



Using MBSE on a Working Project

Presenters:

Kerry McGuire, PhD

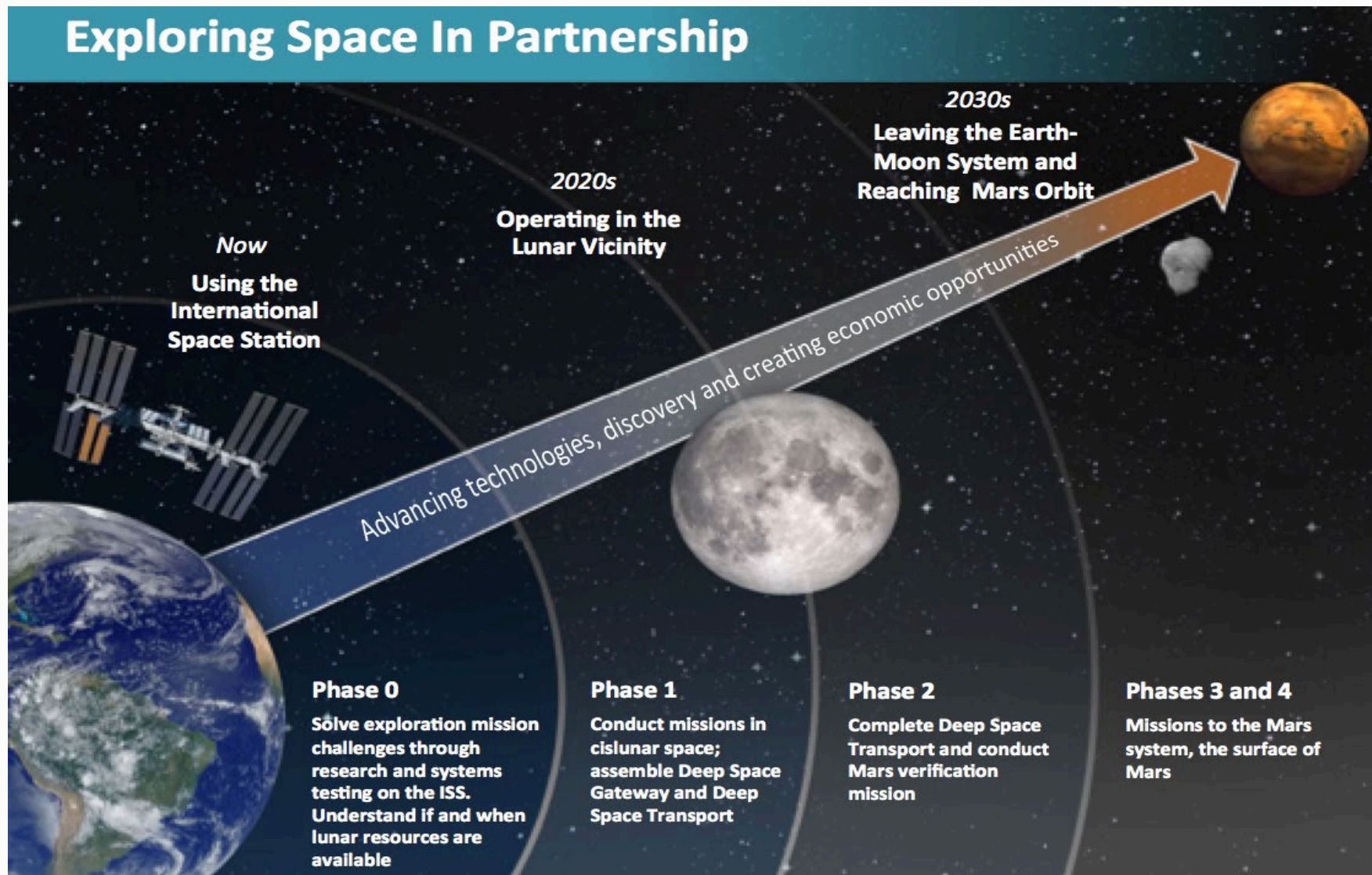
Jeff Cohen, PE

Moderator:

Karen Weiland, PhD

NESC Webinar – November 4, 2020

Exploring Space In Partnership



New challenges:

- Limited to no resupply
- Delayed communication
- Limited to no evacuation
- Unknown effects on crew health and performance
- Limited flight resources
- Increased crew autonomy

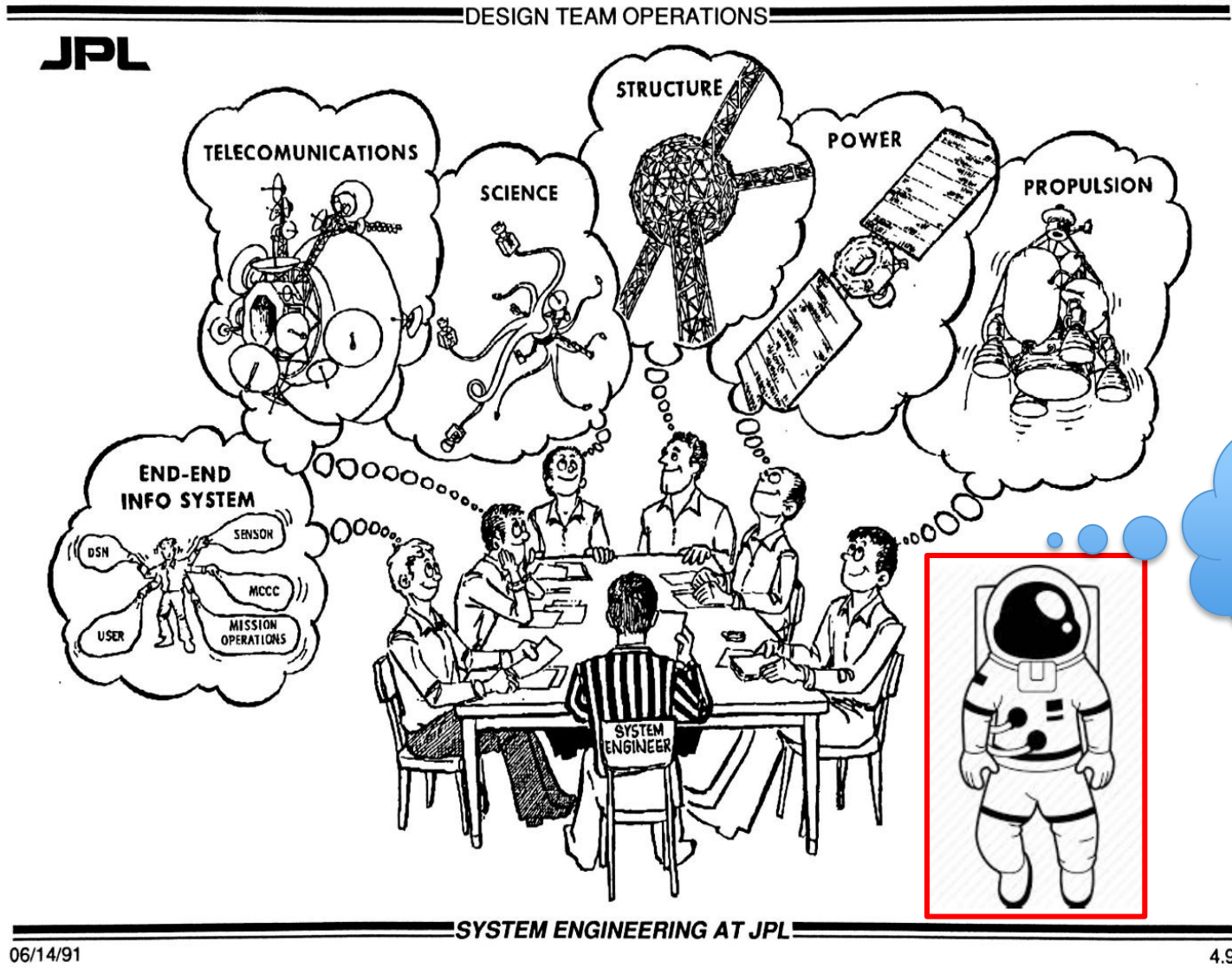
The Human Research Program ([HRP](#)) Exploration Medical Capability Element ([ExMC](#)) uses a Systems Engineering (SE) approach to understand the needs of exploration medical systems.

NASA-STD-3001 Levels of Care



Level 1 LEO <8d	Space Motion Sickness	First Aid / Anaphylaxis Response	Basic Life Support	Private Audio
Level 2 LEO <30d	Clinical Diagnostics	Ambulatory Care	Private Video	Private Telemedicine
Level 3 Post LEO <30d		Limited Dental Care	Limited Advanced Life Support	Trauma Care
Level 4 Lunar >30d	Medical Imaging	Dental Care	Sustainable Advanced Life Support	Limited Surgical Care
Level 5 Lunar/Planetary >210d		Autonomous Ambulatory Care	Autonomous Advanced Life Support	Basic Surgical Care

What is Systems Engineering?





Questions engineers ask...

- What do you need to bring?
- How much mass/power/volume/data?
- How will you use it? How often?
- Who is going to use it?
- How do you make a medical decision?
- What medical events are you expecting?
- What skills do you need for each medical event?
- Are you sure you really need all that stuff?
- What happens if I take things out of your system?

Questions doctors ask...

- How do we do medicine in Exploration Missions?
- What is likely to happen and how often?
- What resources do we need and why?
- How do we communicate to engineers?

Systems Engineering Approach to Get There



Stakeholder needs, goals

NASA Standards

Program requirements & architecture

System functions & behaviors

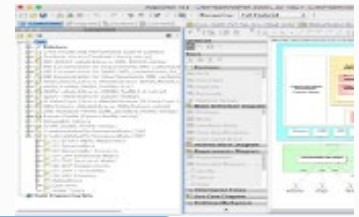
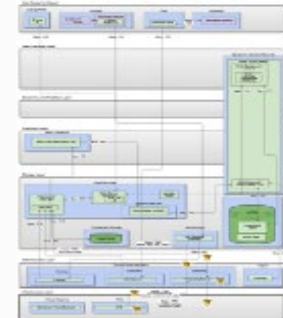
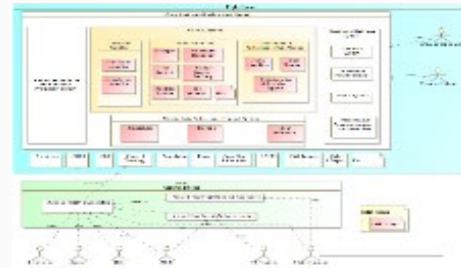
System requirements & architecture

Subsystem requirements & architecture

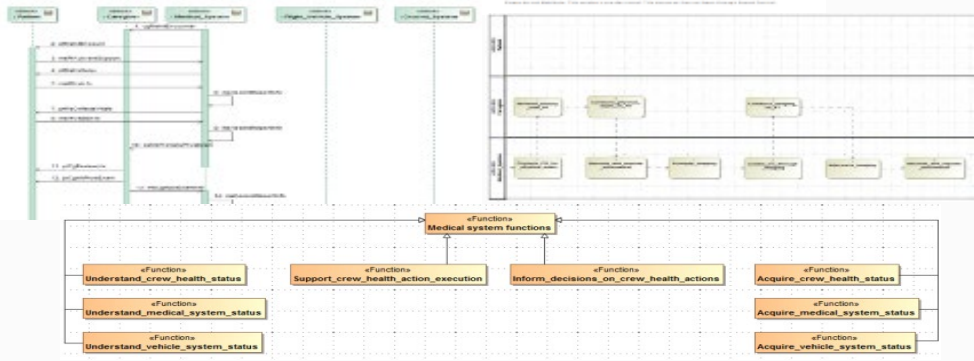
Characterize system

Analyze & trade

Design & Build



Using Model-Based Systems Engineering:



Do we have the capabilities to meet the needs?
Do we need altered allocations?

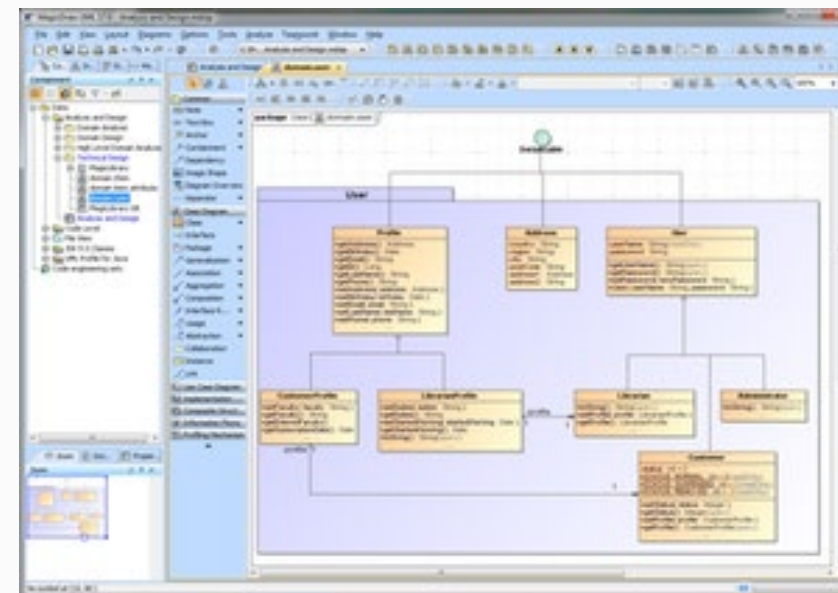
What is MBSE?



Model Based Systems Engineering (MBSE) IS Systems Engineering!

Difference:

Moves from a bunch of separate text based documents to an integrated, visual method for showing information



How is the Model Used?



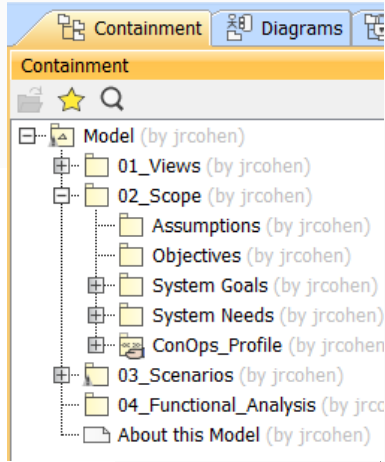
The Foundation(s)

- Define the needs of a medical system for a Level of Care
- A place for mission planners/engineers to start when defining the medical system for an exploration mission
- Examples
 - Short Duration Lunar Orbit
 - Long Duration Lunar Orbit and Lunar Surface

IMPACT

- Perform trade studies on candidate medical systems
- Helps comparing candidate medical systems by mass, volume, and power
- Model provides subset of content and relationships among
 - Clinical Capabilities
 - Clinical Conditions
 - Clinical Resources
 - Requirements

How Do You Visually Represent a ConOps?



Lunar Surface Base Scenarios

	Self-Care		Directed-Care		Medical System Maintenance		Medical Training and Education		Emergent Care	
	Autonomous	Semi-Autonomous	Autonomous	Semi-Autonomous	Autonomous	Semi-Autonomous	Autonomous	Semi-Autonomous	Autonomous	Semi-Autonomous
Planned	02 Exercise	12 Family Conference	10 Physical Exam	08 Psychological Conference				11 Family Training		
Unplanned	03 Headache	06 Allergies		13 UTI		05 Exercise Hardware Malfunction	07 Just in Time Training		09 Emergent Care Arrhythmia	14 Arm Injury

7.4.1.6. Headache (IVA, Unplanned, Self-Care, Autonomous)

7.4.1.6.1. Context

This scenario was developed in the context of a headache.

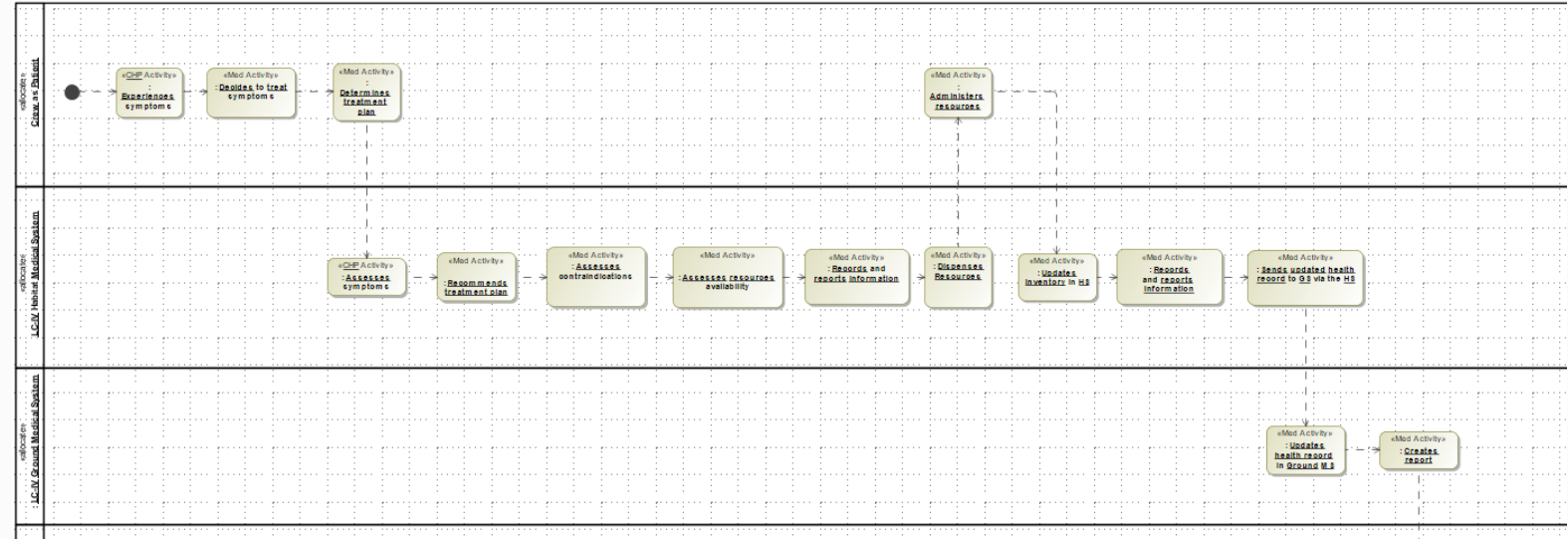
7.4.1.6.2. Highlighted Functionality

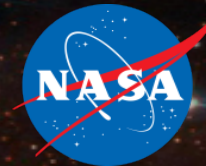
This scenario shows that the Gateway Habitat Medical System can:

- Prompt and facilitate data collection for unplanned medical events.
- Receive data entry from the patient about the patient.
- Provide limited decision support for self-care conditions.
- Assess known inventory and report storage locations to the crew via the Gateway Habitat Medical System interface.
- Automatically report inventory status to the Ground Medical System.
- Generate alerts for the Ground Medical System based upon inflight interactions with the system.
- Record and transmit medically oriented, attributable information to ground clinicians.
- Retrieve reports in the Ground System that can be reviewed by the Gateway Habitat Medical System.

This scenario shows that the Ground System can:

- Receive data entry from the caregiver about the patient.





How Do You Model Requirements?

Requirement Sources and Types

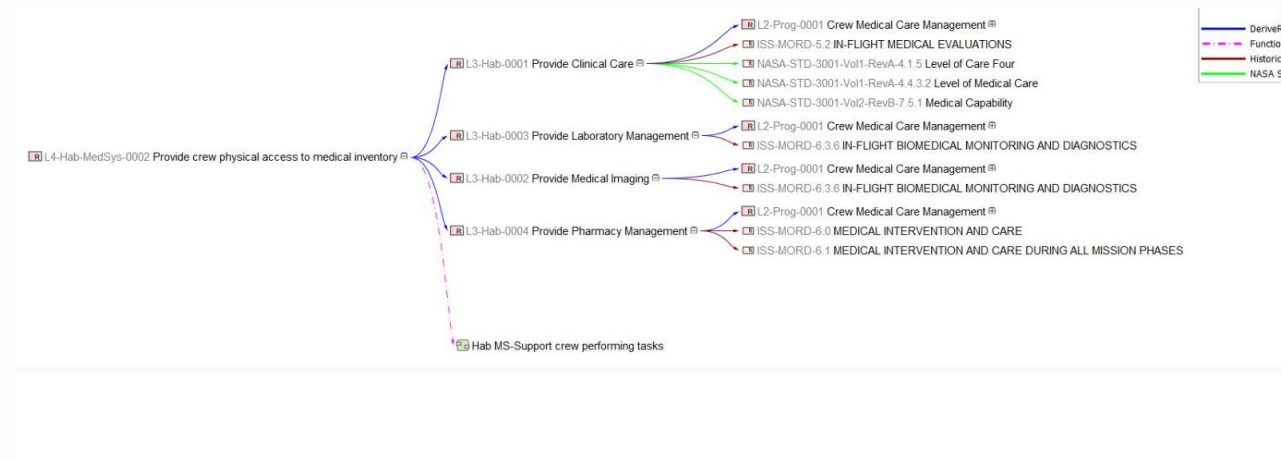
- NASA-STD-3001
- Historical (ISS) Documents
- Level 2, Level 3, Level 4, Level 5 Requirements

Generic Table Level 3 Level of Care IV CHP Requirements List

#	CHP Requirement Level	Id	Name	Text	Rationale_Req
1	Level 3	L3-Hab-0055	Validate Integration of Spaceflight Data with CHP Systems	The Habitat shall validate the integration of spaceflight data with crew health and performance systems for progressively Earth-independent operations	Validate that usable human system and vehicle performance data and metrics collected from spacecraft instruments, sensors, and other sources are integrated and deemed adequate for 1) on-board, in-mission interpretation of relevant data by crews, 2) near-real-time and delayed interpretation by ground support, and 3) post-flight analysis by research and occupational health practitioners. This will include: vibration, radiation (intra-vehicular and extra-vehicular), acceleration, thermal, acoustics, lighting, habitable volume, cabin atmosphere, video and still imagery, communication (video and data), habitability, human performance, and operations data.
2	Level 3	L3-Hab-0054	Validate Multimodal Crew/System Interactions, Communication and Alerting	The Habitat shall validate the efficiency and effectiveness of multimodal crew/system interactions, communication, and alerting	Validate a prototype multimodal communication/alerting system in flight. Select non-flight-critical alerts and messages to convey with the multimodal system. Compare salience of the signaling method with traditional methods, collecting time to respond to signal, errors in response, and subjective comments. Use the activity to test current designs and identify needed capabilities/requirements for future communication/alerting systems.
3	Level 3	L3-Hab-0053	Validate Maintenance and Repair Processes	The Habitat shall validate the efficiency and effectiveness of methods and processes for flight crew to maintain and repair systems in support of progressively Earth-independent operations	Validate the crew effectiveness of maintainability and reparability methods and processes. Deep space and long duration missions will necessitate a much greater level of system-wide maintainability and reparability due to the long periods of time from launch to end of mission during which the vehicle and habitat systems will be operational. Crew will need to have supplies and skills to execute routine and critical repair and maintenance issues. The effectiveness of such methods and skillsets need to be evaluated and proven on the ground and on ISS before being relied upon for long duration missions. These validations need to consider systems engineering, mission/process/task design, habitability concerns, usability, workload, training, and more.

Tracing

- Requirements to Parent Requirement
- Functions to Requirement
- Clinical Capabilities to Clinical Conditions
- Clinical Resources to Clinical Capabilities

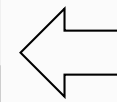


Take away = There isn't one way



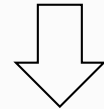
What Requirement Information Is Modeled?

CHP Requirem Level	Id	Name	Text	Rationale_Req													
Level 4	L4-Hab-MedSys-0002	<input type="checkbox"/> Provide crew physical access to medical inventory	The Habitat Medical System shall enable crewmembers physical access to medical inventory.	This requirement focuses on providing the crew physical access to inventory as a complement to accessing information through medical records. Physical access to inventory for the medical system is necessary to ensure that medical inventory (supplies, equipment, and medications) is available at all times when inventory is dispensed to support clinical activities in the prevention, diagnosis and treatment of clinical conditions. Requirements for the habitat need to ensure this physical access accommodation.													
Level 4	L4-Hab-MedSys-0003	<input type="checkbox"/> Prepare habitat for medical activities	The Habitat Medical System shall enable crewmembers to prepare the habitat for medical activities.	Preparation of the habitat for medical purposes involves crew actions such as gathering consumables and equipment, creating appropriate volume for medical tasks, placing restraints, and creating a location that affords privacy and improved cleanliness. Both the medical system and the broader habitat must ensure these activities are accommodated.													
Level 4	L4-Hab-MedSys-0006	<input type="checkbox"/> Access knowledge augmentation	The Habitat Medical System shall access knowledge augmentation data for the performance of medical activities.	The Habitat Medical System needs to be able to access knowledge augmentation data for the performance of medical activities information to during medical activities. Knowledge-based technology can aid crew members in how to perform medical procedures as well as provide clinical decision support. Knowledge augmentation data is data that was not present in the medical system database of information at the start of the mission, but becomes added to the system from the ground medical system.													
Level 4	L4-Hab-MedSys-0007	<input type="checkbox"/> Synthesize health data	The Habitat Medical System shall synthesize health data.	The Habitat Medical System will combine health data from the medical system (including the patient), the relevant physical and environmental data from the vehicle, and the information and data from the ground medical system to support the caregiver.													
Level 4	L4-Hab-MedSys-0016	<input type="checkbox"/> Collect medical data throughout caregiver	The Habitat Medical System shall collect medical information throughout caregiver	Collecting history of present illness, verifying past medical history, and examination findings from caregiver and patient													
Level 4	L4-Hab-MedSys-0017	<input type="checkbox"/> Conduct screening exam	This requirement focuses on providing the crew physical access to inventory as a complement accessing information through medical records. Physical access to inventory for the	<table border="1"> <thead> <tr> <th>Rationale_Req</th> <th>DeriveReq</th> <th>Derived From</th> <th>NASA STD_Derived</th> <th>Historical Trace</th> <th>Refined by Function</th> <th>Refine</th> </tr> </thead> <tbody> <tr> <td></td> <td> <ul style="list-style-type: none"> L3-Hab-0004 Provide Pharmacy Management L3-Hab-0001 Provide Clinical Care L3-Hab-0003 Provide Laboratory Management L3-Hab-0002 Provide Medical Imaging </td> <td></td> <td></td> <td><input type="checkbox"/> Hab MS-Support crew performing tasks</td> <td> <ul style="list-style-type: none"> Ground/Inflight Inventory Monitoring Medication - Chronic Disease Management Inventory monitoring & maintenance - consumable, non Inventory monitoring & maintenance - consumable, non </td> </tr> </tbody> </table>	Rationale_Req	DeriveReq	Derived From	NASA STD_Derived	Historical Trace	Refined by Function	Refine		<ul style="list-style-type: none"> L3-Hab-0004 Provide Pharmacy Management L3-Hab-0001 Provide Clinical Care L3-Hab-0003 Provide Laboratory Management L3-Hab-0002 Provide Medical Imaging 			<input type="checkbox"/> Hab MS-Support crew performing tasks	<ul style="list-style-type: none"> Ground/Inflight Inventory Monitoring Medication - Chronic Disease Management Inventory monitoring & maintenance - consumable, non Inventory monitoring & maintenance - consumable, non
Rationale_Req	DeriveReq	Derived From	NASA STD_Derived	Historical Trace	Refined by Function	Refine											
	<ul style="list-style-type: none"> L3-Hab-0004 Provide Pharmacy Management L3-Hab-0001 Provide Clinical Care L3-Hab-0003 Provide Laboratory Management L3-Hab-0002 Provide Medical Imaging 			<input type="checkbox"/> Hab MS-Support crew performing tasks	<ul style="list-style-type: none"> Ground/Inflight Inventory Monitoring Medication - Chronic Disease Management Inventory monitoring & maintenance - consumable, non Inventory monitoring & maintenance - consumable, non 												
Level 4	L4-Hab-MedSys-0018	<input type="checkbox"/> Perform physical exam	Preparation of the habitat for medical purposes involves crew actions such as gathering consumables and equipment, creating appropriate volume for medical tasks, placing restraints, and creating a location that affords privacy and improved cleanliness. Both the medical system and the broader habitat must ensure these activities are accommodated.	<table border="1"> <thead> <tr> <th>Rationale_Req</th> <th>DeriveReq</th> <th>Derived From</th> <th>NASA STD_Derived</th> <th>Historical Trace</th> <th>Refined by Function</th> <th>Refine</th> </tr> </thead> <tbody> <tr> <td> <ul style="list-style-type: none"> L3-MW-0703 Caregiver Restraint Provision L3-MW-0705 Patient Restraint Provision L3-MW-0126 Crewmember Privacy L3-MW-0109 Physical Access L3-MW-0106 Operational Volume L3-MW High Level Requirement </td> <td> <ul style="list-style-type: none"> L3-Hab-0001 Provide Clinical Care L3-Hab-0003 Provide Laboratory Management L3-Hab-0002 Provide Medical Imaging L3-Hab-0004 Provide Pharmacy Management </td> <td> <ul style="list-style-type: none"> NASA-STD-3001-V02-RevB-7.3.2 Medical Treatment Spatial Accommodation </td> <td></td> <td><input type="checkbox"/> Hab MS-Dispense Inventory</td> <td> <ul style="list-style-type: none"> Relocate to private treatment area </td> </tr> </tbody> </table>	Rationale_Req	DeriveReq	Derived From	NASA STD_Derived	Historical Trace	Refined by Function	Refine	<ul style="list-style-type: none"> L3-MW-0703 Caregiver Restraint Provision L3-MW-0705 Patient Restraint Provision L3-MW-0126 Crewmember Privacy L3-MW-0109 Physical Access L3-MW-0106 Operational Volume L3-MW High Level Requirement 	<ul style="list-style-type: none"> L3-Hab-0001 Provide Clinical Care L3-Hab-0003 Provide Laboratory Management L3-Hab-0002 Provide Medical Imaging L3-Hab-0004 Provide Pharmacy Management 	<ul style="list-style-type: none"> NASA-STD-3001-V02-RevB-7.3.2 Medical Treatment Spatial Accommodation 		<input type="checkbox"/> Hab MS-Dispense Inventory	<ul style="list-style-type: none"> Relocate to private treatment area
Rationale_Req	DeriveReq	Derived From	NASA STD_Derived	Historical Trace	Refined by Function	Refine											
<ul style="list-style-type: none"> L3-MW-0703 Caregiver Restraint Provision L3-MW-0705 Patient Restraint Provision L3-MW-0126 Crewmember Privacy L3-MW-0109 Physical Access L3-MW-0106 Operational Volume L3-MW High Level Requirement 	<ul style="list-style-type: none"> L3-Hab-0001 Provide Clinical Care L3-Hab-0003 Provide Laboratory Management L3-Hab-0002 Provide Medical Imaging L3-Hab-0004 Provide Pharmacy Management 	<ul style="list-style-type: none"> NASA-STD-3001-V02-RevB-7.3.2 Medical Treatment Spatial Accommodation 		<input type="checkbox"/> Hab MS-Dispense Inventory	<ul style="list-style-type: none"> Relocate to private treatment area 												



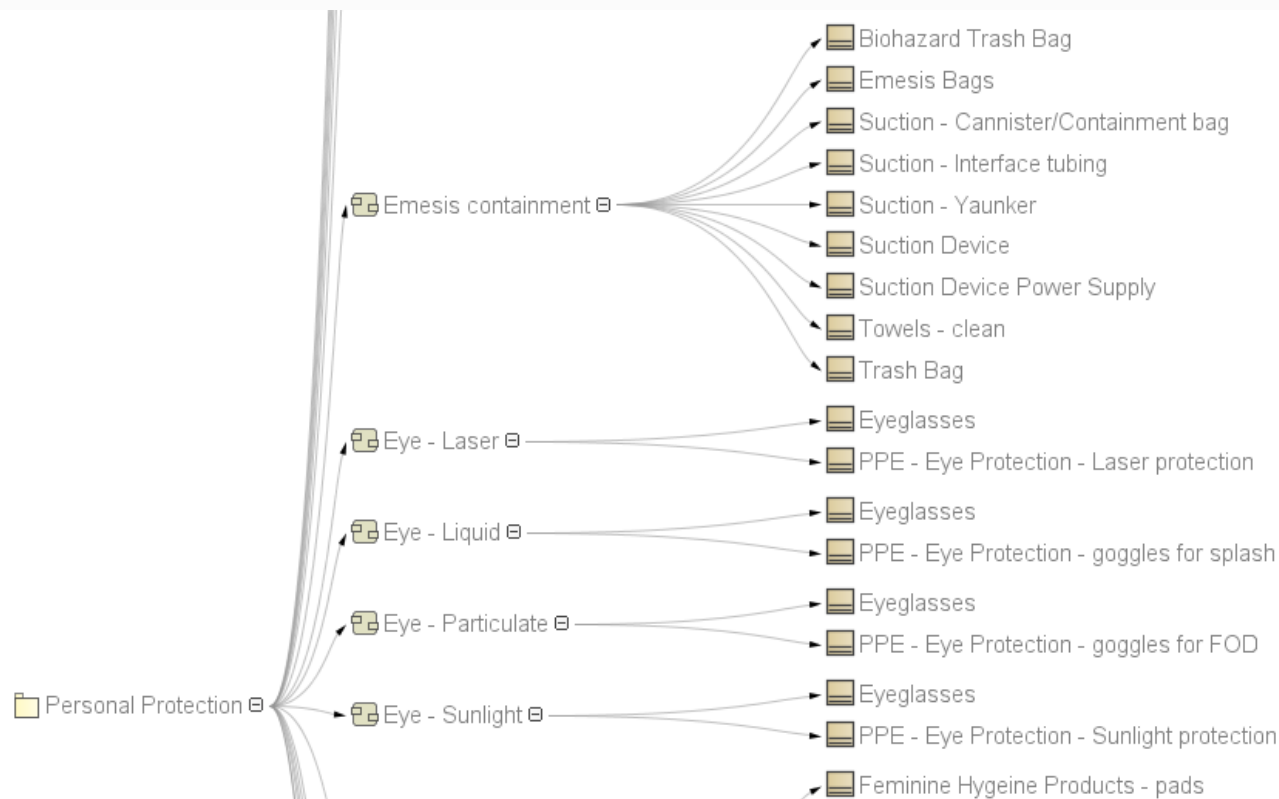
Requirement id, text, rationale

Traces to specifications, requirement levels, clinical data



Rationale_Req	DeriveReq	Derived From	NASA STD_Derived	Historical Trace	Refined by Function	Refine
<ul style="list-style-type: none"> L4-Hab-DataSys-0023 Provide diagnostics analytics L4-Hab-MedSys-0154 Provide in-flight exercise protocol L4-Hab-MedSys-0064 Provide medical data reliability L4-Hab-MedSys-0009 Present medical data to crewmembers L4-Hab-MedSys-0011 Guide crew on medical activity L4-Hab-MedSys-0153 Provide in-flight equipment procedure L4-Hab-MedSys-0010 Present patient clinical status to caregiver L4-Hab-MedSys-0013 Present options to support medical decision-making L4-Hab-MedSys-0082 Provide in-flight decision support capability L4-Hab-MedSys-0012 Notify crew of medically-relevant information 	<ul style="list-style-type: none"> L3-Hab-0003 Provide Laboratory Management L3-Hab-0001 Provide Clinical Care L3-Hab-0002 Provide Medical Imaging L3-Hab-0004 Provide Pharmacy Management 			<ul style="list-style-type: none"> Habitat MS-Augment crew knowledge Hab MS-Support crew performing tasks CCG-Maintain clinical competence 	<ul style="list-style-type: none"> Adequate assessment/diagnostic skills (ability to record) Decision Support 	
<ul style="list-style-type: none"> L3-Hab-0021 Provide Data Descriptive Analytics L3-Hab-0001 Provide Clinical Care 				<input type="checkbox"/> Hab MS-Analyze health data		
<ul style="list-style-type: none"> L3-MW-0809 Fluid Containment Provision L3-MW High Level Requirement 	<ul style="list-style-type: none"> L3-Hab-0015 Provide Waste Management 	<ul style="list-style-type: none"> NASA-STD-3001-V02-RevB-7.3.1.1 Body Waste Management Capability 		<input type="checkbox"/> Hab MS-Support crew performing tasks	<ul style="list-style-type: none"> Menstrual flow absorption 	
	<ul style="list-style-type: none"> L3-Hab-0001 Provide Clinical Care 	<ul style="list-style-type: none"> NASA-STD-3001-V01-RevA-4.4.2.5 Circadian Shifting Operations and Fatigue Management NASA-STD-3001-V02-RevB-6.1 Trend Analysis of Environmental Data 		<input type="checkbox"/> Hab MS-Analyze health data	<ul style="list-style-type: none"> Environmental Status Consult 	
	<ul style="list-style-type: none"> L3-Hab-0001 Provide Clinical Care 	<ul style="list-style-type: none"> NASA-STD-3001-V01-RevA-4.4.3.5.1 Physiologic NASA-STD-3001-V02-RevA-7.3.1 Medical Capability NASA-STD-3001-V02-RevB-7.3.1 Medical Capability 		<input type="checkbox"/> Hab MS-Analyze health data		

How Have You Involved and Designed to Users?



DISCLAIMER: This is a representative example

Goal is to capture and visualize the information provided by subject matter experts (e.g., Clinicians) and other sources to meet the needs of our users.

Clinicians:

- **Identify the medical conditions**
- **Map the treatment of conditions to the medical capabilities**
- **Identify medical resources needed by those capabilities to treat the conditions**

Systems Engineers:

- **Import information into a model**
- **Show relation maps that visualize the traces**
- **Derive and trace requirements**

How Do You Share To Modelers and Non-Modelers?



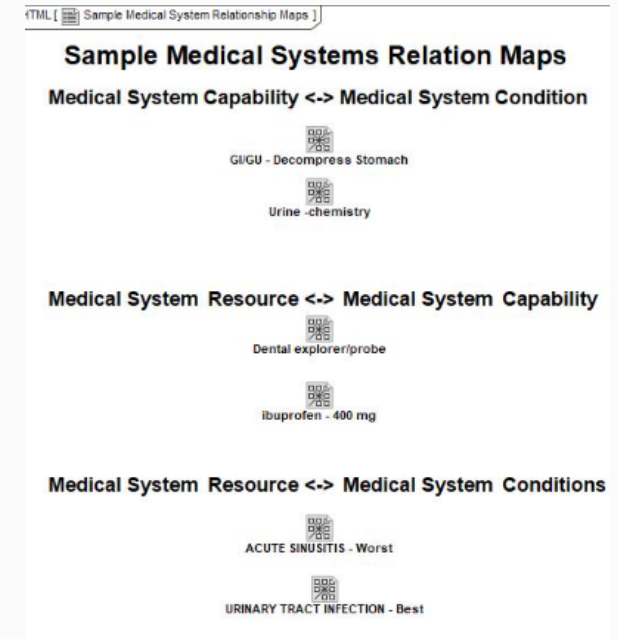
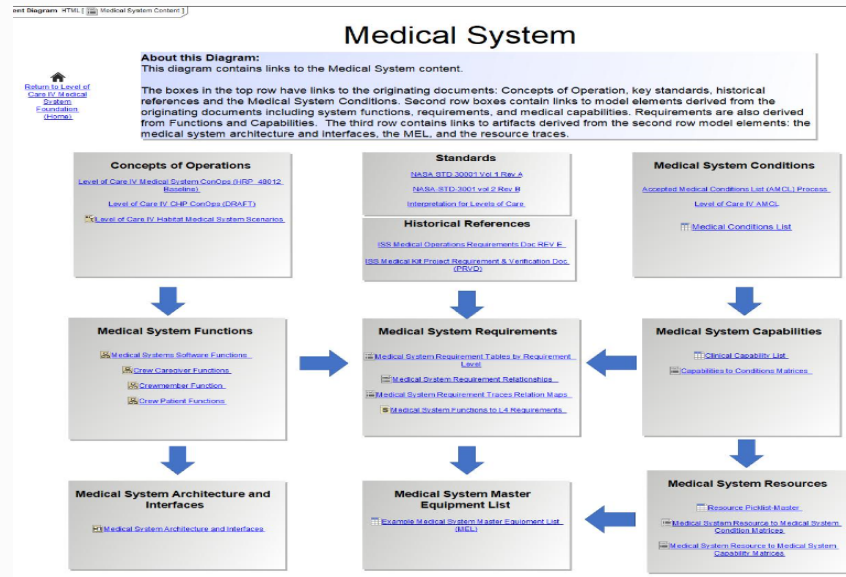
Level of Care IV: Short-Duration Lunar Orbit Medical System Foundation

Version 5.9
Date: 10 July 2020

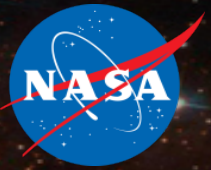
About this HTML Report:
This HTML report contains visualizations and links that pertain to a Medical System for a Level of Care IV: Short-Duration Lunar Orbit mission. The general format and content stem from a Systems Engineering modeling tool which uses specific language and format for consistent modeling across systems. This link provides an overview of the Medical System Foundation model: [About this Model](#)

This HTML report shows a subset of the entire model. It is meant to give the reader an idea of the kind of information that the model can provide. For more information or more detail, please contact the ExMC Element's MBSE Lead.

About this Diagram:
This diagram represents the system architecture for the Habitat System and its component systems. Each gray box shows one of the Habitat systems and its constituent parts. The Medical System is dark gray and the focus of the current model. It includes the full content. Light gray boxes represent systems for which the model has Medical System content to be implemented by the system. Click the System Content icon to see the Medical System content for each of the systems. For detailed information, start with the [Guide for Using HTML Report](#).



- DENTAL CROWN LOSS - Best (Diagnosis)
- DENTAL CROWN LOSS - Worst (Acute_Treatment)
- DENTAL CROWN LOSS - Worst (Diagnosis)
- DENTAL EXPOSED PULP - Best (Acute_Treatment)
- DENTAL EXPOSED PULP - Best (Diagnosis)
- DENTAL EXPOSED PULP - Best (Long_Term_Treatment)
- DENTAL EXPOSED PULP - Worst (Acute_Treatment)
- DENTAL EXPOSED PULP - Worst (Diagnosis)
- DENTAL EXPOSED PULP - Worst (Long_Term_Treatment)
- DENTAL FILLING LOSS - Best (Acute_Treatment)
- DENTAL FILLING LOSS - Best (Diagnosis)
- DENTAL FILLING LOSS - Best (Long_Term_Treatment)
- DENTAL FILLING LOSS - Worst (Acute_Treatment)
- DENTAL FILLING LOSS - Worst (Diagnosis)
- DENTAL FILLING LOSS - Worst (Long_Term_Treatment)
- Dental - Extraction multi root tooth
- Dental - Extraction single root tooth
- Dental - Repair loose crown /Replace lost filling
- Ear - Ear Wax Removal
- Focused Physical Exam - ENT
- Provide knowledge, skills, and abilities - Physician (First year)



- Custom Page
- Includes information to guide users

Content Diagram HTML [Level of Care IV Medical System Foundation]

Level of Care IV: Short-Duration Lunar Orbit Medical System Foundation

Version 0.9
Date: 10 July 2020

About this HTML Report:
This HTML report contains visualizations and links that pertain to a Medical System for a Level of Care IV: Short-Duration Lunar Orbit mission. The general format and content stem from a Systems Engineering modeling tool which uses specific language and format for consistent modeling across systems. This link provides an overview of the Medical System Foundation model: [About this Model](#)
This HTML report shows a subset of the entire model. It is meant to give the reader an idea of the kind of information that the model can provide. For more information or more detail, please contact the ExMC Element's MBSE Lead.

About this Diagram:
For detailed information on how to use this report, start with the [Guide for Using HTML Report](#). This diagram on the right represents the system architecture for the Habitat System and its component systems.
Each gray box shows one of the Habitat systems and its constituent parts. The Medical System is dark gray and the focus of the current model. It includes the full content. Light gray boxes represent systems for which the model has Medical System content to be implemented by the system. Click the System Content icon to see the Medical System content for each of the systems.

Medical System
Medical System Content
: Clinical Care
: Imaging
: Laboratory Management
: Pharmacy Management

Environmental Monitoring System
Environmental Monitoring System Content
: Acoustic Environment Monitoring
: Internal Atmosphere Monitoring
: micro-g/Acceleration Environment Monitoring
: Microbial Environment Monitoring
: Radiation Environment Monitoring
: Toxicological Environment Monitoring

Data System
Data System Content
: Advanced Analytics
: Data Source Interfaces
: Data Storage
: Data User Interfaces
: Descriptive Analytics

Wellness System
Wellness System Content
: Behavioral Health Management
: Nutrition Management
: Physiological Health Management
: Sleep Management

Task Performance Support System
Task Performance Support System Content
: Crew Interfaces
: Task Management
: Training

Maintenance System
Maintenance System Content

Testbed & Research System
Testbed & Research System Content
: Research
: Testbed

Extravehicular Activity Support System
Extravehicular Activity Support System Content
: EVA Crew Health Support
: EVA Performance Support

Waste Management
Waste Management System Requirements with Relationships

Comm & Tracking
: C&D

Power
: Thermal

Propulsion
: Payload

EVA
: GNC

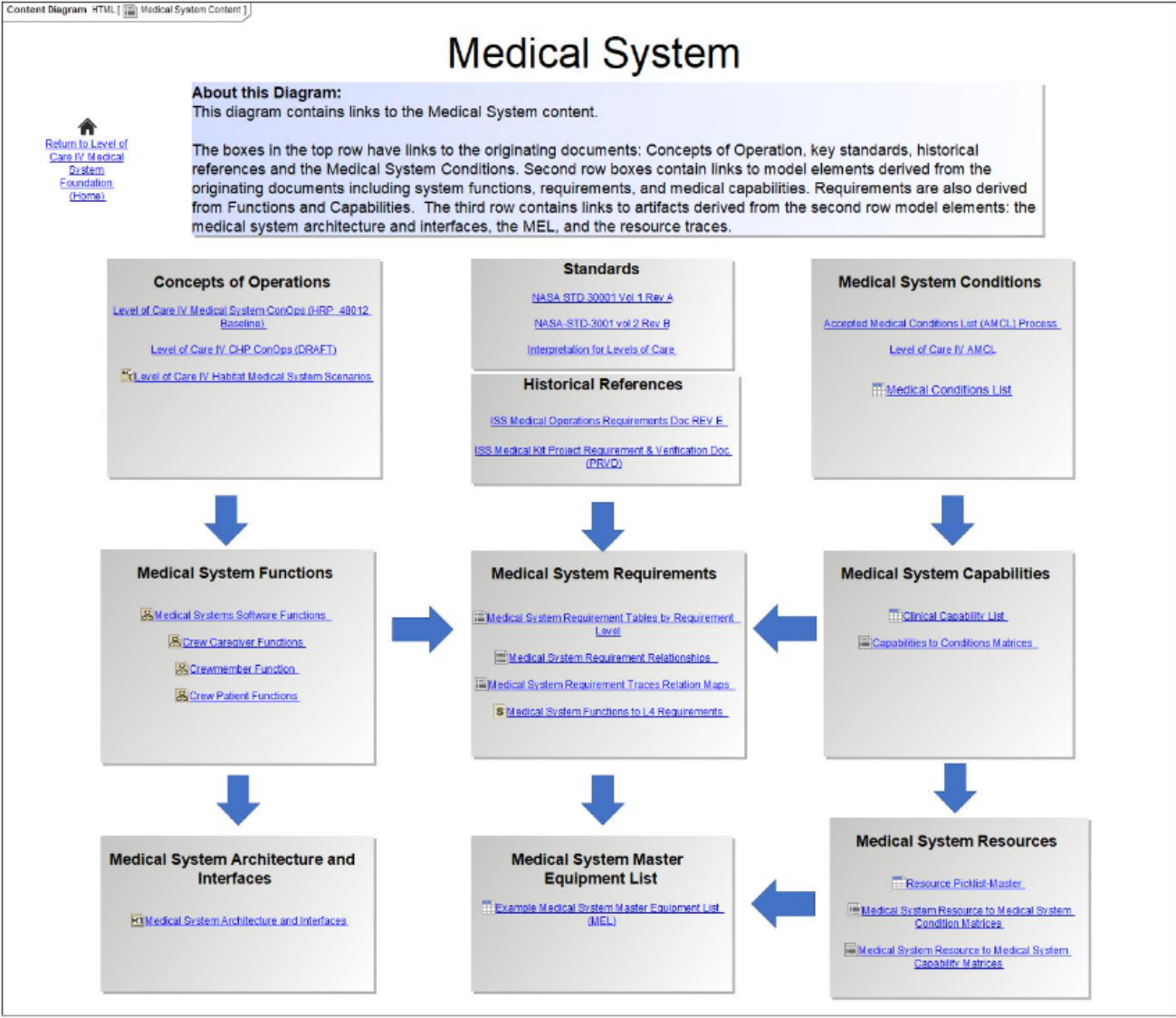
ECLSS
: Crew Disp. & Controls

Structures
Structures Requirements with Relationships

Glossary
A - D
L - R
E - K
S - Z

Acronyms
Acronyms

Legend
Habitat System
Medical System
Crew Health and Performance System
Habitat System Constituent Part



- Custom page in the model
- Links to information
- One page for each (sub)system



- Custom diagrams
- Links to requirement tables
- Links to relationship maps

Content Diagram HTML | Medical System Requirement Relationships]

[Return to Level of Care IV Medical System Foundation \(Home\)](#)

MEDICAL SYSTEM RELATIONSHIP MAPS

Sample Medical System Relationship Maps

MEDICAL SYSTEM RELATIONSHIP TABLES

LEVEL 2 AND LEVEL 3 REQUIREMENTS WITH TRACES

Level 2 Habitat Requirements

Level 3 CHP Requirement Table

LEVEL 4 MEDICAL SYSTEM REQUIREMENTS TABLES AND TRACES

Medical System Functional Requirement with Relationships

Medical System Non-Functional Requirements with Relationships

Medical System Functions to Level 4 Requirements

Clinical Capability to Level 4 Requirements

LEVEL 4 MEDICAL SYSTEM REQUIREMENTS LEVIED ON OTHER SYSTEMS

[Wellness System Requirements with Relationships](#)

[Environmental Monitoring System Requirements with Relationships](#)

[Data System Requirement with Relationships](#)

[Task Performance Support System Requirements with Relationships](#)

[Maintenance System Requirements with Relationships](#)

[Testbed & Research Requirements with Relationships](#)

[Waste Management System Requirements with Relationships](#)

[Structures Requirements with Relationships](#)

About this Diagram:
This diagram contains links to the Medical System requirements and traces.

Medical System Relationship Maps contains links that trace sample Medical Systems Clinical conditions, capabilities, and resources.

Level 2 and Level 3 Requirements with Traces contains links to the Level 2 and Level 3 CHP requirements that pertain to the Medical System

Level 4 Medical System Requirements Tables and Traces contain links to Level 4 Medical System Requirements, the Performance Requirements, and the tables that trace Medical System Functions and Clinical Capabilities to Medical System Requirements.

The Level 4 Medical System Requirements Levied on other CHP Systems section contains links to tables with Medical System requirements that must be implemented by the other CHP Systems.



Sample Medical Systems Relation Maps

Medical System Capability <-> Medical System Condition



Medical System Resource <-> Medical System Capability



Medical System Resource <-> Medical System Conditions

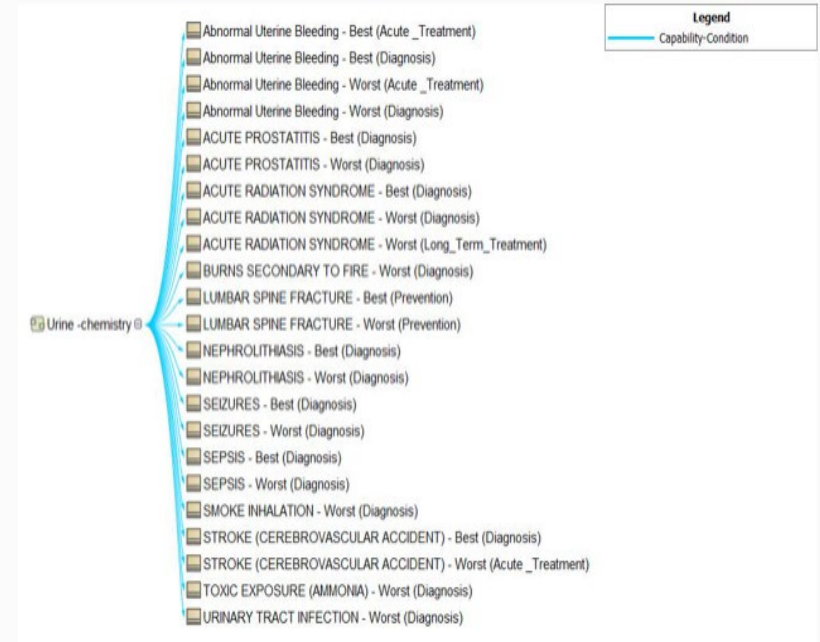
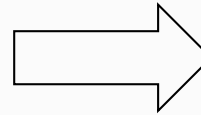


About this Diagram.

This diagram contains links to Relation Maps. Relation Maps show the traces among model elements. In this case, they show traces among Medical Capabilities, Medical Conditions, and Medical Resources.

To read these maps, start on the left side of the diagram. Find the Level 4 Medical System Requirement. Follow the arrows to see the related model elements. The color of the arrow indicates the type of the relation. See the legend and the HTML Report Guide for guidance on the type of relation.

This View shows a subset of the entire model. The model contains the complete set of Relation Maps. For more information or more detail, please contact the ExMC Element MBSE Lead



- **Sharing with non-modelers**
- **Who can do the work**
- **Supporting multiple schedule demands**
- **Model centric requires some training**
- **Expect to reorganize (refactor) the model**
- **Need good supporting processes**
- **Have an architecture that supports future uses**
- **Create and use a model management plan**





- **NPR 7123.1C – NASA Systems Engineering Handbook**
- **JPR 7210.3C – Program/Project Management and Systems Engineering**
- **SP 6105 rev2 – NASA Systems Engineering Handbook**
- **Expanded Guidance for NASA Systems Engineering – Volume 1 and 2**
- **SP-2015-3079 – HSI Practitioners Guide**
- **NASA-STD-3001, Volume 1 – NASA Spaceflight Human-Systems Standard Volume 1**
- **TM 2017-219290 – Interpretation of NASA-STD-3001 Levels of Care for Exploration Medical System Development**



Concept of Operations

- HRP 48012 – Recommendation for a Medical System Concept of Operations for a Gateway Mission
- JSC 67070 - Medical System Concept of Operations for Mars Exploration Missions

Conference Papers

- Amador, J., et al. (2020). Enabling Space Exploration Medical System Development Using a Tool Ecosystem. *IEEE Aerospace Conference*. Big Sky, MT.
- Mindock, J., et al. (2019). A Model-Based Systems Engineering Approach to Exploration Medical System Development. *IEEE Aerospace Conference*. Big Sky, MT.
- Antonsen, E., et al. (2018). Prototype Development of a Tradespace Analysis Tool for Spaceflight Medical Resources. *Aerospace Medicine and Human Performance*, 108-114.
- Mindock, J., et al. (2017). Systems Engineering for Space Exploration Medical Capabilities. *Proceeding of the AIAA Space and and Astronautics Forum and Exposition*.
- Canga, M., et al. (2016). A Strategic Approach to Medical Care for Exploration Missions. *International Astronautical Congress*. Guadalajara, Mexico.

2020 NASA Systems Engineering Webinar Series



Date	Title	Presenter
✓ June 8 th	How to Get Started Using MBSE: The Basics of What, How and Who	Trevor Grondin
✓ July 20 th	Systems Engineering and Model Based Systems Engineering Stakeholder State of the Discipline	Jessica Knizhnik
✓ August 17 th	An Innovative Jump Start for MBSE Tooling, NTL Results	Samantha Infeld
✓ October 14 th	MBSE to MIAMI to Implementation An Overview	Jessica Knizhnik
✓ October 26 th	Future Model-Based Systems Engineering Vision and Strategy Bridge	Karen Weiland
November 4 th	Using MBSE on a Working Project	Kerry McGuire and Jeff Cohen



Backup



From NASA Systems Engineering Handbook

What is Systems Engineering?

- A methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system

What is a “System”?

- Collection of different elements producing results not obtainable by elements alone
 - Elements = people, hardware, software, facilities ...
- Value created by relationship among parts - how they are interconnected

Systems Engineering IS:

- a way of looking at the “big picture” when making technical decisions
- a way of achieving functional, physical, and operational performance requirements
- the art and science of developing a system within opposed constraints
- a holistic, integrative discipline, wherein the contributions of e.g.,
 - structural engineers, electrical engineers, mechanism designers, power engineers, human factors engineers, and many more disciplines (**medical!**)are evaluated and balanced... to produce a coherent whole that is not dominated by the perspective of a single discipline.

¹Rechtin, *Systems Architecting of Organizations: Why Eagles Can't Swim*.

²Comments on systems engineering throughout the handbook's Chapter 2.0 are extracted from the speech "Systems Engineering and the Two Cultures of Engineering" by Michael D. Griffin, previous NASA Administrator.

The System Must...



- **Protect from environmental hazards**
 - Radiation (SPE, GCR)
 - Noise, vibration, CO₂, etc.
 - Microbiome of the built environment
- **Keep healthy crew well**
 - Exercise
 - Other physiological countermeasures
 - Food
 - Behavioral health
- **Prevent, diagnose, treat, manage long-term health care**
 - Data system
 - Medical devices
 - Medical supplies
- **Support crew to accomplish mission tasks**
 - Procedures
 - Training
 - User interfaces

