Feasibility of Suited 10-km Ambulation "Walkback" on the Moon

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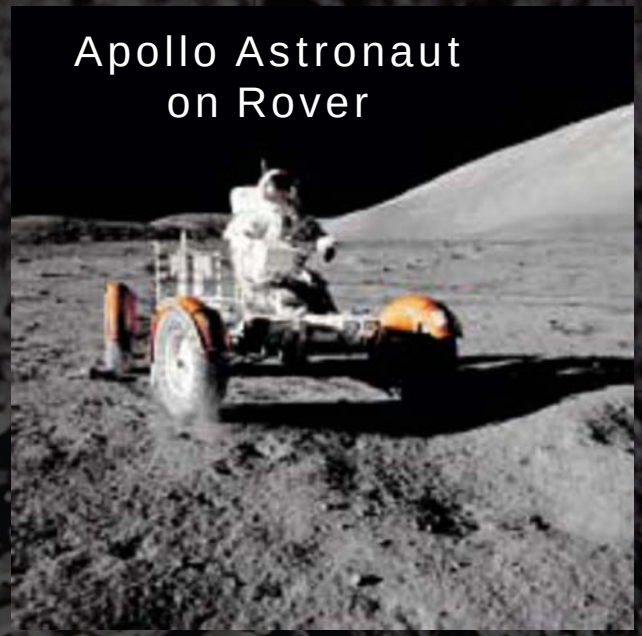
Introduction

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



Apollo Astronaut on Rover

MKIII Prototype EVA Suit

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

	Mean ± SD	Range
Age (yrs)	46.8 ± 4.3	40 - 51
Height (cm)	180.3 ± 5.0	175 -188
Body Mass (kg)	81.4 ± 7.8	71.2 - 89.4
VO_2pk ($ml \cdot kg^{-1} \cdot min^{-1}$)	48.7 ± 5.7	40.8 - 55.6

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

- VO_2pk 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

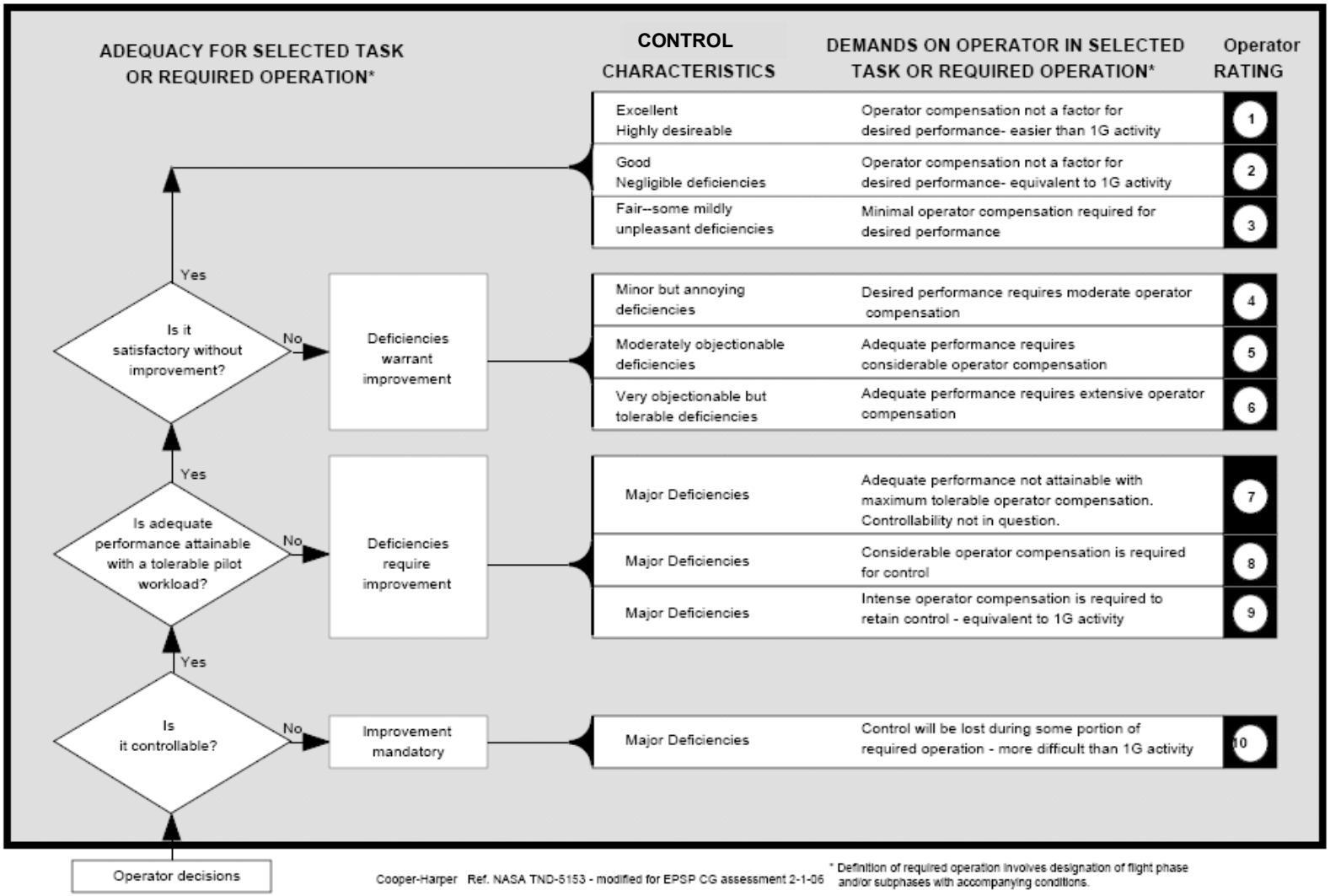
Data Collected

- Physiological Data
  - Oxygen consumption, CO_2 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

Cooper-Harper

HANDLING QUALITIES RATING SCALE



Cooper-Harper Ref. NASA TND-5153 - modified for EPSP CG assessment 2-1-06

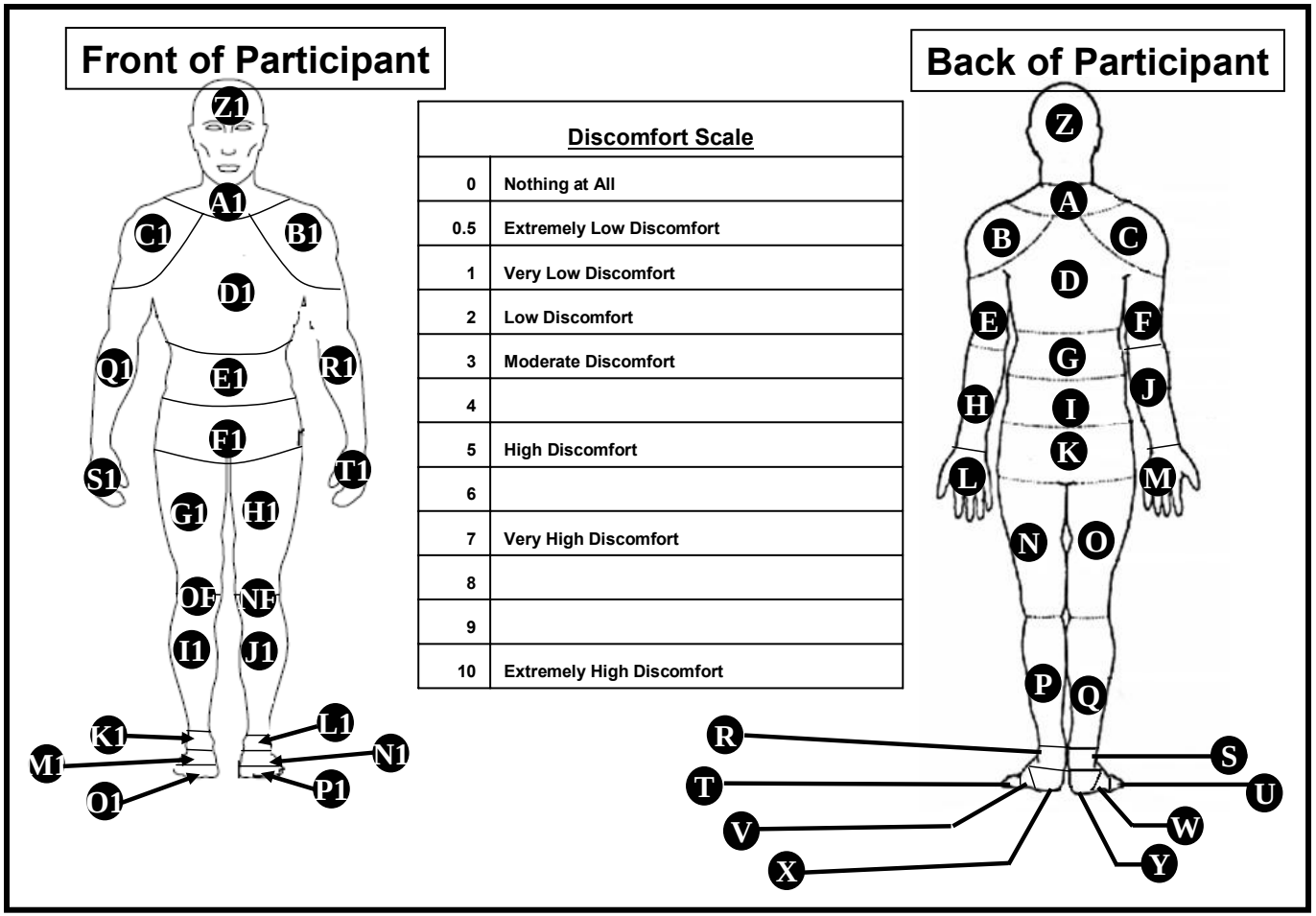
* Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

Subjective Measurements

RPE

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Discomfort

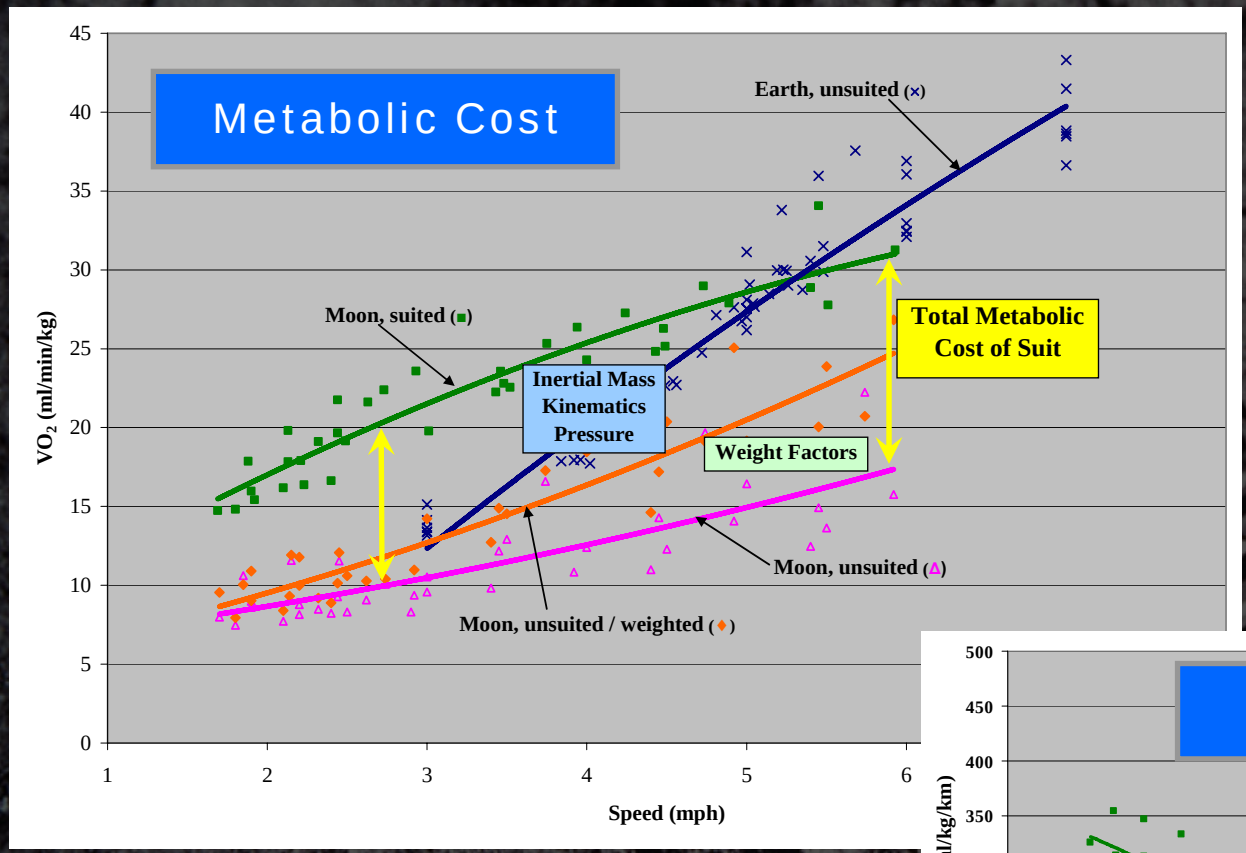


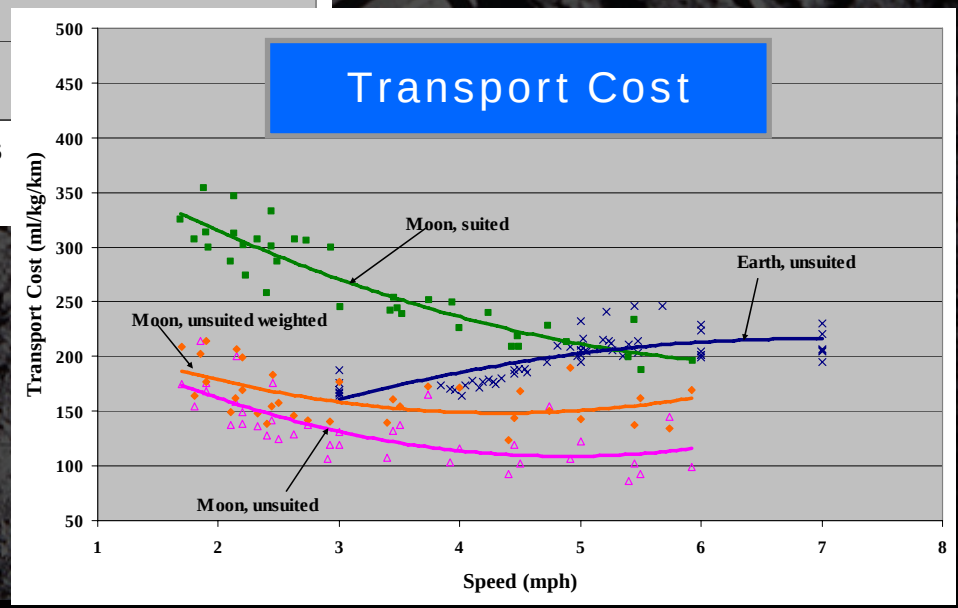
Discomfort Scale	
0	Nothing at All
0.5	Extremely Low Discomfort
1	Very Low Discomfort
2	Low Discomfort
3	Moderate Discomfort
4	
5	High Discomfort
6	
7	Very High Discomfort
8	
9	
10	Extremely High Discomfort

Examples of Suited and Unsuited Locomotion

- Differences include:
  - Weight
  - Inertial mass
  - Pressure
  - Kinematic constraints
  - Stability
  - Overhead suspension methods

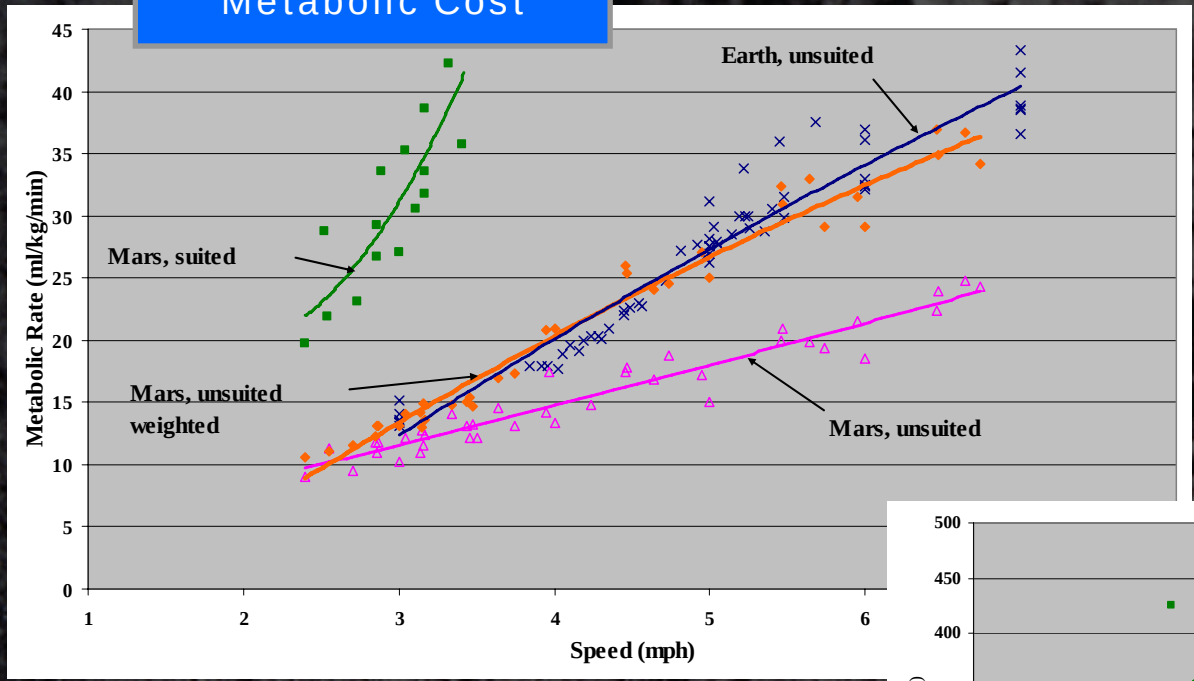
Energy-Velocity Series Results - Moon



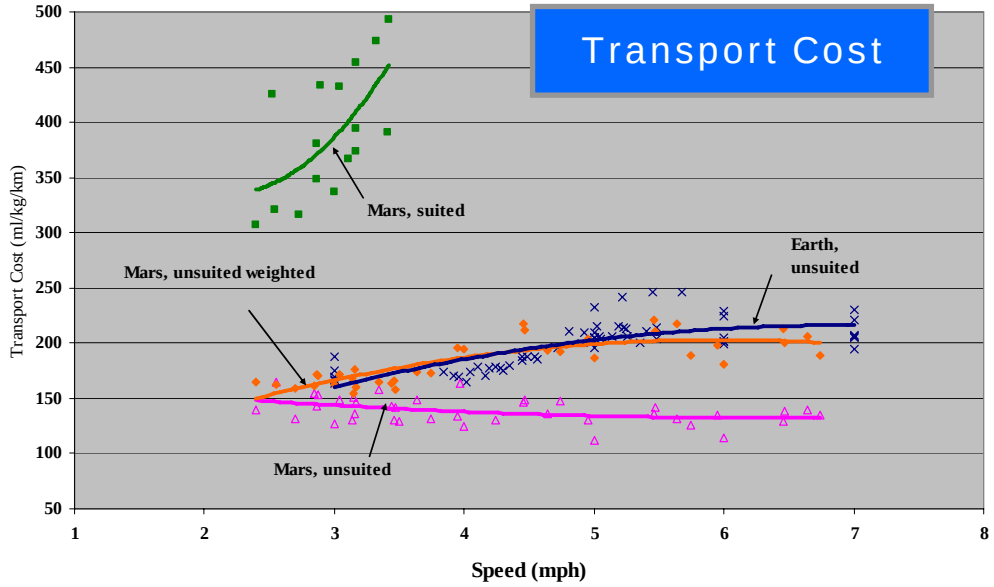


Energy-Velocity Series Results - Mars

Metabolic Cost

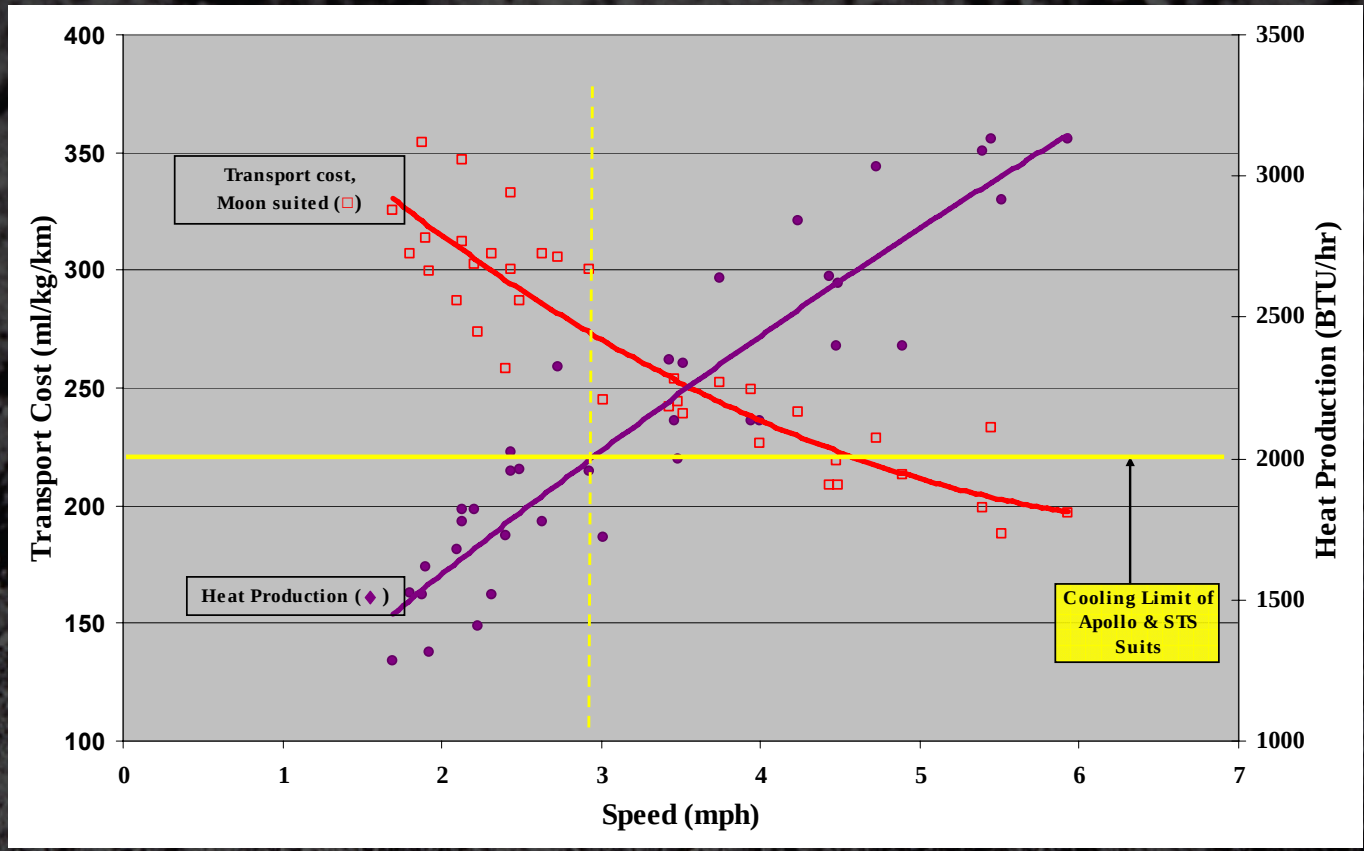


Transport Cost

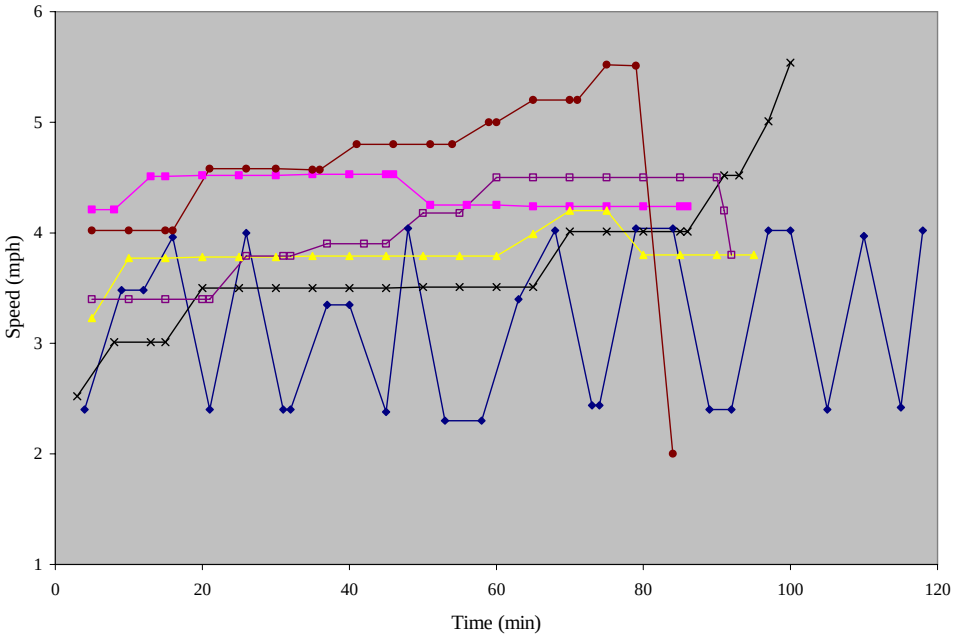


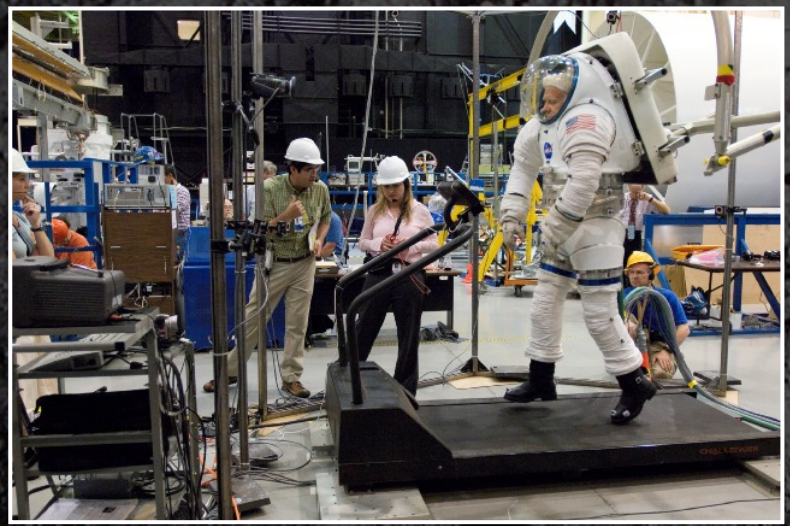
Implications for Walkback

1. Faster speeds provide improved efficiency, but require higher per-minute metabolic cost
2. Cooling may be a limiting factor



10 km Walkback Summary





10 km Walkback Summary Data (averaged across entire 10 km unless noted)	MEAN	SD
Avg walkback velocity (mph)	3.9	0.5
Time to complete 10 km (min)	95.8	13
Avg %VO_2pk	50.8%	6.1%
Avg met rate (BTU/hr)	2374	303.9
Max. 15-min-avg met rate (BTU/hr)	*2617*	*315*
Total energy expenditure (kcal)	944.2	70.5
RPE	11.8	1.6
Cooper-Harper	3.5	1.4
Water used for drinking (oz)	~24-32	N/A
Planning / PLSS Sizing Data	**Walkback**	**Apollo**
O_2 Usage	0.4 lbs/hr	0.15 lbs/hr
BTU average	2374 BTU/hr	933 BTU/hr
Cooling water	3.1 lbs/hr	0.98 lbs/hr
Energy expenditure	599 kcal/hr	233 kcal/hr

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% VO_2pk 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