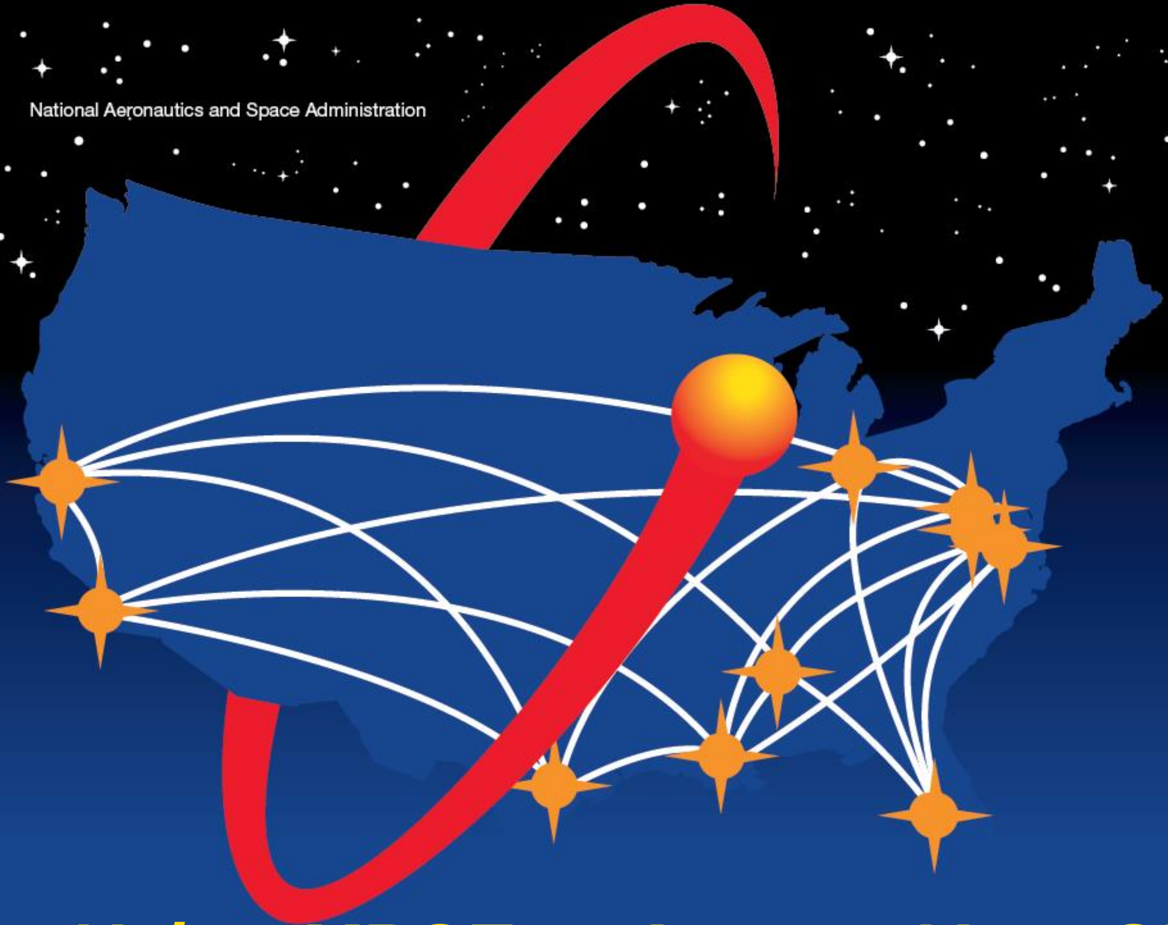
National Aeronautics and Space Administration



Using MBSE to Answer Your SE Questions
A Tutorial

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NASA Systems Engineering
MODEL BASED SYSTEMS ENGINEERING

www.nasa.gov

MBSE

MBSE…Emphasis is on *Systems Engineering*

- Model Based Systems Engineering *IS* Systems Engineering
  - A more formalized application to perform systems engineering functions typically performed using traditional, but disparate, desktop tools (e.g. PowerPoint, Visio, Excel and Word)

- Core Activities of the Program/Project Systems Engineer

  (Ref: NASA Systems Engineering Handbook NASA/SP-2007-6105 Rev 1)
  - Perform Technical Management of the program/project consisting of 1) Payload System, 2) Launch System, 3) Mission Operations System:
    - Define Concept of Operations
    - Derive Requirements enabling Mission Objectives
    - Perform Trades
    - Capture Design that meets Requirements
    - Manage Payload/Launch System/Mission Operations System Interfaces
    - Manage Risk and Assure Mission Success
    - Certify Mission for Flight through Analysis and V&V

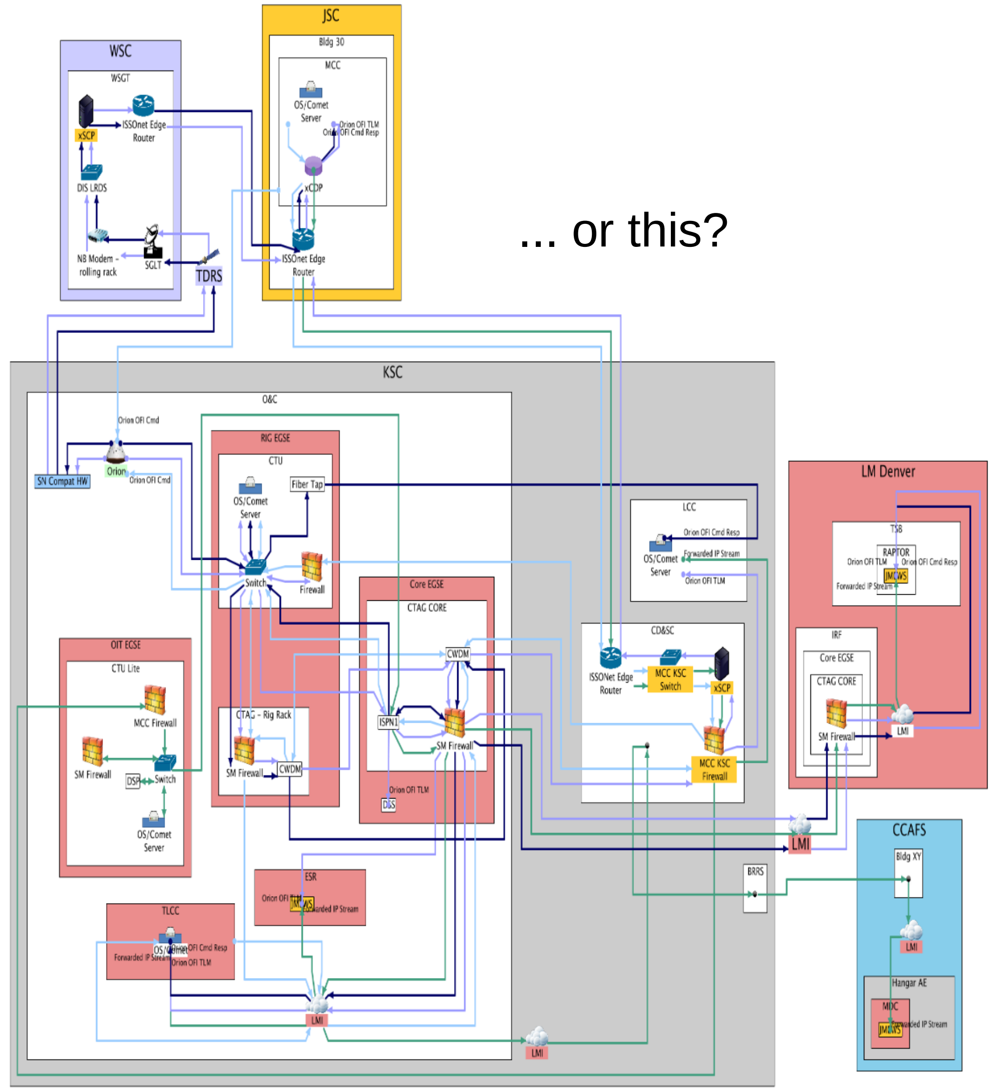
- Why MBSE?
  - Increase Rigor and Reliability (over and above that of traditional SE techniques)
  - Create mechanism to easily Repeat Rigor and Reliability throughout SE lifecycle

Why MBSE?

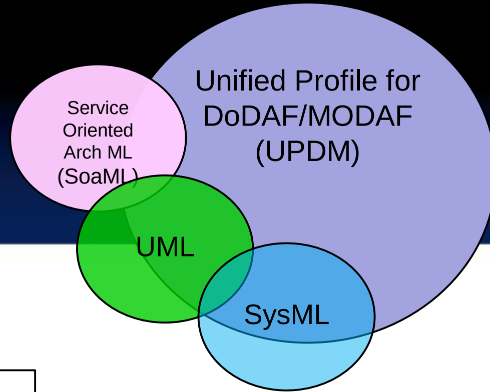
Document centric

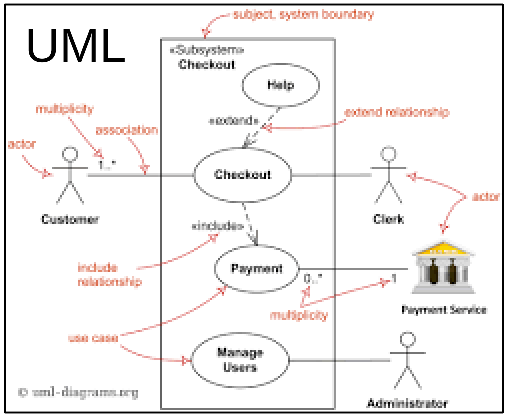
Systems Engineer & Analyze this…

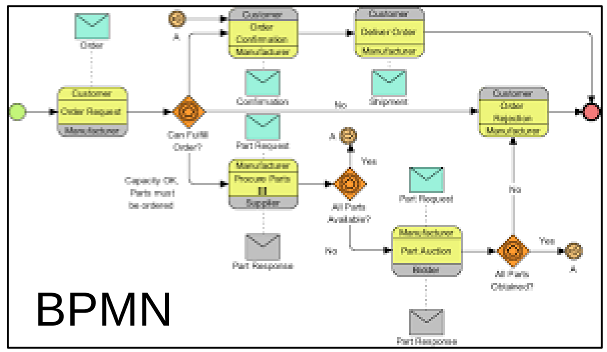
… or this?

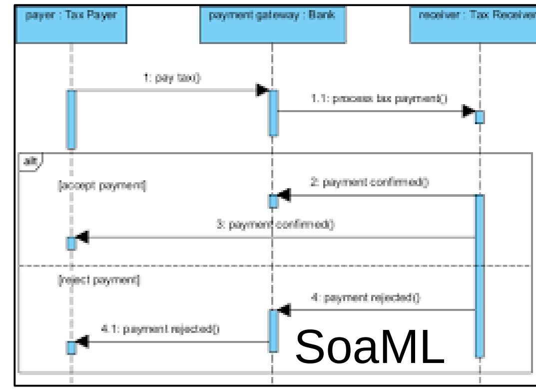


Why SysML

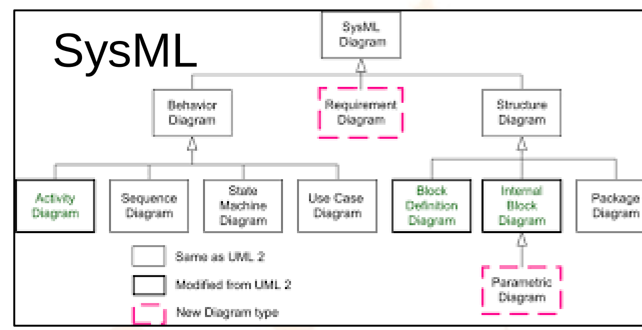








- Many modeling languages exist
- MPP3 within purview of SE TDT
  - Assume focus is on modeling and engineering Systems
  - Thus the decision to utilize a Systems Modeling Language (SysML)
- Enables modeling of systems, their interfaces and supports generation of systems engineering products per NPR 7123.1
- Products using other modeling languages typically focus on different stakeholder needs and support completion of different products



MPP3 SE Products (Inferred from Work Plans)

SRR Level of Maturity
- P-1) System Requirements & Traceability
- P-2) Verification → Test Objectives (DTOs)
- P-3) Experiment-to-SR Interfaces
- S-a) ConOps
- S-b) SR/MaGIXS/Ground Interfaces

SRR thru FRR
- P-1) Experiment-to-SR Interfaces
- P-2) Payload planners guide/Ground
- S-a) Design, driven by Science Objectives
- S-b) ConOps
- S-c) SR/MaGIXS/Ground Interfaces
- S-d) Requirement Traceability
- S-e) V&V Matrices

Pre-Phase A
- P-1) No specific MIAMI deliverables

PDR
- P-1) Model single Subsystem
- P-2) Produce FMECA, LLA and FTA

Pre-Phase A (SRR)
- P-1) Develop Mission Architecture
- P-2) Document ConOps
- P-3) Top-Level Requirements
- P-4) System Definition & Allocation
- P-5) Trade Studies

Name	Team	Center	Role
George Plattsmier	Experiment	MSFC	Lead
Cameron Jerry	Experiment	GSFC	Member
Miriam Sargusingh	Experiment	JSC	Member
Paul Schwindt	Experiment	KSC	Member
Karl Vaden	Experiment	GRC	Member
Anupa Bajwa	Experiment	ARC	Associate
Thad Henry	Experiment	MSFC	Associate
Vincenzo LeBoffe	Experiment	LaRC	Associate
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Steven Cornford	Rocket	JPL	Member
Rebecca Deschamp	Rocket	SSC	Member
David Kotsifakis	Rocket	GSFC-WFF	Member
Michael Mitchell	Rocket	MSFC	Member
George Turner	Rocket	GSFC	Member
Nicholas Waldram	Rocket	JPL	Member
Hector Chavez	Rocket	JSC	Associate
Franci Hamaker	Rocket	KSC	Associate
Jeff Cerro	ExMC Medical SE&I	LaRC	PoC
Meng Chiao	XARM/Resolve	GSFC	PoC
Frank Huy	WFIRST IV&V, RDDS	GSFC-IV&V	PoC
Nancy Lindsey	MBSMAI	GSFC	PoC
Scott Miller	Resource Prospector	ARC	PoC
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Paul Schwindt	EM-2 EUS Umbilical Design	KSC	PoC
Karl Vaden	SCaN Network Architecture through MBSE	GRC	PoC

Pre-Phase A
- P-1) Capture/Evaluate FMEA
- P-2) Produce Payload MEL
- P-3) Generate Payload ICD
- P-4) Rover ConOps

Pre-Phase A
- P-1) MMS System Model
- P-2) MCR Review Products
- P-3) IDL Use Cases

CDR
- P-1) System Design & Interfaces
- P-2) Systems Analysis
- P-4) Rqmnts Ver. Matrix

MPP3 Projects Spanning the NASA Project Life Cycle

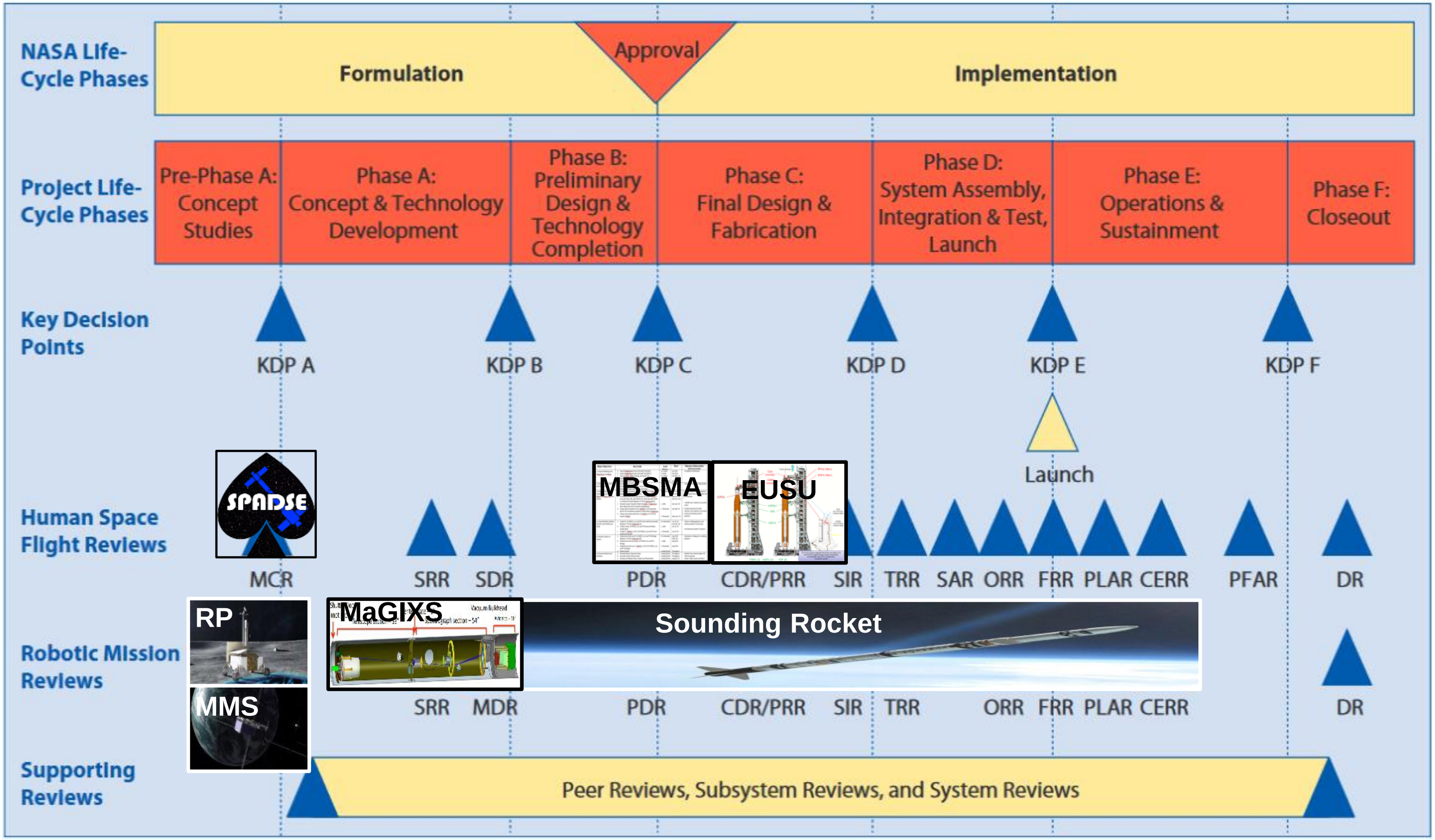


Figure 3.0-2 NASA project life cycle

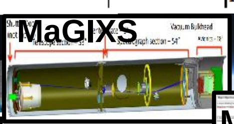
MPP3 Products by Review Gate

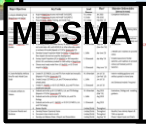
Table 3.0-1 SE Product Maturity from NPR 7123.1

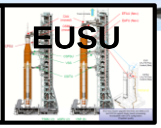
Products		Formulation				Implementation					
	Uncoupled/ loosely Coupled		KDP 0	KDP I	Periodic KDPs						
	Tightly Coupled Programs			KDP 0	KDP I		KDP II		KDP III		Periodic KDPs
	Projects and single Project Programs	Pre-Phase A	Phase A		Phase B	Phase C		Phase D		Phase E	Phase F
		KDP A		KDP B	KDP C		KDP D		KDP E	KDP F	
		MCR	SRR	MDR/SDR	PDR	CDR	SIR	ORR	FRR	DR	DRR
Stakeholder identification and		**Baseline	Update	Update	Update						
Concept definition		**Baseline	Update	Update	Update	Update					
Measure of Effectiveness definition		**Approve									
Cost and schedule for technical		Initial	Update	Update	Baseline	Update	Update	Update	Update	Update	Update
SEMP		Preliminary	**Baseline[1]	**Baseline[1]	Update	Update	Update				
Requirements		Preliminary	**Baseline	Update	Update	Update					
Technical Performance Measures definition				**Approve							
Architecture definition				**Baseline							
Allocation of requirements to next lower level				**Baseline							
Required leading indicator trends				**Initial	Update	Update	Update				
Design solution definition				Preliminary	**Preliminary	**Baseline	Update	Update			
Interface definition(s)				Preliminary	Baseline	Update	Update				
Implementation plans (Make/code, buy, reuse)				Preliminary	Baseline	Update					
Integration plans				Preliminary	Baseline	Update	**Update				
Verification and Validation plans		Approach		Preliminary	Baseline	Update	Update				
Verification and Validation results							**Initial	**Preliminary	**Baseline		
Transportation criteria and instructions						Initial	Final	Update			
Operations plans					Baseline	Update	Update	**Update			
Operational procedures						Preliminary	Baseline	**Update	Update		
Certification (flight/use)								Preliminary	**Final		
Decommissioning plans					Preliminary	Preliminary	Preliminary	**Baseline	Update	**Update	
Disposal plans					Preliminary	Preliminary	Preliminary	**Baseline	Update	Update	**Update

**Item is a required product for th

[1]SEMP is Baselined at SRR for proj







MPP3 SE Products (Inferred from Work Plans)

Gate Product Compliant
Common Thread

SRR Level of Maturity
- **P-1)** System Requirements & Traceability
- P-2) Verification → Test Objectives (DTOs)
- **P-3)** **Experiment-to-SR Interfaces**
- **S-a)** ConOps
- **S-b)** **SR/MaGIXS/Ground Interfaces**

SRR thru FRR
- **P-1)** Experiment-to-SR Interfaces
- **P-2)** Payload planners guide/Ground
- **S-a)** Design, driven by Science Objectives
- **S-b)** ConOps
- **S-c)** **SR/MaGIXS/Ground Interfaces**
- **S-d)** Requirement Traceability
- **S-e)** V&V Matrices

Pre-Phase A
- P-1) No specific MIAMI deliverables

PDR
- P-1) Model single Subsystem
- **P-2)** Produce FMECA, LLA and FTA

Pre-Phase A (SRR)
- **P-1)** Develop Mission Architecture
- **P-2)** ConOps
- **P-3)** Top-Level Requirements
- **P-4)** System Definition & Allocation
- **P-5)** Trade Studies

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Pre-Phase A
- **P-1)** Capture/Evaluate FMEA
- P-2) Produce Payload MEL
- P-3) **Generate Payload ICD**
- **P-4)** Rover ConOps

Pre-Phase A
- **P-1)** MMS System Model
- **P-2)** MCR Review Products
- **P-3)** IDL Use Cases

CDR
- **P-1)** **System Design/Interfaces**
- **P-2)** Systems Analysis
- **P-3)** Rqmnts Ver. Matrix

TUTORIAL

SYSTEM INTERFACES

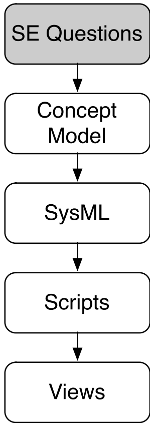
Interface Definition Identified in many MPP3 Plans

- MaGIX
  - **P-3) Experiment-to-SR Interfaces**
  - **S-b) SR/MaGIXS/Ground Interfaces**
- Sounding Rocket
  - **S-c) SR/MaGIXS/Ground Interfaces**
- Resource Prospector
  - P-3) **Generate Payload ICD**
- EM-2 EUS Umbilical Design
  - **P-1) System Design/Interfaces**

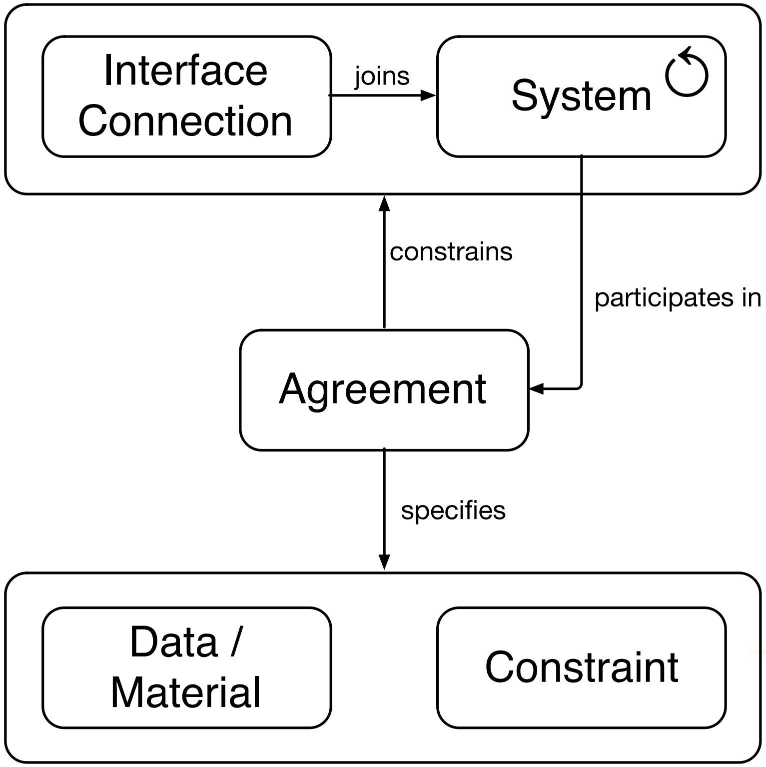
System Engineering Questions for Interfaces

- What are <u>all</u> the interfaces?
  - This is the comprehensive list of interfaces we care about
  - Restrict to cross-organization interfaces if desired
- What are the properties of a given interface?
  - Which systems participate in it?
  - What exchanges of data or material does it specify?
  - What are its mathematical or physical constraints?
- What are all the interfaces between System A and System B?
  - Filter the comprehensive list to a single pair of systems
- With which systems does a given system interface?
  - Filter to a single system
  - To which other systems is it directly connected?

- The above list is meant to *support* analysis by engineers, not replace it.

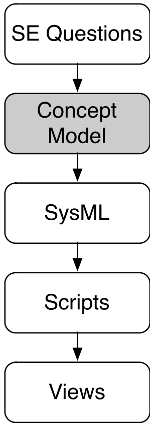


Concept Model for Interfaces



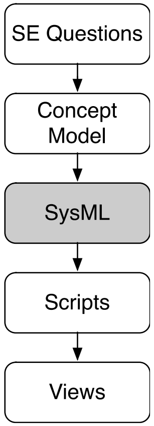
- In this example, an Agreement is a single commodity flow

- Human-friendly descriptions of the elements in your model, and the relationships between them
- Independent of any tool you may choose
  - MagicDraw, Visio, SQL, Excel, pencil and paper
- Must adapt to your chosen language (e.g. SysML)



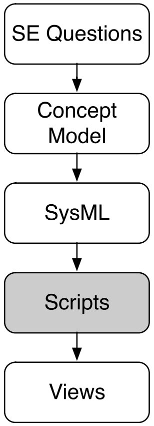
Modeling Approach

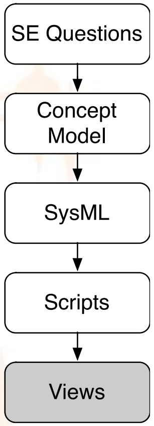
- Take concept model from previous slide and transform to SysML
- In this case, SysML has many ‘native’ features we can use, so we didn’t need to create many stereotypes of our own
- Your job as a modeler is *not* to draw pretty SysML diagrams
- Your job is to capture the information about your system in a regular and analyzable way
- You must conform to the concept model and SysML profile so that you can write analysis scripts to answer your SE questions
- We find that most of our day-to-day work is done in MagicDraw tables and matrices – the diagrams we do have are ‘working’ diagrams, and look ugly
- Software development effort needed to analyze and report on the contents of the model



Modeling Approach

- Trying to make your SysML diagrams pretty may lead to bad choices of ways to represent information in the model
- SysML diagrams have a half-life
- They decay over time as you and others change the content of the model
- SysML diagrams are always *consistent* with the model – elements correctly disappear from your diagrams when they are deleted from the model
- They are not always *complete* for your purpose – new elements do not automatically appear on the diagrams when you want them
- The cost of maintaining diagrams over time is much greater than the cost of creating them
- All this reinforces the need for analysis scripts that do not rely on SysML diagrams, but only on model content
- The scripts produce the tables, lists and diagrams that are your work product (views)





Hestia

- This was our task from the MBSE Pathfinder last year

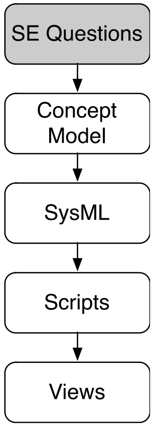
- Needed to understand how the Habitat and ISRU interact in the context of all the other systems on the Martian surface

- Resulted in definition of any interfaces and commodity flows between the systems
  - Power, Atmosphere, Regolith, Oxygen, Water, CO_2, CH_4 etc.

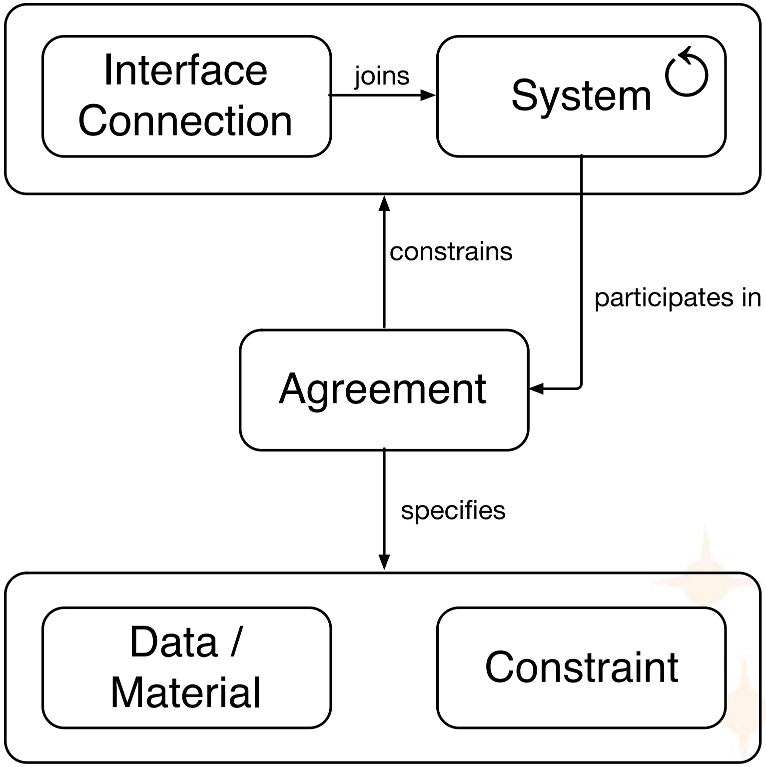
- Now a walkthrough of process:
  - Hestia was in pre-phase A of the program/project lifecycle
  - Identified appropriate pre-phase A list of questions we wanted to answer
  - Development of Concept Model
  - Creation of SysML profile
  - Generation of “Views” that answer the questions

Pre-phase A Hestia List of Questions

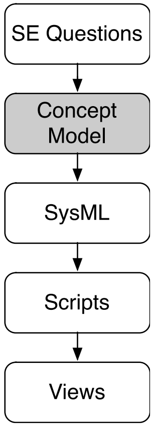
- Which architectural options are considered?
- Compare the options in each of these dimensions
  - What systems are in each option?
  - What commodities do the systems produce and consume?
  - How are the systems connected?
  - How operable is each system in each option?
  - How does the operability of each system affect the other systems?
  - What is the mass roll up of each option?
  - How many landings are required to put all the systems on the surface?
  - How much mass is in each landing?



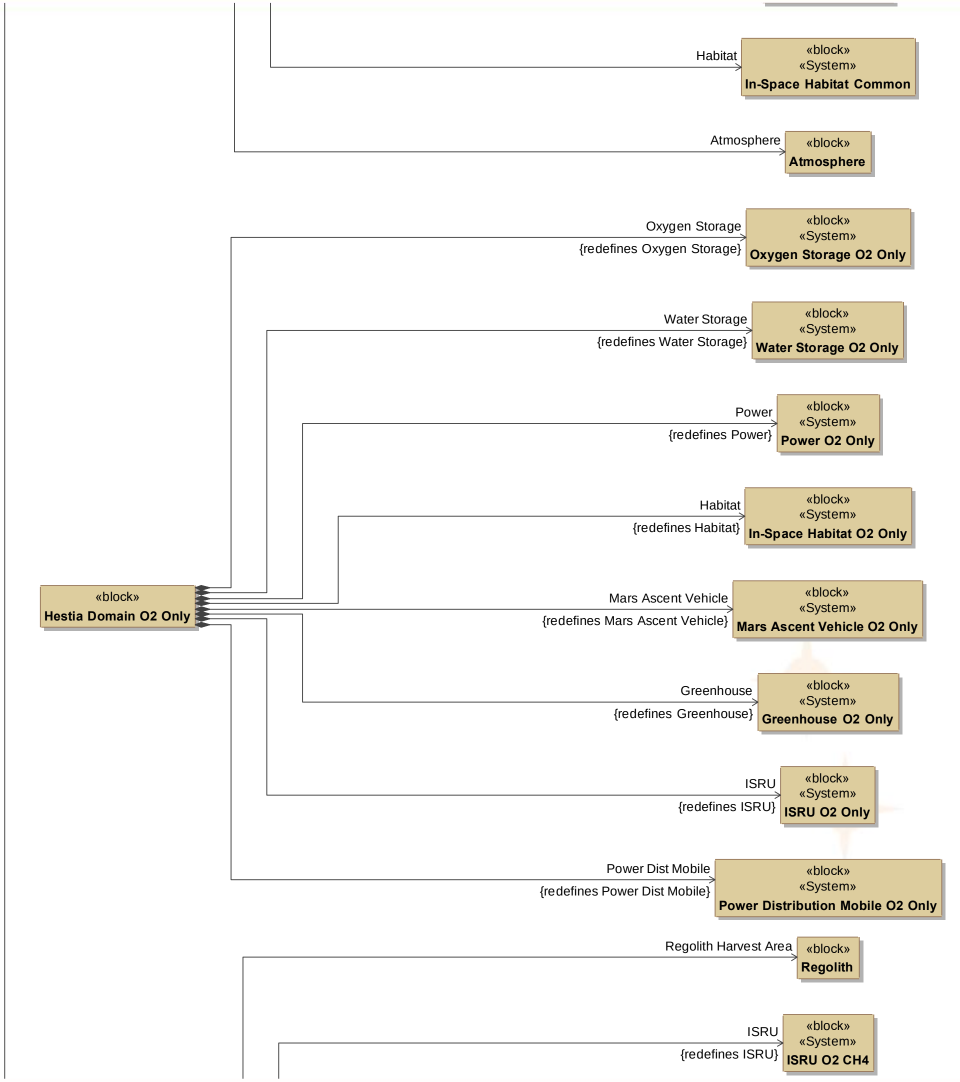
Hestia Concept Model



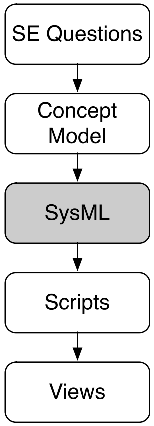
- Hestia Concept model is fundamentally the same as the generic interface concept model



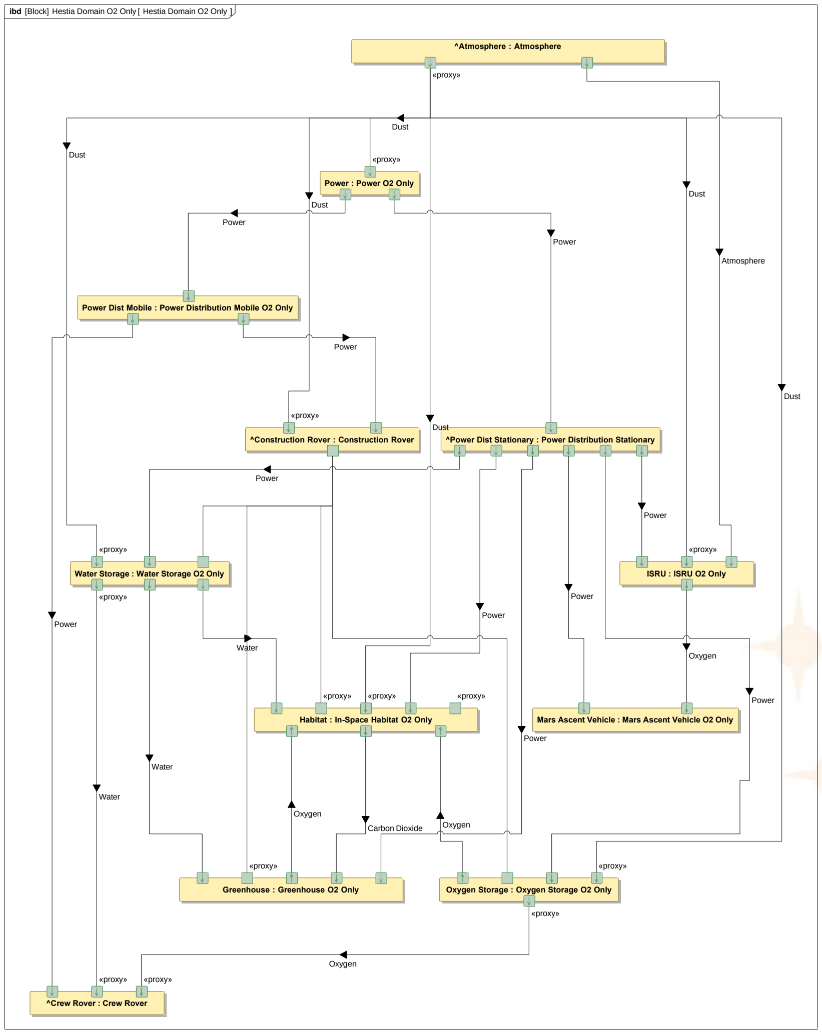
Transform to SysML



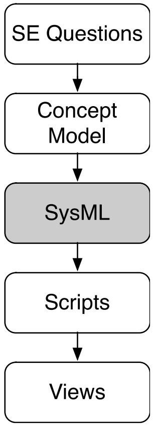
- This diagram shows the hierarchy of Systems from the concept model
- There are two options, O_2 Only and O_2 CH_4
- This model content will answer questions about which systems are present



O2 Only Commodity Flows



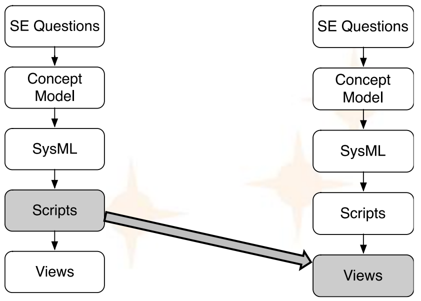
- This diagrams shows the O_2 Only variant
- It shows all the systems present in that variant, and all the commodity flows
- In this diagram (an IBD), systems are parts and commodity flows are item flows on connectors



Simple Analysis Result

#	Conveyed	Source and Target	Variant
1	Atmosphere	Atmosphere : Atmosphere ISRU : ISRU Common	Hestia Domain Common
2	Carbon Dioxide	Habitat : In- Space Habitat Common Greenhouse : Greenhouse Common	Hestia Domain Common
3	Dry Regolith	ISRU : ISRU O2 CH4 Regolith Rejection Area : Dry Regolith	Hestia Domain O2 CH4
4	Dust	Atmosphere : Atmosphere ISRU : ISRU Common	Hestia Domain Common
5	Dust	Atmosphere : Atmosphere Water Storage : Water Storage Common	Hestia Domain Common
6	Dust	Atmosphere : Atmosphere Construction Rover : Construction Rover	Hestia Domain Common
7	Dust	Atmosphere : Atmosphere Commodity Rover : Commodity Rover	Hestia Domain O2 CH4
8	Dust	Atmosphere : Atmosphere Habitat : In- Space Habitat Common	Hestia Domain Common
9	Dust	Atmosphere : Atmosphere Regolith Harvest Area : Regolith	Hestia Domain O2 CH4
10	Dust	Atmosphere : Atmosphere Oxygen Storage : Oxygen Storage Common	Hestia Domain Common
11	Dust	Atmosphere : Atmosphere Power : Power Common	Hestia Domain Common
12	Methane	ISRU : ISRU O2 CH4 Mars Ascent Vehicle : Mars Ascent Vehicle Common	Hestia Domain O2 CH4
13	Oxygen		
14	Oxygen		
15	Oxygen		
16	Oxygen	ISRU : ISRU Common Mars Ascent Vehicle : Mars Ascent Vehicle Common	Hestia Domain Common
17	Oxygen	ISRU : ISRU O2 CH4 Oxygen Transport Tank : Oxygen Transport Tank	Hestia Domain O2 CH4
18	Oxygen	Oxygen Storage : Oxygen Storage Common Crew Rover : Crew Rover	Hestia Domain Common
19	Power	Power Dist Mobile : Power Distribution Mobile Common Commodity Rover : Commodity Rover	Hestia Domain O2 CH4
20	Power	Power Dist Mobile : Power Distribution Mobile Common Construction Rover : Construction Rover	Hestia Domain Common
21	Power	Power Dist Stationary : Power Distribution Stationary Greenhouse : Greenhouse Common	Hestia Domain Common
22	Power	Power Dist Stationary : Power Distribution Stationary Habitat : In- Space Habitat Common	Hestia Domain Common

- This table from MagicDraw shows a simple analysis result
- It is a list of all the commodity flows in both the O_2 Only and O_2 CH_4 variants
- It's easy to construct using the generic table capability, with some OCL
- DEMO – Scripts to create Views



References

References

- The ISRU architecture described here was based on the one from the 2017 AIAA SciTech paper, “An ISRU Propellant Production System to Fully Fuel and Mars Ascent Vehicle” by Kleinhenz and Paz.