

## **Musculoskeletal Modeling Component of the NASA Digital Astronaut Project**

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### **INTRODUCTION**

The NASA Digital Astronaut Project's (DAP) objective is to provide computational tools that support research of the physiological response to low gravity environments and analyses of how changes cause health and safety risks to the astronauts and to the success of the mission. The spaceflight risk associated with muscle atrophy is impaired performance due to reduced muscle mass, strength and endurance. Risks of early onset of osteoporosis and bone fracture are among the spaceflight risks associated with loss of bone mineral density.

### **METHODS**

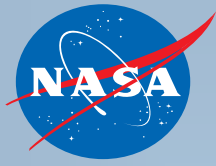
Tools under development include a neuromuscular model, a biomechanical model and a bone remodeling model. The neuromuscular model will include models of neuromuscular drive, muscle atrophy, fiber morphology and metabolic processes as a function of time in space. Human movement will be modeled with the biomechanical model, using muscle and bone model parameters at various states. The bone remodeling model will allow analysis of bone turnover, loss and adaptation. A comprehensive trade study was completed to identify the current state of the art in musculoskeletal modeling. The DAP musculoskeletal models will be developed using a combination of existing commercial software and academic research codes identified in the study, which will be modified for use in human spaceflight research. These individual models are highly dependent upon each other and will be integrated together once they reach sufficient levels of maturity.

### **ANALYSES**

The analyses performed with these models will include comparison of different countermeasure exercises for optimizing effectiveness and comparison of task requirements and the state of strength and endurance of a crew member at a particular time in a mission.

### **DISCUSSION**

The DAP musculoskeletal model has the potential to complement research conducted on spaceflight induced changes to the musculoskeletal system. It can help with hypothesis formation, identification of causative mechanisms and supplementing small data samples.



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## BACKGROUND

### NASA's Digital Astronaut Project (DAP) Objectives

- Provide computational tools that support research of the physiological response to low gravity environments
- Provide computational tools to aid in analyses of how spaceflight induced physiological changes cause health and safety risks to the astronauts and to the success of the mission

### Human Research Program Risks the DAP Musculoskeletal Modeling Addresses

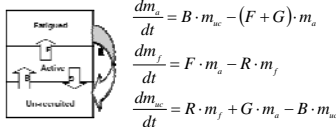
- The spaceflight risk associated with muscle atrophy is impaired performance due to reduced muscle mass, strength and endurance
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## METHODS

### Neuromuscular Subcomponent

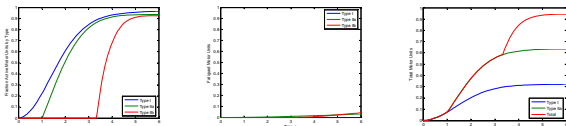
- Neuromuscular drive and activation
- Muscle atrophy and fiber morphology
- Metabolic processes
- Blood flow and intramuscular pressure
- Fatigue

Neural Activation Model Theory (Adapted from Ref. 1)



B is the rate of motor unit recruitment,  $m_a$  is the number of active motor units  
 F is the rate of motor unit fatigue, is the number of fatigued motor units  
 R is the rate of motor unit recovery, is the number of inactive motor units  
 G is the rate of release from an active state to an inactive state

### Example Neural Activation Model Output

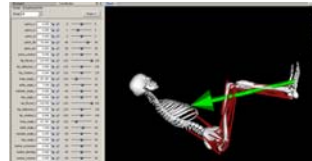


## METHODS (Con't)

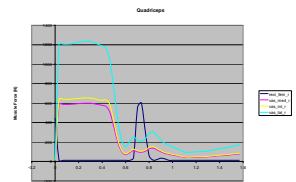
### Biomechanical Subcomponent

- Human exercise/movement simulation
- Prediction of muscle and muscle forces used in the movements
- Predictions of energy consumed and work performed

### Example OpenSim Leg Press Model



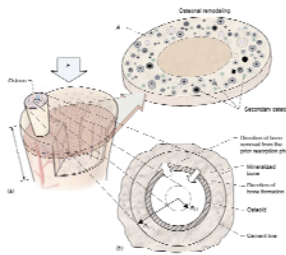
### Example OpenSim Muscle Force Calculation



### Bone Remodeling Subcomponent

- Biochemical equations
- Cellular dynamics
- Mechanical stimulus
- Cortical bone tissue rate of change
- Bone fluid calcium rate of change

### Sketch of Bone Remodeling Model (Ref. 3)



### Example Output of Bone Remodeling Model (Ref. 3)

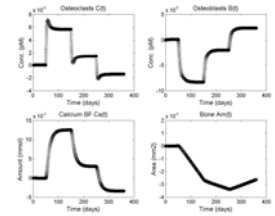


Figure 4—(left) sketch of the model. A cylindrical section of cortical bone carries a shear load. It has a single  $\alpha_1$  and cortical area. A bone cross section contains calcium remodeling sites which are housing osteoclasts (orange), active osteons (green) or completed,  $\alpha_2$ -osteons (blue) and a resting osteon (yellow). The model is the cortical bone. (right) Example of the model output. A. An osteoclast is recruited to the site of the remodeling site. B. The osteoclasts are active and resorbing bone. C. The osteoclasts are completed and the remodeling site is now a resting osteon. D. The osteoclasts are completed and the remodeling site is now a resting osteon. E. The osteoclasts are completed and the remodeling site is now a resting osteon. F. The osteoclasts are completed and the remodeling site is now a resting osteon.

Figure 4. (left) shows the changes in osteoclasts, osteons, bone fluid calcium, and bone area obtained by setting  $\tau = 0$  on day 50, increasing  $\tau$  to 20 on day 150, and then increasing the average load  $\tau$  to 30 on day 200.

## ANALYSES

### Uses For DAP Musculoskeletal Tools

- Comparison of different countermeasure exercises and exercise prescriptions to optimize effectiveness
- Comparison of task requirements and the state of strength and endurance of a crew member at a particular time in a mission

## DISCUSSION

### Model Potential

- The DAP musculoskeletal model has the potential to complement research conducted on spaceflight induced changes to the musculoskeletal system. It can help with hypothesis formation, identification of causative mechanisms and supplementing small data samples.
- Future plans include integration of DAP musculoskeletal subcomponents

## ACKNOWLEDGEMENTS

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## BIBLIOGRAPHY

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