Feasibility of Suited 10-km Ambulation “Walkback” on the Moon

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Introduction

Are 1 or 2 surface rovers required to enable safe and efficient human exploration of the Moon?

- Increased mass, volume, and cost associated with launch and transport of two rovers
- May not be necessary if crewmembers could walk back to habitat if rover failed
- 10-km “walkback” used as starting point based on:
  - Apollo program
  - Anticipated lunar surface operational concepts
Objectives

• Primary objective: Collect biomedical and human performance data and produce a crew consensus regarding the feasibility of performing a suited 10-km walkback

• Secondary objectives:
  – Understand specific biomedical and human performance limitations of the suit compared to matched shirt-sleeve controls
  – Collect metabolic and ground-reaction force data to develop an EVA simulator for use on future prebreathe protocol verification tests
  – Provide data to estimate consumables usage for input to suit and portable life support system (PLSS) design
  – Assess the cardiovascular and resistance exercise associated with partial-gravity EVA for planning appropriate exploration exercise countermeasures
Subjects

• NASA crewmembers
  – n = 6
  – Typically members of the EVA Branch
• Good fit with MKIII EVA Suit
• All males
  – Females were not excluded, but were not included either due to inadequate suit fit or unavailability
• Current Air Force Class III physical

<table>
<thead>
<tr>
<th></th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>46.8 ± 4.3</td>
<td>40 - 51</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180.3 ± 5.0</td>
<td>175 -188</td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>81.4 ± 7.8</td>
<td>71.2 - 89.4</td>
</tr>
<tr>
<td>$\text{VO}_2\text{pk}$ (ml$\cdot$kg$^{-1}\cdot$min$^{-1}$)</td>
<td>48.7 ± 5.7</td>
<td>40.8 - 55.6</td>
</tr>
</tbody>
</table>
Test Hardware

- Partial gravity simulator (Pogo)
  - Overhead suspension
  - Spider/gimbal attachment for suited test
  - Spreader-bar and harness for unsuited tests
- MKIII EVA Suit
  - Hybrid of hard (torso/brief) and soft (arms/legs) components
  - Multi-axial mobility for planetary environments
  - 121 kg total suit weight
- Challenger Treadmill
  - COTS product
  - 27" x 72" walking surface
  - Mounted forceplates at each corner
Testing Protocols

- **VO₂pk Test (Treadmill)**
- **Preferred Transition Speed (PTS) Determination**
  - Walk to run transition determined at 1/6 g and 3/8 g both unsuited and suited
- **Unsuited Energy-Velocity Test**
  - 3 minutes at 6 different speeds (3 below PTS and 3 above PTS), 0% grade
  - 1 g, 1/6 g, 3/8 g, 1/6 g weight-matched, 3/8 g weight-matched
- **Suited Energy-Velocity Test**
  - 3 minutes at 6 different speeds (3 below PTS and 3 above PTS), 0% grade
  - 1/6 g, 3/8 g
- **Suited 10 km Walkback Test**
  - Unlimited time to complete 10 km on level treadmill at 1/6 g
Data Collected

- **Physiological Data**
  - Oxygen consumption, CO₂ production, etc.
  - Heart rate
  - Skin and core temperatures (limited)

- **Biomechanical Data**
  - Ground reaction forces (GRF)
  - Gait parameters (stride length, cadence, etc.)
  - Kinematics

- **Subjective Measures**
  - Rating of Perceived Exertion
  - Modified Cooper-Harper Scale (operator compensation, controllability)
  - Discomfort Scale (Corlett and Bishop)

- **Video/Photo**
  - All sessions were videotaped
  - Photos taken of any medical or discomfort issues for later use in suit trauma countermeasures work
Subjective Measurements

HANDLING QUALITIES RATING SCALE

<table>
<thead>
<tr>
<th>ADEQUACY FOR SELECTED TASK OR REQUIRED OPERATION*</th>
<th>CONTROL CHARACTERISTICS</th>
<th>DEMANDS ON OPERATOR IN SELECTED TASK OR REQUIRED OPERATION</th>
<th>Operator RATING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Excellent Highly desirable</td>
<td>Operator compensation not a factor for desired performance - easier than 1G activity</td>
<td>1</td>
</tr>
<tr>
<td>Is it satisfactory without improvement?</td>
<td>Good Negligible deficiencies</td>
<td>Operator compensation not a factor for desired performance - equivalent to 1G activity</td>
<td>2</td>
</tr>
<tr>
<td>No</td>
<td>Fair - some mildly unpleasant deficiencies</td>
<td>Minimal operator compensation required for desired performance</td>
<td>3</td>
</tr>
<tr>
<td>New but annoying deficiencies</td>
<td></td>
<td>Desired performance requires moderate operator compensation</td>
<td>4</td>
</tr>
<tr>
<td>Is it adequately attained with a tolerable pilot workload?</td>
<td>Moderately objectionable deficiencies</td>
<td>Adequate performance requires considerable operator compensation</td>
<td>5</td>
</tr>
<tr>
<td>No</td>
<td>Very objectionable but tolerable deficiencies</td>
<td>Adequate performance requires extensive operator compensation</td>
<td>6</td>
</tr>
<tr>
<td>Major Deficiencies</td>
<td>Adequate performance not attainable with maximum tolerable operator compensation. Controllability not in question.</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Is it controllable?</td>
<td>Major Deficiencies</td>
<td>Considerable operator compensation is required for control</td>
<td>8</td>
</tr>
<tr>
<td>Yes</td>
<td>Major Deficiencies</td>
<td>Intense operator compensation is required to retain control - equivalent to 1G activity</td>
<td>9</td>
</tr>
<tr>
<td>Improvement mandatory</td>
<td>Major Deficiencies</td>
<td>Control will be lost during some portion of required operation - more difficult than 1G activity</td>
<td>10</td>
</tr>
</tbody>
</table>

* Definition of required operation involves designation of tight phase and/or subphase with accompanying conditions.

Cooper-Harper - Ref: NASA TNO-5153 - modified for EPSP CG assessment 3-1-08
**Subjective Measurements**

### Discomfort Scale

<table>
<thead>
<tr>
<th>RPE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Nothing at all</td>
</tr>
<tr>
<td>0.5</td>
<td>Extremely Low Discomfort</td>
</tr>
<tr>
<td>1</td>
<td>Very Low Discomfort</td>
</tr>
<tr>
<td>2</td>
<td>Low Discomfort</td>
</tr>
<tr>
<td>3</td>
<td>Moderate Discomfort</td>
</tr>
<tr>
<td>4</td>
<td>High Discomfort</td>
</tr>
<tr>
<td>5</td>
<td>Very High Discomfort</td>
</tr>
<tr>
<td>6</td>
<td>Extremely High Discomfort</td>
</tr>
<tr>
<td>7</td>
<td>Maximal exertion</td>
</tr>
</tbody>
</table>

**Front of Participant**

**Back of Participant**

- **Extremely High Discomfort**: 10
- **Very High Discomfort**: 9
- **High Discomfort**: 8
- **Moderate Discomfort**: 7
- **Low Discomfort**: 6
- **Very Light**: 5
- **Light**: 4
- **Somewhat hard**: 3
- **Hard (heavy)**: 2
- **Very light**: 1
- **No exertion at all**: 0

**Disco**  

**mfort**  

**6**  

**7**  

**8**  

**9**  

**10**  

**11**  

**12**  

**13**  

**14**  

**15**  

**16**  

**17**  

**18**  

**19**  

**20**  

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“Feasibility of Suited 10 km Walkback on the Moon” - Jason Norcross
Examples of Suited and Unsuited Locomotion

• Differences include:
  – Weight
  – Inertial mass
  – Pressure
  – Kinematic constraints
  – Stability
  – Overhead suspension methods
Energy-Velocity Series Results - Moon

**Metabolic Cost**

- **Inertial Mass**
- **Kinematics**
- **Pressure**
- **Weight Factors**

**Transport Cost**

- **Moon, suited**
- **Earth, unsuited**
- **Moon, unsuited**
- **Moon, unsuited weighted**

“Feasibility of Suited 10 km Walkback on the Moon” - Jason Norcross
Energy-Velocity Series Results - Mars

Metabolic Cost

Transport Cost

“Feasibility of Suited 10 km Walkback on the Moon” - Jason Norcross
Implications for Walkback

1. Faster speeds provide improved efficiency, but require higher per-minute metabolic cost

2. Cooling may be a limiting factor
# 10 km Walkback Summary Data

(averaged across entire 10 km unless noted)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MEAN</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg walkback velocity (mph)</td>
<td>3.9</td>
<td>0.5</td>
</tr>
<tr>
<td>Time to complete 10 km (min)</td>
<td>95.8</td>
<td>13</td>
</tr>
<tr>
<td>Avg %VO₂pk</td>
<td>50.8%</td>
<td>6.1%</td>
</tr>
<tr>
<td>Avg met rate (BTU/hr)</td>
<td>2374</td>
<td>303.9</td>
</tr>
<tr>
<td>Max. 15-min-avg met rate (BTU/hr)</td>
<td>2617</td>
<td>315</td>
</tr>
<tr>
<td>Total energy expenditure (kcal)</td>
<td>944.2</td>
<td>70.5</td>
</tr>
<tr>
<td>RPE</td>
<td>11.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Cooper-Harper</td>
<td>3.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Water used for drinking (oz)</td>
<td>~24-32</td>
<td>N/A</td>
</tr>
</tbody>
</table>

## Planning / PLSS Sizing Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Walkback</th>
<th>Apollo</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂ Usage</td>
<td>0.4 lbs/hr</td>
<td>0.15 lbs/hr</td>
</tr>
<tr>
<td>BTU average</td>
<td>2374 BTU/hr</td>
<td>933 BTU/hr</td>
</tr>
<tr>
<td>Cooling water</td>
<td>3.1 lbs/hr</td>
<td>0.98 lbs/hr</td>
</tr>
<tr>
<td>Energy expenditure</td>
<td>599 kcal/hr</td>
<td>233 kcal/hr</td>
</tr>
</tbody>
</table>
Key Findings

• Suited locomotion had higher metabolic rates than unsuited and unsuited weight-matched controls

• Locomotion in Mars gravity required higher metabolic rates than Moon gravity for both suited and unsuited trials
  – MKIII EVA Suit functioned acceptably throughout all speeds on the Moon, but was extremely limited on Mars

• Lunar transport cost decreased as speed increased and leveled off around 4 mph, but these improvements in efficiency may be offset by limited cooling capacity to handle the higher average metabolic rate

• All subjects completed the 10 km walkback and with little difficulty
  – Averages of 51% VO₂pk and RPE=12
  – Subjects experimented to find the highest speed they could comfortably tolerate with most stating that cooling was a limiting factor
  – Cooper-Harper of 3.5 ± 1.6 indicates that improvements are warranted
  – Average Discomfort rating of 1.5 ± 1.1 (knees, feet, toes)
Study Limitations

- Smooth, level treadmill
- Subjects free to stop at any time
- No hills
- No stress (life not at stake)
- No navigation or real-time troubleshooting
- Subjects’ balance possibly supported by overhead Pogo/gimbal structure
Forward Work

• Determine which components of the suit have the greatest effect on metabolic rate
  – Weight, inertial mass, pressure, center of gravity, kinematic constraints

• Move beyond level locomotion
  – Evaluate exploration tasks (shoveling, picking up rocks, construction)
  – Inclined / declined locomotion

• Evaluate a different suit design

• Evaluate study limitations
  – Increase the operational aspects: time requirements, navigation, troubleshooting
  – Introduce hill profiles
  – Introduce surface variations