
Concept Study of using a Passive Mechanism to Simulate Walking on the Moon

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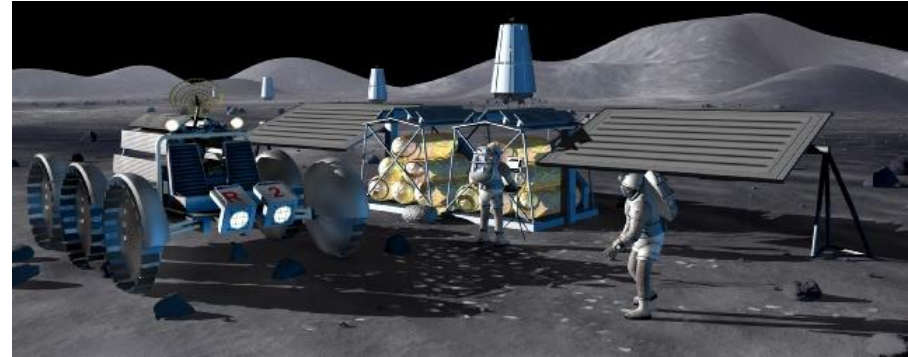
Overview

- Background
- Project Objectives
- Research Results
- Education Results
- Follow-up Work
- Conclusions

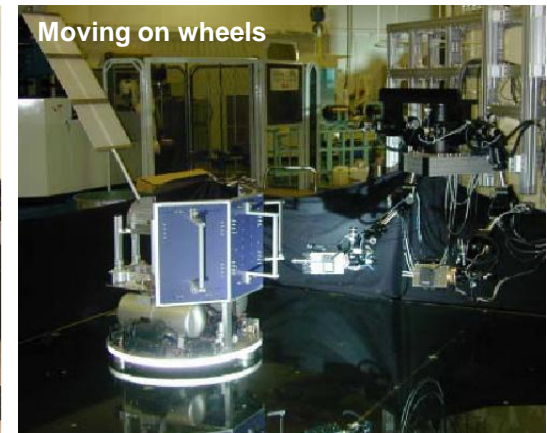
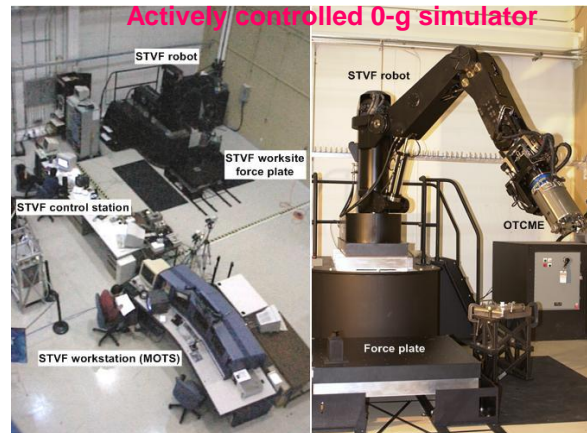
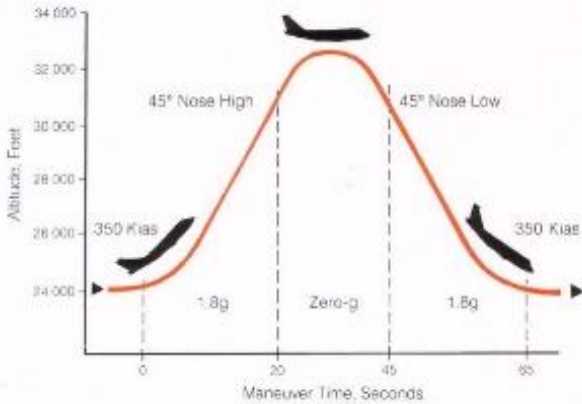
Background

- ❑ **Astronauts usually spend an order more time in training than the real time in space**
- ❑ **Future manned missions (to Moon and Mars) obviously require lots of EVA training**
- ❑ **NASA needs innovative and cost-effective EVA training technologies**
- ❑ **Statically balanced mechanisms can compensate partial body weight very reliably.**
- ❑ **Similar technology has been used for healthcare applications.**
- ❑ **It can also be used for EVA training which is the hypothesis being investigated by this research.**

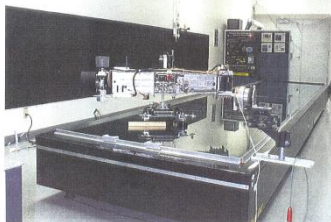
Background



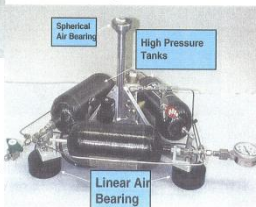
Current Reduced-Gravity Simulation Methods



Sliding on air-bearing

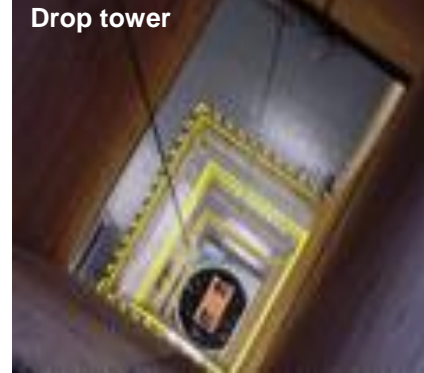
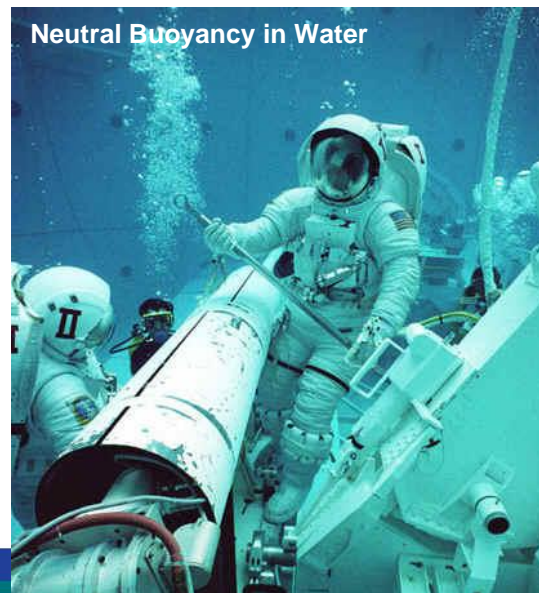


- Features:
- Extends the conventional 3 Degree-of-freedom (DOF) spherical air bearing with 2 DOF translations
 - Simulates micro-gravity environment
 - Test line-of-sight (LOS) stability in the presence of lateral divers
 - Provides a rapid turnaround testbed for resolving real-time software & hardware integration issues



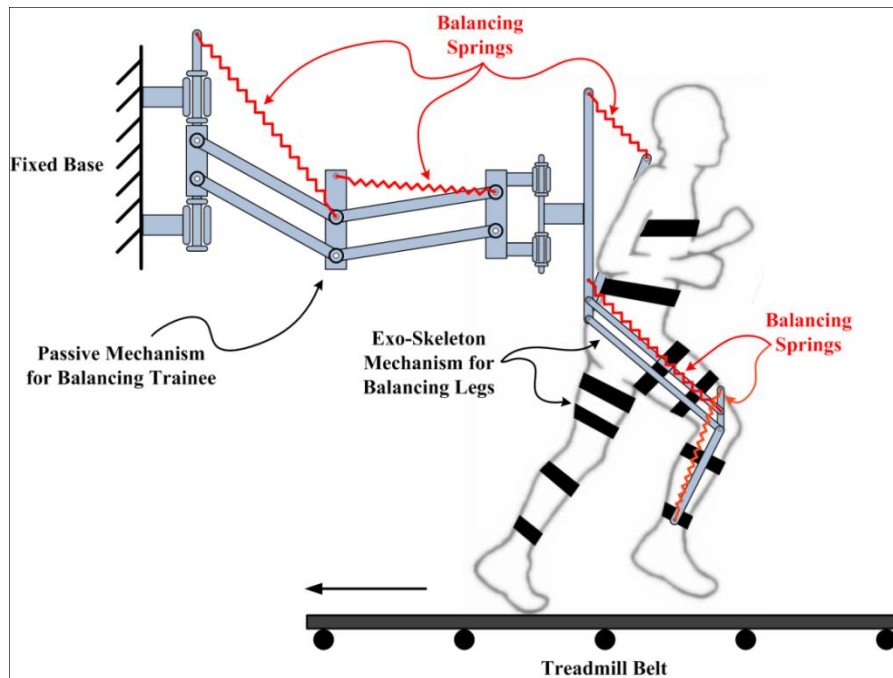
- Accomplishments to date:
- Performed over 400 ground flight tests in 10 month period - Peak rate of 70 tests in 4 days
 - Demonstrated autonomous ability to acquire, track, image, and inspect a moving point target while diverting at low gee

MicroSat Technologies Program - AGL 92996



Our Concept

A passive mechanical system capable of simulating walking, running, hopping, jumping, etc., in a reduced-gravity environment.



Pros:

- Unpowered (unactuated)
- Simple and reliable
- Low cost
- Low maintenance
- Easy operation
- Easy access

Cons:

- Static balancing only
- Inertia forces remain
- Limited workspace
- Joint friction

Technical Challenges:

- Unknown human inertia distribution (everyone is different)
- Solution to the dynamic loading and friction problems
- Design challenges (springs, ergonomics, etc. and safety)

Theory

Lagrangian equations of motion:

1) When no joint torques (because of passive joints)

$$\boldsymbol{\tau} = \frac{d}{dt} \left(\frac{\partial T}{\partial \dot{\boldsymbol{\theta}}} \right) - \frac{\partial T}{\partial \boldsymbol{\theta}} + \frac{\partial V}{\partial \boldsymbol{\theta}} = \mathbf{0}$$

2) For static balancing

$$T = 0$$

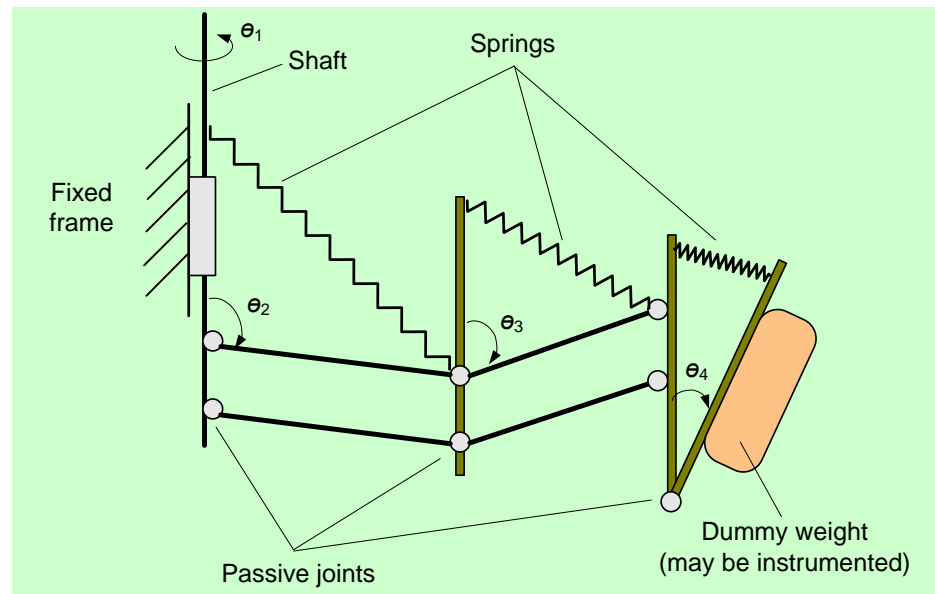
Therefore

$$\frac{\partial V}{\partial \boldsymbol{\theta}} = \mathbf{0} \quad \Rightarrow \quad V = \text{constant}$$

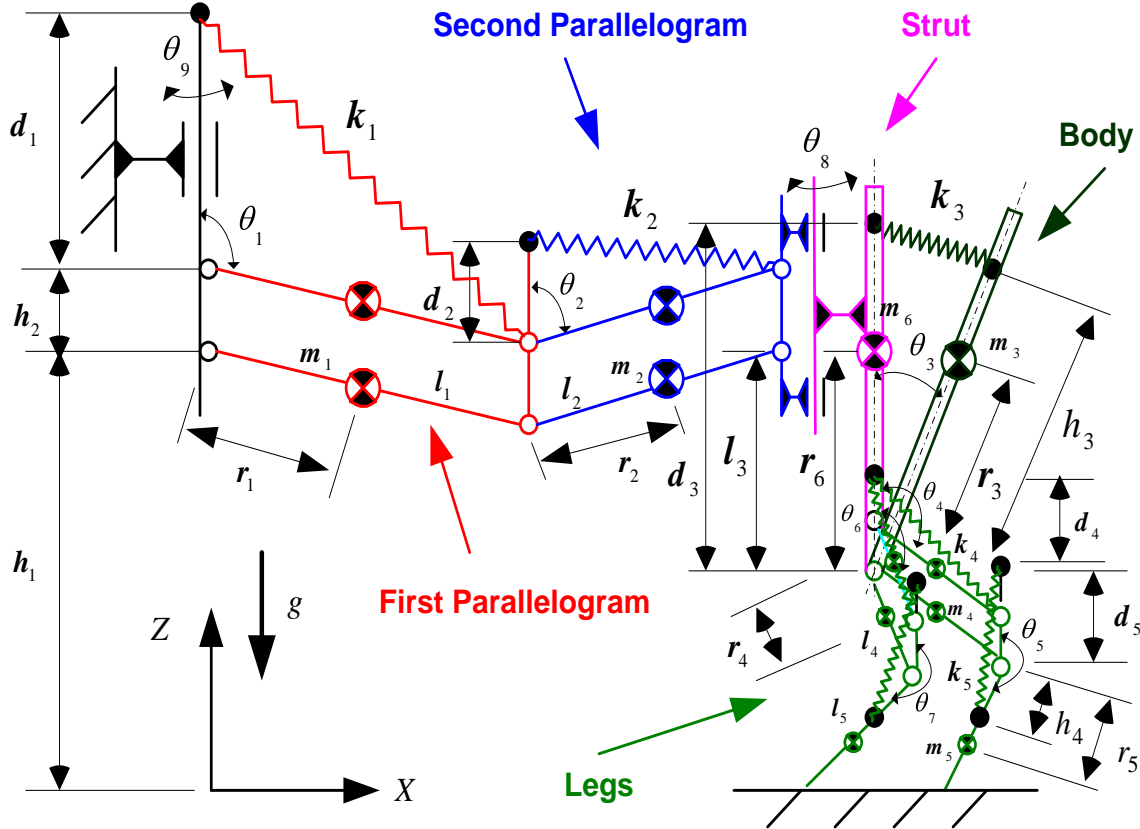
Project Objectives

- 1) Conduct a preliminary feasibility study of the new concept.
- 2) Design a simplified prototype for experiment, as shown below.
- 3) Training students by engaging them in the theory, design and test of the innovative system.

All of these objectives were accomplished as defined in the original proposal.



Research Results - Design



$$k_1 = \frac{2m_1 r_1 + l_1 (2m_2 + M_M + \rho M_B) g}{l_1 d_1} g$$

$$k_2 = \frac{2m_2 r_2 + l_2 (M_M + \rho M_B) g}{l_2 d_2} g$$

$$k_3 = \frac{\rho m_3 r_3}{h_3 d_3} g$$

$$k_4 = \frac{(2m_4 + \rho m_{ul}) r_4 + (m_5 + m_{ll}) l_4}{l_4 d_4} g$$

$$k_5 = \frac{(m_5 + m_{ll}) r_5}{h_4 d_5} g$$

Research Results - Simulation

Total mass: 150 kg (75-kg mechanism and 75-kg human)

$$m_1 = m_2 = 10 \text{ kg}$$

$$m_3 = 60 \text{ kg}; m_4 = 15 \text{ kg}; m_5 = 10 \text{ kg}; m_6 = 20 \text{ kg}$$

$$l_1 = l_2 = 0.5 \text{ m}; l_4 = 0.35 \text{ m}; l_5 = 0.35 \text{ m}$$

$$h_3 = 0.3 \text{ m}; h_4 = 0.1 \text{ m}$$

$$d_1 = d_2 = 0.2 \text{ m}; d_3 = 0.6 \text{ m}; d_4 = d_5 = 0.1 \text{ m}$$

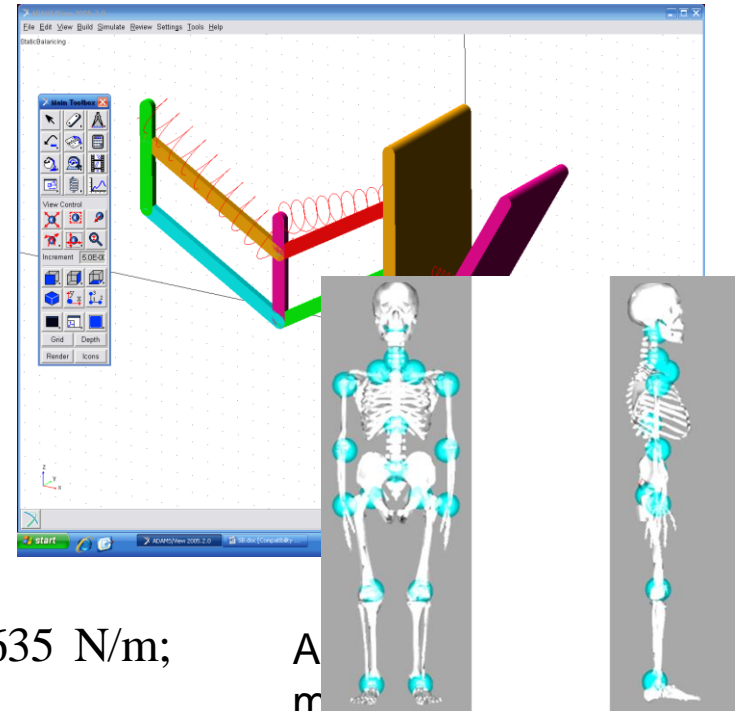
$$r_1 = r_2 = 0.25 \text{ m}; r_3 = 0.5 \text{ m}; r_4 = 0.25 \text{ m};$$

$$r_5 = 0.3 \text{ m}; g = 9.81 \text{ m/s}^2$$

Design results: spring stiffness values

$$k_1 = 9319.5 \text{ N/m}; k_2 = 8338.5 \text{ N/m}; k_3 = 1635 \text{ N/m};$$

$$k_4 = 3083 \text{ N/m}; k_5 = 2943 \text{ N/m}$$

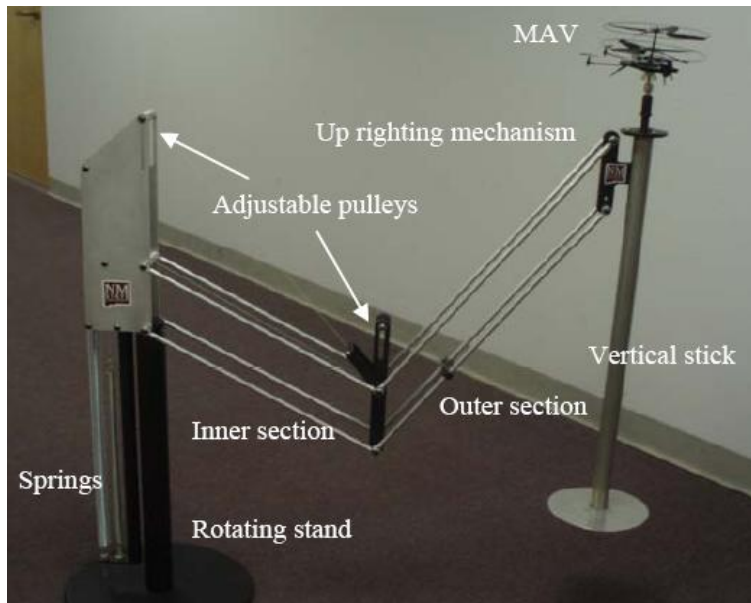


A human skeleton is modeled into the rigid links

Research Results - MAV Test Stand

A gravity-balanced stand for testing micro UAV:

MAVs usually have zero or little payload capability. This makes them difficult to be tested with a conventional test stand. The gravity-balanced test stand can solve this problem.



This physical prototype makes us feel more confidence on the new technology

Research Results - Publications

- 1) Lu, Q., McAvoy, J., and Ma, O., " A Simulation Study of using a Gravity-Balanced Mechanism to Simulate Human Walking in a Reduced-Gravity Environment", submitted to the 2009 *ASME Dynamic Systems and Control Conference*, Oct.12-14, 2009, Hollywood, CA.
- 2) Ortega, C., Ma, O., and Ruble, K., "Gravity-Balanced Test Stand for Testing Micro Air Vehicles", accepted by the *AIAA Atmospheric Flight Mechanics Conf.*, Aug. 10-13, 2009, Chicago, IL.
- 3) Qi, L., Ortega, C. and Ma, O., "A gravity balanced test stand for flight testing of small/micro unmanned aerial vehicles", *Proc. ASME Int. Mech. Eng. Congress*, Boston, MA, Oct.31-Nov.6, 2008, paper #IMECE2008-67978.

Ma, O., Ortega, C. and Ruble, K., "A Gravity-Balanced Test Stand for Testing Micro Air Vehicles (MAVs)", US Patent (pending).

Interaction with NASA

- ✓ Made a visit to Jonson Space Center.
 - Presented the research concept and had discussion with NASA scientists/engineers
 - Visited the ARGOS lab (a new lunar EVA training facility) and the VR Lab
 - Visited the Simulation and Robotics group.

- ✓ Kept regular contact with the following NASA people
 - Dr. Robert Savely, chief scientist, Simulation, Robotics and Software, NASA/JSC
 - Mr. Leslie Quicho, group leader, Simulations, NASA/JSC
 - Mr. Larry Dungan, manager, AGROS, NASA/JSC

- ✓ Jesse MacAvoy will be working in NASA/JSC for the summer working in ARGOS Lab

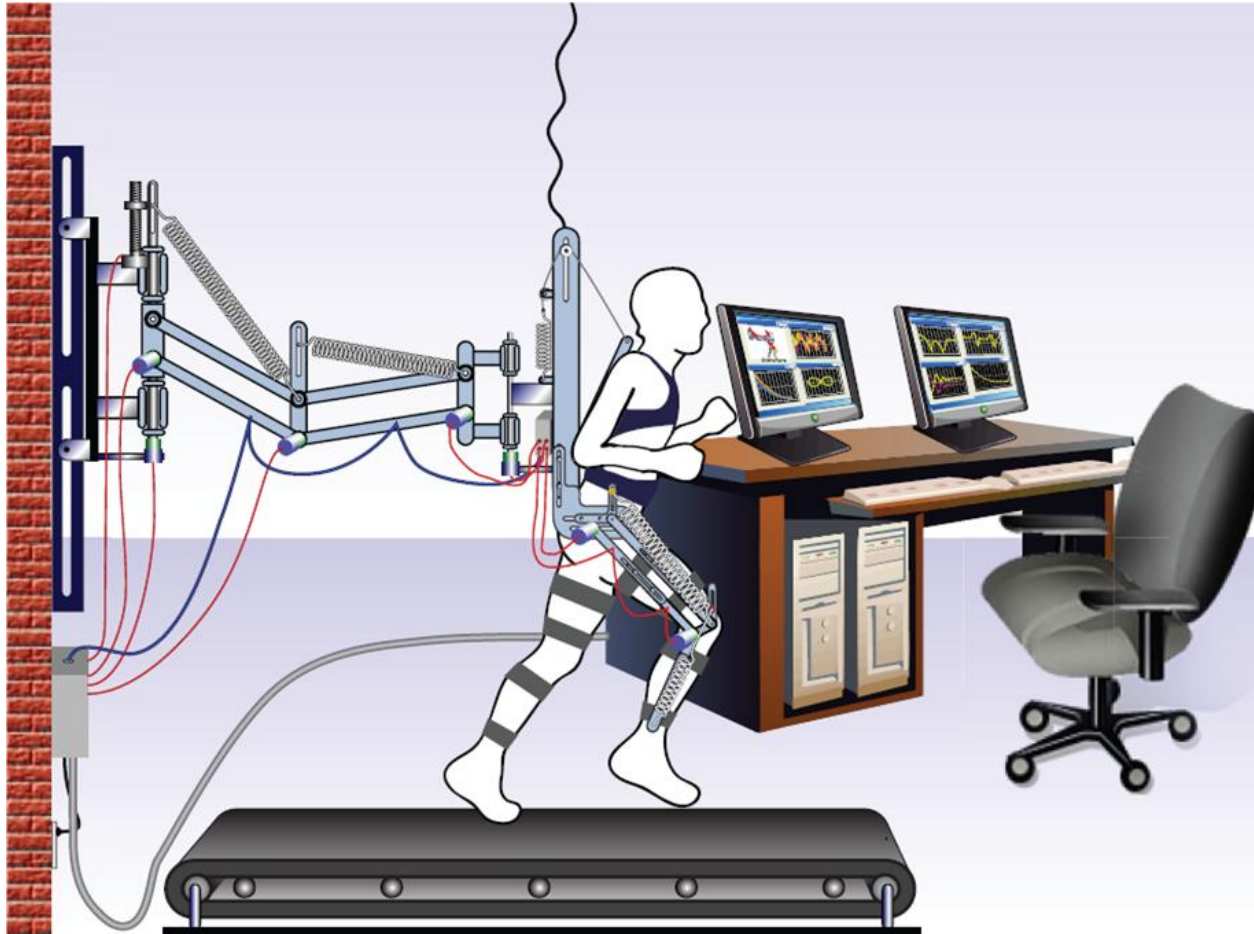
Education Results

- ✓ 5 students directly participated in and trained by the project:
 - Jesse McAvoy - Ph.D. student (system design and analysis)
 - Qi Lu - Ph.D. student (modeling and simulation)
 - Carrols Ortega - Master student (detailed mechanical design & hardware testing)
 - Ken ruble - Undergraduate student (hardware construction)
 - Paul Hamilton - Undergraduate student (hardware implementation support)
- ✓ Students were trained through a whole development cycle including concept design, modeling & simulation, detailed parts design and analysis, hardware fabrication, and testing.
- ✓ Mixing all levels of students (Ph.D., master and undergraduate) in the same team benefited their training for collaboration and complement abilities.
- ✓ *These students were trained in technical writing by co-authoring research papers.*

Proposal Efforts for Follow-Up Research

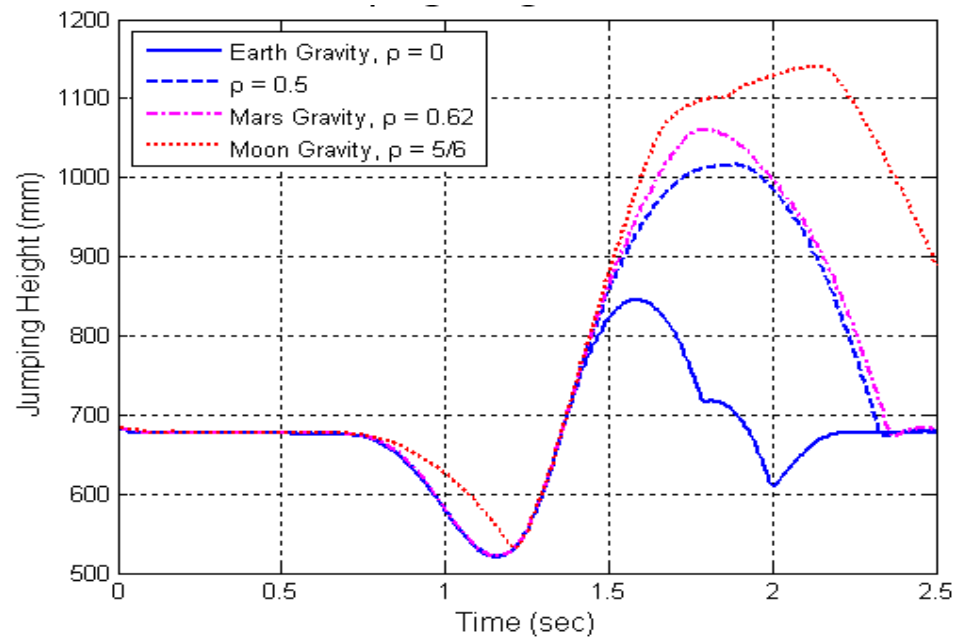
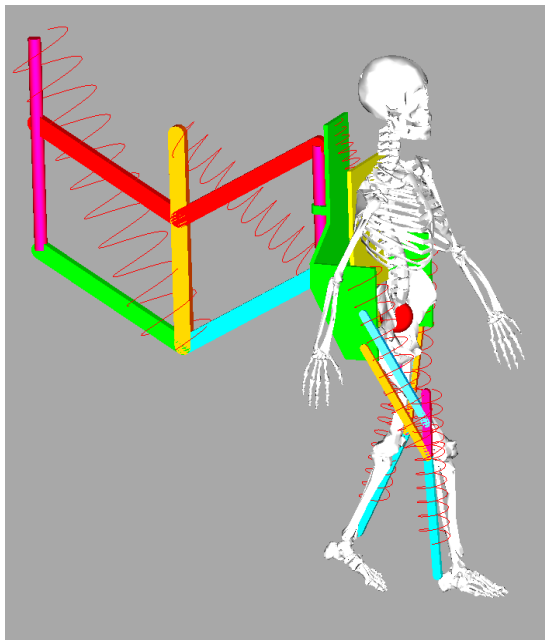
- ✓ EPSCoR RID grant of \$50,000 for March 2009 – March 2010
Title: “Feasibility Study of using Passive Mechanisms to Simulate Reduced Gravity for Training Astronauts”
- ✓ NASA Graduate Research Fellowship (to Jesse McAvoy) \$30,000/year for 3 years
Title: “Development of Reduced Gravity Simulation Technology”
- ✗ NASA URC – a part of the 2008 URC proposal
Rated “Excellent” but not awarded
- ? A proposal to NIH for developing human-model identification technology
Title: “An Innovative Technology for Dual Uses: Enhancing Human Modeling and Rehabilitation”

Proposal Efforts for Follow-Up Research



Follow-up Work – Human Dynamics Simulation

Use a multi-DOF human dynamics model – on going research



Follow-Up Work - Hardware Test

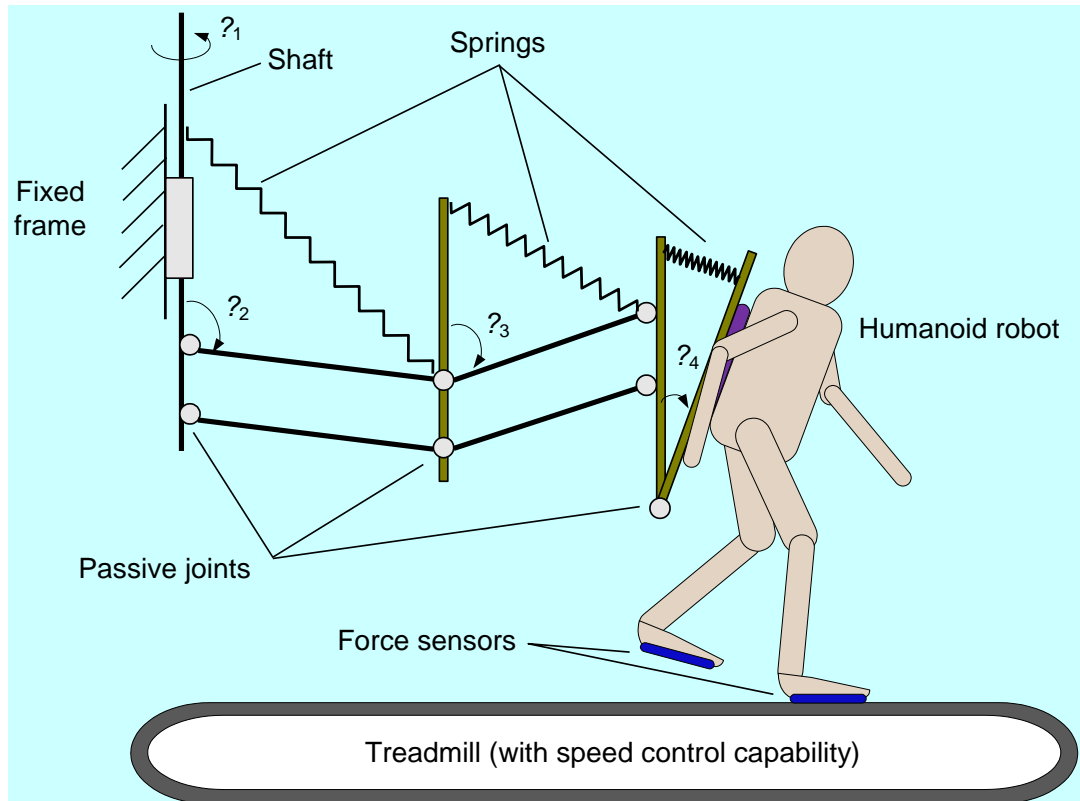
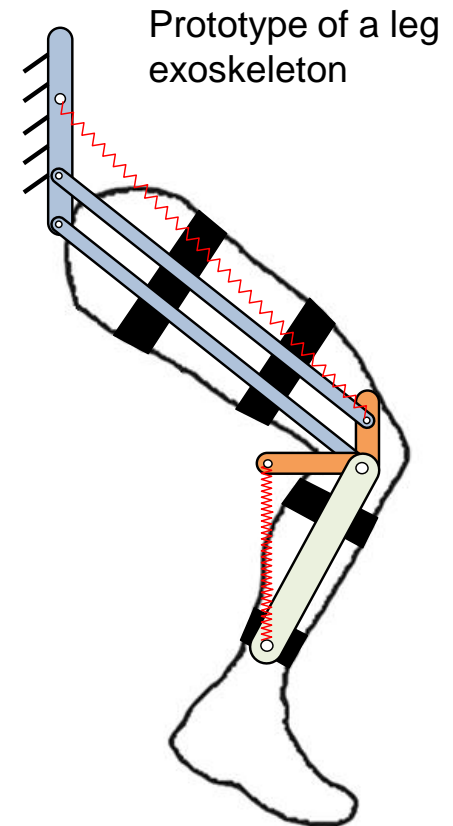


Fig.3 A robot based testbed for testing the engineering principle of the new method



Conclusion

- ❑ **Proposed a concept of using passive mechanism to simulate walking and in a reduced-gravity environment.**
- ❑ **Did a simulation-based preliminary study.**
- ❑ **Designed a concept of using a robot to do experimental test.**
- ❑ **Trained 5 students with grades spanning from undergraduate to Ph.D.**
- ❑ **Visited and discussed with NASA's EVA facility development group**
- ❑ **Developed a micro UAV test stand as a spin-off application**
- ❑ **Wrote a proposal to NIH proposing to use the technology for enhancing human dynamics modeling and simulation.**

Follow-up work:

- ❑ **NASA awarded Jesse McAvoy a graduate fellowship to do the research**
- ❑ **NASA/NMSGC awarded a follow-up grant to continue the feasibility study**
- ❑ **To propose a major instrumentation proposal to NSF.**

2008 Group 4 Review

Panel Evaluation	
Proposal Information	
Proposal #:	08-URC-0035
Title:	Center for Modeling, Simulation, and Validation (MSV) in the Aerospace Sciences
PI:	Burton, Thomas
Submitting Org:	NEW MEXICO STATE UNIVERSITY
Solicitation:	NNH08ZNE002C
Evaluation Information	
Overall Grade:	Excellent
Review:	NASA Group 4 University Research Centers [URC 2008]

Evaluation Criteria	
Intrinsic Merit - Strengths	
<p>The proposal has stated with reasonable clearness a set of goals and objectives that are aligned with NASA and the institution where the URC is to reside. Sufficient technical details are described for each of the proposed projects. The plan for partnerships with NASA, industry and government labs is also described. Some of the projects, such as the reduced-G simulation, are highly relevant to the ESMD's objectives. The investigators have the expertise and experience to complete the proposed projects. The proposal identifies a good plan for attracting underrepresented and under-served groups from the state of New Mexico. A reasonable plan is presented for documenting outcomes and demonstrating progress toward the stated objectives. The proposal addresses very key issues of advancing technology by giving emphasis on modeling, simulation, and visualization in the four different areas.</p>	
Intrinsic Merit - Weaknesses	
<p>The identification of the role and responsibility of partnerships is relatively weak. The proposal does not show a clear path toward sustainability beyond the direct NASA funding period. While, at the outset, the research appears to be multi-disciplinary, the proposers showed little connection among the four proposed laboratories. The innovations in terms of modeling and simulations are not clearly identified in the proposal. Student support is built into the budget but not fully explained in the proposal. There are no clear outcomes for increasing student interest in STEM. Success of education support hinges on an NSF funded project. It is not clear how students will be involved in the project.</p>	
Intrinsic Merit - Rating	
Very Good	

Research Labs under the URC:

- Contact Dynamics and Reduced-G Lab
- Space Trajectory Optimization and Control Lb
- Gasketetics and Space Propotion Lab
- Structure Health Monitoring and Protection Lab

The proposal is relatively weak in identifying specific means of making direct use of NASA content, people, and facilities.

Relevance to NASA Objectives - Rating

Excellent

Budget/Cost - Strengths:

The proposed budget is in line with the guidelines as described in the announcement.

Budget/Cost - Weaknesses

None.

Budget/Cost - Rating

Excellent

Overall Comments

The proposal has stated with reasonable clearness a set of goals and objectives that are aligned with NASA and the institution where the URC is to reside. Sufficient technical details are described for each of the proposed projects. The plan for partnerships with NASA, industry and government labs is also described. However, the proposers showed little connection among the four proposed laboratories. The proposal identifies a plan for attracting underrepresented and under-served groups from the state of New Mexico, and presents an effort to collaborate with New Mexico Alliance for Minority Participation (AMP). Student support is built into the budget but not fully explained in the proposal. It is not clear how students will be involved in the project. This proposal scores Very Good in Intrinsic Merit and Excellent in Relevance. It is ranked in the Excellent category, but not in the top 4 of all ESMD proposals.

