National Aeronautics and Space Administration

Human Factors Applications of Biomechanical Modeling

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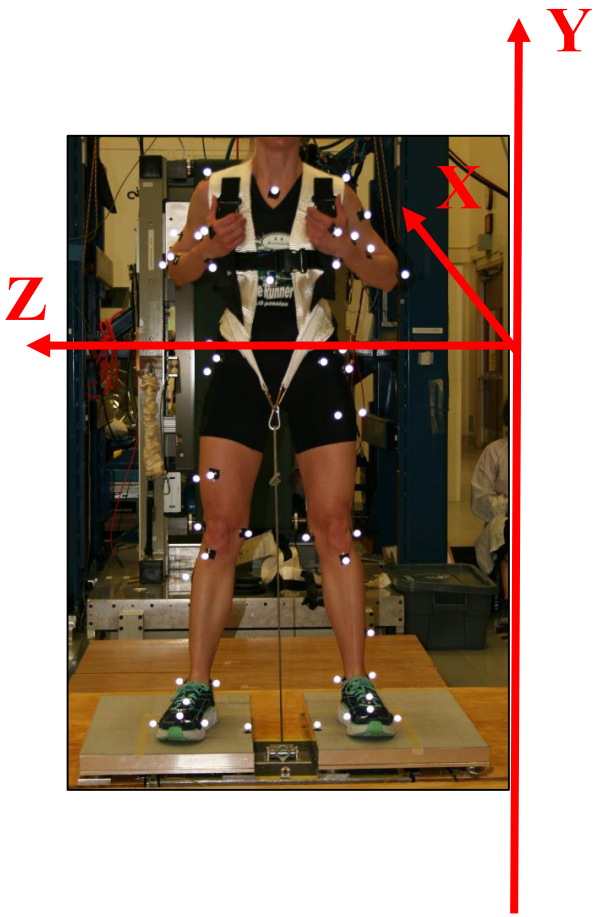
Beth Lewandowski, NASA Glenn Research Center
Chris Gallo, NASA Glenn Research Center
Aaron Godfrey, ZIN Technologies, Inc.
Brad Humphreys, ZIN Technologies, Inc.
William Thompson, NASA Glenn Research Center

Operational Volume
Methodology
Applications

Operational Volume - Methodology

- **Laboratory motion capture system:**
  - BTS Bioengineering (Brooklyn, NY) Smart-DX 12 camera system
  - Reflective markers placed on subjects
  - BTS tracker software produces (x,y,z) vs. time for all markers
  - Live video

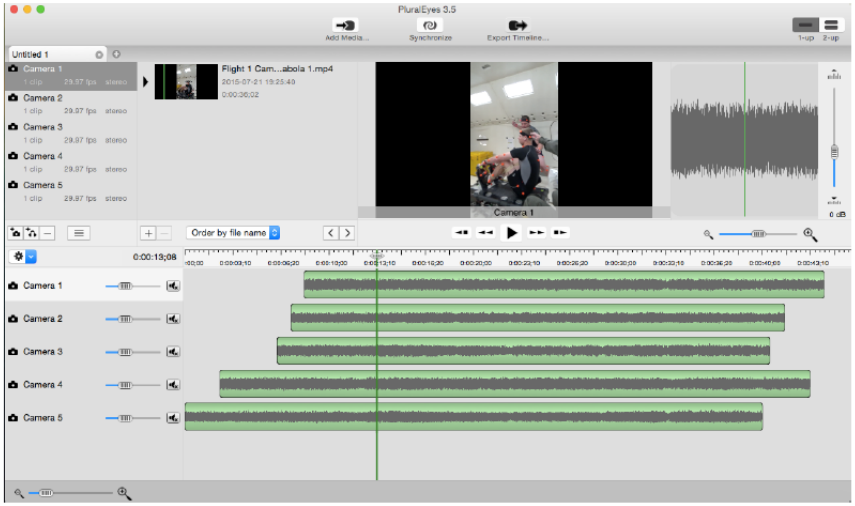
Infrared Illuminators

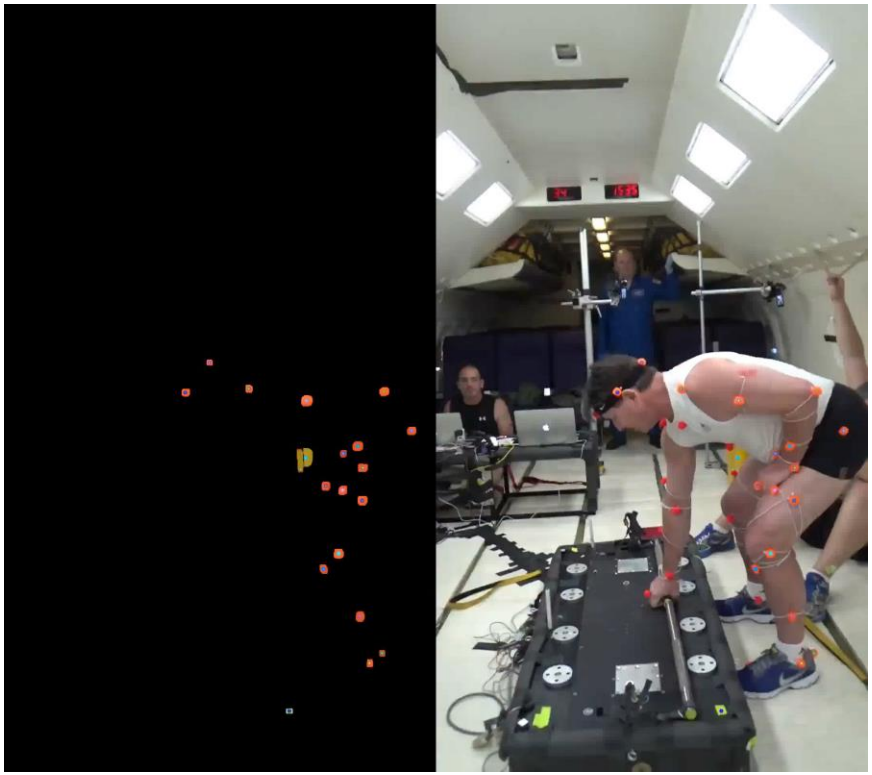


Operational Volume - Methodology

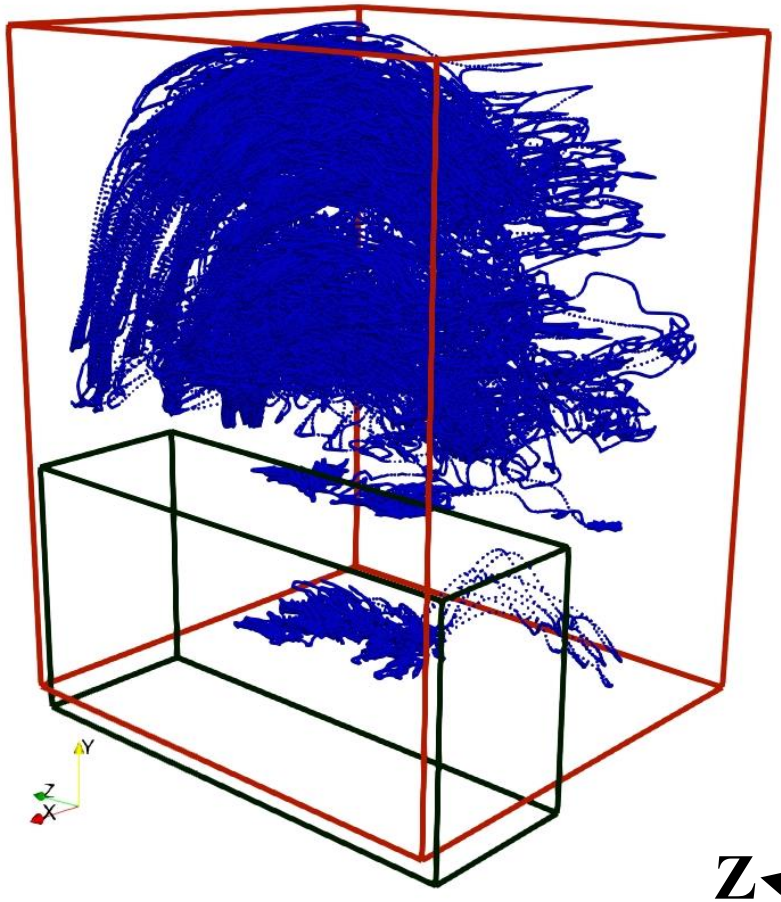
“Low Resolution,” small foot print, motion capture system for Zero-Gravity Flights, ISS and other operational settings

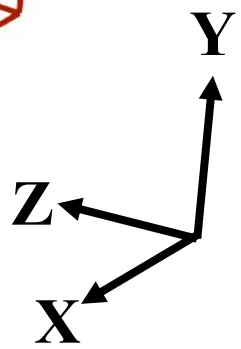
- Uses commercially available video cameras and software
- Custom software developed to perform calibration, tracking, identify kinematics and operational volume



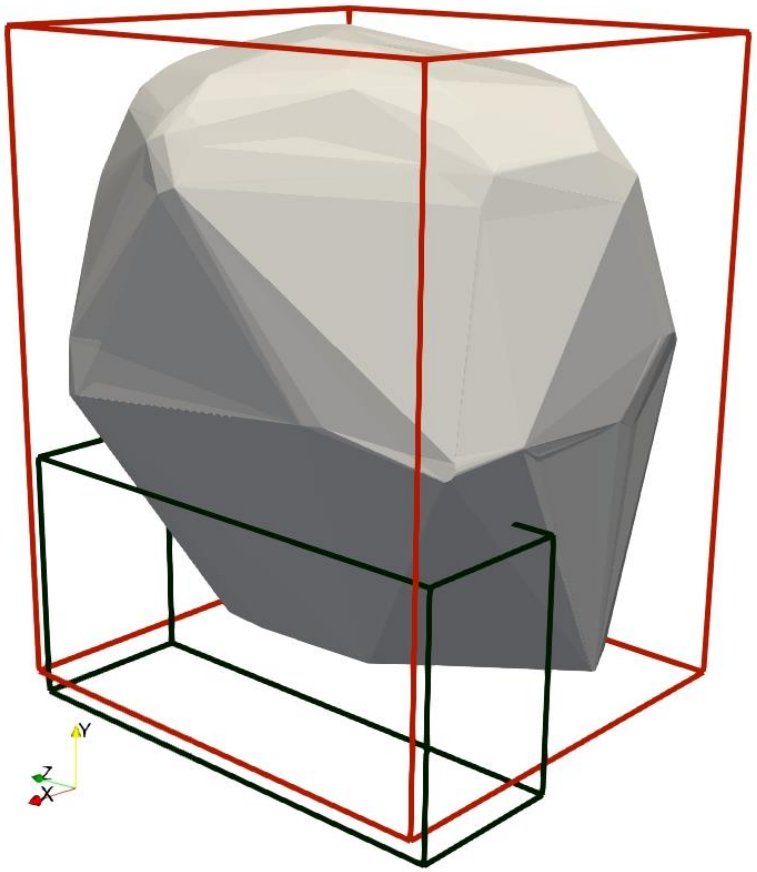


Operational Volume - Methodology





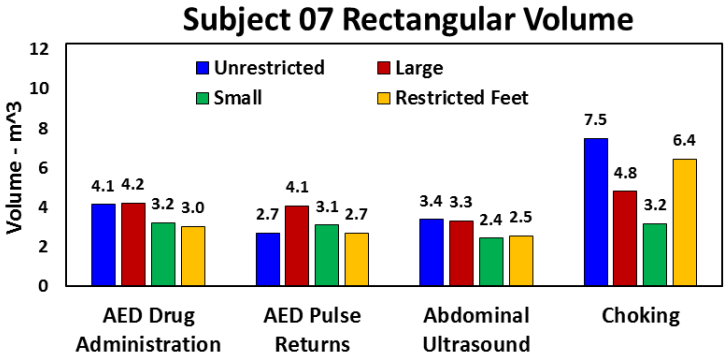
Plot of all markers at all time steps within a rectilinear volume

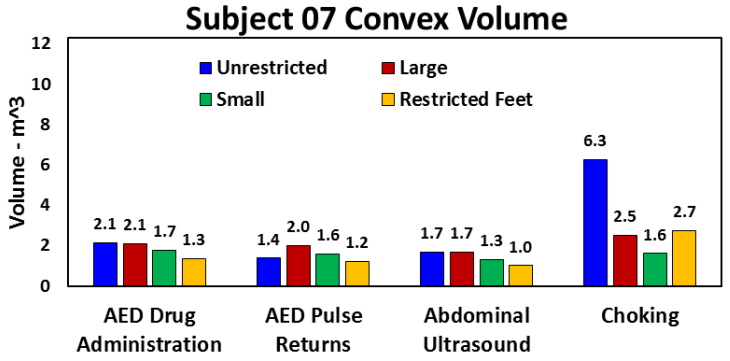


Plot of convex hull volume containing all markers

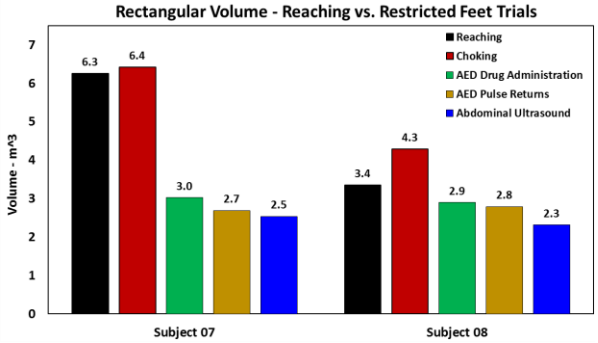
Operational Volume - Methodology

- **Summary of maximum dimensions and maximum volume for various tasks for inclusion in volume databases**





Exercise Type	Maximum Dimension - meter			Maximum Volume - m^3	
	Fore-Aft (X)	Vertical (Y)	Lateral (Z)	Convex	Cube
Back Squat	0.79	1.94	1.10	0.84	1.63
Bench Press	1.49	0.95	1.06	0.57	1.43
Bent Over Row	0.83	1.75	1.04	0.60	1.46
Cross Body Pull	1.12	2.13	1.19	0.94	2.21
Dead Lift	0.89	1.80	1.03	0.63	1.61
Front Squat	0.70	1.82	1.04	0.63	1.30
Hang Clean	0.90	1.82	1.07	0.88	1.75
Hang Clean Press	0.86	2.22	1.12	1.05	1.97
Heel Raise	0.83	1.96	1.10	0.97	1.66
High Pull	0.84	1.77	1.04	0.77	1.53
Kettle Bell Swing	1.45	2.10	0.84	0.95	2.15
Modified Get Up	1.39	2.23	1.22	1.02	2.69
Overhead Press	0.85	2.19	1.13	1.01	1.88
Seated Aerobic Row	1.98	1.14	0.85	0.76	1.77
Thruster	0.86	2.21	1.11	0.88	1.90

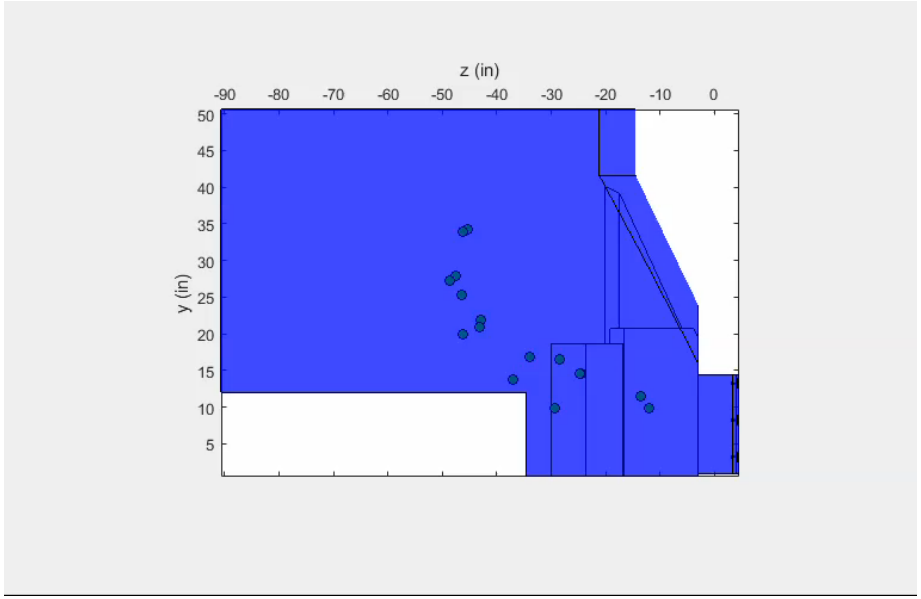


Operational Volume - Applications

- **How much space is required to perform a task?**
  - Exercise operational volume on HULK
  - Exercise operational volume on ATLAS
  - Medical station operational volume
- **Can a task be performed within a specified volume?**
  - Will the motion used to perform a task fit within an allocated volume?
  - The space used may not be the minimum space needed
- **Example: Determine if the volume allocated for exercise within the MPCV adequately accommodates exercise performance**

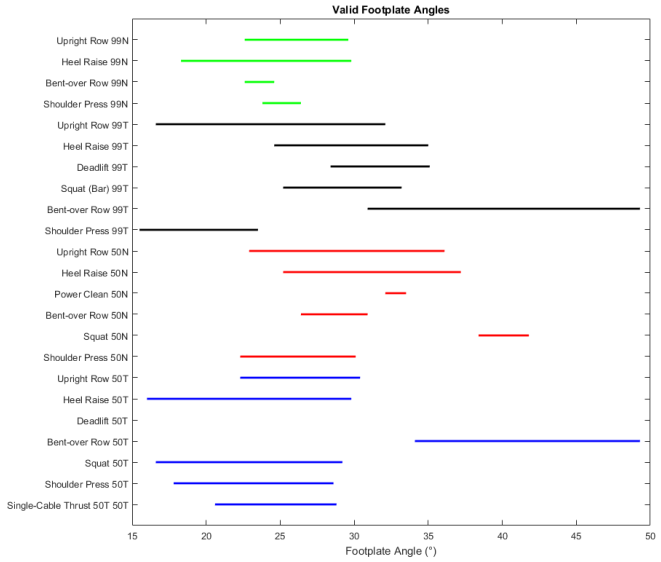
Operational Volume - Applications

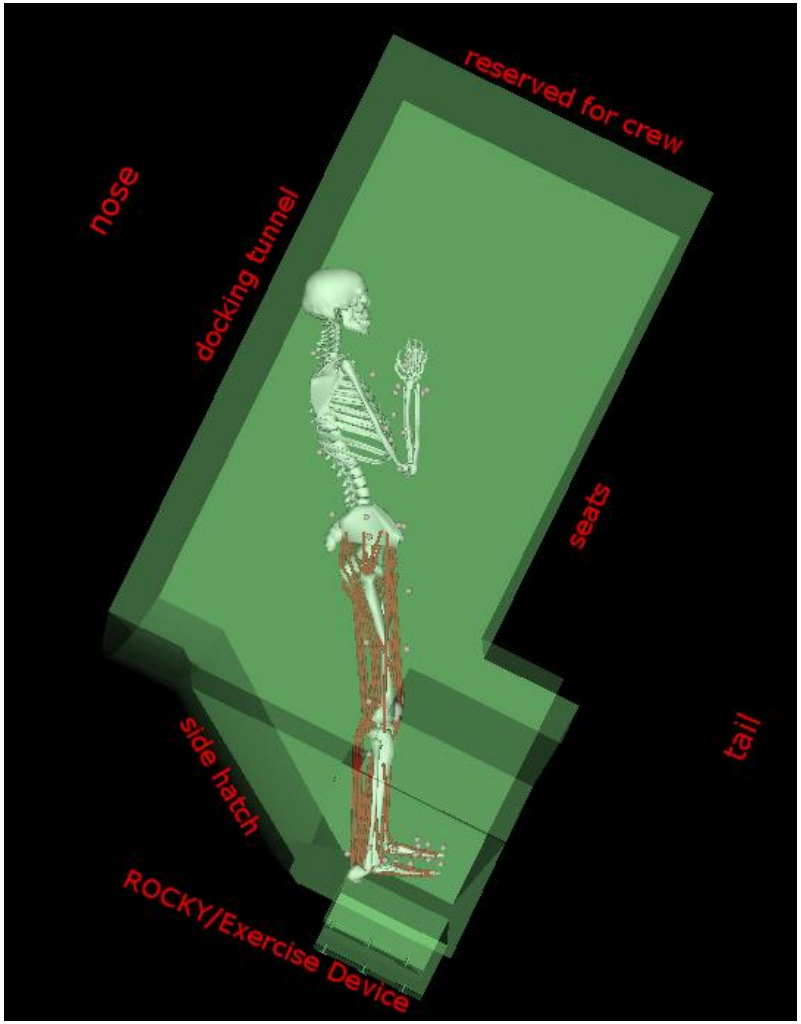
Data collection and processing



Operational Volume - Applications

- **Findings:**
  - Orientation of the exerciser was a factor in how well the exercise was accommodated
  - An adjustable footplate was recommended

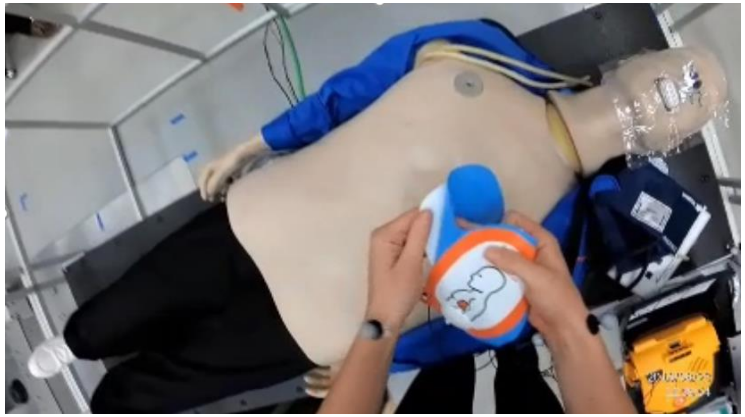


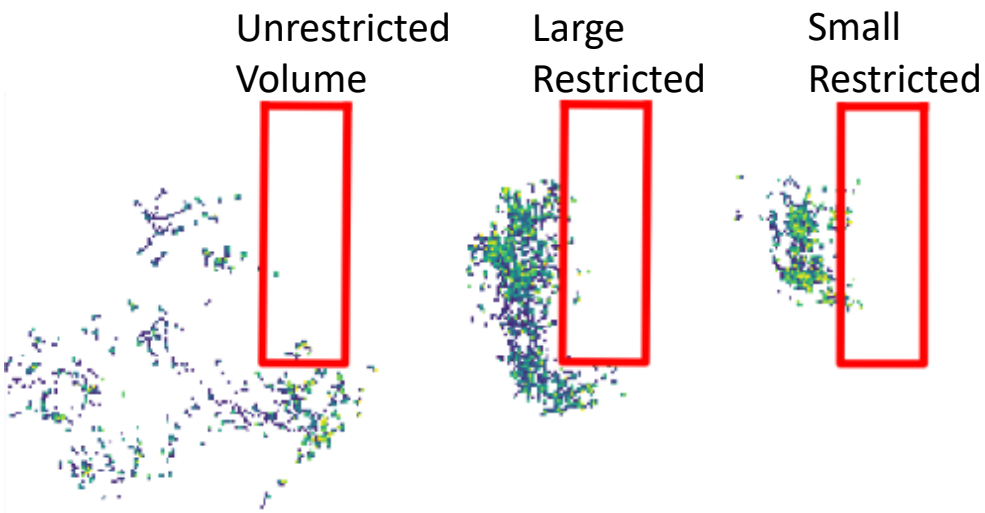


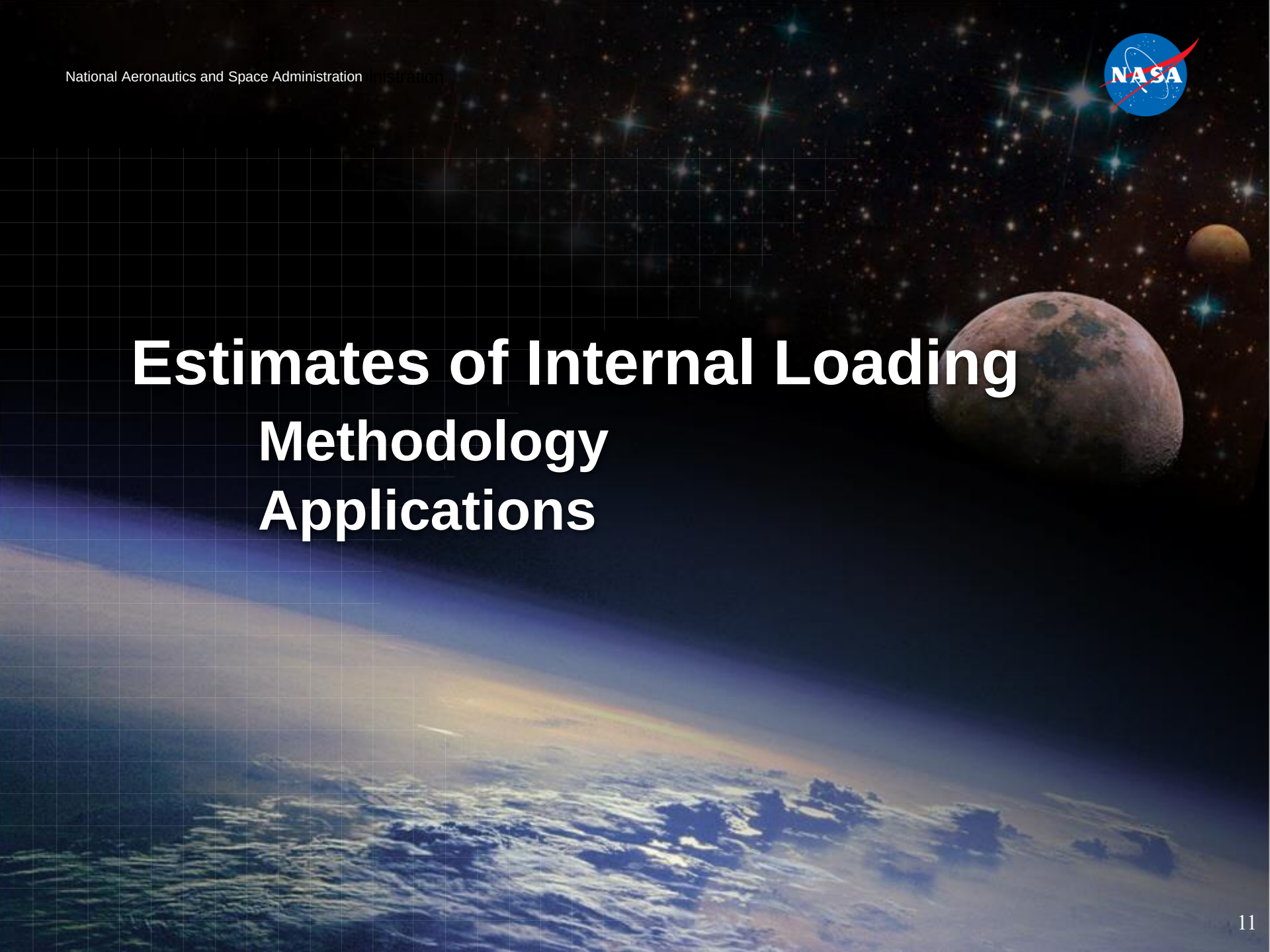
Operational Volume - Applications

- **Example: Provide procedure simulations, operational volume, video, event plots to aid the development of the medical station design and guidance**

- **Findings:**
  - The operational volume decreased when volume restrictions were in place, but care was still successfully provided
  - The caregiver primarily occupied volume at the patient's side and at the patient's head
  - The ultrasound machine placement needs to factor in the dominant hand of the caregiver
  - When giving care the feet stayed in general locations either by the patient's side or at the patient's head, the limiting factor becomes the extent to which the caregiver can reach for equipment and supplies.







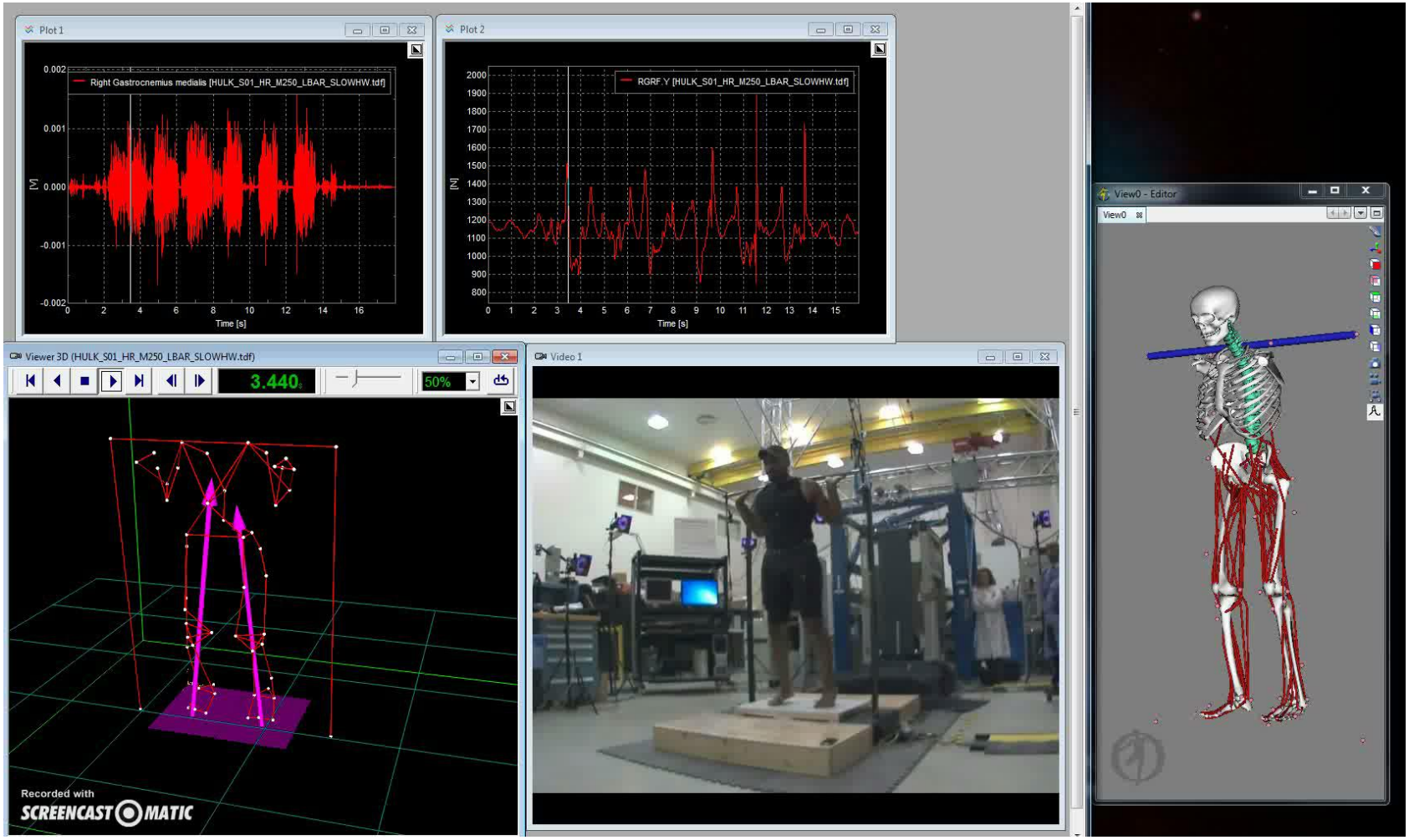
Estimates of Internal Loading

Methodology

Applications

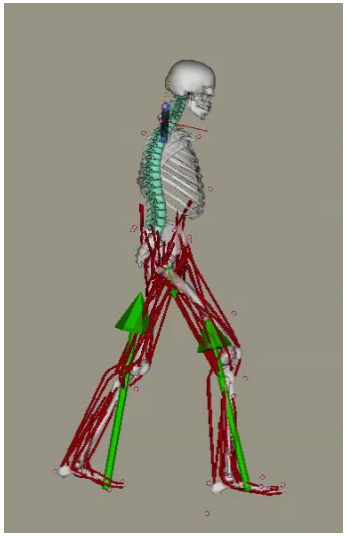
Estimates of Internal Loading - Methodology

- **Biomechanical data collection**

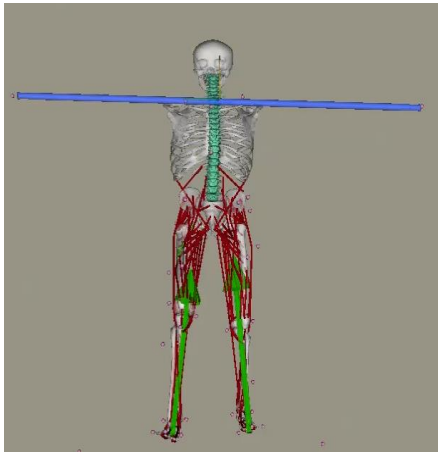


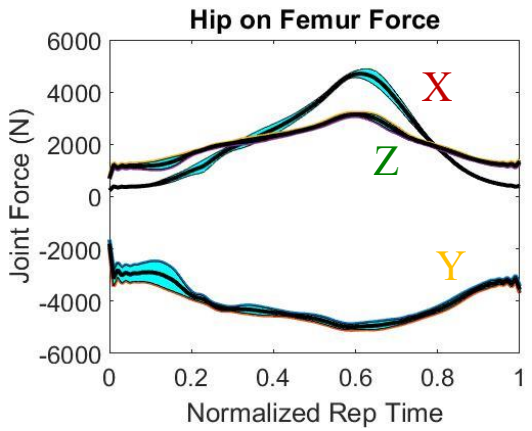
Estimates of Internal Loading - Methodology

- **Laboratory based biomechanical modeling process**
  - Motion data
  - Ground reaction force data
  - Other external forces
  - Biomechanical modeling software to solve equations of motion and force



- **Biomechanical modeling outcome**
  - Kinematic calculations
  - Joint torque estimates
  - Muscle force estimates

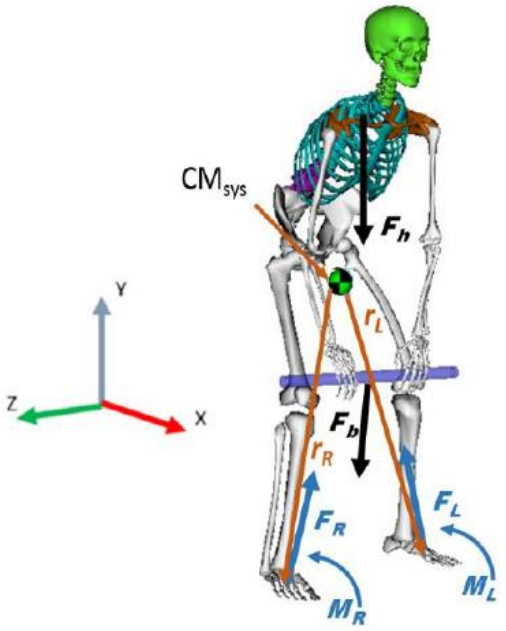


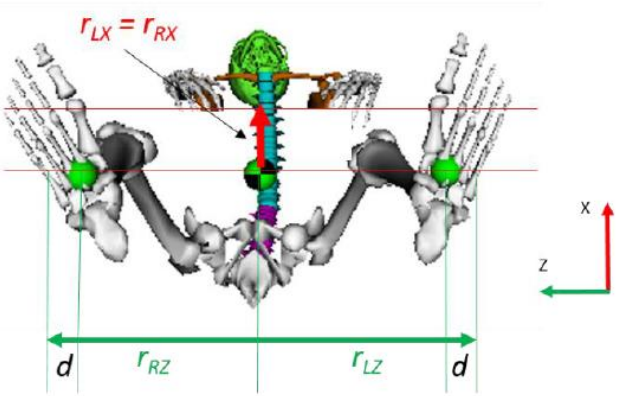


Estimates of Internal Loading - Methodology

- **If there is no availability to ground reaction forces and moments (GRF&M) in an operational setting, can internal forces be estimated with kinematics and exercise device loads alone?**

- **Four key assumptions about GRF&M used to reduce the number of unknowns**
  - Ground reaction moments are negligible
  - The lateral/medial location of the center of pressure (COP) is fixed
  - The fore/aft location of the COP between the feet is equal
  - The ground reaction force vector relative to the vertical in the frontal plane is constant

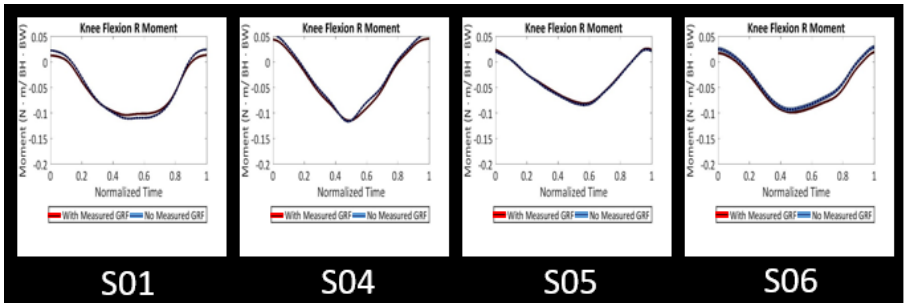




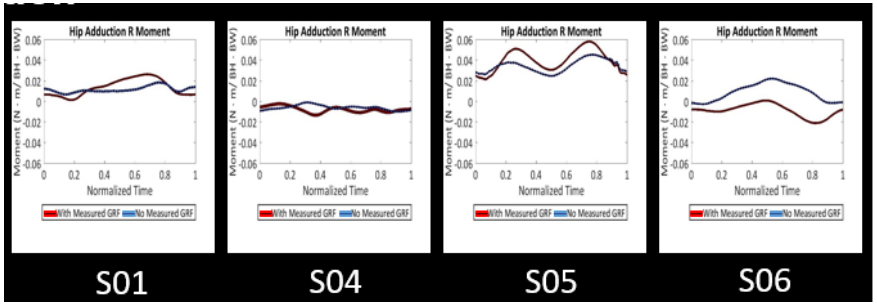
Estimates of Internal Loading - Methodology

- **Comparison of joint torques resulting from squat and deadlift exercises estimated with traditional methods and this method resulted in**
  - Comparable flexion/extension joint moments
  - Larger errors for abduction/adduction and rotational joint moments

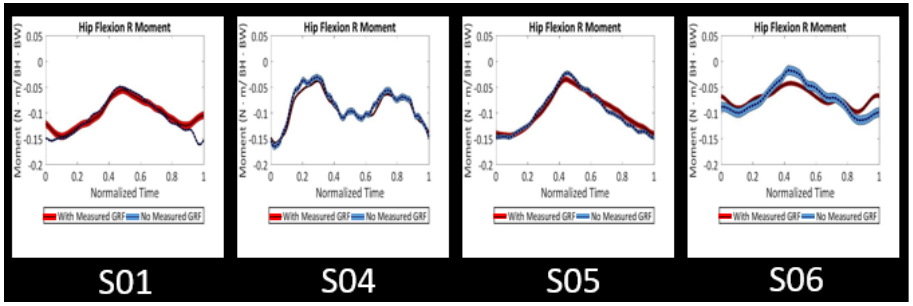
Squat Knee Flexion



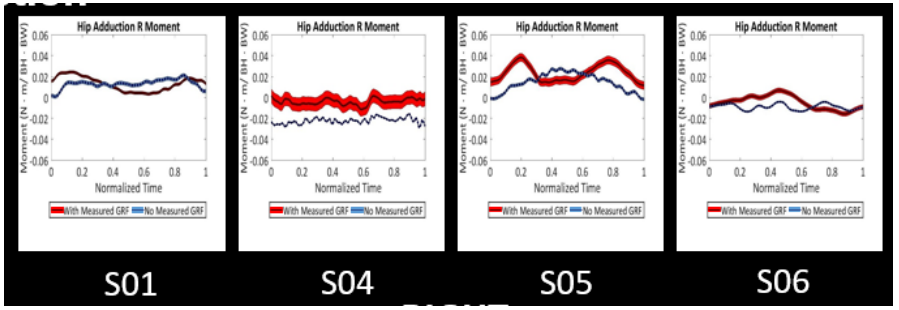
Squat Hip Adduction



Deadlift Hip Flexion



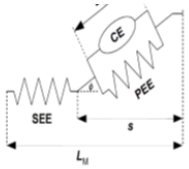
Deadlift Hip Adduction



Estimates of Internal Loading - Methodology

Calculation of muscle dynamics without motion or force data through optimization routines

Force Balance Equation for a Muscle



Force In Fiber *Force In Tendon*

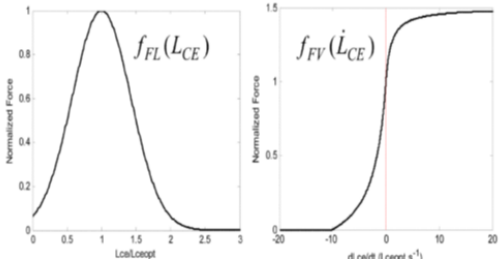
$$\left[a \cdot F_{max} \cdot f_{FL}(L_{CE}) \cdot f_{FV}(\dot{L_{CE}}) + f_{PEE}(L_{CE})\right]cos\phi - f_{SEE}(L_M - L_{CE}cos\phi) = 0$$

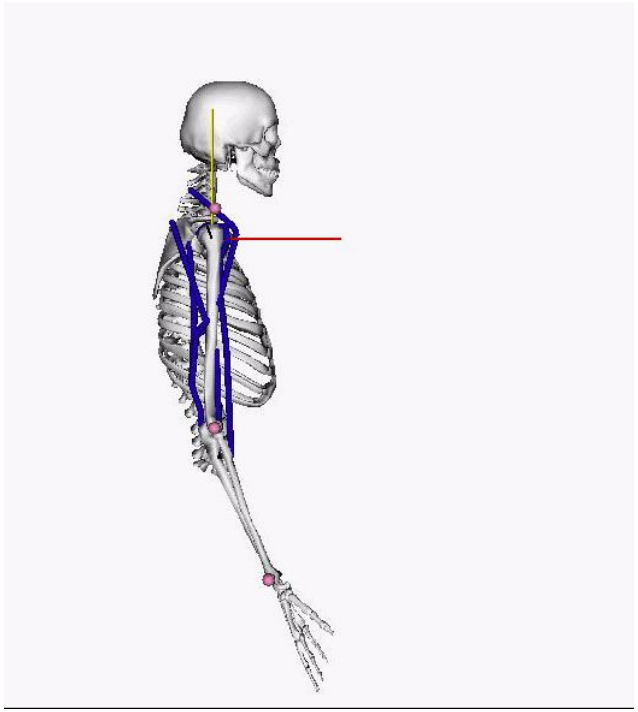
Solving to get Fiber Force-Velocity Relationship

$$f_{FV}(\dot{L_{CE}}) = \frac{f_{SEE}(L_M - L_{CE}cos\phi)}{a \cdot F_{max} \cdot f_{FL}(L_{CE}) \cdot cos\phi} - \frac{f_{PEE}(L_{CE})}{a \cdot F_{max} \cdot f_{FL}(L_{CE})} = f(L_M, L_{CE}, \phi, a)$$

Problem becomes stiff (singularities) when

- Activation, a ≈ 0
- The muscle gets long $f_{FL}(L_{CE})$≈0
- Pennation angle, p ≈ 90deg





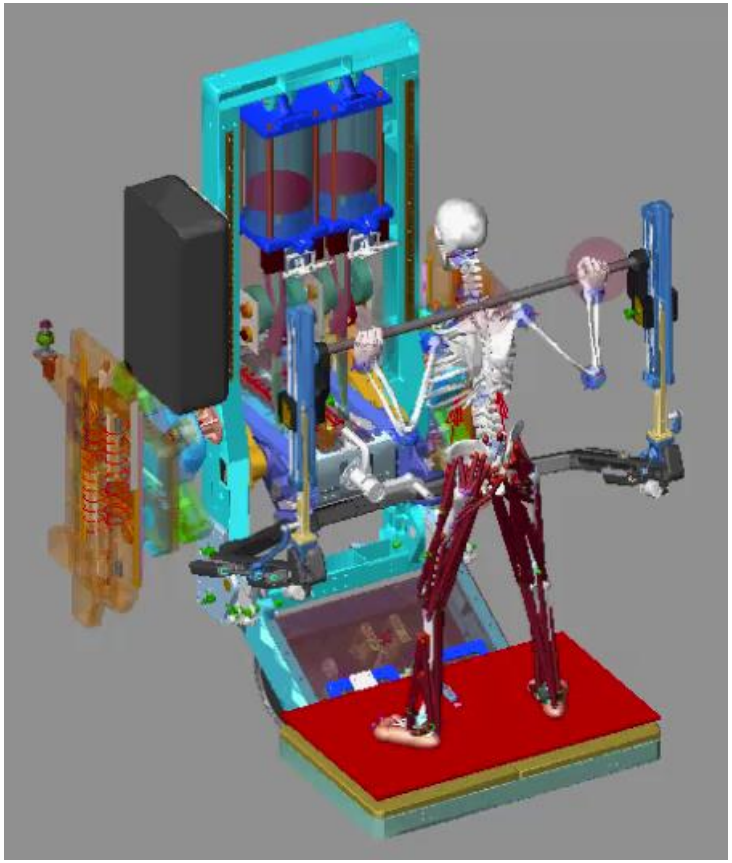
Instead formulate muscle dynamics in an implicit form and solve through optimization

$$\left[a \cdot F_{max} \cdot f_{FL}(L_{CE}) \cdot f_{FV}(\dot{L_{CE}}) + f_{PEE}(L_{CE})\right]cos\phi - f_{SEE}(L_M - L_{CE}cos\phi) = F_{Res} = 0$$

$$F_{Res} = f(L_M, L_{CE}, \phi, a)$$

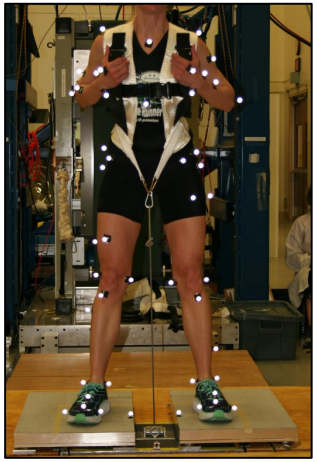
Estimates of Internal Loading - Methodology

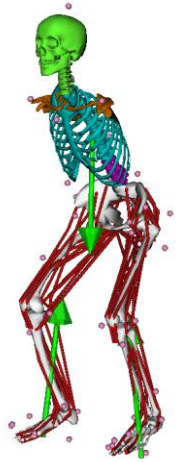
- **Model the interaction of the human with an object**
- **Example: a biomechanical model of an exerciser linked to a mechanical model of the advance resistive exercise device**
- **What is the effect of the human-device interaction on posture, forces and torques at anatomical sites**

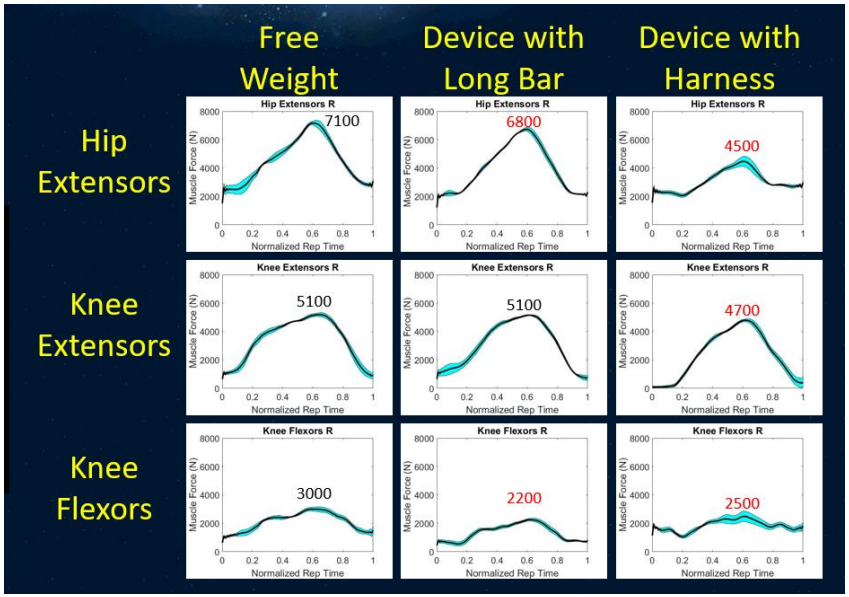


Estimates of Internal Loading - Applications

- **Questions that were answered using biomechanical modeling:**
  - Will the small exploration exercise devices provide comparable mechanical stimulus to Earth-based free weight exercise?
  - What is the difference in mechanical stimulus between a harness interface and an exercise bar interface?
  - How does differences in the load profile provided by an exercise device influence the resulting mechanical stimulus?

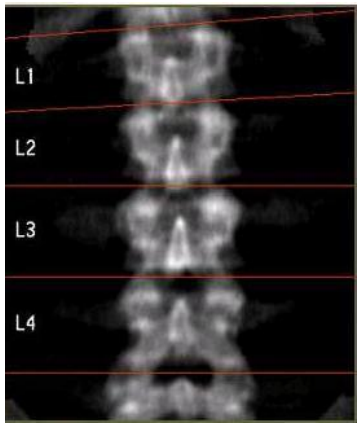


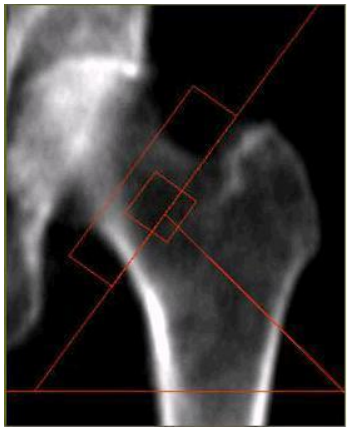


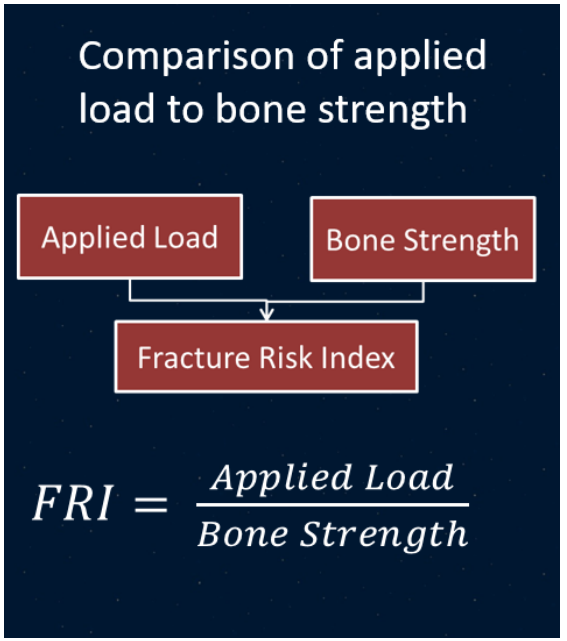


Estimates of Internal Loading - Applications

- **How does the internal loading generated during performance of a task compare to injury thresholds?**
- **How do the joint forces generated compare to ultimate bone strength?**
- **How do the muscle forces generated compare to values associated with muscle strain injuries?**







This presentation provided methodologies and applications for:

- **Operational volume estimation**
- **Internal loading estimation**

Thank you, Questions?