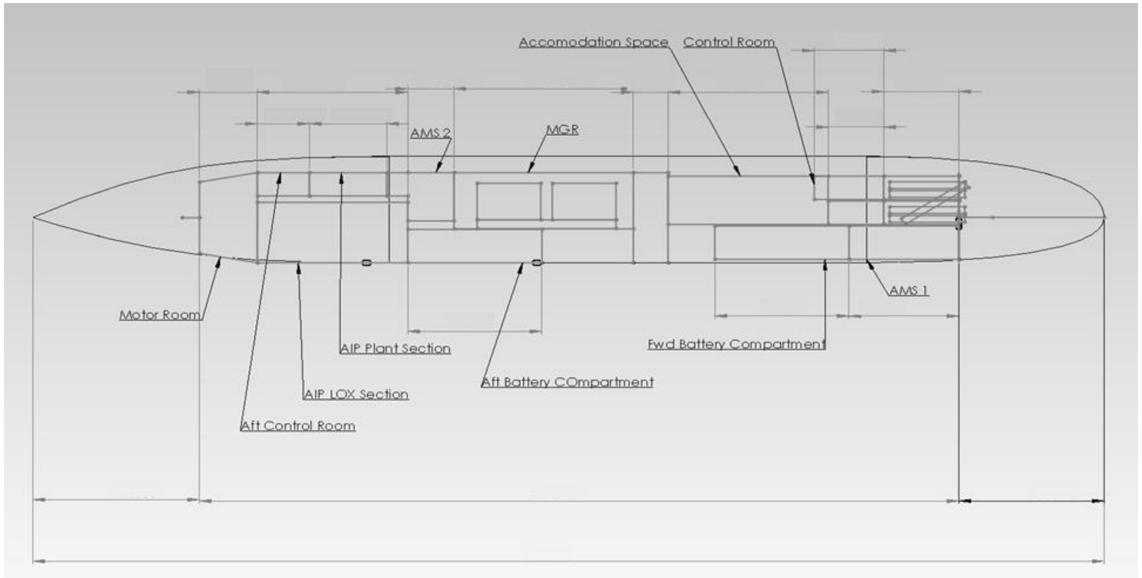
- The current concept iteration in DBT is A4.
- Designed against an internally developed set of customer requirements
- Continues to build on an integrated toolset and framework of processes
- Increased project monitoring and planning

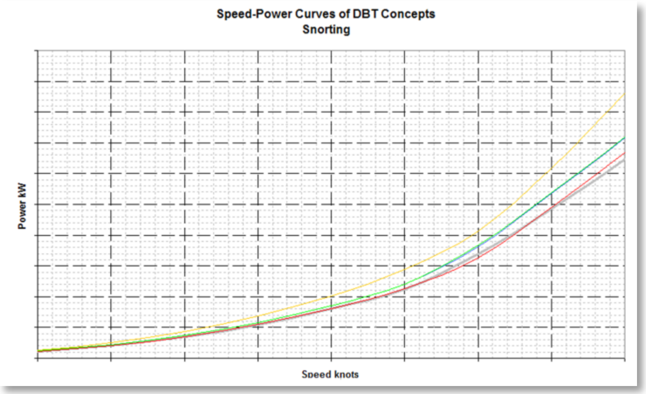
Observations: Concept Design

- Early submarine concept design is about numbers
  - Sizing and layout: i.e. length, diameter, equipment volumes
  - Weight
  - Buoyancy
  - Energy
- Key requirements identified and used to drive design
  - Transit speed of advance (SOA)
  - Transit range
  - Patrol duration
  - Indiscretion ratio
  - Sprint Speed (and duration)
  - Crew sizes
  - Payloads (size and number)



Observations: Concept Design





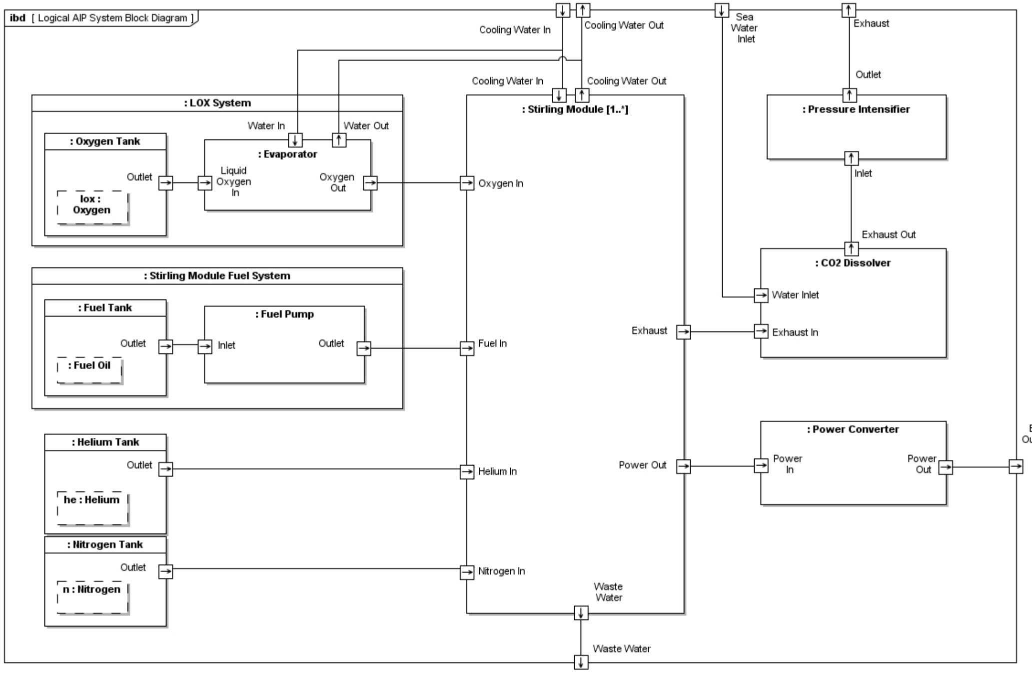
- Parametric sizing tools are the primary tools used.
- Source of ‘truth’ is a windows directory containing a number of spread-sheets
- Strongly iterative design.
- Sensitivity studies performed where potential trade-spaces are identified (e.g. compartment layouts, technology options)
- A lot of data passed between individuals verbally and via email.
- Weekly meetings.

Observations: Concept Design

- Contrast with classic SE approach:

  Requirements & scenarios → functions → systems and their interfaces

SRS-001-13	**2.3.1 Overall AIP System**	
SRS-001-59	The AIP System shall provide the submarine with electric power	Sufficient number of power modules such that system can provide propulsion power and hotel load at knots with one power module not operating. Suitable for connecting directly to the dc mains network
SRS-001-72	The AIP System shall allow the submarine to operate without discharging the main battery.	AIP endurance shall be no less than days at knots (essential) AIP endurance should be no less than days at knots (desired)



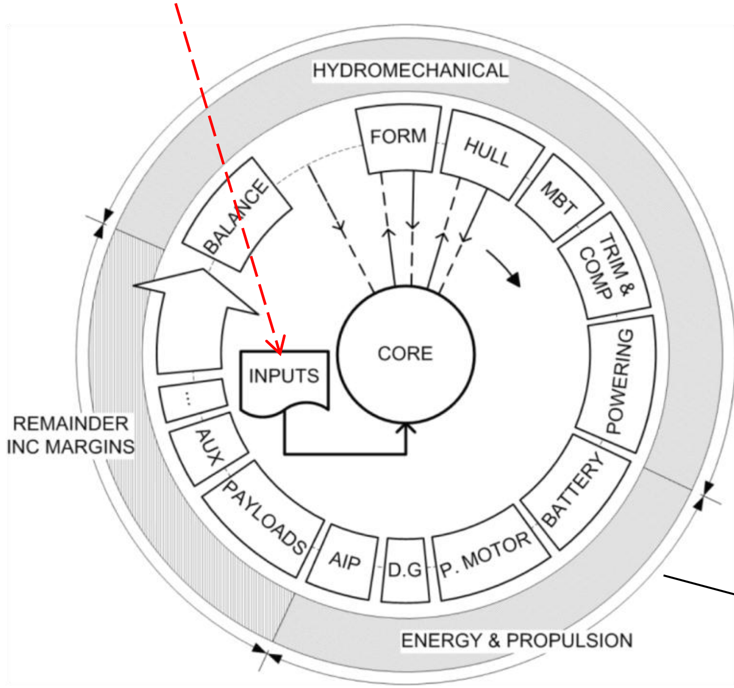
The Challenge

- Critically, any MBSE approach must become an integral part of submarine concept design activities. How can we do this?
  - Record trace between DOORS requirements and model elements in a System Model.
  - Provide a common definition of key system properties and system decompositions
  - Document role of key sizing tools

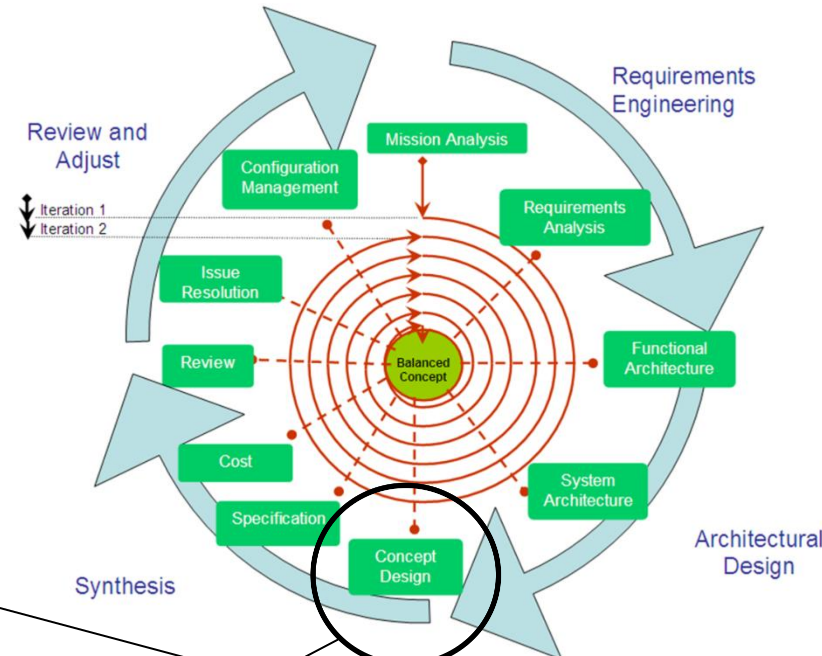
The Evolving Ship Design Spiral

Traditional View of Naval Architects

Requirements Analysis & Architectural Design



Current DBT SE Process



Requirements Traceability

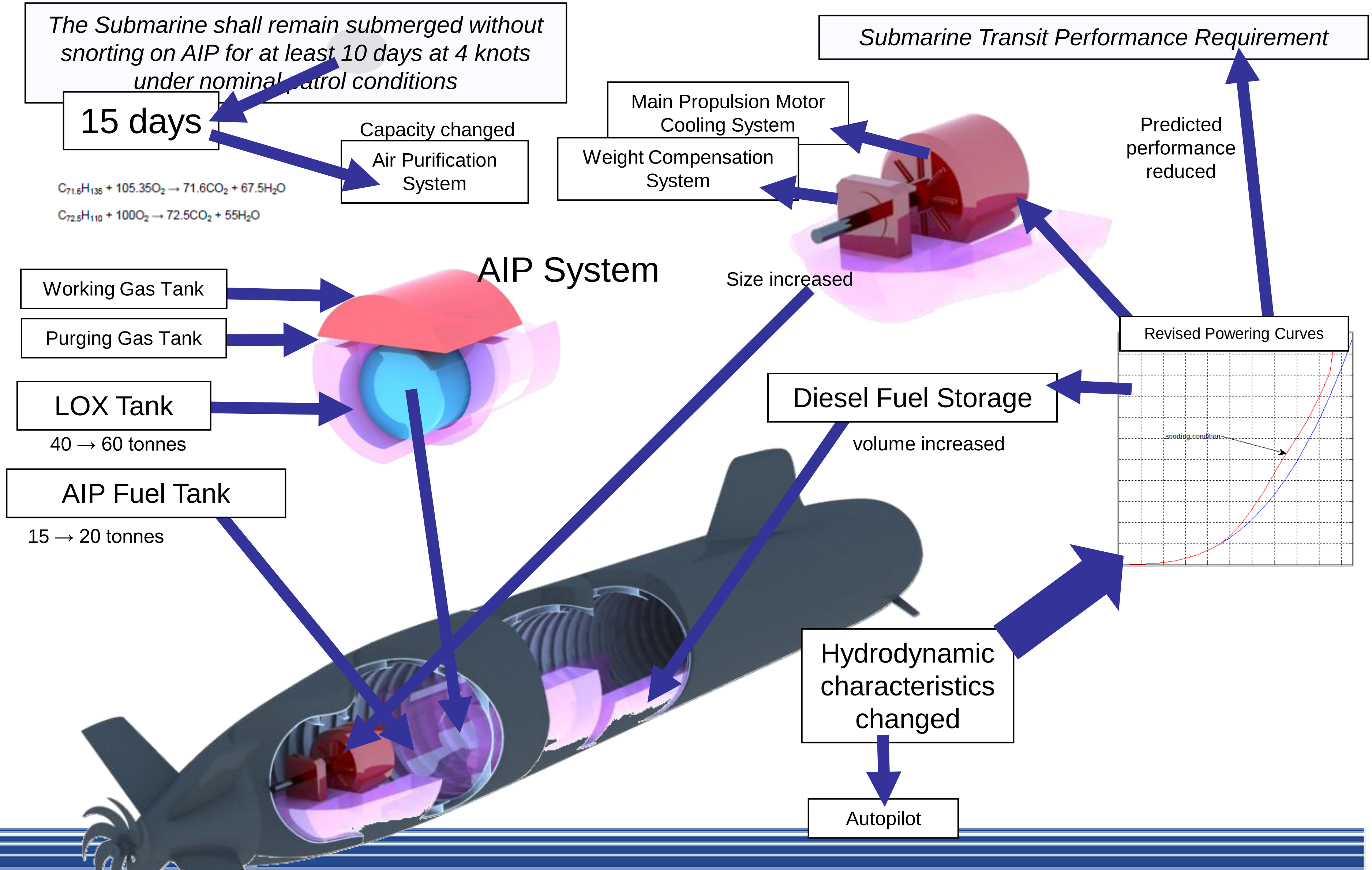
Requirements

System Properties

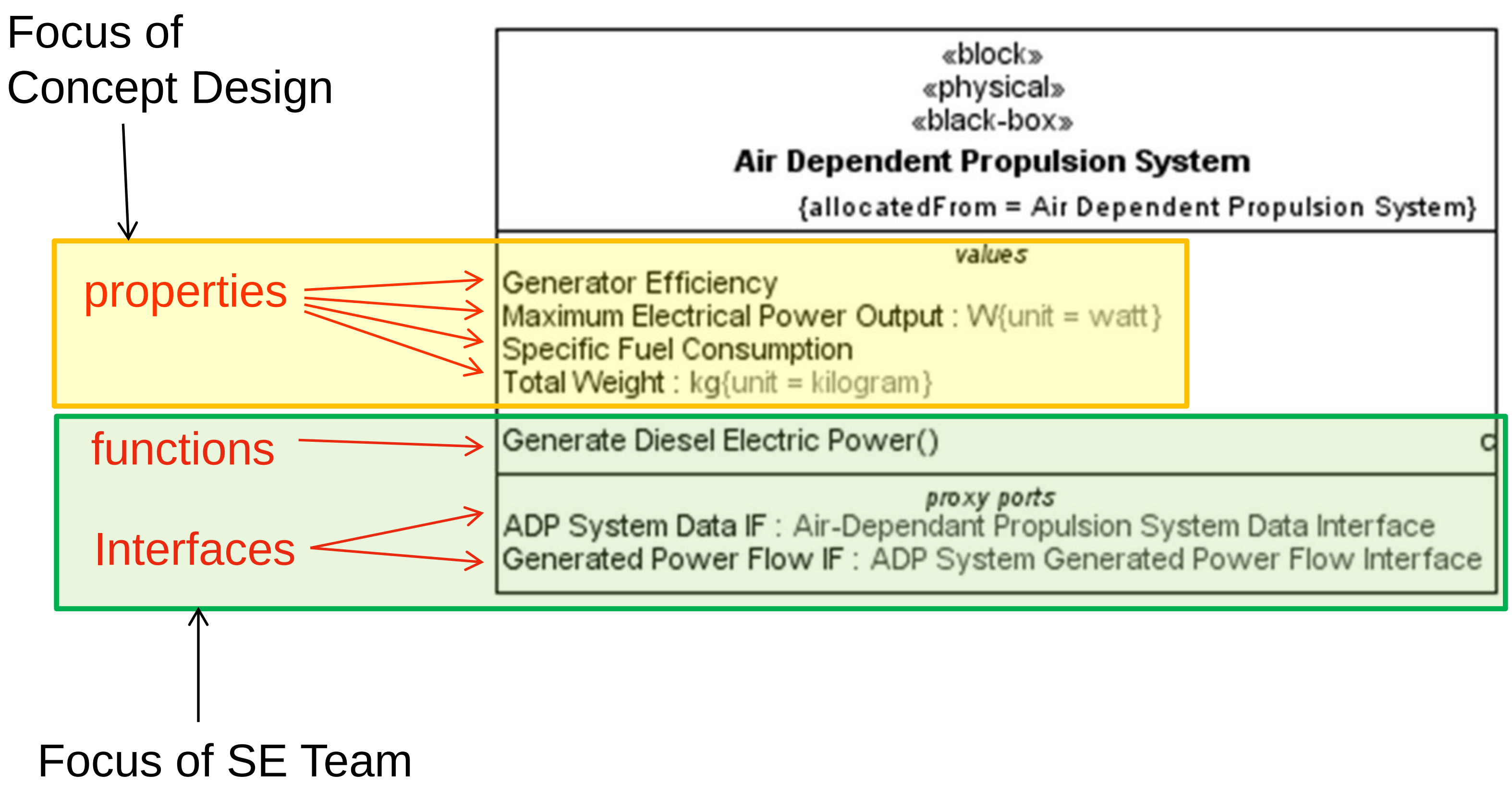
Latest Calculated Values

#	Realizing Element	Name	Min	Max	Standard Deviation	Mean	Type
1	A4_FPS_238 < > A4_FPS_331 < >	Transit SOA					knots
2	A4_FPS_260 < >	Transit Indiscretion Ratio					percentage
3	A4_FPS_239 < >	Radius of Action					nautical miles
4	A4_FPS_240 < >	Patrol Endurance					days
5	A4_FPS_259 < >	Mission Crew Endurance					days
6	A4_FPS_256 < >	Mission Crew					Integer
7	A4_FPS_318 < >	Maximum Embarked Personnel Endurance					days
8	A4_FPS_257 < >	Maximum Embarked Personnel					Integer
9	A4_FPS_252 < > A4_FPS_331 < >	High Speed Repositioning					knots
10	A4_FPS_242 < >	Duration between Snorting					hours
11	A4_FPS_246 < >	Deep Diving Depth					m
12	A4_FPS_258 < >	Core Crew Endurance					days
13	A4_FPS_255 < >	Core Crew					Integer
14	A4_FPS_251 < > A4_FPS_331 < >	Average Patrol Speed					knots

Traceability: Following the Cascade



The Black-Box Specification



Observations

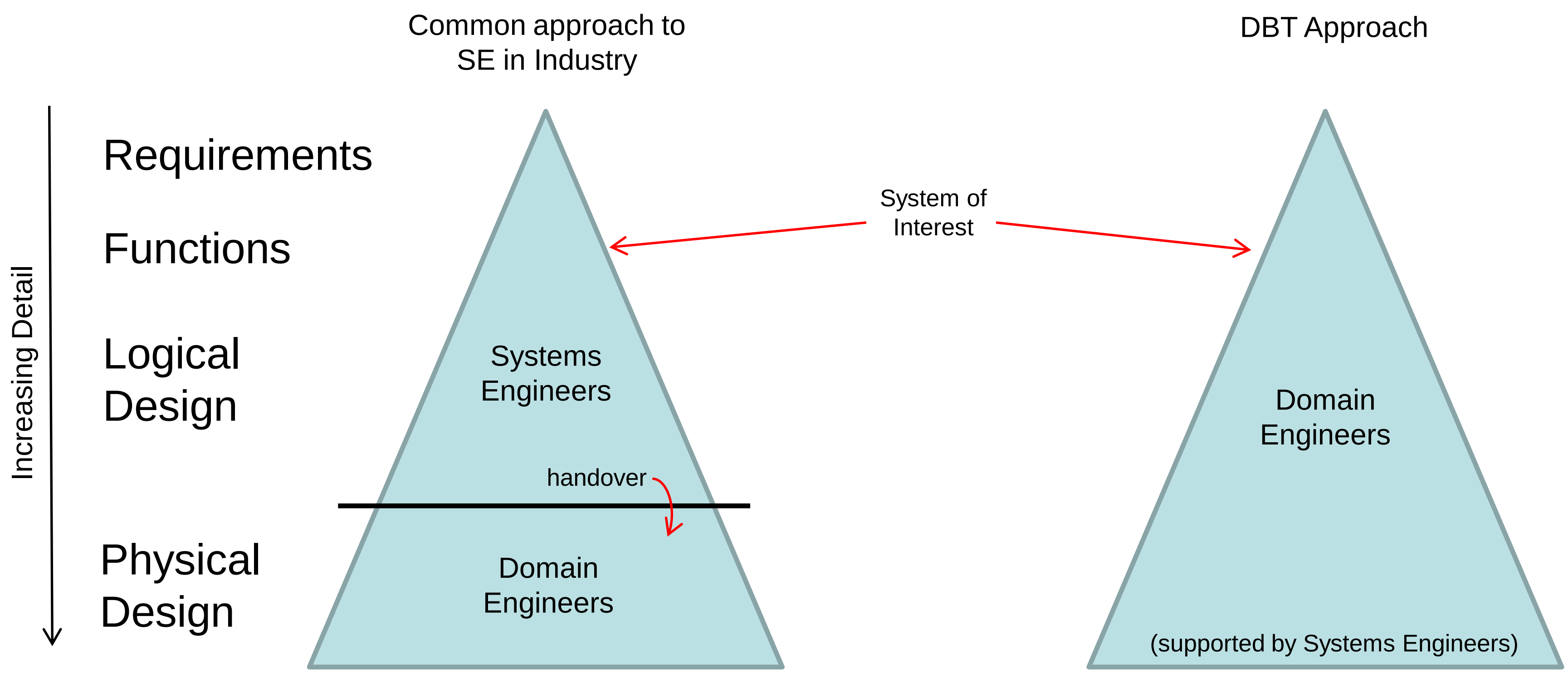
- The following are not emphasised during early concept design:
  - Functions
    - The system decomposition at the submarine level is well-established in DBT
    - Building a pure functional decomposition from scenarios and formulating a different list of systems appears unnecessary.
    - Most domain engineers involved in the concept design don't see the benefit of such an abstract representation.
  - Interfaces
    - In general, early concept design locates, but does not 'connect' the boxes. This detail will be added in the Preliminary Design phase.
- Solution:
  - The Black-Box Specification provides a placeholder to accumulate properties, functions and interfaces for any system of interest (whole-of-submarine, sub-systems or components)

Roles and Responsibilities

- In DBT, there are three broad roles:
  - ‘Domain’ Engineers: responsible for a part of the system design, such as a complete sub-system.
  - Systems Engineers: custodians of the SE process, managing requirements and providing SE guidance to the team
  - Interdisciplinary Engineers, such as reliability, cost, safety and signatures, working across systems.

Ownership of Design

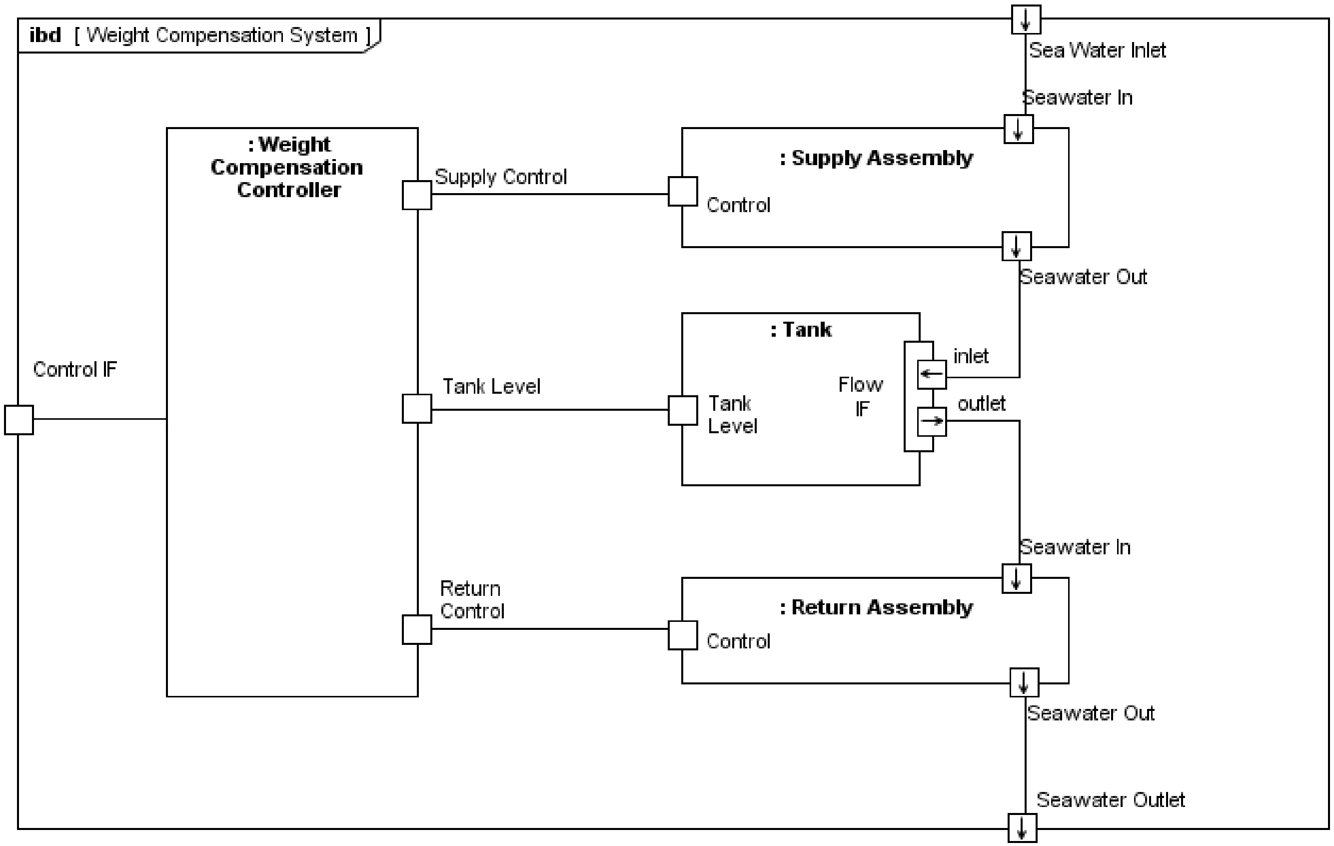
- Ownership of design by domain engineers is fundamental.



Implications of DBT Approach

- At the ‘top-end’ of the design, domain engineers need to think like systems engineers
  - Abstract away unnecessary details
  - Define the problem before the solution
  - Traceability is second-nature

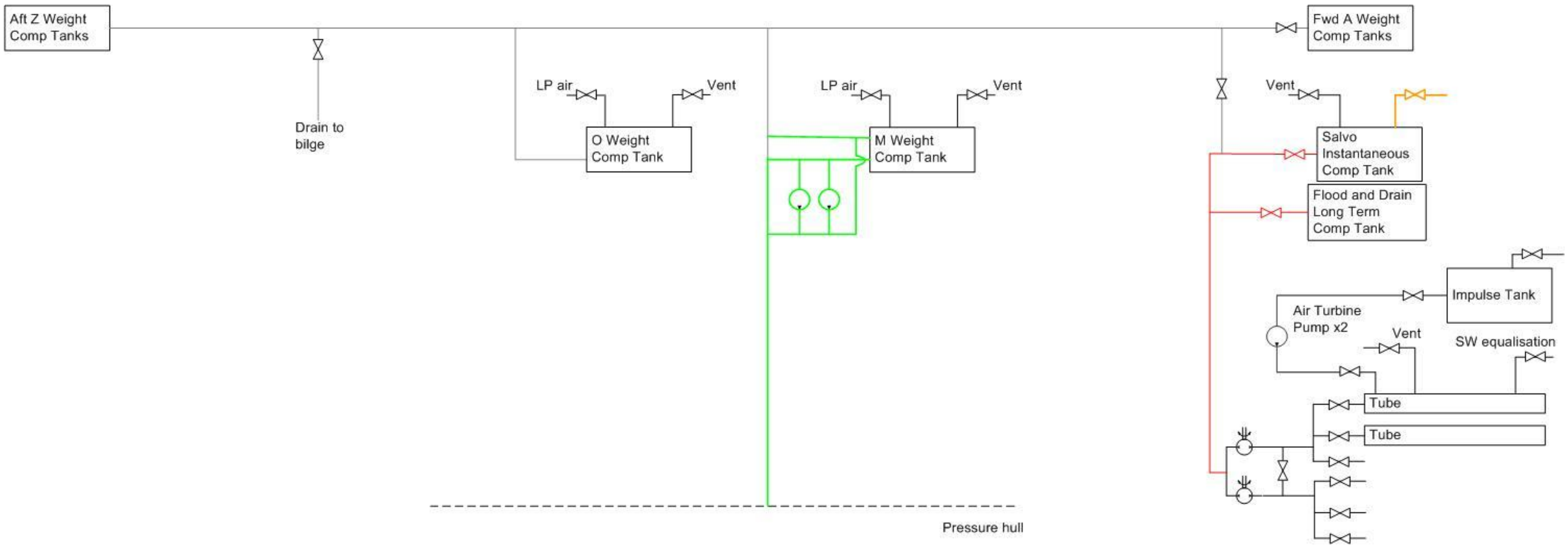
Example #1: Submarine Weight Compensation System



Very abstract (no mention of pumps or valves yet), but still some solution involved: i.e. sea-water used to adjust buoyancy via a tank (could have said ‘storage assembly’)

It is possible to make the definition so abstract it becomes meaningless.

Example #2: Submarine Weight Compensation System



More detail – ‘secondary’ functions included e.g. drain & vent, recirculation loop for pumps, multiple tanks, interconnects with other systems

Implications of DBT Approach

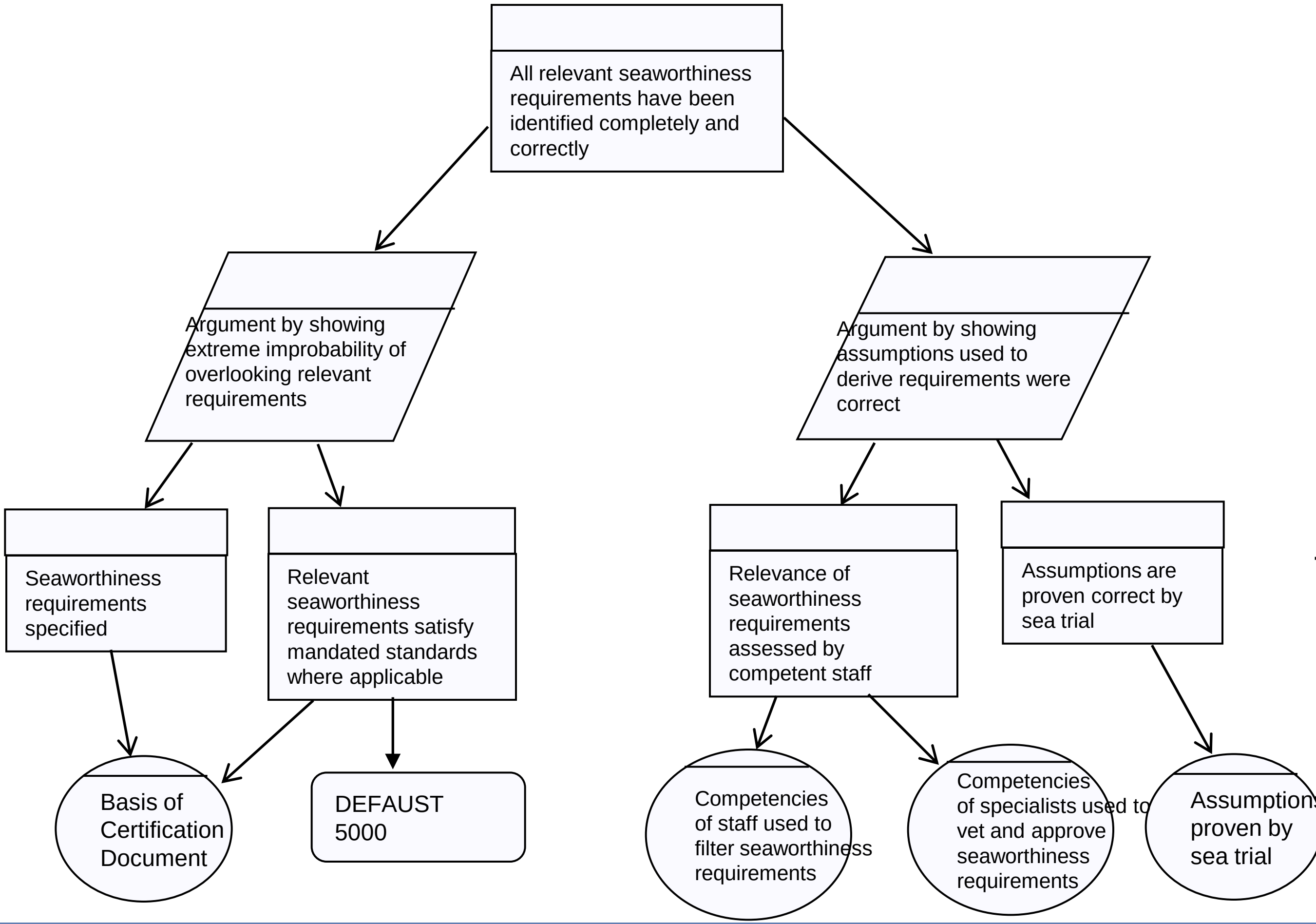
- In DBT, domain engineers are expected to do the system modelling supported by systems engineers with systems modelling skills and tools.

Other considerations

- Safety Case
- Technology Readiness Levels
- Production

Supporting the Safety Case

- Claim-Argument-Evidence (CAE) approach



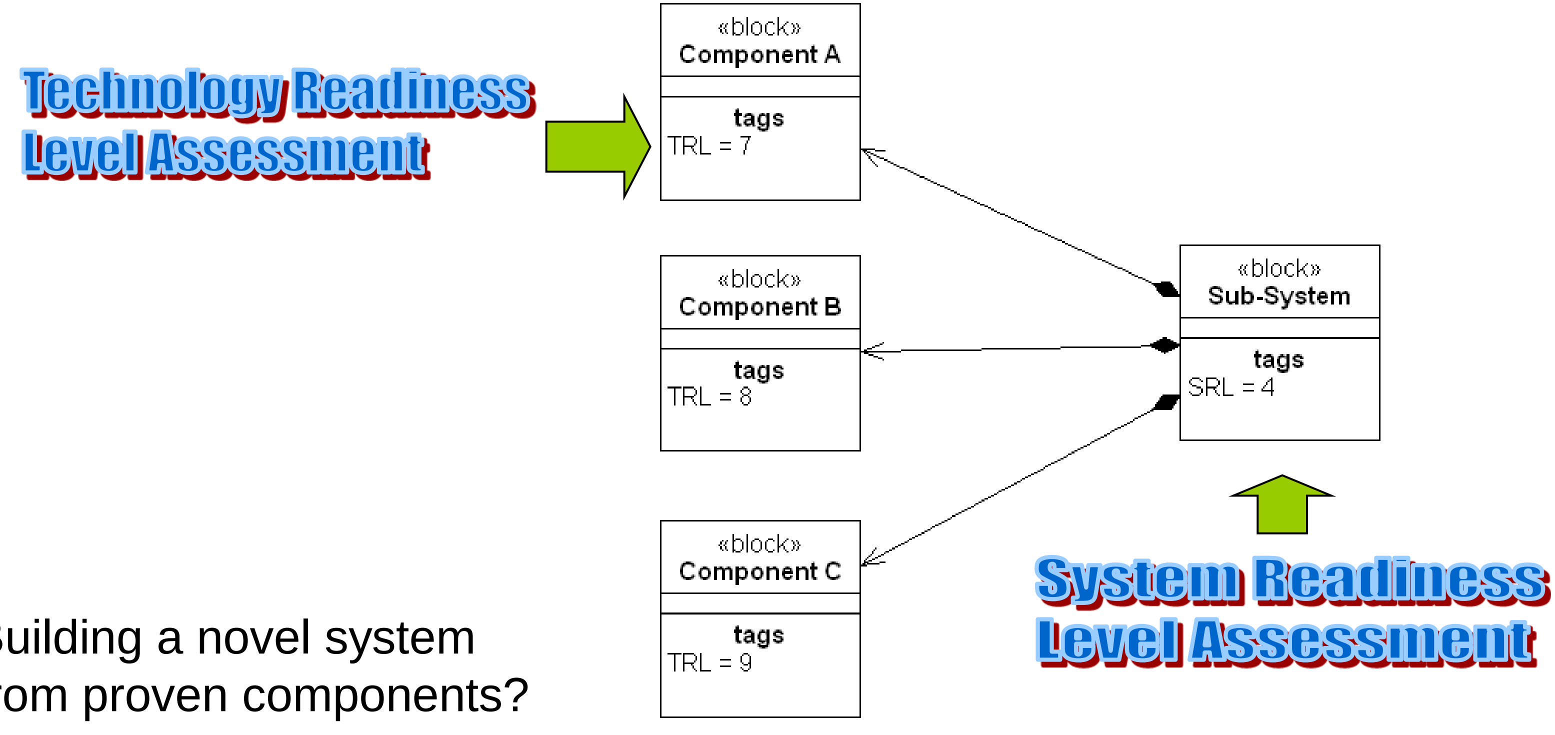
- Create CAE model in SysML (pictured)

or

- Link diagrams and elements in SysML model, to a CAE model in another tool, as supporting evidence

Diagram adapted from M.C. Hause, F. Thom, An Integrated Safety Strategy to Model Driven Development with SysML, 2007

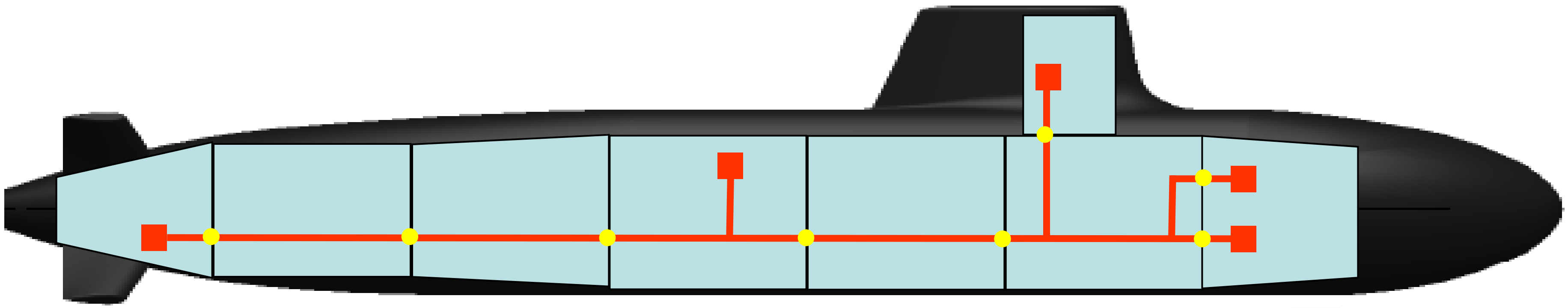
System Readiness Level (SRL) Assessment



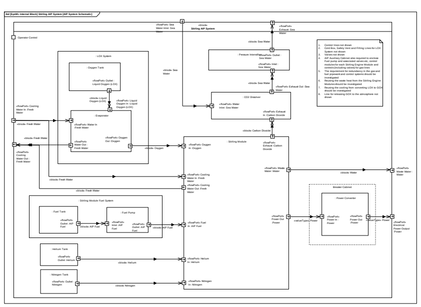
Building a novel system
from proven components?

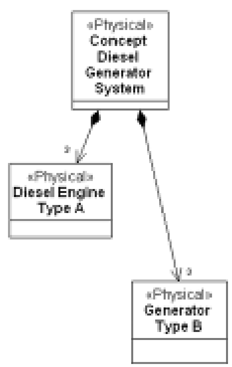
Building a non-novel system
from novel components?

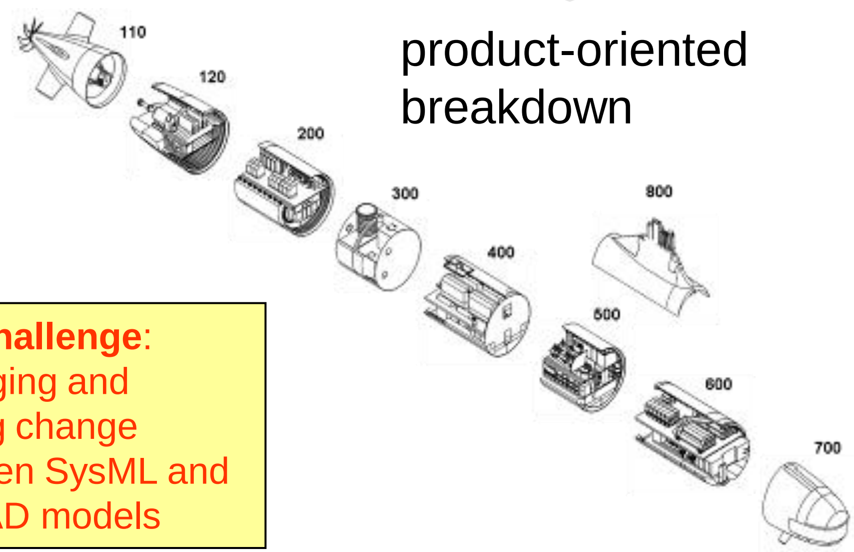
Transition from System to Product



system-oriented breakdown







product-oriented breakdown

Big Challenge: managing and tracing change between SysML and 3D CAD models

Moving forward…

- Increasing perceived usefulness of SE to Naval Architects who are leading the design
- Leveraging the design process
- Promoting the System Model to help the team specify and develop submarine designs.

Questions?