Lunar Orbit Mission Risk Analysis using the Integrated Medical Model

Aerospace Medical Association

2014 Annual Scientific Meeting – San Diego

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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
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
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

Untreated Case:
- Best-case Scenario
- Worst-case Scenario

Medical Event

Worst-case Scenario

Worst-case resources available?

Yes
No
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
• 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 cm³*
- **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

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## 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>
</tr>
<tr>
<td>Amoxicillin</td>
<td>30</td>
<td>Blood Pressure Cuff</td>
<td>1</td>
</tr>
<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>
</tr>
<tr>
<td>Bacitracin</td>
<td>1</td>
<td>Finger Splint</td>
<td>1</td>
</tr>
<tr>
<td>Bactrim</td>
<td>20</td>
<td>Fluorescein Strips</td>
<td>3</td>
</tr>
<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>
</tr>
<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>
</tr>
<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>
<td>1</td>
<td>Silver Nitrate Stick</td>
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<tr>
<td>Sudafed</td>
<td>29</td>
<td>Tourniquet</td>
<td>1</td>
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<tr>
<td>Tobradex Eye Drops</td>
<td>1</td>
<td>Urine Chemstrips</td>
<td>2</td>
</tr>
<tr>
<td>Tylenol</td>
<td>50</td>
<td>Urinary Catheter</td>
<td>1</td>
</tr>
<tr>
<td>Vicodin HP</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zithromax</td>
<td>6</td>
<td></td>
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</tr>
</tbody>
</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>
</tr>
<tr>
<td>Abdominal Injury</td>
<td>Altitude Sickness</td>
</tr>
<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>
</tr>
<tr>
<td>Finger Dislocation</td>
<td>Toxic Exposure</td>
</tr>
<tr>
<td>Fingernail Delamination (EVA)</td>
<td></td>
</tr>
<tr>
<td>Head Injury (TBI)</td>
<td></td>
</tr>
<tr>
<td>Hip/Proximal Femur Fracture</td>
<td></td>
</tr>
<tr>
<td>Hypovolemic Shock</td>
<td></td>
</tr>
<tr>
<td>Lower Extremity Stress Fracture</td>
<td></td>
</tr>
<tr>
<td>Lumbar Spine Fracture</td>
<td></td>
</tr>
<tr>
<td>Neck Injury</td>
<td></td>
</tr>
<tr>
<td>Neurogenic Shock</td>
<td></td>
</tr>
<tr>
<td>Paresthesias/Hot Spots (EVA)</td>
<td></td>
</tr>
<tr>
<td>Shoulder Dislocation</td>
<td></td>
</tr>
</tbody>
</table>
# Medical Conditions by Category

<table>
<thead>
<tr>
<th>Medical Illness</th>
<th>Urinary Retention</th>
<th>Visual Impairment (VIIP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal Uterine Bleeding</td>
<td>Dental Crown Replacement</td>
<td>Medication Overdose</td>
</tr>
<tr>
<td>Acute Arthritis</td>
<td>Dental Exposed Pulp</td>
<td>Mouth Ulcer</td>
</tr>
<tr>
<td>Acute Prostatitis</td>
<td>Dental Filling Replacement</td>
<td>Nasal Congestion (SAS)</td>
</tr>
<tr>
<td>Allergic Reaction</td>
<td>Depression</td>
<td>Nosebleed (SAS)</td>
</tr>
<tr>
<td>Anaphylaxis</td>
<td>Diarrhea</td>
<td>Otitis Externa</td>
</tr>
<tr>
<td>Angina</td>
<td>Eye Corneal Ulcer</td>
<td>Otitis Media</td>
</tr>
<tr>
<td>Anxiety</td>
<td>Eye Infection</td>
<td>Pharyngitis</td>
</tr>
<tr>
<td>Appendicitis</td>
<td>Gastroenteritis</td>
<td>Respiratory Infection</td>
</tr>
<tr>
<td>Afib/Aflutter</td>
<td>Acute Glaucoma</td>
<td>Shingles</td>
</tr>
<tr>
<td>Back Pain (SAS)</td>
<td>Headache (late)</td>
<td>Seizures</td>
</tr>
<tr>
<td>Behavioral Emergency</td>
<td>Headache (SAS)</td>
<td>Sepsis</td>
</tr>
<tr>
<td>Biliary Colic</td>
<td>Hemorrhoids</td>
<td>Sinusitis</td>
</tr>
<tr>
<td>Cardiogenic Shock</td>
<td>Hypertension</td>
<td>Skin Infection</td>
</tr>
<tr>
<td>Choking</td>
<td>Indigestion</td>
<td>Skin Rash</td>
</tr>
<tr>
<td>Constipation (SAS)</td>
<td>Influenza</td>
<td>SMS (SAS)</td>
</tr>
<tr>
<td>Dental Abscess</td>
<td>Insomnia (SAS)</td>
<td>Stroke</td>
</tr>
<tr>
<td>Dental Avulsion</td>
<td>Insomnia (late)</td>
<td>Sudden Cardiac Arrest</td>
</tr>
<tr>
<td>Dental Caries</td>
<td>Kidney Stone</td>
<td>Urinary Incontinence</td>
</tr>
<tr>
<td>Urinary Tract Infection</td>
<td>Vaginal Yeast Infection</td>
<td>Urinary Retention</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
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