Lunar Orbit Mission Risk Analysis using the Integrated Medical Model

Aerospace Medical Association

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Eric Kerstman, MD, MPH
Aerospace Medicine Physician/Flight Surgeon
Clinical Lead – Integrated Medical Model
Advanced Technologies for Engineering and Medicine
Wyle Integrated Science and Engineering

[Email]

(281) 212-1305

Millennia Foy, PhD
Lead Modeler – Integrated Medical Model
Advanced Technologies for Engineering and Medicine
Wyle Integrated Science and Engineering
Orion Multipurpose Crew Vehicle

- Carries the crew to orbit and exploration destinations
- Sustains the crew while in space
- Provides safe re-entry from deep space
Exploration Flight Test–1 (EFT-1)

- Scheduled for September of 2014
- High earth orbit of 3600 miles
- Re-entry speed of 20,000 mph
Exploration Mission-1 (EM-1)

- An un-crewed mission beyond earth orbit (lunar flyby)
- Planned for 2017
Exploration Mission-2 (EM-2)

- A crewed mission beyond earth orbit (lunar orbit)
- Planned for 2021
- Mission duration of 10 to 14 days
- Mission Objectives
  - Demonstrate safe crewed flight beyond low earth orbit
  - Validate the life support system
  - Validate crew operations
EM-2 Design Reference Missions

- **EM-2 Crewed Lunar Orbit (CLO)**
  - 14 days
  - 4 crew members
  - No extravehicular activity

- **EM-2 Distant Retrograde Orbit (DRO)**
  - 25 days
  - 2 crew members
  - No extravehicular activity

- **EM-2 Hybrid**
  - 12 days
  - 2 crew members
  - No extravehicular activity
EM-2 Medical Risk Analysis

• What is the probability of loss of crew life (death) due to a medical event during a lunar orbit mission?
Integrated Medical Model (IMM)

- IMM Background
  - Software model used to simulate manned space flight missions
  - Simulates medical events during space flight missions
  - Estimates the impact of these medical events on crew health and mission success
  - Outputs include estimates of crew health, probability of medical evacuation, and probability of medical loss of crew life
  - Optimization routines can be used to design medical systems which maximize crew health and probability of mission success
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 should be in the Exploration Medical Kit?

Clinical Outcomes and Mission Impact

ISS Medical System Resources

Mission Duration and Profile

Crew Member Attributes

Risks due to EVAs

Medical Condition Incidence Data

Functional Impairments

Medical Resource Attributes

Diagnosis and Treatment of Medical Conditions

Flight Surgeon
IMM Conceptual Model

**Inputs**
- Medical Conditions & Incidence Data
- Crew Profile
- Mission Profile & Constraints
- Potential Crew Impairments
- Potential Mission End states
- In-flight Medical Resources

**Outputs**
- Medical Condition Occurrences
- Crew Impairments
- Clinical End States
- Mission End States
- Resource Utilization
- Optimized Medical System

Integrated Medical Model
Medical Event

Best-case Scenario

Best-case resources available?

Yes

Treated case: Decrement medical resources

No

Untreated Best-Case

Worst-case Scenario

Worst-case resources available?

No

Untreated Worst-Case

Yes

Treated case: Decrement medical resources

Calculate End States:
• Evacuation (EVAC)
• Loss of Crew Life (LOCL)
  • Crew Functional Impairment
  • Type and Quantity of Medical Events (organized by Medical, Injury, or Environmental categories)
• Resource Utilization and Depletion
Life Now with IMM

Mission Specific Inputs
- Crew Member Attributes
- Crew Composition
- Mission Duration and Profile

Monte Carlo Simulations
- Integrated Medical Model
- 13,500+ data elements

Quantified Outputs
- Type and Quantity of all Medical Events
- Risk of EVAC
- Risk of Loss of Crew
- Medical Resources Used
- Optimized Medical System within Vehicle Constraints

Informed Analysis
- Flight Surgeon

ISS Medical System Resources
- Diagnosis and Treatment of Medical Conditions
- Medical Condition Incidence Data
- Risks due to EVAs

IMM Relational Database

Mission Duration and Profile
Crew Composition
Crew Member Attributes
Risk of EVAC
Risk of Loss of Crew
Medical Resources Used
Optimized Medical System within Vehicle Constraints
Flight Surgeon

Quantified Outputs
Type and Quantity of all Medical Events

Informed Analysis
Mission Specific Inputs Monte Carlo Simulations
Crew Member Attributes
Crew Composition
Mission Duration and Profile
Integrated Medical Model
13,500+ data elements
Methods

• What is the probability of loss of crew life (death) due to a medical event during a lunar orbit mission?
• IMM Analysis of EM-2 CLO
  • Define DRM (4 crew, 14 days, no extravehicular activity)
  • Define medical system constraints (13.6 kg, 6144 cm³)
  • Simulate 100K missions using Monte Carlo methodology
  • Use the IMM optimization routine to minimize the probability of LOCL within the above medical system constraints
Results

- Optimized medical kit had a mass of 4 kg and a volume of 6144 cm$^3$
- **Probability of LOCL = 0.1% (1 in 1000 missions)** with 95% confidence interval of 0.08% to 0.11%
- Probability of EVAC = 2.45%
- Crew Health Index = 87.52%

*No allowance for packing factor (typically 20% to 30%)
Summary and Conclusions

- A crewed mission beyond earth orbit (lunar orbit) is planned for 2021
- DRM EM-2 Crewed Lunar Orbit (CLO) is a 14 day mission with 4 crew members and no scheduled EVAs
- Based on IMM analysis, the probability of LOCL due to a medical event is estimated as 0.1%
- The optimized medical kit reached volume constraints prior to mass constraints
- IMM can be used to estimate crew health, and probabilities of LOCL, EVAC for exploration missions
- IMM can be used to help optimize medical kits for exploration missions with mass and volume constraints
Questions and Discussion

IMM

ekerstman@wylehou.com
# Medical Kit Contents

<table>
<thead>
<tr>
<th>Medications</th>
<th>Quantity</th>
<th>Equipment</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Afrin</td>
<td>1</td>
<td>ACE Bandage</td>
<td>1</td>
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<tr>
<td>Amoxicillin</td>
<td>30</td>
<td>Blood Pressure Cuff</td>
<td>1</td>
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<tr>
<td>Aspirin</td>
<td>24</td>
<td>Camera</td>
<td>1</td>
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<tr>
<td>Azithromycin</td>
<td>6</td>
<td>Dental Mirror</td>
<td>1</td>
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<tr>
<td>Bacitracin</td>
<td>1</td>
<td>Finger Splint</td>
<td>1</td>
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<tr>
<td>Bactrim</td>
<td>20</td>
<td>Fluorescein Strips</td>
<td>3</td>
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<tr>
<td>Bactroban</td>
<td>1</td>
<td>IV Administration Set</td>
<td>1</td>
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<tr>
<td>Imodium</td>
<td>16</td>
<td>Otoscope</td>
<td>1</td>
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<tr>
<td>Levaquin</td>
<td>2</td>
<td>Ophthalmoscope</td>
<td>1</td>
</tr>
<tr>
<td>Motrin</td>
<td>40</td>
<td>Medical Oxygen</td>
<td>1</td>
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<tr>
<td>Pepto-Bismol</td>
<td>12</td>
<td>Pulse Oximeter</td>
<td>1</td>
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<tr>
<td>Prilosec</td>
<td>7</td>
<td>SAM Splint</td>
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<tr>
<td>Rocephin</td>
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<td>Silver Nitrate Stick</td>
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<tr>
<td>Sudafed</td>
<td>29</td>
<td>Tourniquet</td>
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<tr>
<td>Tobradex Eye Drops</td>
<td>1</td>
<td>Urine Chemstrips</td>
<td>2</td>
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<tr>
<td>Tylenol</td>
<td>50</td>
<td>Urinary Catheter</td>
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<tr>
<td>Vicodin HP</td>
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<tr>
<td>Zithromax</td>
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</table>
# Medical Conditions in IMM by Category

<table>
<thead>
<tr>
<th>Injury/Trauma</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute Compartment Syndrome</td>
<td>Acute Radiation Sickness</td>
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<tr>
<td>Abdominal Injury</td>
<td>Altitude Sickness</td>
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<tr>
<td>Back Injury</td>
<td>Barotrauma (ear/sinus block)</td>
</tr>
<tr>
<td>Chest Injury/Pneumothorax</td>
<td>Burns</td>
</tr>
<tr>
<td>Dental Tooth Avulsion</td>
<td>Decompression Sickness (EVA)</td>
</tr>
<tr>
<td>Eye Abrasion</td>
<td>Eye Chemical Burn</td>
</tr>
<tr>
<td>Eye Penetration</td>
<td>Headache (CO(_2) induced)</td>
</tr>
<tr>
<td>Elbow Dislocation</td>
<td>Smoke Inhalation</td>
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<tr>
<td>Finger Dislocation</td>
<td>Toxic Exposure</td>
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<tr>
<td>Fingernail Delamination (EVA)</td>
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</tr>
<tr>
<td>Head Injury (TBI)</td>
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<tr>
<td>Hip/Proximal Femur Fracture</td>
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<tr>
<td>Hypovolemic Shock</td>
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<tr>
<td>Lower Extremity Stress Fracture</td>
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<tr>
<td>Lumbar Spine Fracture</td>
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<tr>
<td>Neck Injury</td>
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<tr>
<td>Neurogenic Shock</td>
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<tr>
<td>Paresthesias/Hot Spots (EVA)</td>
<td></td>
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<tr>
<td>Shoulder Dislocation</td>
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<tr>
<td>Medical Illness</td>
<td>Urinary Retention</td>
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<tr>
<td>-----------------------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Abnormal Uterine Bleeding</td>
<td>Dental Crown Replacement</td>
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<tr>
<td>Acute Arthritis</td>
<td>Dental Exposed Pulp</td>
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<tr>
<td>Acute Prostatitis</td>
<td>Dental Filling Replacement</td>
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<tr>
<td>Allergic Reaction</td>
<td>Depression</td>
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<tr>
<td>Anaphylaxis</td>
<td>Diarrhea</td>
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<td>Angina</td>
<td>Eye Corneal Ulcer</td>
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<tr>
<td>Anxiety</td>
<td>Eye Infection</td>
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<tr>
<td>Appendicitis</td>
<td>Gastroenteritis</td>
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<tr>
<td>Afib/Aflutter</td>
<td>Acute Glaucoma</td>
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<tr>
<td>Back Pain (SAS)</td>
<td>Headache (late)</td>
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<tr>
<td>Behavioral Emergency</td>
<td>Headache (SAS)</td>
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<tr>
<td>Biliary Colic</td>
<td>Hemorrhoids</td>
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<tr>
<td>Cardiogenic Shock</td>
<td>Hypertension</td>
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<tr>
<td>Choking</td>
<td>Indigestion</td>
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<tr>
<td>Constipation (SAS)</td>
<td>Influenza</td>
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<tr>
<td>Dental Abscess</td>
<td>Insomnia (SAS)</td>
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<tr>
<td>Dental Avulsion</td>
<td>Insomnia (late)</td>
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<tr>
<td>Dental Caries</td>
<td>Kidney Stone</td>
</tr>
<tr>
<td>Urinary Tract Infection</td>
<td>Vaginal Yeast Infection</td>
</tr>
</tbody>
</table>

SAS = Space Adaptation Syndrome
IMM Team

- Douglas Butler, MBA – Project Manager
- Eric Kerstman, MD, MPH – Clinical Lead
- Millennia Foy, PhD – Lead Modeler/Epidemiologist
- Marlei Walton, PhD – Project Scientist
- Lynn Saile, RN, MS - Clinical Informatics Lead
- Lynn Boley, RN, MSN - Clinical Researcher
- Ronak Shah, DO, MPH – Medical Reviewer
- Alexander Keenan, MS - Modeler
- Jerry Myers, PhD – External Module Lead