National Aeronautics and Space Administration

Considerations for range of motion testing during spacesuit mobility characterization

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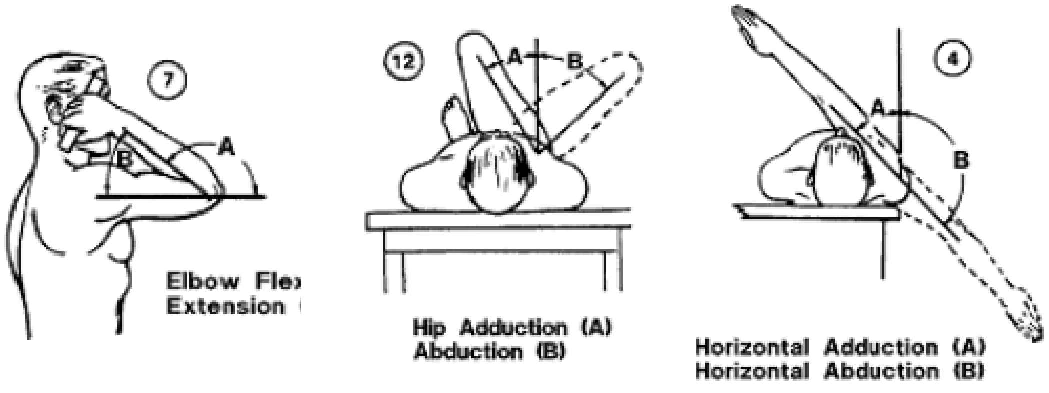
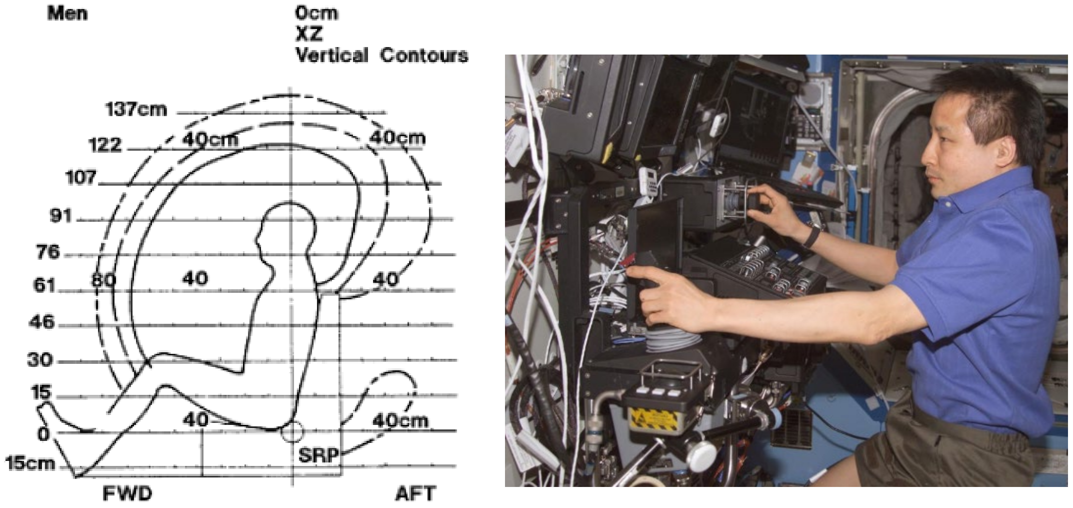
Introduction – Range of Motion Assessments

- Range of motion (ROM) evaluations are often performed to characterize the voluntary mobility of a subject
- ROM measurements are often taken with respect to human joints of the body
- There are a variety of applications for ROM measurements:
    - Inform the design of workspaces to maximize comfort and efficiency
    - Screen for abnormalities and limitations before and after medical treatment



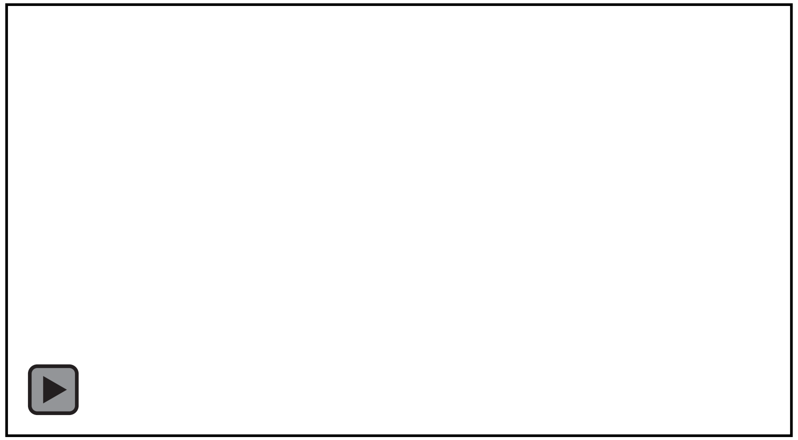
Examples of joint range of motion

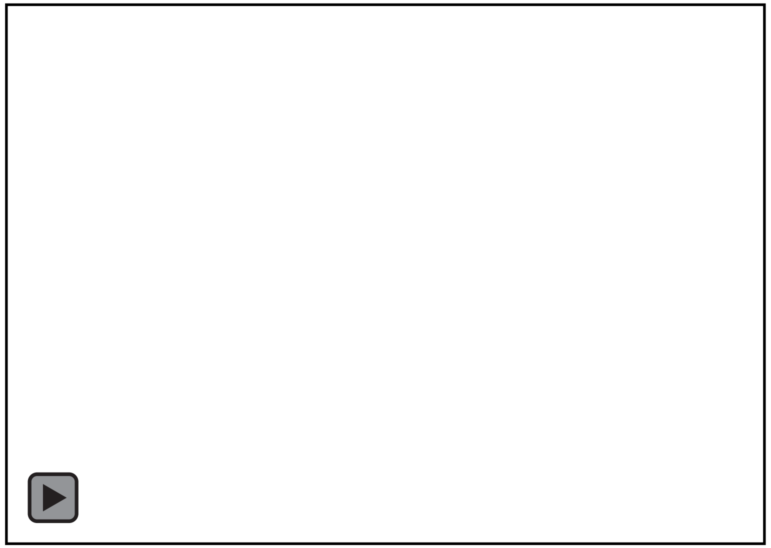


Hand grasp reach limits for workstation design

ROM for spacesuit applications

- On EVA, astronauts will be expected to move and perform various tasks while in a pressurized spacesuit
- Due to the mass and mechanical joint configurations of the spacesuit, suited movement may be unique or dissimilar to unencumbered human movement
- There have been several studies that have characterized the EMU spacesuit ROM for microgravity ExtraVehicular Activities (EVA)
- With the upcoming NASA Artemis program, planetary spacesuit mobility characteristics will also be important to inform the design of:
    - Spacesuits
    - Vehicles
    - Lunar EVA tasks
    - Payload dimensions
    - Science and geology hardware

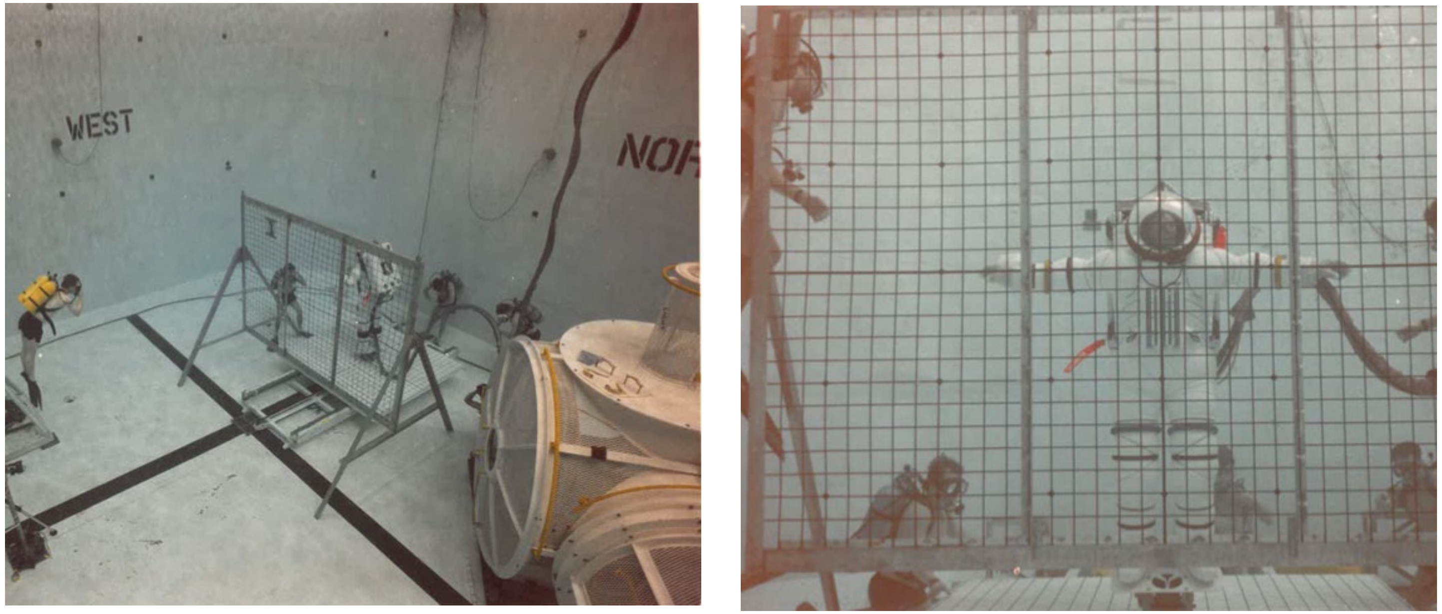




Examples of microgravity EVAs tasks (top) and Apollo lunar EVA tasks (bottom). Video credit: NASA

Suited ROM measurement collection

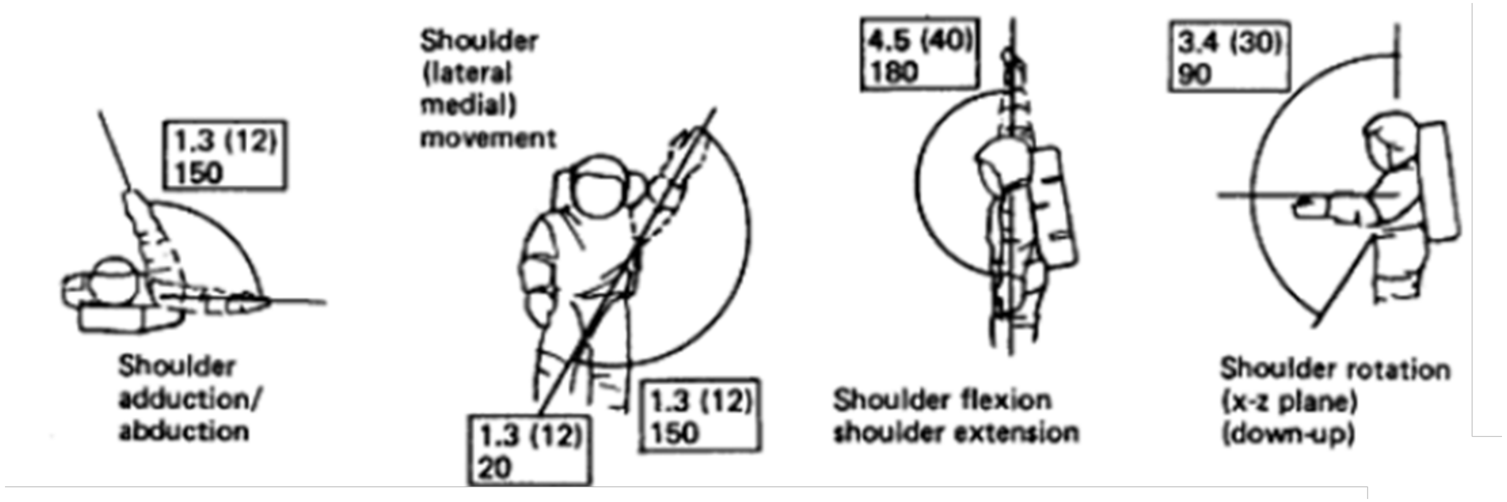
- Historically, suited ROM data has been collected using videography, goniometry, and motion capture technologies
- Suited test subjects are asked to perform tasks that maximize their reach in various directions
- The motion path of suited joints are tracked and suited mobility is interpolated from the data
- For individual tasks, the data can be combined to create a graph showing the achieved ROM for fixed postures



Photogrammetry using gridboard

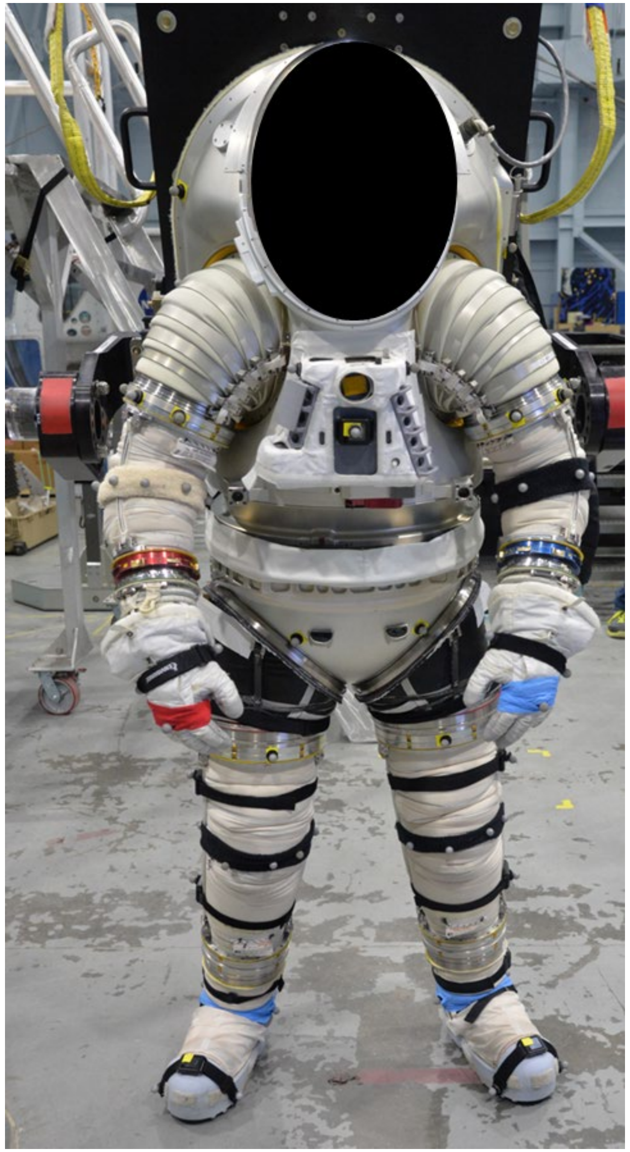
Purpose

- Traditionally, suited range of motion has been defined from movements in the cardinal planes of the body (sagittal, frontal, and transverse) to characterize suited mobility
- However, suited range of motion interpretation has a myriad of factors that need to be considered for human factors applications
- The purpose of this presentation is to describe these considerations in collecting ROM measurements and characterizing spacesuit mobility capabilities
- Motion capture data from the xEMU spacesuit testing will be used to illustrate different examples cases



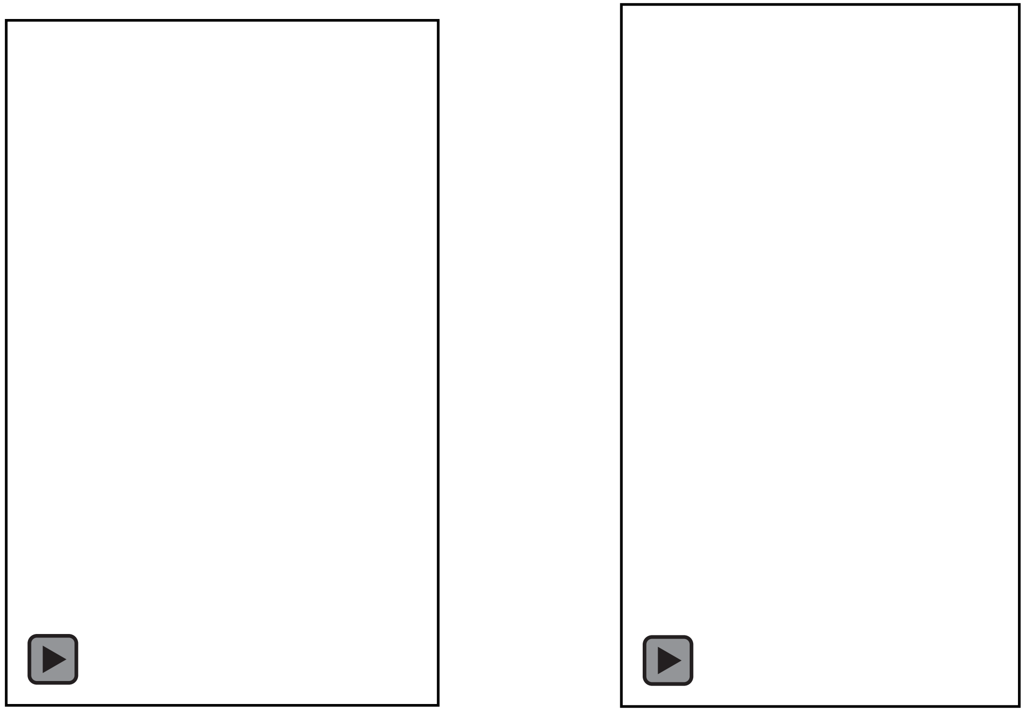
Methods – Motion capture data collection

- In the xEMU Design Verification Testing (DVT), retro-reflective markers were placed on the suited subject to quantify full-body kinematics
- Vicon optical motion capture data was collected at 100 Hz for the following tasks:
  - Planar shoulder range of motion movements
  - Planar hip range of motion movements
  - In-place and side-step squats
  - Step-up onto surface
  - Treadmill walk (0°, 20 °, -10° incline) at preferred speed
  - 1-knee kneeling object pickup
  - Camera photograph task
  - Open toolbelt
  - Overhead object reach
  - Hatch lever turning
  - Trenching
  - Scooping with hand scoop
  - Helmet visor reach

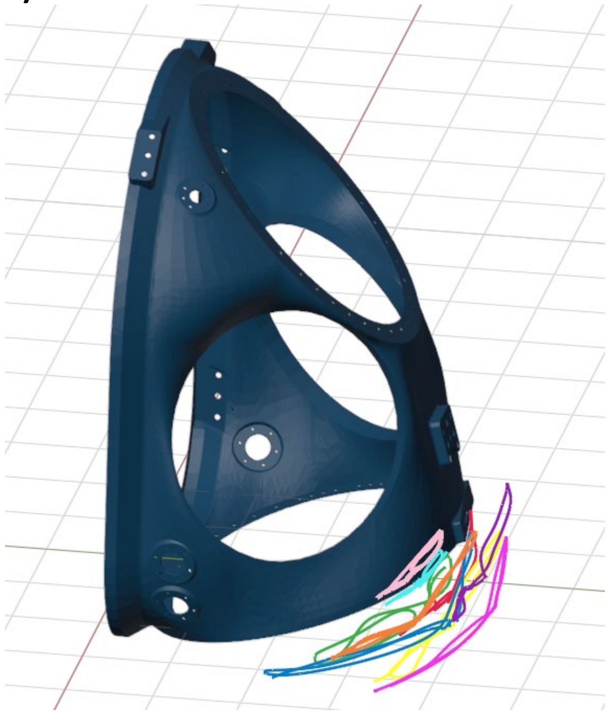


Methods – Joint trajectory processing

- 3D models of suit hardware were aligned to the motion capture data via landmark correspondence
- The elbow and knee joint trajectories were aligned with respect to the suited HUT (Hard Upper Torso) or hip (Brief) orientation
    - A 2^{nd} order low-pass Butterworth filter was applied to the joint trajectory data



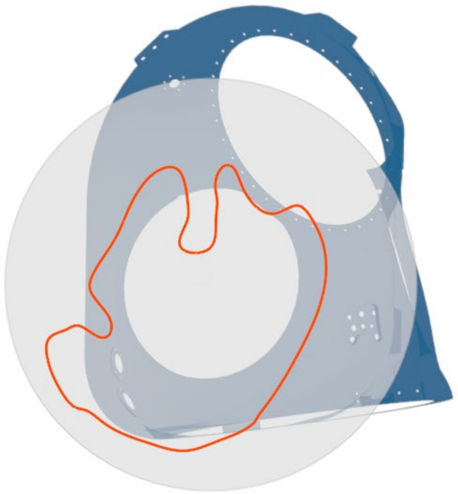
3D Suit component model alignment

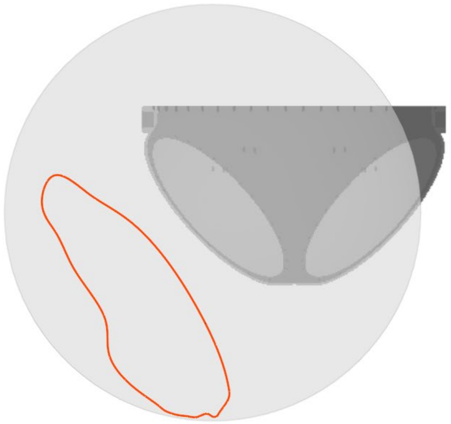


HUT-aligned elbow joint trajectories across subjects

Methods – joint trajectory analyses by task

- To illustrate how joint mobility can differ across tasks, upper body (elbow) and lower body (knee) joint trajectories were evaluated across 9 suited subjects (N = 9)
    - Only right-hand side joint trajectories were evaluated for symmetric motions and full body data were evaluated for complex motions
- For each task, the relative joint position was projected onto a semi-sphere that was centered in the HUT or brief opening (e.g., elbow joint position for upper body motion, knee joint for lower body motion)
- The joint position data was converted to normalized spherical coordinates
- A gaussian kernel density estimation was used to estimate the probability density of the joint center of distribution
- The 90th percentile contour line was visualized to represent the joint ROM
    - Caveat: this data may not necessarily reflect the required mobility to accomplish the task, but the overall movement variation across test subjects

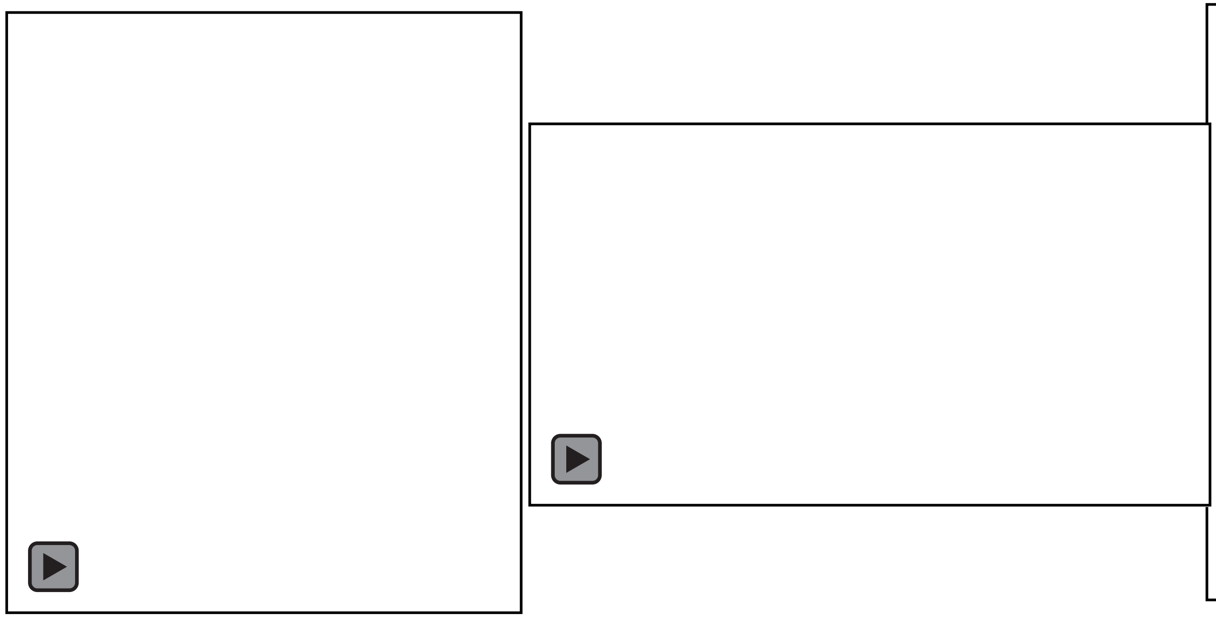




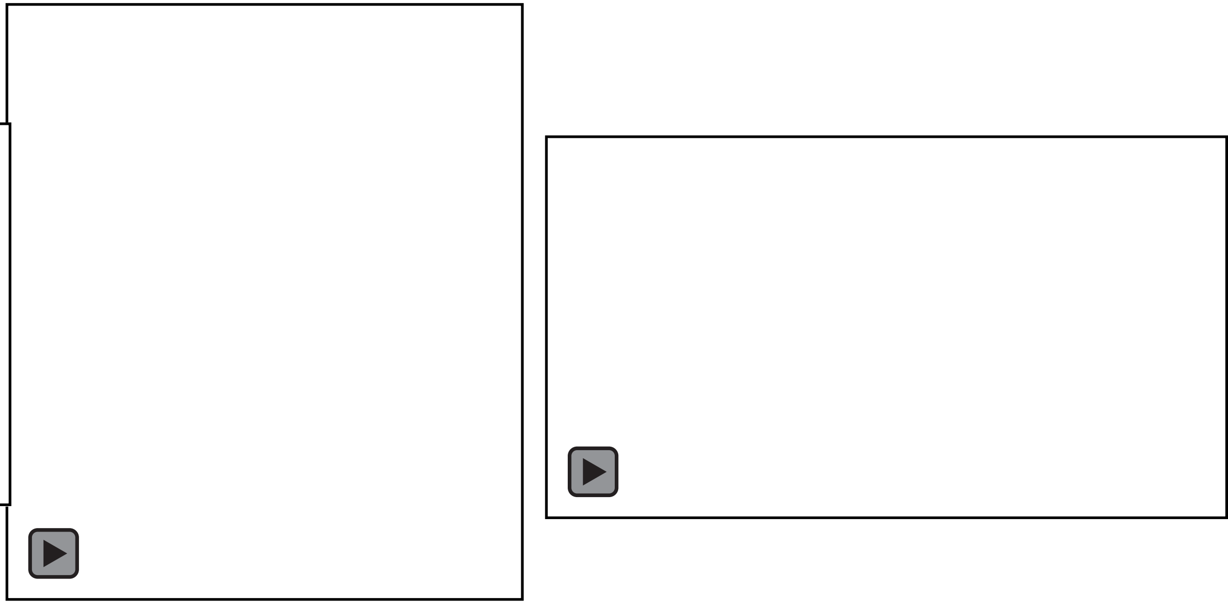
Aggregate contours across select upper body (top) and lower body (bottom) tasks

Results – suited movement occurs out of plane

- When subjects are instructed to perform planar, cardinal movements (e.g., shoulder flexion/extension), the data indicates that the spacesuit motion is not perfectly aligned with the anatomical planes
- The elbow joint center is consistently in front of the body during these movements
- The joint movement seems to follow the contours of the hardware configuration of the suit rather than cardinal planes



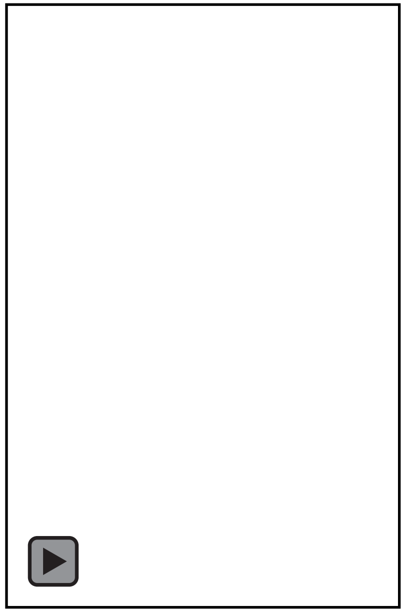
Shoulder flexion/extension



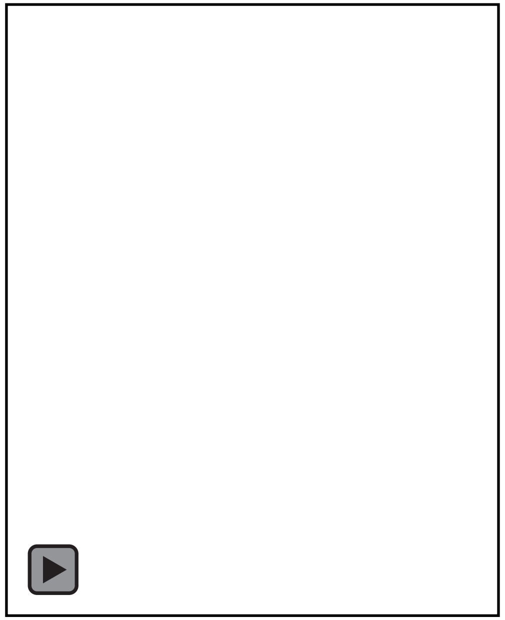
Shoulder abduction/adduction

Results – ROM is affected by task demands

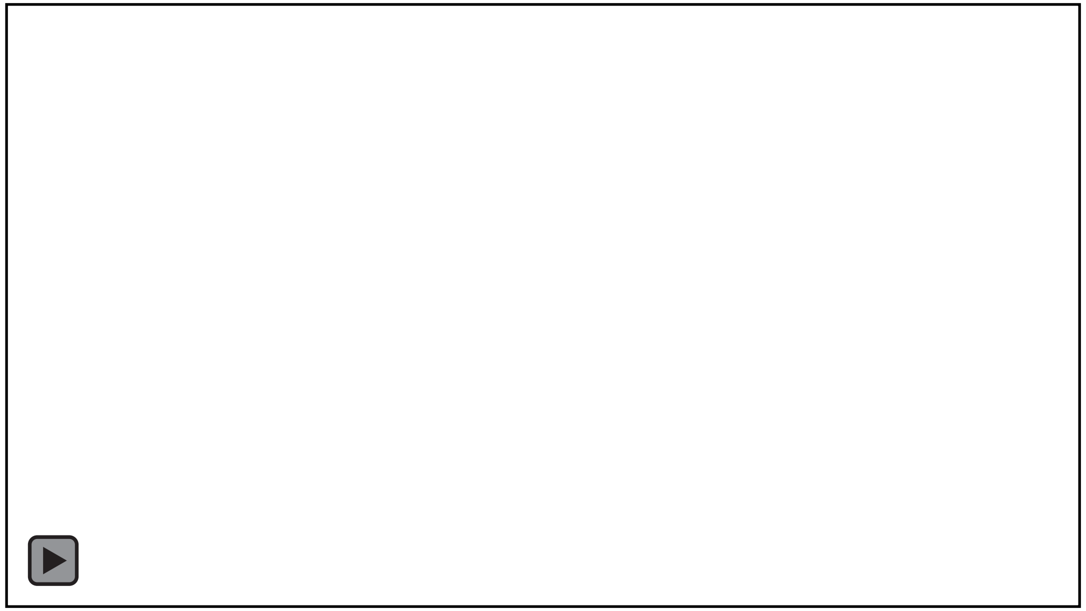
- Joint ROM can vary greatly based on task demands as illustrated by comparisons of knee joint center trajectories for isolated hip flexion/extension movements and squat tasks
- During the squatting task, the subject can leverage the weight of the suit to achieve greater hip mobility compared to the hip flexion/extension task
- In-depth joint mobility differences across different tasks are going to be shown in the subsequent slides



Hip flexion/extension



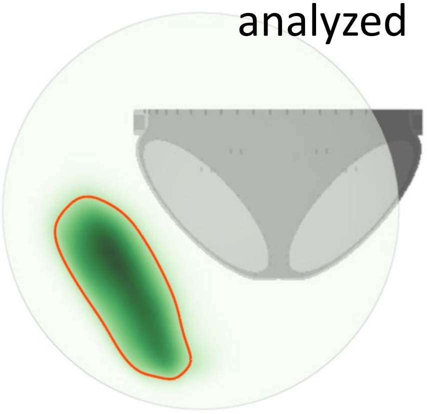
Squat



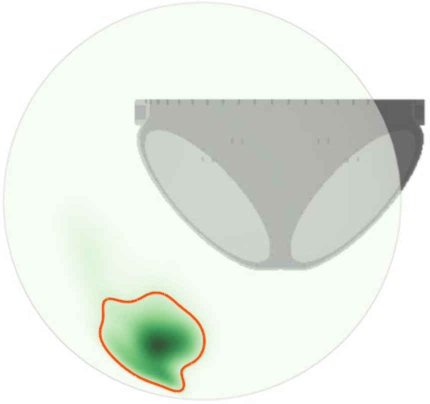
Hip flexion/extension (red) and squat (purple) knee joint center trajectories for subject right knee

Results – Knee ROM variations

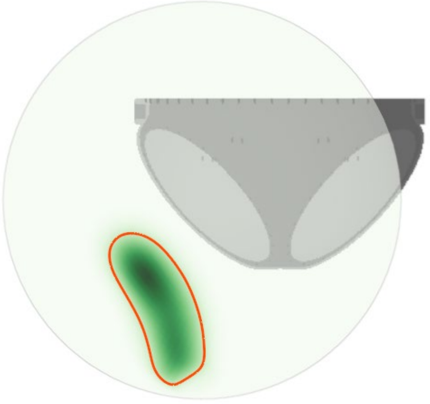
- The lower body ROM requires much greater joint excursions for in-place squat and 1-knee kneeling pickup tasks
  - Note: Only the leading right leg motion during side-step squat, step up, and 1-knee kneeling tasks was analyzed



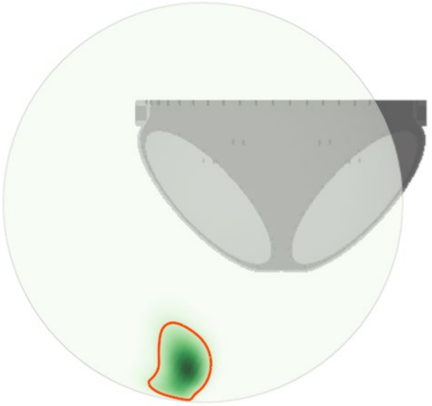
In-place squat



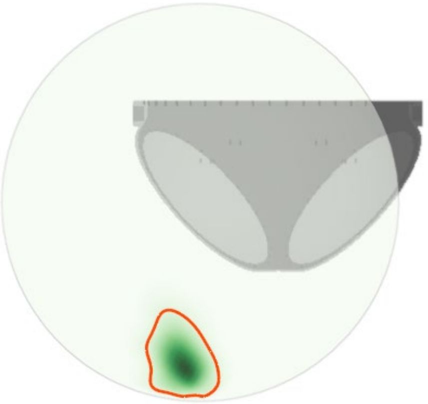
Side-step squat



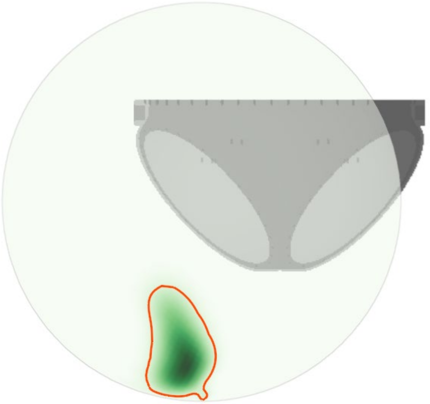
Step-up onto surface



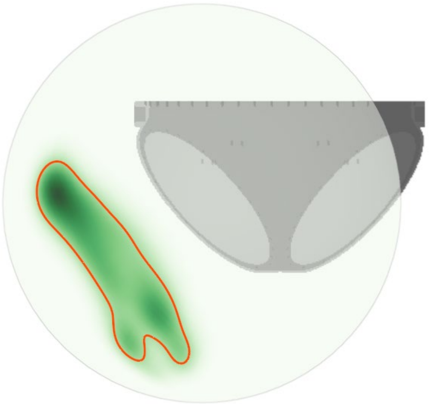
Treadmill walk (0°)



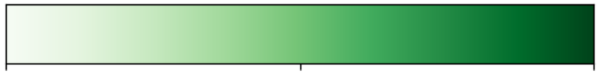
Treadmill walk (-10°)



Treadmill walk (20°)

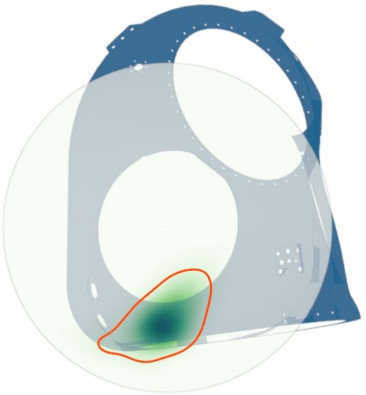


1-knee kneeling object pickup

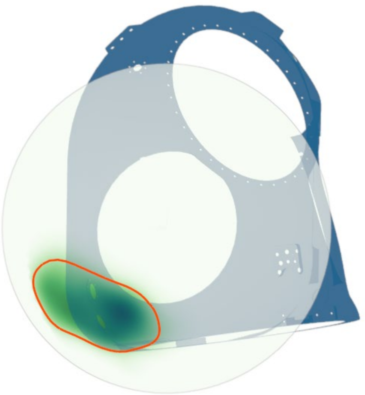


Results – Elbow ROM variations

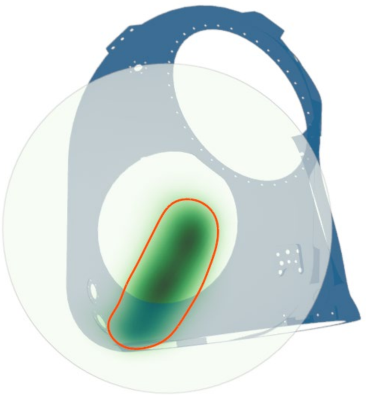
- There are differences between elbow and knee ROM, with some upper body tasks having bimodal patterns



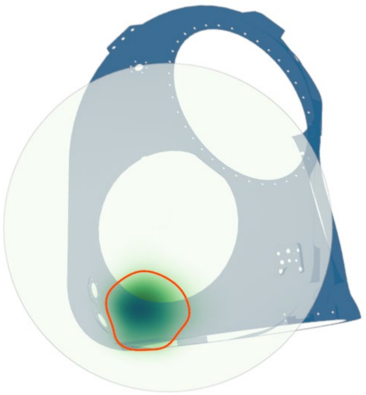
Camera photograph



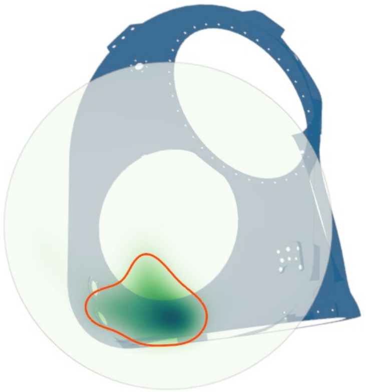
Open toolbelt



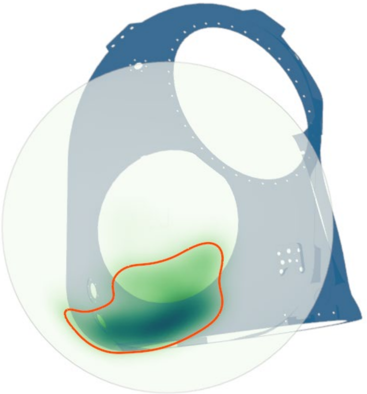
Overhead object reach



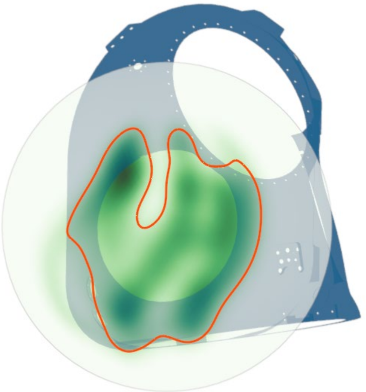
Hatch lever turning



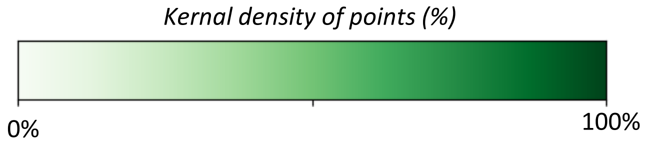
Trenching



Scooping with hand scoop



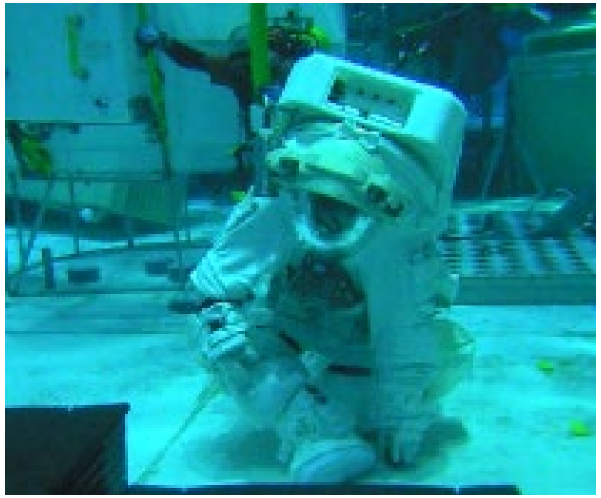
Helmet visor reach



Additional suited data collection considerations

- There are several additional factors that should be considered when suited ROM data is collected:
    - Test environment
        - Water drag in the Neutral Buoyancy Laboratory (NBL)
        - Non-offloaded arms and legs in Active Response Gravity Offload System (ARGOS)
    - Spacesuit fit
    - Overall body posture
    - Experience level with the suit
    - Physical strength
    - Anthropometry
- All these variables can influence the mobility capabilities of the test subjects during ROM data collection

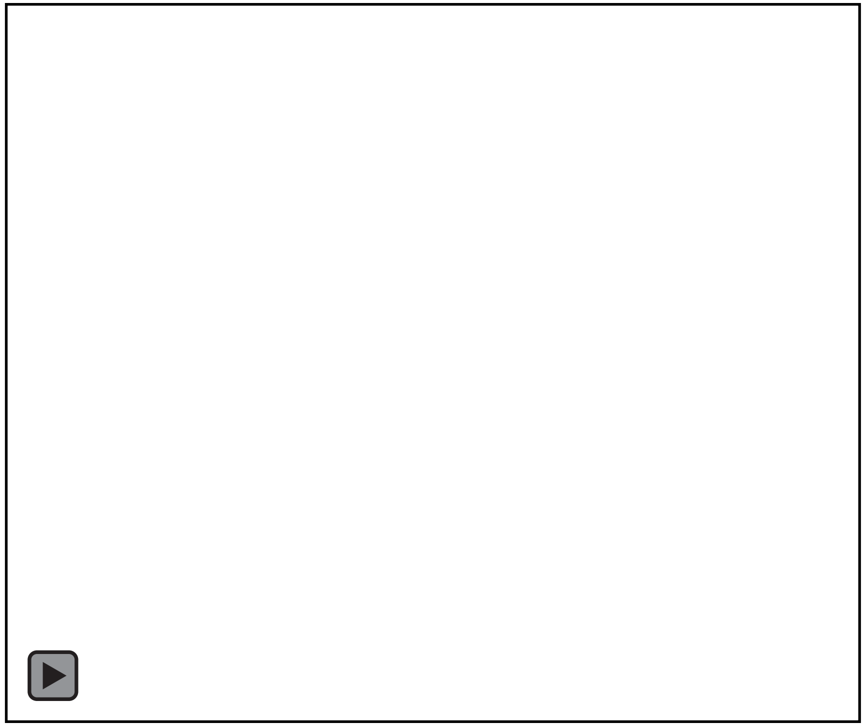
ARGOS



NBL

Discussion

- There can be specific challenges in using traditional planar ROM tasks to define suited mobility
    - It can be difficult to interpret joint angles in the cardinal anatomical reference frame when the suited movements occurs out of plane
    - Joint ROM can differ between traditional cardinal plane movements and functional tasks, where functional tasks may even induce greater joint excursion distances
- Given that suit ROM results can vary across task, environmental analogs, suit fit, and subject attributes, it is important to extensively document the test conditions to provide appropriate context
- As suited reach is also dependent on joint elevation and distance from the body, reach envelope testing and visualizations can provide more comprehensive insight into suited mobility
- The use context of suited ROM also needs to be considered when being used for designing interfaces and workspaces. Especially with enhanced mobility suits, suited ROM should not only be limited to a single arm or single joint motion. Other suit joints can work in conjunction to achieve an enhanced ROM.



1st and 99th Percentile Reach Envelopes

Conclusion

- Suited ROM evaluations are important for human factors assessments of the spacesuit and various spaceflight hardware
- Case studies using motion capture data from the xEMU spacesuit testing were provided to demonstrate the nuances of suited ROM data collection
    - Future work will evaluate off-limb joint trajectories
- Thus, these factors should be accounted for when designing suited ROM studies, analyses, and interpretations
- Proper consideration of suited mobility in the mission and hardware design will better enable the astronauts to perform EVAs safely and effectively

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