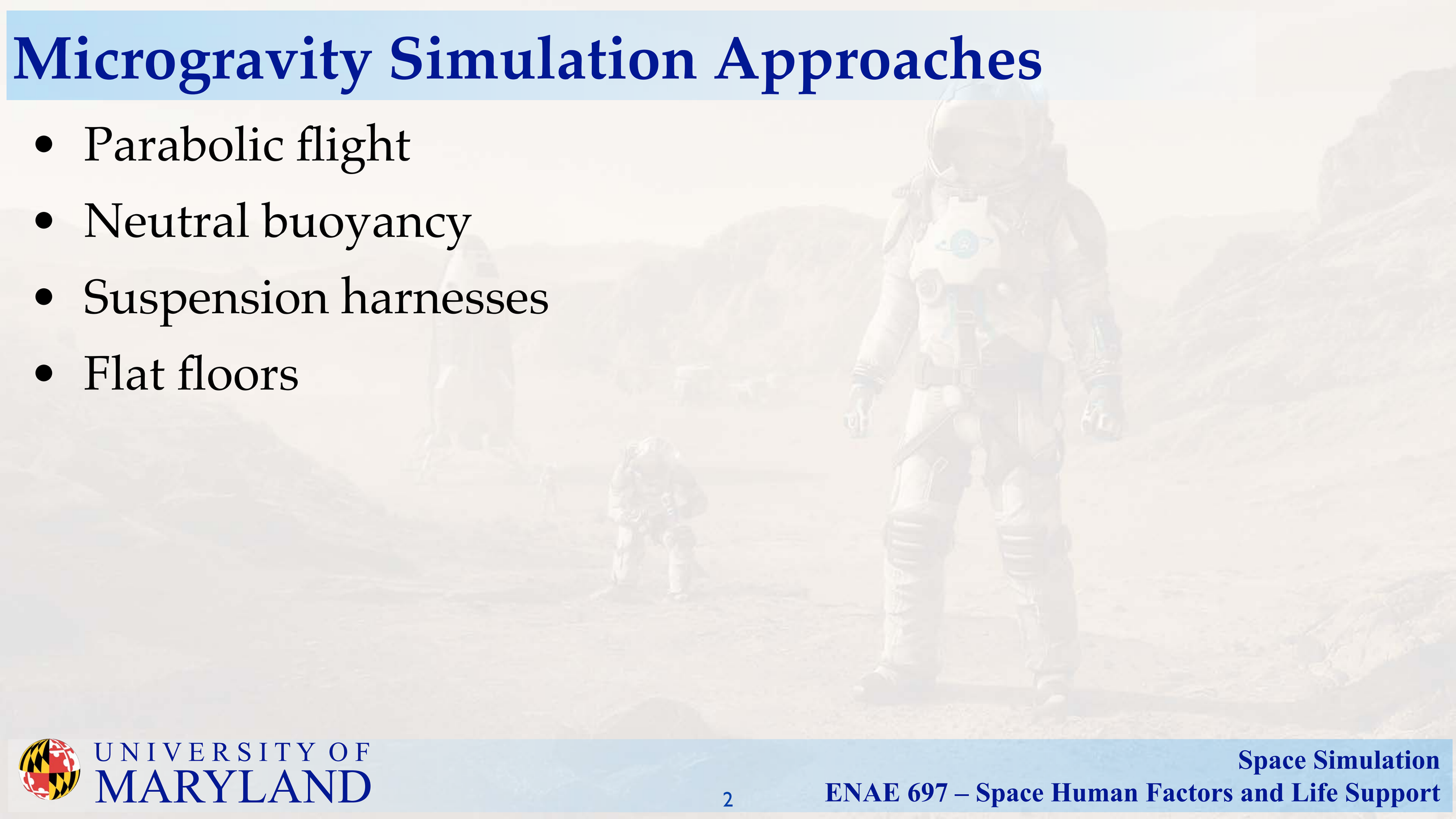
Space Simulation

- Focus of this lecture is on human-in-the-loop operational simulations, not component sims (e.g., thermal vacuum chambers)
- Microgravity
- Planetary surfaces
- Specialty simulations

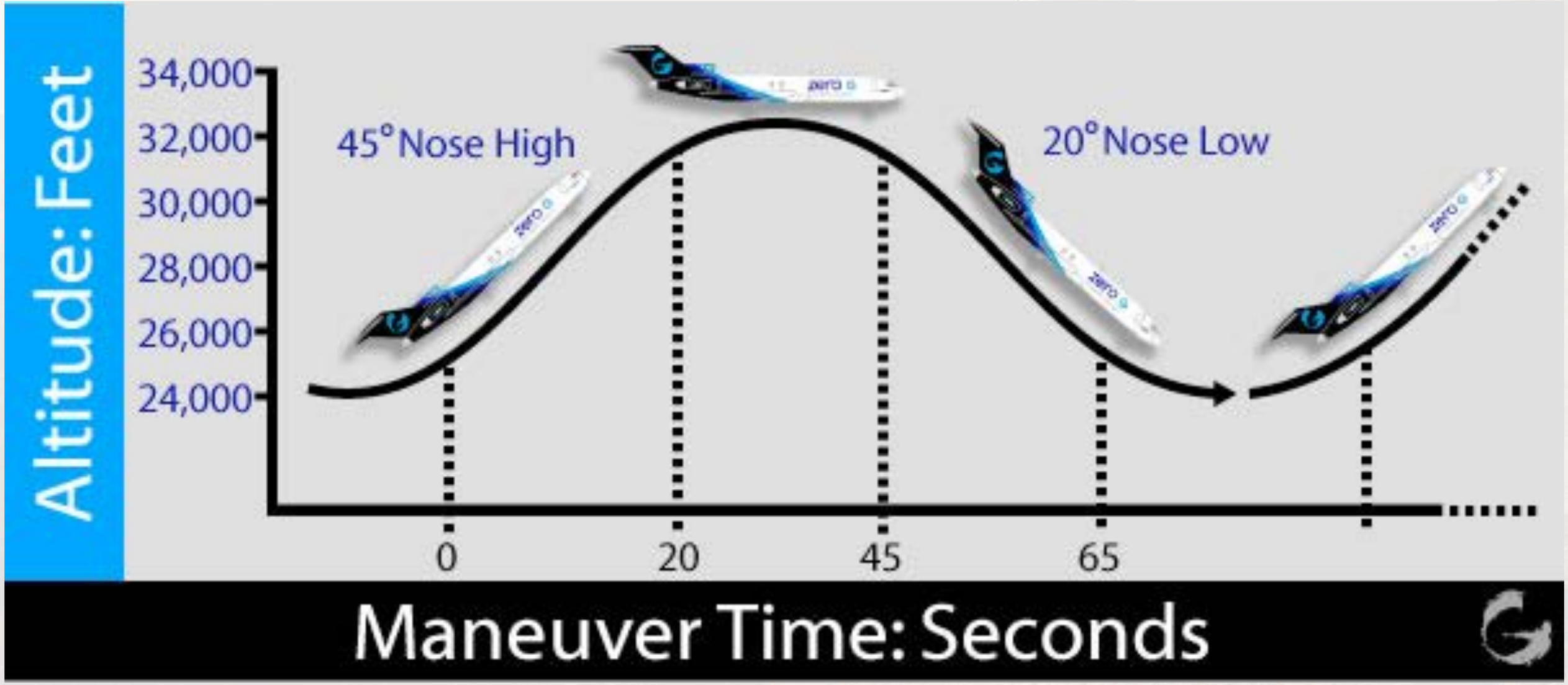
Microgravity Simulation Approaches

- Parabolic flight
- Neutral buoyancy
- Suspension harnesses
- Flat floors



NASA KC-135 in Parabolic Flight

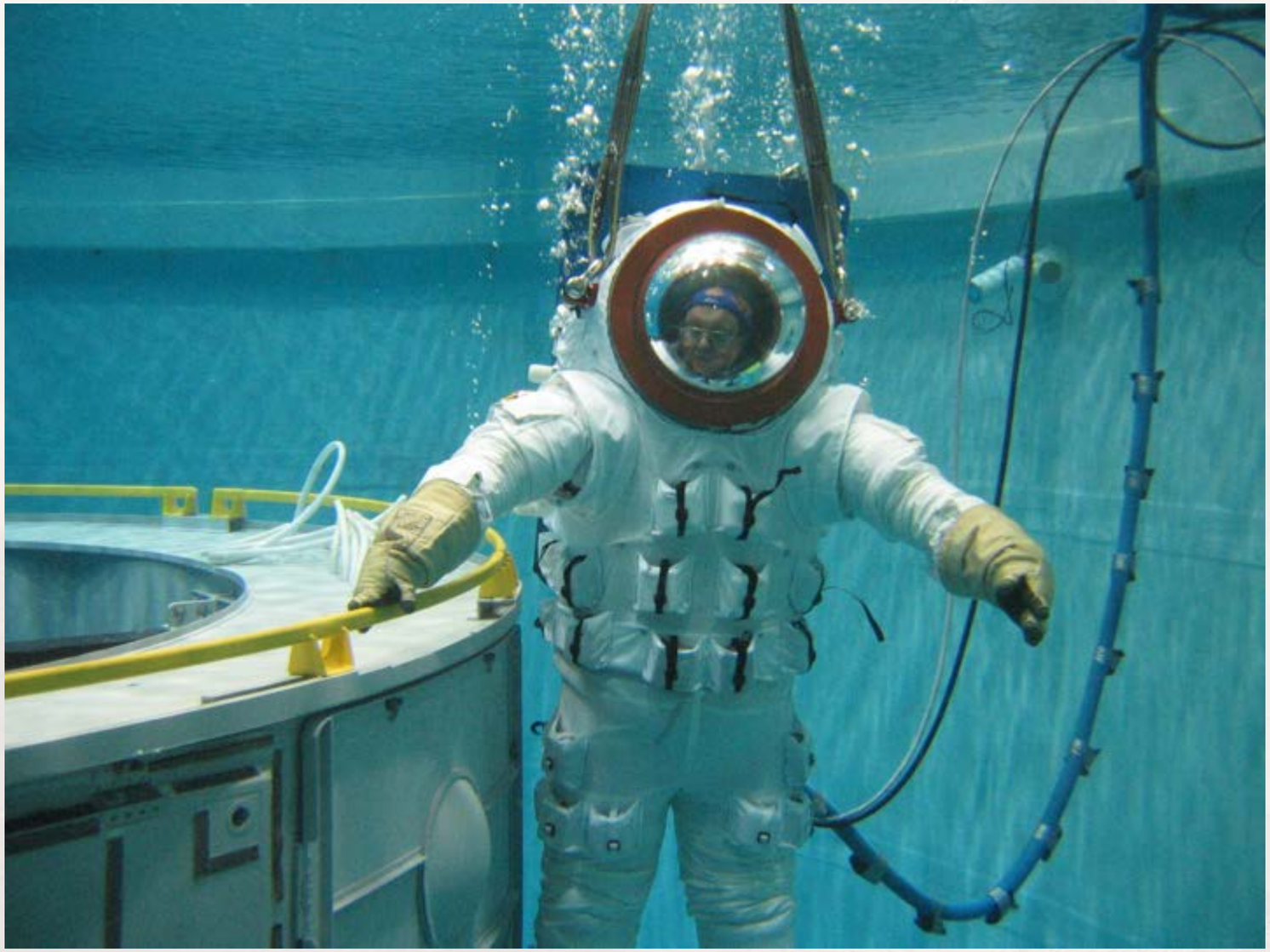
Parabolic Flight Profile



Parabolic Flight Summary

- Advantages
  - Actual microgravity
- Disadvantages
  - Motion sickness
  - Limits of cabin volume
  - Limited time
  - Limited crew size
  - Substantial certification requirements
  - High cost (~$5-10K/flight hour)

Neutral Buoyancy Simulation of μG



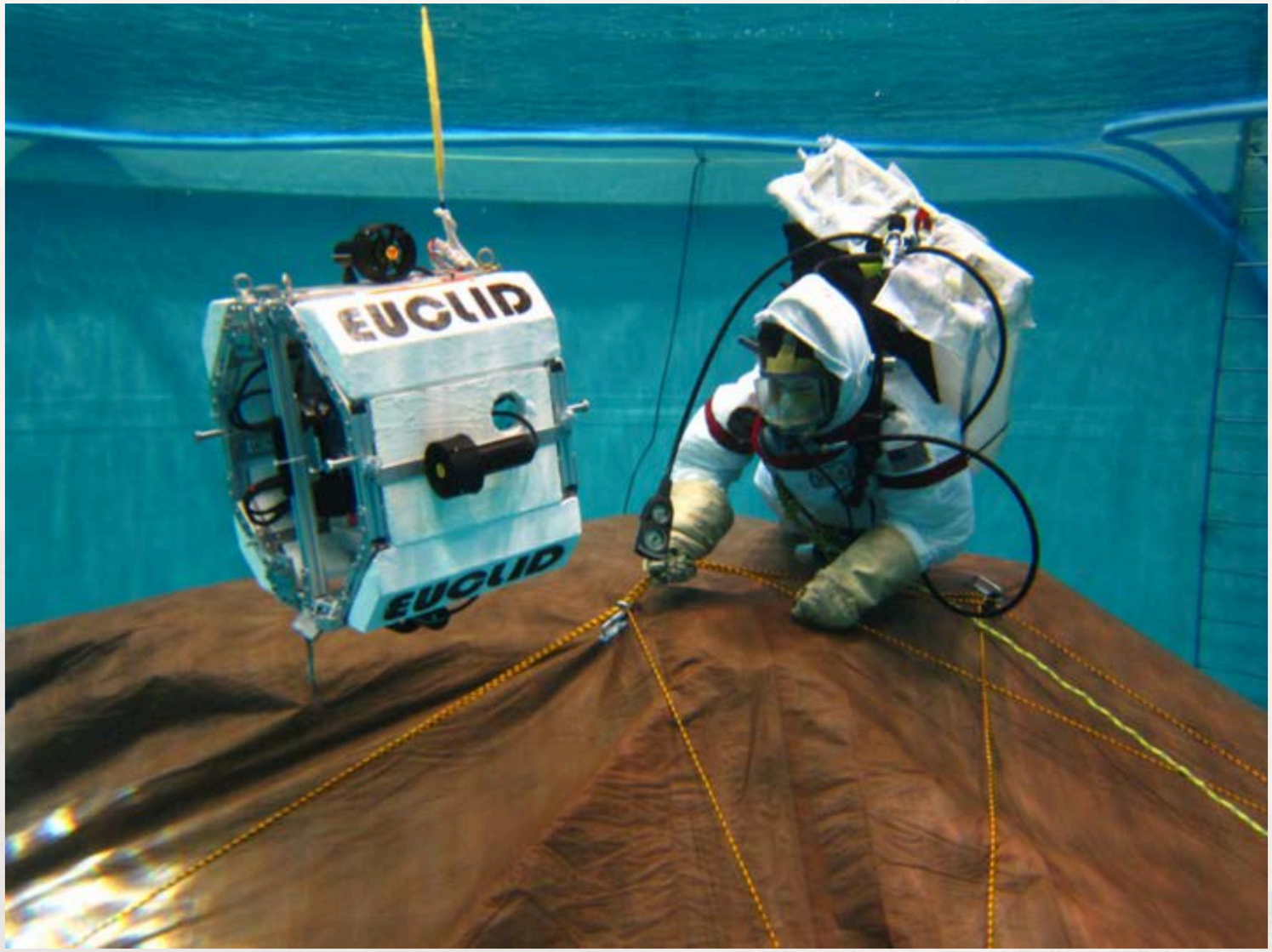
Potential Applications of UW Simulation

- EVA Interfaces
  - Installation of science packages
  - Rover ingress/egress/seating
  - Habitat access (e.g., ladders, stairs, ramps)
  - Pressure suit design evaluation (e.g., foot visibility, recovery from fall)
- Ergonomics and human factors
  - Partial gravity neutral body posture and postural maintenance
  - Effects of backpack weight and CG on balance
  - Reach envelopes with strength correlation
- Walking and other gaits
  - Use of treadmill to reduce effects of water drag (primarily leg motion)
  - Useful for evaluating pressure suit design for mobility, understanding effect of backpack size and mass on gaits and stability

Neutral Buoyancy Summary

- Advantages
  - No restrictions on number or relative position of items
  - No significant time limitations
  - Few size limitations to workspace
- Disadvantages
  - Hydrodynamic effects (especially damping)
  - Need to waterproof hardware (particularly sensors)
  - All items must have net specific gravity=1
  - Significant subject qualification requirements
  - Limited access to test environment (except us!)

MX-B Suit Simulator in Asteroid Tests



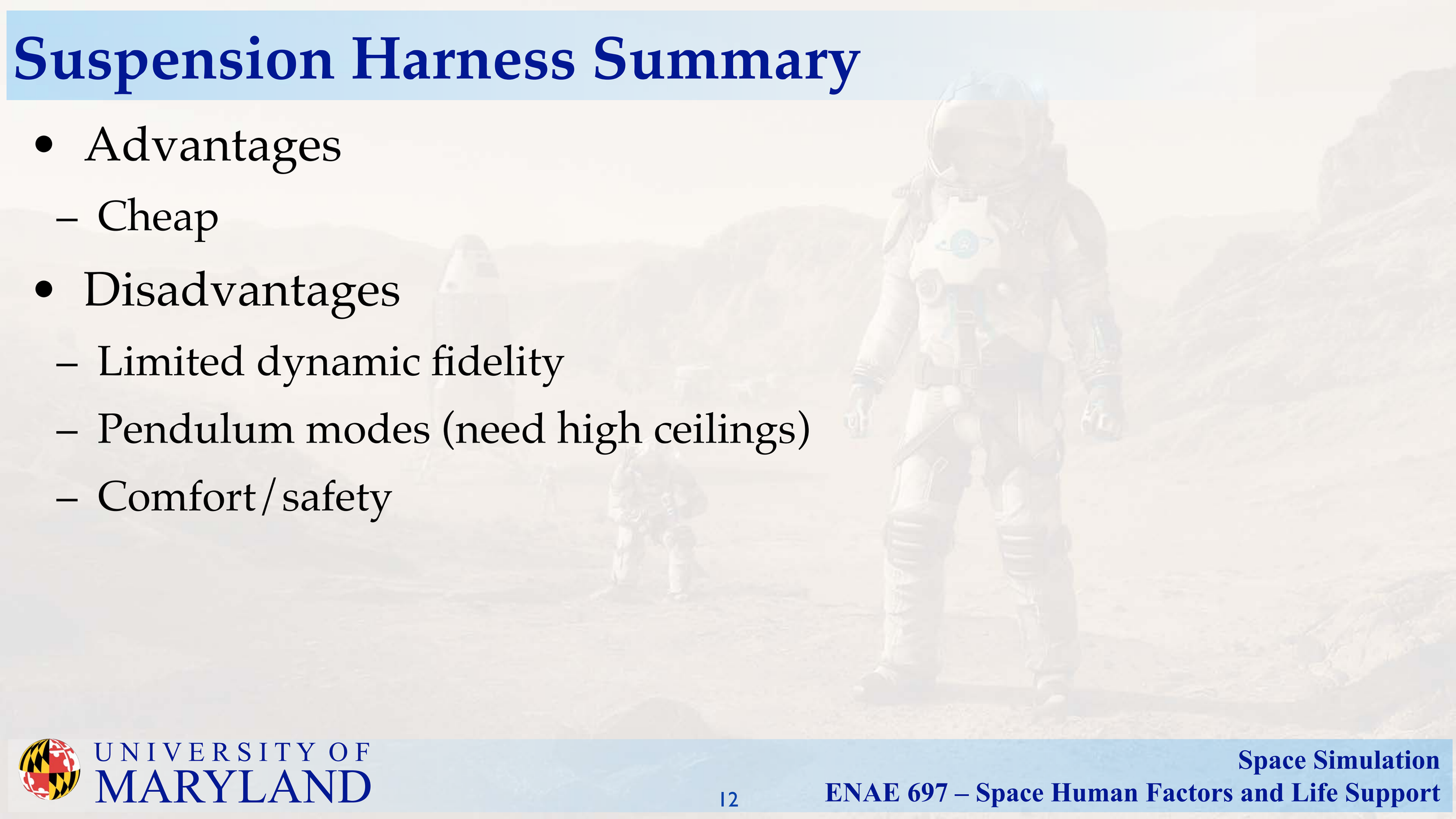
Air-Bearing Floor/Suspension Harness

Air-Bearing Floor Summary

- Advantages
  - Somewhat realistic 2D dynamics
- Disadvantages
  - Dedicated facility requirements
  - Acoustic issues
  - Boundary control
  - Limited configurations (no over/under transits)

Suspension Harness Summary

- Advantages
  - Cheap
- Disadvantages
  - Limited dynamic fidelity
  - Pendulum modes (need high ceilings)
  - Comfort/safety

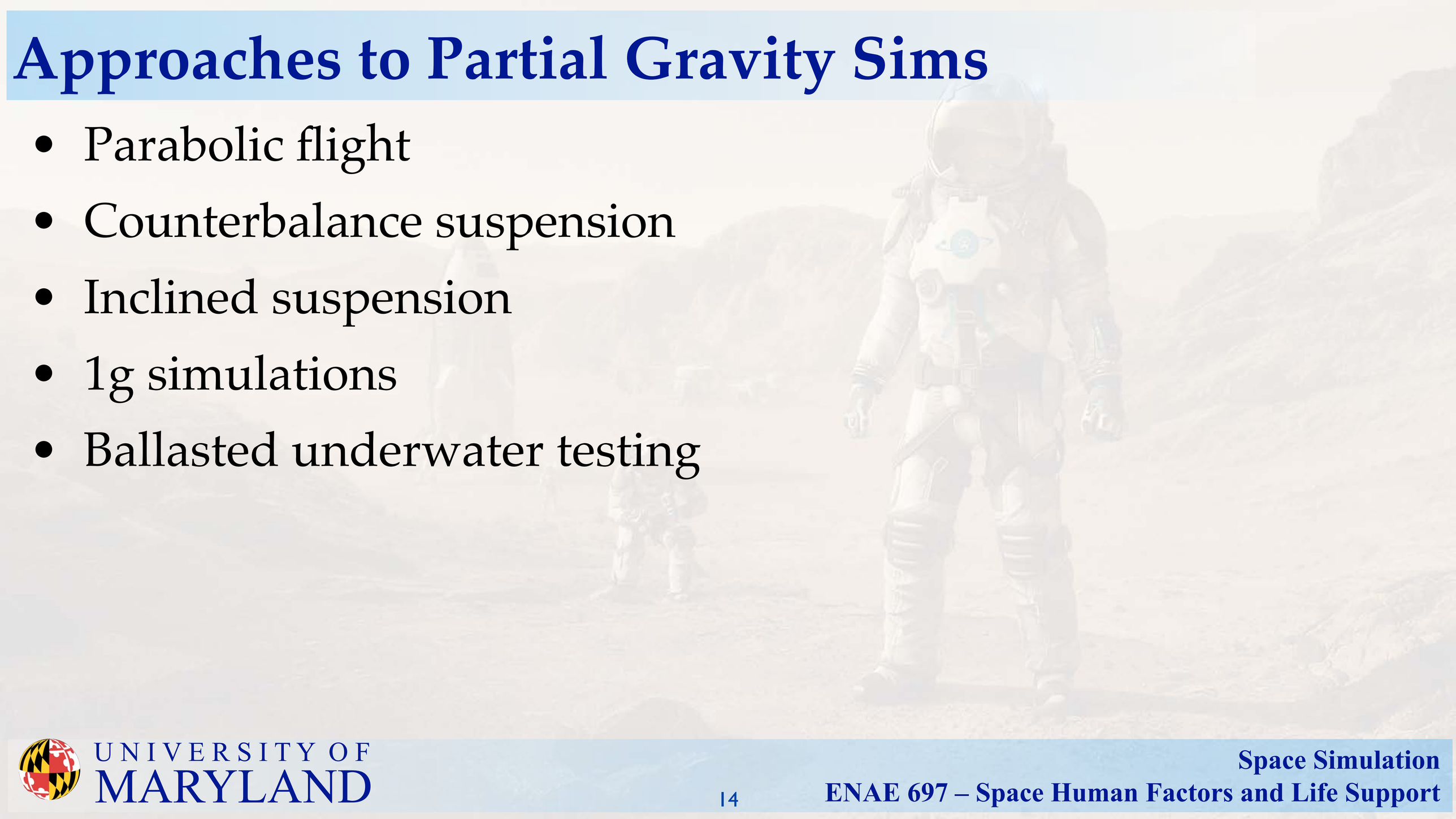


Simulation of Partial Gravity Ops

- Only major activity dates back to Apollo
- Science and operational issues to be examined
  - Biomechanics
  - Mobility
  - Sampling
  - Instrument placement
  - Equipment development
  - Pressure suit design
  - Field exploration

Approaches to Partial Gravity Sims

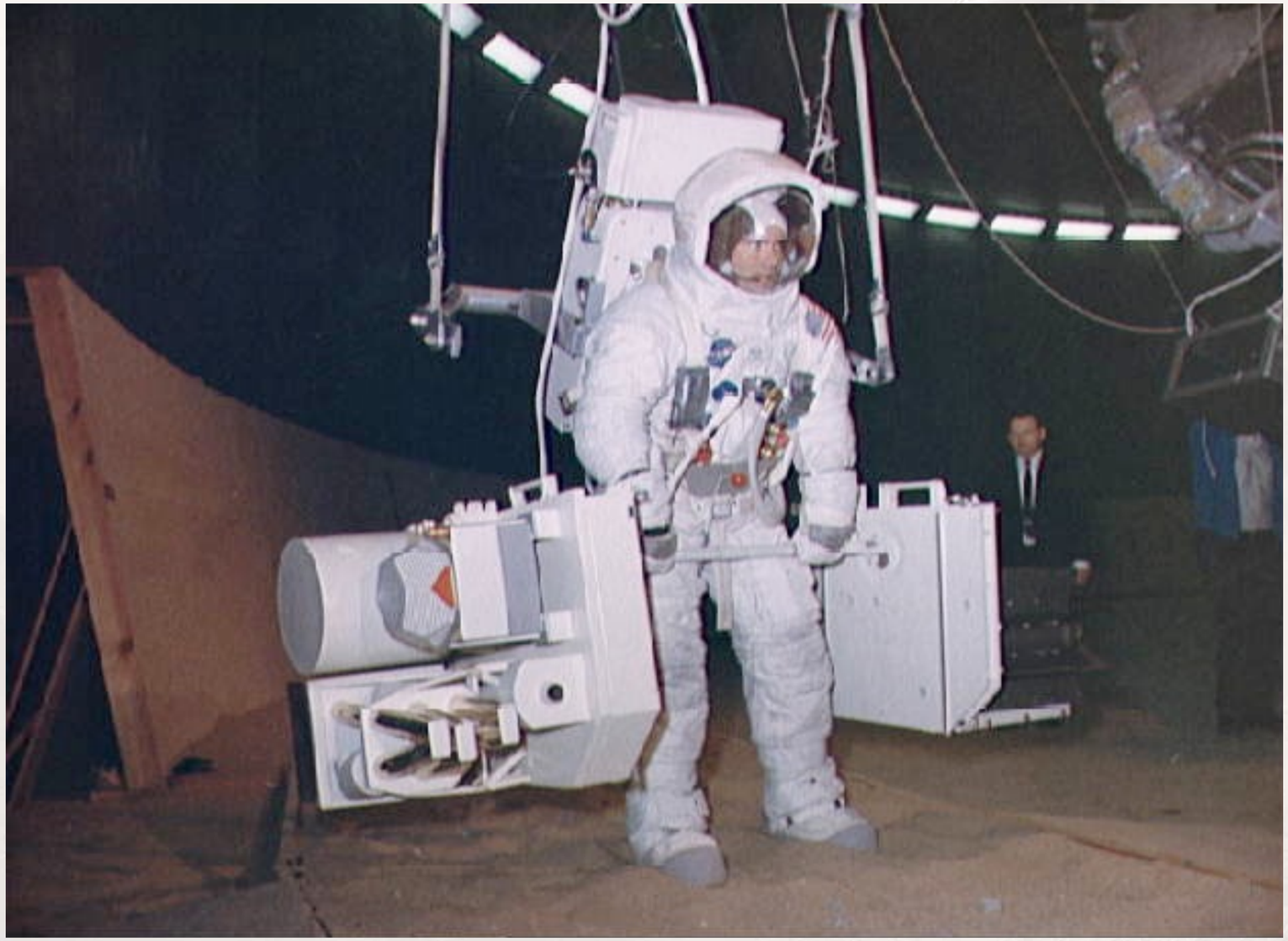
- Parabolic flight
- Counterbalance suspension
- Inclined suspension
- 1g simulations
- Ballasted underwater testing



Parabolic Flight

- True “partial gravity” during parabolic pushover
- Same disadvantages as in microgravity section
- Primarily used for interface testing

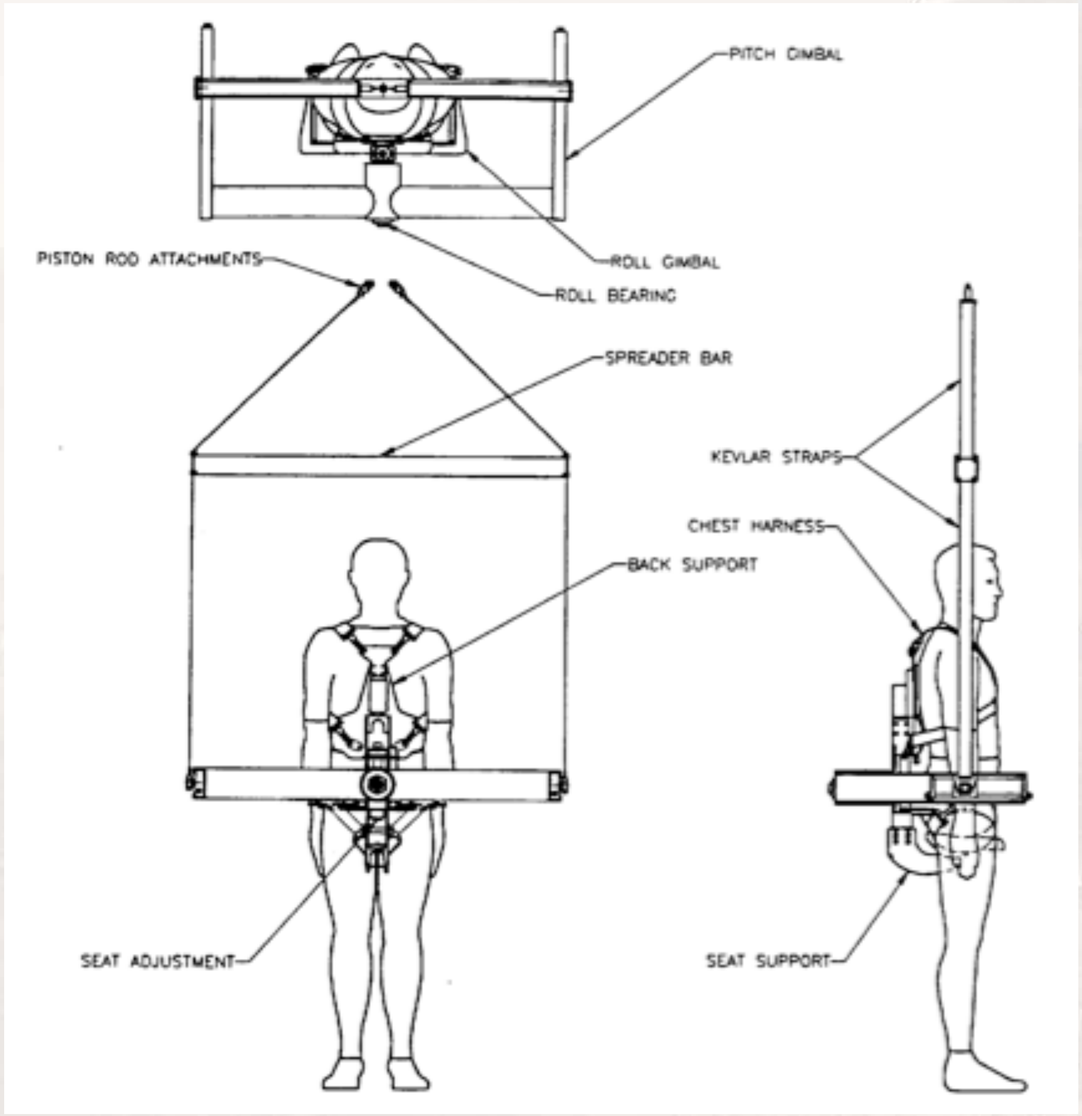
Counterweighted Suspension



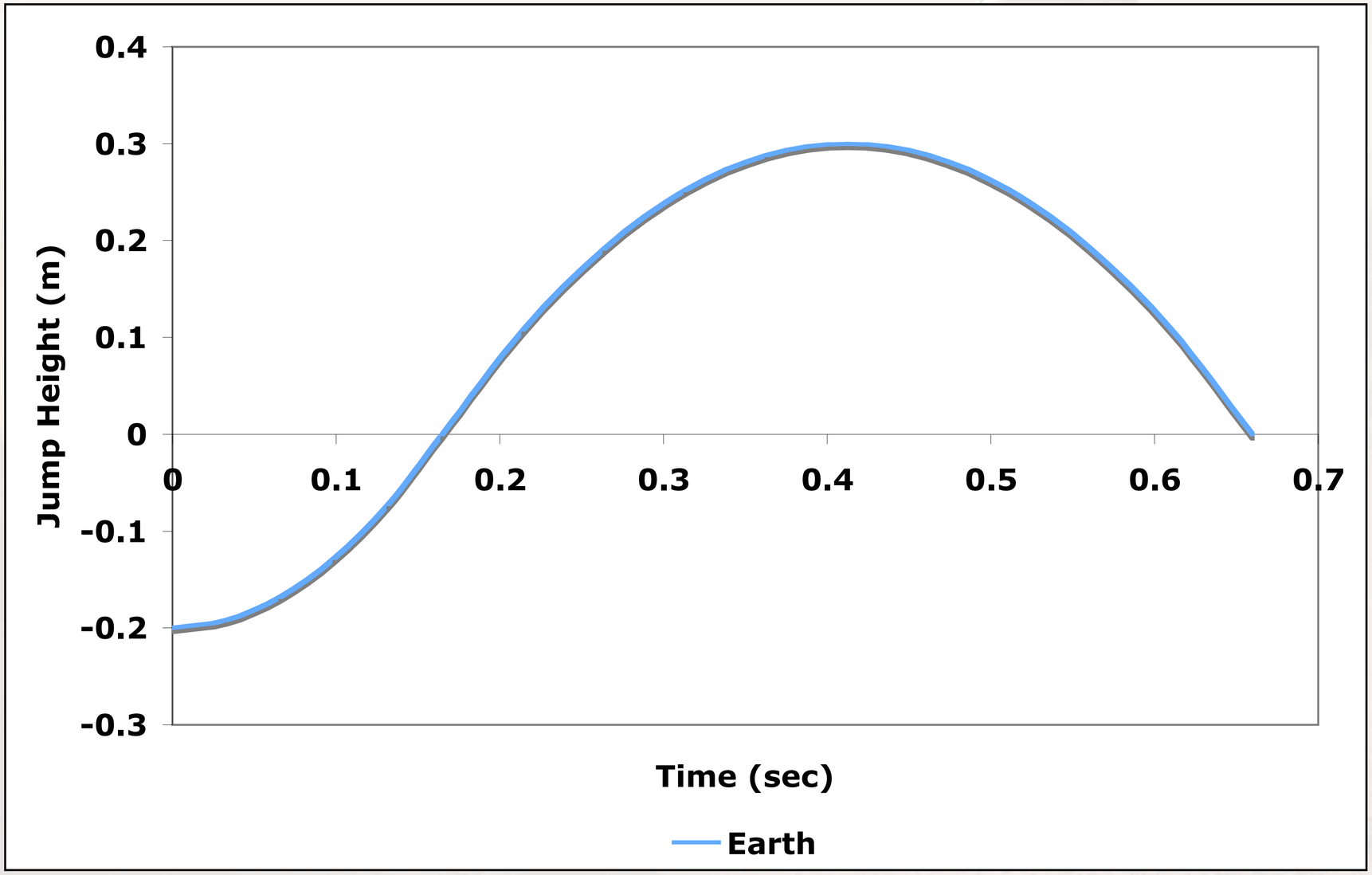
Counterweighted Suspension

- Numerous approaches to offsetting portion of Earth weight
  - Mass counterbalance
  - Linear springs
  - Nonlinear (e.g., constant-force) springs
  - Active force control
  - Buoyant offset (e.g., balloons)
- Generally limited to counterbalance of gross body weight
  - Gimbaled harness required for body rotational freedom
  - Difficult to counterbalance individual limbs
- Additional complexity required to maintain suspension point above test subject, provide counterbalance for test hardware
- Best suited to interior simulations with limited traverses

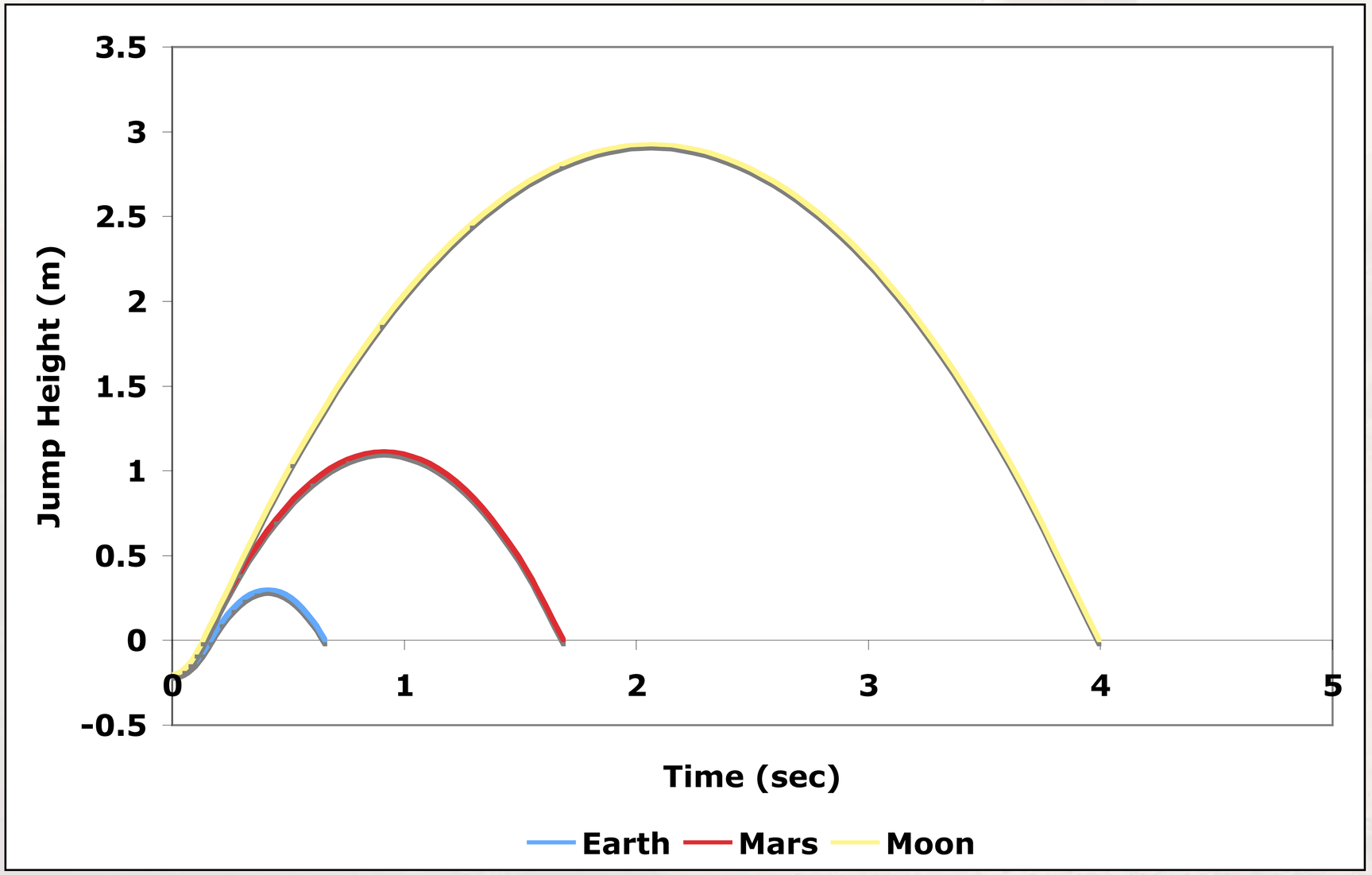
Active Suspension Body Gimbals



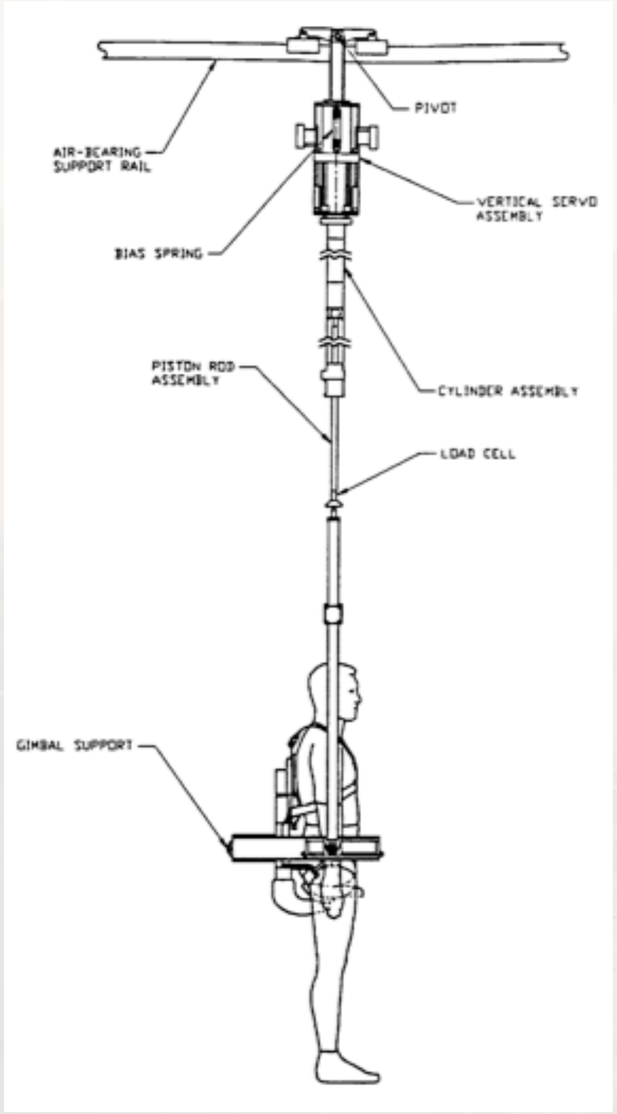
Vertical Jump Profile (Earth)

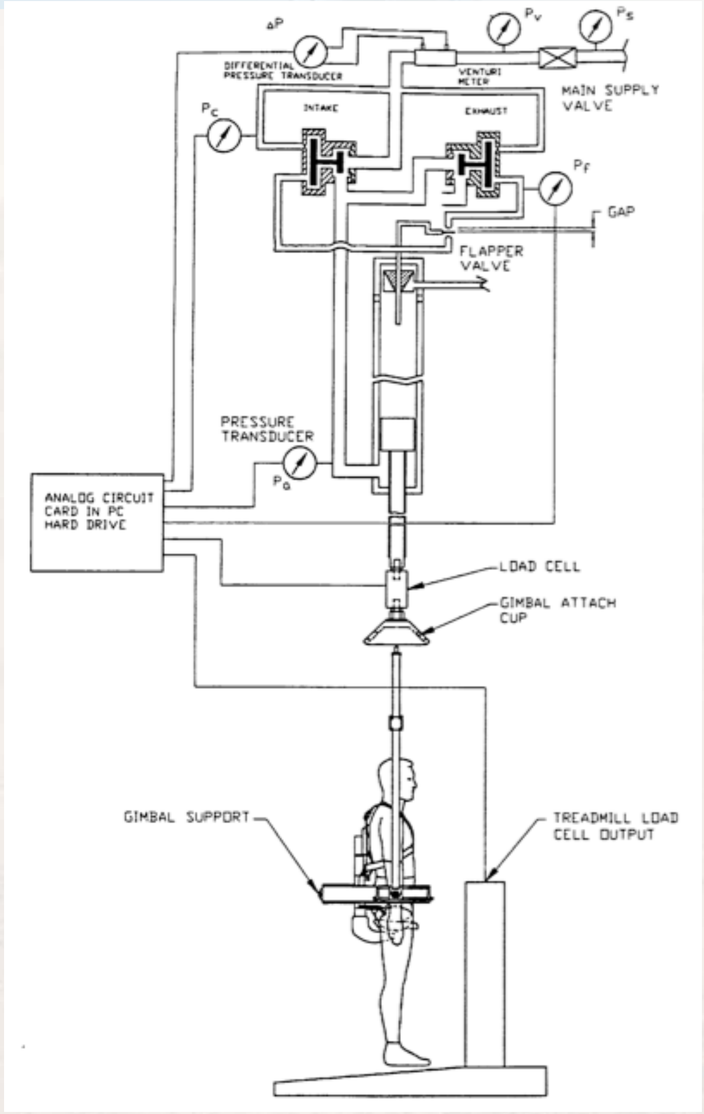


Comparative Vertical Jump Profiles



Active Suspension Approaches

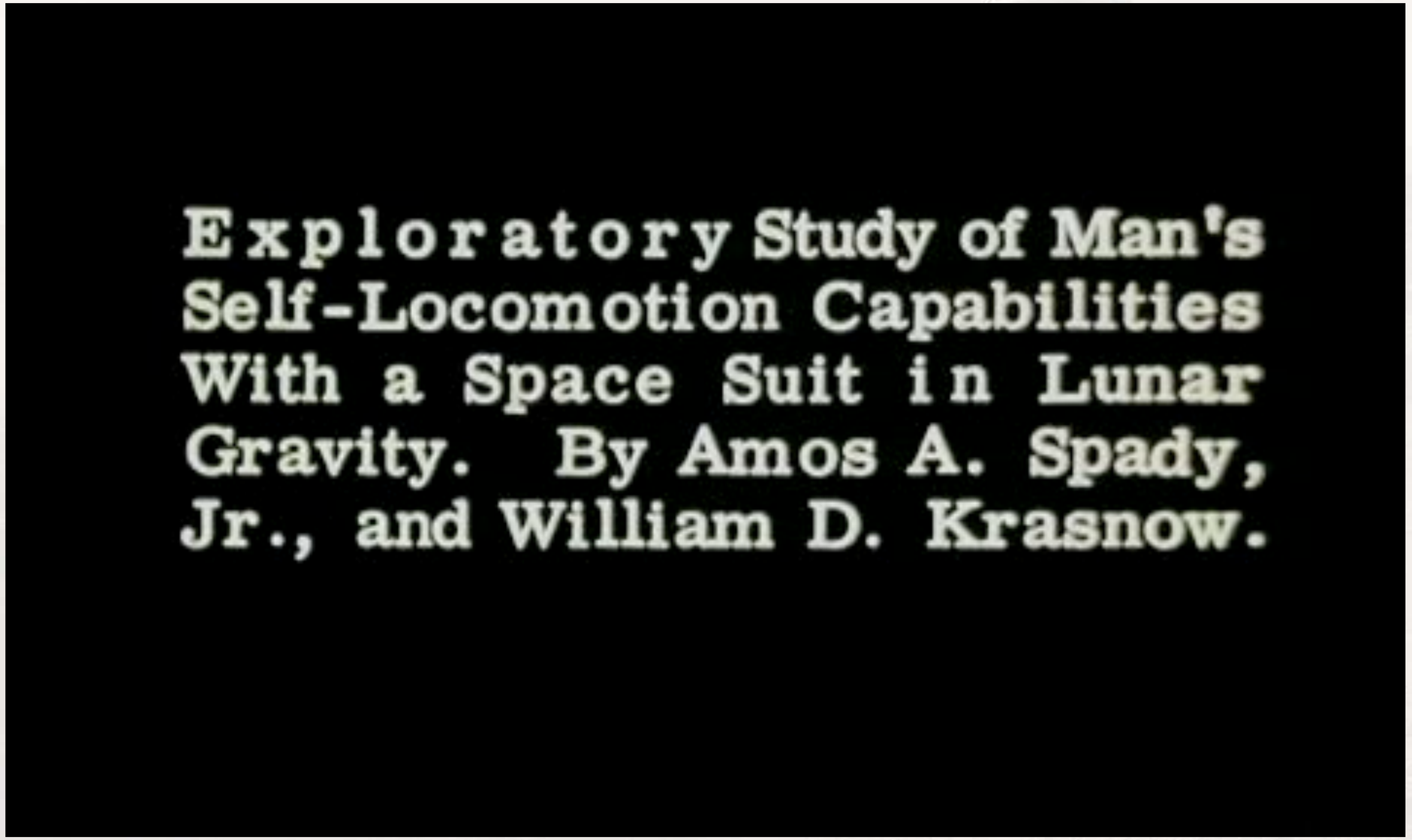




Inclined Suspension

- Provides appropriate normal force to inclined wall
  - Lunar simulation angle 80.8°
  - Mars simulation angle 67.7°
- Requires complex suspension system
  - Complex rigid harness required to suspend lower leg without interference to upper leg
  - Pendulum dynamics based on length of wires
  - Overhead suspension point must follow subject motion
- Best suited to mobility studies

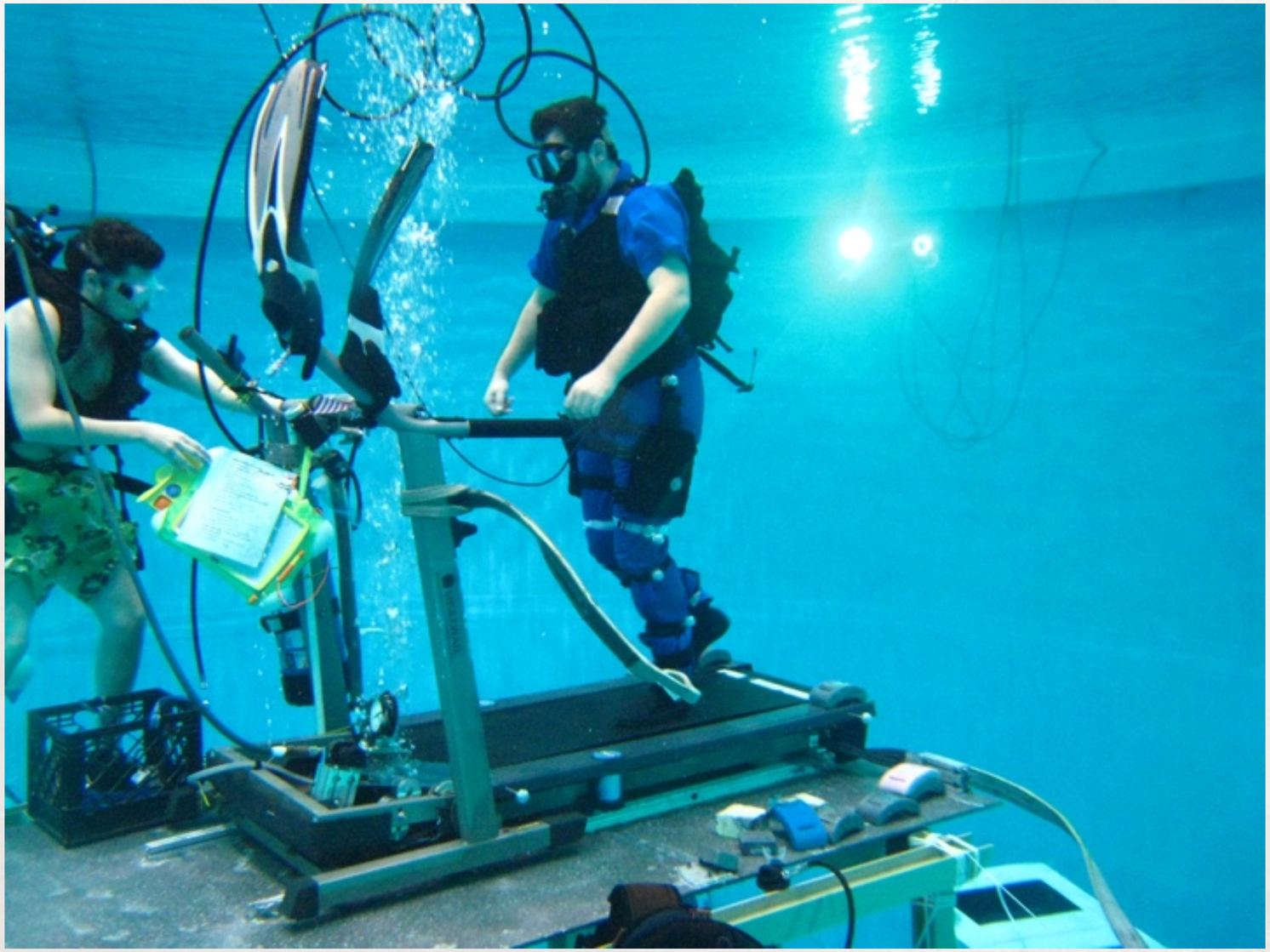
NASA LaRC Video of Inclined Sims



1 g Testing

- Approach: ignore entire issue of partial gravity; test in Earth-normal conditions
- Enabled by non-flight configuration for selected systems
  - External life support
  - Lightweight backpacks, instrument mockups
  - Use of additional personnel for relieving crew from some tasks
  - Omission of pressure suit for some field testing
- Primarily used for crew training

Partial Gravity Simulation Underwater



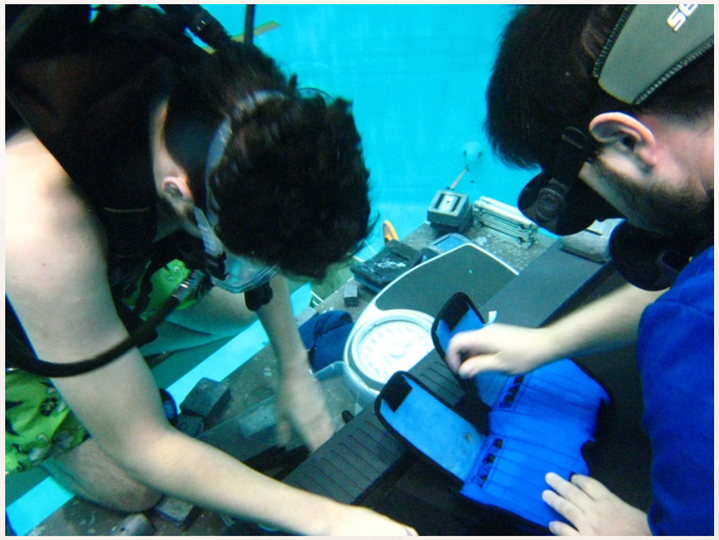
Ballasting for UW Planetary Simulation

IVA Simulation assuming 150 lb test subject

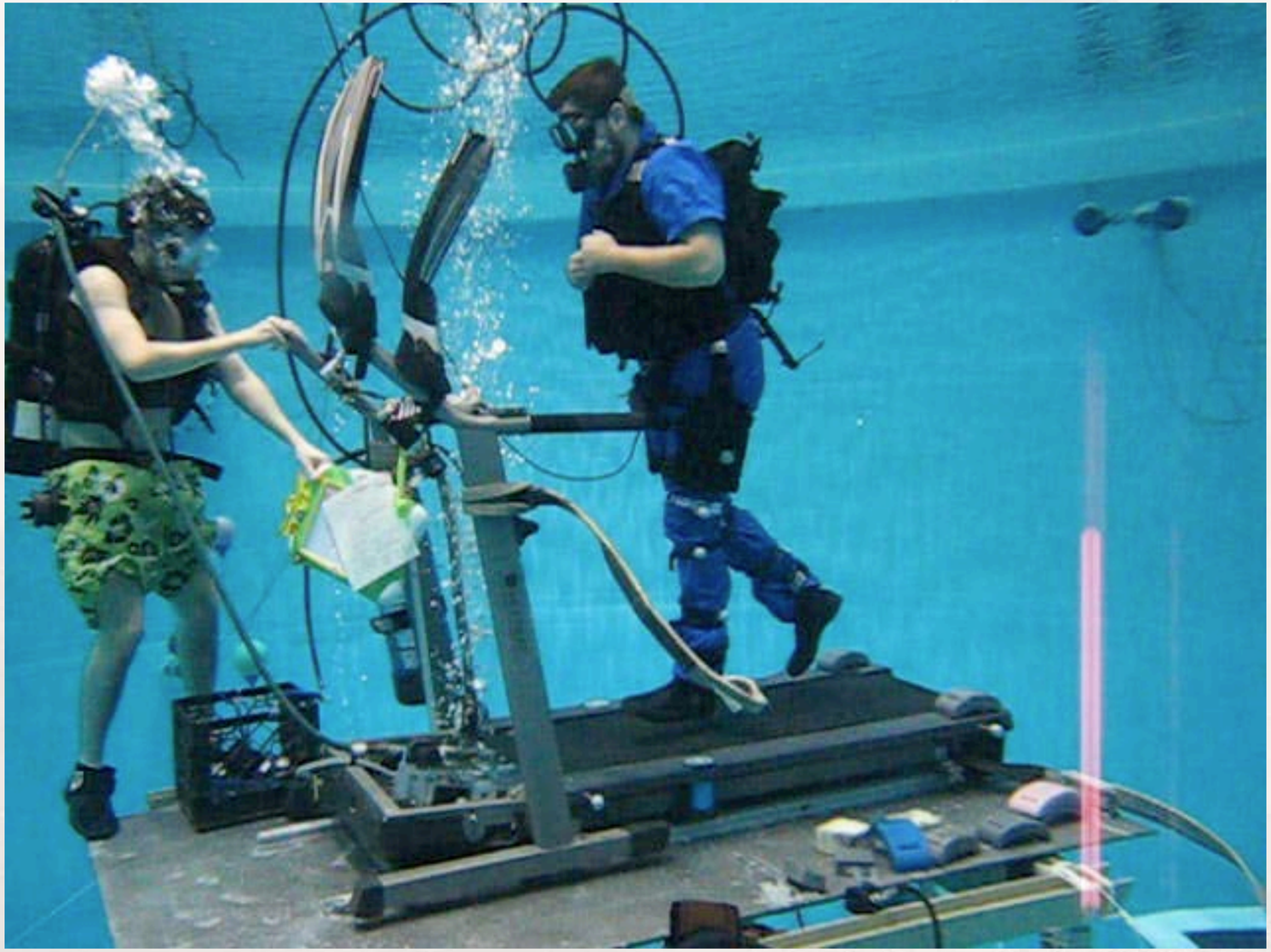
Body Segment	Lunar Ballast	Mars Ballast
Torso/Head	12.1	28.5
Upper Arm (each)	0.7	1.5
Lower Arm (each)	0.5	1.3
Thigh (each)	3.4	8.1
Lower Leg (each)	1.4	3.2
Totals	24	57

All ballast weights in pounds

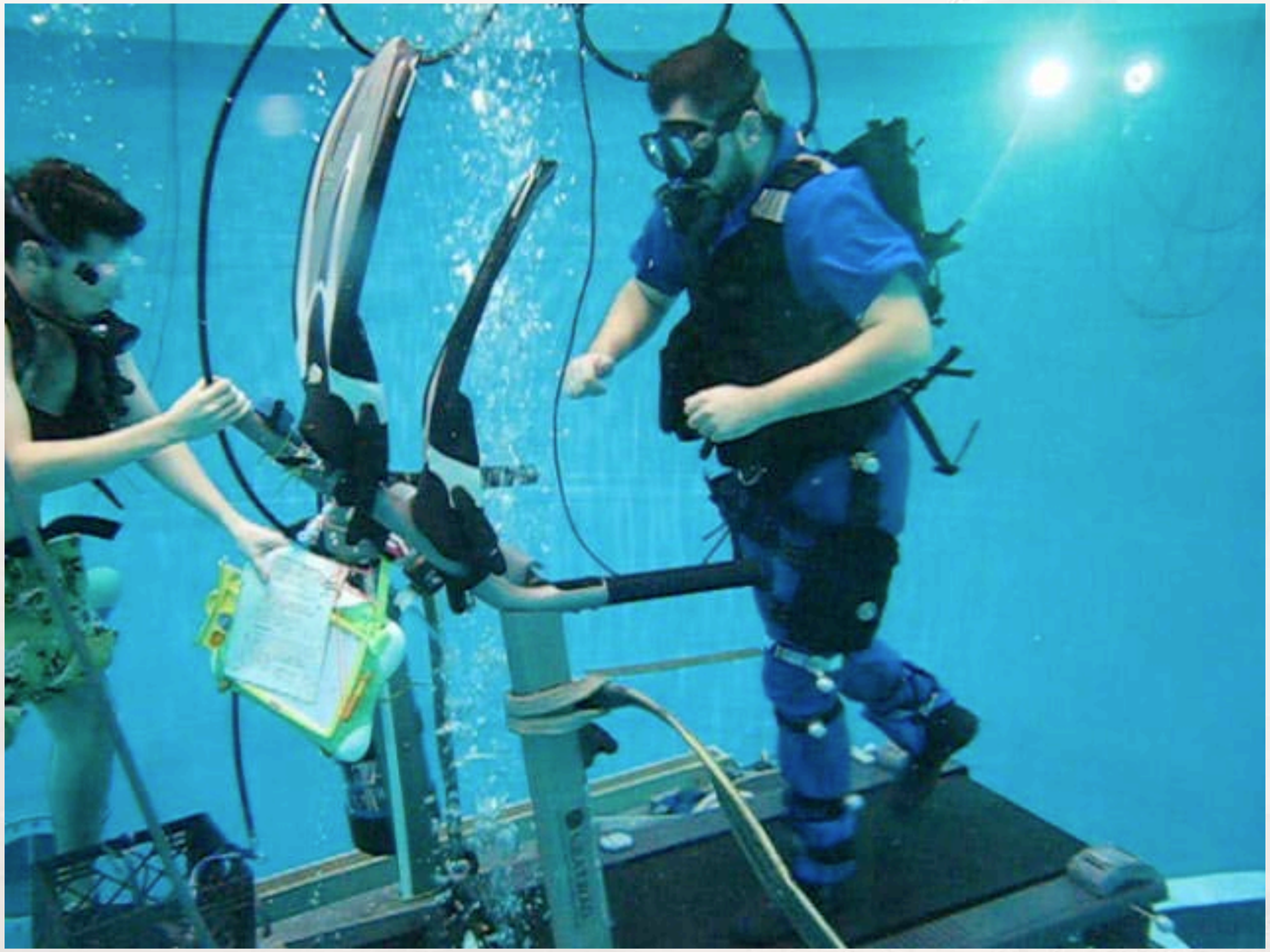
Ballasting the Test Subject



Lunar Gravity - Slow Speed

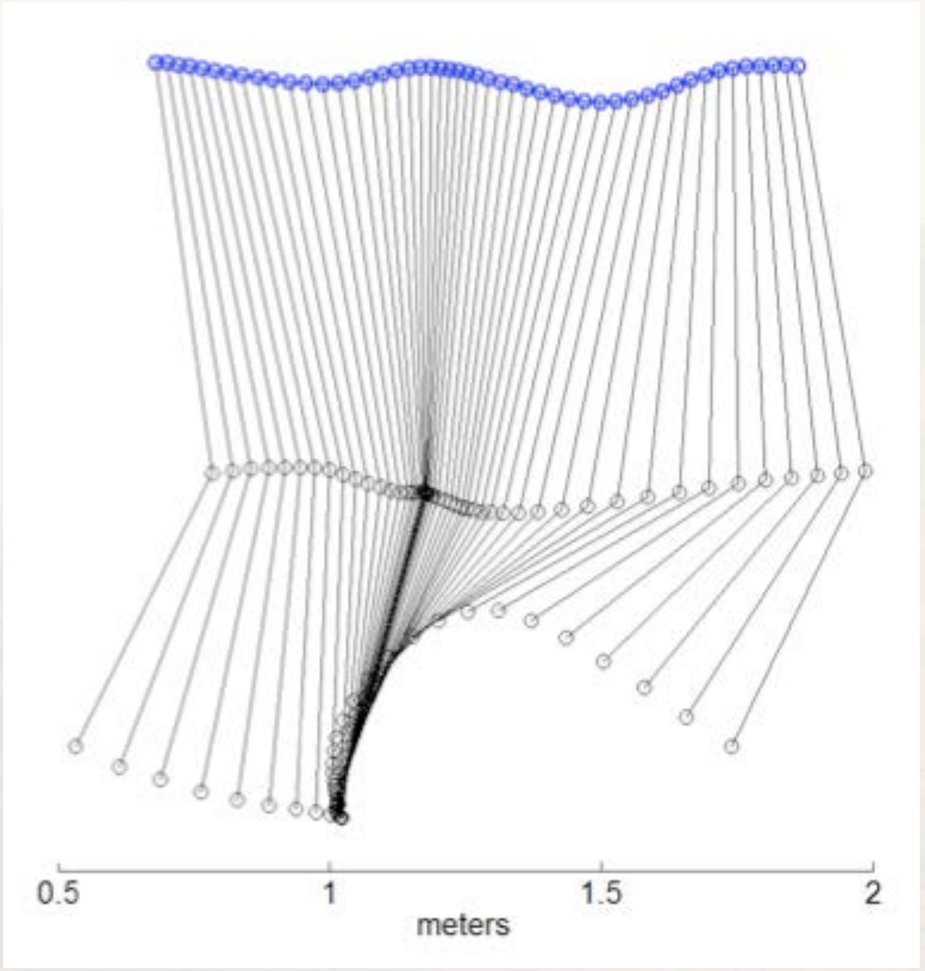


Lunar Gravity - High Speed

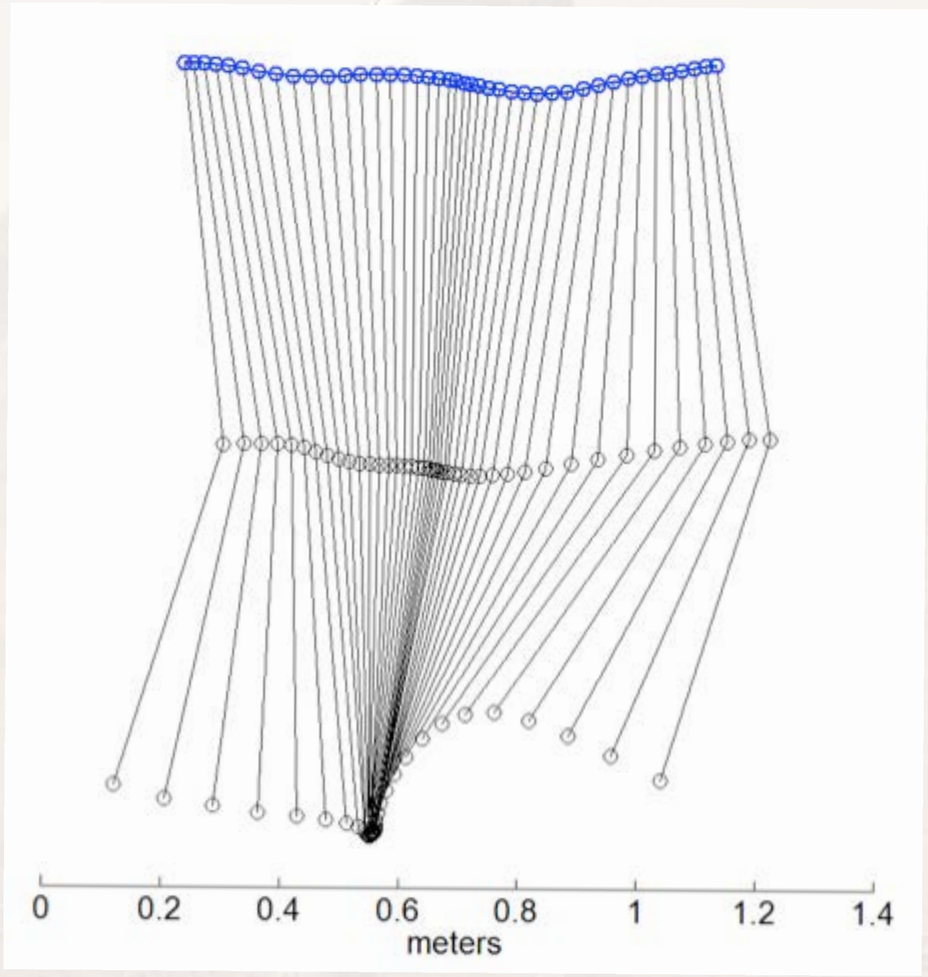


Earth Gravity - High Speed

Comparison of 1-G Leg Motions

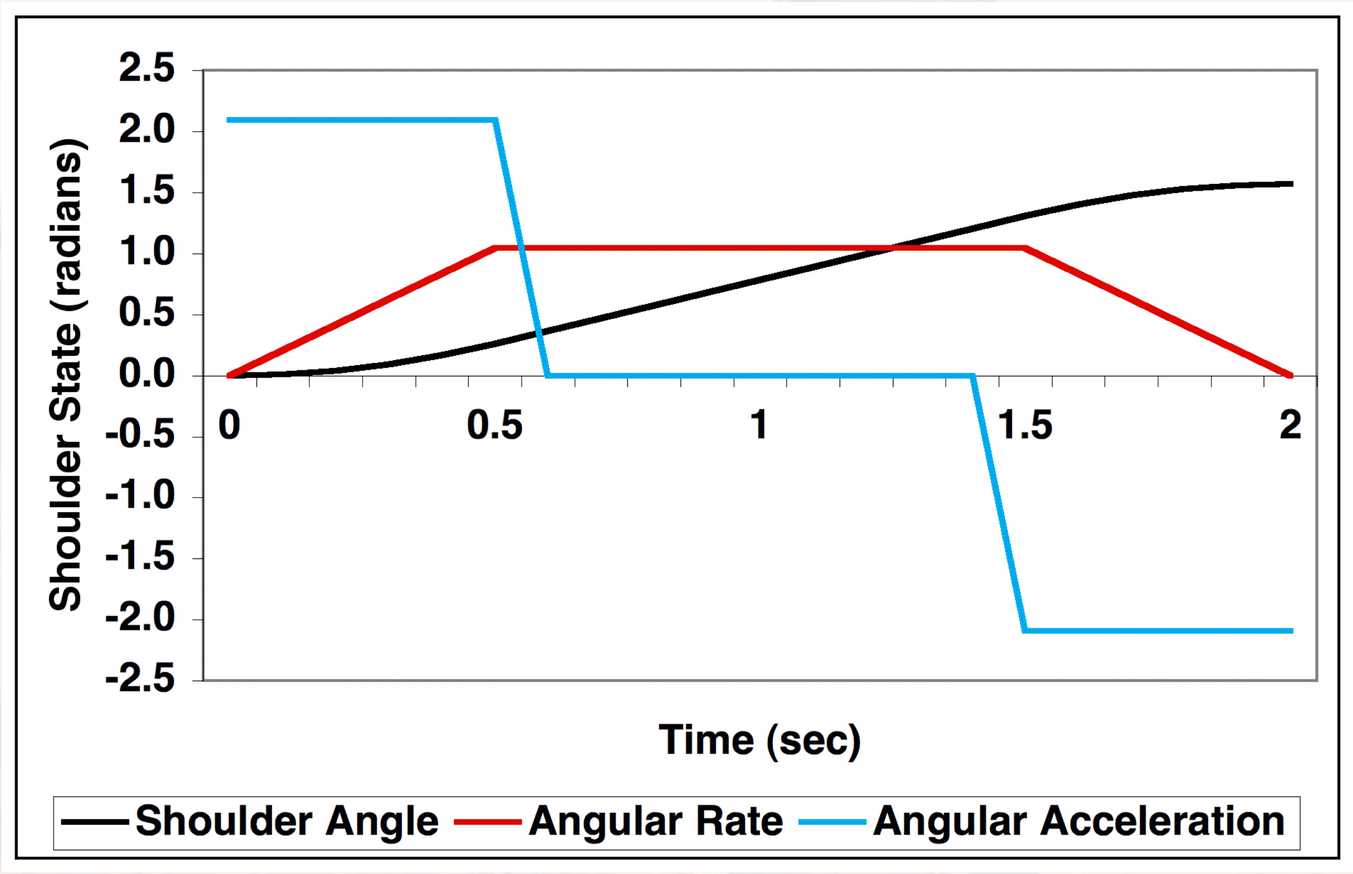


Underwater

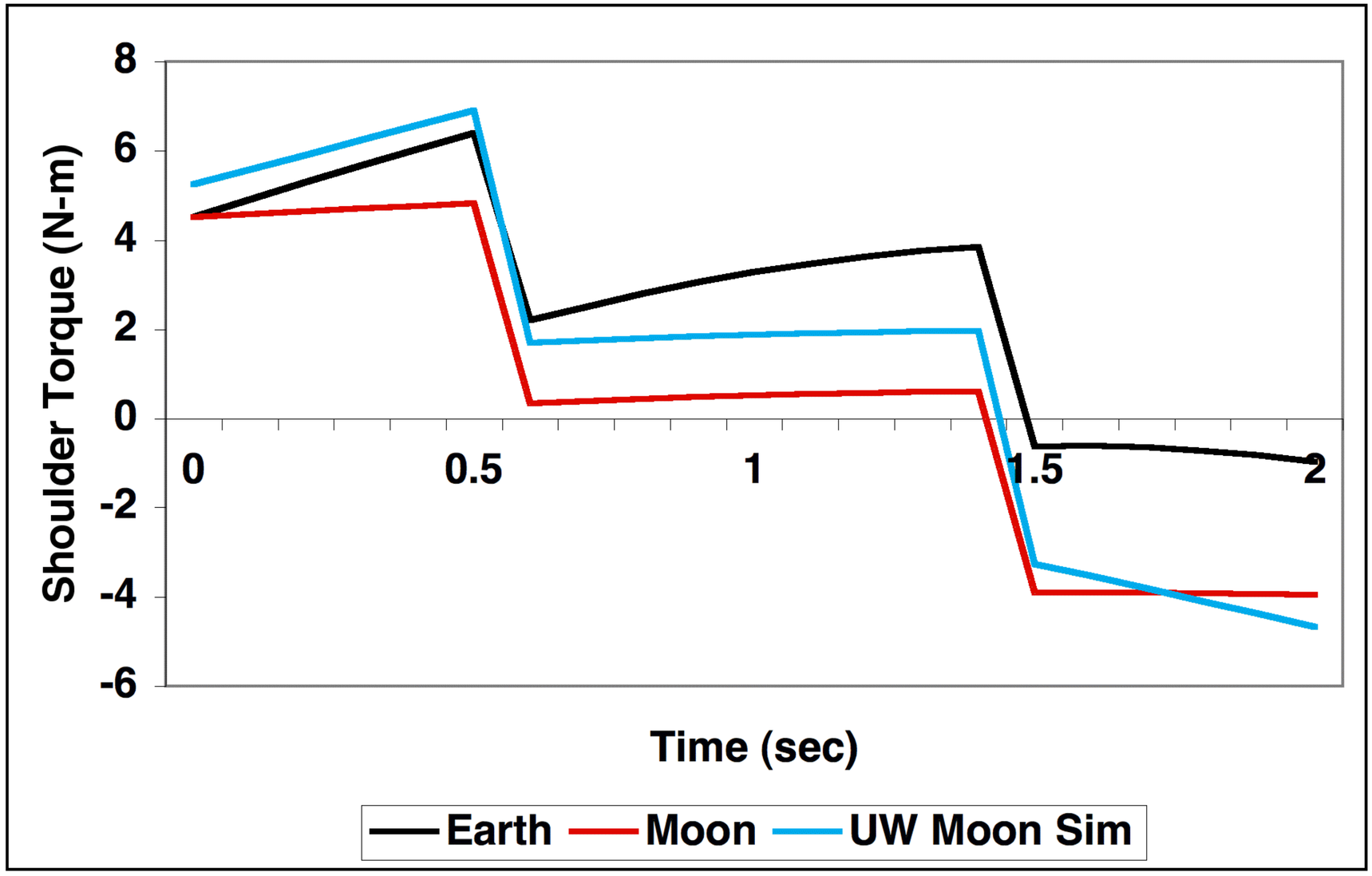


Laboratory

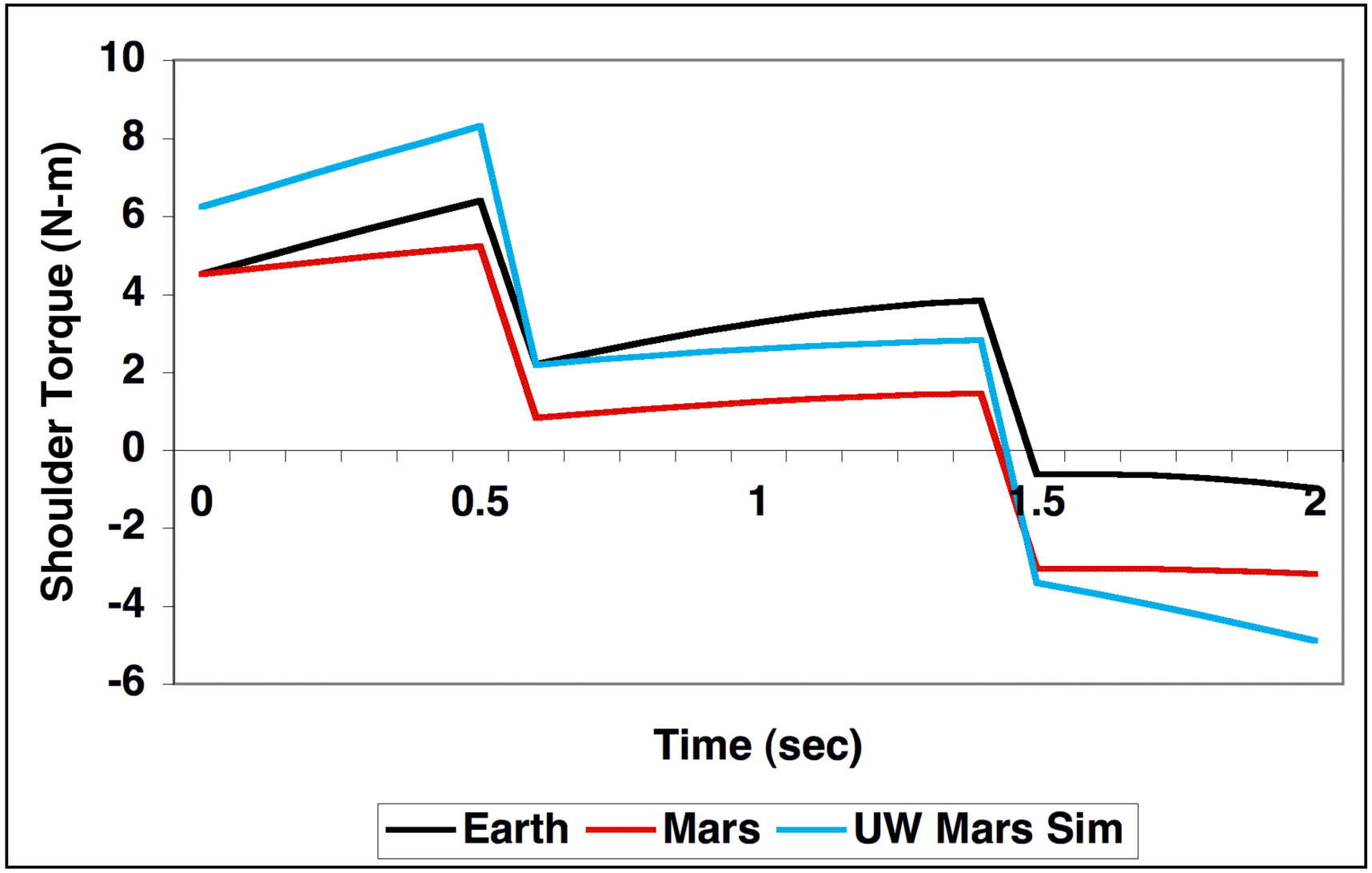
Sample Motion Analysis



Effects of Lunar & Sim Environments



Effects of Mars & Sim Environments



Ballasted UW Simulation - Advantages

- Simple arm torque analysis shows 52% reduction in RMS torque error compared to 1 g Lunar case; Mars error reduced by 9%
- Produces accurate levels of preload on legs
  - Sensorimotor control loops closer to actual partial gravity
  - Accurate simulation of postural responses
- Ability to work with test hardware of realistic mass and complexity
- Freedom from wires or other simulation-specific interferences
- Realistic static and quasistatic test applications
  - Balance and postural studies
  - Reach and force envelopes
  - Surface sampling

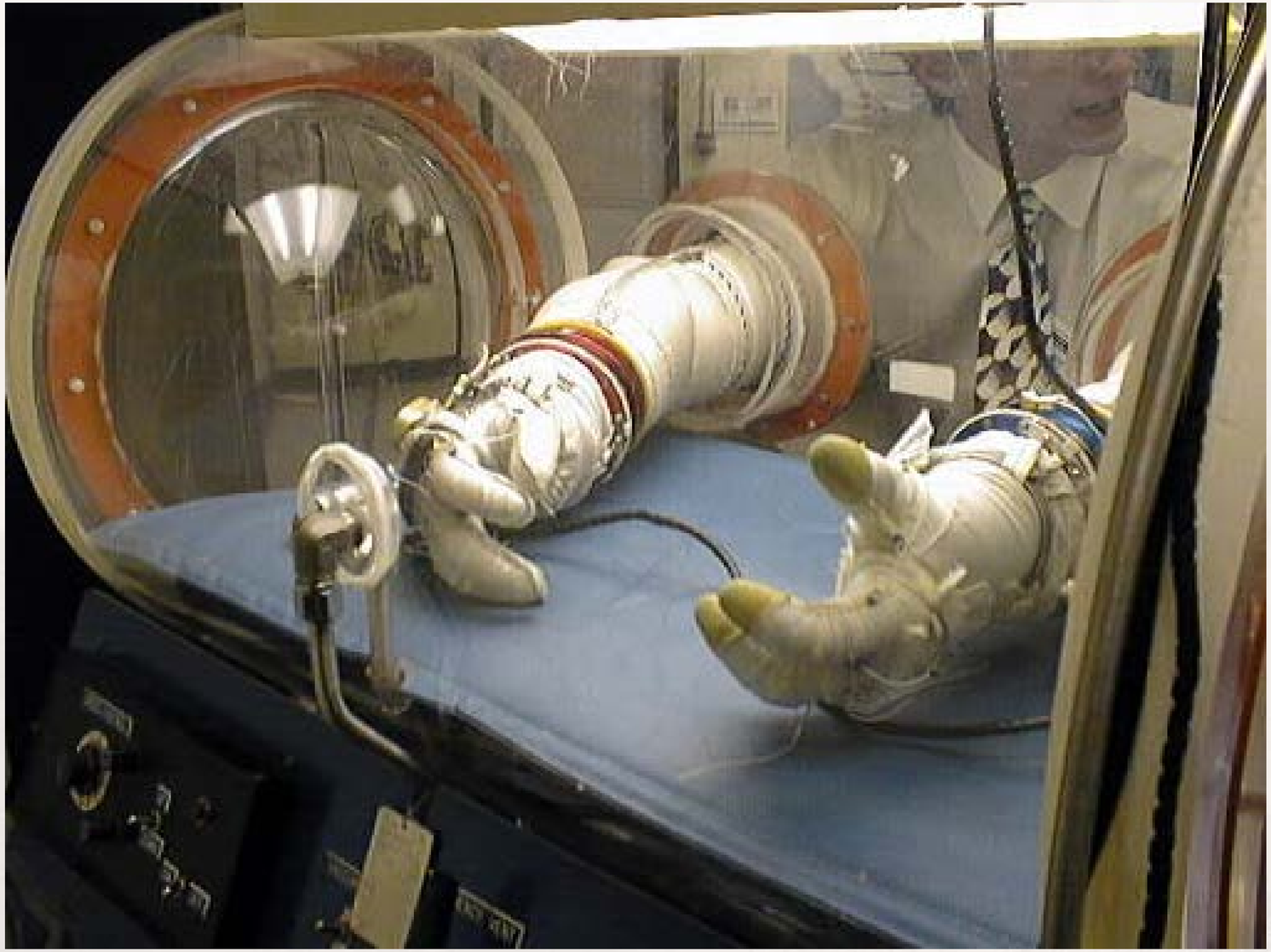
Ballasted UW Simulation - Disadvantages

- Dynamics effects of underwater environment
  - Water drag
  - Virtual mass
- Requires added inertial mass to achieve desired counterweight
- Safety implications of underwater testing
  - Life support of test subject
  - Emergency extraction
- Access to pressure suits for EVA simulations

Specialty Simulations

- Glove box testing
- Thermal vacuum testing
- Pressurized and unpressurized vehicles
- Habitat evaluation and habitability simulations

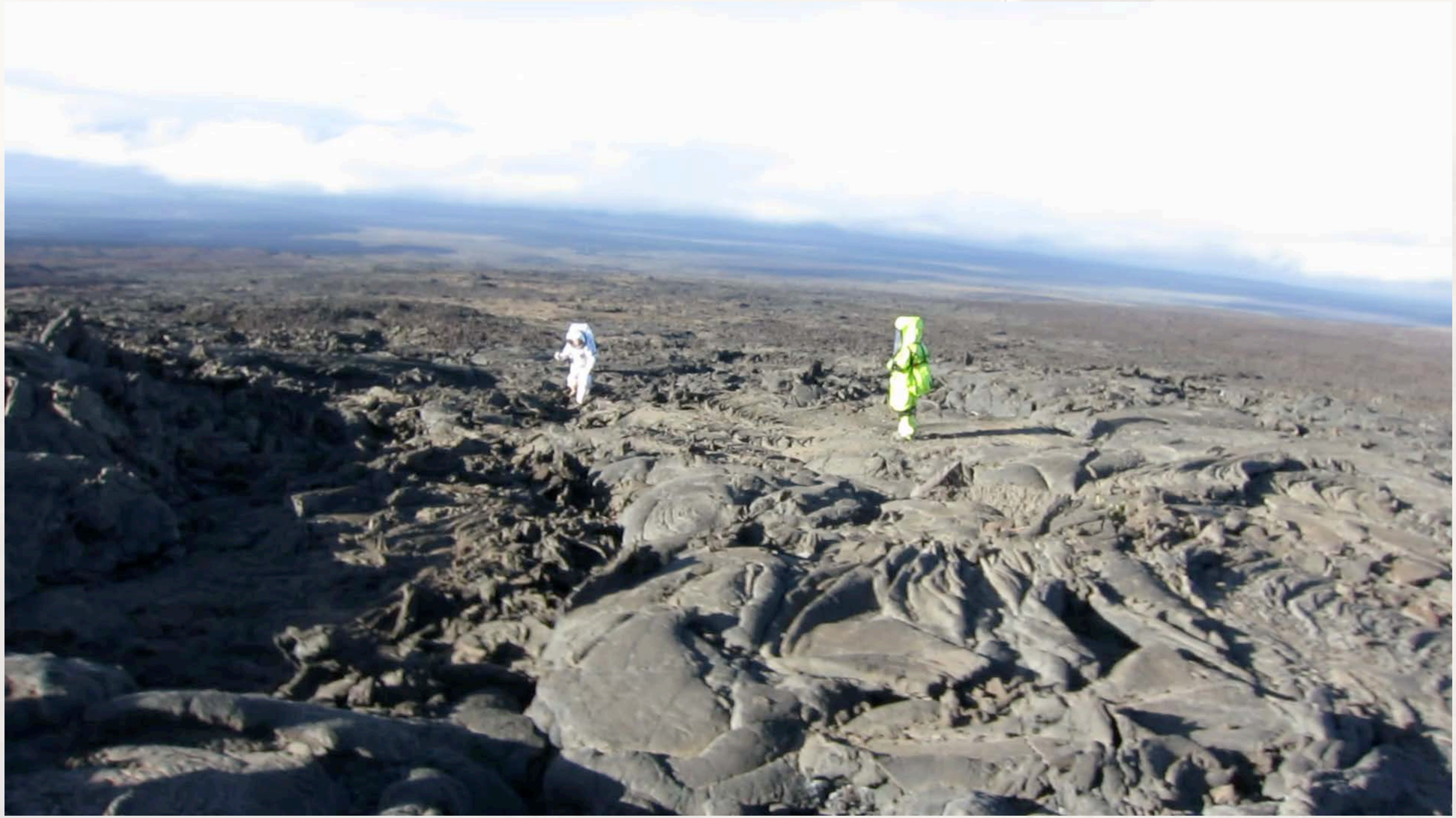
Glove Box Testing



TURTLE Pressurized Rover Sim 2008

ECLIPSE Lunar Habitat Sim 2010

HI-SEAS EVA Simulation



Skylab Medical Experiments Altitude Test

Extended-Duration Altitude Testing

IVA Simulation - Mars 500

Guidelines for Simulation Activities

- Simulation is not an alternative to analysis!
- Use standard design analysis wherever feasible
- Simulation is appropriate for issues which are not amenable to analysis
  - Human in the loop control functions
  - Subjective assessments (e.g., habitability)
- Supports ancillary goals (e.g., outreach, publicity, competition status)
- Expensive in terms of both money and personnel time