Computational Modeling of Space Physiology for Informing Spaceflight Countermeasure Design and Predictions of Efficacy

Aerospace Medical Association
88th Annual Scientific Meeting
May 1, 2017

B.E. Lewandowski, NASA GRC
J.K. DeWitt, KBRWyle
C.A. Gallo, NASA GRC
K.M. Gilkey, NASA GRC
A.P. Godfrey, ZIN Technologies
B.T. Humphreys, ZIN Technologies
K.M. Jagodnik, Baylor College of Medicine
M. Kassemi, CWRU
J.G. Myers, NASA GRC
E.S. Nelson, NASA GRC
J.A. Pennline, NASA GRC
G.P. Perusek, NASA GRC
W.K. Thompson, NASA GRC
C.R. Werner, ZIN Technologies
M.M. Nall, NASA GRC

Disclosure Information

88th Annual Scientific Meeting
Beth Lewandowski

I have no financial relationships to disclose.

I will not discuss off-label use and/or investigational use in my presentation.

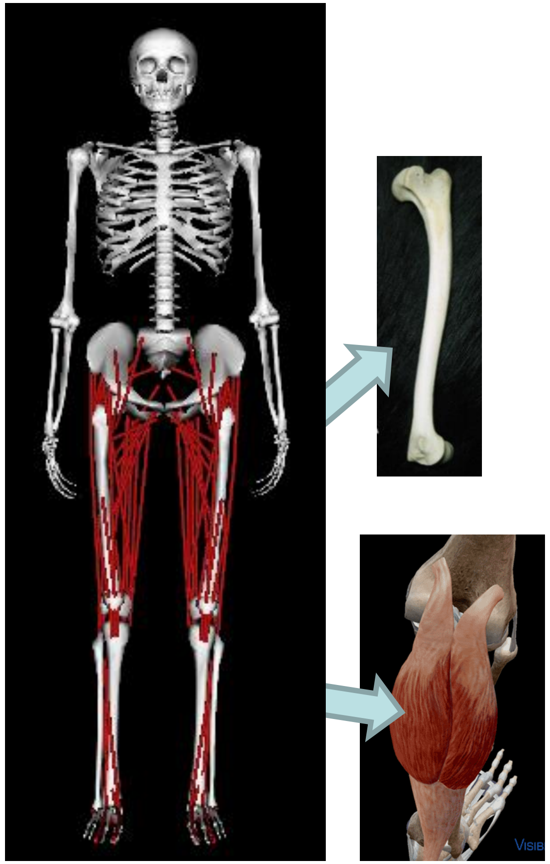
Spaceflight Countermeasures

- Exercise
- Lower body negative pressure/blood flow occlusion
- Artificial gravity

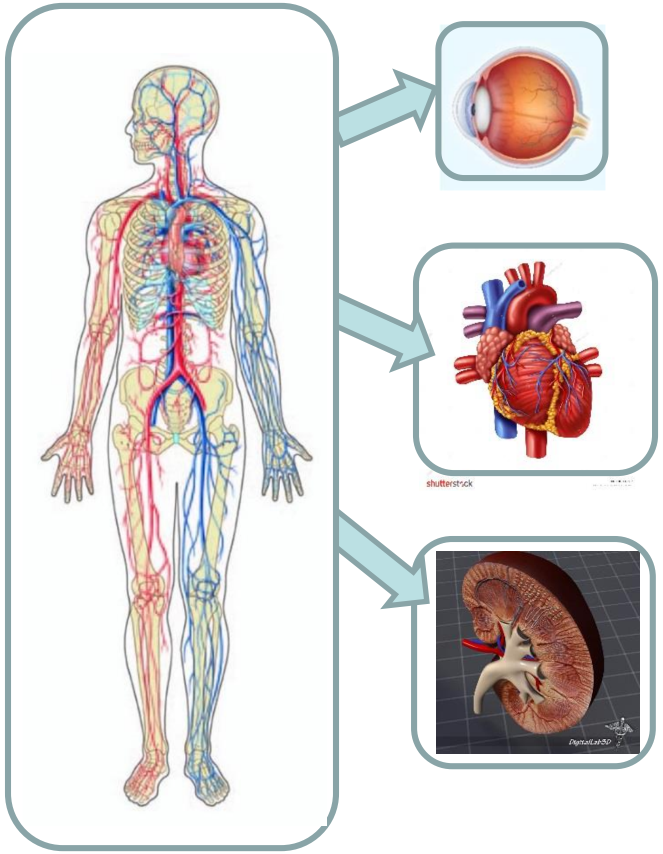




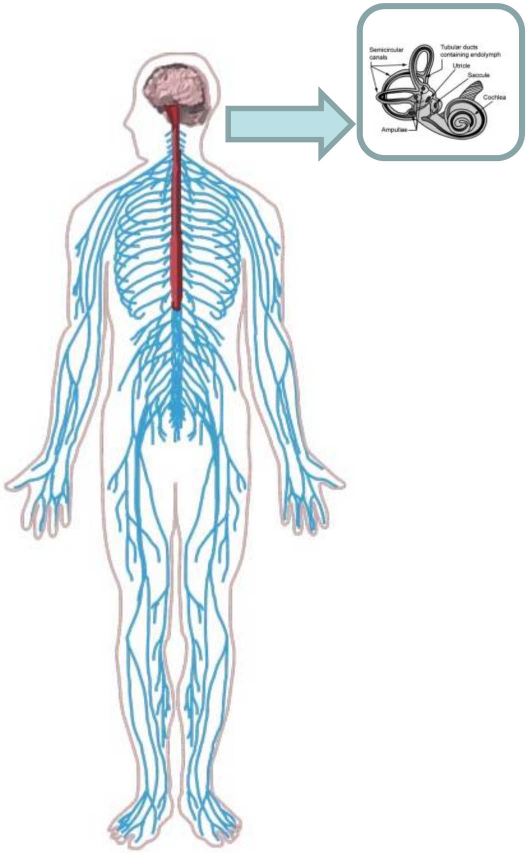
Computational Models Used to Inform Spaceflight Countermeasure Design and Efficacy Prediction



Musculoskeletal system & Biomechanical modeling
Bone and muscle



Lumped-parameter whole body model
Vasculature, cerebral spinal fluid and lymphatic fluid, heart, eye, kidney

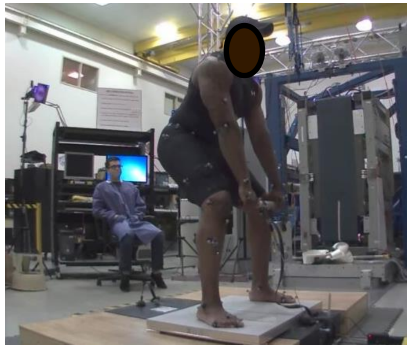


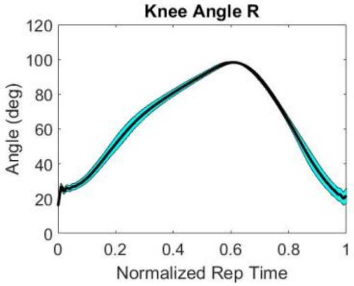
Central nervous system
Vestibular organs

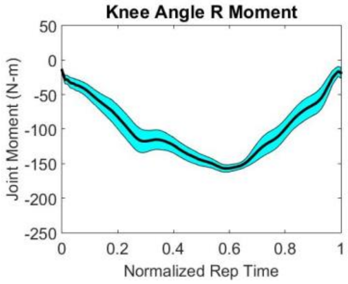
Biomechanical Modeling

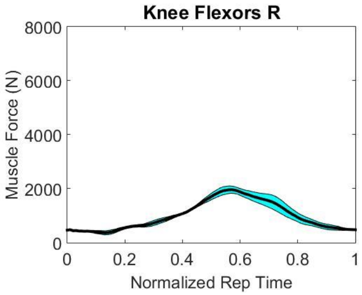
- **Estimation of kinematics, joint torques, muscle forces and joint reaction forces**

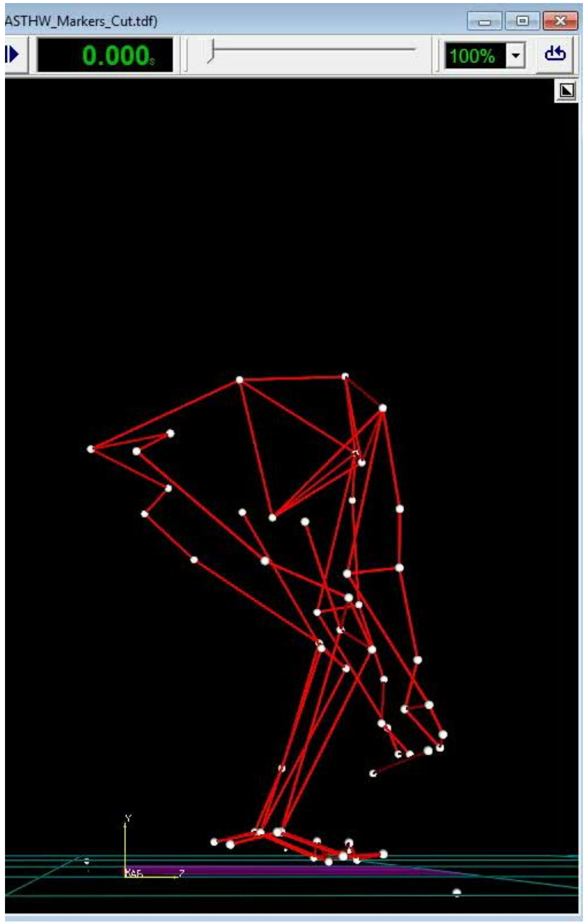
- **Data includes: motion data, ground reaction forces, device loads and subject anthropometrics**











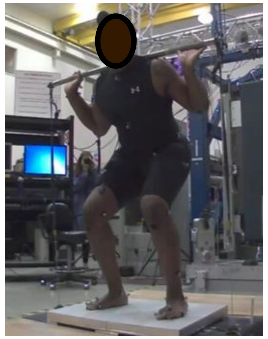
Applications of Biomechanical Modeling

- **Comparison of new exploration exercise devices to ground-based free weight exercises**

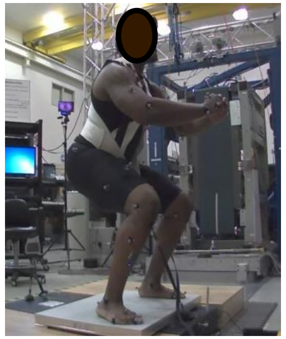
- **Determination of exercise operational volume**

- **Interface load estimation**

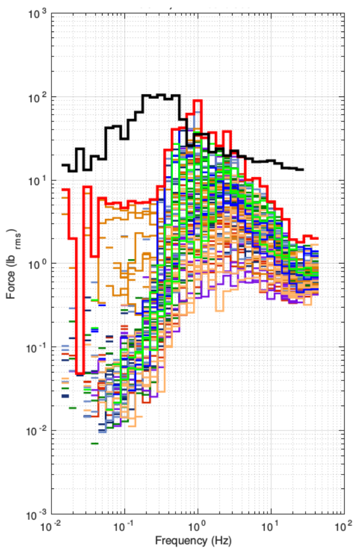
Barbell Free Weight

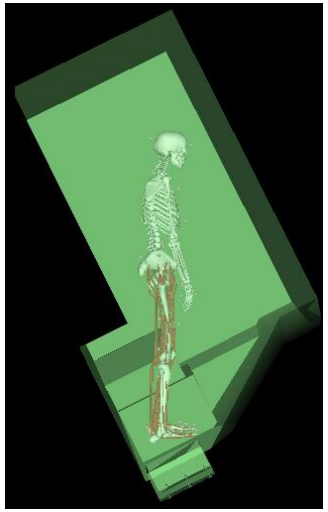


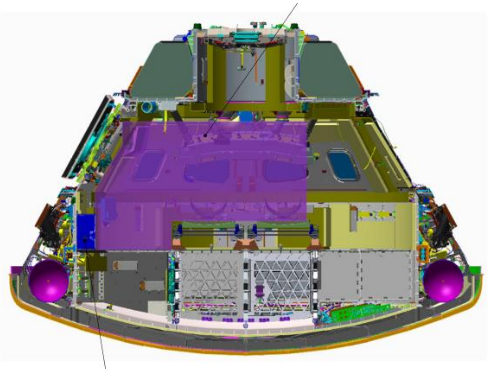
HULK Long Bar

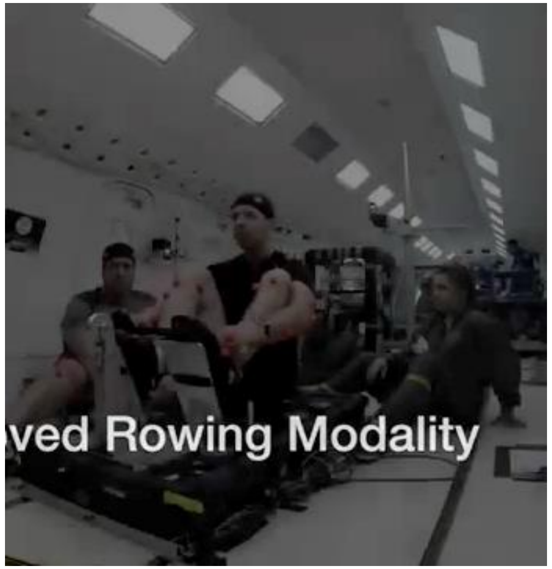


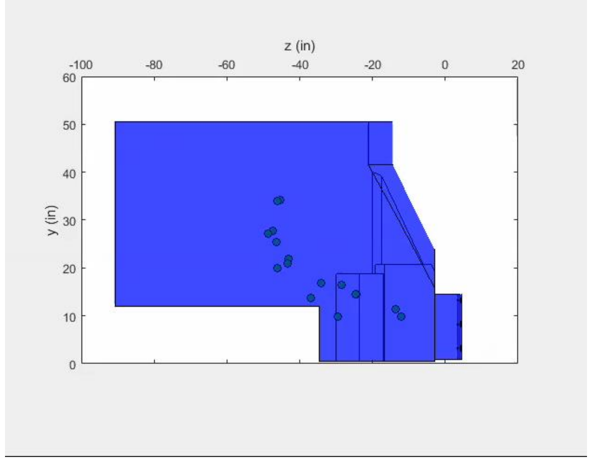
HULK Yo-Yo Harness







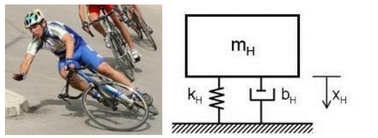




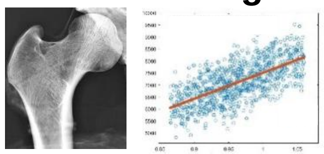
Musculoskeletal Modeling

- **Muscle atrophy model**
- **Models for estimating changes in bone mineral density and bone strength**
- **Prediction of bone fracture probability**

Applied Load

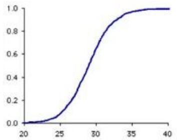


Bone Strength

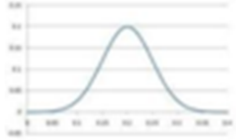


Bone fracture risk model

Fracture Risk Index

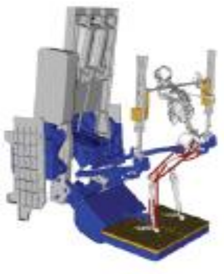


Fracture Probability



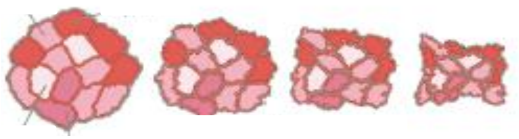
Muscle Atrophy Model
PI Silvia Blemker, University of Virginia

Dynamic simulation of exercises

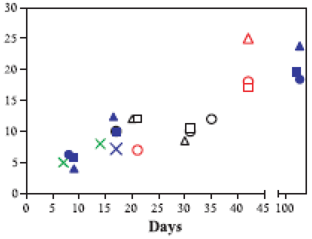


3D simulation of muscle tissue contraction

Agent-based simulation of muscle adaptation

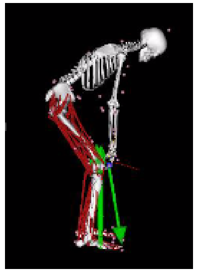


Adams et al., Skeletal muscle unweighting: spaceflight and ground-based models, *J Appl Physiol*, 95, 2185-2201, 2003

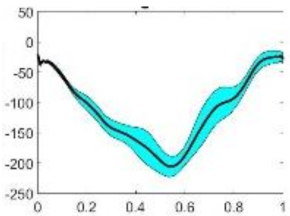


Percent decrease in muscle size for spaceflight, bed rest, immobilization and unilateral limb suspension

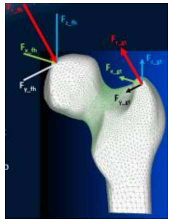
Biomechanical model



Joint forces

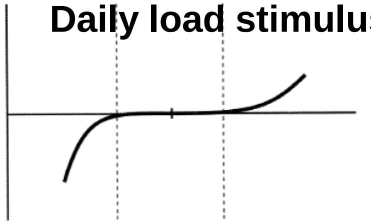


Strain within the bone

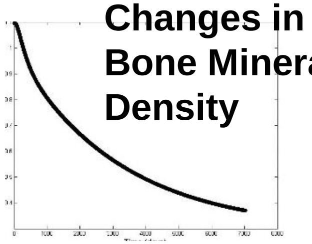


Bone Physiology Model

Daily load stimulus

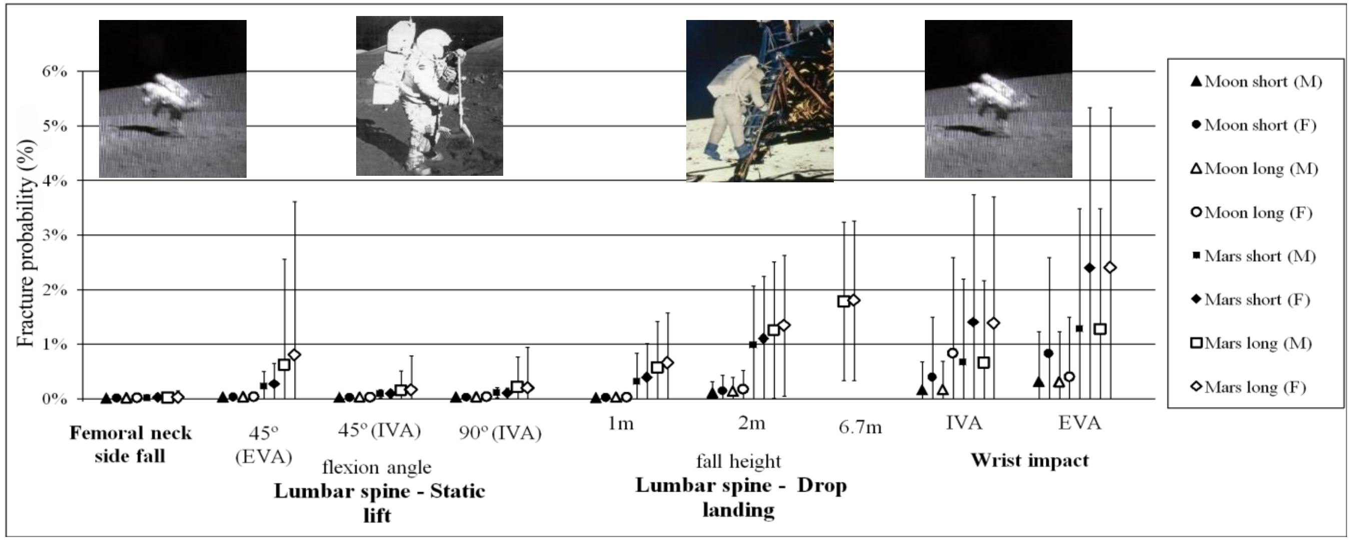


Changes in Bone Mineral Density

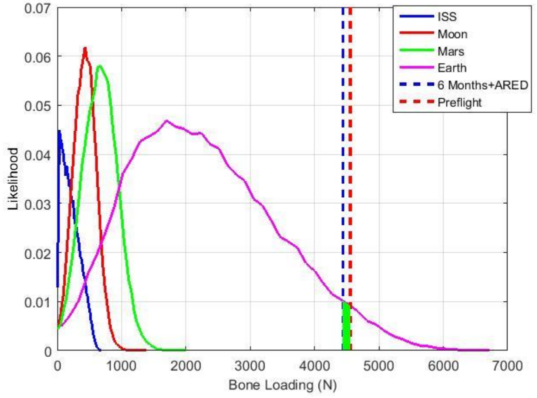


Applications of Musculoskeletal Modeling

Predictions of the likelihood of bone fracture



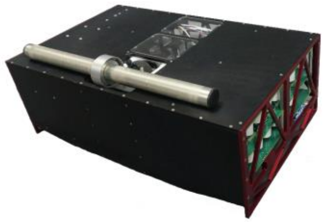
Comparison of pre- and post-flight mean bone strengths associated with ISS missions to applied loads

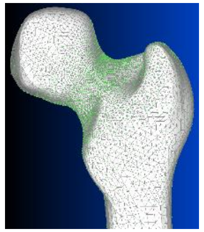


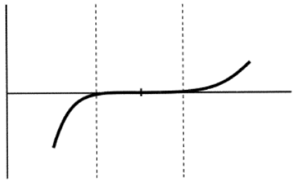
Deconditioning factor for vehicle load limit design

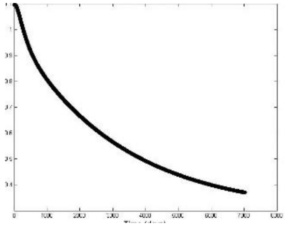
Investigation to determine if spaceflight increased the probability of the fracture

Estimation of countermeasure efficacy



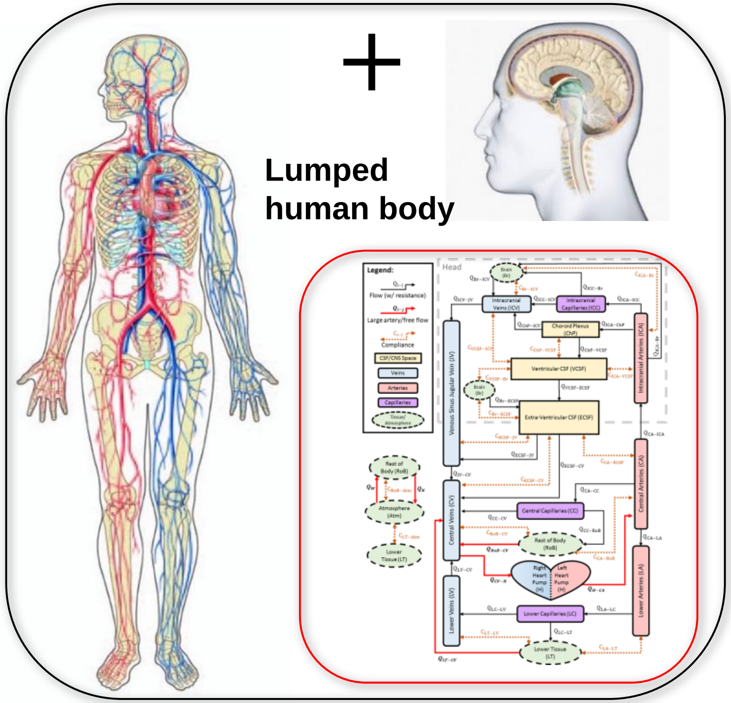


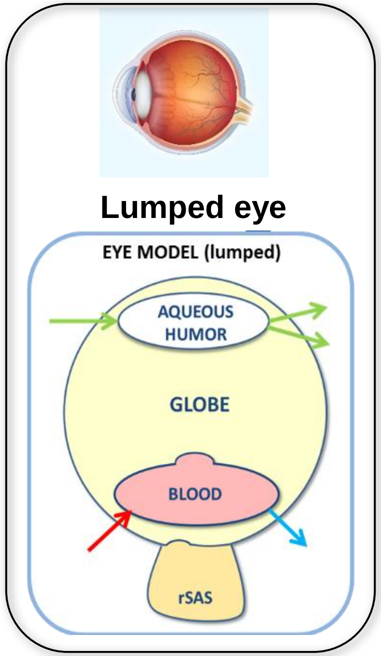




Cardiovascular and Ocular Modeling

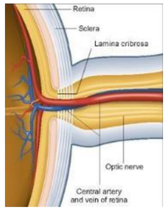
- **A human body model of cardiovascular, cerebral spinal, interstitial and lymphatic fluids that provides mean arterial pressure (MAP) and intracranial pressure (ICP) in response to gravity-driven fluid shifts**
- **A lumped eye model that provides intraocular pressure (IOP) and globe and blood volume estimates**
- **A finite element model of the optic nerve head that includes tissue properties so that tissue strains can be estimated when subjected to different MAP, ICP and IOP**

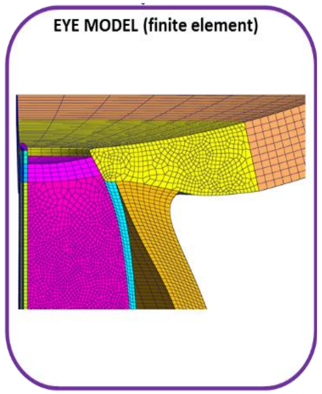




PI C. Ross Ethier
Georgia Institute of Technology

FE eye



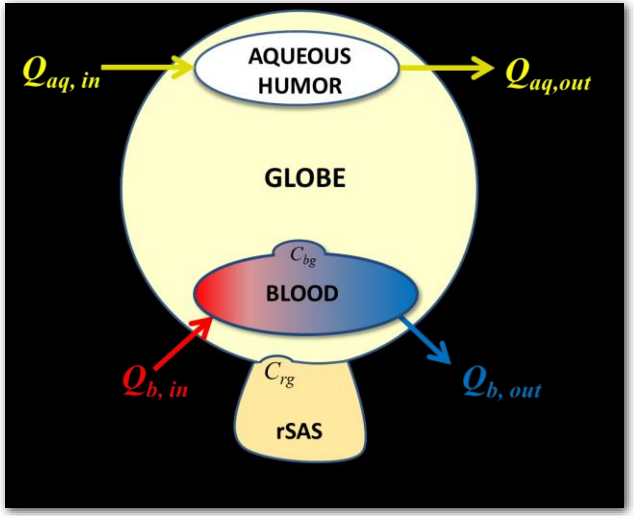


Modeling capabilities across multiple spatial scales

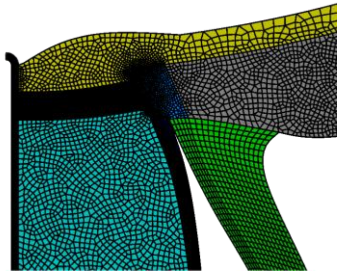
Applications of Cardiovascular and Ocular Modeling

- **Support Visual Impairment and Intracranial Pressure (VIIP) syndrome research**
  - Provide insight on how intraocular pressure and aqueous humor volume change during acute gravitational changes
  - Determine physiological factors that most affect the IOP changes
  - Explore the hypothesis that the pathology of VIIP is due to altered biomechanical loads on ocular tissues, which causes remodeling of the ocular tissues
  - Determine factors with the largest influence on strain
  - Determine characteristics describing the population that would experience peak strains in the optic nerve during microgravity

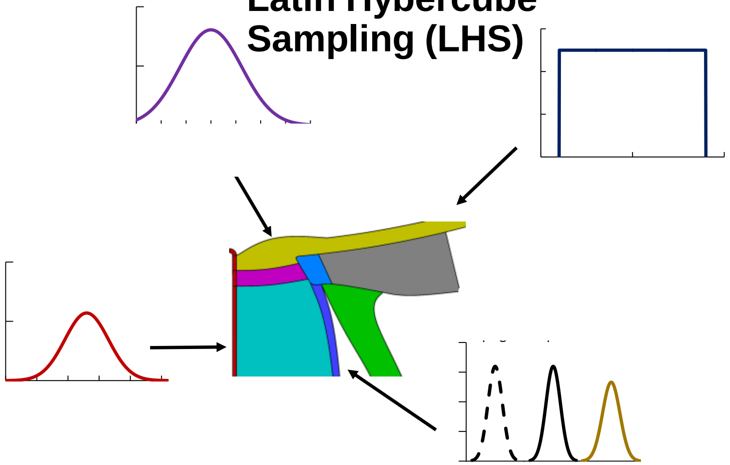
- **Inform countermeasure design**
  - Incorporate countermeasures simulation capabilities into compartment models to evaluate the effects of microgravity and countermeasures on CSF and blood flows and pressures

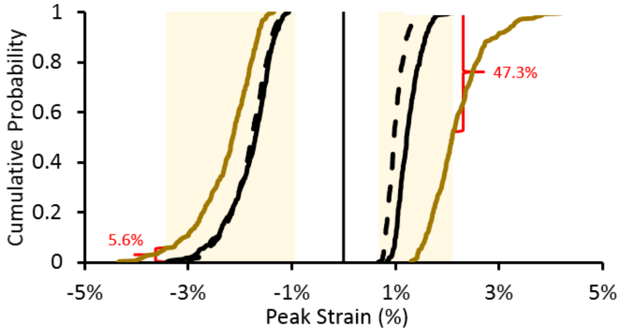


Finite Element Model of the Optic Nerve Head



Latin Hybercube Sampling (LHS)

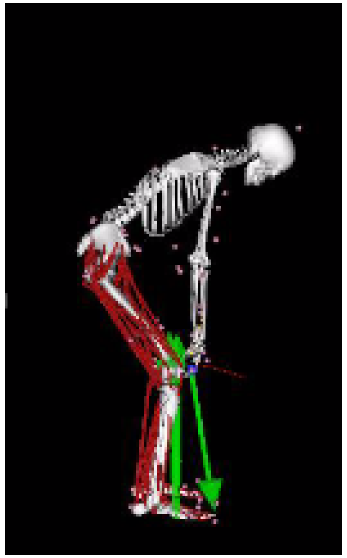


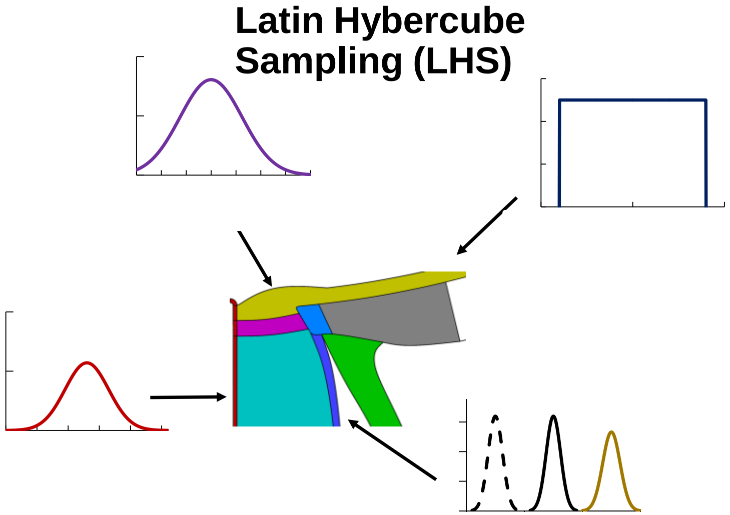


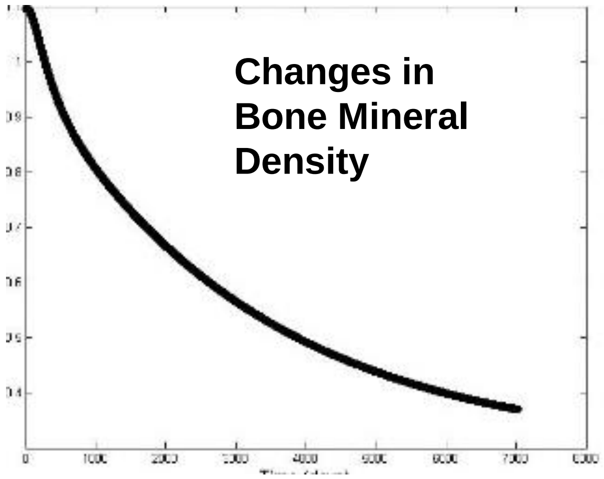
Conclusions

- **Computational modeling can be used to support spaceflight research and countermeasure design**
  - Develop and perform simulations to test hypotheses
  - Determine key factors of the system to aid experimental design

- **Computational modeling can be used to perform simulations that reduce the number of required experimental tests**
  - Provide predictions and answers to ‘What If?’ questions
  - Perform simulated experimental trials







Thank You!!

Questions?