Jet Propulsion Laboratory
California Institute of Technology
Mars 2020 Project

Inheriting Curiosity

Leveraging MBSE to Build Mars2020

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MSL Overview

- Mars Science Laboratory (MSL), Curiosity
- Landed August 6, 2012
- Pursues evidence of a past environment well-suited for microbial life
- Met it's major science objective within a year of landing
- Still in operations

Mars2020 Overview

- Inherits a majority of MSL's Flight System design
  - Cruise, Entry, Descent, and Landing systems are build to print
  - The Rover is a mixture of new and heritage designs
    - New **science instruments** seeking signs of past life on Mars
    - New **sample caching system** collecting and storing soil and rock samples for possible future return to Earth
    - New **technology demonstrations** benefiting future robotic and human exploration of Mars
    - Heritage hardware procured early in the project lifecycle
    - Heavy reuse of flight software
- Risk Areas
  - Heritage constraints
  - New arm and caching system
    - Cache needs to be forwards compatible with to-be-designed sample return mission
  - Payload scope creep
  - Parts/personnel obsolescence

MSL to M2020: SE Challenges

Technical baseline by "boxology"

Increased risk of late discovery of design problems

Trades/concurrent engineering

Varied design maturity made it hard to understand full of work scope

Information silos

S/C complexity resulted in mutually inconsistent, disparate sources of information

SE product alignment

Work had to slow to prepare for management/gate products

Personnel/artifact discontinuity

Increased risk due to knowledge and investment lost at launch slip

SE product relevance

Struggled to keep design design documents reflective of as-built s/c

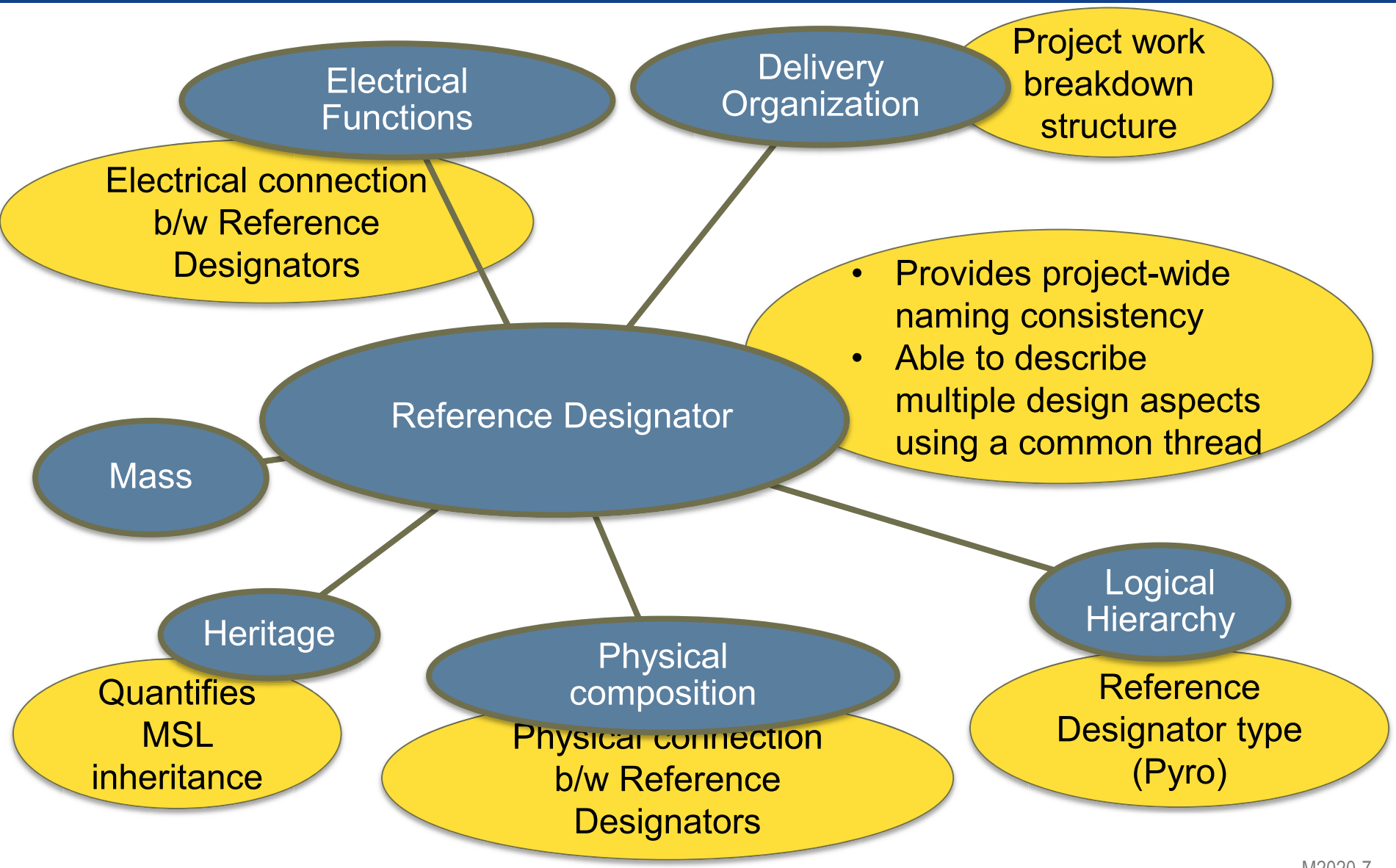
M2020 FS MBSE Goals

- Better awareness of the technical baseline
  - Capture the MSL as-flown design accurately
  - Move from “design by boxology” to an **integrated information technical baseline**
- Improve the communication, understanding, and visibility of the design
  - Provide an **authoritative source of information** that is easily accessible by the entire team
  - Create a **common language** to describe the system
  - Avoid information silos
  - Increase visibility and traceability of changes
- Focus on heritage design deviations
  - Rover first, then incorporate other stages
- Let FSSE products drive model implementation
  - Only model what is needed to create FSSE products

Mars2020 Implementation

Model-Generated Visualizations	• Auto layout of model elements • Web deployed
Model-Generated Documents	• FSSE deliverables • Web deployed
FS Design Model	• Implementation of patterns • Reconciled MSL as-flown info
Modeling Framework	• M2020 specific patterns • Extension of SysML

Modeling Framework Concepts



Modeling Framework Methodology

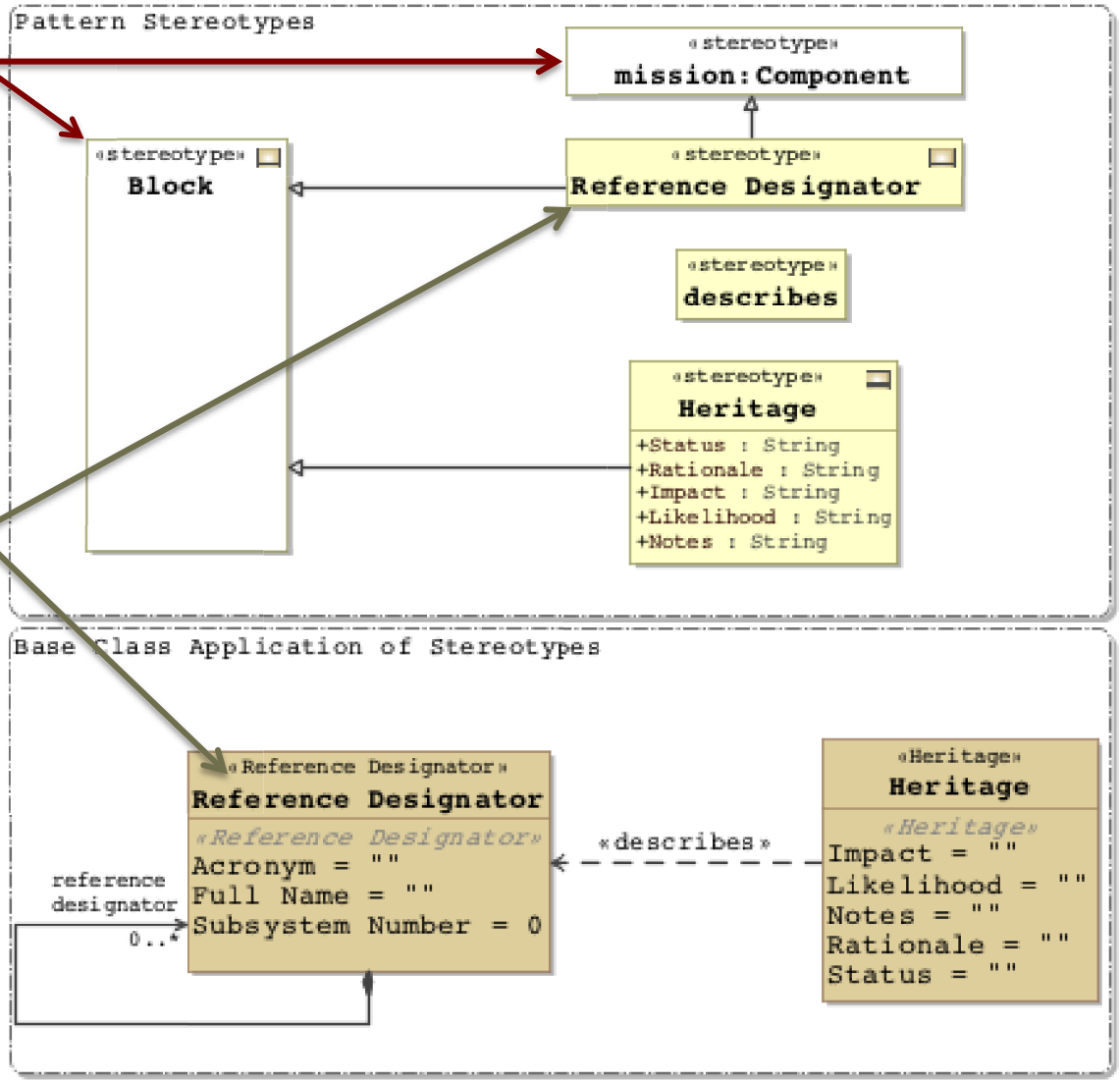
Extend SysML and JPL-provided stereotypes

Create M2020 specific terminology

Apply M2020 specific stereotypes to base elements

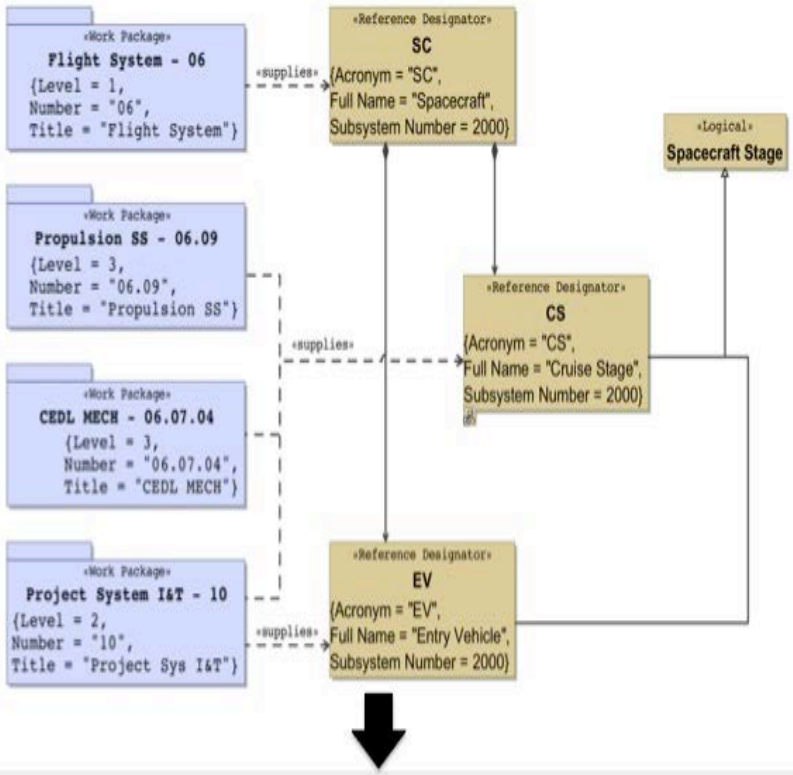
Relate base elements to create a re-usable pattern

Utilizes SysML inheritance and redefinition concepts



Model Generated Products

- Transforms the FS model into documents
- SysML Viewpoint definition coupled with python scripts
  - Scripts collect, filter, and define how to display the model data
- Read only
- Web accessible



	Subsys Number	ACRONYM	NAME	PHYSICAL HIERARCHY	LOGICAL HIERARCHY	DELIVERY ORGANIZATION
	2000	FS	Flight System			
Ref Des	2000	BS	Backshell	EV	Stage Element	CEDL MECH - 06.07.04 & Propulsion SS - 06.09
Ref Des	2000	CS	Cruise Stage	SC	Spacecraft Stage	Project System I&T - 10 & CEDL MECH - 06.07.04 & Propulsion SS - 06.09
Ref Des	2000	EV	Entry Vehicle	SC	Spacecraft Stage	Project System I&T - 10

Reference Designator List
Electrical Function List
Reference Designator Heritage List
Mass Equipment List
Electrical Switch List
Mass Trending Report
Electrical Resource Metrics
Electrical Interface Derived Heritage

Leveraging Consolidated Information

Electrical Function List

Table 1.1. Function List — COMMON FSSE PRODUCT

Function Number	Function Name	Subsystem 1	Assembly 1	Flow	Subsystem 2	Assembly 2	SUB-SUB Name
111-111-[illegible]	[illegible]2 Position Sensors from SPAH	2008	RMCS-4	>	2014	SCS	MCA-SCS (2008-2014)
111-111-112	RLCC-1B BusPwr: Driver to PAE-GUIDE-RLY-B-PYRO-B-ENABLE	2004	RLCC-1B	<	2005	PAE	PWR-PYRO (2004-2005)
111-111-113	RMCP-CSW-15 Position Sensors from SPAH	2008	RMCP	<	2014	SCS	MCA-SCS (2008-2014)
111-111-114	RTMC-A Analog: Voltage from RHPCU-B-TMC_+12V-MON	2004	RHPCU-B	>	2006	RTMC-A	PWR-CDH (2004-2006)
111-111-115	28 V PWR to CIPA Liq Press Xdcr	2004	CLCC-1B	<	2011	CPLPX	PWR-THERM (2004-2011)

1. Electrical Function List

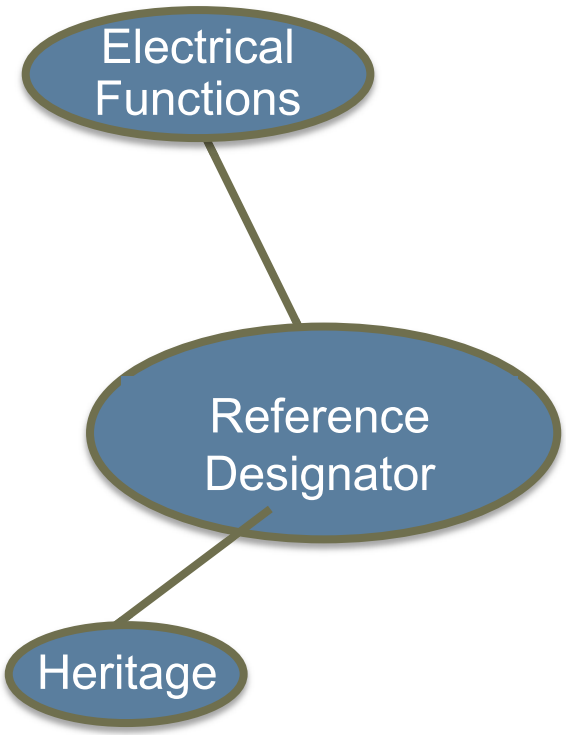
Electrical Interface Resource Metrics

Table 1.1. Resource Metrics — COMMON FSSE PRODUCT

	A-Side Eng	B-Side Eng	SCS A-Side Allocation	SCS B-Side Allocation	A-Side Open	B-Side Open	Total	Margin
RPAM Power Switches								
2A	25	25	15	15	20	20	120	33.3%
4A	7	7	3	3	6	6	32	37.5%
10A	4	4	0	0	4	4	16	50.0%
[illegible]								

Electrical Function Heritage Derivation

Function Number	Function Name	Subsystem 1	Assembly 1	Flow	Subsystem 2	Assembly 2	SUB-SUB Name	Notional?	Stages Involved	Heritage Designation
TEL-PWR (2002-2004)			INFORMAL PRODUCT							
002-004-001	28 V PWR to TWTA	2002	TWTA	<	2004	DLCC-A1, DLCC-B1	TEL-PWR (2002-2004)		Descent Stage	Heritage
002-004-002	28 V PWR to SSPA	2002	SSPA	<	2004	RLCC-A1, RLCC-B1	TEL-PWR (2002-2004)		Rover Internal	Heritage



Validation

- Standardized language coupled with domain specific patterns gives greater situational awareness about the design
- Re-usable validation rules can be written against the model
- Can ask questions about completeness and work left to go in a quantifiable manner.

1. Reference Designators (D-79381 Rev D)

Table 1.1. Reference Designators

	Subsys Number	ACRONYM	NAME	PHYSICAL HEIRARCHY	LOGICAL HIERARCHY	DELIVERY ORGANIZATION
	2000	**FS**	**Flight System**			
RefDes	2000	BS	Backshell	EV	Reference Designator	Project System I&T - 10
RefDes	2000	BUD	Bridle Umbilical Device	DS	Reference Designator	Mech SS - 06.07

Reference Designators should only have another Reference Designator identified as it's physical heir

2. Validation Suite Summary and Detail

Table 2.1. M2020 Reference Designators Validation Suite Summary

Validation Rule	Description	Severity	Violations Count
Ref Des Parent	A Reference Designator should only be black diamond associated with another Reference Designator	ERROR	0
Ref Des Single Parent	A Reference Designator should have only 1 black diamond association point to it	ERROR	0
AOC Relation	Aggregators of Convenince (AOC) should only relate to other elements by white diamond associations	ERROR	0
Ref Des Not Associated to Itself	A Reference Designator should not be associated to itself	ERROR	0
AOC Not Associated to Itself	An Aggregator of Convenience (AoC) should not be associated to itself	ERROR	0
Ref Des Has WBS	All Reference Designators should be related to a WBS	ERROR	663

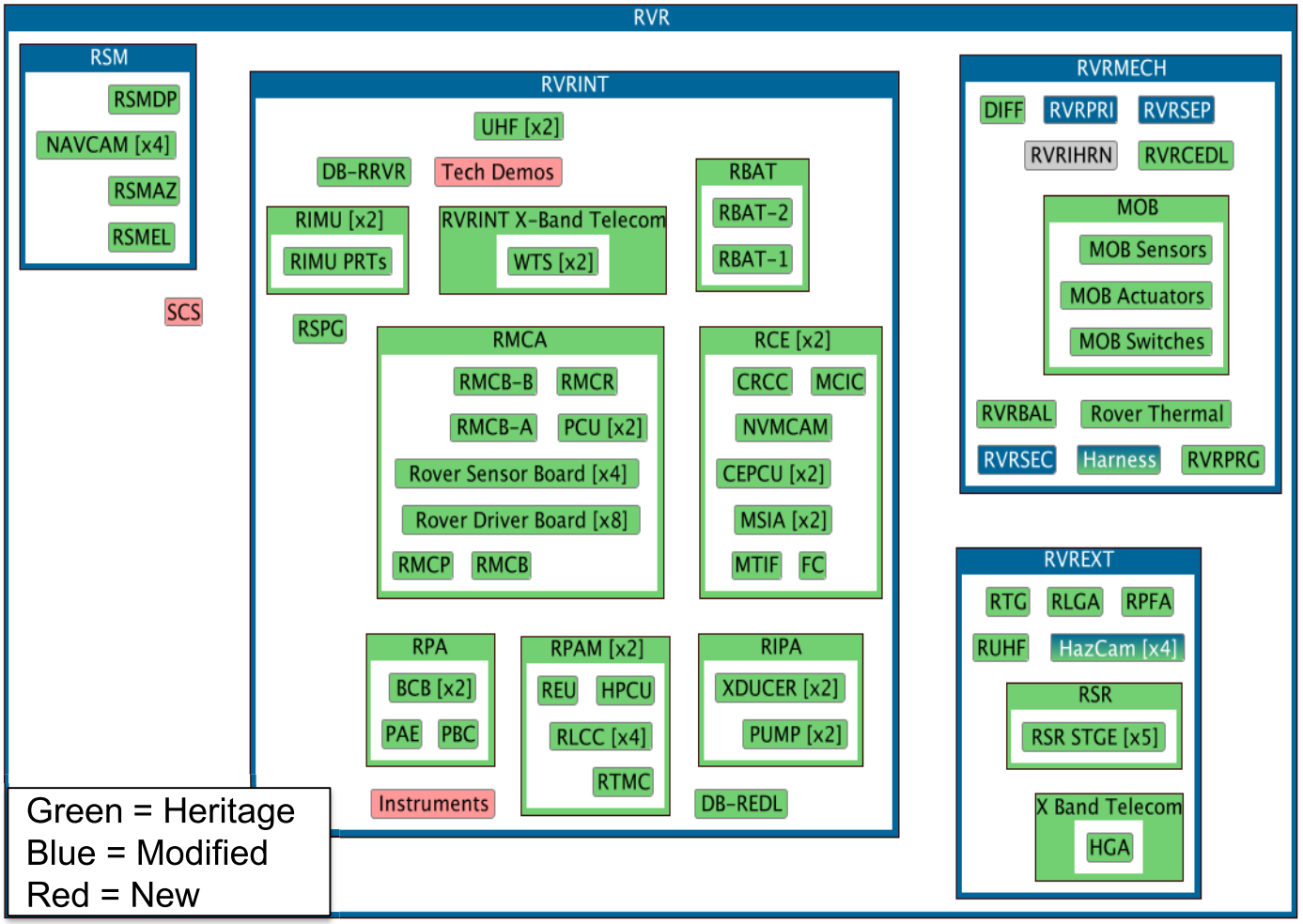
Validation results can be displayed as a report or live-linked within the modeling tool

Automatic Diagram Creation

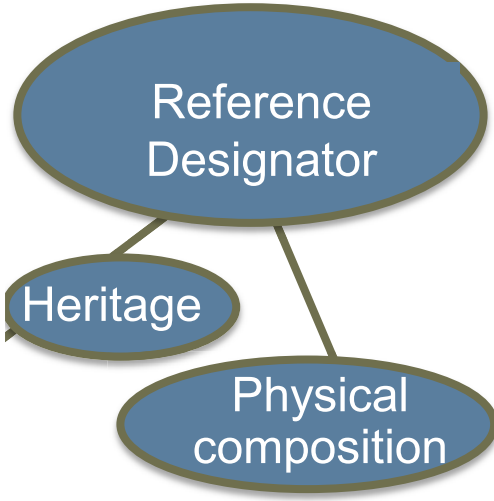
- Visual representations of model info (IBDs, BDDs) are typically created and maintained by hand
  - Decays as information evolves
  - Technical information representations often communicate poorly to stakeholders/reviewers
  - No way to validate that what is being shown is complete
- Wanted to create rules that dictate the layout of elements on a diagram
  - *"All rover avionics boxes should be inside the rover structure"*
- Wanted to create presentation rules:
  - *"All 1553 Data connections are shown as dashed lines"*
- Deploy the visual representation as either static diagrams or interactive applications

Rule Based Diagram

What is the rover heritage story at the "box" level?



Green = Heritage
Blue = Modified
Red = New

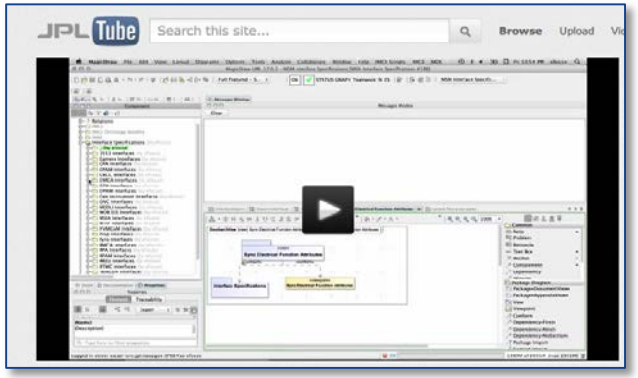


Rule based
- Color coding
- Element nesting

Automatic Layout

MBSE Infusion

- June 2013-December 2014: Initial FS MBSE effort
  - FSSE team members were unfamiliar with SysML and MBSE methodology
  - Six MBSE practitioners were added to the team
  - Significant portion of MSL as flown design information was imported
  - Preliminary document views were created
  - Framework was defined
- December 2014-present: FS MBSE Infusion
  - FSSE information owners use the model to maintain design information
  - Two MBSE practitioners remain (<1 FTE total)
    - Framework extension
    - Validation rules
    - Report and visualization generalization
    - SysML software usability
- Documented process and created M2020-specific video tutorial



Benefits

- FS model forced the integration of disparate MSL as-flown information
  - Drove out inconsistencies early
  - Allows team to focus on what's new and likely to change
- Inclusion of the less mature design aspects in the model allows the FSSE's to work in the same environment/use the same patterns to describe both new and old
- Consumers of the FS design information are looking to extend the work into their domains:
  - End to End Information Systems
    - Enabling assessment of operational differences between MSL and Mars2020 due to communication relay asset obsolescence
  - Ground Data System
    - Leverage patterns and visualization products to populate a domain specific model

MBSE Infusion Barriers

- Difficult to support “sandbox” type work/analysis
  - Mass Equipment List (MEL) is maintained in the model
  - Not conducive to “what-if” analysis during meetings
    - Opening up the SysML model, navigating to the mass information, re-calculating the MEL
  - Instead the MEL owner duplicates information and performs such work outside of the model
- Attention must be paid to communicating usefulness of new tools
  - Training for Tom Sawyer, how to interpret the deployed visualization
  - Training for M2020-specific framework
- Ability to create useful views within the modeling environment for editing
  - Tables v. specification windows

Conclusion

Model-Generated Visualizations

- Prevents artifact discontinuity
- Aligns design artifacts
- Reduces information silos
- Increases visibility of design

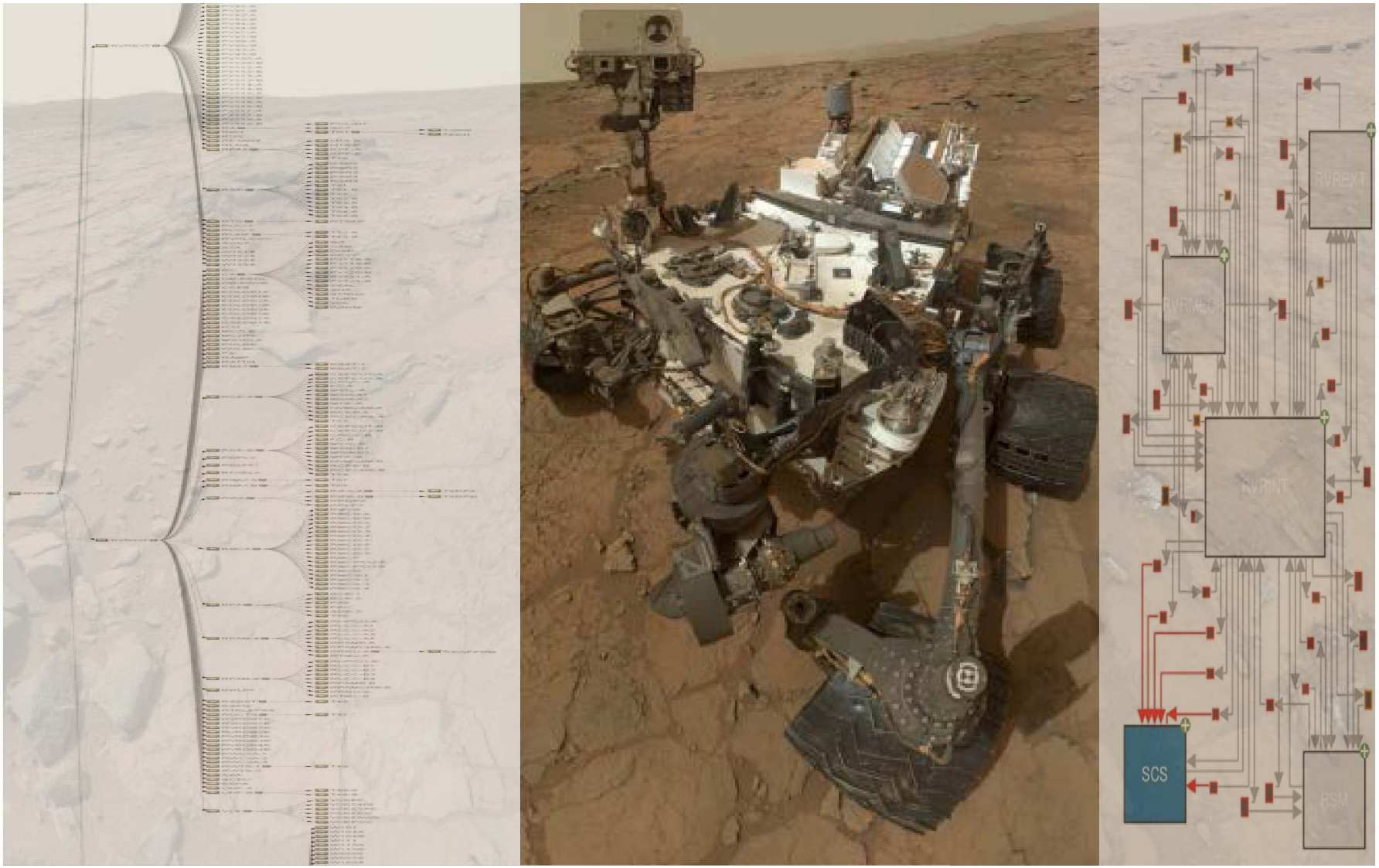
Model-Generated Documents

- Prevents artifact discontinuity
- Aligns design artifacts with SE design work
- Reduces information silos

FS Design Model

- Authoritative source of info
- Technical baseline
- Reduces information silos by forcing integration

Modeling Framework

- Common language
- Consistency

Questions?