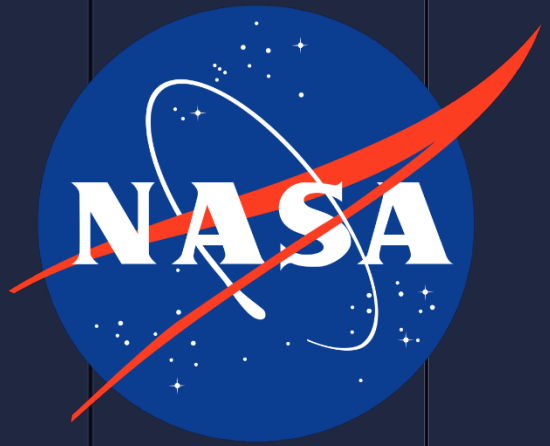
Advanced Space Suit Performance in Lunar Simulation Environments



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DATE

7/23/2024

CONTRIBUTORS

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PREPARED BY

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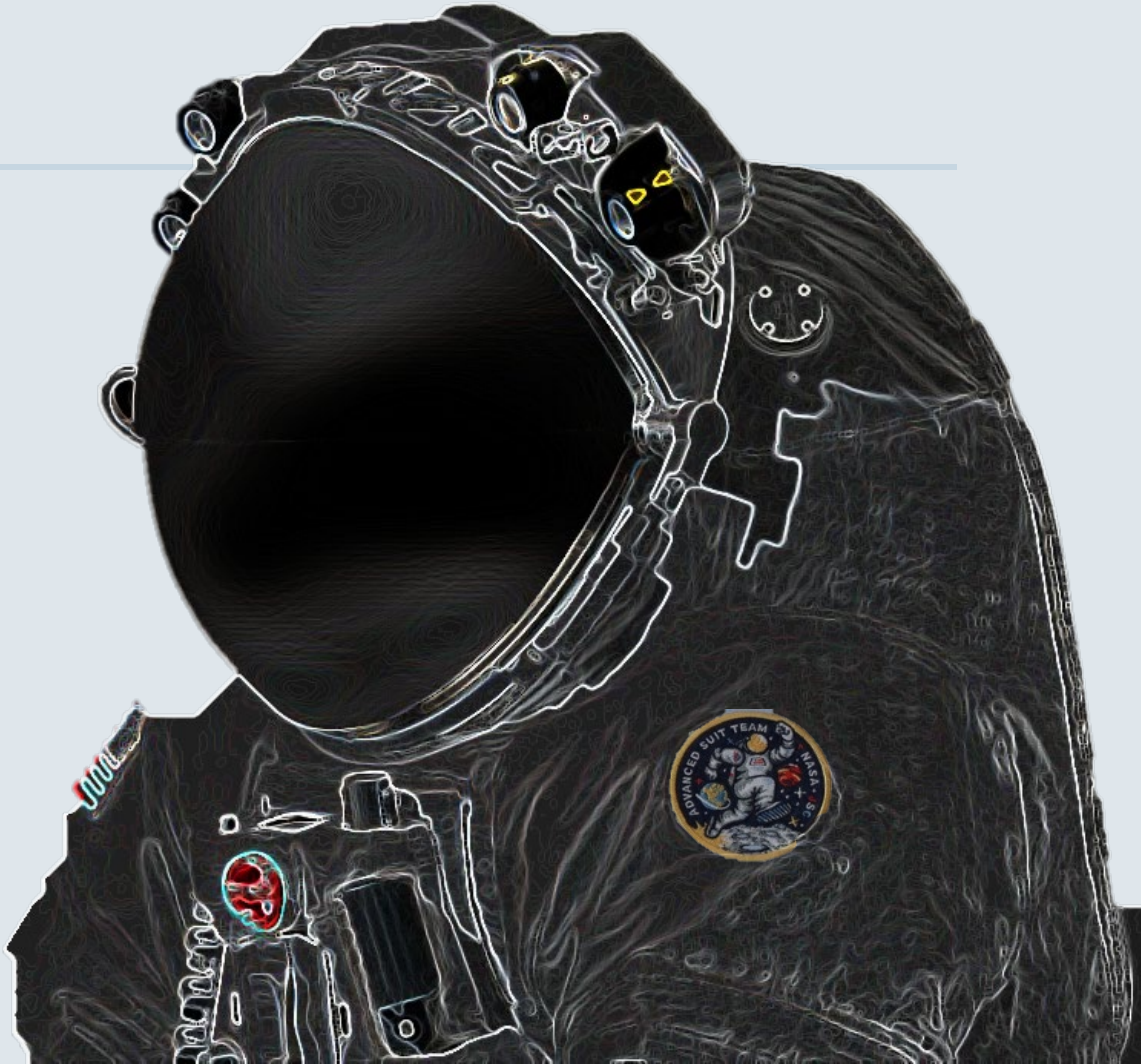
Agenda

- Intro and Background
- Facility Review
  - ARGOS
  - Field
  - NBL
  - RGA
  - Suit Lab
- Conclusions



Intro

- For decades NASA has been focused on the microgravity environment with minimal focus on maintaining or developing new Lunar test environments
- Recent resurgence in Lunar simulation environments in order to prepare for Artemis missions
- Critical to understand how our simulated environments impact spacesuit performance because simulation quality impacts:
  - What are and are not valid objectives for the different sim environments
  - Our ability to determine the cause of what subjects and crewmembers are experiencing
  - How confident we are that our results are applicable to the actual Lunar environment
- Our focus is on gravity simulations but there are other factors such as vacuum, dust, thermal, and many others that are just as important depending on test objectives

NASA's Advanced Spacesuits



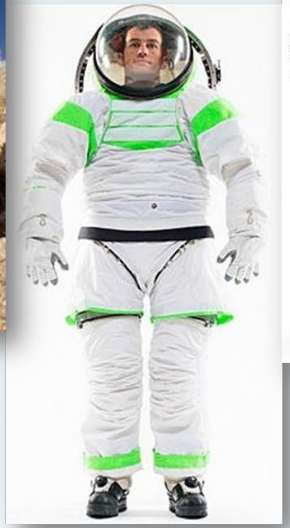
Mark III
1989



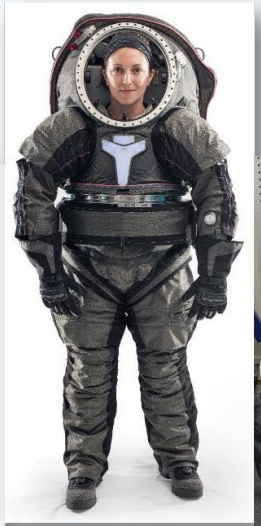
WEI-Suit
1997



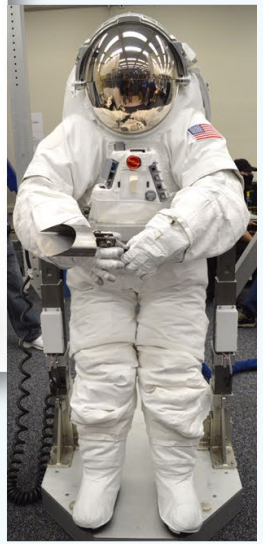
REI-Suit
2005



Z-1
2011



Z-2
2015



xEMU
2021

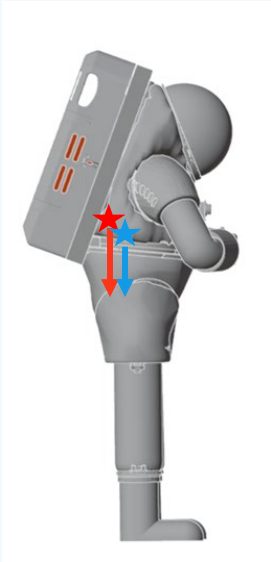
Key Gravity Sim Techniques

- 1G
  - No suit/subject offloading (or static offloading)
  - Many different locations but most commonly labs, hangars, and rockyard
- Underwater (NBL)
  - Utilize buoyancy to offload suit/subject
- Lifting (ARGOS and POGO)
  - Crane-like system to physically lift the suit/subject
- Reduced Gravity Aircraft (RGA)
  - Parabolic flights with 1/6G profiles

Suit/Subject Weight

★ Suit Force
★ Subject Force

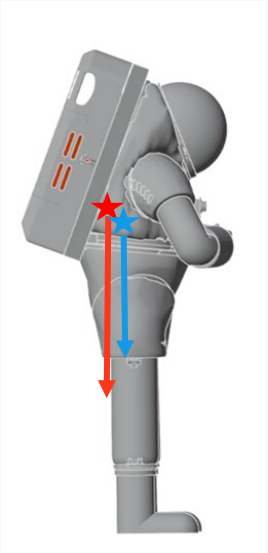
Lunar Surface and Parabolic Flight



Suit and subject both at 1/6g with respective weights

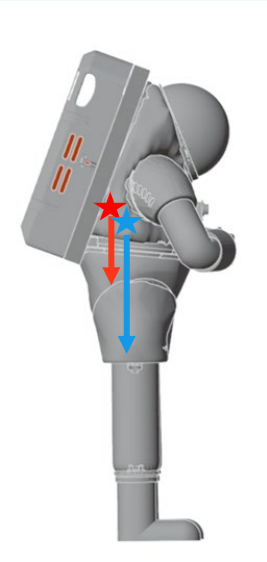
Earth-Based Sims

1G



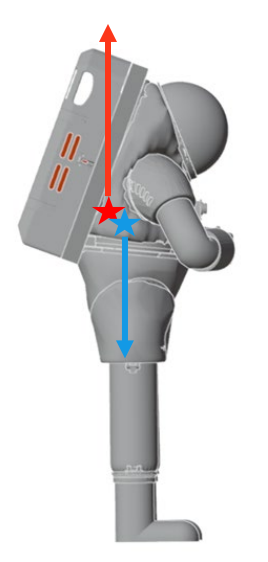
No offloading. Suit and subject at 1G weight

Simulate Suit Weight



Suit weight is offloaded to 1/6g of its Earth weight
Expected Lunar Shoulder Loading

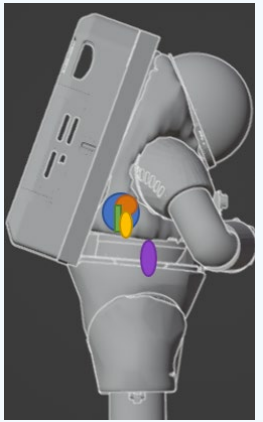
Simulate Suit/Subject Weight



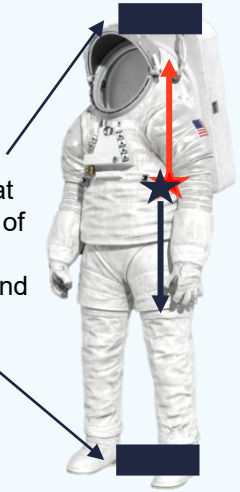
Suit weight is completely offloaded and “lifting” subject
Realistic Ground Reaction Forces

Effective CG

- Effective Center of Gravity (CG) is the location where the subject feels the CG
  - The reality is much more complex, moments can be created with how the reduced gravity is being simulated
- Goal: Model the flight system CG and conduct ground testing with Effective CG in that position
- Effective CG is dependent on posture
  - ARGOS: Changes in location of the Center of Mass (CM) and Gimbal
  - NBL: Changes in location of the CM and Center of Buoyancy (CB)



- Modeled Flight CG (Best available source)
- ARGOS xEMU Tested Pivot Points
- ARGOS xEMU Subject CG Locations
- ARGOS xEMU Preferred Pivot Point Locations
- NBL 2.1 & 2.2 CB/CG Locations

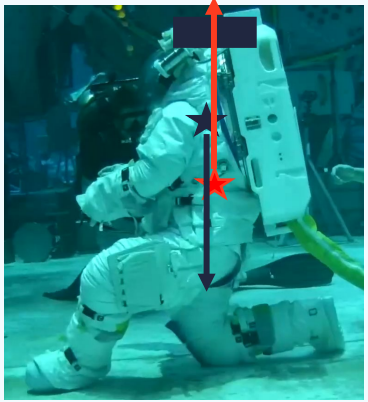


Large weights at top and bottom of suit results in coaligned CB and CG in upright posture

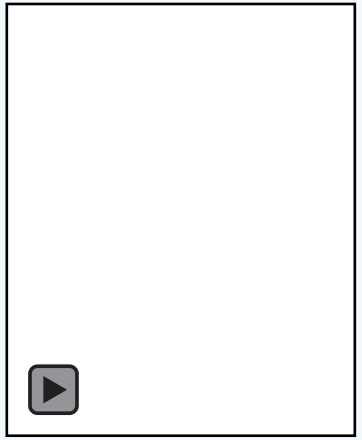
★ CG

★ CB

In a kneel the CG shifts up relative to the CB. Now subject is fighting a moment that wants to pitch their head down







Facilities

- Facility by facility overview of simulation quality
- This is not what you will be evaluating as a test subject, it is to inform you about potential impacts to the things you are evaluating
  - What we think the simulation environment does well
  - What we think is unrealistic about the simulation environment

ARGOS



Field



NBL



RGA



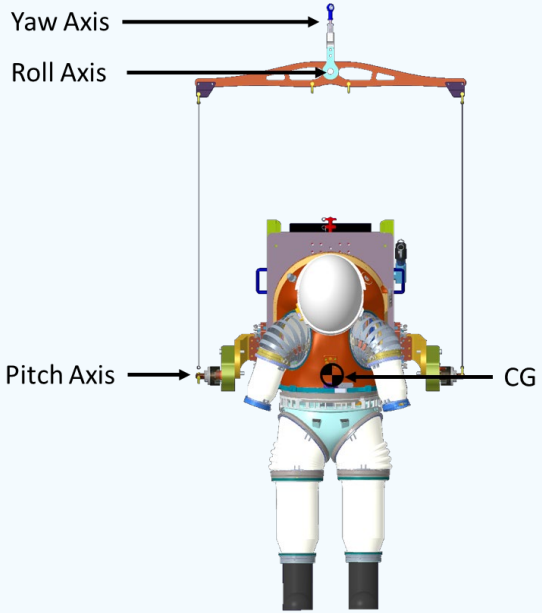
Suit Lab



ARGOS Intro

- ARGOS 2B is a robotic system that simulates a reduced gravity environment
- Feedback controlled 3-DOF robot
  - Vertical system (Z-axis)
    - Control system commands the motor to raise or lower the test participant to maintain a constant offload force
  - Horizontal system (XY-axes)
    - A cable angle laser sensor provides data which commands the system to keep the lifting mechanism centered above the load
- Typical Use: Hardware evaluations, Suit dynamics, HHP testing, Task evals



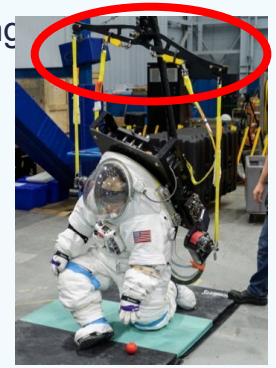


Adjustability in gimbal settings and PLSS weight to simulate the full system mass with an adjustable CG

ARGOS

- Key Positives
  - Realistic ground reaction forces
  - Realistic momentum management
  - Realistic force required to manipulate the suit
- Key Negatives
  - Pivot point settings are usually a compromise between realism and performance
  - Gimbal has limited roll
    - Can provide unrealistic stability in some postures
    - Can prevent some tasks and techniques
  - Human to suit interaction different compared to flight due to suit lifting subject
  - Arms, legs, and tools are not off-loaded
  - Limited to single pressurized suit operations
  - Gimbal structure volume
  - Limited test area size







Field Intro

- Several locations
  - Flagstaff, Iceland, Nevada National Security Site, etc.
- Typical Use: Full scale EVAs, Geology training
- Only considering mockup suits such as the EXCON

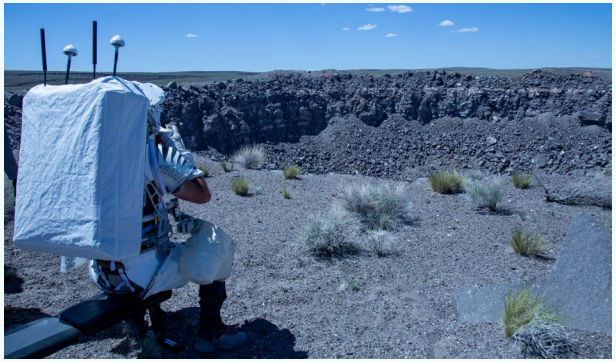




Field

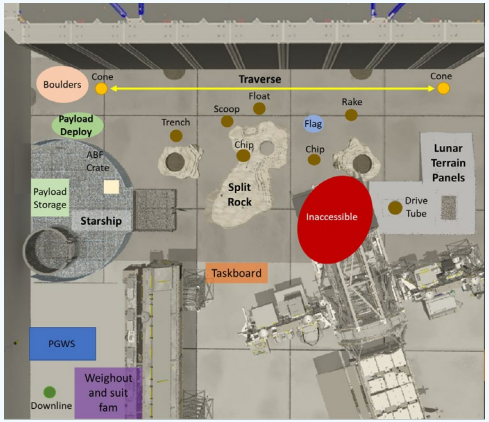
- Key Positives
  - Some mechanical limitations and mental realism
    - Keeps subjects from “cheating”
  - Some realistic tool management aspects
  - Test area can be full scale with realistic geology
- Key Negatives
  - Significant impacts with lack of pressure
  - Human to suit interaction is very different
  - Arms, legs, and tools are not off-loaded



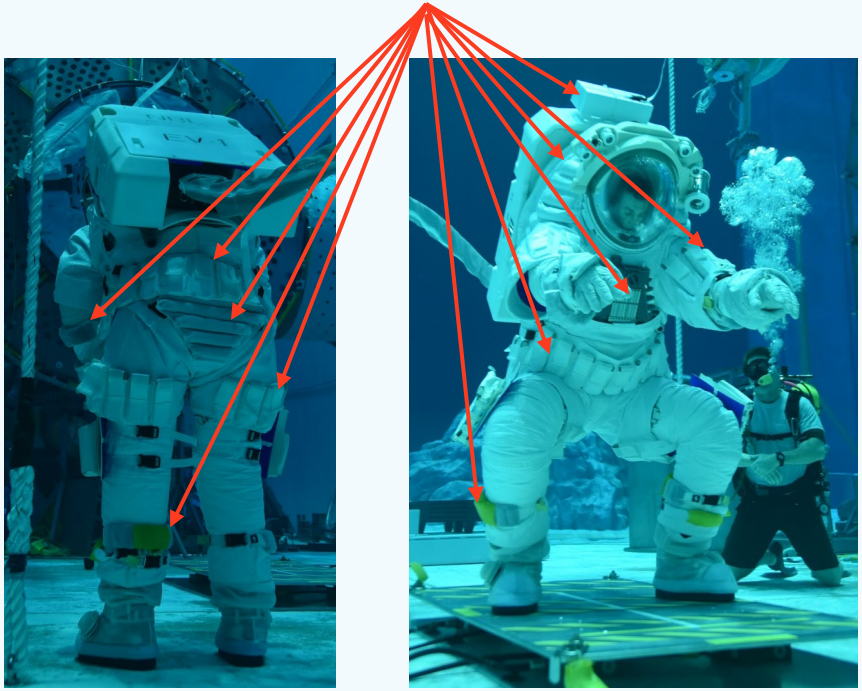


NBL Intro

- Recently developed to provide Lunar simulation capability
- Add foam and weights to adjust suit/subject weight to 1/6G weight
  - ~100lbs more than EMU
- Typical Use: Operational Evals, Dual suited tasks



xEMU Foam and Weights



NBL

- Key Positives
  - Arms and legs can be realistically offloaded and provide for improved static interaction
  - Dual suit test operations
  - Test area environmental factors: rocks, mockups, lighting, dirt, etc.
- Key Negatives
  - Water drag significantly impacts dynamic motion
  - Realistic static postures and movement have proven challenging to obtain, leaving unrealistic righting moments
  - Human to suit interaction different compared to flight due to suit lifting subject
  - Addition of ~150-180lbs to the suit can impact or interfere with some motions



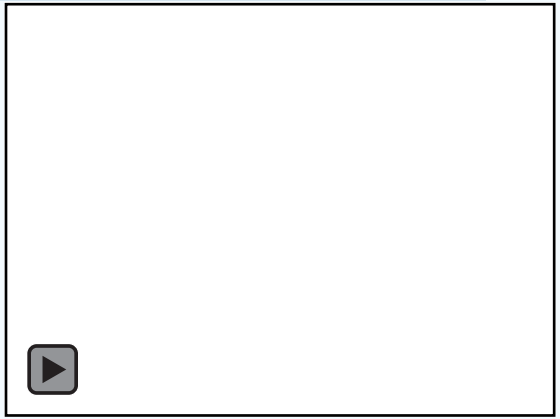
RGA Intro (Not a Current Facility)

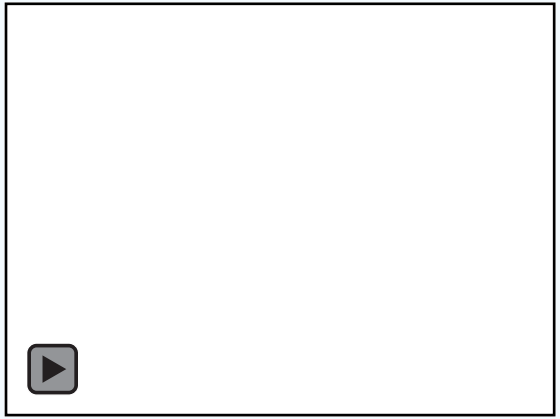
- Various Reduced Gravity Aircraft (RGA) have been utilized in the past (none currently rated for NASA use)
- Parabolic flight with short duration, realistic 1/6G simulation followed by high G pullout
- Ideal use:
  - Validate Effective CGs for ARGOS and NBL
  - Very short hardware or task evaluations
  - Training specific dynamic skills (e.g. supine recovery)



RGA

- Key Positives
  - Able to achieve a true 1/6G simulation
  - Human to suit interaction is representative
  - Accurate CG placement
  - Only place to realistically evaluate some tasks such as supine recovery
- Key Negatives
  - Good for only 15-20 seconds of task time, followed by 2G pull-out
  - Very limited volume (particularly cabin height)
  - Very limited use for operational assessments, except to train specific dynamic skills





Suit Lab Intro

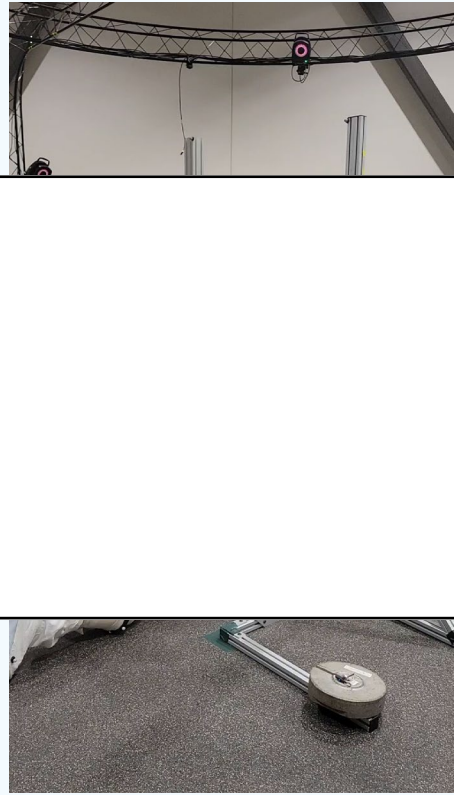
- Several locations
  - Various suit labs, rockyard, other facilities
- Could be un-offloaded or have some static offload
- Typical Use: Fitchecks, some specific evaluations



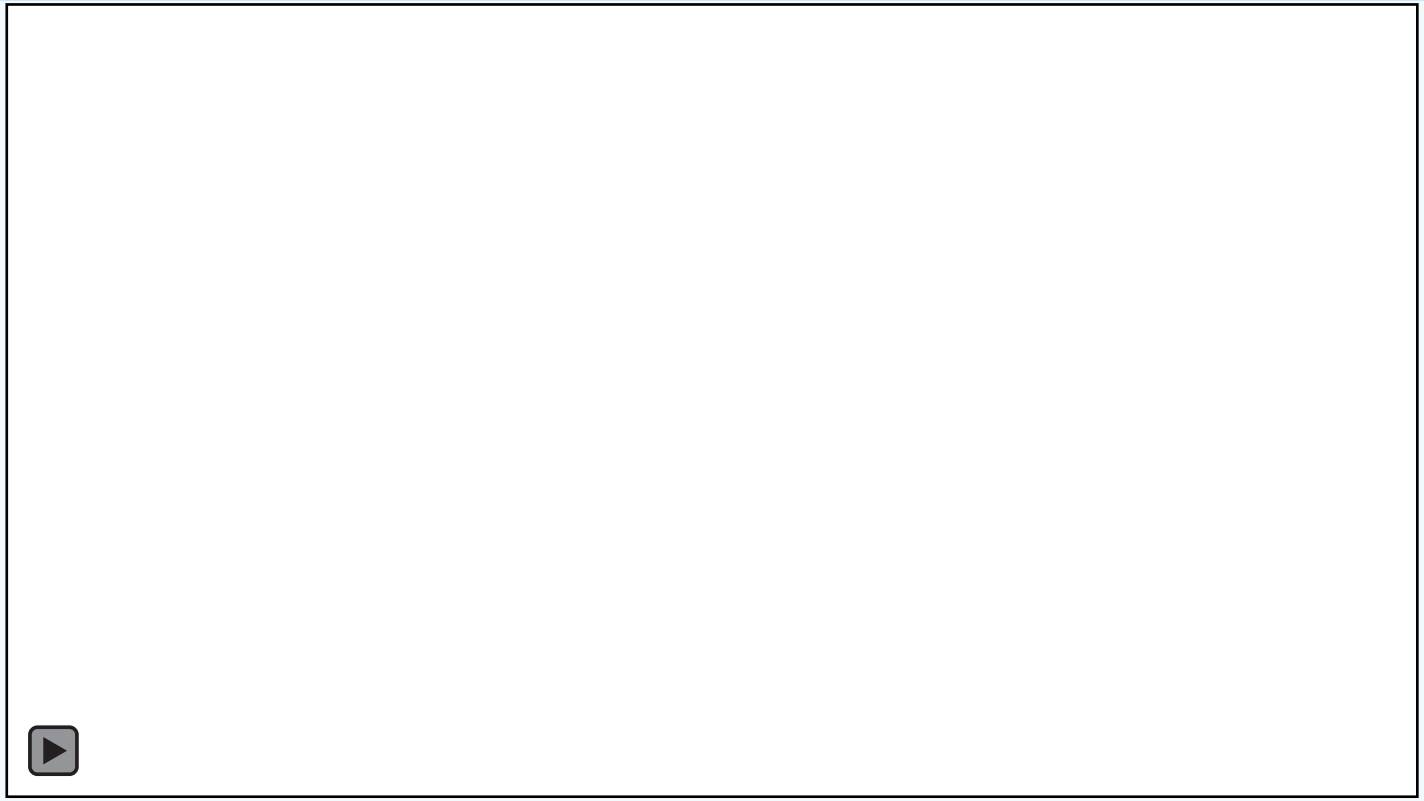
Suit Lab

- Positive Factors
  - Mobility of some joints fairly accurate
  - Realistic force required to manipulate the suit
  - Access to suit and test area is easy
- Negative Factors
  - Weight management dominates mobility, range of motion
  - Unrealistic ground reaction forces and momentum; full body motions impacted
  - Human to suit interaction is different compared to flight
  - Arms, legs, and tools are not off-loaded





Object Pickup

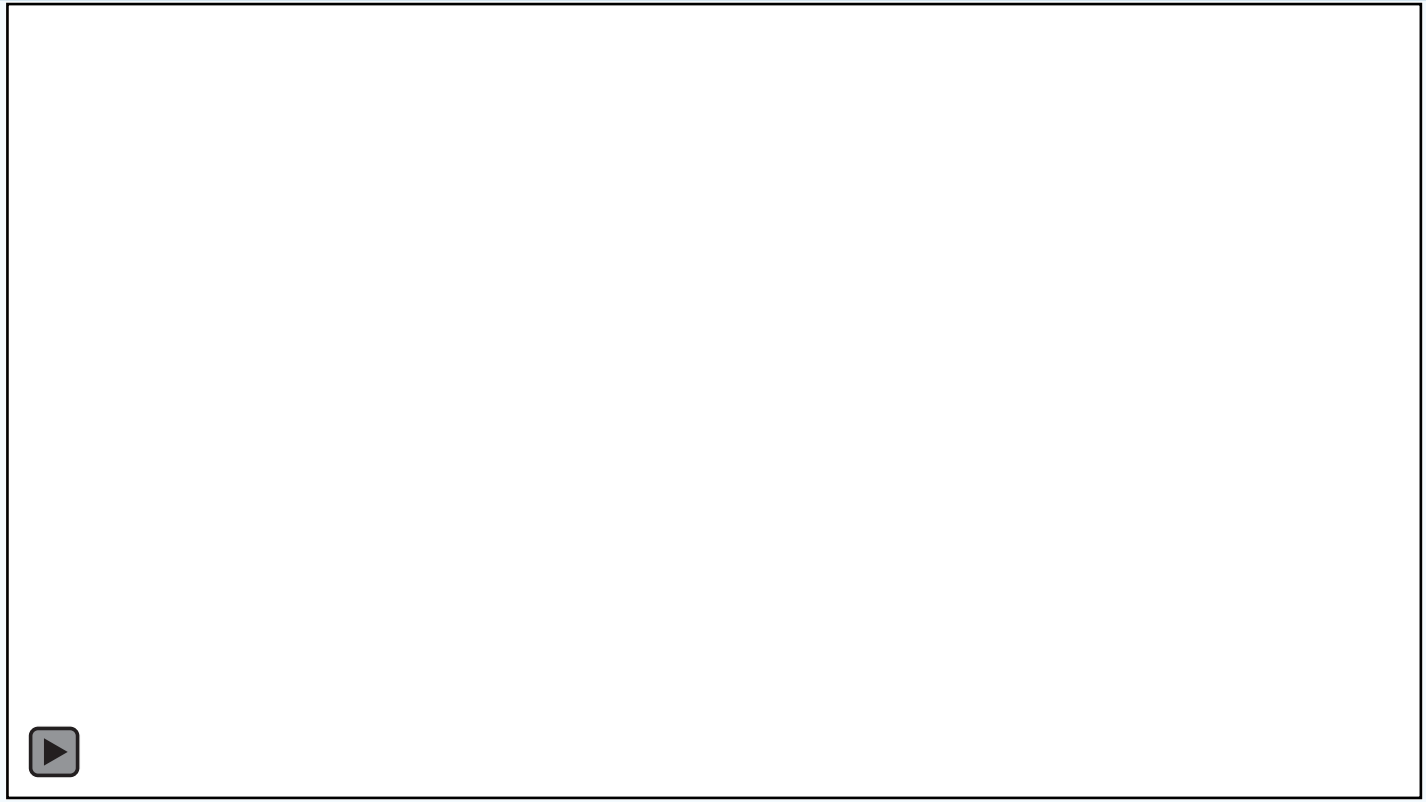


xEMU / NBL
Sept 19, 2022

Mark III / RGA
Sept 3-5, 1996

xEMU / ARGOS
April 25, 2022

Dynamic Motion



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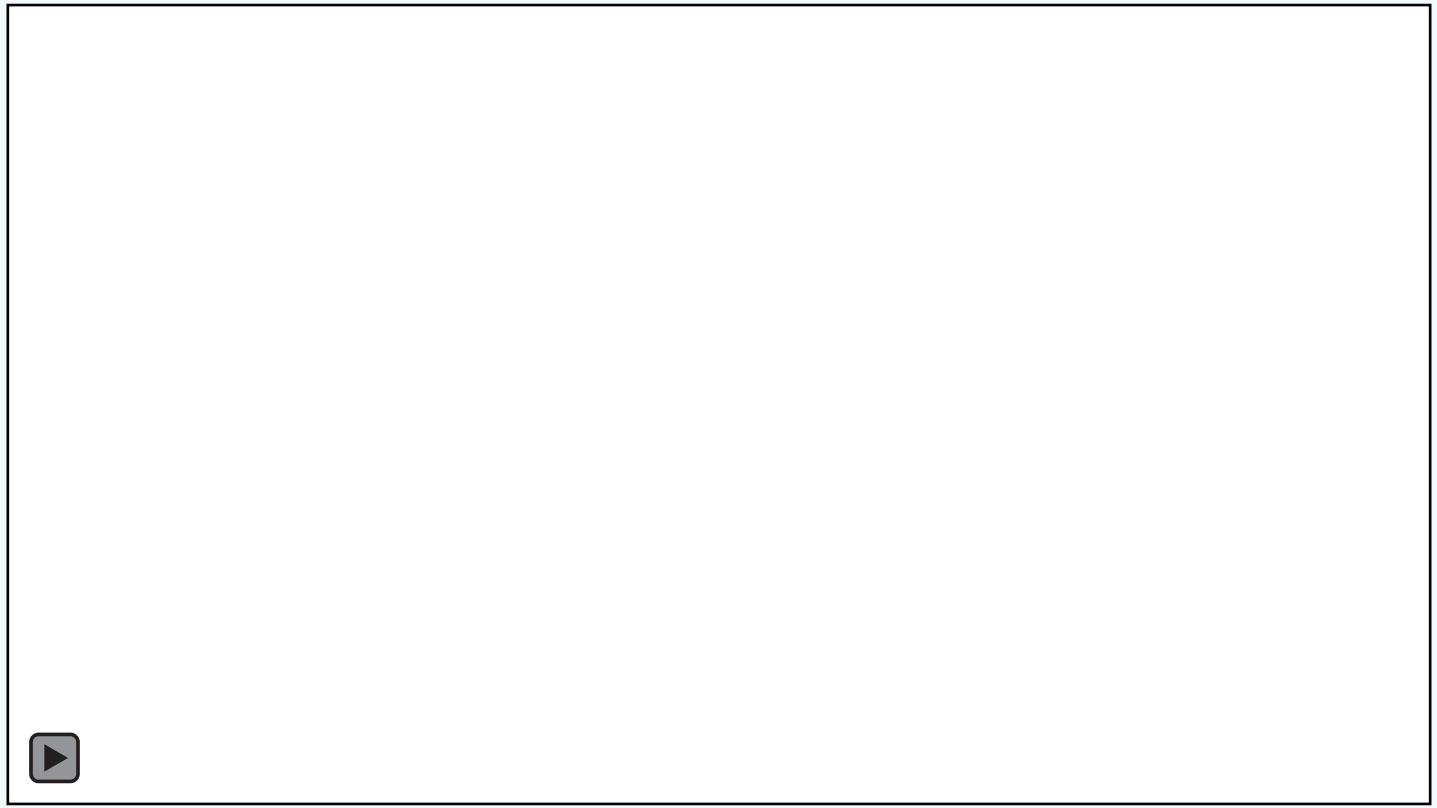
Prone Recovery



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Sim Quality Quick Look

	ARGOS	Field	NBL	RGA	Suit Lab
Dynamic Motion	Good ground reaction force Good inertia management	Unpressurized Not fully mocked up	Good ground reaction force Water dominates inertia and dynamic motions	Real 1/6g effects on entire system	Some significant suit weight impacts
Operational Factors	Limited mockups Single offloaded suit	MCC integration Dual suit	Good mockups Developed lunar station Dual Suit	Limited duration	Minimal, can develop task specific capabilities
Environmental Factors	Small space Requires mockup logistics	Real rocks Full scale EVA	~Size of lunar station	Very small workspace	Very small workspace

*Highly simplified and generalized overview

Conclusions

- All simulation environments have things they do well and things they don't
- Understanding the simulation environments is paramount to ensure valid data and results
  - The ARGOS and NBL environments have not been validated to ensure that the simulation quality provided is well understood
- Important to optimize what is tested in each location to maximize the strengths of the available environments
  - Testing the wrong thing in the wrong environment can have significant impacts
    - Wasted time, incorrect lessons learned, poor hardware designs, etc
- Upgrades to existing simulated environments and potentially even new simulated environments are warranted as we continue working towards planetary EVAs
  - Re-introduction of RGA testing is critical
-

