DEVELOPMENT OF A HIGH FIDELITY DYNAMIC MODULE OF THE ADVANCED RESISTIVE EXERCISE DEVICE (ARED) USING ADAMS®

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NASA’s Digital Astronaut Project (DAP) implements well-vetted computational models to predict and assess spaceflight health and performance risks, and enhance countermeasure development. DAP provides expertise and computation tools to its research customers for model development, integration, or analysis.

DAP is currently supporting the NASA Exercise Physiology and Countermeasures (ExPC) project by integrating their biomechanical models of specific exercise movements with dynamic models of the devices on which the exercises were performed. This presentation focuses on the development of a high fidelity dynamic module of the Advanced Resistive Exercise Device (ARED) on board the ISS. The ARED module, illustrated in the figure below, was developed using the Adams (MSC Santa Ana, California) simulation package.

The Adams package provides the capabilities to perform multi rigid body, flexible body, and mixed dynamic analyses of complex mechanisms. These capabilities were applied to accurately simulate:

- Inertial and mass properties of the device such as the vibration isolation system (VIS) effects and other ARED components
- Non-linear joint friction effects
- The gas law dynamics of the vacuum cylinders and VIS components using custom written differential state equations
- The ARED flywheel dynamics, including torque limiting clutch

Design data from the JSC ARED Engineering team was utilized in developing the model. This included solid modeling geometry files, component/system specifications, engineering reports and available data sets.

The Adams ARED module is importable into LifeMOD (Life Modeler, Inc., San Clemente, CA) for biomechanical analyses of different resistive exercises such as squat and dead-lift. Using motion capture data from ground test subjects, the ExPC developed biomechanical exercise models in LifeMOD. The Adams ARED device module was then integrated with the exercise subject model into one integrated dynamic model.

This presentation will describe the development of the Adams ARED module including its capabilities, limitations, and assumptions. Preliminary results, validation activities, and a practical application of the module to inform the relative effect of the flywheels on exercise will be discussed.
### Background

**NASA's Digital Astronaut Project (DAP) Vision**

The Digital Astronaut Project implements well-vetted computational models to predict and assess space flight health and performance risks, and enhance countermeasure development by:

- Partnering with subject matter experts to inform HRP knowledge gaps and countermeasure development decisions;
- Modeling and simulating the adverse physiologic responses to exposure to reduced gravity and analog environments; and
- Ultimately providing timely input to mission architecture and operations decisions in areas where clinical data are lacking.

**HRP Risks/Gaps Addressed by This Effort**

Risk of Muscle Atrophy: impaired performance due to reduced muscle mass, strength and endurance

- **Gap M7:** Can the current in-flight performance be maintained with reduced exercise volume?
- **Gap M8:** What is the minimum exercise regimen needed to maintain fitness levels for tasks?
- **Gap M9:** What is the minimal set of exercise hardware needed to maintain those fitness levels?

Risk of Loss of Bone Mineral Density: early onset of osteoporosis and bone fracture

- **Gap B16:** How can where necessary to maintain skeletal health and (b) can exercise hardware be designed to provide these?
- **Gap B17:** Is there an increased lifetime risk of fragility fractures/osteoporosis in astronauts? (b) is bone strength completely restored after flight, and does BMD reflect it? (c) what are the risk factors for poor recovery of BMD/bone strength?

**Integration of Biomechanical and Device Modeling**

**Biomechanical Module**

- Forward dynamics modules in LifeMOD® (a plug-in to ADAMS®) representative of the subject's anthropometrics and motions during the performance of various exercises, including squat, single-leg squat and deadlift.

**Integrated Device & Biomechanics Module (nasa std)**

- ARED Module and Biomechanical module integrated and simulated together

**ARED Device Module**

**Capabilities**

- Directly importable into LifeMOD®
- Full configurable device (load setting, bar position, etc.)
- Forward and inverse (kinematic) driven dynamics
- Configurable for ground or ISS (VIS) use
- Inertial and mass properties of the device such as vibration isolation system (VIS) effects and other ARED components
- Non-linear joint friction effects
- Gas law dynamics of vacuum cylinders and VIS components using custom written differential state equations
- ARED Flywheel dynamics, including torque limiting clutch

**Limitations**

- Bar Exercise Only (Cable Exercises not implemented)
- Rigid body dynamics

**Source Data**

- JSC ARED Engineering Team
- Gold modeling geometry data
- Component/Srtem Specifications
- Engineering verification data sets

**Vacuum Cylinders**

**Flywheels**

**Load Adjustment Mechanism**

**VIB (VIS)**

- **Superimposed Motion Plot of ARED**

**FUTURE WORK**

- Models of other exercise devices
  - ZIN Cam Air Spring Device
  - Multi-mode Exercise Device – NSBRI
  - Streamline® Compact Controlled Force Exercise Device – SBIR

**ACKNOWLEDGEMENTS**

This work is funded by the NASA Human Research Program, managed by the NASA Johnson Space Center. Specifically, this work is part of the Digital Astronaut Project (DAP), which directly supports the Human Health and Countermeasures Element. The DAP project is managed out of NASA/Glenn research center by DeVan W. Griffin, Ph.D., Lealem Mulugeta of USRA serves as Project Scientist.