Engineering a Medical System for Human Spaceflight

April 1, 2019

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Aerospace Medicine Clerkship
Conflicts of Interest Disclosure

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I have financial interests in the above entities.
The opinions shared here are my own and not necessarily reflective of the above institutions.
Outline

• An Historical Look at Exploration Medicine

• Upcoming Missions and Medical Challenges

• Risk and Spaceflight Events

• Getting the Medicine into the Engineering System
AN HISTORICAL LOOK AT EXPLORATION MEDICINE
19

1,000,000,000

~530

12
Observation Hill
1911 - 1912
Amundsen and Scott Pole Race

Differences between Scott and Amundsen expeditions

Scott
• Overtechnologization (16 men, 23 dogs, 10 ponies, 13 sledges, 2 motor sledges)
• Followed what was tried before “because it worked”
• Thin margin of error
• Last minute decisions
• Died 12 miles short of his last food depot

Amundsen
• Focused preparation (5 men, 20 dogs)
• Made a new path
• Significant margin of error
• Lots and lots of preparation and field testing
• Got to Pole first and lived
There are evidence-based ways to systematically identify and match what is needed from a health perspective with what gets fielded in a mission.
Our work continues…

• From Conclusion 6:
• “The human being must be integrated into the space mission in the same way in which all other aspects of the mission are integrated.”

WHERE ARE WE GOING?
NASA Human Spaceflight Missions

- Soyuz Launch and Landings
- International Space Station
- Commercial Crew Program
- MultiPurpose Crew Vehicle
- Gateway Habitat
- Deep Space Transport
- Mars Missions

Near Term (Current - 5 yrs)

Medium Term (within 10 yrs)

Long Term (10 – 20 yrs)
Space Medicine History

1961 2019

5/3/2019 NASA centric – there is more insight to be gained from Russian experiences
What about Mars?
No comparable human experience for Mars

The entire experience of our species fits into that blue dot.

Will not get you here!

Trans-Mars Cruise – 9 mos
Full Mission - ~34 mos

What got you here…
Can we just use what we already know?

- Real Time Communications
- Medical Evacuation Capability
- Consumables Resupply
RISK

- The possibility of losing something of value.

- The intentional interaction with uncertainty.

- Rolling the dice on whether sh** happens today.
Hazards of Spaceflight
Hazards Drive Human Spaceflight Risks

- **Altered Gravity - Physiological Changes**
  - Balance Disorders
  - Fluid Shifts
  - Cardiovascular Deconditioning
  - Muscle Atrophy
  - Bone Loss

- **Distance from earth**
  - Drives the need for additional “autonomous” medical care capacity – cannot come home for treatment

- **Space Radiation**
  - Acute In-flight effects
  - Long term cancer risk

- **Hostile/Closed Environment**
  - Vehicle Design
  - Environmental – CO₂ Levels, Toxic Exposures, Water, Food
  - Decreased Immune Function

- **Isolation & Confinement**
  - Behavioral aspect of isolation
  - Sleep disorders
  - Team dynamics
**Exploration Medical Conditions**

**SKIN**
- Burns secondary to Fire
- Skin Abrasion
- Skin Laceration

**EYES**
- Acute Glaucoma
- Eye Corneal Ulcer
- Eye Infection
- Retinal Detachment
- Eye Abrasion
- Eye Chemical Burn

**EARS, NOSE, THROAT**
- Barotrauma (sinus block)
- Nasal Congestion (SA)
- Nosebleed (SA)
- Acute Sinusitis
- Hearing Loss
- Otitis Externa
- Otitis Media
- Pharyngitis

**DENTAL**
- Abscess
- Caries
- Exposed Pulp
- Tooth Loss
- Crown Loss
- Filling Loss

**CARDIOVASCULAR**
- Angina/Myocardial Infarction
- Atrial Fibrillation / Atrial Flutter
- Cardiogenic Shock secondary to Myocardial Infarction
- Hypertension
- Sudden Cardiac Arrest
- Traumatic Hypovolemic Shock

**GASTROINTESTINAL**
- Constipation (SA)
- Abdominal Injury
- Acute Cholecystitis
- Acute Diverticulitis
- Acute Pancreatitis
- Appendicitis
- Diarrhea
- Gastroenteritis
- Hemorrhoids
- Indigestion
- Small Bowel Obstruction

**Pulmonary**
- Choking/Obstructed Airway
- Respiratory Infection
- Toxic Exposure: Ammonia
- Smoke Inhalation
- Chest Injury

**NEUROLOGIC**
- Space Motion Sickness (SA)
- Head Injury
- Seizures
- Headache
- Stroke
- Paresthesia
- Headache (SA)
- Neurogenic Shock
- VIIP (SA)

**MUSKULOSKELETAL**
- Back Pain (SA)
- Abdominal Wall Hernia
- Acute Arthritis
- Back Injury
- Ankle Sprain/Strain
- Elbow Dislocation
- Elbow Sprain/Strain
- Finger Dislocation
- Fingernail Delamination (EVA)
- Hip Sprain/Strain
- Hip/Proximal Femur Fracture
- Knee Sprain/Strain
- Lower Extremity Stress fracture
- Lumbar Spine Fracture
- Shoulder Dislocation
- Shoulder Sprain/Strain
- Acute Compartment Syndrome
- Neck Injury
- Wrist Sprain/Strain
- Wrist Fracture

**PSYCHIATRIC**
- Insomnia (Space Adaptation)
- Late Insomnia
- Anxiety
- Behavioral Emergency
- Depression

**GENITOURINARY**
- Abnormal Uterine Bleeding
- Acute Prostatitis
- Nephrolithiasis
- Urinary Incontinence (SA)
- Urinary Retention (SA)
- Vaginal Yeast Infection

**INFECTION**
- Herpes Zoster (shingles)
- Influenza
- Mouth Ulcer
- Sepsis
- Skin Infection
- Urinary Tract Infection

**IMMUNE**
- Allergic Reaction
- Anaphylaxis
- Skin Rash
- Medication Reaction

**ENVIRONMENT**
- Acute Radiation Syndrome
- Altitude Sickness
- Decompression Sickness (EVA)
- Headache (CO2)
Fire and Toxic Exposure
Near Drowning in EVA
SANS – adaptation or pathology?
Urinary Tract Infections and Sepsis

In-flight Post-void Ultrasound

Ground Post-void Ultrasound
Risk Mitigation Framework

Evidence

Human System Risks

Policy
- Health & Performance Standards

Research & Technology Development
- Risk Mitigations

Operations
- Countermeasure Implementation
- Program Requirements
Human Spaceflight functions at the Intersection of Engineering and Medicine

- Medical Operations needs quantitative techniques to optimize mission planning and medical resources – inform Requirements

- Engineering and design teams need quantitative medical information to balance medical risk with resource limitations

- Medical SMEs have not historically had the capability to provide this

Enter Probabilistic Risk Assessment
Translating between Medicine and Engineering

The Integrated Medical Model

Medical Evidence Base

- Mission Duration and Profile
- Crew Composition and Attributes
- Risks due to Extravehicular Activities (EVAs)
- Medical Condition Incidence Data
- Medical Condition Diagnosis and Treatment Data
- ISS Medical System Resources
- Medical Condition Impairment and Outcomes Data

Clinical Outcomes and Mission Impact

- What is the likelihood of a medical evacuation?
- What is the risk of Loss of Crew Life due to illness on ISS?
- What medical devices should we have on ISS?
- What medications should be supplied?
IMM Example Output - Total Medical Events

IMM Run S-20180531-405, 100,000 simulations
Considering Evacuation

Probability of EVAC

IMM Run S-20180531-405, 100,000 simulations
How do models compare to real life?

**IMM Simulation Data**

- Medical Illness
  - VIIP/SANS
  - Dental Abscess
  - Kidney Stone
  - Sepsis
  - Stroke
  - Angina/MI
  - Afib/Aflutter

- Environmental
  - Smoke/Toxic Exposure

- Injury/Trauma
  - Hypovolemic Shock
  - Wrist Fracture
  - Back Injury

**Actual Russian Flight Data**

- EVAC
  - Urosepsis
  - Cardiac Arrhythmia
  - Smoke Inhalation

- Close Call EVAC
  - Kidney Stone
  - Dental Abscess
  - Toxic Exposure

* Russian medical data not used in IMM
Spaceflight Medical Risk

~100 Medical Conditions

Medical Conditions for which we have not planned.
Consumables Resupply

Gateway 2024

Deep Space Transport 2027

Precursor 2029

Mars 2033

26-41 days

190-221 days

1 year

2 years

3 years

100% 100% 100%? 80%? 16%?

Current Operational Models Sufficient For Pharmacy Provision

Current Operational Models Inadequate For Pharmacy Provision
Understanding the Trade Space

- Mass/Volume of Medical System
- Mission Risk
- Medical Risk
- Non-Medical Risk
- Total Risk

Ideal Mission Risk

Notional
Implementation requires a Health and Performance System
GETTING THE MEDICINE INTO THE ENGINEERING SYSTEM
Medical Systems Engineering

From “System Engineering at JPL” training course material, June 1991.

Crew Health and Performance System
System Interfaces with the Flight System

- Crew Displays and Controls
- Comm and Tracking
- ECLSS
- Structures
- Power
- EVA Support
- Command and data handling
- Crew Health and Performance System
Example: Mars Telecommunication - Three Main Challenges

- Three major challenges face all communication with deep space (CLA):
  - **Capacity**: The link data rate or average daily volume
  - **Latency**: Speed of light delay between the planets
  - **Availability**: The percentage of time (over a day/Sol, week, month or year) that an asset has access to a link

- Deep Space Network CLA needs to be considered for the case of crew support needs
- What data rates are acceptable for Store-and-Forward type crew support? Emergency medical support? Behavioral health support?
- What if emergencies occur during planned daily link outages (due to Mars occultation)?
### NASA Life-Cycle Phases

<table>
<thead>
<tr>
<th>Project Life-Cycle Phases</th>
<th>Approval for Formulation</th>
<th>Formulation</th>
<th>Approval for Implementation</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-Phase A:</strong></td>
<td>KDP A</td>
<td>KDP B</td>
<td>KDP C</td>
<td>KDP D</td>
</tr>
<tr>
<td>Concept Studies</td>
<td>MCR</td>
<td>SRR &amp; SDR</td>
<td>PDR</td>
<td>CDR</td>
</tr>
<tr>
<td><strong>Phase A:</strong></td>
<td>KDP A</td>
<td>KDP B</td>
<td>KDP C</td>
<td>KDP D</td>
</tr>
<tr>
<td>Concept &amp; Technology Development</td>
<td>SRR &amp; SDR</td>
<td>PDR</td>
<td>CDR</td>
<td>ORR</td>
</tr>
<tr>
<td><strong>Phase B:</strong></td>
<td>KDP A</td>
<td>KDP B</td>
<td>KDP C</td>
<td>KDP D</td>
</tr>
<tr>
<td>Preliminary Design &amp; Technology Completion</td>
<td>SRR &amp; SDR</td>
<td>PDR</td>
<td>CDR</td>
<td>ORR</td>
</tr>
<tr>
<td><strong>Phase C:</strong></td>
<td>KDP A</td>
<td>KDP B</td>
<td>KDP C</td>
<td>KDP D</td>
</tr>
<tr>
<td>Final Design &amp; Fabrication</td>
<td>SRR &amp; SDR</td>
<td>PDR</td>
<td>CDR</td>
<td>ORR</td>
</tr>
<tr>
<td><strong>Phase D:</strong></td>
<td>KDP A</td>
<td>KDP B</td>
<td>KDP C</td>
<td>KDP D</td>
</tr>
<tr>
<td>System Assembly, Integration &amp; Test, Launch &amp; Checkout</td>
<td>SRR &amp; SDR</td>
<td>PDR</td>
<td>CDR</td>
<td>ORR</td>
</tr>
<tr>
<td><strong>Phase E:</strong></td>
<td>KDP A</td>
<td>KDP B</td>
<td>KDP C</td>
<td>KDP D</td>
</tr>
<tr>
<td>Operations &amp; Sustainment</td>
<td>SRR &amp; SDR</td>
<td>PDR</td>
<td>CDR</td>
<td>ORR</td>
</tr>
<tr>
<td><strong>Phase F:</strong></td>
<td>KDP A</td>
<td>KDP B</td>
<td>KDP C</td>
<td>KDP D</td>
</tr>
<tr>
<td>Closeout</td>
<td>SRR &amp; SDR</td>
<td>PDR</td>
<td>CDR</td>
<td>ORR</td>
</tr>
</tbody>
</table>

*See 7120.5E for acronym definitions.*
Why Systems Engineering?

Improved communication with exploration mission development activities

“Problem space, not solution space”
Or “What, not How”

Do we have solutions? If no, research & development are required!

https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=9c591a66-8f59-49dd-a61d-4096e7b3086c
Provide a crew that is fit for duty when the mission calls.
Crew Health and Performance System Must…

- **Protect from environmental hazards**
  - Radiation protection
  - Noise, vibration, $\text{CO}_2$, etc.

- **Keep healthy crew well**
  - Exercise
  - Other physiological countermeasures
  - Food
  - Behavioral health

- **Prevent, diagnose, treat, manage long-term health care**
  - Data system
    - Medical Data Capture
    - Medical Training
  - Medical devices
  - Medical supplies

- **Support crew to accomplish mission tasks**
  - Procedures
  - Training
  - User interfaces
Applying Systems Engineering to Integrate CHP
Getting from Medical Need to Requirements

### Medical Domain Activities

- NASA-STD-3001 Interpretation
- History of conditions (IMM)
- Accepted Medical Condition List
- Planned activities
- Unplanned activities
- Med Sys Capabilities
- Med Sys Resources

### Sys Eng Activities

- DRM Inputs
- Higher Level Requirements
- Med Sys ConOps
- Med Sys Functions
- Med Sys Detailed Requirements
- Med Sys Functional Requirements

### Key:
- Medical domain products
- Systems Engineering products

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Team works closely together

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

Scheduled medical care that is expected or required to occur

– Maintain crew health
– Monitor for potential contingency medical events
– Provide a test bed for future exploration missions

Examples

Planned Activities
• Private Medical Conference
• Periodic Eye Exam

Testbed Planned Activities
• Periodic Dental Exam
• Bone Health Evaluation
• Process uses list of conditions that influence mission planning

• Start with the IMM Conditions List
  – Has evidence base and metrics that support the likelihood of occurrence
  – Each condition as defined by best case and worst case

• Decide what is realistic to diagnose and treat (based on your mission)
  – Probability of occurrence
  – Complexity score – Large # resources or difficult management
  – Futility score – likely to result in death or disability despite treatment

Source: Development of an Accepted Medical Condition List for Exploration Medical Capability Scoping, ExMC Working Group, July 2018
<table>
<thead>
<tr>
<th>Medical Condition</th>
<th>Best / Worst</th>
<th>Definition</th>
<th>Plan to Treat</th>
<th>Characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKIN RASH</td>
<td>Best</td>
<td>The best case scenario is defined as mild to moderate and uncomplicated skin rash that responds to treatment.</td>
<td>Plan to Treat</td>
<td>N/A</td>
</tr>
<tr>
<td>SKIN RASH</td>
<td>Worst</td>
<td>The worst case scenario is defined as a moderate to severe skin rash, covering an extensive area and that might be refractory to treatment.</td>
<td>Plan to Treat with Conditions</td>
<td>Treat to best case only</td>
</tr>
<tr>
<td>SMALL BOWEL OBSTRUCTION</td>
<td>Best</td>
<td>The best case scenario is defined as an uncomplicated course of small bowel obstruction which responds to conservative medical treatment (antibiotics and symptomatic treatment) and involves relatively minor functional impairment.</td>
<td>Plan to Treat</td>
<td>N/A</td>
</tr>
<tr>
<td>SMALL BOWEL OBSTRUCTION</td>
<td>Worst</td>
<td>The worst case scenario is defined as having a complicated course of small bowel obstruction that is not responsive to conservative treatment and involves significant systemic symptoms, such as severe pain, such as fever, leukocytosis, tachycardia, elevated BUN, serum amylase or alkaline phosphatase, metabolic acidosis and a major functional impairment.</td>
<td>Plan to Treat with Conditions</td>
<td>Treat to best case, add antipyretics/pain control, IV fluids; consider medical evac</td>
</tr>
</tbody>
</table>
• What clinical capabilities are included?
  – Action(s) provided by a caregiver to address a condition or planned activity
  – 18 categories of capabilities, 165 unique capabilities

• What resources are needed to realize those capabilities?
  - Tangible and intangible assets used for a planned activity or condition
### Capabilities / Resources - Examples

<table>
<thead>
<tr>
<th>Condition</th>
<th>Capability Category</th>
<th>Capability</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>DENTAL AVULSION (TOOTH LOSS)</td>
<td>Administer and Manage Medications</td>
<td>Medication - Injectable (IV, IO, SQ, Intraarticular)</td>
<td>EMR interface, Refrigerator, Needle (23G) 1.5&quot;, Needle [25g] 1.5&quot;, Syringe (3cc), Syringe (10cc), Syringe (5cc), Intraosseous Injection device, Bandaid (2x3), Bandaid Dot, Bandaid strip (1x3), Syringe (1cc Insulin syringe with SQ needle), PPE - Nitrile gloves (multiple sizes, pair), Sharps container, Biohazard Trash Bag, BZK wipes</td>
</tr>
<tr>
<td>DENTAL AVULSION (TOOTH LOSS)</td>
<td>Administer and Manage Medications</td>
<td>Medication - Oral</td>
<td>EMR interface, Potable water</td>
</tr>
<tr>
<td>DENTAL AVULSION (TOOTH LOSS)</td>
<td>Administer and Manage Medications</td>
<td>Medication - Topical</td>
<td>EMR interface, Refrigerator, Cotton swabs - sterile, Cotton swabs - clean, Cotton balls, PPE - Nitrile gloves (multiple sizes, pair), Biohazard Trash Bag</td>
</tr>
</tbody>
</table>
### Capabilities / Resources - Examples

<table>
<thead>
<tr>
<th>Resource</th>
<th>Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Syringe (10cc)</strong></td>
<td>Airway - Endotracheal Intubation, Medication - Injectable (IV, IO, SQ, Intraarticular), Breathing - Needle Thoracostomy, Circulation - IO Access, Circulation - IV Access, GI/GU/Chest - Percutaneous drainage Bladder/Gallbladder/Appendix/Chest, Nose - Nasal Packing (Anterior + Posterior), GI/GU - Urinary Catheterization, Screening Exam/Test - Intracranial pressure, Wound Care - Repair, multiple layer, Wound Care - Repair, Single layer</td>
</tr>
<tr>
<td><strong>Syringe (1cc Insulin syringe with SQ needle)</strong></td>
<td>Medication - Injectable (IV, IO, SQ, Intraarticular)</td>
</tr>
<tr>
<td><strong>Syringe (3cc)</strong></td>
<td>Medication - Injectable (IV, IO, SQ, Intraarticular)</td>
</tr>
<tr>
<td><strong>Syringe (5cc)</strong></td>
<td>Medication - Injectable (IV, IO, SQ, Intraarticular)</td>
</tr>
</tbody>
</table>
1. Purpose

1. Provides a **vision** for the design reference mission of interest (Gateway)

2. Defines the problem space, not solution

3. Informs the ExMC systems engineering effort, providing a foundation on which human-centered activities should be developed and eventually used to derive system functions & requirement for the medical system.

2. Scope

1. Medical system for Gateway

2. Integration of the medical system with other vehicle systems

3. Integration of the medical system with ground systems

3. Stakeholder Need

• **Maintain Crew Health**

Stakeholders need a medical system that maintains crew health.

4. System Goals

1. Health Management

2. Crew Autonomy

3. Continual Information Application & Learning

4. System Flexibility and Extensibility

5. System, Habitat, and Mission Systems Integration

6. Crew and Medical System Integration

7. Ground Awareness

8. Crew Performance

9. Crew Health Privacy Protection

10. Research Support

11. Future Capabilities Test Bed
For the past few hours a crewmember has been experiencing a headache of moderate intensity that he recognizes as typical of those he has had in the past. Given that he has no other symptoms, he decides that there is no need to involve the crew medical officer or ground flight surgeon and will treat it with acetaminophen, as he had for the previous headaches. He accesses his personal medical record within the medical system on his portable computing device and logs his symptoms.

The medical system takes him through a series of questions that assesses symptoms. Based on data entered by the crewmember, the medical system provides a recommended medication, dose and location. He locates the pharmacy kit in the medical rack, finds the medication, and removes the dose. He washes the tablet down with water from a drink bag and then logs the medication use in the medical system on his personal computing device. This information is stored for automated downlink to the ground medical system at the end of the workday. The crewmember’s flight surgeon will have a notification on the ground medical system to alert him of the medication consumption when he arrives in mission control the next morning.

At the end of the workday, an automated RFID scan of the medical rack shows one-unit dose of acetaminophen was taken from the medical pharmacy kit. This information is queued for automated downlink at the next available opportunity to the ground medical system which then updates the pharmacy kit’s inventory. The ground medical system generates an automated report for the flight surgeon that is available for use in support of the crewmember’s weekly private medical conference.

Example Scenario - Headache

This scenario shows that the medical system can:

a) Prompt and facilitate data collection for unplanned medical events.
b) Receive data entry from the patient about the patient.
c) Provide limited decision support for self-care conditions.
d) Assess known inventory and report stowage locations to crew via the Gateway Habitat Medical System interface.
e) Automatically report inventory status to the Ground Medical System.
f) Generate alerts for the Ground Medical System based upon inflight interactions with the system.
g) Record and transmit medically oriented, attributable information to ground clinicians.
h) Retrieve reports in the Ground System that can be reviewed by the Gateway Habitat Medical System.
ConOps scenarios in model - Headache (1 of 2)

- Team converges on same understanding of behavior and terminology
- Analysis of scenarios supports identification of needed functions

* = relevant to a pharmacy need
Team converges on same understanding of behavior and terminology

Analysis of scenarios supports identification of needed functions

* = relevant to a pharmacy need

ConOps scenarios in model - Headache

(2 of 2)
Thematic Analysis$^1 \rightarrow$ Medical System Functions

<<Function>>

Hab MS-Analyze health data

attributes

: Assesses contraindications
: Provides treatment options
: Suggests treatment options

Activities from across multiple scenarios

## Requirement Examples

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Text</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hab-MedSys-0024</td>
<td>Provide pharmacy</td>
<td>The Habitat Medical System shall provide an in-flight pharmacy to the crew members.</td>
<td>Pharmaceutical intervention and prevention, as provided by the in-flight pharmacy, is an essential component of risk management planning for crew healthcare during spaceflight. This includes prepare, administer, document, monitoring, inventory, analyze efficacy of med, titrate, or choose new medication if needed. Pharmaceutics assist crewmembers with adaptation to the spaceflight environment as well as help manage unexpected medical events that could occur, such as illness or injury. Types of medications needed are specified at Level 5.</td>
</tr>
<tr>
<td>Hab-MedSys-0005</td>
<td>Track medical inventory</td>
<td>The Habitat Medical System shall track medical inventory.</td>
<td>Ensure that medical inventory (supplies, equipment, and medications) is tracked at all times including when inventory is dispensed. Specific medical inventories, including quantities, availability, track history, etc., are specified at Level 5.</td>
</tr>
<tr>
<td>Hab-MedSys-0204</td>
<td>Perform genitourinary procedures</td>
<td>The Habitat Medical System shall enable caregivers to perform genitourinary procedures.</td>
<td>The medical system needs to provide capabilities (e.g., tools, technology, skills, medications) to perform genitourinary (GU) procedures (such as decompression of bladder). These procedures are needed for treatment of conditions such as urinary retention. Types of GU procedures are specified at Level 5.</td>
</tr>
</tbody>
</table>
Requirements relationships to discipline inputs

Input from clinicians - Capability Category: Administer and Manage Medications

Output from Rqmts Team - Rqmt: Provide Pharmacy

This is building the bridge between Medical content and Engineering language!
Model output: Visualizing the requirement “legs to stand on”

Level 4 rqmt name

Rationale supported by clinical capability category (green) inputs and ConOps-derived functions (pink)

Child rqmts will be based on more detailed input (e.g., clinical capabilities) (blue)
We’re not bringing an Intensive Care Unit

These technologies exist today

Crew Health and Performance System

Medical

Notional
Can we replace the doctor?

- Full Artificial Intelligence
- Integrative Health and Performance Prediction
- Condition Specific Guidance
- Differential Diagnosis Generation
- Automated Image/Data Analysis
- Knowledge Support/Known Algorithm Provision
- Preventive Care Strategies
Where are we today?

Data Sent/Collective by MDA System via Telemetry with CFS (CCSDS Protocol)
• Medical system design for human spaceflight faces many challenges
  – Evidence base is small
  – Lots of competing interests just to get vehicle flying

• Methods to quantify medical risk are improving.
  – No person can calculate this in their head
  – These get us in the ballpark, must be vetted by people
  – These are critical to getting insight into what should be included and what can safely be excluded

• Marrying medical need and evidence base with systems engineering processes
  – provide a starting point for medical doctors to evaluate and work from
  – provides a defensible and traceable set of capabilities that can be shown to reduce risk
How is medical care example

- Live remote guidance

- Live monitoring

- Store and forward

- Autonomous?
Stepwise Progression

**Human System Requirements**
- Test System Data Management
- Ground Optimize for 42 Day Mission

**Ground System Requirements**
- Deploy System Data Handling
- Initial Ground Operations Changes
- Deploy Revised Ground Ops
- Exercise Deep Space Comm, Autonomy, and Decision Paths
- Optimally Autonomous Crew
- Redefined Ground Operations Paradigm

**Timeline**
- Gateway 2024
- Deep Space Transport 2027
- Precursor 2029
- Mars 2033
27Apr17 crew note from HMS-ULTRSN-SCAN-CMO:

You know what would really help us? If we had pictures of a "perfect case" for each type of image. Given the time lag between ground and ISS - and the minute adjustments we are making for the correct image - the ground is like "3 seconds ago". If we had a picture of what we should make each image look like, we will print it out and have it above the machine so we can more quickly get to what you want and then stabilize for the ground to catch up. I think it will also help cosmonauts considerably given the high amount of commanding/translation. Just a thought - but I think it would help us be more efficient.
27 Apr 17 crew note from HMS-ULTRSND-SG-CMO:

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Remote -> Autonomy

Augmented Reality Training
Tietronix
Sensor Technology

Reveal LINQ ICM + MyCareLink Patient Monitor

In-flight Post-void Ultrasound

Ground Post-void Ultrasound
Return to Earth gravity