2018 NIST MBE Workshop

Thad W Henry
Office of Chief Engineer
Systems Engineering Office

April 2, 2018

National Aeronautics and Space Administration

MARSHALL SPACE FLIGHT CENTER

Co-Presenter

"MBSE Real World Deployment Issues"

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Space Launch System

EXPANDING HUMAN PRESENCE IN PARTNERSHIP

CREATING ECONOMIC OPPORTUNITIES, ADVANCING TECHNOLOGIES, AND ENABLING DISCOVERY

Now

Using the International Space Station

2020s

Operating in the Lunar Vicinity (proving ground)

After 2030

Leaving the Earth-Moon System and Reaching Mars Orbit

Phase 0

Continue research and testing on ISS to solve exploration challenges. Evaluate potential for lunar resources. Develop standards.

Phase 1

Begin missions in cislunar space. Build Deep Space Gateway. Initiate assembly of Deep Space Transport.

Phase 2

Complete Deep Space Transport and conduct yearlong Mars simulation mission.

Phases 3 and 4

Begin sustained crew expeditions to Martian system and surface of Mars.

Additive Manufacturing NASA | MSFC

Omar Mireles
Zachary Jones
Kenneth Cooper
Brian West

James Lydon
Phillip Steele
Susan Barber
Mariana Chaidez

December 2017

Advantages

- Advantages:
  - Increased design freedom and customization
  - Near net-shape
  - Complex geometry
  - Weight reduction
  - Improved performance
  - Part count reduction
  - One-off and discontinued parts
  - Shorter lead times
  - Properties better than cast, 10% below wrought
- Apply to highly complex, low production rate parts
  - Supplement traditional manufacturing
  - Low complexity, high production rate parts will cost more when compared to traditional manufacturing and take longer
- High hourly rates offset by reducing labor costs

First 3D printed jet engine demo. Courtesy GE.

Topology optimized & printed bracket. Courtesy Airbus.

Lattice Structure

Disadvantages

- Misconceptions
  - *MORE* expensive than traditional manufacturing (hourly basis)
  - Waste generation: spent powder, build plates, failed builds
  - Substantial touch labor

- Disadvantages:
  - Powder Bed Fusion (PBF) limited to weldable alloys
  - Build envelope size limits
  - Design constraints: overhang surfaces, minimum hole size
  - Surface roughness
  - As built microstructure will likely require post processing

- Property Variability
  - Properties dependent on starting powders, process parameters, and post-processing
  - Anisotropic properties in the build direction (Z)
  - Size: small-scale vs. full-scale builds
  - Build volume spatial location

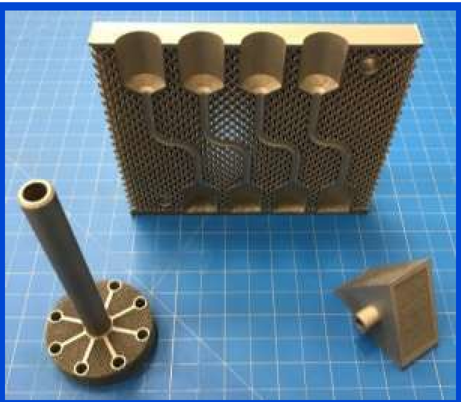
Spent build plates and oversized powder

Vacuumed power

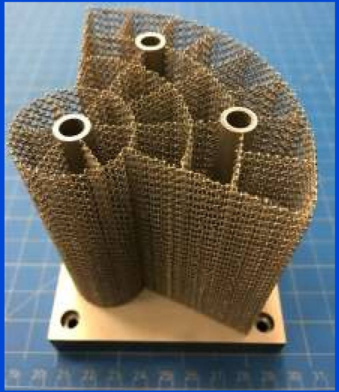
Expand AM to Enable Capability


Green Propulsion Thruster & Stand-Off


Topology Optimized M1 Reduced Area Piston

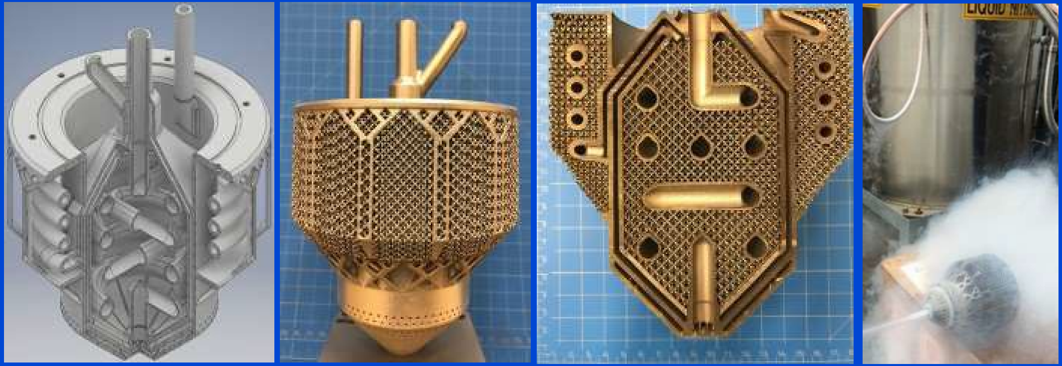

CFM Magnetically Coupled Rotor, Heat Exchanger, LAD concepts


Lattice Regen Chamber


ECLSS CO_2 Removal Demo


KSC O_2 Generator Cold-Head


GRC ASRG Displacement Springs


Cryo Heat Exchanger-Injector-Condenser Demo


AMPed LOX Impeller Iterations

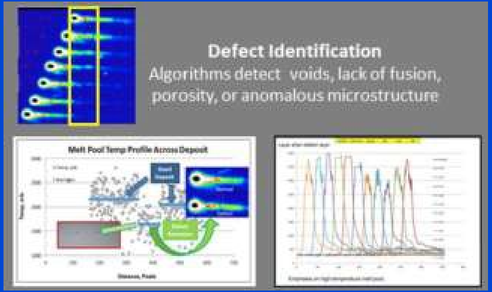
Near Term Activities

- New alloy parameter development
- Custom AM Alloys
- Design for Additive
  - Methods & file lock down process
  - Lattice structure optimization
  - Topology Optimization
- In-Situ Monitoring & Closed loop feedback
  - PrintRite 3D by SigmaLabs & ThermViz by Stratonics
  - Currently 4 SBIRs funding for 2017/18
- Multi-Material (bi-metallic, functional gradients)
  - Identify promising efforts (blown powder, wire, friction stir)
  - Evaluate development (metallography, mechanical test).

Current Alloys	Licensed Alloys	Alloys of Interest
IN625	AlSi10Mg	Monel K500
IN718	CoCr	Hanes 230
GRCop-84	Hasteloy X	Haynes 282
Ti64*	Marginal Steel	Mar M-247
	316L SS	Refractories
	Ti64	Many others!

Topology optimized & printed bracket.

EOS M100
Build Size: Ø100x100 mm
Power: 200 W
Spot Size: 40 µm



ISM courtesy Stratonics

IN625-GRCop84 Bimetallic ASTM E8 Tensile Bar

MBSE Infusion And Modernization Initiative (MIAMI)

FY16: **Learn & Align**

FY17: **Learn & Apply**

FY18 & FY19: **Develop Recognized Core Capability**

FY20: **Targeted Deployment**

MBSE Vis

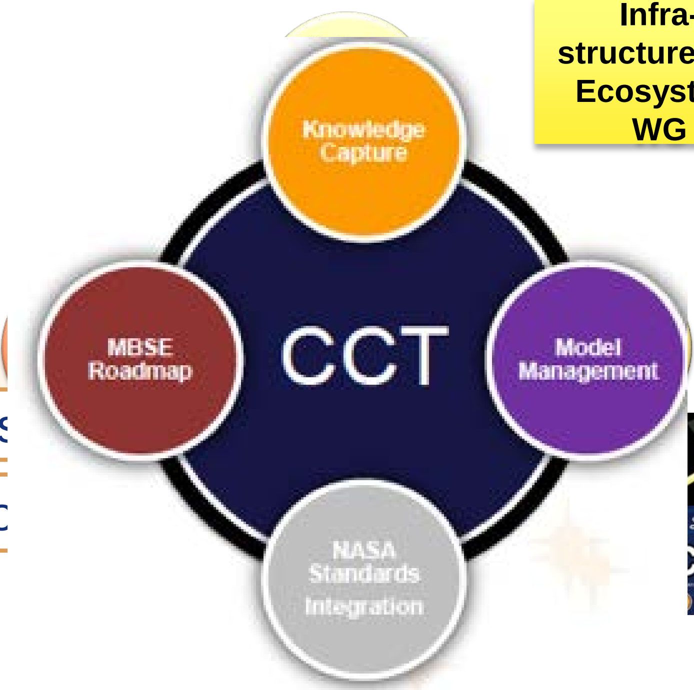
MBSE Ro

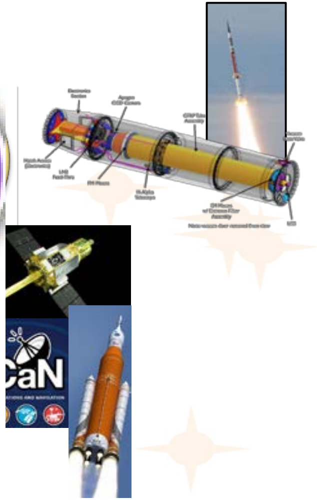
Systems Modeling WG

Systems Analysis and Data Visualization WG

Infra-structure and Ecosystem WG

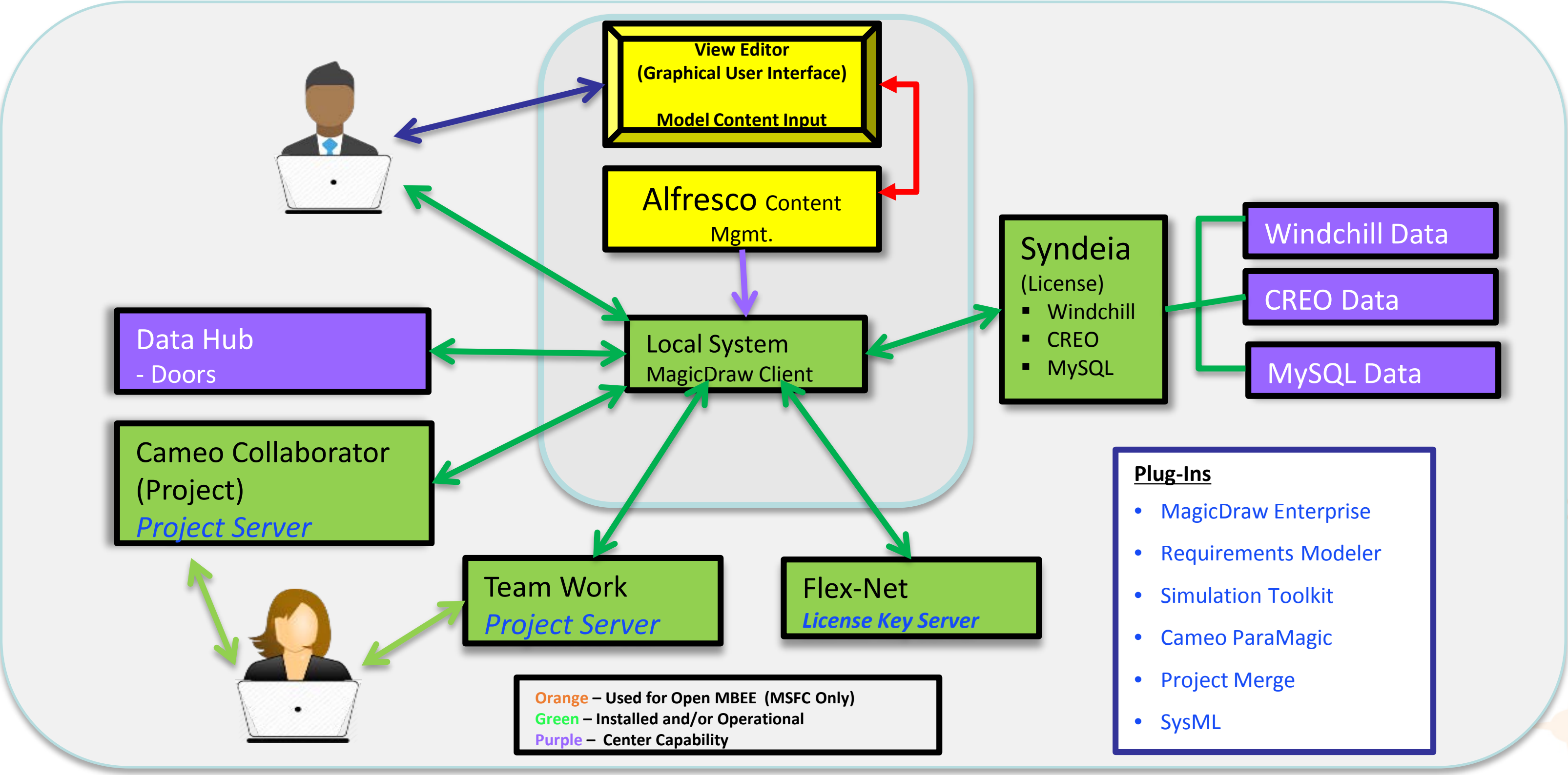
Digital Practitioner Community





MBSE Infusion And Modernization Initiative (MIAMI)

MBSE Integrated Architecture Deployment (Ecosystem)



PDES is an International Team of Aerospace Practitioners who partner with INCOSE:

- Identify existing MBSE Data Standards and Tools
- Define reusable process for OEMs-Suppliers
- Develop new Standards and identify alternative Tools and Processes, to FILL The GAPS!

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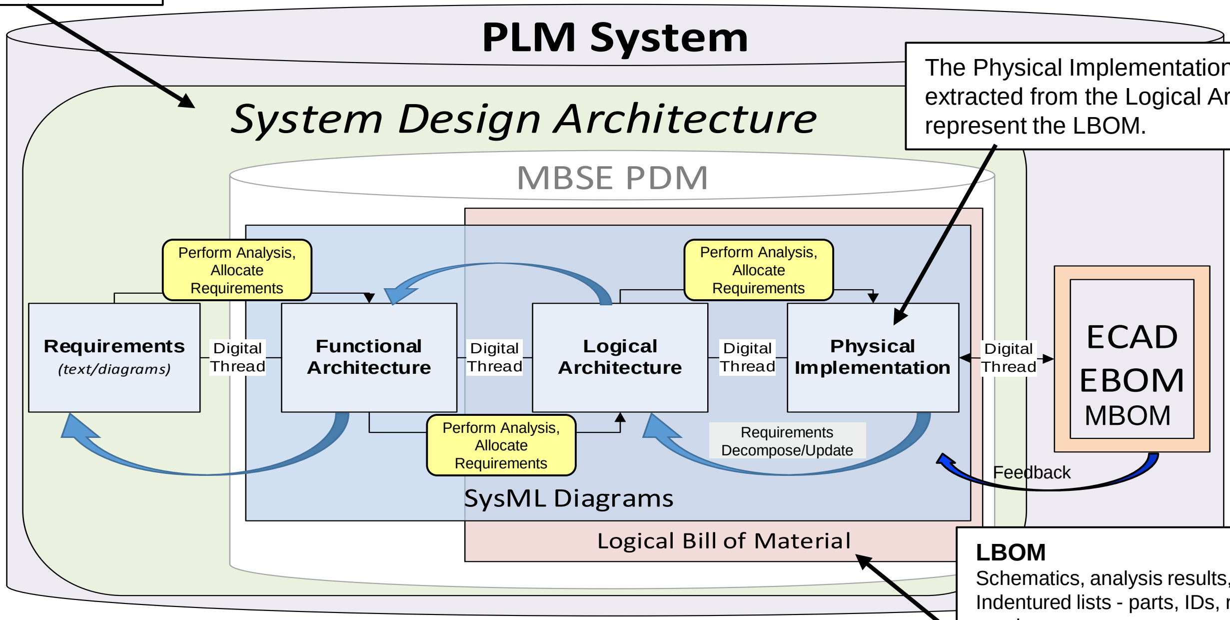
Many of the NIST MBE Summit presentations highlight the connection between ECAD and MCAD using PMI.

"Add MBSE, and you could build a Digital Thread"

MBSE

"Interdisciplinary architecture and analysis defined as integrated digital models that are coherent, and consistent."

RFLP Process
(from an MBSE view)



The Physical Implementation represents the views extracted from the Logical Architecture that represent the LBOM.

LBOM
Schematics, analysis results, sizing, materials, connectivity
Indentured lists - parts, IDs, requirements, verification needs
Work statement narratives - Mfg Testing Criteria
Safety Needs - protection, containment, handling, separation, restrictions

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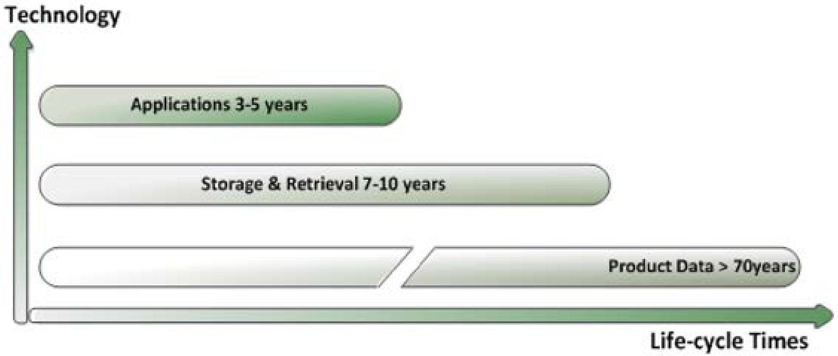
MBSE Digital Thread

The Transition to MBSE – Maturing the Analysis and Simulation Process ,
Credit: Hubertus Tummescheit (Modelon) and Mark Williams (Boeing)

LOTAR

Long-Term Archiving and Retrieval



- ✓ Assuming stable application versions for at least 3yrs
  - ✓ *Tool Vendors want to sell application upgrades*
- ✓ An enterprise needs effective digital data storage and access for 10 years.
- ✓ Be able to translate digital data to stable formats for 20-50 year reuse.
- ✓ LOTAR is Enabled by Standards

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MBSE to LOTAR

CREDIT: PDES Presentation www.incose.org/IW2018

http://www.lotar-international.org

- Establish existing Data Standards and Tools

  AIA, ASIC, INCOSE, PDES, NDIA
- Define reusable process for OEMs-Suppliers

  Implementers Forums
- Identify Process, Tools and Standards GAPS!
  - ADL/SysML Exchange
  - Library of Data Models, Profiles, and Standard Architectures
  - Digital Thread, formalize LBOM to EBOM (PMI to MCAD)
  - Requirements Traceability

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Project Goals and Opportunities

Why is a System Model Important?

- Systems Engineers are all about
  - *getting to good requirements* and then
  - *tracking them* into system development
  - … operational requirements, functional requirements, performance requirements, interface requirements…

- Doing this well is more than writing “shall” statements!
  - Understanding and describing user/stakeholder needs
  - Articulating quality attributes/success criteria
  - Documenting desired capability, operations, functionality, and performance
    - Some of these factors drive analysis and simulation, others drive key technology
  - Developing methods to test the system during and after development

- SysML provides a language to model these concepts!

Understanding SysML Models/Diagrams

- General SysML concepts
  - The diagram frame represents a model element. Knowing which one helps you understand the perspective of the diagram.
  - Naming convention helps understanding (property_name : Type_Name)

- Internal Block Diagram (***ibd***): contextualized structure, typical "system block diagrams" with connections and flows

- Block Definition Diagram (***bdd***): parts trees, BOM, definition and use of reusable things

- Behavior can be modeled 3 different ways:
  - *Owned* (state machine ***stm***), Un-owned or allocated *Function* (activity ***act***), or message *Sequence* (interaction/sequence ***sd***)

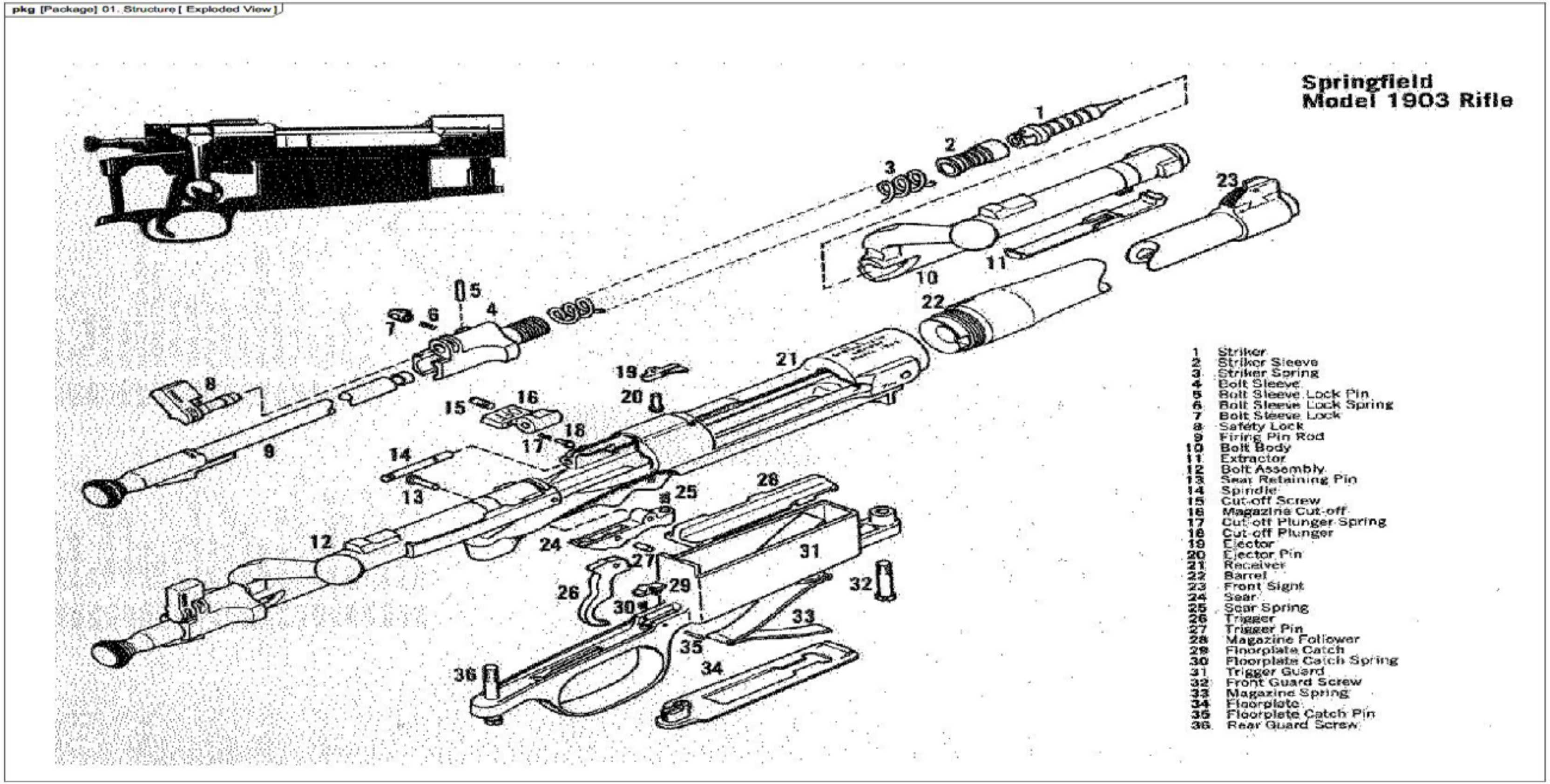
Example of a SysML model of a Fundamentally Mechanical System

- Subject is a historically significant **US Army bolt-action rifle**
  – Service use in both WWI and WWII
  – Same design pattern is used in vast majority of modern hunting rifles
- Straightforward design with no electronics or software
  – Suitable to demonstrate part hierarchy as well as connection/interfaces between parts
- Has requirements, analysis, functional aspects

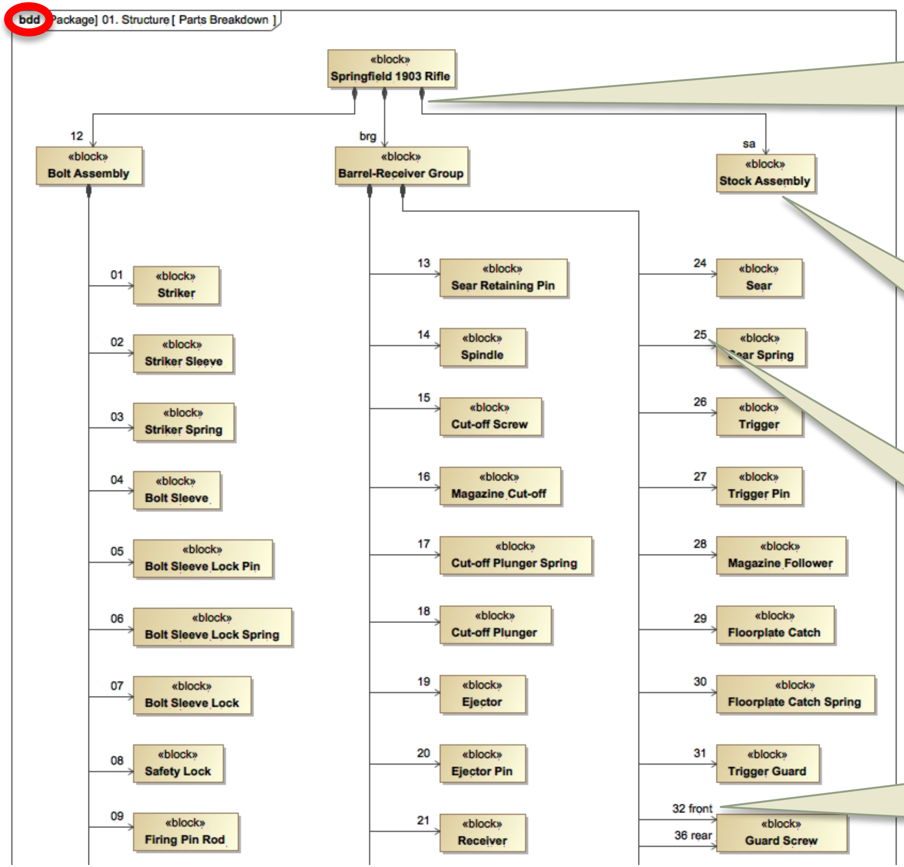
Link to SysML Model

Source Data for SysML Model

Exploded View



Duplicating the Parts Breakdown in SysML:
Block Definition Diagram (bdd)



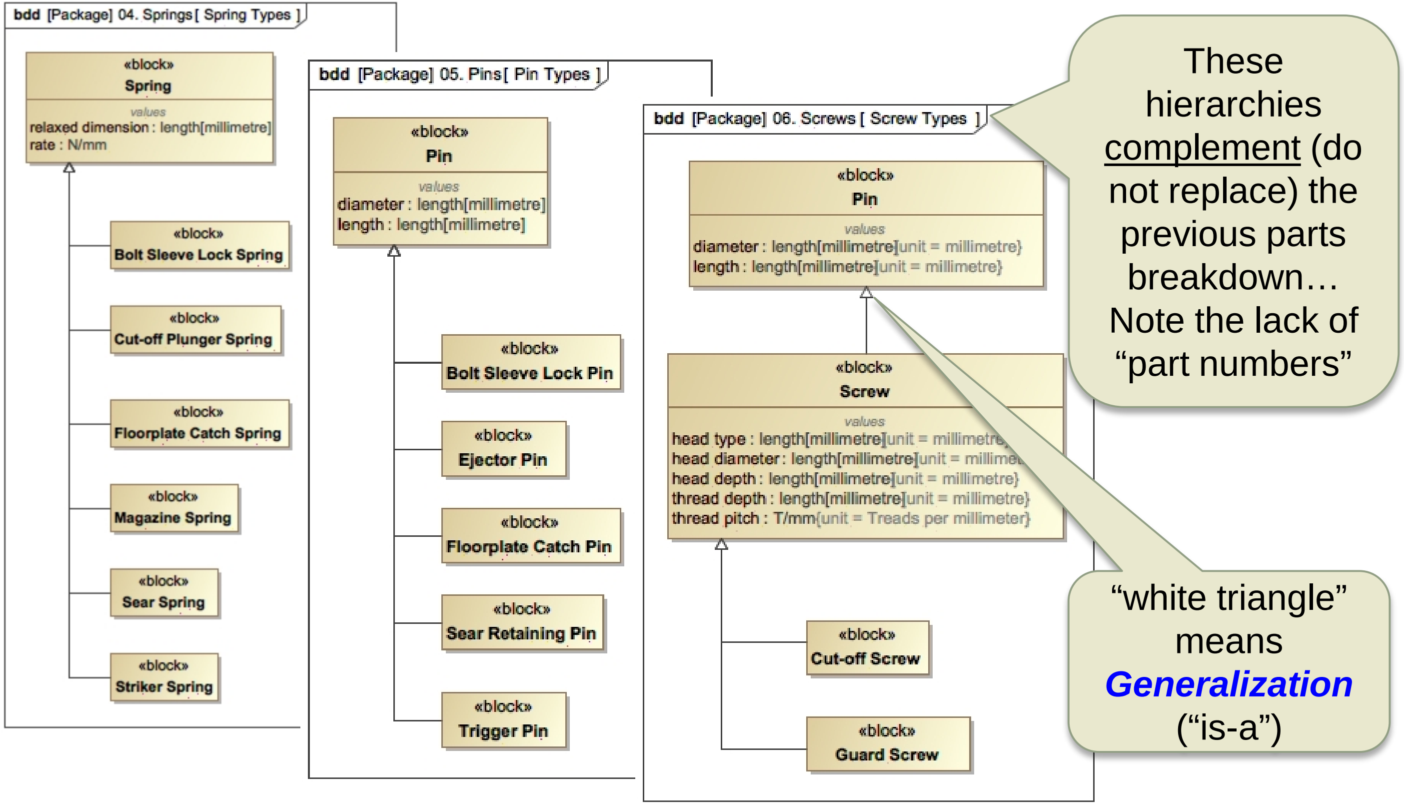
"black diamond" means ***Composition*** ("has-a")

Logical Part Groupings Established

Part Numbers Map to Source Data

Identical Parts Noted

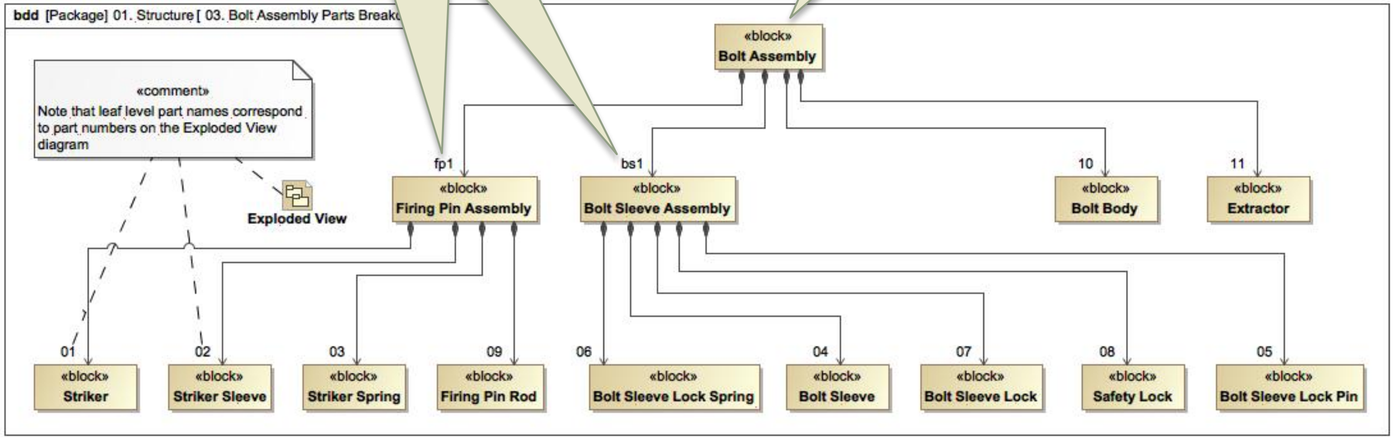
Making Parts Re-Usable (bdd): *Generalization*

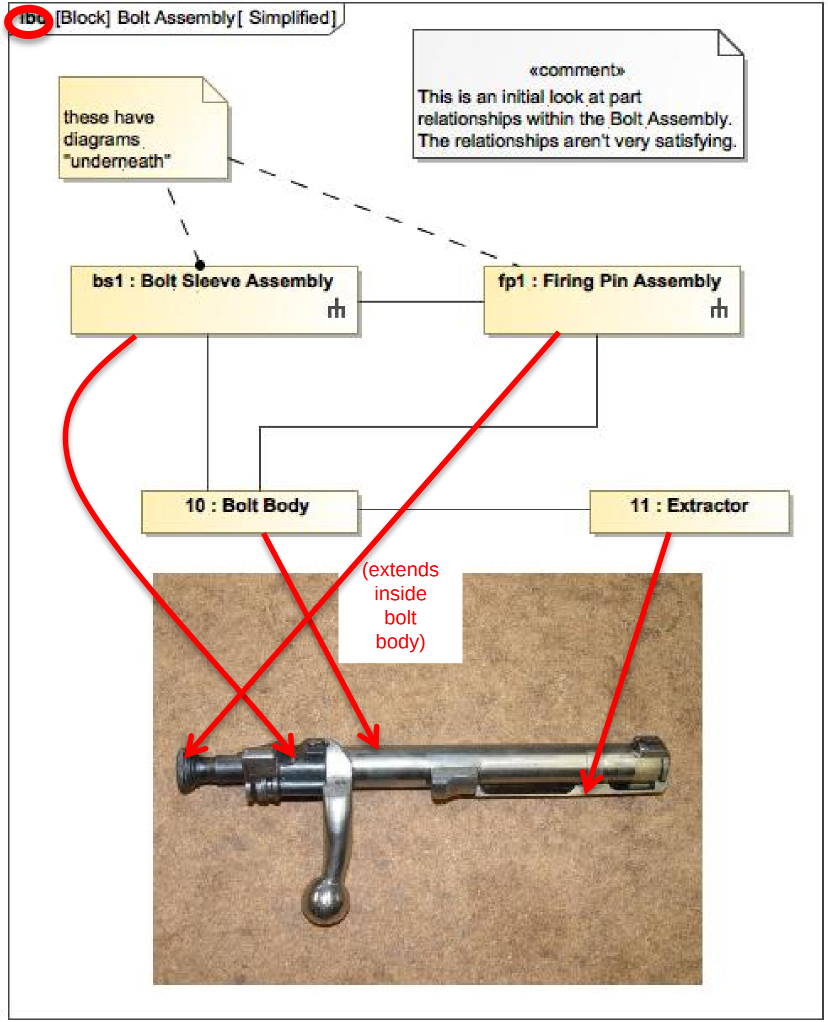


Bolt Assembly Parts Breakdown (bdd)

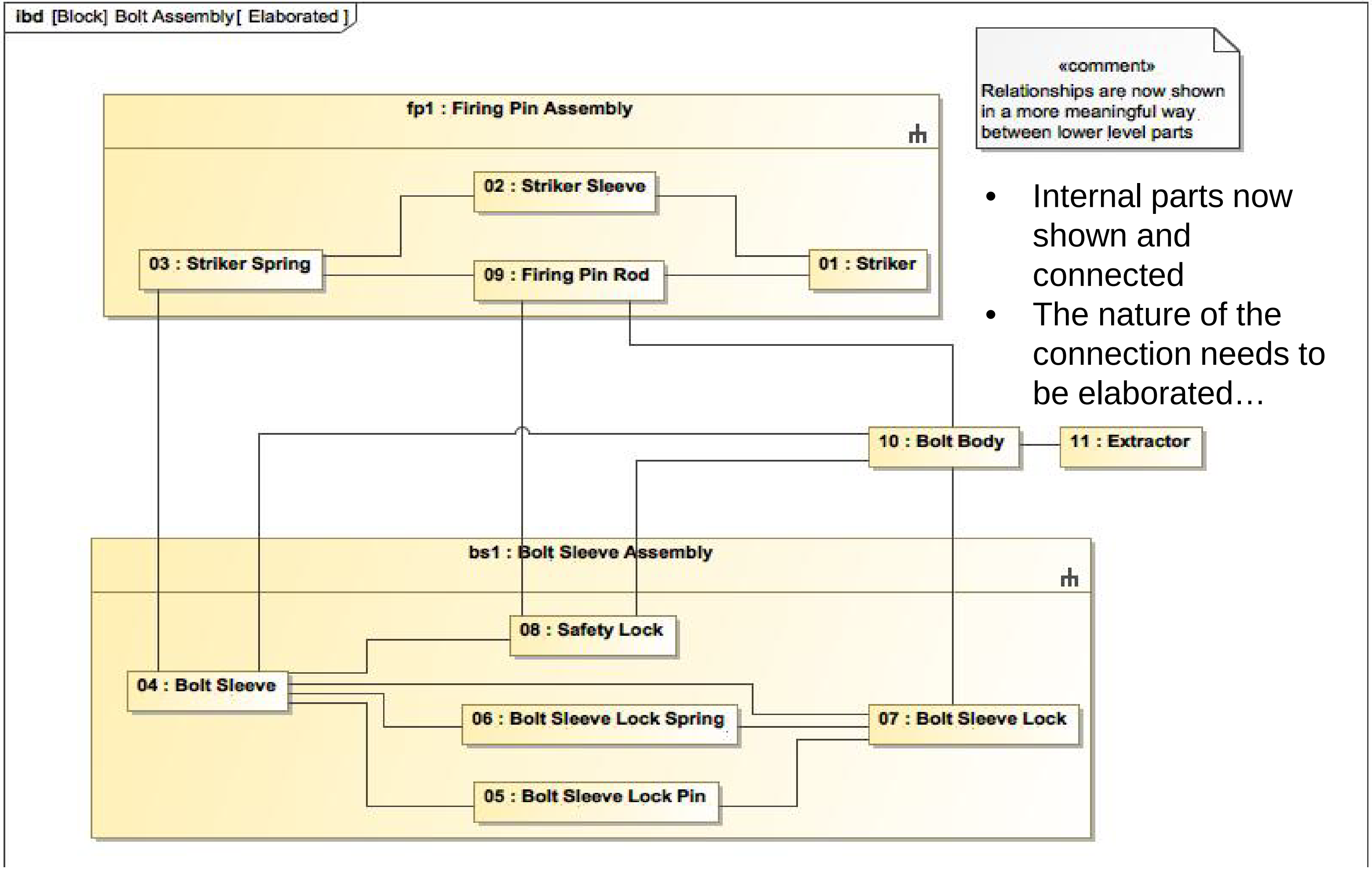
Additional Part Groupings Established to better manage concepts

Consider the connection between parts of Bolt Assembly…

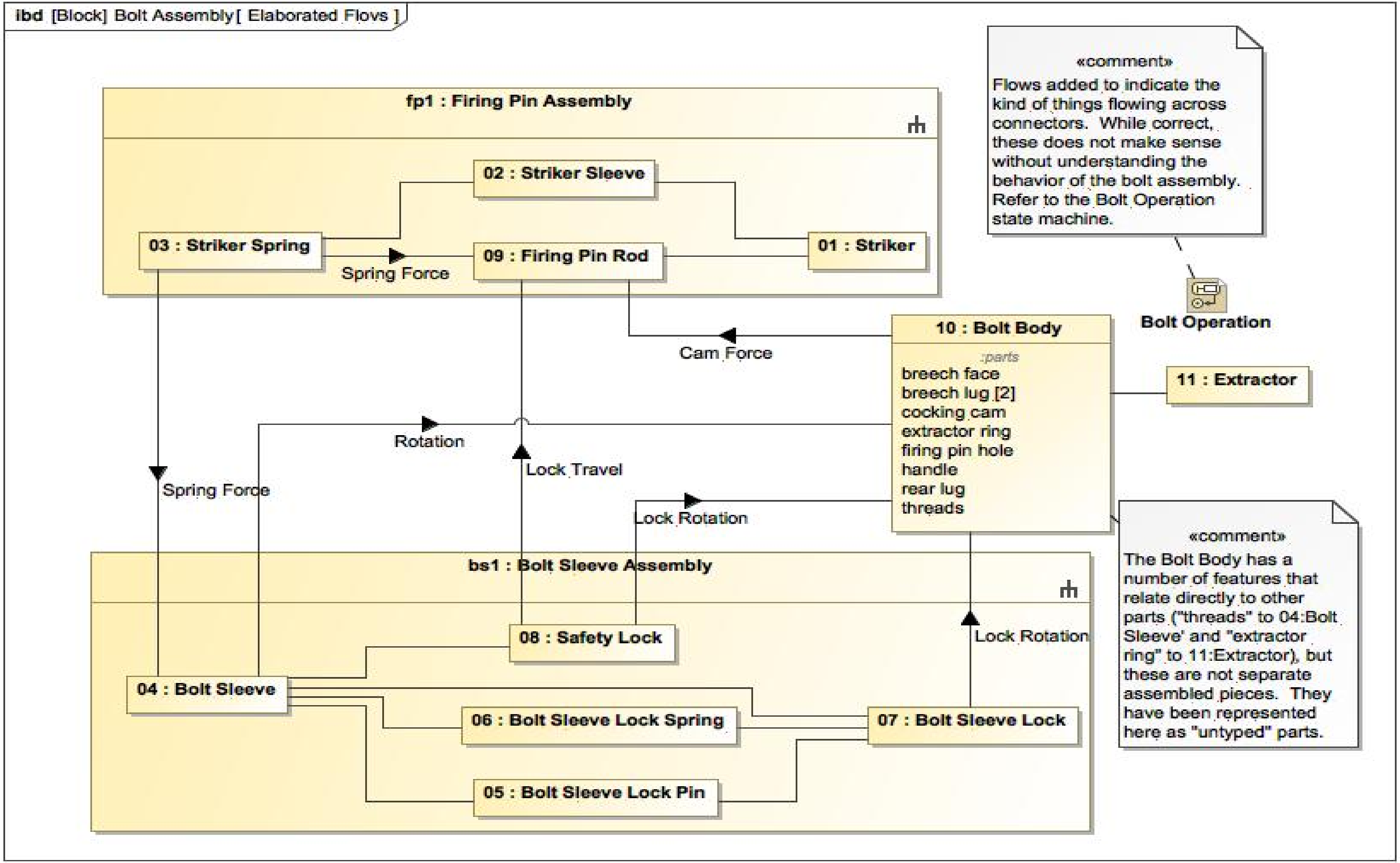




- Top level connection: ***Internal Block Diagram*** (ibd)
- Connections identified, but not elaborated
- Will need more detail…

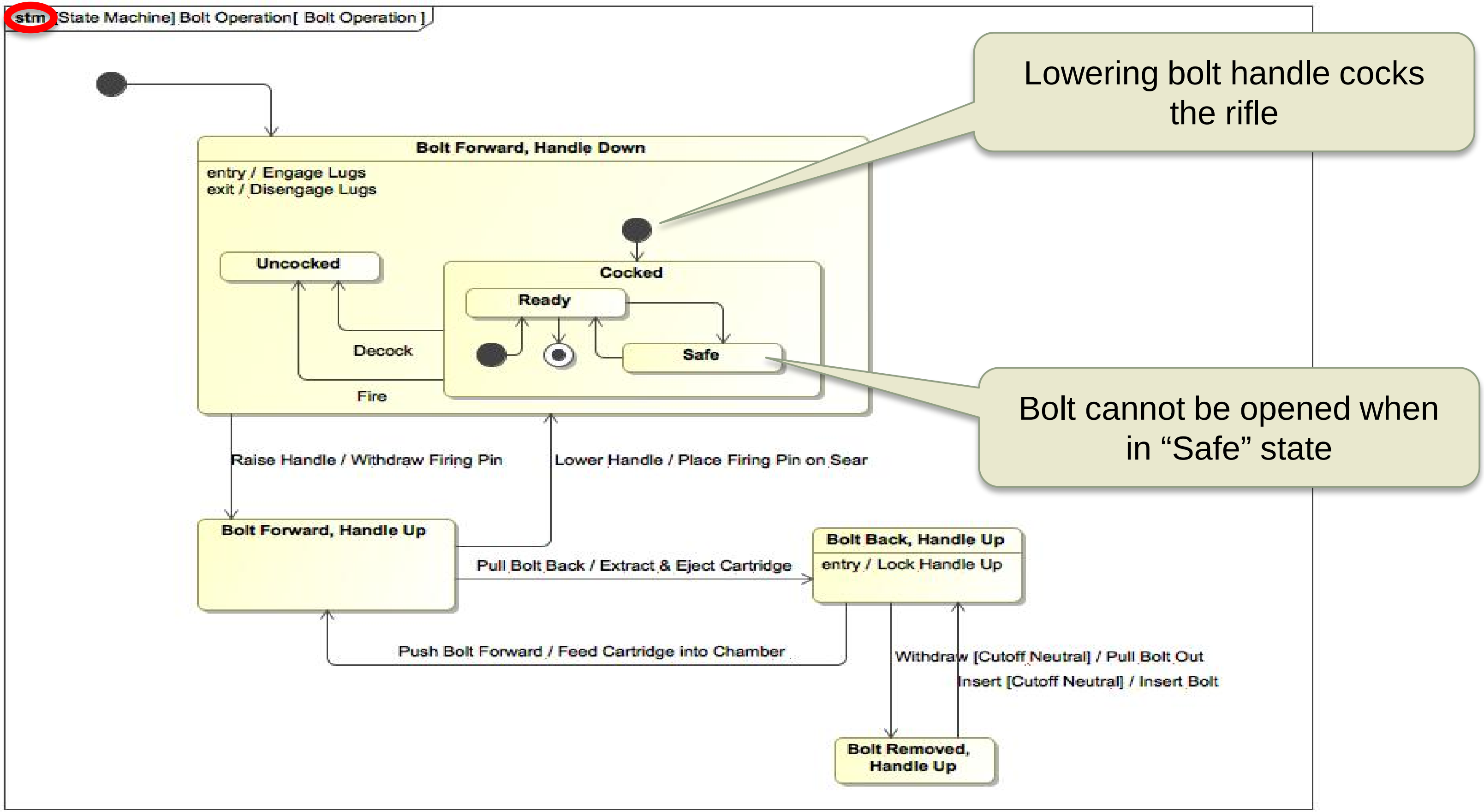


- Internal parts now shown and connected
- The nature of the connection needs to be elaborated…

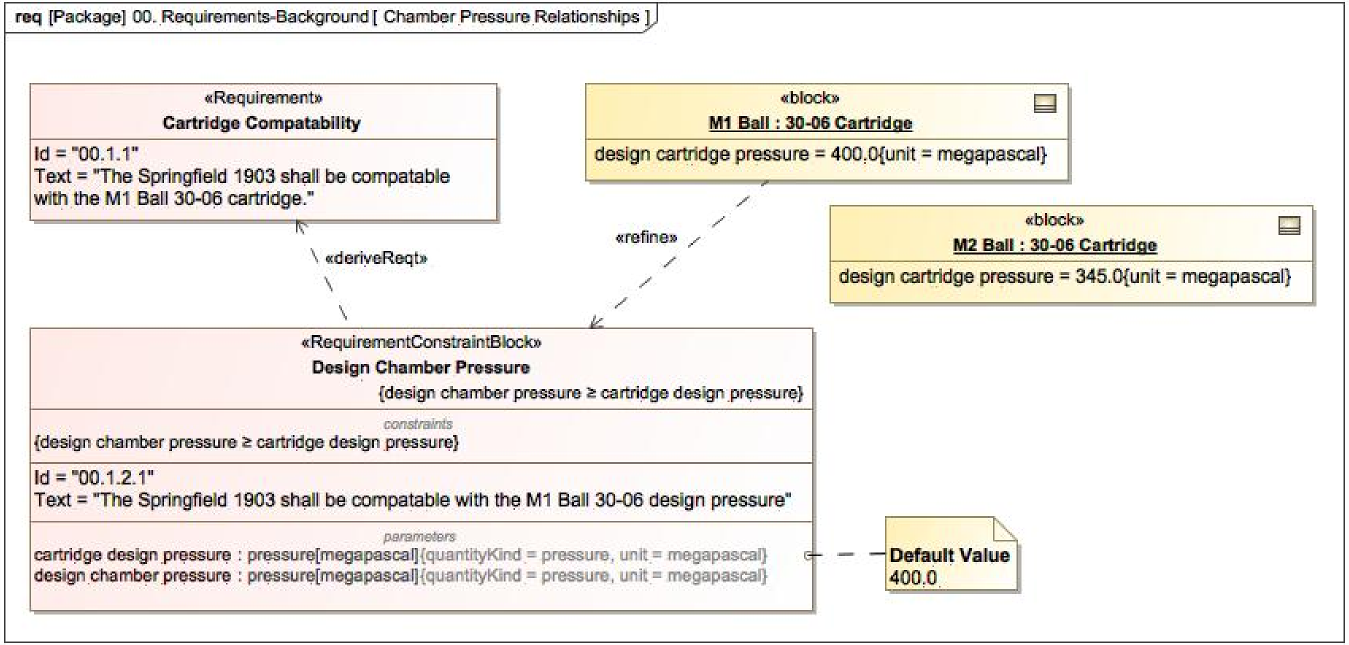


ibd [Block] Bolt Assembly[Elaborated Flovs]
«comment»
Flows added to indicate the kind of things flowing across connectors. While correct, these does not make sense without understanding the behavior of the bolt assembly. Refer to the Bolt Operation state machine.
fp1 : Firing Pin Assembly
02 : Striker Sleeve
03 : Striker Spring
09 : Firing Pin Rod
01 : Striker
Spring Force
Bolt Operation
10 : Bolt Body
:parts
breech face
breech lug [2]
cocking cam
extractor ring
firing pin hole
handle
rear lug
threads
Cam Force
11 : Extractor
Rotation
Lock Travel
Spring Force
Lock Rotation
«comment»
The Bolt Body has a number of features that relate directly to other parts ("threads" to 04:Bolt Sleeve' and "extractor ring" to 11:Extractor), but these are not separate assembled pieces. They have been represented here as "untyped" parts.
bs1 : Bolt Sleeve Assembly
Lock Rotation
08 : Safety Lock
04 : Bolt Sleeve
06 : Bolt Sleeve Lock Spring
07 : Bolt Sleeve Lock
05 : Bolt Sleeve Lock Pin

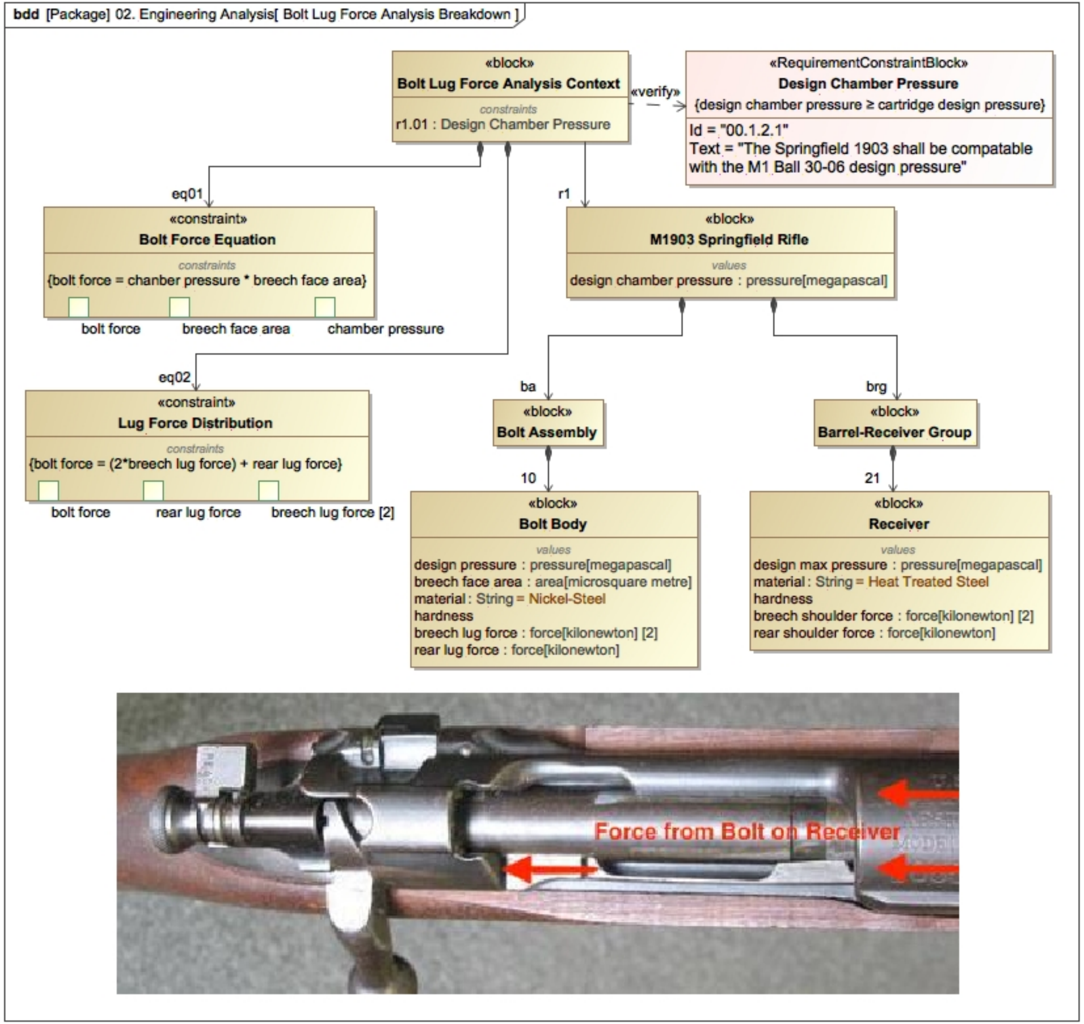
Operation of the Bolt Assembly:
State Machine diagram (stm)



Understanding Requirements: Property Based Requirements

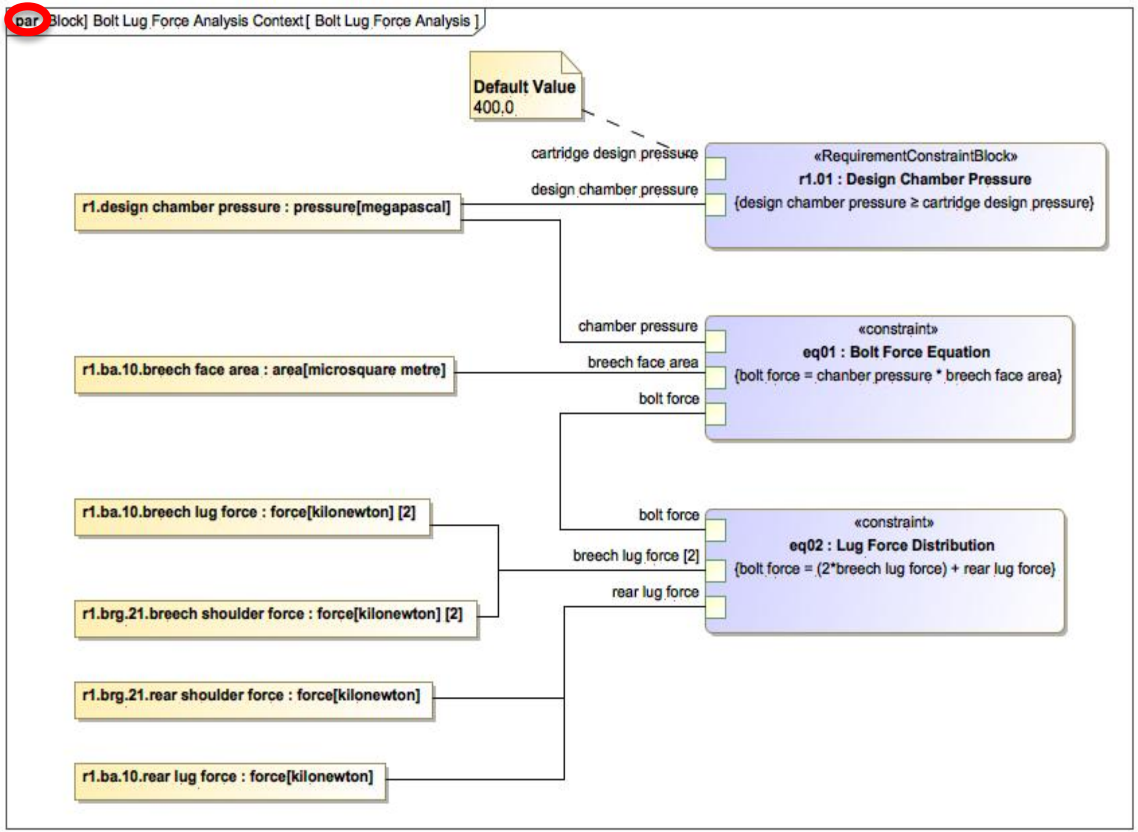


#	Name	Text
1	00. Requirements-Background	
2	00.1 Springfield 1903 Rifle Specification	
3	00.1.1 Cartridge Compatability	The Springfield 1903 shall be compatable with the M1 Ball 30-06 cartridge.
4	00.1.2 Design Values	



- Establishes context for conducting lug force analysis
- Ties back to requirement

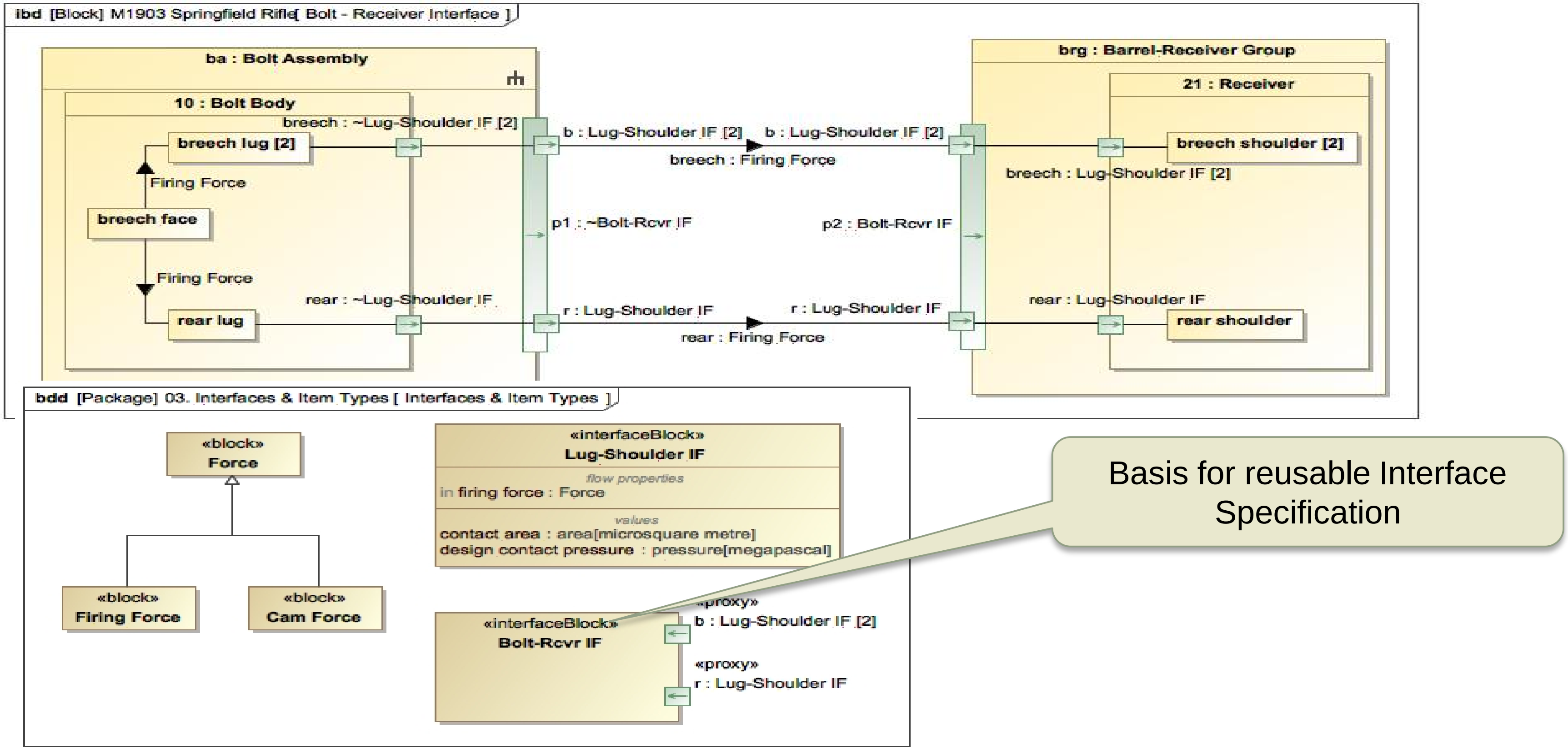
Setting Up for Parametric Analysis:
Parametric diagram (par)



SysML parametric models are ***acausal***:

- To solve equations, will additionally need:
  - Initial/fixed values (instance slot values)
  - Goal/target (direction) and
  - A solver (tool) - some SysML tools provide this, or use plug-ins
- ***par*** can be reused and solved in any direction

Developing Interface Specifications
Proxy Ports, typed by Interface Blocks

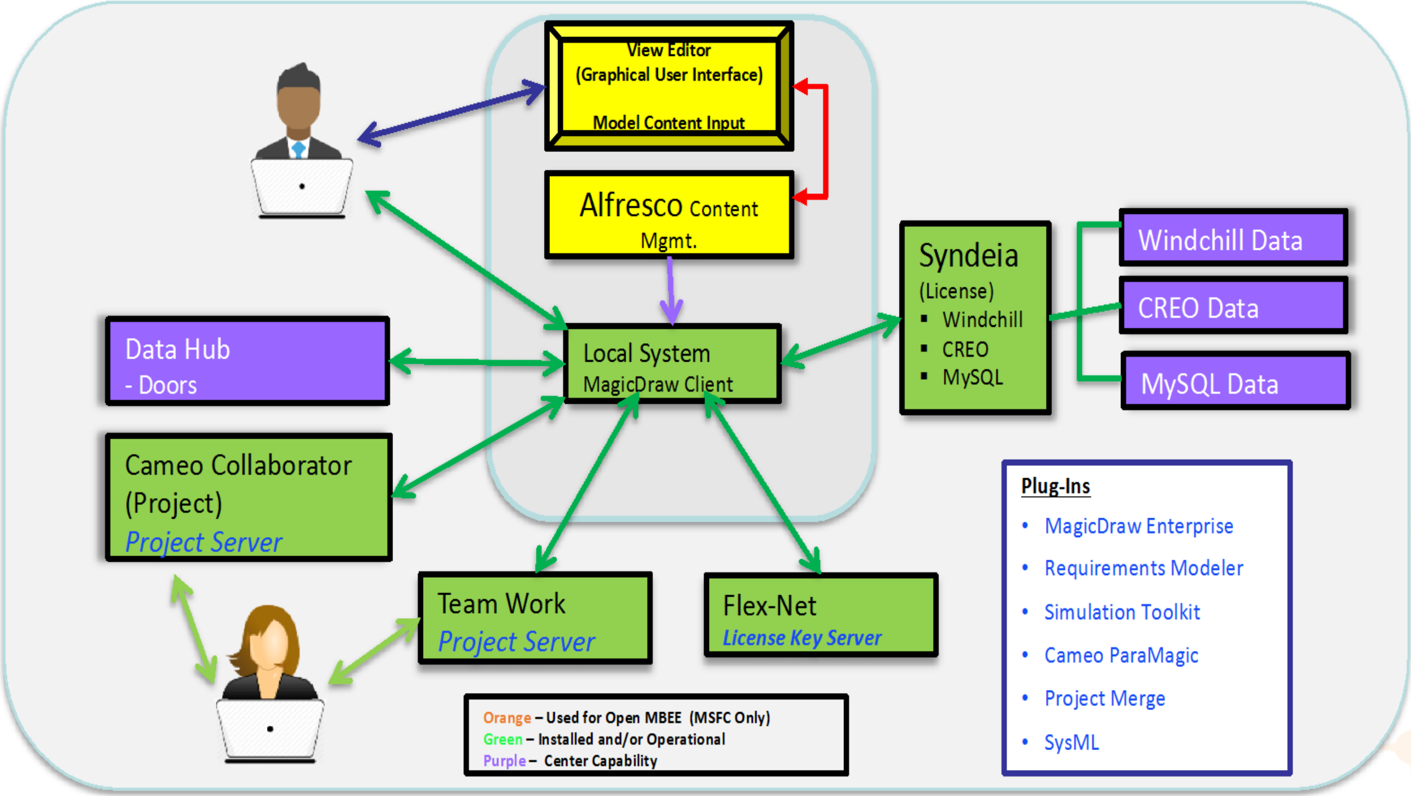


Why is a System Model Important? (slight refrain)

- It helps in understanding the overall goals of the project
- It provides a common context and background for project terms, objectives, and requirements
- It helps in interpreting and understanding design requirements and parameters
- It facilitates collaboration across multiple engineering domains
  - Collaboration is a dialog… to critique/contribute, you must first understand.
  - Honest dialog is always appreciated (eventually).
- The system model should have value to <u>you</u>!
  - If not, understand why not and start collaborating to fix it!

MBSE Infusion And Modernization Initiative (MIAMI)

MBSE Integrated Architecture Deployment (Ecosystem)



OpenMBEE Users: Current Deployments

(per responses from participants in Jan 23, 2018 workshop)

Organization	Projects Using OpenMBEE	OpenMBEE Deployment Status
Boeing	Various programs (*it is their enterprise model-based solution*)	Production
Ford	Various pilots	*Pilot*
GT/ASDL	~5 research projects/demos	*Pilot/Demo*
GTRI	Various projects (*after setup is ready*)	*WIP*
Lockheed	Various programs	Production
NASA JPL	~8 main flight projects (Europa Clipper, Mars 2020, Mars Sample Return, ...)	Production
OMG [1]	SysML 1.6 spec; SysML v2 SST proposal	Production
Stevens/SERC	Several research projects/demos	*Pilot/Demo*
www.tmt.org [1]	Thirty Meter Telescope (TMT)	Production

[1] = Using openmbee.org semi-public instance

INCOSE

Summary

- MBSE provides framework for linking/synching requirements, system architecture, and detailed design information
- SysML is the default language of MBSE
  - Requirements, including required values
  - Top level structural hierarchy (composition/parts, generalization/types)
  - Top level structural connection (flow, interfaces, interface specification)
  - Behavior (state, function, message sequence)
  - Analysis framework (key properties, values, and equations)
- SysML models can/should be “connected” and synched with MCAD models (blocks/parts, properties, values), as well as ECAD/SW models
- SysML models can/should be “connected” and synched with analysis tools and simulations
- ***It’s worth reviewing the SysML model to ensure it is correct and complete from a design engineering perspective!***

Back Up

Product Data Exchange using STEP

PDES, Inc.
Model-Based
Sys Eng.

Participation Benefits

Through pilot projects and implementer forums, *PDES, Inc.* participants gain hands-on experience in using STEP and implementing the standard within their own organizations. In addition to realizing competitive advantages from their use of STEP, the participants work together to influence both enhancement of the STEP standard and the development strategies of organizations that provide commercial STEP software products. Benefits of participating in *PDES, Inc.* activities include:

- Participation in focused projects in high-payoff areas
- STEP product testing in a dynamic environment
- Insight into industry Enterprise Integration strategies
- Ability to work closely with customers and suppliers
- Rapid access to STEP experts and expertise
- Knowledge sharing through technical workshops
- Awareness of vendor product capabilities and plans
- Access to Recommended Practices and extensive Lessons Learned from STEP deployments in industry
- Hands-on experience using STEP tools and technology
- Direct influence on setting and extending the STEP standard
- Focused cost sharing and collaboration through resource pooling
- Leverage vendors to support new requirements
- Up-to-date knowledge on how industry implements standards across the supply chain and product life cycle

PDES, Inc.
Connecting the Digital Enterprise

Contact us today for more information:

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Connecting the Digital Enterprise

VISION: Provide the Digital Enterprise strong business value through collaboration in standards development and best practices

CRITICAL STANDARDS FOR THE DIGITAL ENTERPRISE

AIRBUS BAE Systems Boeing Boost-conseil Capvidia CT Core Technologies Dassault Systèmes Engisis Eurostep Georgia Institute of Technology International TechneGroup, Inc. (ITI) JOTNE EPM Technology Lockheed Martin	National Aeronautics and Space Administration (NASA) National Institute of Standards and Technology (NIST) Office of the Secretary of Defense (OSD) ManTech Purdue University PTC Sandia National Laboratories Theorem Solutions University of South Carolina Wichita State University

Marshall Advances 3-D Printed Rocket Engine Nozzle Technology

Video Link

Rocket engine nozzles operate in extreme temperatures and pressures from the combustion process and are complex and expensive to manufacture. That is why a team of engineers at NASA's Marshall Space Flight Center developed and proved out a new additive manufacturing technique for nozzle fabrication that can greatly reduce costs and development time.

A new process called Laser Wire Direct Closeout (LWDC) was developed and advanced at NASA to build a less-expensive nozzle in significantly less time. LWDC is a different process than most 3-D printing technologies, which are powder-based and fabricated in layers. It uses a freeform-directed energy wire deposition process to fabricate material in place. This new NASA-patented technology has the potential to reduce build time from several months to several weeks.

Marshall Star, March 2018 / Jonathan Deal

- ✓ How does your Company's organization structure enable MBSE and the Digital Thread? (Experts, SE group, Design Teams?)
- ✓ Is use of an architecture modeling tool (like SysML/UML) a company policy?
- ✓ How would you estimate the Cost/Benefit of exchanging digital models? What would you spend to improve your model exchange results?
- ✓ Does your company archive digital models for future retrieval and reuse? Is the target 5, 20, or 40 years?

✓ Respond to Thad Henry – thad.w.henry@nasa.gov

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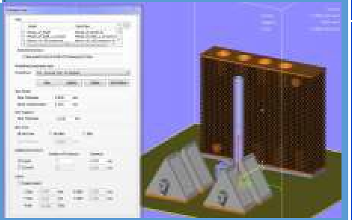
PDES MBSE Survey

CREDIT: PDES Meeting Minutes, 3/7/2018

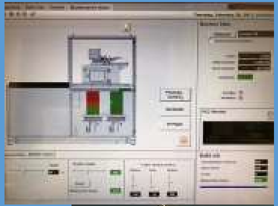
AM Process Flow

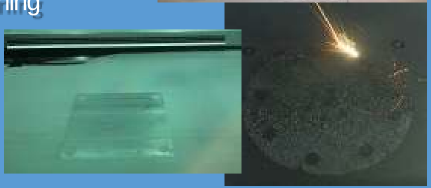
DESIGN & ANALYSIS
- Performance Requirements
-Design for AM, GD&T, export .stl

BUILD PREPARATION
- Repair .stl
- Build placement & orientation
- Thermal stress/distortion prediction
- Support generation
- Slicing
- Scan strategy



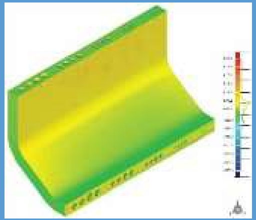
BUILD OPERATIONS
- Machine preparation
- Build via parameters
- Process Controls
- Powder refill
- Lens cleaning
- Restarts





POST-PROCESS
- Powder Removal
- Stress Relieve
- Support Removal
- Plate Separation
- HIP
- Heat Treatments
- Machine/Surface mod
- Mechanical Testing

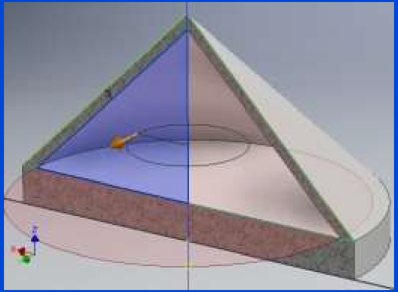
NONDESTRUCTIVE EVALUATION
- Structured light scanning
- X-ray CT
-Compare inspection models to CAD



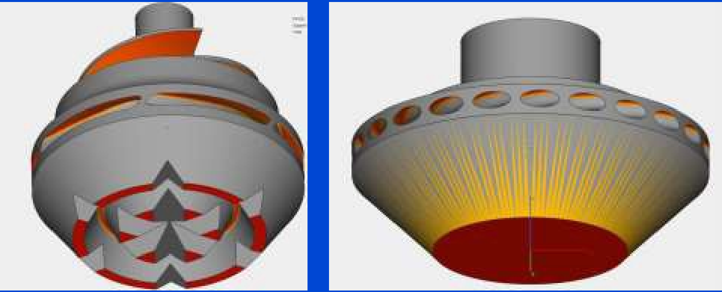
IMPLEMENTATION
- Test & post-ops inspection
- NDE / Destructive evaluation

Design Considerations

The design engineer of the 21st century is successful if parts can be repeatedly and economically manufactured.



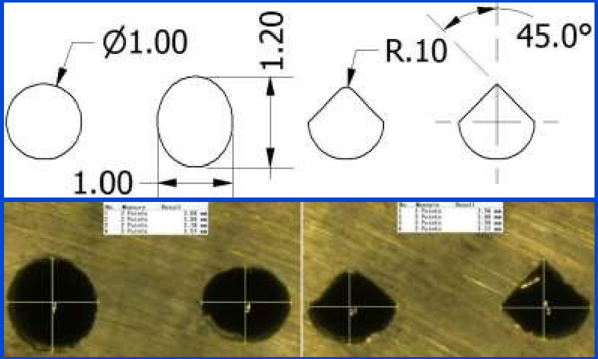
Design relative to the Z-axis



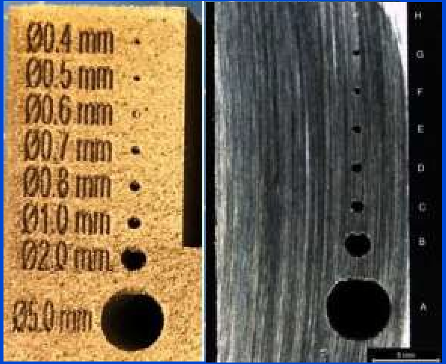
Overhang surfaces

- Holes & Passages
  - Size limits (min & max).
  - Hole sag in the Z-axis: circular hole becomes a horizontal ellipse, vertical ellipse becomes near-circular hole.
  - Rough channel surfaces from powder sintering.

Hole Test



1 mm hole array micrographs (45°)



Min Hole Size Test

Hole size & surface roughness