National Aeronautics and Space Administration

Model Based Systems Engineering

Title: Model Based Systems Engineering: A stepping stone on the path to Digital Engineering

GSFC Systems Engineering Seminar

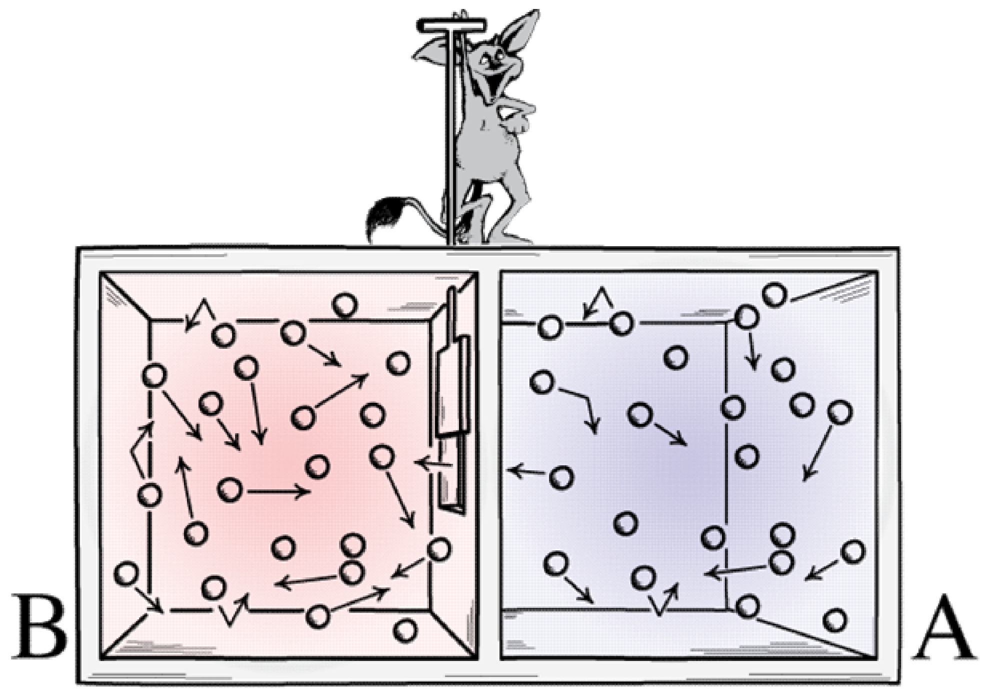
February 11, 2020

www.nasa.gov

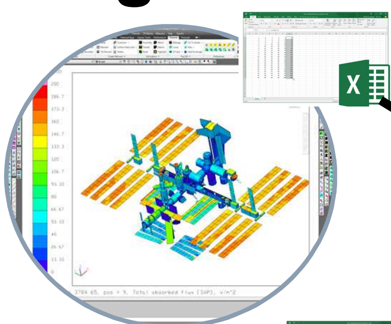
Model Based Systems Engineering

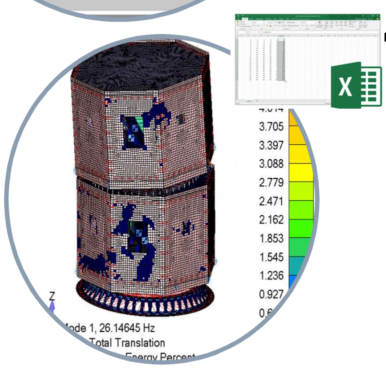
Recap – What we discussed in 2017 & 2018

James Maxwell



Systems Engineering

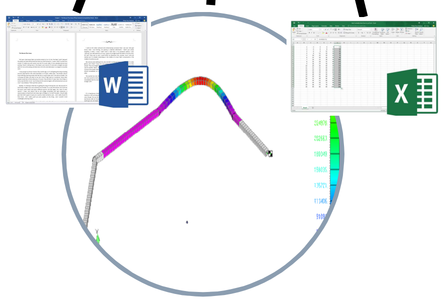


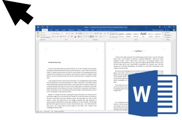


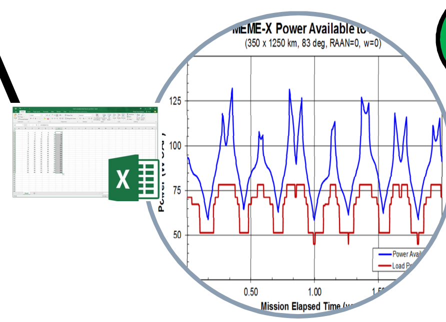
$$A = \int f(Excel, Word, Power\ Point)d_{Engineering}$$

Description of the System

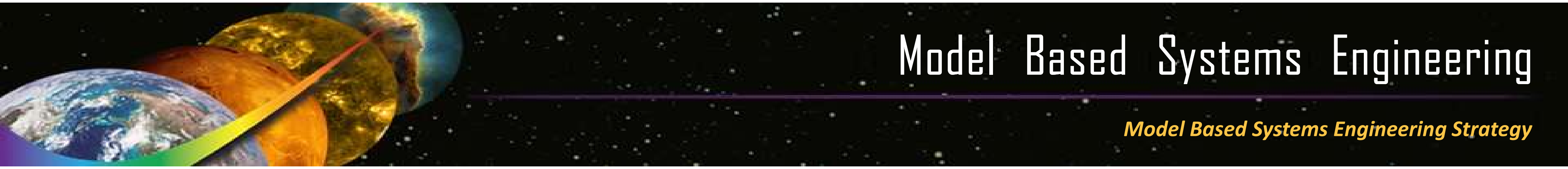
**** Defined architecture, including major tradeoffs and options ready to be baselined after review comments are incorporated.**
** Allocation of requirements to next lower level ready to be baselined after review comments is incorporated.
** MOPs, TPM, and other key driving requirement ready to be approved.
**Initial trending information on the mass margins (for projects involving hardware), power margins (for projects that are powered) and closure of review actions (RFA, RID, and/or Action Items).





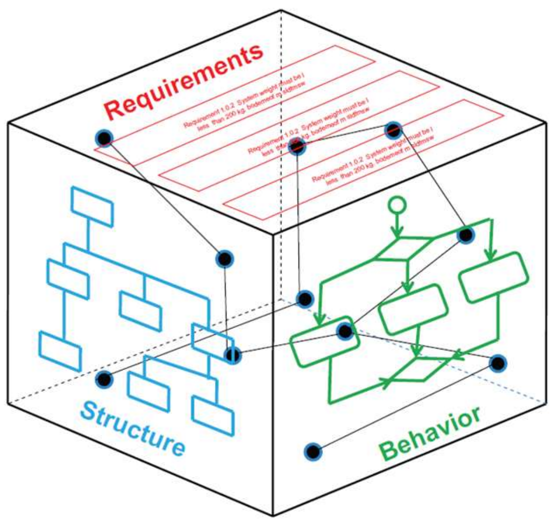


A multitude of sometimes redundant, sometimes obsolete, oftentimes out-of-sync documents, spreadsheets, e-mails or whatever…
-An un-named SE



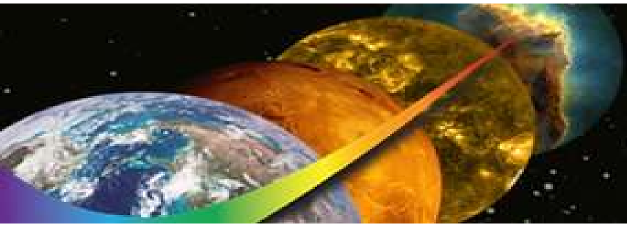
Can better knowledge of the system enable the reduction of its ‘entropy’?

Maxwell: …such a being, whose attributes are still as essentially finite as our own, would be able to do what is at present impossible to us.



[1]Model-Based Systems Engineering (MBSE): The **<u>formalized application of modeling</u>** 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 International Council on Systems Engineering (INCOSE) - http://www.omgwiki.org/MBSE/doku.php



MBSE **offers process improvement for SE throughout the entire project lifecycle**

Process efficiencies:
Reduced effort, time, and cost in executing SE processes

- Clearly articulated concepts
- More rapid communication within team
- Improved support for program reviews, decision milestones, etc.
- Improved reuse of known-good designs and exiting architectural elements
- Faster convergence on multi- discipline / multi-organizational problems
- Automatic generation of documents, briefing materials, etc.
- Ready availability of information on system baselines

What's in it for the SE team?

Leading to:
Enhanced quality and integrity in system architectures

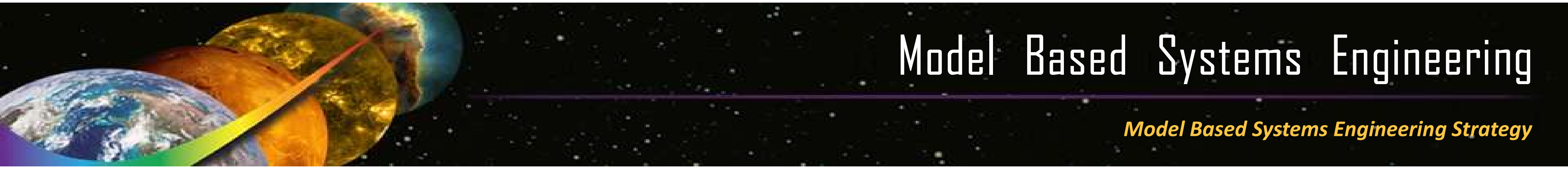
- Improved communication and shared understanding among disciplines, teams, and stakeholders
- Improved and earlier detection of design errors, wrong or missing requirements, conflicting interface definitions, etc.
- Improved tools for requirements analysis, allocation, and tracing
- Architecture Re-use - Abstraction/Inheritance, Modularity, Loose Coupling, Interface Management, and others
- Framework for modeling and simulation at multiple levels

What's in it for the Program/Project?

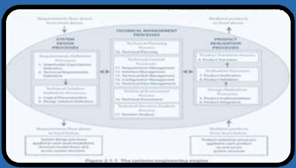
Enabling:
Efficient and robust Mission Development and Execution

- Model reuse for detailed and informed candidate concepts
- Embedded lessons learned facilitating informed decision making
- "Digital twin" – enabling automatic interface verifications
- Engineering efficiency through digital-centric certification processes to inform and reduce cost for physical certification
- More timely identification of discrepancies between elements, improving design closure for major gate reviews
- "Real-time review", with interactive information
- Recovers ability to understand systems across disciplines and subsystems in the context of growing complexity

What's in it for the Enterprise?



Recap – So…what is MBSE…?

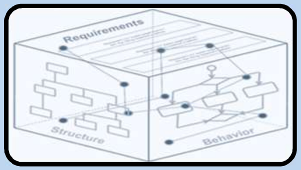


Systems Engineering

- System: The combination of elements that function together to produce the **capability** to meet a **need**.
- SE Domain is an SE team, that interacts with stakeholders to turn external needs, goals and objectives into a system description, a system design, and a realized product that can be operated to meet the need
- Technical System Development & Technical Information Management
- …a methodical, multi-disciplinary approach for the design, realization, technical management, operations, and retirement of a system.
- Governed by NASA NPR 7123

System Architecture (Product Architecture)

- The architecture of the system to be realized: Description of the system elements: all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. [i.e. System Structure, System Functions/Behaviors, System Requirements [For operation and development]
- A SE team, executing the SE Process
- Workflow, precise language for description of systems to perform tasks
- Organization principles of the system architecture description (NASA Architecture Framework)

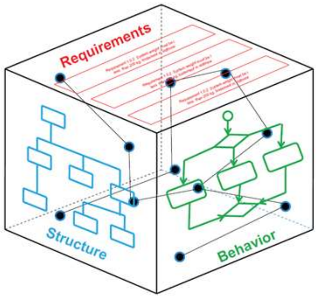


Digital System Model

- A comprehensive description of the system architecture and architecture of the Project Team's design and delivery efforts
- A comprehensive set of work products to communicate the ability of the system to meet the need, and the ability of the Project Team to design and deliver the system
- A Modeling Language (e.g. SysML - A modeling language specific to engineering systems), and "Rule set" for model elements and what they represent
- Appropriate level of rigor for the task at hand
- Supports the analysis, design and verification of complex systems
- Organization Structure of the system architecture description (NASA Architecture Framework)

Modeling Engine

- "Modeling Tool" – Cameo Systems Modeler (MagicDraw) is one (of many)
- Enables creation of models
- Provides display and export of "model artifacts"



Agenda

- Digital Engineering
  - Digital Engineering – what is it?
  - Why do we want to do it?
  - Some external points of view
- What does it mean to NASA-what does it mean to my branch/domain?
- Changing our (Instrument & Payload SE) processes: Design Reference Architecture
  - Concept
  - Example
- Recap

[1]What is Digital Engineering?

Digital technology combines engineering data and the art of design.

Digital engineering is the practice in which new applications are conceived and delivered.

Digital engineering is the art of creating, capturing and integrating data using a **digital** skillset.

Digital Engineering is much more than creating models. It's about unlocking knowledge and stimulating insight, creating data and a platform for true project collaboration that is set to be the building block for 21st century construction.

[1] Google search "What is Digital Engineering?"

[1]Why pursue Digital Engineering? National Aeronautics and Space Act (Some key objectives)

- ***The establishment of long-range studies of the potential benefits*** to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes. (***DE is certainly in a long range study phase***)
- The ***preservation of the role of the United States as a leader*** in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere. (***DE is necessary to preserving a leadership role for US***)
- The ***making available to agencies directly concerned with national defenses*** of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of ***information as to discoveries which have value or significance to that agency***; (***DE will benefit the entire Aerospace Enterprise***)
- The ***most effective utilization of the scientific and engineering resources*** of the United States, with close cooperation among all interested agencies of the United States ***in order to avoid unnecessary duplication of effort, facilities, and equipment***. (***DE will improve utilization of Government science and engineering resources***)

[1] https://en.wikipedia.org/wiki/National_Aeronautics_and_Space_Act#cite_note-SpaceAct1958-3

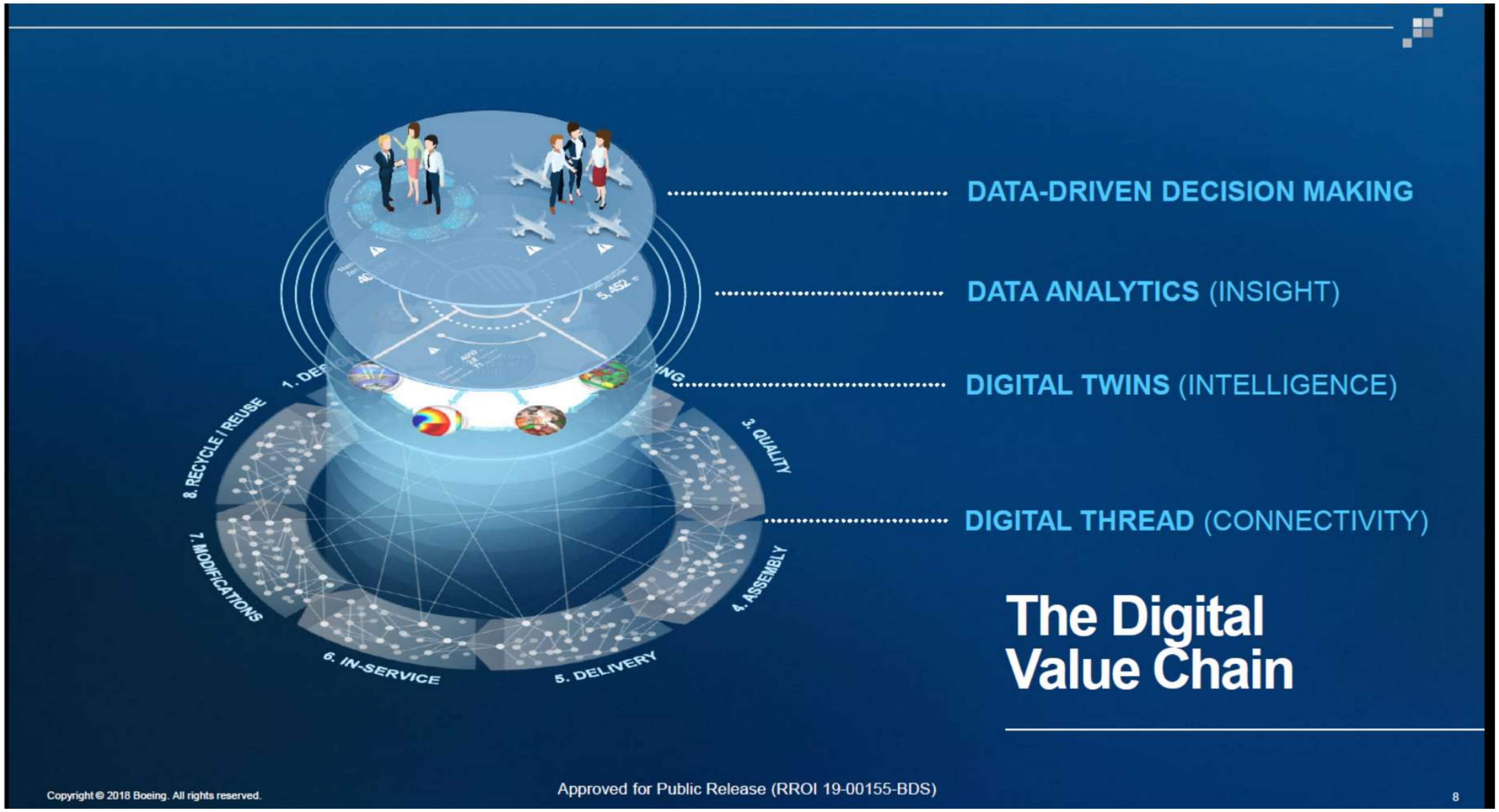
So…where should we begin the discussion?

- **Boeing**
  - How Does DT/DTw Enable Model-Based Aerospace Enterprise? (Dan Seal, Boeing Defense, Space & Security, March 27, 2019, RROI 19-00155-BDS)
  - The System Engineering "V" - Is It Still Relevant In the Digital Age? (Daniel Seal, Senior Manager, PLM, Boeing Defense, Space & Security, daniel.w.seal@Boeing.com, RROI 18-00101-BDS)

- **Analytical Graphics, Inc.**
  - Digital Mission Engineering 2019 FORUM, Columbia, MD

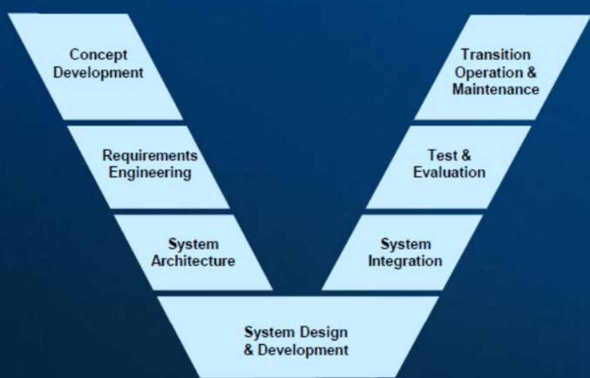
- **Department of Defense**
  - Digital Engineering Strategy & Implementation Status - Philomena Zimmerman, Deputy Director, Engineering Tools & Environments OUSD(R&E) or Office of the Under Secretary of Defense (Research & Engineering), NDIA Washington, DC| Thursday June 6, 2019

What is Digital Engineering to Boeing?



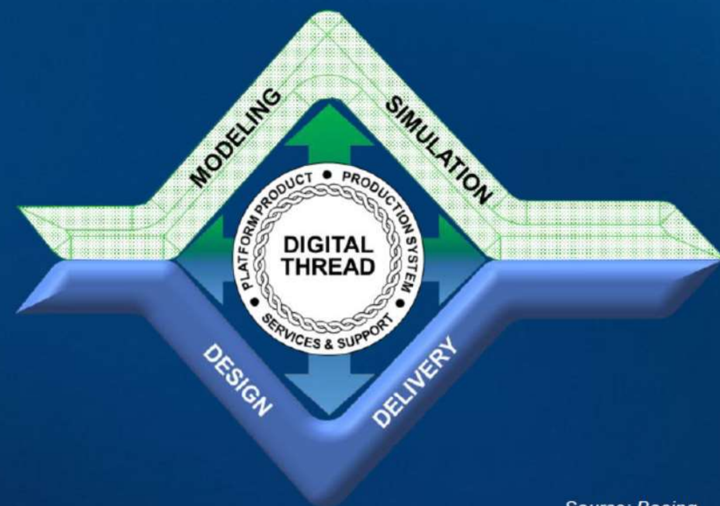
Transforming to a Model-Based Aerospace Enterprise

SE V



Source: Mitre

MBE Diamond



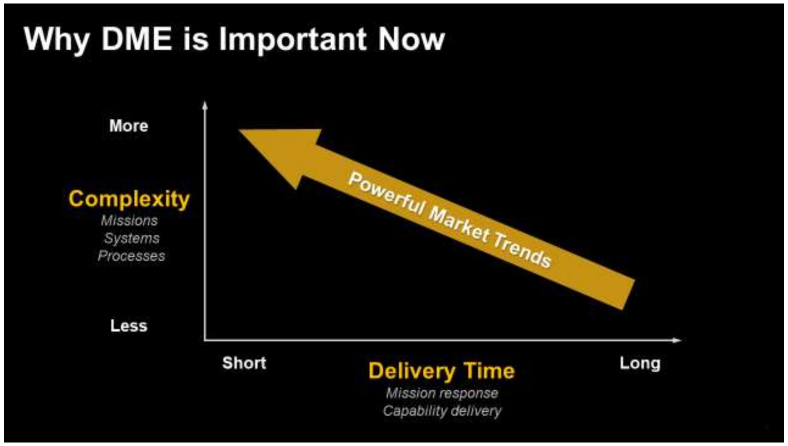
Source: Boeing

Moving from a document era to a digital engineering era with information flow across the lifecycle

Approved for Public Release (RROI 19-00155-BDS)

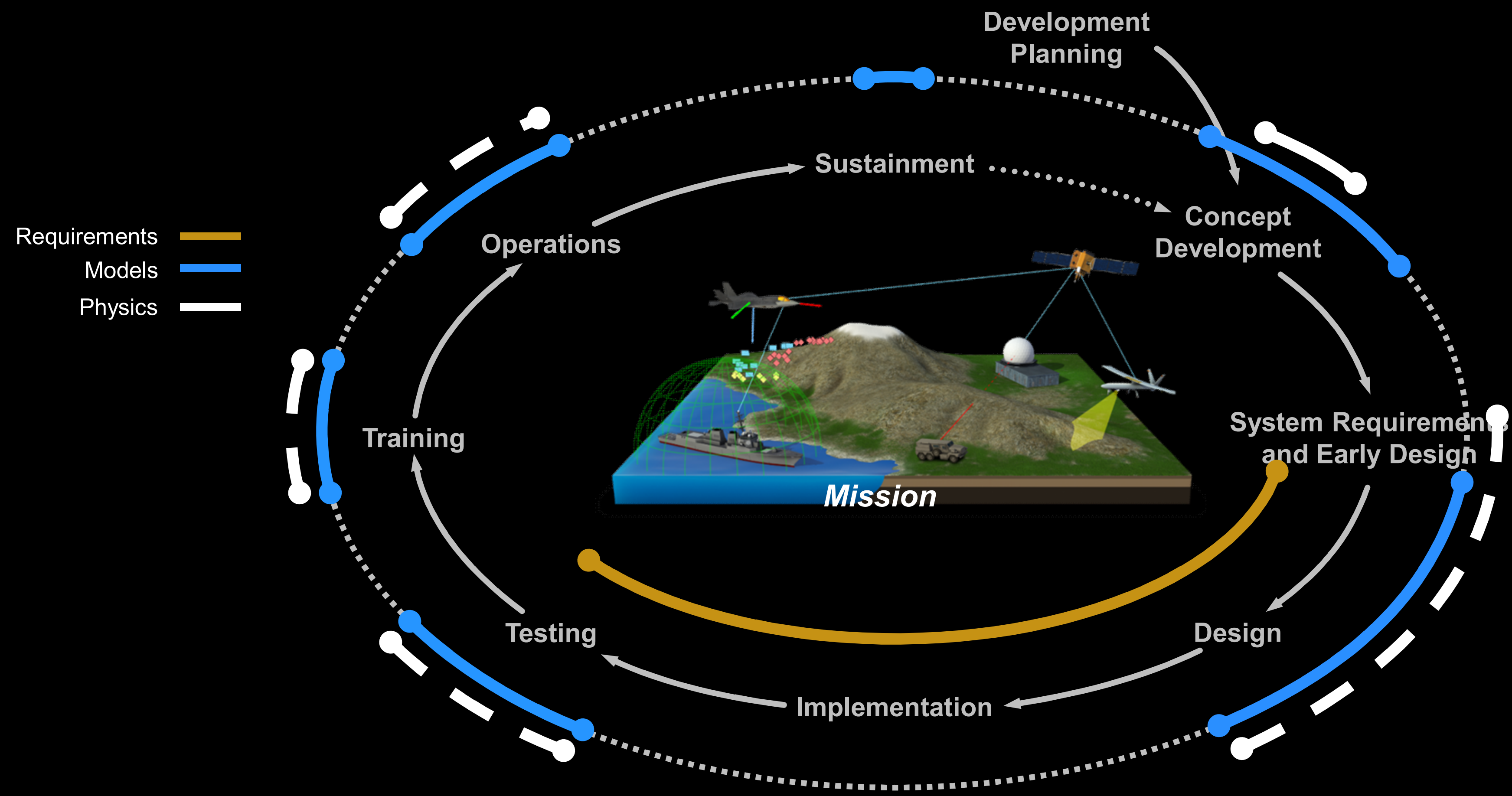
[1]What is Digital Engineering to Analytical Graphics, Inc.?

- Digital Mission Engineering?
  - Connecting the Model to the Mission
  - ***<u>The integration of the mission environment and operational objectives into the digital thread throughout the entire product lifecycle.</u>***



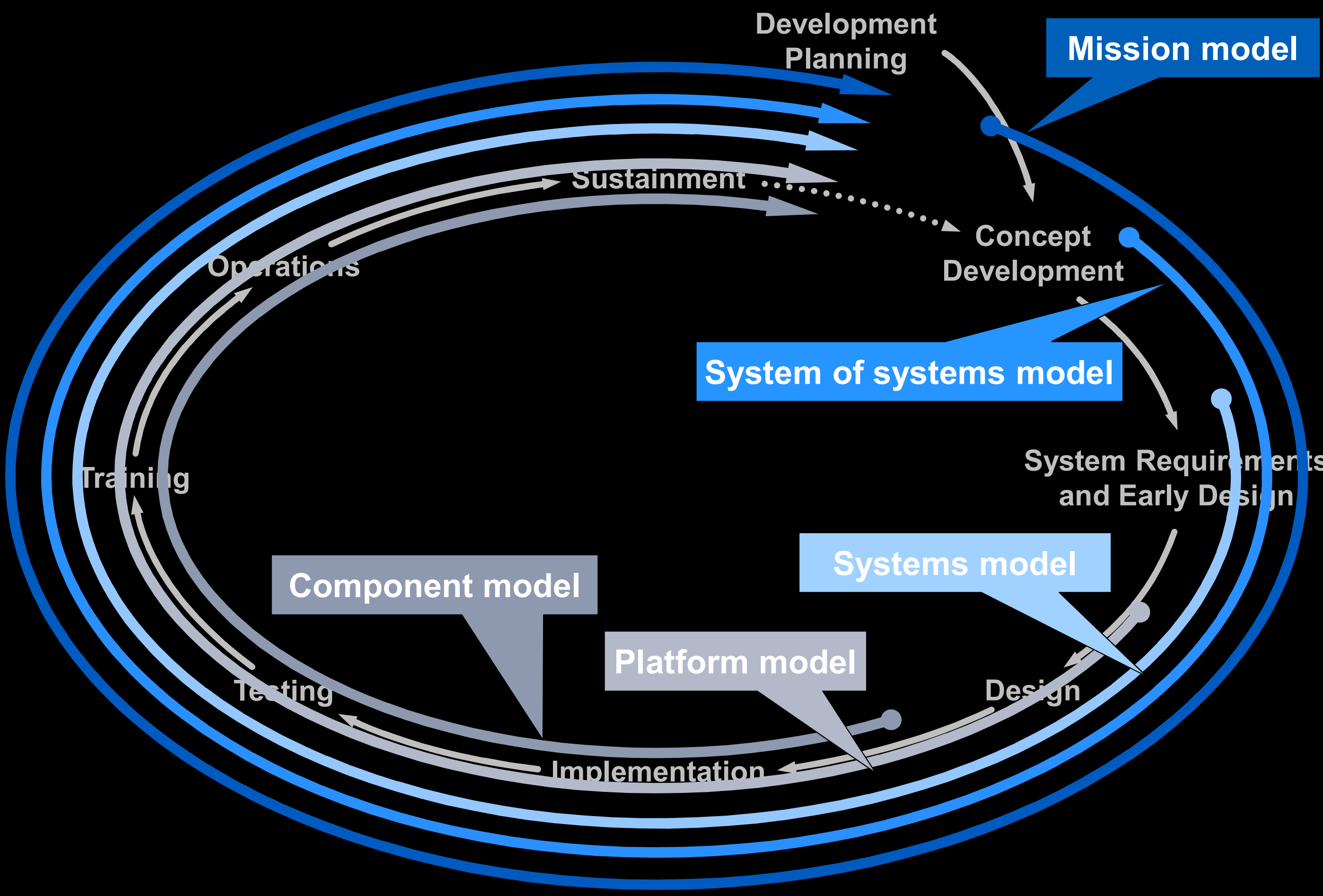
[1] AGI Digital Mission Engineering Forum, 2019

Need for DME: Life Cycle Perspective



[1] AGI Digital Mission Engineering Forum, 2019

Need for DME: The Vision



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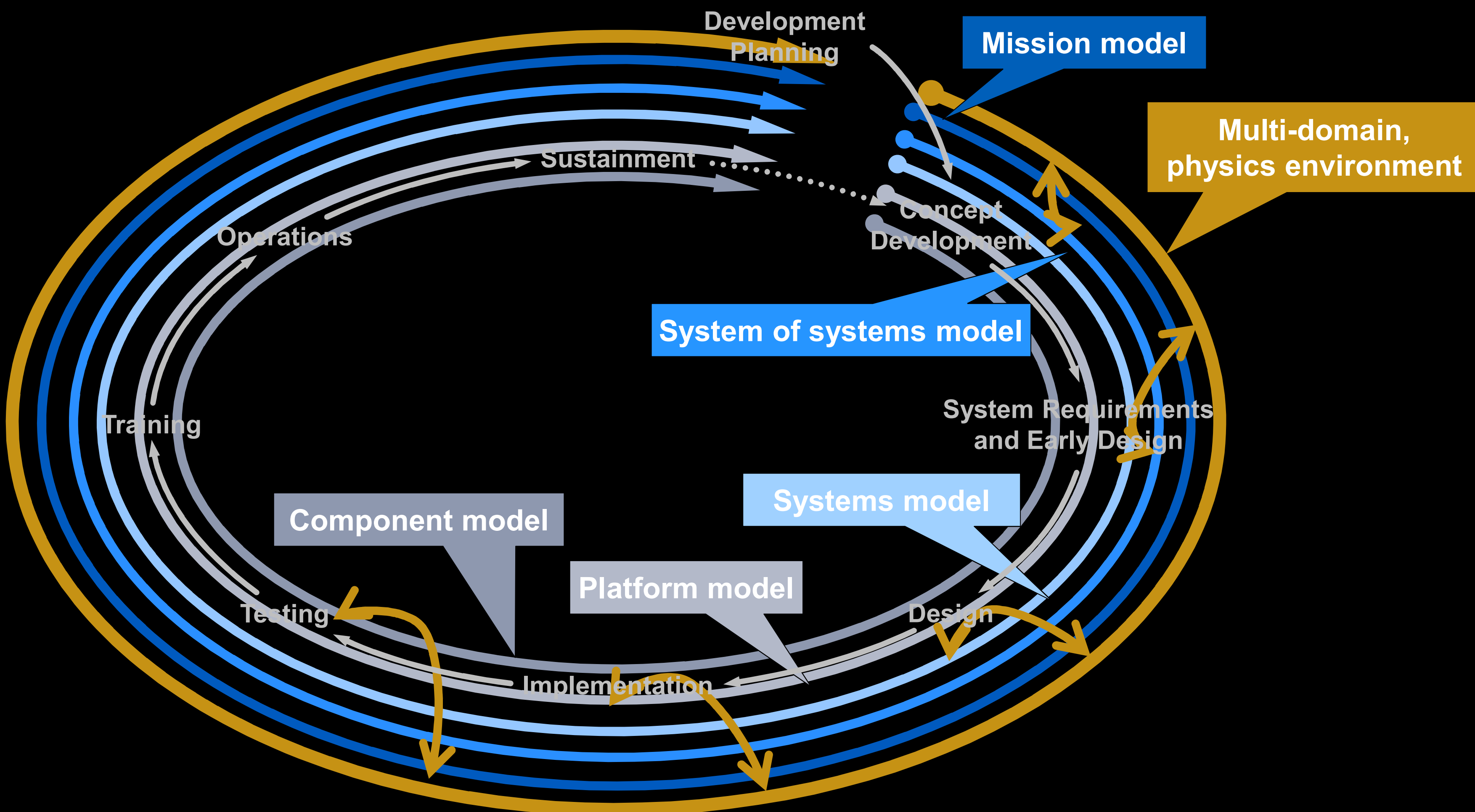

[1] AGI Digital Mission Engineering Forum, 2019

[1]What is Digital Engineering to DoD?

- What is Digital Engineering?
  - Combines ***model-based techniques***, ***digital practices***, and ***computing infrastructure***
  - Enables ***delivery of high pay off solutions*** to the warfighter at the ***speed of relevance***

- Reforms Business Practices
  - Digital enterprise ***connects*** ***people, processes, data, and capabilities***
  - Improves technical, contract, and business practices through an authoritative source of truth and digital artifacts

[1] Digital Engineering Strategy & Implementation Status: Philomena Zimmerman, Deputy Director, Engineering Tools & Environments, NDIA Washington, DC| Thursday June 6, 2019

Digital Engineering Overview

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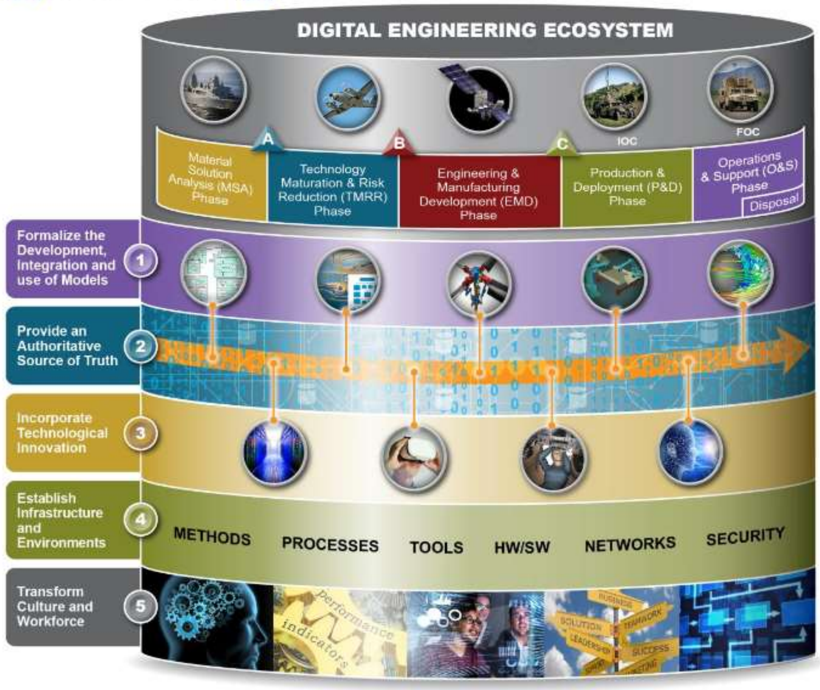


Modernizes how we design, operate, and sustain capabilities to outpace our adversaries

NDIA
June 6. 2019

Distribution Statement A: Approved for public release. Distribution is unlimited.

7

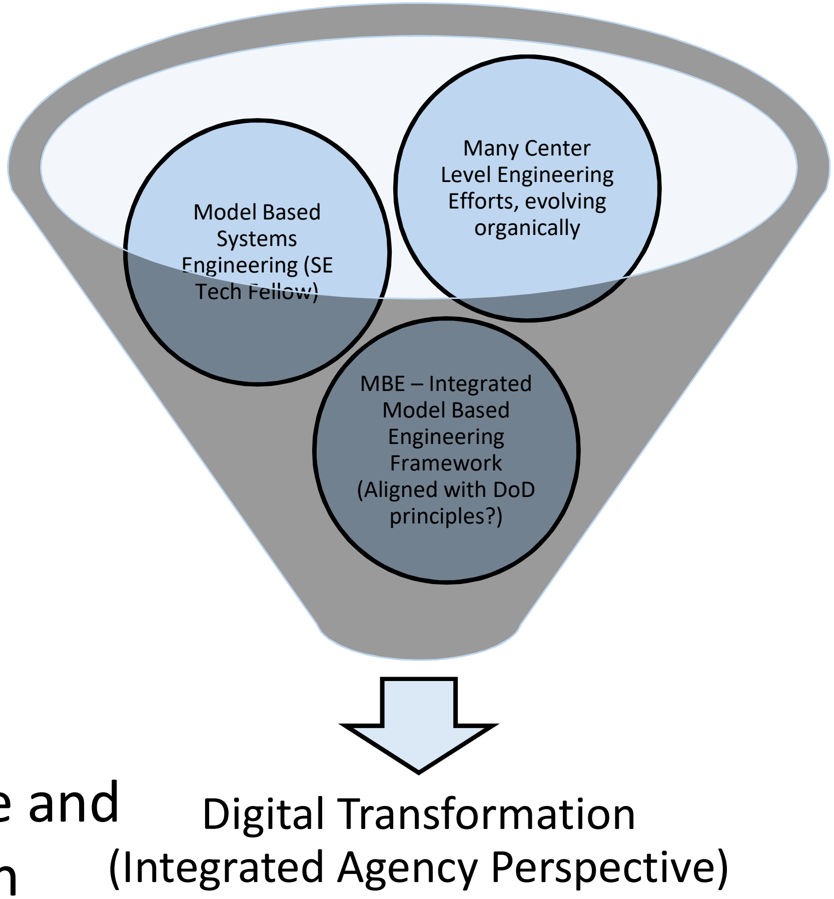
Reforms business practices

Cultural design principles

Integrates people, process, tools and data

What about NASA?

- The Agency is looking at what a Digital Engineering future could, and ***must*** be.
- There are many organizations at all levels exploring digital engineering approaches
- Integrating and aligning the agency digital approach is a significant undertaking
- Leveraging other efforts will help streamline and lessen the negative impacts of the transition



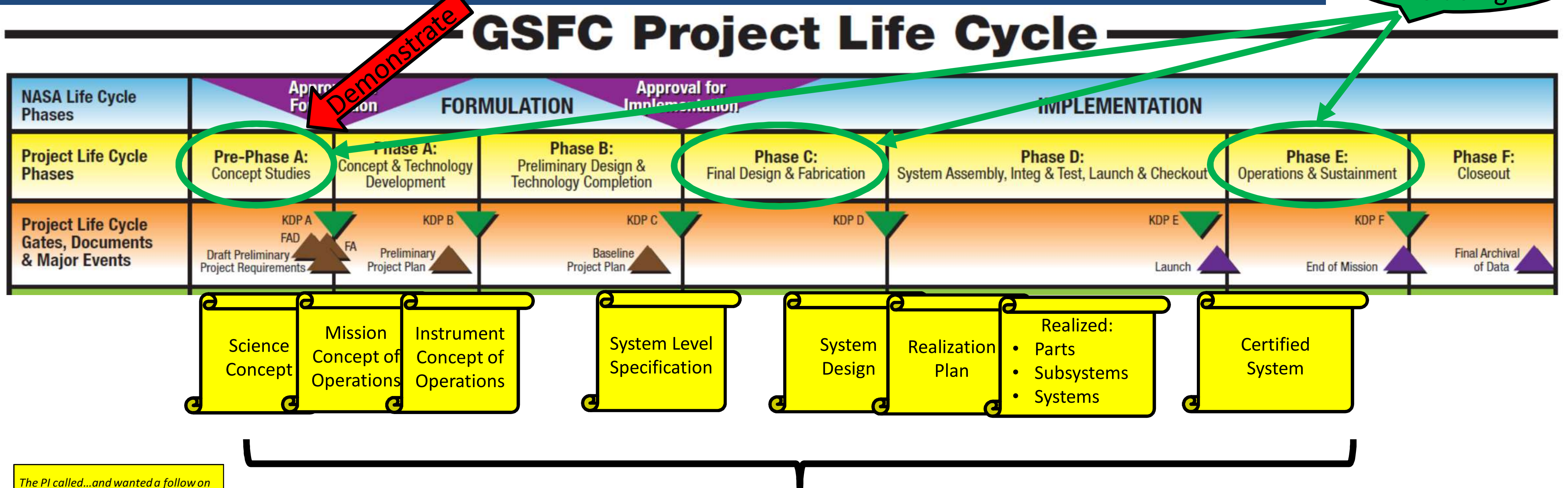
So, an SE walks into his manager's office…

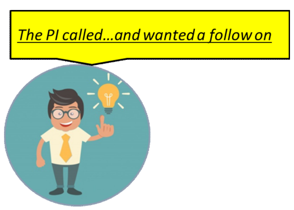
While preparing for CDR, my challenges were:

- Keeping all my diagrams consistent
- Keeping my state machines up to date
- Managing TPMs (Spreadsheets!)
- Hardware failure (good luck with that!)
- *The PI called…and wanted a follow on*
- *Can you show me a better way?!*

To support a PI, the ISE must capture the instrument architecture over the entire system lifecycle – and ***demonstrate a plan for this at TMR!***

What are we doing?





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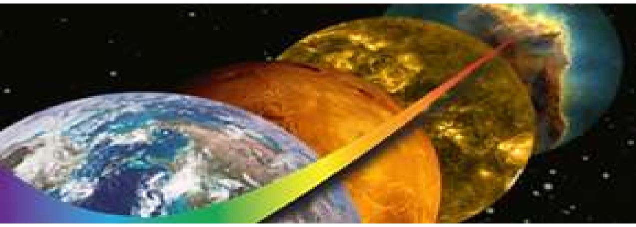

Lets build a better future!

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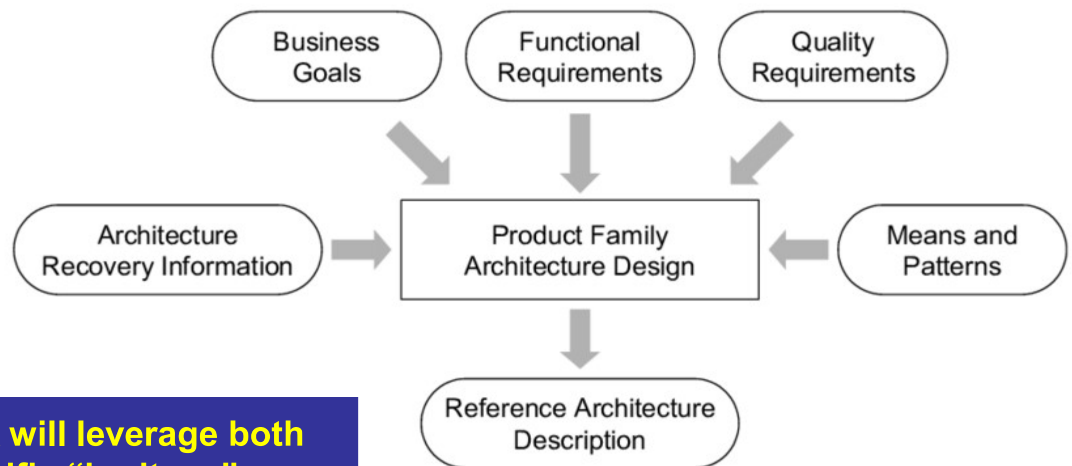
Reform business practices:

Design Reference Architectures

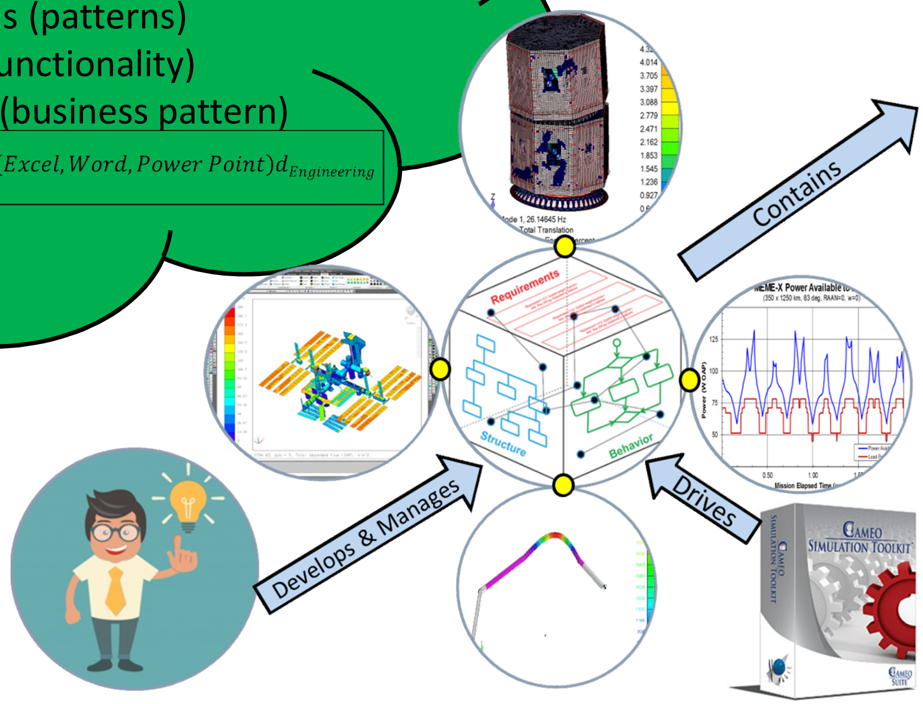


A future *model repository* of DRA will leverage both "generic" architectures, and specific "heritage" architectures

Change our processes… (Realistically, this will only work for new concepts with similar instrument architectures)

Hmmm…Empower the ISE to find ***path to TMR in 1 week***?

- Pre-defined block diagrams (patterns)
- State/behavior diagrams (patterns)
- Pre-configured TPMs (functionality)
- STM logic/connectivity (business pattern)
- System model > $A = \int f(Excel, Word, Power\ Point)\, d_{Engineering}$



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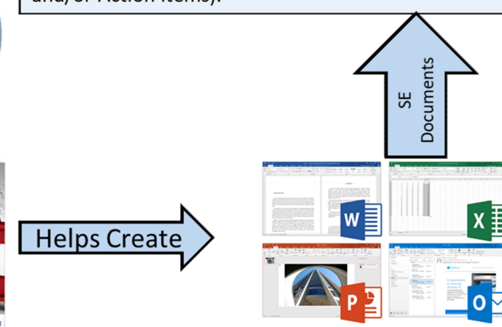
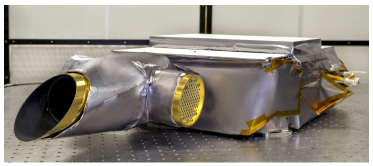


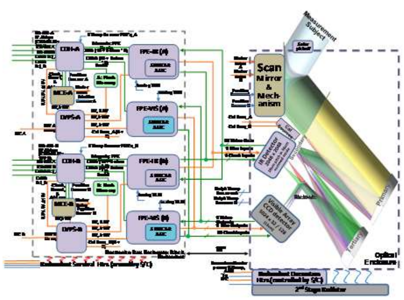
Model Based Systems Engineering Strategy

Abstract common characteristics to create a DRA in a SysML model

Start with relevant, successful legacy products



OVIRS



Ralph

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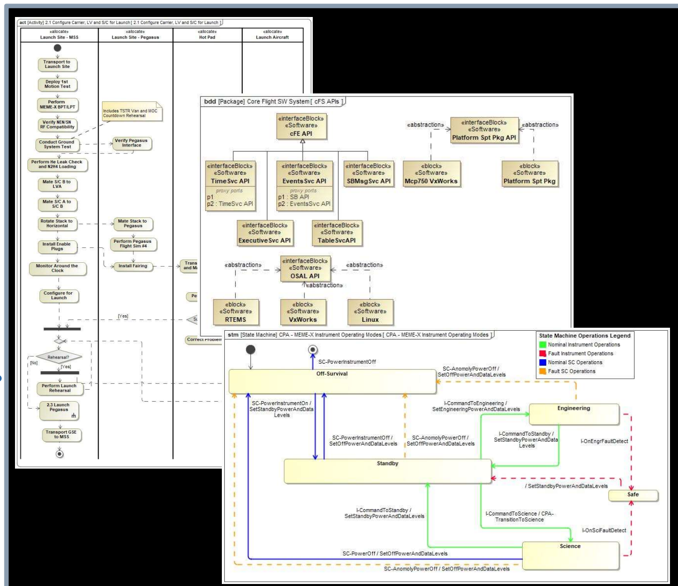
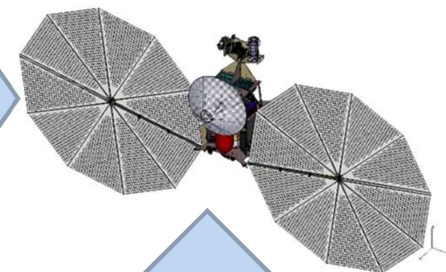


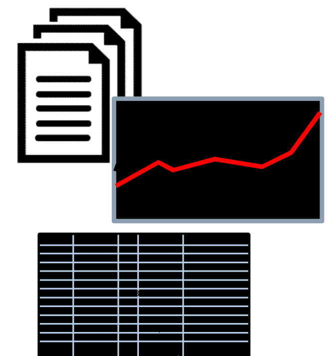
Goddard Model-Based Systems Engineering (GMBSE) Methodology

Reuse and tailor DRA content to create a new instrument architecture



Science Goals and Objectives, Heritage, Mission Requirements

Export model content to accelerate TMR preparation



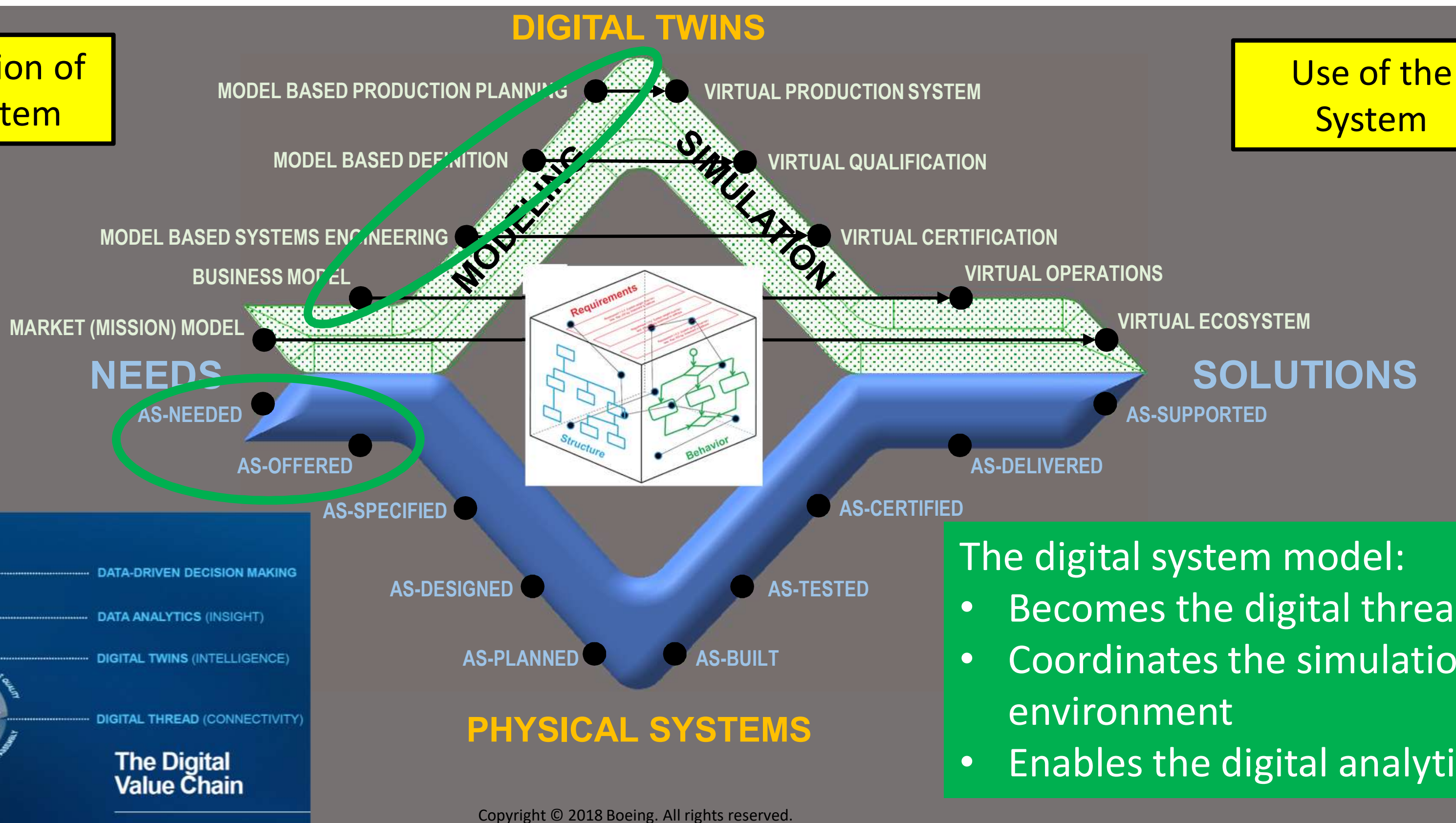
Review criteria: TMR guidance, 7120, 7123, et al.

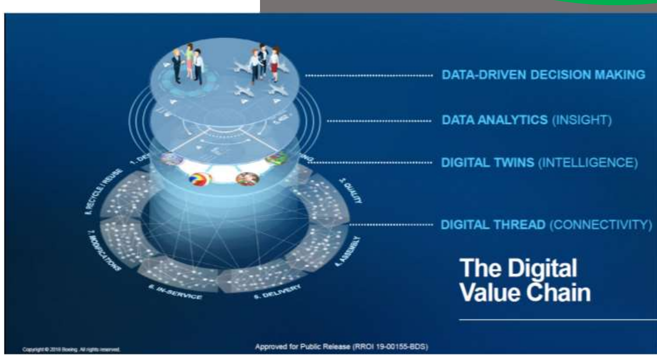
From upcoming DRA for Imaging Instruments Training Event – 03-26-20

Evolution from SE to MBSE…a stepping stone

Description of the System

Use of the System





The digital system model:

- Becomes the digital thread
- Coordinates the simulation environment
- Enables the digital analytics

<u>MB</u>SE offers process improvement for SE throughout the entire project lifecycle

Process efficiencies:

Reduced effort, time, and cost in executing SE processes

- Clearly articulated concepts
- More rapid communication within team
- Improved support for program reviews, decision milestones, etc.
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Digital Thread

What's in it for the SE team?

Leading to:

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- Improved communication and shared understanding among disciplines, teams, and stakeholders
- Improved and earlier detection of design errors, wrong or missing requirements, conflicting interface definitions, etc.
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- Architecture Re-use - Abstraction/Inheritance, Modularity, Loose Coupling, Interface Management, and others
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Re-use / Rapid planning

What's in it for the Program/Project?

Enabling:

Efficient and robust

Mission Development and Execution

- Model reuse for detailed and informed candidate concepts
- Embedded lessons learned facilitating informed decision making
- "Digital twin" – enabling automatic interface verifications
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- "Real-time review", with interactive information
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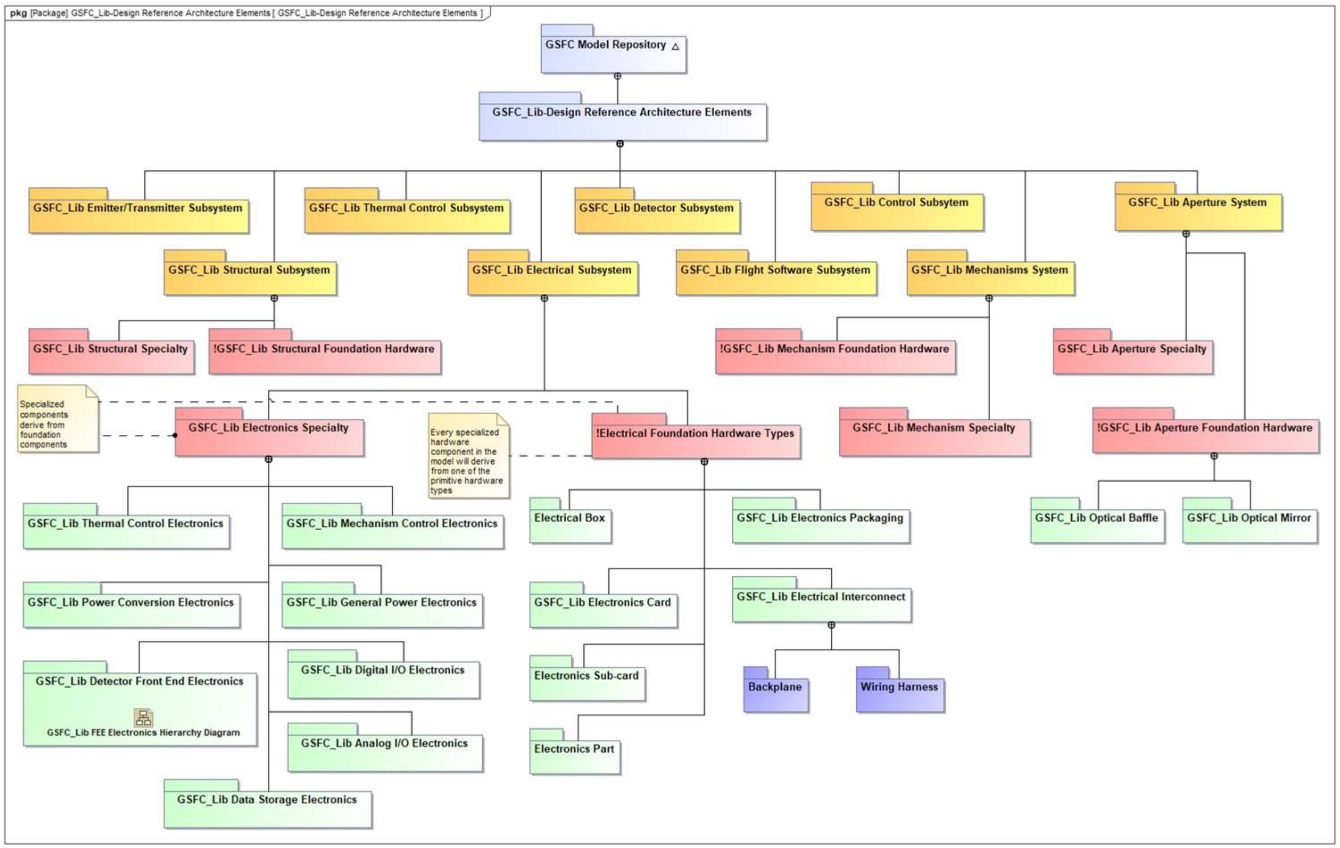
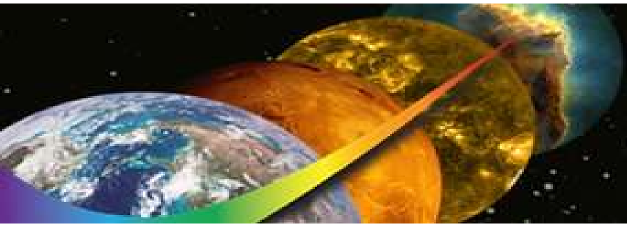
Data Driven Decision Making

What's in it for the Enterprise?

So…what does that look like?



- Imagine a repository of re-usable models
- They represent:
  - Foundation elements, like “mirrors” and “electronics cards”
  - More complex elements, like “mirror assemblies” and “electronics boxes”
  - Even more complex elements, like “Telescope Assemblies”, “Instruments” and “Space craft bus”
- Imagine the RSDO catalog transformed into a models



Model Based Systems Engineering

Model Based Systems Engineering Strategy

GSFC Generic Modeling Library

Missions/Lines of Business
- Earth Science
- Astrophysics
- Heliophysics
- Planetary Science
- Space Comms/Nav
- Sounding & Range Services
- Orbital Servicing

Payloads/Instruments
- Radar/Radiometer
- Spectrophotometer
- EM Field Probes
- Particle/Plasma Analyzers
- Imagers/Telescopes
- Seismometers
- Others

Other Applications
- Processes (Management, Engineering, Mission Assurance, et al.)
- Organizations
- Resources, Facilities, & Staff

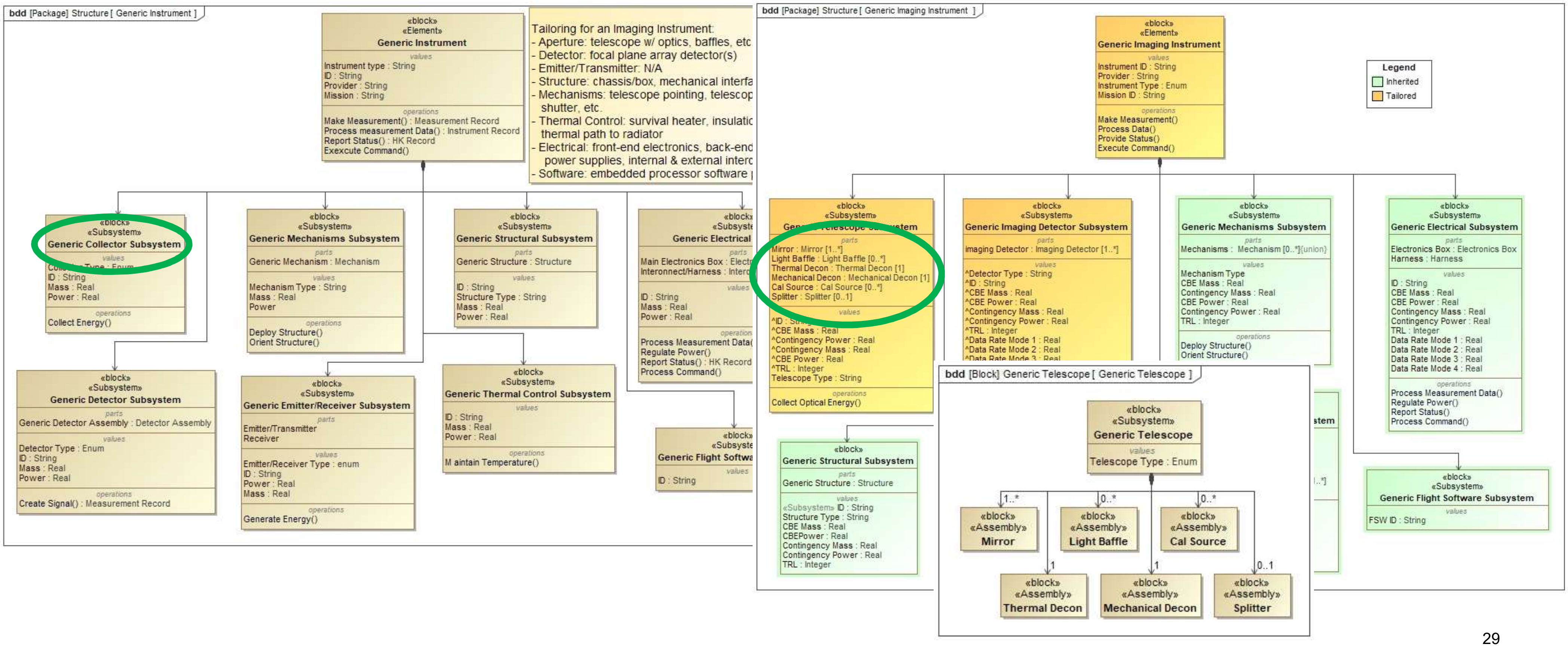
Generic Instruments/ Taxonomies Design Reference Architectures

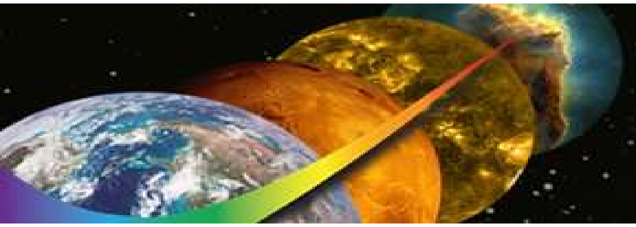
Generic Imaging Instrument

L'Ralph Example: DRA-to-Phase A Model via Reuse of Library Materials
- Diagrams & Specs
- SE Products for TMR

Current activities

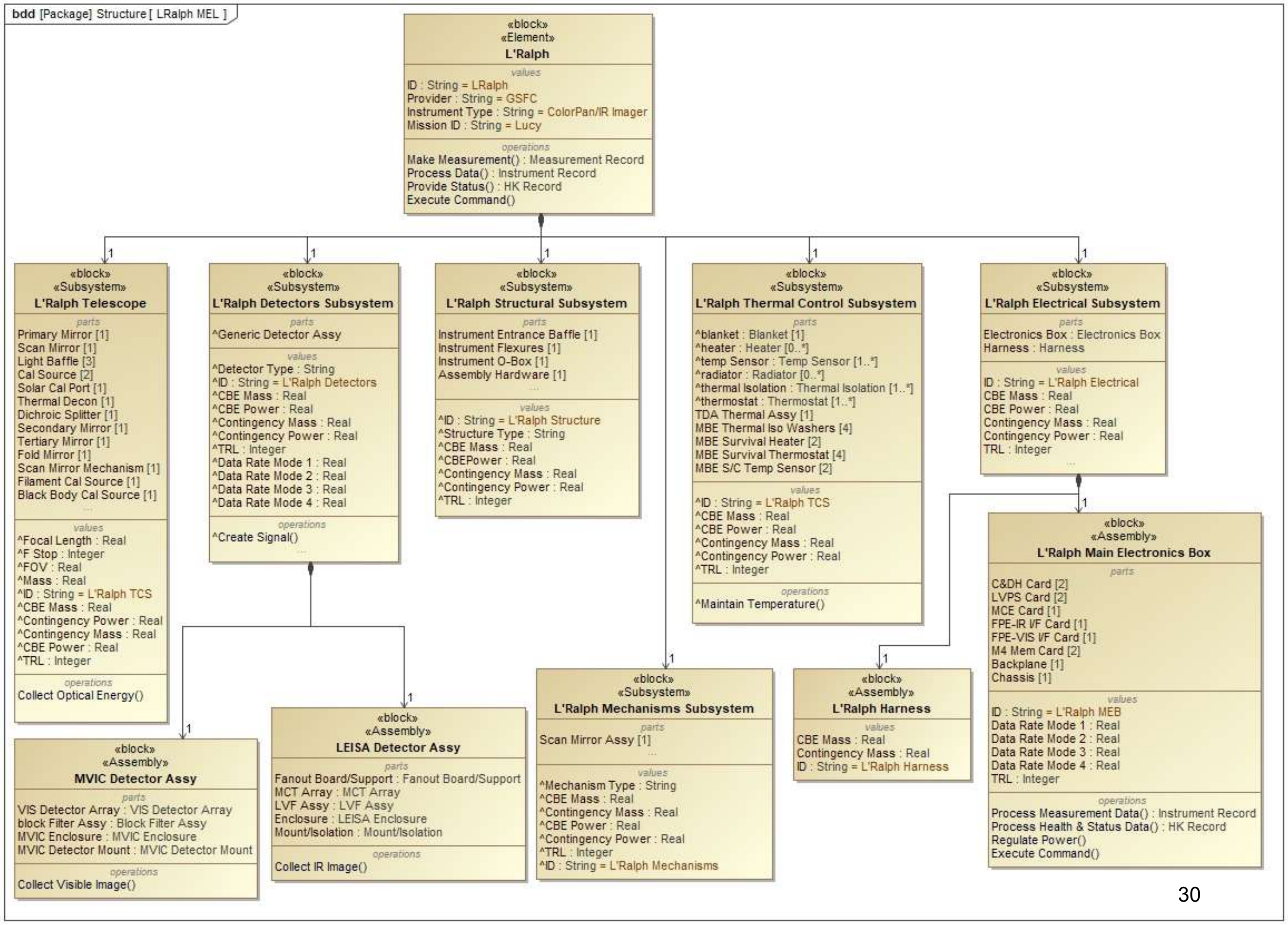
The PI called…and wanted a follow on


bdd [Package] Structure [Generic Instrument]
«block» «Element» Generic Instrument
Instrument type : String
ID : String
Provider : String
Mission : String
Make Measurement() : Measurement Record
Process measurement Data() : Instrument Record
Report Status() : HK Record
Exexcute Command()
Tailoring for an Imaging Instrument:
- Aperture: telescope w/ optics, baffles, etc
- Detector: focal plane array detector(s)
- Emitter/Transmitter: N/A
- Mechanisms: telescope pointing, telescop shutter, etc.
- Thermal Control: survival heater, insulatic thermal path to radiator
- Electrical: front-end electronics, back-end power supplies, internal & external interc
- Software: embedded processor software
«block» «Subsystem» Generic Collector Subsystem
ID : String
Mass : Real
Power : Real
Collect Energy()
«block» «Subsystem» Generic Mechanisms Subsystem
Generic Mechanism : Mechanism
Mechanism Type : String
Mass : Real
Power
Deploy Structure()
Orient Structure()
«block» «Subsystem» Generic Structural Subsystem
Generic Structure : Structure
ID : String
Structure Type : String
Mass : Real
Power : Real
«block» «Subsystem» Generic Detector Subsystem
Generic Detector Assembly : Detector Assembly
Detector Type : Enum
ID : String
Mass : Real
Power : Real
Create Signal() : Measurement Record
«block» «Subsystem» Generic Emitter/Receiver Subsystem
Emitter/Transmitter
Receiver
Emitter/Receiver Type : enum
ID : String
Power : Real
Mass : Real
Generate Energy()
«block» «Subsystem» Generic Thermal Control Subsystem
ID : String
Mass : Real
Power : Real
M aintain Temperature()
Process Measurement Data(
Regulate Power()
Report Status() : HK Record
Process Command()
bdd [Package] Structure [Generic Imaging Instrument]
«block» «Element» Generic Imaging Instrument
Instrument ID : String
Provider : String
Instrument Type : Enum
Mission ID : String
Make Measurement()
Process Data()
Provide Status()
Execute Command()
Legend
Inherited
Tailored
Mirror : Mirror [1..*]
Light Baffle : Light Baffle [0..*]
Thermal Decon : Thermal Decon [1]
Mechanical Decon : Mechanical Decon [1]
Cal Source : Cal Source [0..*]
Splitter : Splitter [0..1]
^Contingency Power : Real
^Contingency Mass : Real
^CBE Power : Real
^TRL : Integer
Telescope Type : String
Collect Optical Energy()
«block» «Subsystem» Generic Imaging Detector Subsystem
Imaging Detector : Imaging Detector [1..*]
^Detector Type : String
^ID : String
^CBE Mass : Real
^CBE Power : Real
^Contingency Mass : Real
^Contingency Power : Real
^TRL : Integer
^Data Rate Mode 1 : Real
^Data Rate Mode 2 : Real
«block» «Subsystem» Generic Mechanisms Subsystem
Mechanism Type
CBE Mass : Real
Contingency Mass : Real
CBE Power : Real
Contingency Power : Real
TRL : Integer
Deploy Structure()
Orient Structure()
«block» «Subsystem» Generic Electrical Subsystem
Electronics Box : Electronics Box
Harness : Harness
ID : String
CBE Mass : Real
CBE Power : Real
Contingency Mass : Real
Contingency Power : Real
TRL : Integer
Data Rate Mode 1 : Real
Data Rate Mode 2 : Real
Data Rate Mode 3 : Real
Data Rate Mode 4 : Real
Process Measurement Data()
Regulate Power()
Report Status()
Process Command()
«block» Generic Structural Subsystem
Generic Structure : Structure
Structure Type : String
CBE Mass : Real
CBEPower : Real
Contingency Mass : Real
Contingency Power : Real
TRL : Integer
«block» «Subsystem» Generic Flight Software Subsystem
FSW ID : String
bdd [Block] Generic Telescope [Generic Telescope]
«block» «Subsystem» Generic Telescope
Telescope Type : Enum
«block» «Assembly» Mirror
«block» «Assembly» Light Baffle
«block» «Assembly» Cal Source
«block» «Assembly» Thermal Decon
«block» «Assembly» Mechanical Decon
«block» «Assembly» Splitter



The PI called...and wanted a follow on

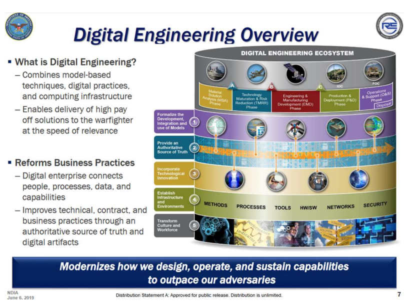
- Evolve the general model into the new specific model
- …or…
- Modify a heritage model to turn it into the new model

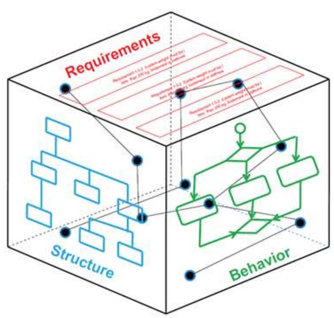


Yeah, but…why not just get someone's spreadsheet?

- What is Digital Engineering?
  - Combines ***model-based techniques***, ***digital practices***, and ***computing infrastructure***
  - Enables ***delivery of high pay off solutions*** to the warfighter at the ***speed of relevance***

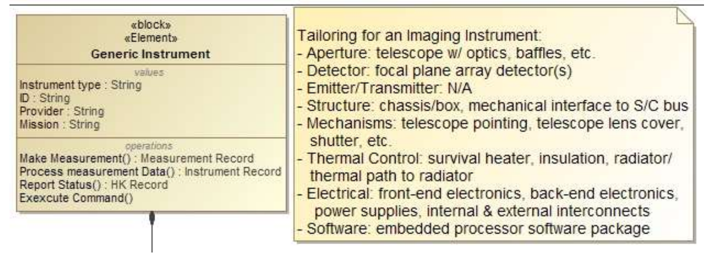
- Reforms Business Practices
  - Digital enterprise ***connects*** ***people, processes, data, and capabilities***
  - Improves technical, contract, and business practices through an authoritative source of truth and digital artifacts

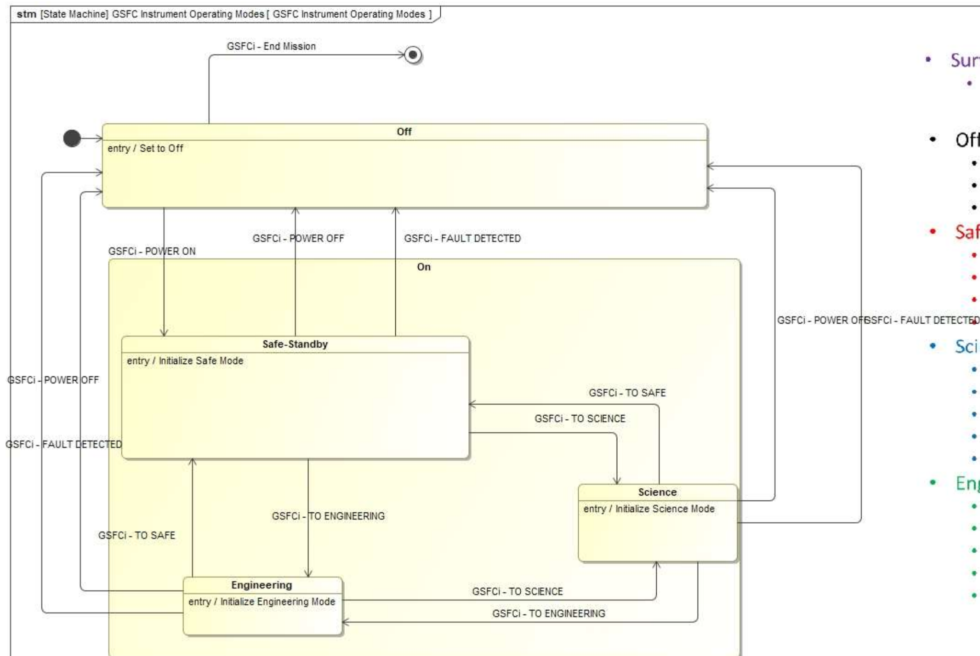




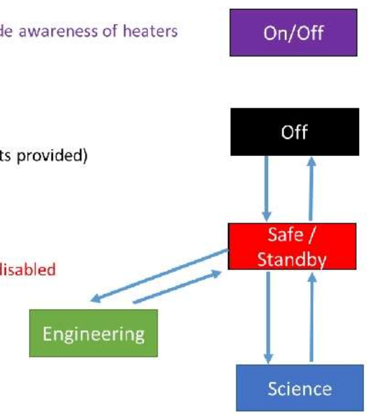
There is more to that model than a block diagram…

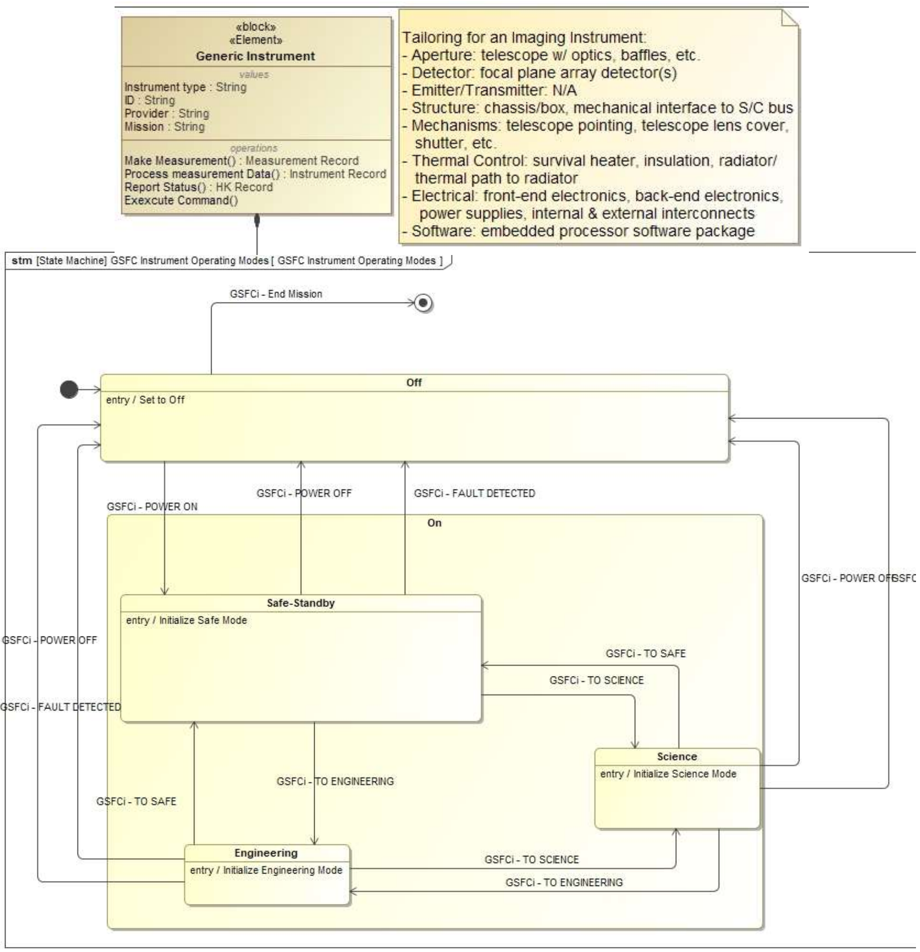
The instrument behaviors are part of the model that can be inherited and modified…

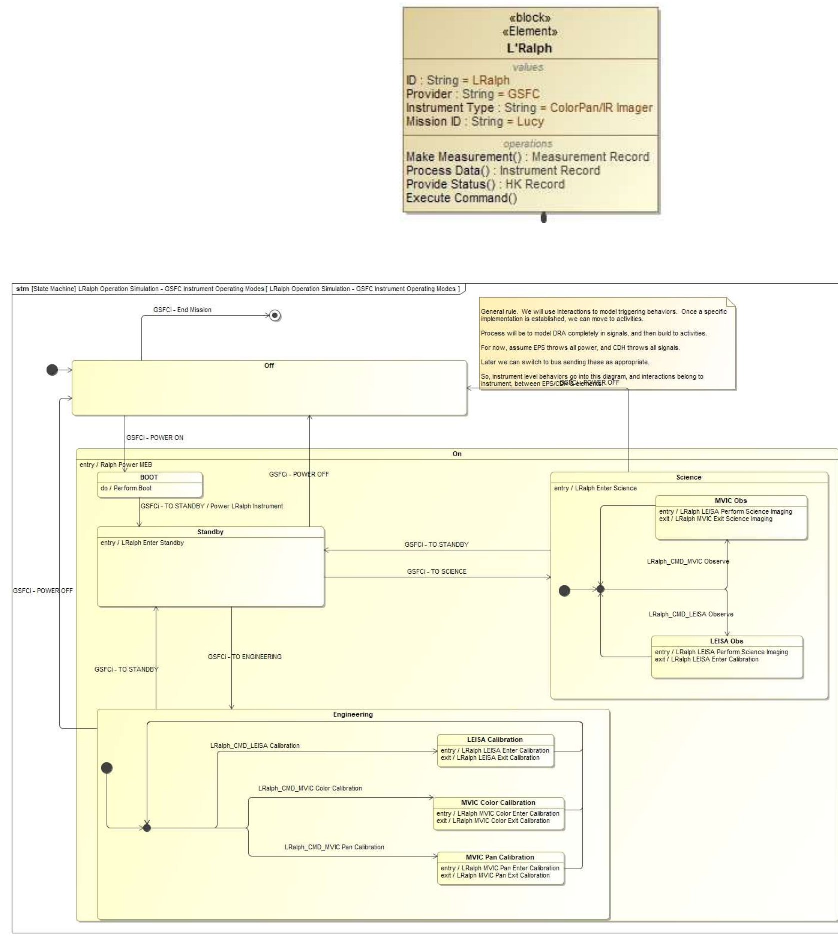




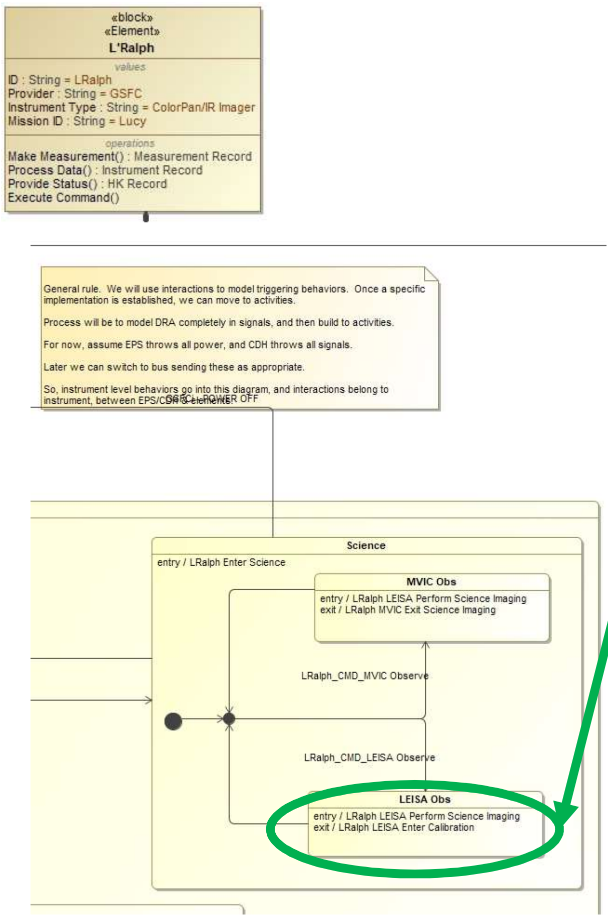
- Survival Heaters On/Off
  - No impact on instrument behavior, but does provide awareness of heaters
- Off
  - No operational power to instrument at all
  - Spacecraft may/may not power survival heater
  - Spacecraft sampled telemetry only (No instruments provided)
- Safe / Standby
  - Minimum operational power
  - Instrument telemetry available
  - Send/receive commands with CDH system
  - Housekeeping telemetry broadcast, science data disabled
- Science
  - Full operational power
  - Instrument telemetry available
  - Send/receive commands with CDH system
  - Housekeeping telemetry broadcast
  - Science data disabled
- Engineering
  - Full operational power
  - Instrument telemetry available
  - Send/receive commands with CDH system
  - Housekeeping telemetry broadcast
  - Run all non-science operations



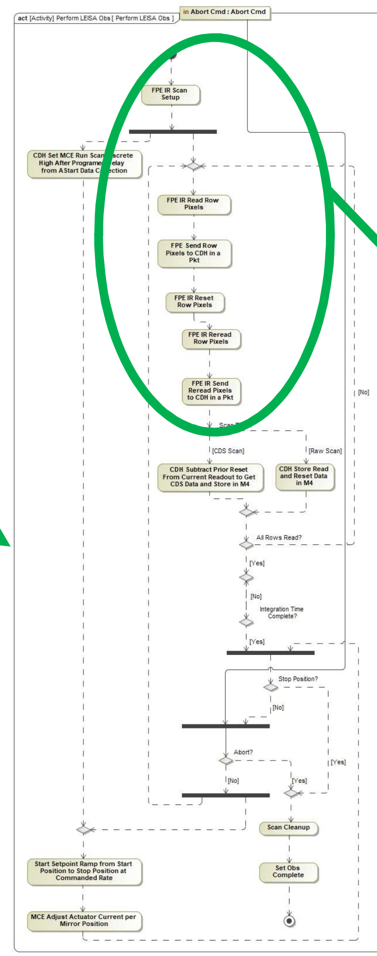


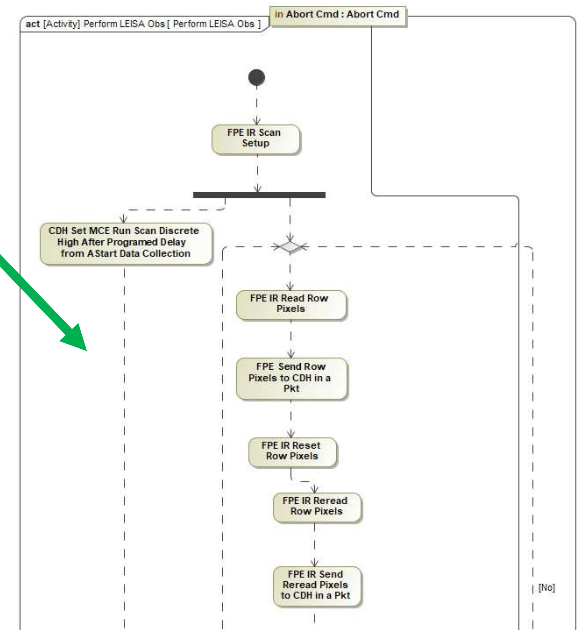


Mode	Description	Condition
Boot-Up	Inst Power = On; MVIC = Off; LEISA = Off; SMM = Off; Cal Targets = Off; Decon Htr = Off; Surv Htr = Enabled	Peak
		Average
Standby	Inst Power = On; MVIC = On (not reading); LEISA = On (not reading); SMM = Point Home; Cal Targets = Off; Decon Htr = Off; Surv Htr = Enabled	Peak
		Average
LEISA Science Imaging	Inst Power = On; MVIC = On (not reading); LEISA = reading; SMM = reading; Cal Targets = Off; Decon Htr = Off; Surv Htr = Enabled	Peak
		Average
LEISA Calibration	Inst Power = On; MVIC = On (not reading); LEISA = reading; SMM = No Drive; Cal Targets = On; Decon Htr = Off; Surv Htr = Enabled	Peak
		Average
MVIC Science Imaging	Inst Power = On; MVIC = reading color; LEISA = On (not reading); SMM = Scanning; Cal Targets = Off; Decon Htr = Off; Surv Htr = Enabled	Peak
		Average
MVIC Color Calibration	Inst Power = On; MVIC = reading color; LEISA = On (not reading); SMM = No Drive; Cal Targets = On; Decon Htr = Off; Surv Htr = Enabled	Peak
		Average
MVIC Pan Calibration	Inst Power = On; MVIC = reading color; LEISA = On (not reading); SMM = No Drive; Cal Targets = On; Decon Htr = Off; Surv Htr = Enabled	Peak
		Average

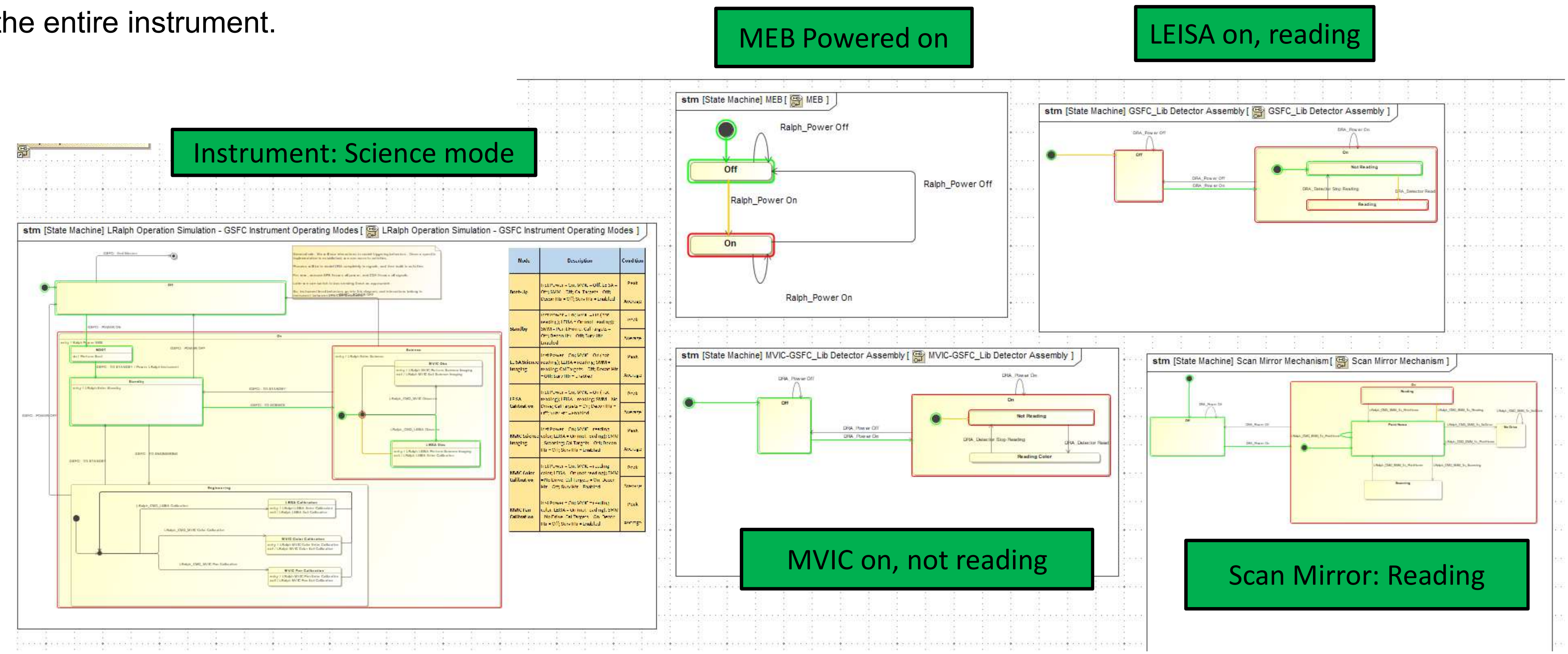


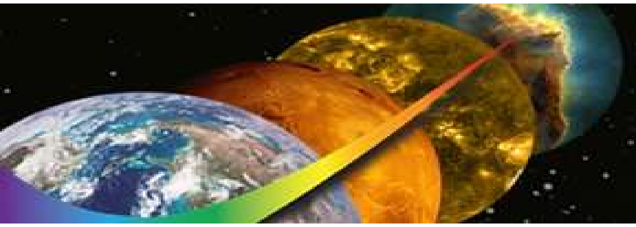
Details for IR imaging detector reading/data processing are inherited for re-use or modification.





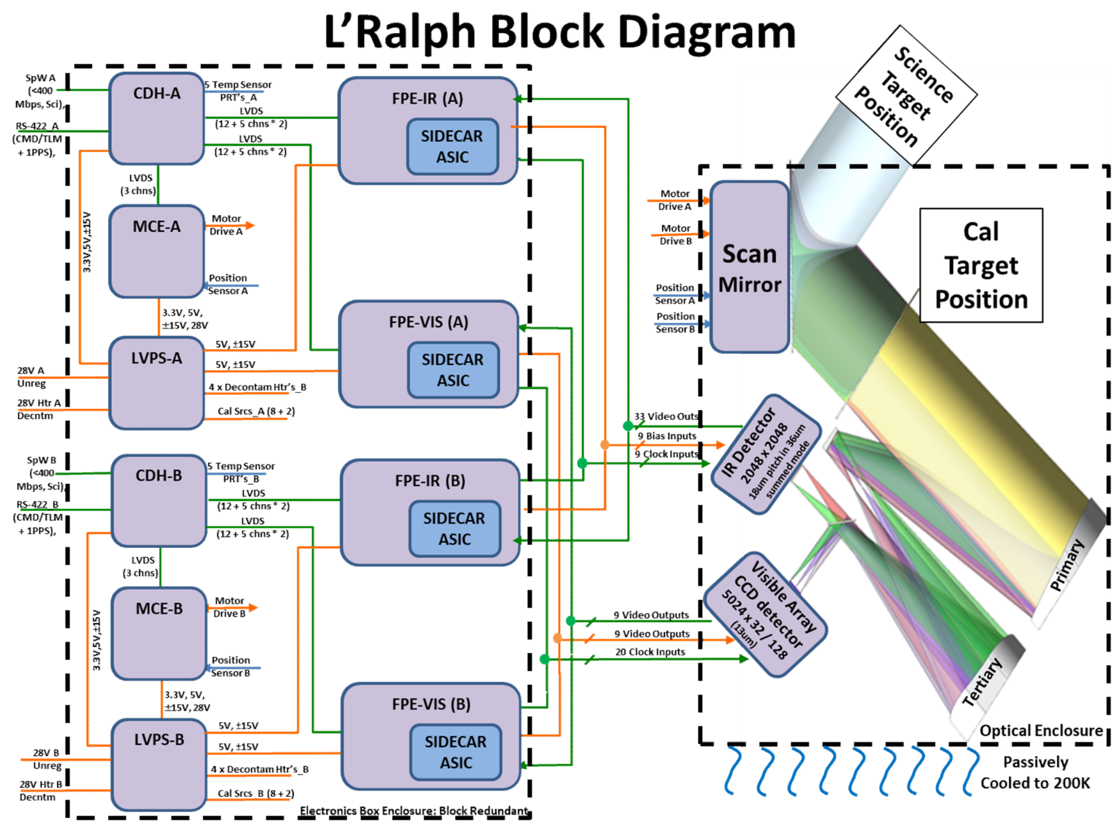
You can even inherit a simulation of the entire instrument.



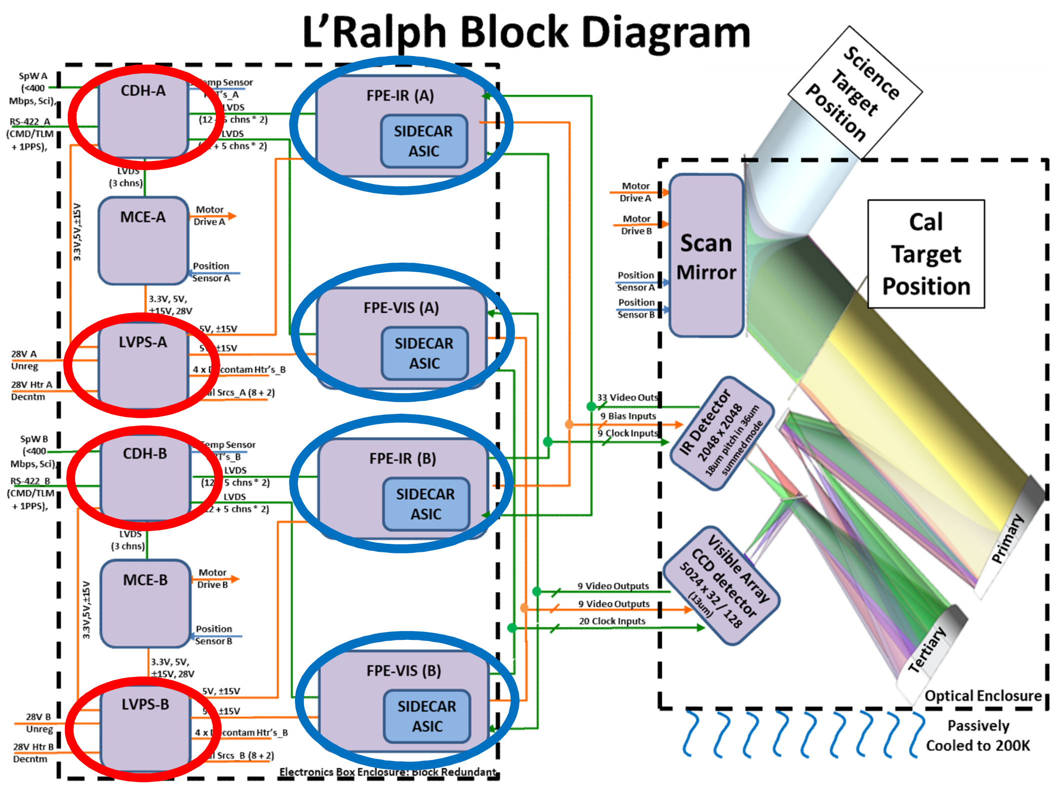


Today…inheriting the Architecture via Documents

Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	# OF UNITS Flight Units	Flight Spares	EMs & Proto-types
Main Electronics Box (S/C deck)		**1**		**5 (not complete builds - see notes)**
C&DH card (3U & single string) - Provides CMD, TLM & science data handling, and overall instrument FSW & control	0.42	2	1	2
LVPS card (SMRT/SMSA, 3U & single strong) - Provides secondary power to C&DH, MCE & FPE cards	0.51	2	1	1
MCE card (redundant on a single 40 sq in board) - Provides power, control & telemetry management of Scan Mirror	0.96	1	1	2
FPE-IR Interface card (A/B Block redundant on same card 6U form factor) - Provides digitization of the science data from the IR detector, detector biasing & clocking, as well as specific command & telemetry management	0.52	1	1	3



Today is good…



- "Functional Flow" BD does not reflect actual physical architecture
- ***Redundant cards*** for LVPS and CDH
- ***Redundant sides*** for Focal Plane Electronics

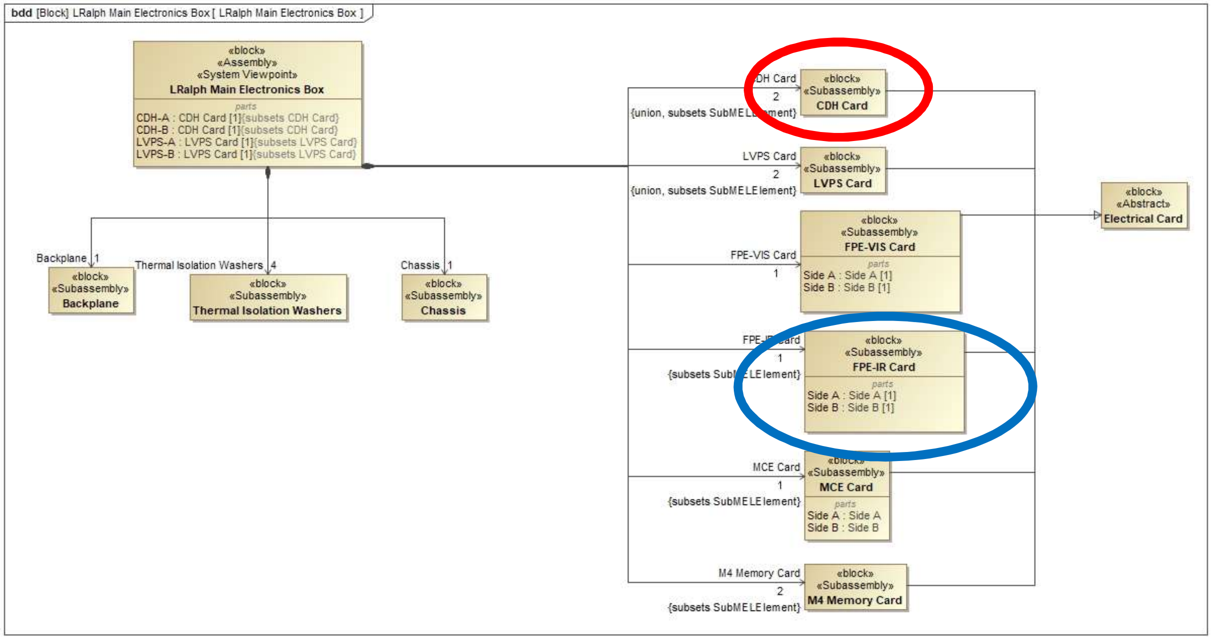
- Now, the purpose if this diagram is more about inter-relation and commodity flow between elements within the Main Electronics Box and the Telescope Assembly

- What if we could change our processes to be more clear about our structure, as we articulate our functional flow… (change our processes)

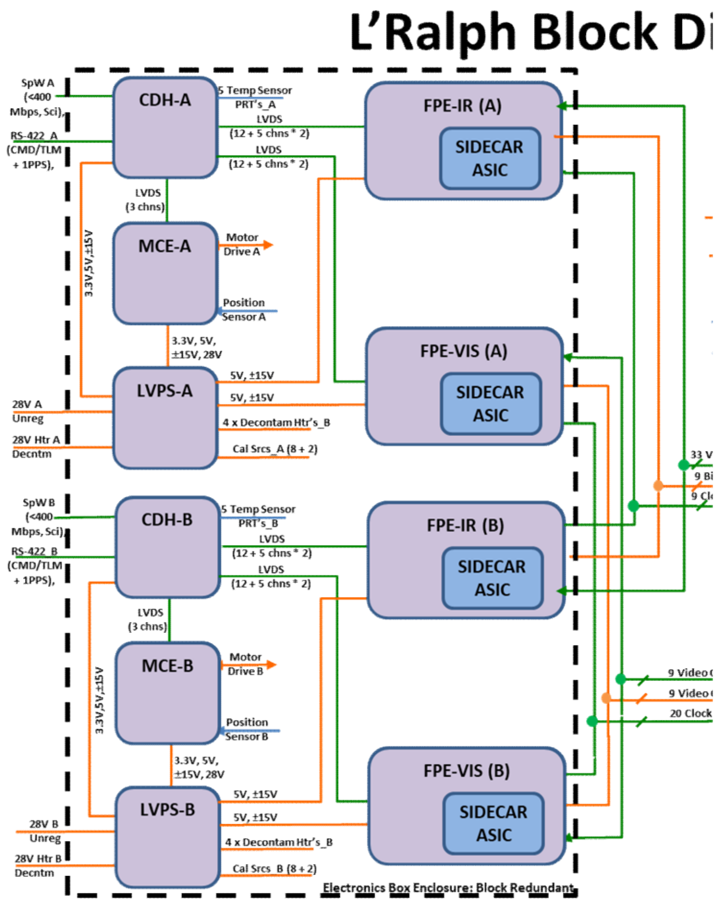
- This would help us evaluate legacy designs to deliberately choose or discard architecture choices

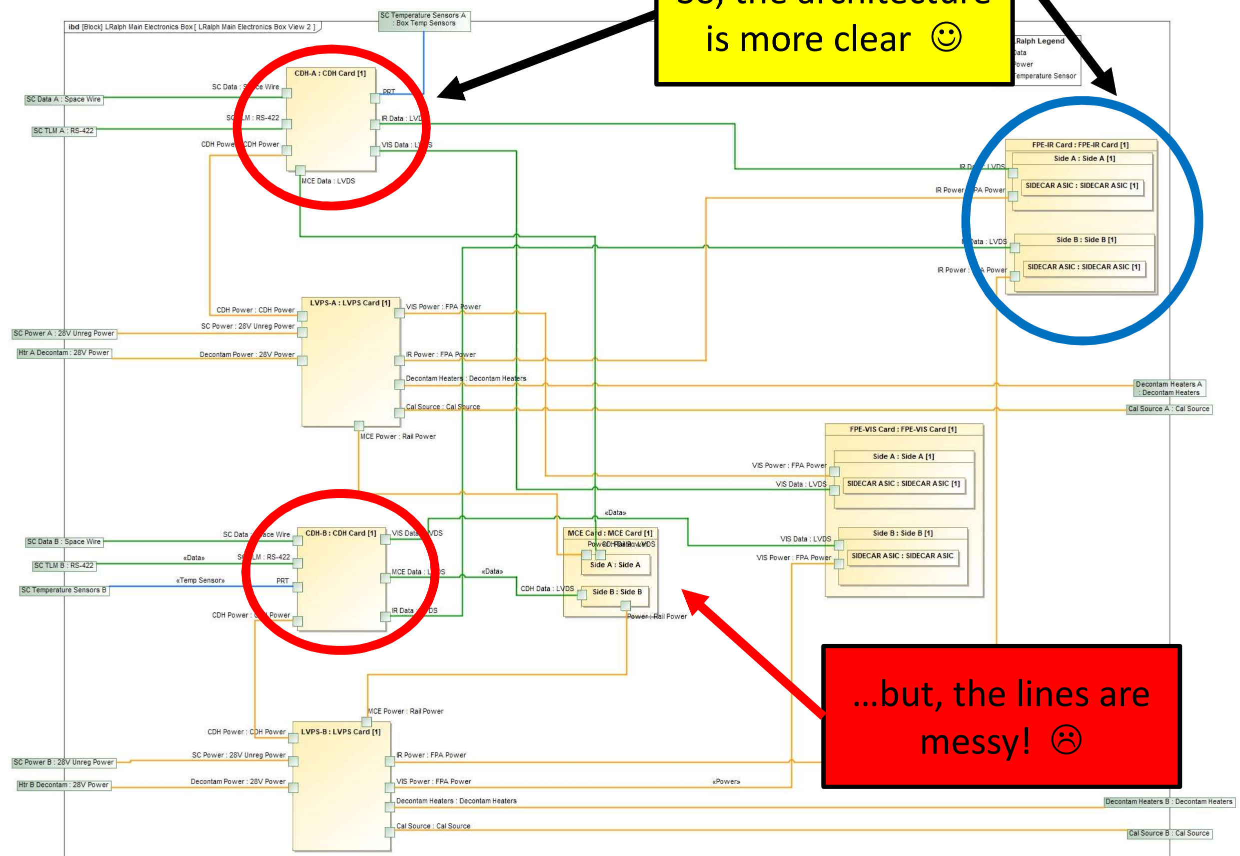
Changing our processes…

Subsystem/Component	Unit Mass, Current Best Estimate (CBE)	# OF UNITS Flight Units	Flight Spares	EMs & Proto-types
Main Electronics Box (S/C deck)		**1**		**5 (not complete builds - see notes)**
C&DH card (3U & single string) - Provides CMD, TLM & science data handling, and overall instrument FSW & control	0.42	2	1	2
LVPS card (SMRT/SMSA, 3U & single strong) - Provides secondary power to C&DH, MCE & FPE cards	0.51	2	1	1
MCE card (redundant on a single 40 sq in board) - Provides power, control & telemetry management of Scan Mirror	0.96	1	1	2
FPE-IR Interface card (A/B Block redundant on same card 6U form factor) - Provides digitization of the science data from the IR detector, detector biasing & clocking, as well as specific command & telemetry management	0.52	1	1	3



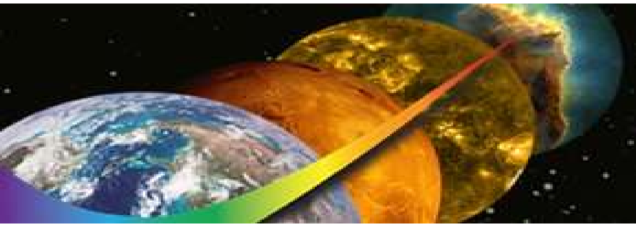
- The actual "Structure" of the electrical box is not shown in a diagram (that I could see)
- This structural architecture (taken from the MEL) shows ***redundant cards*** for LVPS and CDH, and ***redundant sides*** for Focal Plane Electronics





So, the architecture is more clear ☺

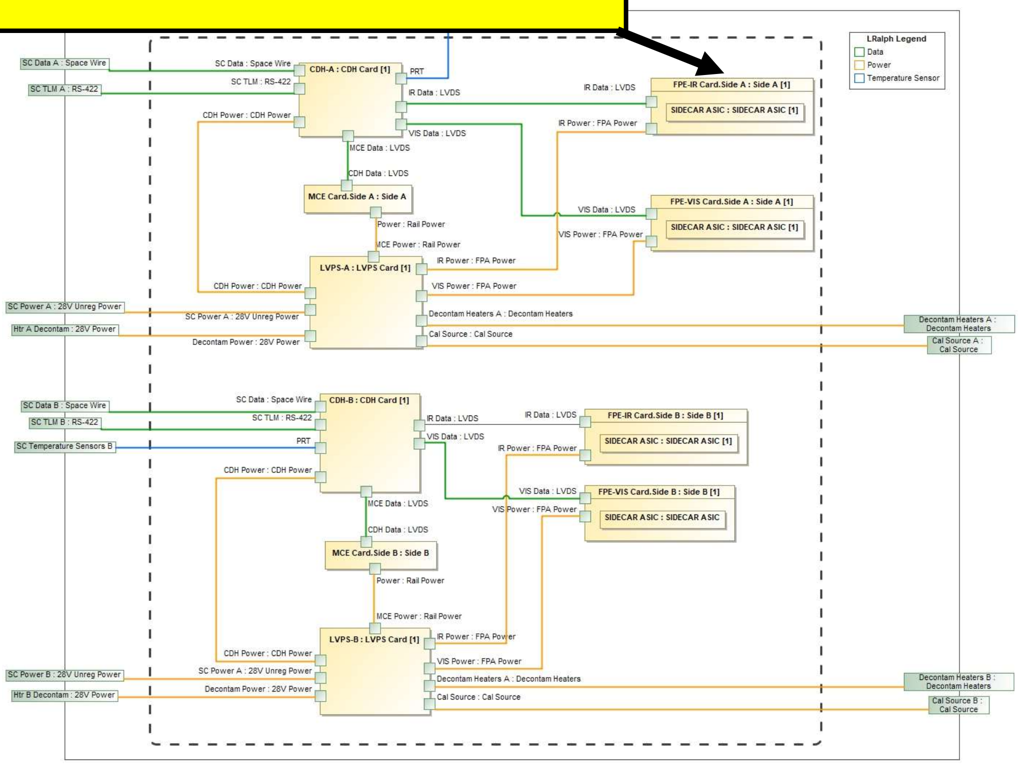
...but, the lines are messy! ☹

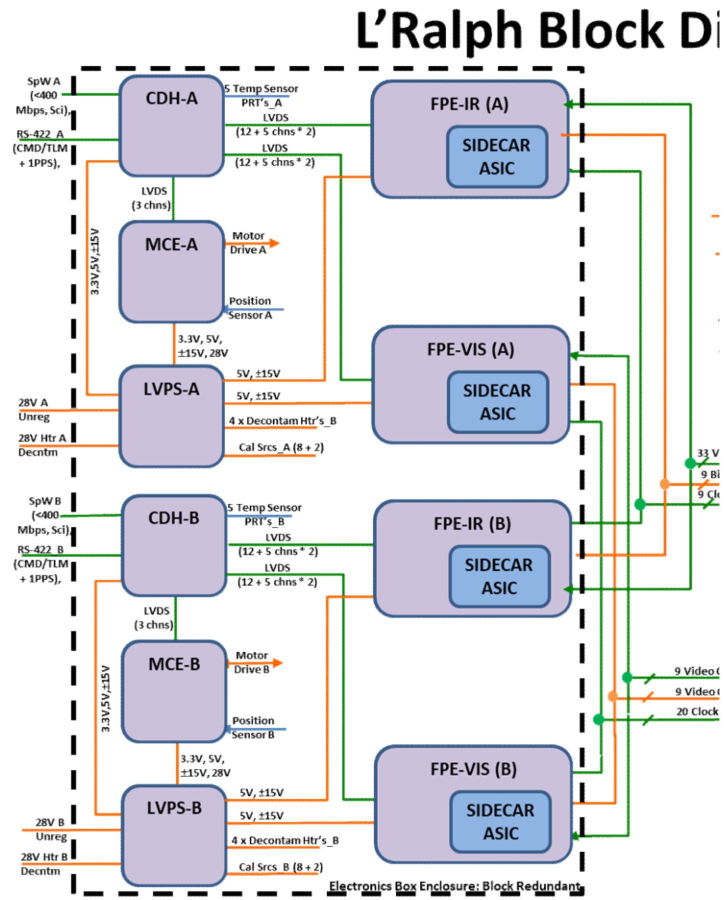


Model Based Systems Engineering

Model Based Systems Engineering Strategy

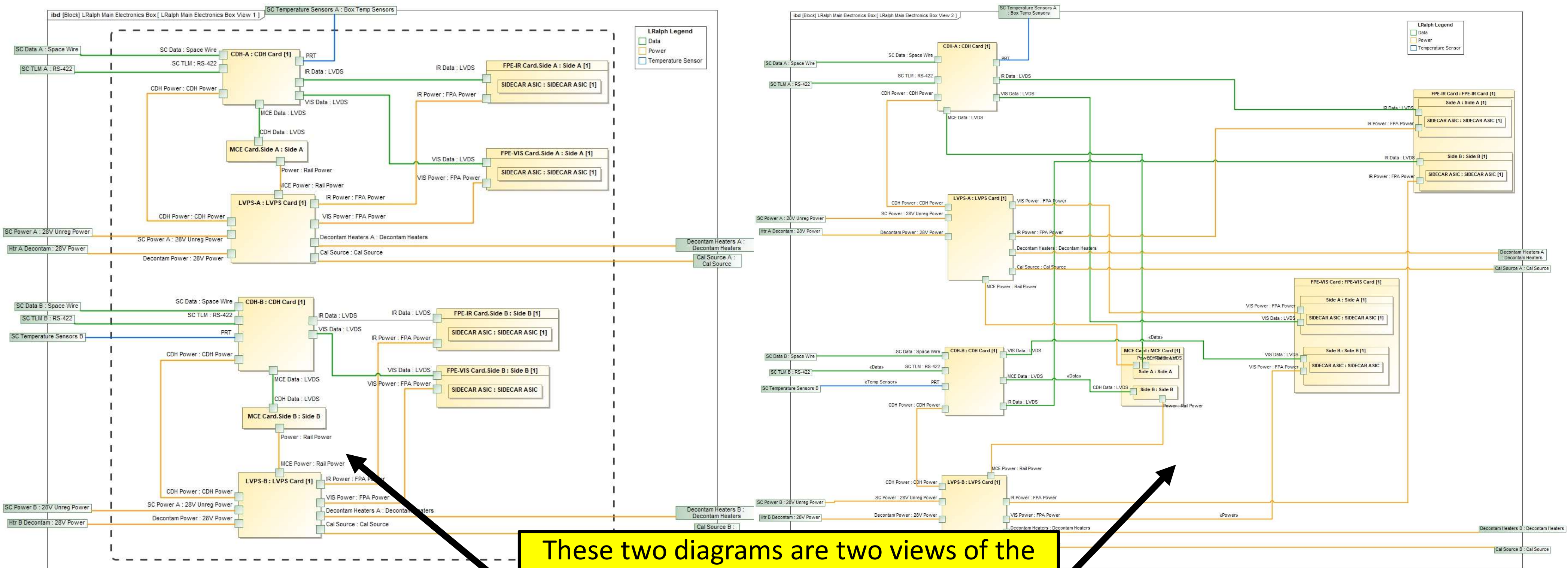
The tool lets you show it differently, and consistent with Architecture! ☺





Model Based Systems Engineering

Model Based Systems Engineering Strategy



These two diagrams are two views of the same thing, so they are consistent. Change one, change both! ☺

And with the click of a button, the interface table is generated…consistent with both diagrams! ☺

#	Part A	Port A	Port A Features	Item Flow	Port B	Port B Features	Part B
1	LRalph Main Electronics Box	Cal Source A : Cal Source			Cal Source : Cal Source		LVPS-A : LVPS Card [1]
2	LRalph Main Electronics Box	Cal Source B : Cal Source			Cal Source : Cal Source		LVPS-B : LVPS Card [1]
3	CDH-A : CDH Card [1]	IR Data : LVDS			IR Data : LVDS		Side A : Side A [1]
4	CDH-A : CDH Card [1]	MCE Data : LVDS		▶ LVDS Data ◀ LVDS Data	CDH Data : LVDS		Side A : Side A
5	CDH-A : CDH Card [1]	VIS Data : LVDS			VIS Data : LVDS		Side A : Side A [1]
6	CDH-B : CDH Card [1]	IR Data : LVDS			IR Data : LVDS		Side B : Side B [1]
7	CDH-B : CDH Card [1]	MCE Data : LVDS			CDH Data : LVDS		Side B : Side B
8	CDH-B : CDH Card [1]	VIS Data : LVDS			VIS Data : LVDS		Side B : Side B [1]
9	LRalph Main Electronics Box	Decontam Heaters A : Decontam Heaters			Decontam Heaters : Decontam Heaters		LVPS-A : LVPS Card [1]
10	LRalph Main Electronics Box	Decontam Heaters B : Decontam Heaters			Decontam Heaters : Decontam Heaters		LVPS-B : LVPS Card [1]
11	LRalph Main Electronics Box	Htr A Decontam : 28V Power			Decontam Power : 28V Power		LVPS-A : LVPS Card [1]
12	LRalph Main Electronics Box	Htr B Decontam : 28V Power			Decontam Power : 28V Power		LVPS-B : LVPS Card [1]
13	LVPS-A : LVPS Card [1]	CDH Power : CDH Power			CDH Power : CDH Power		CDH-A : CDH Card [1]
14	LVPS-A : LVPS Card [1]	IR Power : FPA Power			IR Power : FPA Power		Side A : Side A [1]
15	LVPS-A : LVPS Card [1]	VIS Power : FPA Power			VIS Power : FPA Power		Side A : Side A [1]
16	LVPS-B : LVPS Card [1]	CDH Power : CDH Power			CDH Power : CDH Power	[illegible]	[illegible]
17	LVPS-B : LVPS Card [1]	IR Power : FPA Power			IR Power : FPA Power	[illegible]	[illegible]
18	LVPS-B : LVPS Card [1]	VIS Power : FPA Power			VIS Power : FPA Power	[illegible]	[illegible]
19	Side A : Side A	Power : Rail Power			MCE Power : Rail Power	[illegible]	[illegible]
20	Side B : Side B	Power : Rail Power			MCE Power : Rail Power	[illegible]	[illegible]
21	LRalph Main Electronics Box	SC Data A : Space Wire			SC Data : Space Wire	[illegible]	[illegible]
22	LRalph Main Electronics Box	SC Data B : Space Wire			SC Data : Space Wire	[illegible]	[illegible]
23	LRalph Main Electronics Box	SC Power A : 28V Unreg Power		▶ 28V Power	SC Power : 28V Unreg Power	[illegible]	[illegible]
24	LRalph Main Electronics Box	SC Power B : 28V Unreg Power			SC Power : 28V Unreg Power	[illegible]	[illegible]
25	LRalph Main Electronics Box	SC Temperature Sensors A : Box Temp Sensors			PRT		CDH-A : CDH Card [1]
26	LRalph Main Electronics Box	SC Temperature Sensors B			PRT		CDH-B : CDH Card [1]
27	LRalph Main Electronics Box	SC TLM A : RS-422			SC TLM : RS-422		CDH-A : CDH Card [1]
28	LRalph Main Electronics Box	SC TLM B : RS-422			SC TLM : RS-422		CDH-B : CDH Card [1]

Show details for items conveyed, and characteristics of interfaces themselves.
☺

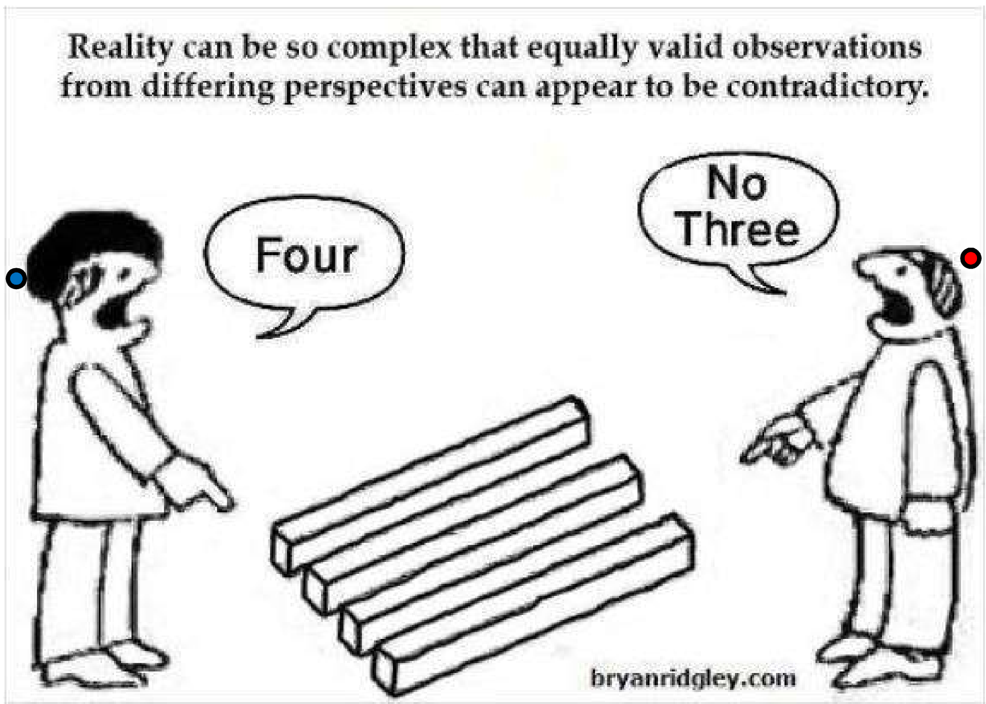
Engineering Perspective

- "Subsystem" view
- Grass roots costing
- Technical Performance Measures
- Typically grouped by Engineering Discipline [ETD Organization]

Management Perspective

- "Product" view
- Resource needs
- Work Breakdown Structure
- Product [Vendor]
- Cross discipline

If only they would use my WBS!



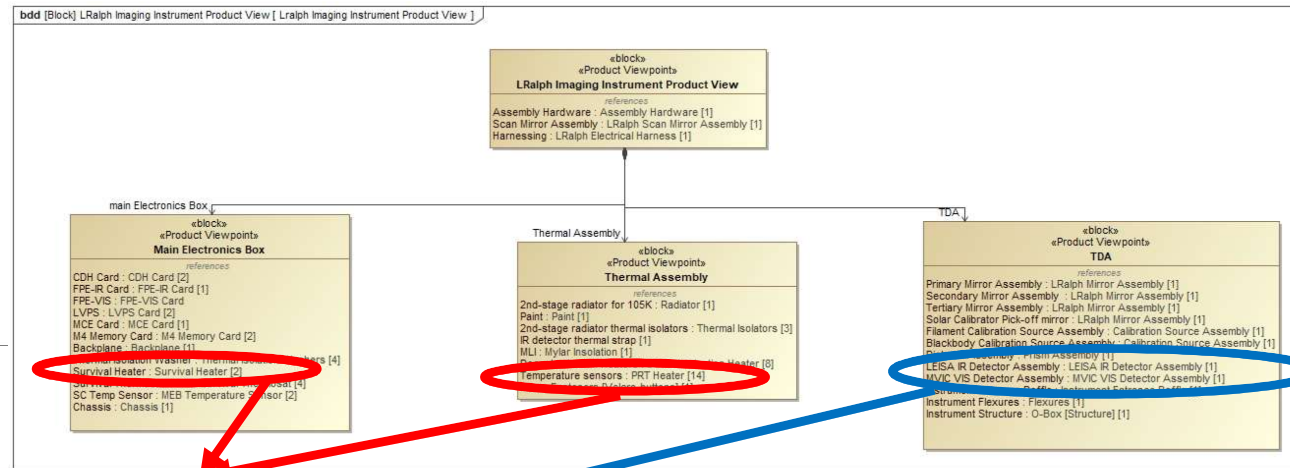
If only they would use my WBS!

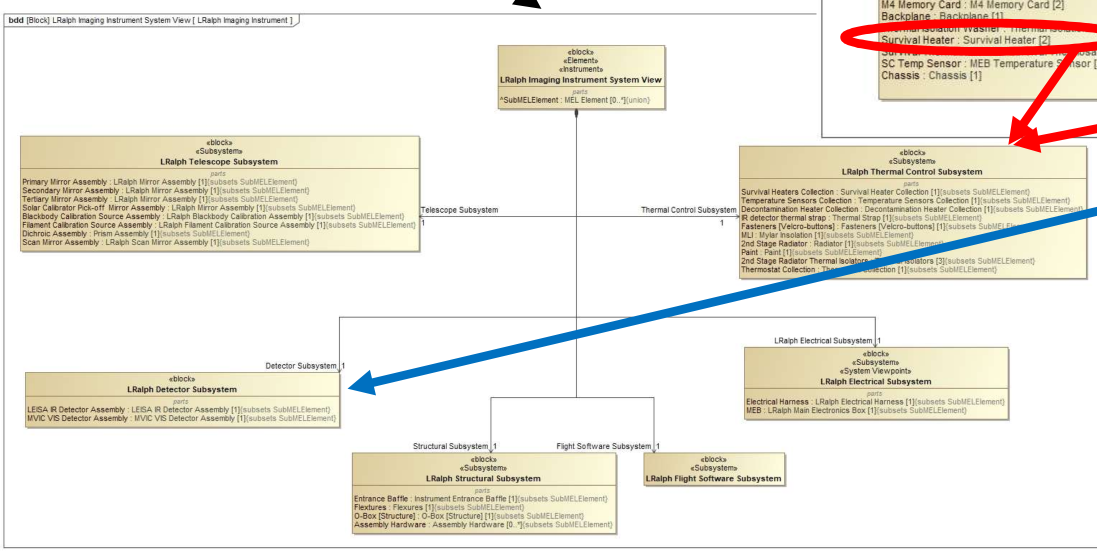
Model Based Systems Engineering

Model Based Systems Engineering Strategy

Engineering Perspective

- **Consistent with ETD Organization**

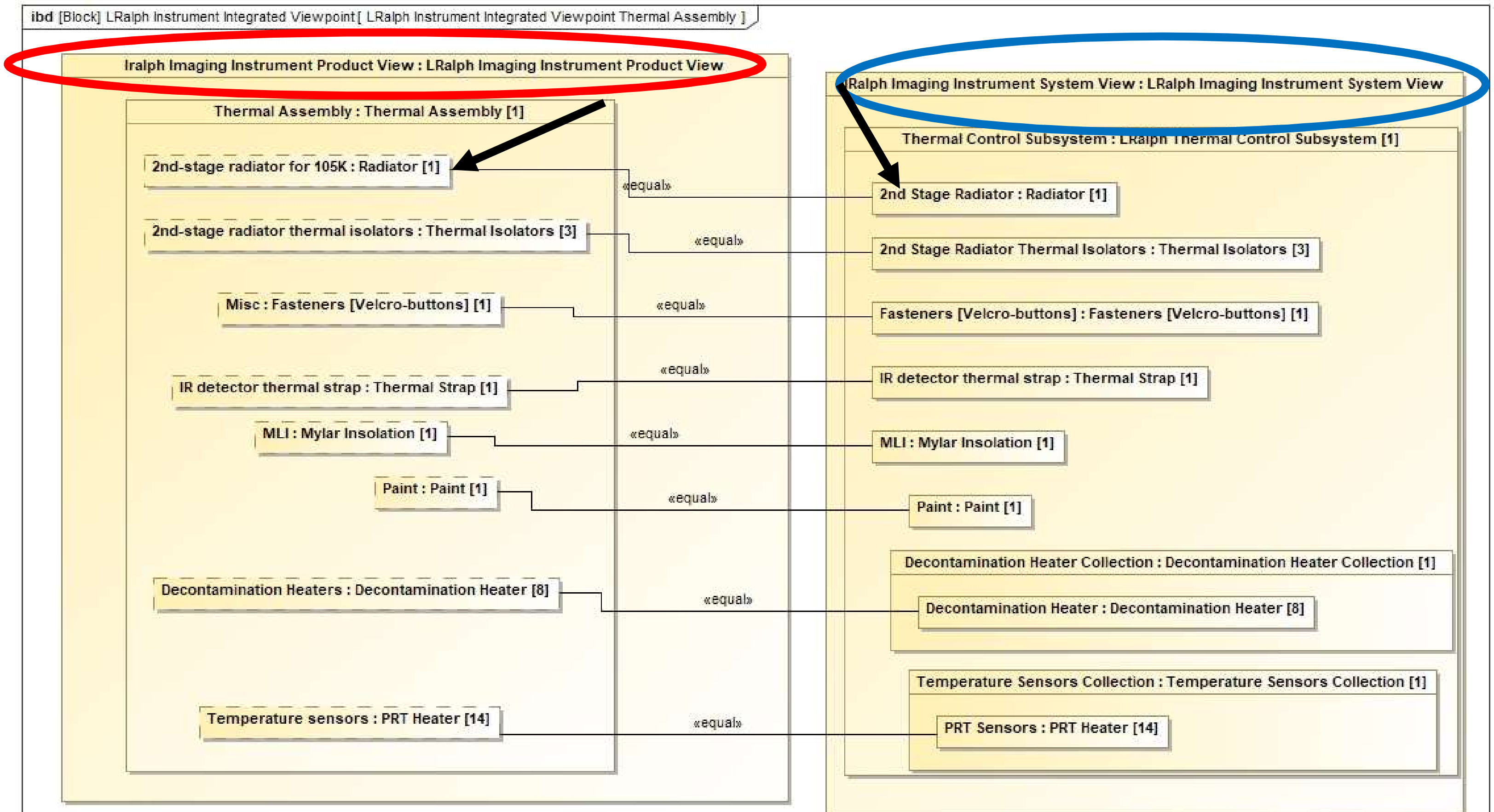


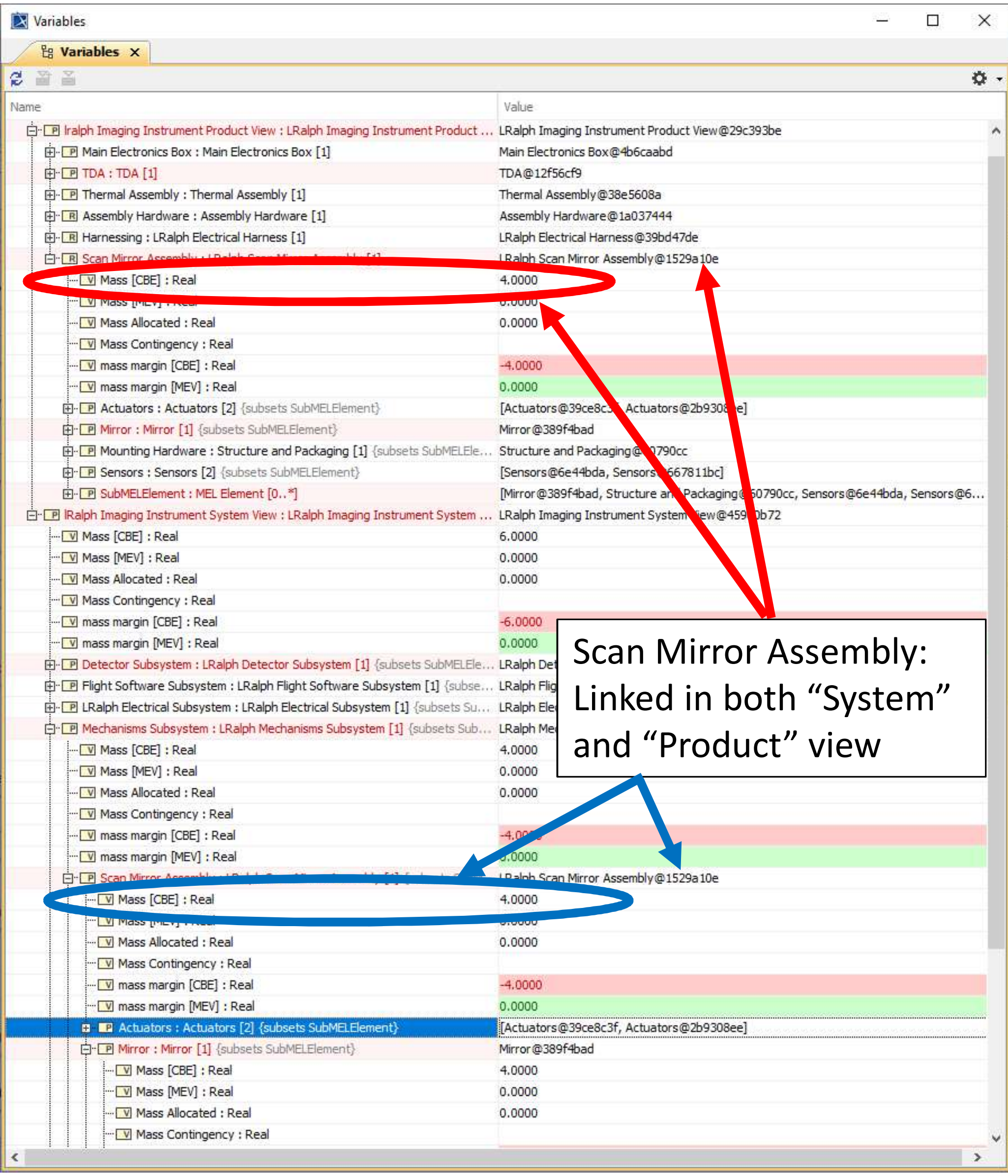


Management Perspective

- **Consistent with the MEL**

- Within the model
  - Link model elements defined in the system viewpoint to those in the product viewpoint
  - Two views of the same system in two structures
  - Data is consistent between them





Model Based Systems Engineering

Model Based Systems Engineering Strategy

- Both the "System View" and the "Product View" are available & changing a value in one, changes it in the other
- The SE is able to track work with the "Engineering Team" and the "Project Team" with the same data
- Grass Roots Cost Estimates will have the same values for sub-assemblies in both views
- "Sub-systems" and "Products" can roll up to different costs/technical budgets and be consistent with one another
- Export to Excel to "publish" into MEL

Recap

- Digital Engineering: An evolving term – and an inevitable future
- MBSE – a stepping stone, and the "Integration" role in DE/MBE
- We have to work differently to evolve
- Design Reference Architectures
  - A "jump start" for the SE (Use the model, don't necessarily build it)
  - Built upon heritage – transfer the knowledge, not the "charts"
  - Access the entire heritage, not just the structure
- System Models
  - Link structure-behavior rules
  - View the same data multiple ways
  - Transform SE process and business processes

Questions?