

Lessons Learned from Performance Testing of Humans in Spacesuits in Simulated Reduced Gravity

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Introduction: The overarching objective of the Integrated Suit Test (IST) series is to evaluate suited human performance using reduced-gravity analogs and learn what aspects of an EVA suit system affect human performance. For this objective to be successfully achieved, the testing methodology should be valid and reproducible, and the partial-gravity simulations must be as accurate and realistic as possible.

Objectives: To highlight some of the key lessons learned about partial-gravity analogs and testing methodology, and to suggest considerations for optimizing the effectiveness and quality of results of future tests.

Methods: Performance testing of suited and unsuited subjects was undertaken in different reduced-gravity analogs including the Space Vehicle Mockup Facility's Partial Gravity Simulator (POGO), parabolic flight on the C-9 aircraft, underwater environments including NASA's Extreme Environment Mission Operations (NEEMO) and the Neutral Buoyancy Lab (NBL), and in field analogs including Desert Research and Technology Studies (RATS), the Houghton Mars Project (HMP), and the JSC Rock Pile. Subjects performed level walking, incline/decline walking, running, shoveling, picking up and transferring rocks, kneeling/standing, and task boards.

Lessons Learned – Analogs: No single analog will properly simulate all aspects of the true partial-gravity environment. The POGO is an ideal environment from the standpoint that there are no time limits or significant volumetric constraints, but it does have several limitations. It allows only 2 translational degrees of freedom (DOF) and applies true partial-gravity offload only through the subject's center of gravity (CG). Also, when a subject is doing non-stationary tasks, significant overhead inertia from the lift column seems to have a negative impact on performance. Parabolic flight allows full translational and rotational DOF and applies offload to all parts of the body, but the simulation lasts less than 30 seconds. When this is coupled with the volumetric constraints of the plane, both task selection and data collection options are significantly limited. The underwater environments also allow all 6 DOF and allow offloading to be applied throughout the body, but the data collection capabilities are limited to little more than subjective ratings. In addition, water drag negatively affects performance of tasks requiring dynamic motion. Field analogs provide the ability to simulate lunar terrain and more realistic mission-like objectives, but all of them operate at 1-g, so suited human performance testing generally must utilize a reduced-mass or "mockup" suit, depending on study objectives. In general, the ground-based overhead-suspension partial-gravity analogs like POGO allow the most diverse data collection methods possible while still simulating partial gravity. However, as currently designed, the POGO has significant limitations. Design of the Active Response Gravity Offload System (ARGOS) has begun and is focusing on adding full x,y,z translational DOF, improved offload accuracy, increased lift capacity, and active control of the x and y axes to minimize offload system inertia. Additionally, a new gimbal is being designed to reduce mass and inertia and to be able to work with different suits, as the current gimbal only supports suited testing with the Mark III Technology Demonstrator Suit (MKIII).

Lessons Learned – Testing: Initially, the tasks selected for the IST series were determined via underwater pilot studies or based solely on treadmill ambulation. Moving many of these tasks from the NEEMO environment to the POGO environment required substantial changes due to limitations of the POGO and gimbal or the desire to collect more advanced data. Executing these tasks in the constrained environment of the C-9 led to further changes. To determine many of the relative strengths and weaknesses of the different test analogs, researchers need to make the tasks more standardized. When designing a test that will cross multiple analogs, one must consider the most limiting analog first and then determine the way those tasks will be performed with respect to the analog limitations, but with an eye toward keeping the tasks as similar to EVA as possible. Once this has been determined, these tasks need to be replicated across the less restrictive analogs and then other tasks can be included as determined by test objectives. In addition to task selection, subject familiarization with the tasks is essential. Familiarization should start with a 1-g shirtsleeve run-through of all the tasks to define baseline human performance data. Suited test days require at least one full familiarization run, especially with novel tasks. During IST-2, the average drop in metabolic cost from the familiarization trial to the research trial ranged from 15 to 31% depending on the task.

Lessons Learned – Subjects: Past studies have relied almost solely on astronaut subjects. Inclusion of astronaut subjects is critical as they are able to provide feedback based on actual EVA experience, even if only from microgravity. However, the availability of astronaut subjects and their limited schedule flexibility can lead to different subjects being used for each test or delays in the test schedule. Appropriate test subjects from the science and engineering fields can and should be included to expand the subject population and thus improve cross-test subject consistency and schedule flexibility. Additionally, past studies have shown significant variation in results between subjects performing the same task in the same suited configuration, and the source of the variation is currently unknown. We propose that all future tests need a thorough characterization of each subject including fitness, strength, anthropometry, and possibly other factors such as education, training, exercise, and life experiences that may be relevant to the tasks being performed.

Conclusion: The IST series is one of the first attempts to systematically look at suited human performance in reduced-gravity analogs. Although the initial goal was to focus almost solely on how the suit affects performance, it has become quite clear that the analog environment, testing methods, and subject population have a significant impact on study results. To the extent possible, analog environments need to be improved, more consistent testing methods need to be applied, and a wider variety of well-characterized subjects need to participate to fully characterize suited human performance in reduced gravity.



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Integrated Suit Test Research Plan Concept

1.0 Inputs to IST

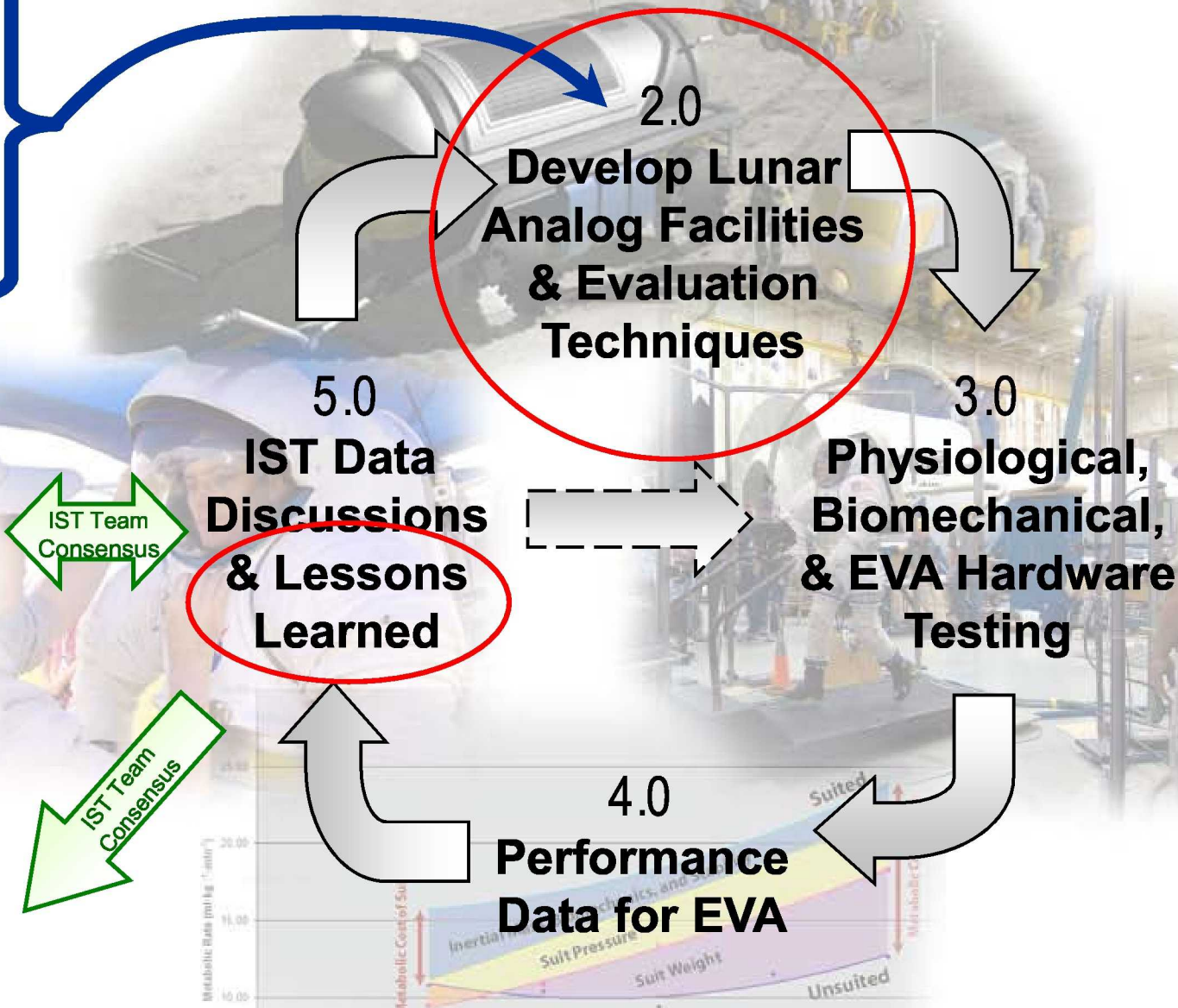
- Ops & Engineering Concepts
 - Suit Designs
 - Architectures
 - Mission Objectives
 - Specific EVA Tasks
- Stakeholder Objectives
 - CxP, HRP, EAMD
- Requirements TBDs

7.0 Provide inputs for requirement development and verification

- HSI Tech Forum (HSIR)
- ESPO A-Team
- Exploration Analogs & Mission Development
- Other Orgs as Required

6.0 Deliverables

- Test Reports
- Presentations
- External Publications





IST Objectives

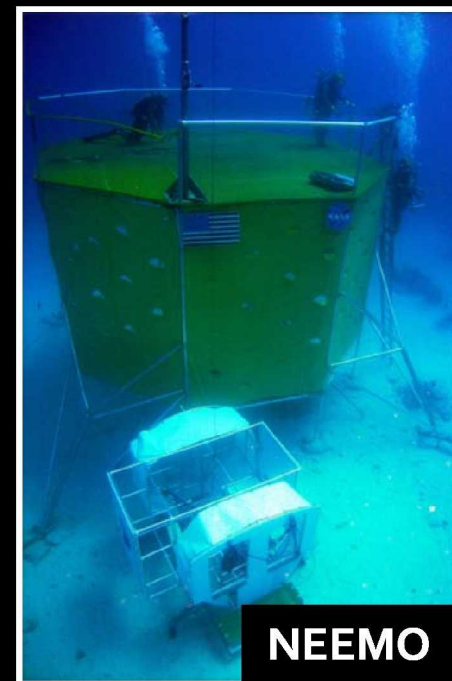
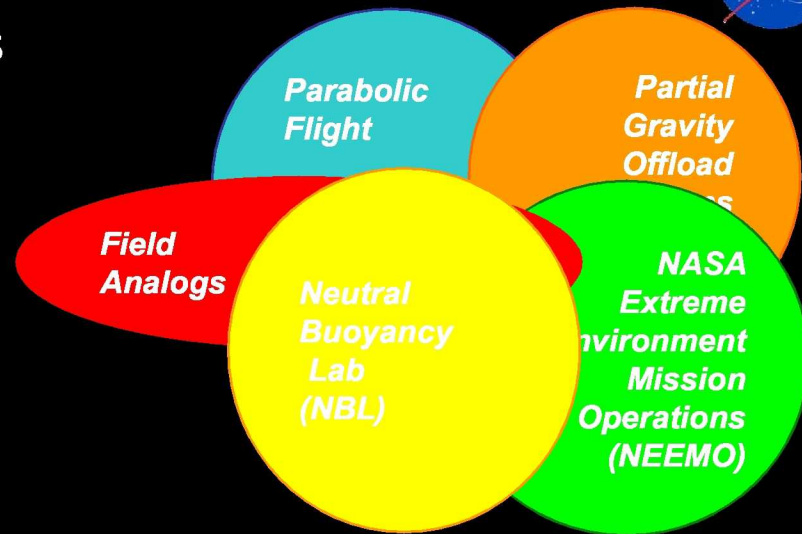
1. To define the usability and limitations of partial-gravity analogs for EVA applications
 - Overhead Suspension Offload Systems
 - Parabolic Flight
 - Underwater
2. To define standard measures and protocols for objectively evaluating future exploration suit candidates and requirements verification of the flight suit

Going in, we understood that all analog environments have certain limitations and our goal was to perform similar tests across different environments to better understand the strengths and limitations of each analog environment



Testing in Analog Environments

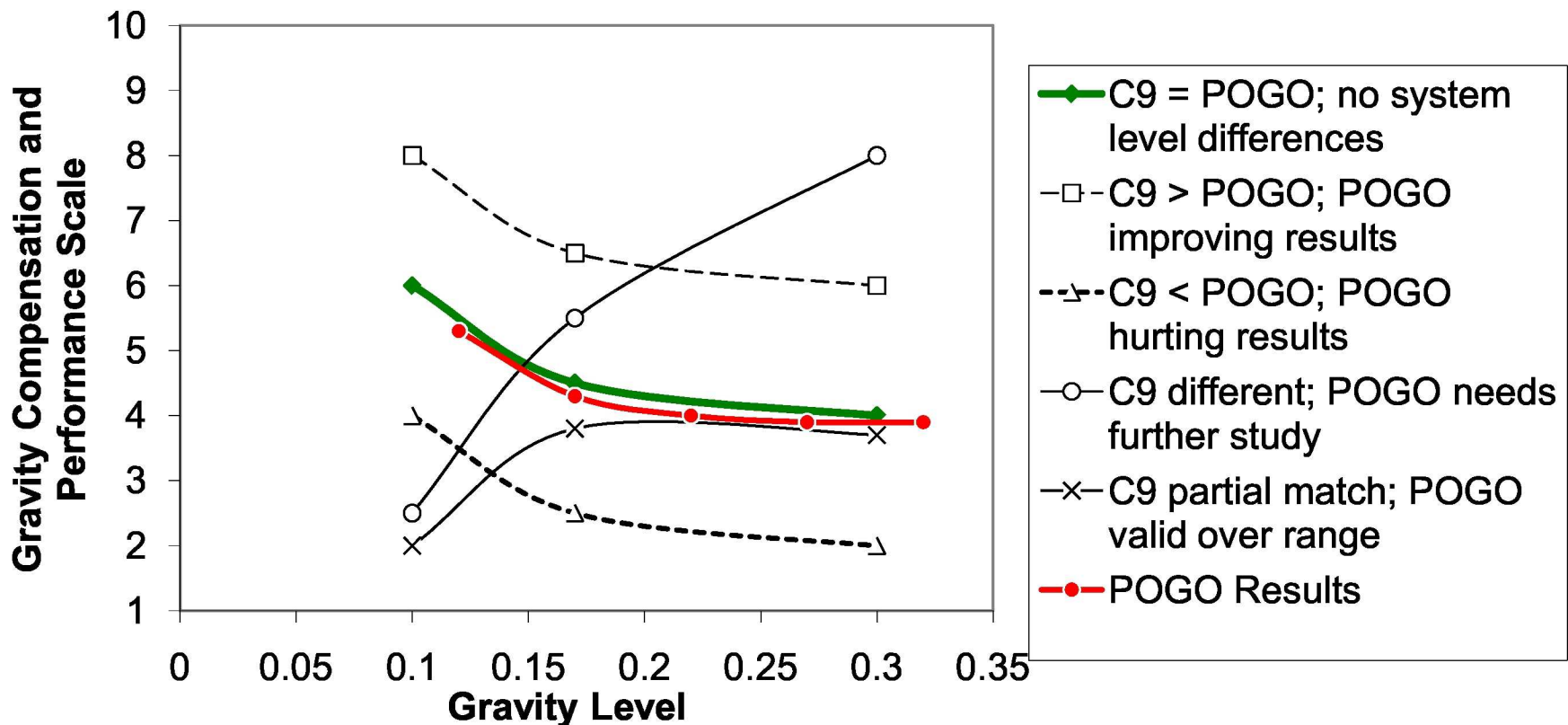
- Tests are performed in multiple analogs, as each environment has limitations for simulating partial gravity and representing a realistic operational environment



Direct Comparison Possibilities



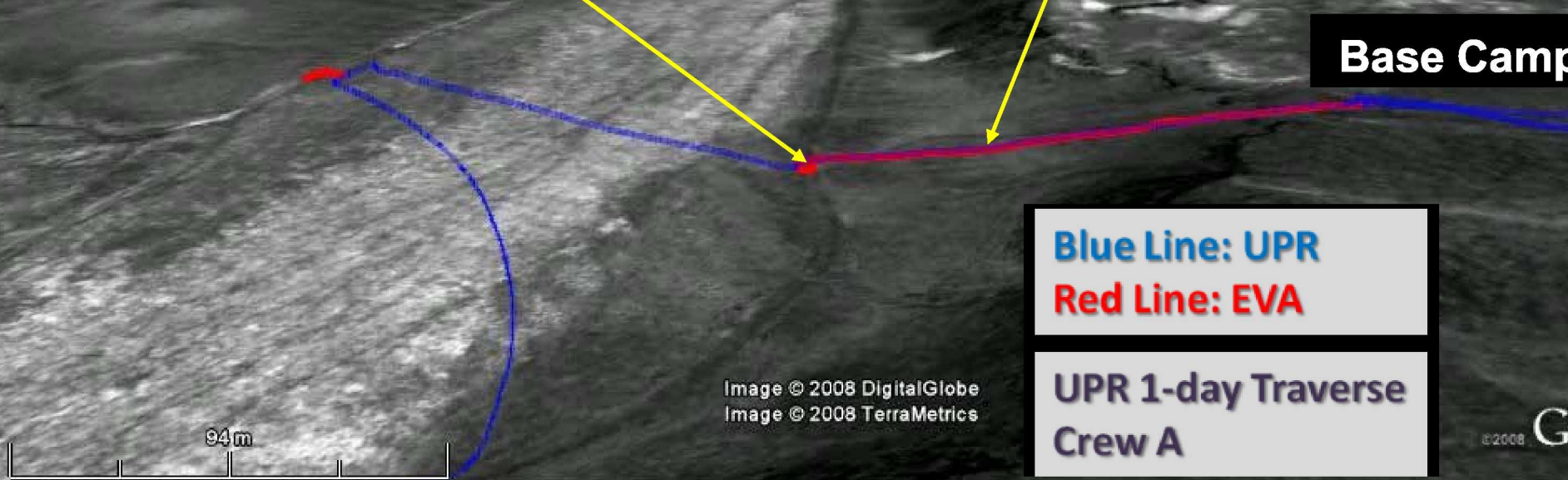
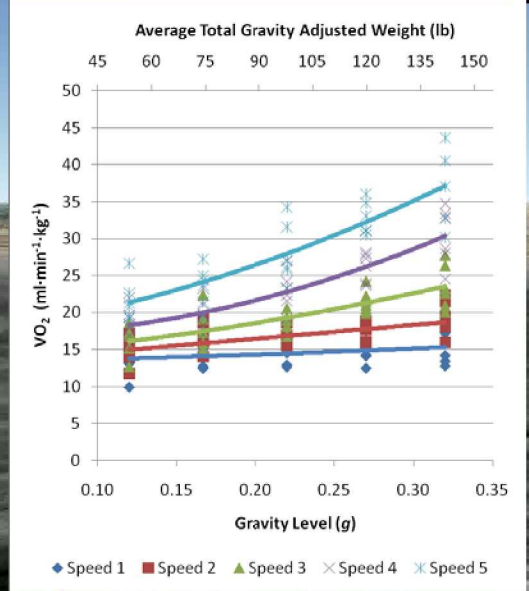
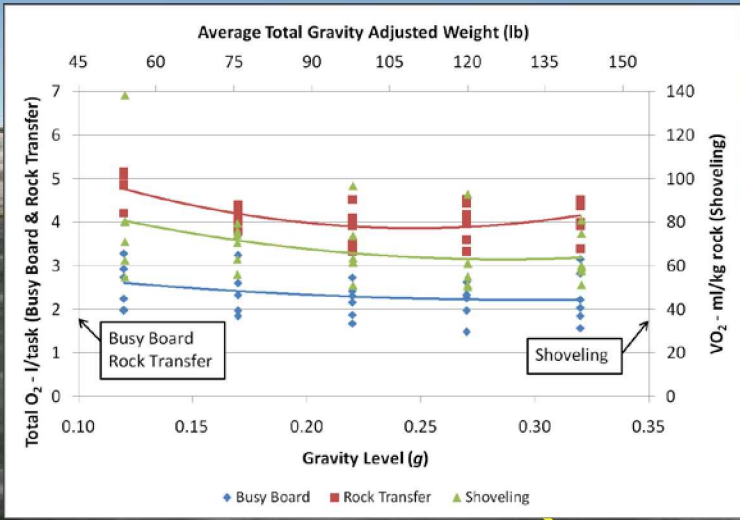
- Exact tasks can sometimes, but not always, be replicated across environments
- Data from some variables can be collected across analog environments





Combining Analog Environments

ex. Field Operational Concept Data with Laboratory Physiological Data from POGO



Analog Environment Comparison



Area of Interest	POGO***	Parabolic Flight	Underwater	Field Analogs	ARGOS*** (TBD)
Translational DOF	X,Z	Limited X,Y,Z	X,Y,Z	X,Y,Z	X,Y,Z
Offload Capacity	~ 450 lb	0-g to 2-g	Unlimited	1-g	~ 625 lb
Task Duration	Unlimited	<30 sec	Unlimited	Unlimited	Unlimited
Metabolic Rate	Yes	No	No	Yes	Yes
Biomechanics	Yes	Yes	No	Maybe	Yes
Impediments to Motion	Inertia from overhead suspension	Severe volumetric limitations	Water drag	None	?
Mockup Inclusion	Yes	Small only	Yes	Yes	Yes
Full EVA Simulation	No	No	Yes	Yes	Yes

***Does not account for gimbal related issues

Items highlighted in red show the biggest problems with the analog

Example of Rock Pickup Task



ROCK PICK-UP TASK



265 LB. SUIT WEIGHT

ESPO Test X Engineering Run 12-9-2008

Example of Ambulation Task



ARGOS Development



Expected Improvements over POGO

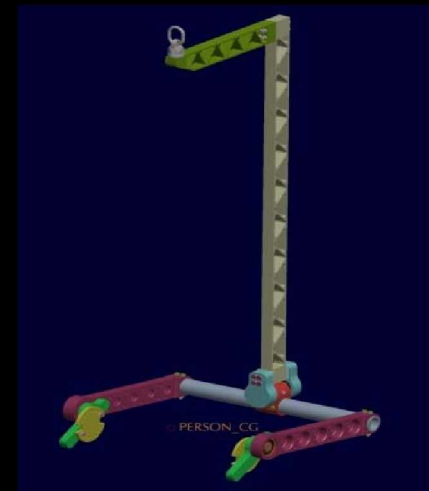
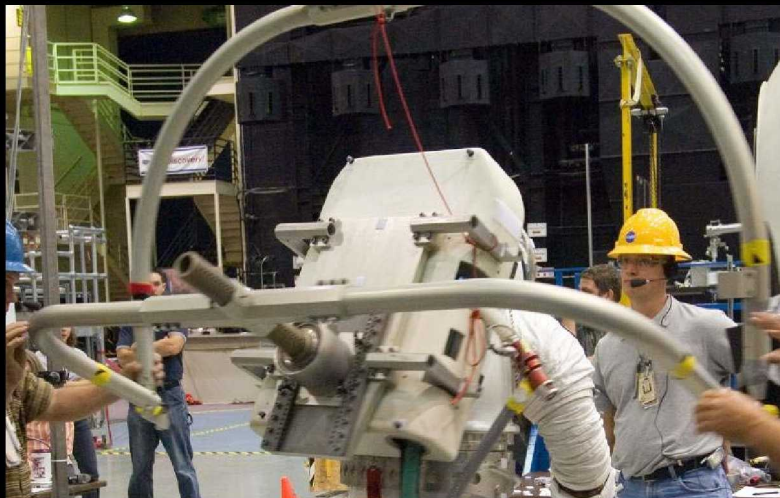
- X/Y/Z translational DOF
 - Increases test flexibility with greater area available to set up tasks ¹
 - Allows subjects to move freely when doing nonlinear tasks ¹
- Active control of X/Y translational DOF
 - Eliminates inertia of POGO overhead support column ¹
 - Eliminates artificial side to side stabilization ²
 - Eliminates artificial fore/aft stabilization ³
- Increased lift capacity
 - Allows varied mass and CG testing
- Improved Z-axis response and accuracy



Gimbal Development



- Decreased moment of inertia
 - Less mass away from subject
 - Compact design
 - Big improvement in yaw axis
 - Example – with current gimbal, lower body movement is predominant ¹
 - Initial calculations indicate new design may have only 10-15% of the moments of inertia of current gimbal
- Decreased mass
 - Current gimbal assembly > 40 kg
 - New designs may be as low as 10 kg
- To be designed to work with other suits
- Same gimbal design will support both suited and unsuited testing



Lessons Learned - Testing



- Familiarization is critical
 - Many subjects requested a few parabolas to just “get a feel” of how to move in the suit
 - 1-g run through is critical to establishing baseline data and helps with familiarization
 - Suited metabolic cost decreased 15-31% between fam and actual trial for exploration tasks
- Think about the most limiting analog first and perform the same set of tasks during ground based operations
 - We modified 3 of 4 tasks for parabolic flight
 - All of these modifications could have been predicted and accounted for in ground based testing
 - Parabolic flight is the most realistic partial-g simulation, but also volumetrically limited
- Tasks need to be performed in the most EVA similar manner but may have to be modified
 - Once improvements are made to the system, don’t stick with the old modified testing methods if they are not EVA like
 - Keep track and report on reasons for modifying any task



- Crew subjects must continually be involved but tests must supplement with other subjects
 - Due to mission schedules, crew subjects may not be able to complete multiple studies
 - Critical for comparison across different analogs
 - Scheduling of crew subjects is complex and sometimes limited
 - Inclusion of scientists and engineers, especially those involved with EVA systems, would increase the available subject population and drastically improve scheduling flexibility
- Significant performance differences have been seen between crew subjects performing the same task in the same configuration
 - Need to characterize subject fitness, strength, anthropometry and possibly other psychological factors (e.g., military vs. civilian)

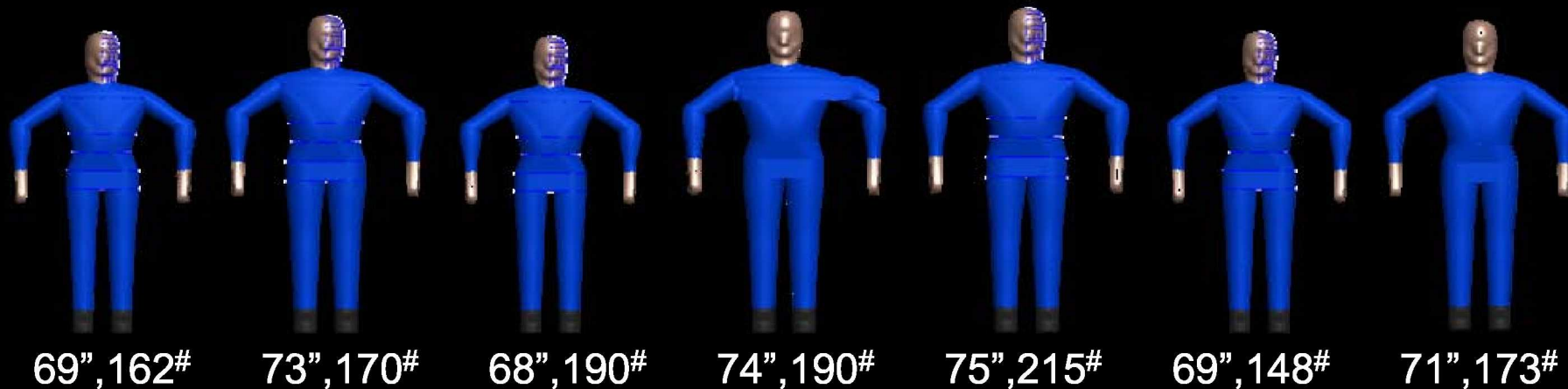
Subject Characterization



- Need to go beyond height and weight
- Included strength, anthropometry, fitness, psychological/personality



Both these guys could be 72" and 180 lb



Integrated Suit Test Research Plan Concept

- 1.0 Inputs to IST**
- Ops & Engineering Concepts
 - Suit Designs
 - Architectures
 - Mission Objectives
 - Specific EVA Tasks
 - Stakeholder Objectives
 - Requirements
 - Team
 - Requirements

2.0 Develop Lunar Analog Facilities & Evaluation Techniques

3.0 Physiological, Biomechanical & EVA Hardware Testing

5.0 IST Data Analysis

- 7.0 Provide inputs for requirement development and verification**
- HSI Tech Forum (HSIR)
 - ESPO A-Team
 - Exploration Analogs & Mission Development
 - Other Orgs as Required

- 6.0 Deliverables**
- Test Reports
 - Presentations
 - External Publications

If we don't properly address the needs in step 2.0, then the system breaks down



