THE VALUE OF BIOMEDICAL SIMULATION ENVIRONMENTS TO FUTURE HUMAN SPACE FLIGHT MISSIONS

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Disclosure Information

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I have no financial relationships to disclose.

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

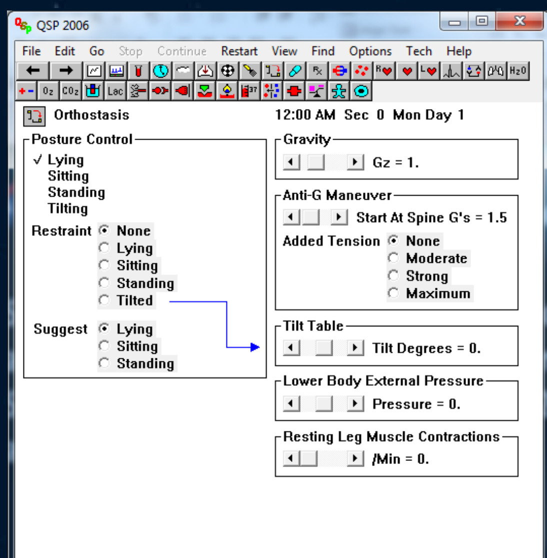
Introduction

- Mars and NEO missions will expose astronaut to extended durations of reduced-gravity, isolation and higher radiation
- These new operation conditions pose health risks that are not well understood and perhaps unanticipated
- Advanced computational simulation environments can beneficially augment research to predict, assess and mitigate potential hazards to astronaut health
- The NASA Digital Astronaut Project (DAP), within the NASA Human Research Program, strives to achieve this goal

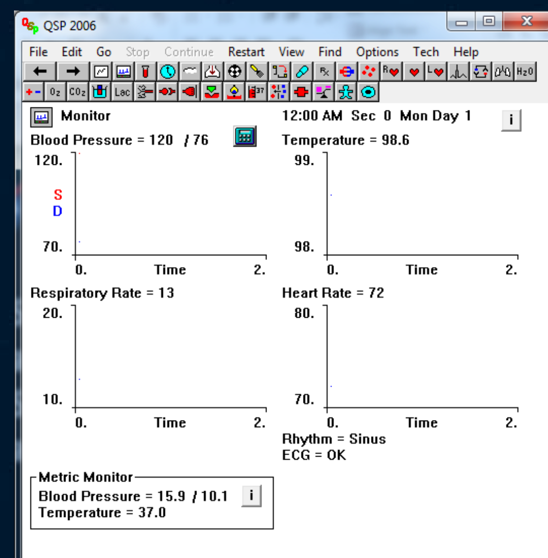
Quantitative Space Physiology

- The University of Mississippi Medical Center's Quantitative Circulatory Physiology education model was adapted for space flight physiology
- The Guyton-Coleman model was substantially expanded to include 4000 variables and equations
- The focus was on physiologic impacts of reduced gravity, analogue environments and nutrition on the cardiovascular system

Orthostasis and Bed rest controls



Monitor for basic vitals



Quantitative Space Physiology Applications

- Predictive simulations for the effect of spaceflight and bed rest on the cardiovascular system
  - Changes in left ventricle mass from preflight to landing day to the third day of the post-flight recovery period of shuttle missions (Summers *et al.,* 2007)
  - Role for lower extremity interstitial fluid volume changes in the development of orthostasis after simulated microgravity (Platts *et al.*, 2007)
  - Mechanisms of cardiac diastolic function changes after microgravity exposure (Summers *et al.*, 2008)

New Initiatives of the DAP

- Musculoskeletal modeling to augment ongoing research within the Exercise Physiology and Countermeasures (ExPC) Project, to address muscle and bone risks and gaps:
  - "RISK OF IMPAIRED PERFORMANCE DUE TO REDUCED MUSCLE MASS, STRENGTH AND ENDURANCE"
    - **SM7:** Can an integrated post-flight functional task performance test be used on returning ISS crew members to obtain performance decrements?
    - **M7:** Can the current in-flight performance be maintained with reduced exercise volume?
    - **M8:** What is the minimum exercise regimen needed to maintain fitness levels for tasks
    - **M9:** What is the minimum set of exercise hardware needed to maintain those (M8) fitness levels?
  - "RISK OF BONE FRACTURE"
  - "RISK OF EARLY ONSET OSTEOPOROSIS DUE TO SPACEFLIGHT"
    - **B1:** **a)** Is there an increased lifetime risk of fragility fractures/osteoporosis in astronauts?
      b) Is bone strength completely recovered post-flight, and does BMD reflect it?
      c) What are the risk factors for poor recovery of BMD/bone strength?
    - **B15:** What exercise protocols are necessary to maintain skeletal health and can exercise hardware be designed to provide these?
    - **B30:** What are the loads applied to bone in-flight and during EVA activities and do they increase fracture risk in light of expected bone loss?

HRP-47065 REV B: HRP Integrated Research Plan (pp. 284-291; 412-436; 455-488) - http://humanresearch.jsc.nasa.gov

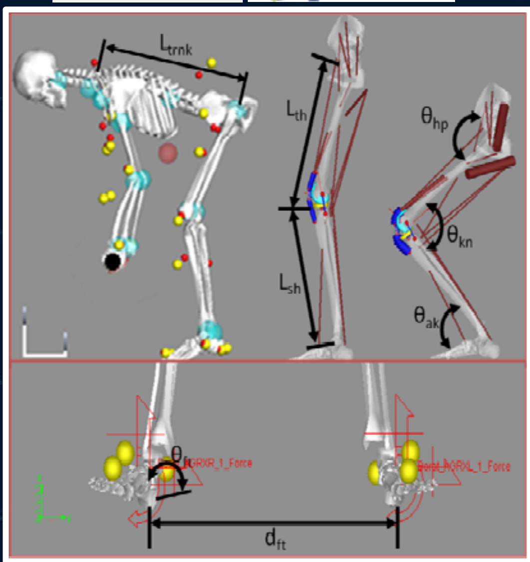
DAP Musculoskeletal Model

Development & Implementation

Johnson Space Center
Project & Science Management
Model Development
(Physiology)
Application to Research

Glenn Research Center
Computation Model
Development for ARED/VIS

LifeModeler Bringing Simulation to Life
OpenSim 1.0



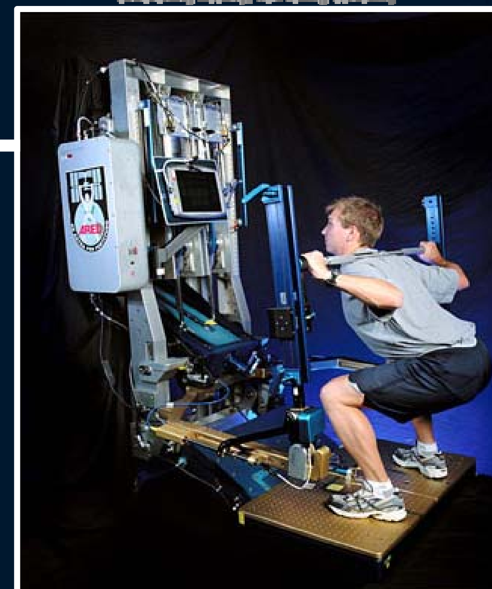
Musculoskeletal Models

V&V

Verification & Validation

V&V

MSC Software ADAMS



ARED/VIS Device Model

Output

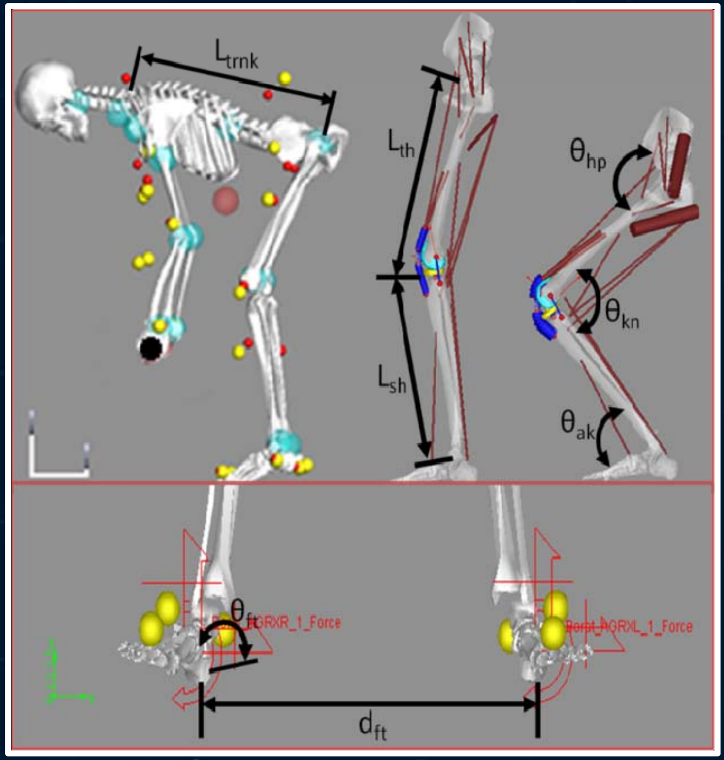
Effect on Muscle, Bone and Joints

Task Optimization w.r.t. Physiological Limits

In silico Analysis

Biomechanical Models

- Human exercise/movement simulation in micro-gravity
  - Squat (regular and single-leg)
  - Dead-lift
  - Heel-raise
  - Hip ab/adduction
  - Hip flexion & extension



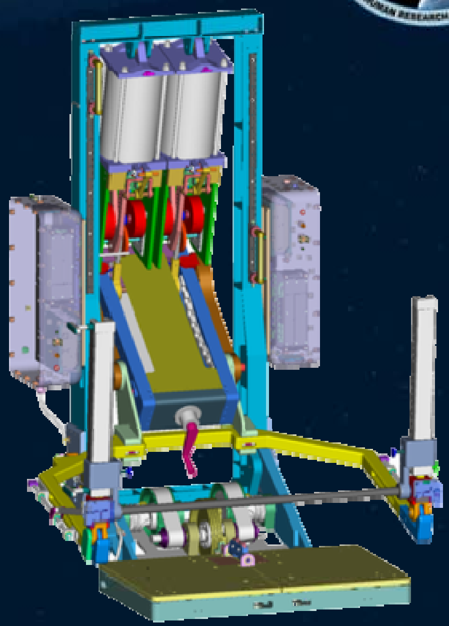
- Prediction of:
  - Muscle forces
  - Ground reaction forces
  - Joint torque
  - Mechanical load bones/joints

- Influence of:
  - Anthropometric variation
  - Stance variation
  - Range of motion

- Being developed by the Exercise Physiology Laboratory at Johnson Space Center and University of Washington

Advanced Resistive Exercise Device Model

- ADAMS kinematic model of Advanced Resistive Exercise Device and Vibration Isolation System
  - Bar exercises
  - Cable exercises

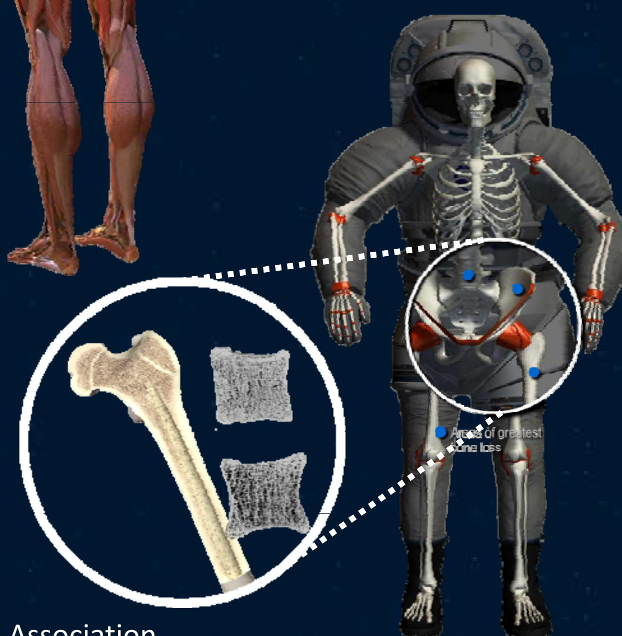


- Model being developed by ZIN Technologies in Cleveland, OH

Muscle and Bone Adaptation Models

- Biomechanical models of exercise countermeasures
- Predicted muscle force is an input to the bone adaptation model
- Models being developed at Glenn Research Center
- Muscle adaptation factors:
  - Neuromuscular drive and activation
  - Muscle atrophy and fiber morphology
  - Blood flow and intramuscular pressure
  - Metabolic processes
  - Fatigue
- Bone adaptation model factors :
  - Cortical bone tissue rate of change
  - Bone fluid calcium rate of change
  - Biochemical equations
  - Mechanical stimulus
  - Cellular dynamics
- Bone adaptation model predicts osteogenesis

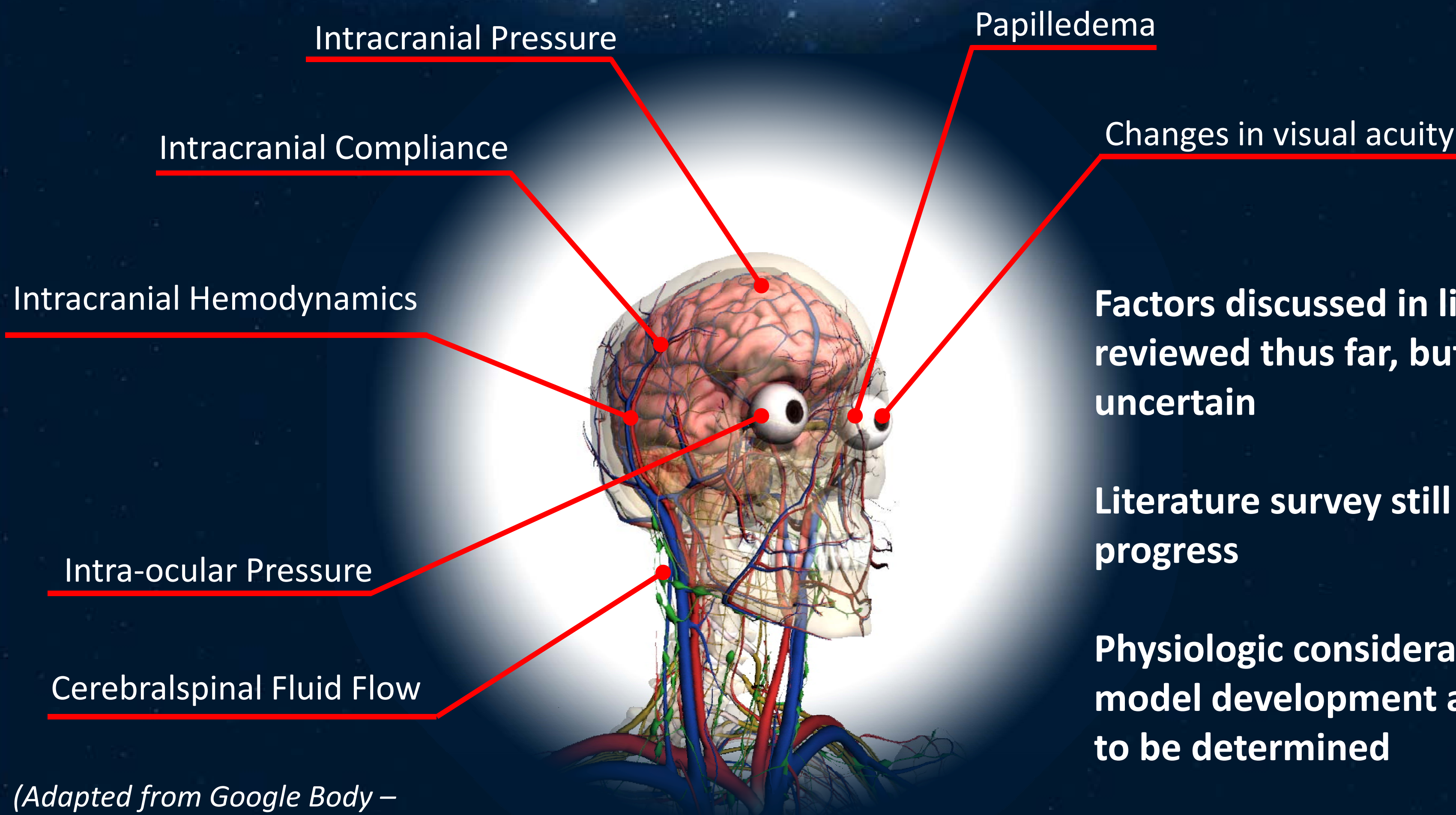
(Pennline, 2009; Lewandowski et al., 2011)



End Goal of DAP Musculoskeletal Modeling Effort

- Load distribution analysis during various exercises
- Customize exercise prescriptions based on individual anthropometrics and needs
- Functional task analysis
- New exercise development (e.g. non-traditional exercise)
- Foundation for advanced exercise device modeling for solar system and planetary surface missions

Future Work: Risk of Impaired Vision

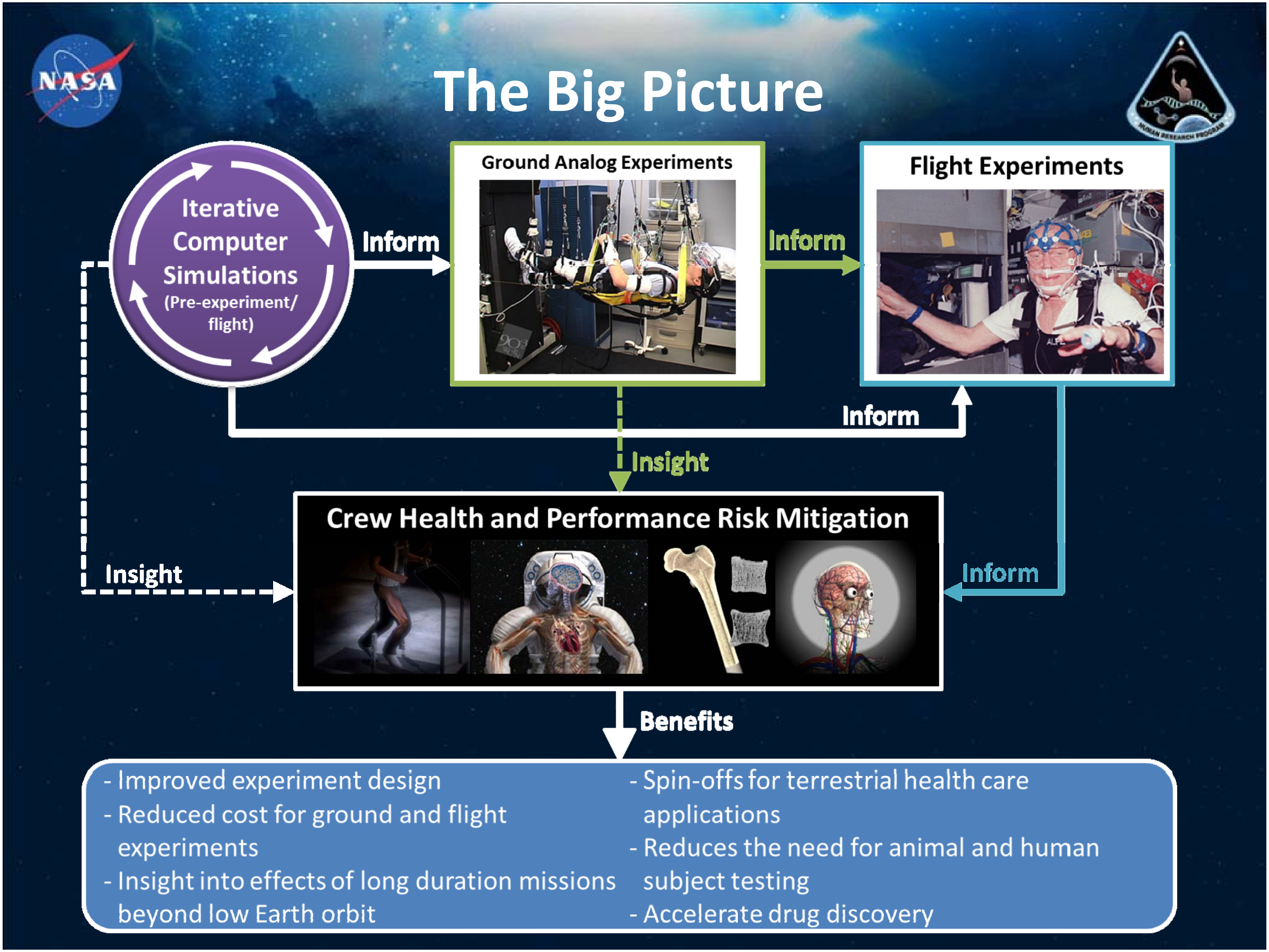


(Adapted from Google Body – http://bodybrowser.googlelabs.com)

Factors discussed in literature reviewed thus far, but cause is uncertain

Literature survey still in progress

Physiologic considerations for model development are still to be determined



The Big Picture
Iterative Computer Simulations (Pre-experiment/ flight)
Inform
Ground Analog Experiments
Inform
Flight Experiments
Inform
Insight
Crew Health and Performance Risk Mitigation
Insight
Inform
Benefits
- Improved experiment design
- Reduced cost for ground and flight experiments
- Insight into effects of long duration missions beyond low Earth orbit
- Spin-offs for terrestrial health care applications
- Reduces the need for animal and human subject testing
- Accelerate drug discovery

Primary References

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Questions?