NASA’S HUMAN RESEARCH PROGRAM AT THE GLENN RESEARCH CENTER: PROGRESS AND OPPORTUNITIES

The NASA Human Research Program is aimed at correcting problems in critical areas that place NASA human spaceflight missions at risk due to shortfalls in astronaut health, safety and performance. The Glenn Research Center (GRC) and partners from Ohio are significant contributors to this effort. This presentation describes several areas of GRC emphasis, the first being NASA’s path to creating exercise hardware requirements and protocols that mitigate the effects of long duration spaceflight. Computational simulations will be a second area that is discussed. This includes deterministic models that simulate the effects of spaceflight on the human body, as well as probabilistic models that bound and quantify the probability that adverse medical incidents will happen during an exploration mission. Medical technology development for exploration will be the final area to be discussed.
NASA’s Human Research Program at The Glenn Research Center: Progress and Opportunities

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http://spaceflightsystems.grc.nasa.gov/Advanced/HumanResearch/
NASA Human Research Program

- **Program goals**
  - Perform research necessary to understand and reduce spaceflight human health and performance risks in support of exploration
  - Enable development of human spaceflight medical and human performance standards
  - Develop and validate technologies that serve to reduce medical risks associated with human spaceflight

-- Clay Anderson centrifuges Nutrition blood samples during Increment 15
-- Seat layout for contingency EVA
-- Example of a study on the effects of center of gravity on performance

http://humanresearch.jsc.nasa.gov/
HRP Leverages Across the Agency

**Ames**
- Space Human Factors & Habitability
- Exploration Medical Capability
- Behavioral Health & Performance
- Space Radiation

**Glenn**
- Human Health Countermeasures
- Exploration Medical Capability

**HQ**
- Advocacy
- Int’l Agreements

**Langley**
- Space Radiation

**Johnson**
- ISS Medical Project
- Space Radiation
- Human Health Countermeasures
- Exploration Medical Capability
- Behavioral Health & Performance
- Space Human Factors & Habitability

**Kennedy**
- ISS Medical Project
GRC Human Research Program

Goals

– Develop effective and reliable on-orbit exercise hardware requirements and validate candidate technologies
– Develop validated, efficient exercise prescriptions that minimize daily time needed for completion of exercise yet maximize performance for mission activities
– Develop medical requirements and technologies to ensure the safety and success of Exploration missions
– Perform hardware development, test and analysis including health care systems and procedures development
– Develop computational physiological and medical risk models for determination of effects of the space flight environment on humans
GRC Human Research Program

- **Exercise Countermeasures:**
  - Develop effective and reliable exercise hardware requirements and validate candidate technologies for long duration exploration crew health maintenance.

- **Exploration Medical Capability:**
  - Quantify medical risk and develop medical technologies to ensure the safety and success of Exploration missions.

- **Digital Astronaut:**
  - Develop computational tools to quantify space normal physiology and guiding research to mitigate risks associated with exploration missions.
Strategic Partnerships

• **Cleveland Clinic Center for Space Medicine**
  – Collaboration via space act agreement to provide an environment and mechanism to promote interdisciplinary research that will exploit the unique skills, capabilities, and facilities of both CCF and NASA GRC in support of long duration spaceflight
  – Congressional appropriation for lecture series and grant seed money

• **John Glenn Biomedical Engineering Consortium**
  – Space act agreement with Case Western Reserve University, Cleveland Clinic Foundation, University Hospitals of Cleveland, the National Center for Space Exploration Research to perform interdisciplinary research leveraging GRC expertise in fluid physics and sensor technology to mitigate critical risks to crew health, safety, and performance.

• **BioEnterprise**
  – Space Act Agreement for collaborative efforts to further the development and commercialization of life science related technologies in Northeast Ohio. Allows NASA access to BioEnterprise clients where technologies may be of benefit to NASA’s mission.

• **Case Western Reserve University/University Hospitals**
  – Leveraging off expertise in the Case Biomedical Engineering Department and the University Hospitals’ Research Institute in the areas of physiological systems, clinical research, and patient care.

• **Wright Patterson Air Force Research Laboratory - Human Effectiveness Directorate**
  – Leveraging off the consolidation of all aerospace medicine and human research activities at WPAFB in response to the BRAC directive. Initiated collaborative effort in the area of circadian rhythm upset and sleep deprivation
NASA’s Human Research Program

Exploration Medical Capability and Digital Astronaut: Tools for Exploration

DeVon Griffin, Ph.D. - Project Manager
Exploration Medical Capability: Overview

- NASA’s Human Research Program (HRP) is now focused on risks
  - No longer based on the NIH model of curiosity-driven research
  - Work is more applied, but fundamental investigations are not precluded
  - All investigations must focus on an identified risk. See http://humanresearch.jsc.nasa.gov/files/hrp-47065_HRP-IRP.pdf

- Exploration Medical Capabilities risk: Inability to adequately treat an ill or injured crew member.
- Most all projects outlined are under work and collaboration is possible
Exploration Medical Capability: Overview

Exploration Medical Capabilities effort at GRC includes the following tasks:

- **Integrated Medical Model (IMM):** Predicts risk associated with exploration missions
- **IntraVenous fluid GENeration for exploration (IVGEN):** Generates IV fluid in situ
- **Reusable Medical Lab Devices:** Lab on a chip that can be reused
- **Oxygen Concentrators:** Fire risk assessment and device development
- **Imaging Integration:** Identify and insure readiness of imaging technologies for diagnosis and treatment
- **Injectable Medications:** Deliver IM and IO pharmaceuticals through the space suit when cabin temperature and pressure are low
Exploration Medical Capability: IVGEN

- Intravenous fluid may be required to treat several potential conditions
  - NASA currently flies bags of 0.9% Normal Saline and rotates them every 18 months
  - Can NASA realize mass and logistics savings by creating hardware to generate fluid in situ on an ad hoc basis?

- Status
  - Trade studies for filtration and mixing technologies completed in 2006
  - Lab studies completed in 2007
  - Flight hardware design approved in November 2008

Planar Laser-Induced Fluorescence image of mixing test
Exploration Medical Capability: IVGEN

- Mixing: Magnetic stir bar
- Filtering: Nuclear grade DI resin
  - Water generated by lab hardware passes the Sterile Water for Injection (SWI) standard of the United States Pharmacopeia (USP)
- Flight test scheduled in early 2010
Exploration Medical Capability: Reusable Medical Lab Devices

Goal

Reduce volume and mass required to conduct medical lab measurements during an exploration mission.

Required Measurements

<table>
<thead>
<tr>
<th>Urinalysis</th>
<th>Blood analysis, priority 1</th>
<th>Blood analysis, priority 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>specific gravity</td>
<td>bicarbonate (HCO3)</td>
<td>white blood cell count</td>
</tr>
<tr>
<td>pH</td>
<td>blood urea nitrogen (BUN)</td>
<td>alanine aminotransferase (ALT)</td>
</tr>
<tr>
<td>leukocytes</td>
<td>chloride</td>
<td>alkaline phosphotase (ALP)</td>
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<tr>
<td>nitrites</td>
<td>creatinine</td>
<td>Amylase</td>
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<td>platelets</td>
<td>creatinine phosphokinase (CPK)</td>
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<td>urate</td>
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<td></td>
</tr>
<tr>
<td>pregnancy test</td>
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</table>
Exploration Medical Capability: Reusable Medical Lab Devices

Status

- Fluid physics experts outlined fluid paths that are amenable to reusability
- Reusable diagnostic capabilities outlined
- Trade study and technology watch to determine appropriate partners and techniques
  - Phase I and II SBIR awards to the DNA Medicine Institute
  - Partner with investigators at the National Space Biomedical Research Institute
  - Tech watch with Maciej Zborowski, CCF, LRI

Detection Schematics from DNA Medicine Institute
Exploration Medical Capability: Oxygen Concentrator

Problem

• Providing bottled oxygen to a patient in a space vehicle quickly raises the oxygen concentration to unsafe levels

Solution

• Use an oxygen concentrator to provide an enriched oxygen stream

Second Problem

• In reduced gravity with no convection, the oxygen may build up around the patient to unsafe levels

Project

• Quantify fire hazard
• Lead flight hardware development

Reduced gravity fire in an endotracheal tube

Velocity map of exhalation in microgravity
Exploration Medical Capability: Imaging Integration

Problem

• Many medical conditions require imaging for diagnosis, treatment or both

• Limitations of spaceflight do not allow NASA to fly CCF’s latest MRI

Project

• Begin with list of expected spaceflight conditions

• Identify imaging techniques that can diagnose or treat those conditions

• Identify any work being done to develop those techniques

• Develop an integrated plan to close the risk of inability to treat
Digital Astronaut
Digital Astronaut: Project Purpose

- Assist in determining space normal physiology by mitigating the small sample size

- Guide development of ground and flight research to mitigate risks associated with exploration missions

- Function as a repository of human spaceflight data

- Identify interactions between physiological systems that are exacerbated by the rigors of space flight
Digital Astronaut: Muscle

- **GRC focus on neuro-muscular control**
  - Rate of motor unit activation
  - Signals for contraction
  - Different activation for different fiber types
  - Fatigue and microgravity exposure

- **Kinematics of skeletal muscle**
  - Maximum contribution of leg muscles pre and post flight
  - Kinematic load/velocity curve
  - Integrate with motor unit activation

- **Verification and validation**
  - Always an ongoing effort
  - GRC the experts in these processes
Digital Astronaut: Cardiovascular

Fidelity

High

Low

Computational Burden

Continuum Analysis

- Single component/organ function
- 3D
- 2nd Order PDE in time and space
- FE or FV analyses

Lumped System Model

- Multiple Compartments/Components
- Spatially averaged variables: 0-D
- 1st Order ODE system
- Analogous to circuit analysis

Compatible Boundary Conditions
Digital Astronaut: Bone Turnover

Bone Loss Rates in μG

+0.6%/mo. (Skull)
+0.1%/mo. (Arm)
-1.07%/mo. (Spine)
-1.35%/mo. (Pelvis)
-1.16%/mo. (Femoral Neck)
-1.58%/mo. (Greater Trochanter)
-1.25%/mo. (Tibia)
-1.5%/mo. (Calcaneus)

Loads in 1G at 70kg

300-1900 N (Arm)
1400-2500 N (Spine)
2000-3000 N (Hip)
1500-2000 N (Calcaneus)

(Data are from: Buckv. I.C.. *Space Physiology*. Oxford University Press. 2006.)
Digital Astronaut: Renal Stone Formation

- Upon returning to a gravitational field, astronauts develop renal stones at a higher rate than the general population: Why?

- What happens after Mars transit and insertion in Martian gravity?

- What happens if fluid intake is restricted from 2.5 l/day to 2 l/day?

- Status:
  - Stone formation module based on crystal growth formalisms is complete
  - Anatomically realistic renal stone transport module is complete
  - Currently verifying, validating, and integrating with QSP
NASA’s Human Research Program
Exploration Medicine Capabilities Project

The Integrated Medical Model (IMM) Project

Jerry Myers, Ph.D.- Project Manager

Sleep Disruption and Medical Intervention Forecasting (SDMIF)
&
Bone Fracture Risk (BFxRM) Modules
Objective

- Develop an evidence-based, probabilistic risk forecasting model that can help guide exploration planning, requirements development, and R&D technology investment activities
- Integrate best evidence in a quantifiable assessment of risk
- Identify medical resources necessary to optimize health and mission success
NASA’s Human Research Program
Exploration Medicine Capabilities Project
Parent Integrated Medical Model (IMM)

- **Scope**
  - Forecast medical outcomes for in-flight operations
  - Forecast medical impacts to mission
  - Does not assess post-mission medical consequences
- **Approach**
  - Use International Space Station data and other flight data when possible
  - Employ best-evidence clinical research methods
  - Collaborate with other NASA centers and organizations to extend capabilities where our experience is insufficient to adequately address reasonable medical incidences
- There exists a number of flight conditions that are unique to space flight, have few ground based analogs and very limited space flight data exists to forecast medical intervention needs and outcomes
  - Bone fracture complicated by localized bone loss
  - Renal stones
  - Sleep disturbance
GRC Core Capabilities applied to IMM

- Advanced capabilities in physiological modeling
  - Devising computational approaches to estimate the changes induced by space flight
  - Stochastic and deterministic modeling expertise

- Cross-disciplinary capabilities
  - Development of flight hardware for preventative and acute medical treatment

- History of successfully partnering with regional expertise
  - Direct collaborations with research and clinical experts to enhance understanding and technology development

- Results in allowing IMM to expand to the next level of complexity
  - Unique perspective
  - Basis of decisions and forecasts from first principle and root cause information
Sleep Disruption and Medical Intervention Forecasting (SDMIF) Tool

Project Goals and Model Concepts

Project Team

Jerry G. Myers, NASA Glenn Research Center
Beth E. Lewandowski, NASA Glenn Research Center
John E. Brooker, NASA Glenn Research Center
J. Lynn Caldwell, Air Force Research Laboratory, Wright-Patterson AFB
Steve R. Hursh, Institutes for Behavior Resources, Inc.
Melissa M. Mallis, Institutes for Behavior Resources, Inc.
Project Goal

- Space flight induces reductions in sleep quality and quantity and can potentially cause performance decrements

- Primary mitigation
  - Consolidated and efficient sleep
    - Power naps
    - Extended sleep opportunities
    - Impacted by scheduling and environmental factors
  - Medications or sleep aids
    - Medication usage rates not explicitly known

- Project goal in support of the IMM:
  - Develop a tool to estimate rates of medical intervention resulting from low sleep quality and duration
Combined GRC/WPAFB effort produced the IMM Sleep Disruption Module

- Model designed to
  - Predict the incidence rate of **clinically significant** sleep disturbance
  - Forecast the per-mission rate of sleep aids
- Conceptual model structure
  - Components encapsulated in a Monte Carlo simulation

Monte Carlo Simulation

- Mission Parameters
- Sleep & Performance
- Metrics Translation
- Diagnosis & Decision
- Probabilities & Rates
Diagnosis and Probability

- Associate sleep intensity used to estimate probability that medication is used
  - Based Logistic regression of ground and flight dta
- Calculations through many missions provides an understanding of the potential usage of sleep aids relative to uncertainty

**Probability Of Sleep Aid Use in 72 Hours**

- \( A \) \( Pr = 0.701 \)
- \( B \) \( Pr = 0.032 \)
Status and Forward work

- Completed 1st SME review on 10/7/2008
  - Model well received
  - Suggested changes incorporated to model structure
- Model structure and components integration code complete
- Currently
  - Finalizing SAFTE modifications for final integration
  - Obtaining flight data from SME panel
- Forward
  - Enhance model to include stimulant and reduction in available work time due to naps/extended sleep periods
  - Other agencies (FAA) interest in collaborating to extend application of model
The Bone Fracture Risk module

Project Goals and Model Concepts

Project Team

Jerry G. Myers, NASA Glenn Research Center
Beth E. Lewandowski, NASA Glenn Research Center
Angelo Licata, The Cleveland Clinic
GRC Activities: Bone Loss and Fracture Risk

• Bone Fracture Risk
  – Given that astronauts could experience significant skeletal loading during planetary activities, particularly in areas where bone is compromised due to BMD reduction from low-g exposure, there is the possibility of bone fracture leading to astronaut impairment or significant mission impact

• Bone Fracture Risk Module (BFxRM)
  – Due to the lack of available data related to the risk of fracture
    • Develop simulation model approach (i.e. PRA and Monte Carlo) to estimate fracture probability
    • Integrates best estimate biomedical engineering, clinical and space data
    • Provide input for the IMM
Bone Fracture Risk Module (BFxRM)

Mission input parameters
(Gender, gravitational environment, mission duration, EVA or TVA activity, body mass, initial BMD level, rate of event or activity occurring)

Load applied to bone during activity or event
(Calculated from biomechanical models)

Ultimate load of the bone
(Mathematical relationship between ultimate load and BMD)

Incidence rate of events/activities
(Number of falls per mission, number of ladder ascents and descents, number of times something is lifted)

Calculation of Fracture Risk Index
(Ratio of applied load to Ultimate load)

Probability of bone fracture
(Combined probability of event occurring and FRI converted to a probability)

Space Induced Bone Loss and Terrestrial Bone Strength Estimates

FRI = \frac{\text{Applied Load}}{\text{Bone Strength}}
Example results
Probability of fracture of the hip by a male or female astronaut due to 1m lateral fall event during an EVA on a Martian mission

<table>
<thead>
<tr>
<th>Gender</th>
<th>Day</th>
<th>Mean Probability</th>
<th>Standard Deviation</th>
<th>5%</th>
<th>95%</th>
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<tr>
<td>Male</td>
<td>10</td>
<td>2.84E-05</td>
<td>1.31E-04</td>
<td>3.45E-13</td>
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<tr>
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<td></td>
<td>150</td>
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<td>3.20E-04</td>
<td>7.62E-13</td>
<td>2.23E-04</td>
</tr>
</tbody>
</table>
BFxRM Application

- Process extended to include Lumbar Spine and Wrist Fractures
- Successfully integrated in the IMM parent module
- Model extended application
  - Used to estimate person specific fracture incidence scenarios
    - Estimate the contribution space-flight bone loss would contribute to an accidental loading event in 1g
  - Used to inform the increased risk of injury for “hard-landing”
    - Results including in the Human Research Program guidance to the Orion Design team
  - Currently being considered as the integrating platform to guide development of injury prevention standards for Med Ops.
Future Work and Opportunities

• Extending Sleep and Performance Module
  – IMM: Include the estimating the rate of stimulants due to lack of sleep
  – BHP: Correlating performance measures to medication use to inform medical operations

• Bone fracture risk
  – IMM: Working to more explicitly understand the role of the EVA suit
  – IMM: Better models of Lunar/Martian tasks and potential excessive skeletal loading scenarios
  – IMM: Better models of localized bone strength wrt localized bone loss and potential skeletal loading

• OTHER Areas
  – IMM: Renal Stones and the effect of reduced water intake
  – IMM: Non-space adaptation back pain
  – IMM: Bayesian updating of ground observations to inform space medical rates of occurrence and potential mission impacts
NASA’s Human Research Program

Exercise Countermeasures Project
Gail P. Perusek, NASA Glenn PM

Exercise Countermeasures Laboratory
Harness Station Development Test Objective
Research Activities and Opportunities
Introduction

• The human is a key component of human spaceflight, and challenges vary;
  – Low earth orbit
  – Moon
  – Mars
• Human Health Countermeasures risk drivers include
  – Risk of Accelerated Osteoporosis
  – Risk of Impaired Performance Due to Reduced Muscle Mass, Strength, and Endurance
  – Risk of Operational Impact of Prolonged Daily Required Exercise
• NASA Exercise Countermeasures Project (ECP) provides expertise and leadership to actively manage human system risks mitigated by exercise
Human Spaceflight Experience

Number of individual exposures vs. Flight Duration

- 1 day or less
- 1 week
- 2-3 weeks
- 1-2 months
- 2-3 months
- 3 months
- 4 months
- 5 months
- 6 months
- 7 months
- 8 months
- 9 months
- 10 months
- 11 months
- 12 months
- 13 months
- 14 months
- 15 months

www.nasa.gov
Space Flight Deconditioning

- **Bone**: Skeletal unloading in microgravity, fluid shifts, loss of bone mass
- **Muscle**: Atrophy, strength & endurance loss, cramps & soreness
- **Cardiovascular**: Endurance reductions (higher heart rate for given workload), lower oxygen carrying capacity, orthostatic intolerance in g-transitions
- **Sensorimotor / Neurovestibular**: Balance and coordination impaired
- **Psychological**: Mental fatigue & stress

**Exercise** is one of the most promising means to mitigate these losses and provides whole-system benefits to crewmembers
Exercise Countermeasures

Operational

Research

www.nasa.gov
Exercise Countermeasures Project

Project Objective

Develop and provide exercise countermeasure prescriptions and systems for space exploration that are effective, optimized, validated and meet medical, vehicle, and habitat requirements.

Project Goals

Develop prescriptions for exercise countermeasures that efficiently reduce the negative effects of zero and partial gravity and meet the medical needs of astronauts.

Establish the requirements for exercise equipment that will provide the prescribed exercise countermeasures within the constraints imposed by the space exploration vehicle and the astronauts' habitat on the Moon or Mars.
Exercise Countermeasures Development

Enhanced Zero-gravity Locomotion Simulator (eZLS)
- Effect of various g-levels on bone density loss studied (Zero-g, Lunar-g, Martian-g)
- Effect of vibration isolation on exercise studied

Integrated Analysis

Dynamic Modeling
- Biomechanics
- Vehicle Structure
- Exercise Platform

Biometric Data Analysis
- Biomechanical modeling
- Medical research on bone density loss phenomenon

Biowatch Instrumentation
- EMG Data processing tool
- Space Acceleration Measurement System
- Principal Investigator: Microgravity Services

On-Orbit Deployment
- RED
- FOOT
- CEVIS
- TVIS

Hardware Development
- Treadmill and rack
- Air bearing system
- Subject load device (variable g-load)

Assembly
- Fluids and Combustion Facility (FCF)
- Space experiments

Heritage:
- CCF Center for Space Medicine
- FOOT
- Microgravity analysis cycle
- FCF microgravity verification models
- Microgravity Environment Laboratory
- Structural Dynamics Laboratory
Supine Suspension Approach to Zero-G Simulation
Supine Suspension Approach to Zero-G Simulation
Exercise Countermeasures Laboratory – NASA GRC
Differences and Similarities to Actual 0-g

Enhanced Zero-g Locomotion Simulator (SM)  C-9 Microgravity Laboratory (AM)
NASA GRC/ ZIN Technologies
- Assisting Cleveland Clinic in developing EMG Data Processing tool for the ISS FOOT Experiment

**FOOT Experiment**

- Surface EMG (Electromyography)
- Muscle Activity
- 7 Muscles in right arm and leg
- Surface Electrodes
- Data taken over 12 hour session several times per increment
- Calibration performed using isometric exercises at beginning of session
  - Output signal from muscle varies from day to day and person to person.
- Relaxed Muscle Level (Muscle Activation threshold also performed)
Purpose

- Investigate an alternate TVIS harness design for better comfort and higher loading during treadmill exercise by providing flight CSM harnesses with instrumentation along with instrumented TVIS harnesses to assess in-flight comfort/loading in a DTO on ISS.

Center for Space Medicine (CSM) Harness
Station Development Test Objective (SDTO)

ISS TVIS Treadmill
CSM Harness Prototype

Right Chest
Right Back
Right Hip
Lunar Small Pressurized Rover Ergometer

Cycle Ergometer developed at GRC/ZIN for Exercise Countermeasures Project

Small Pressurized Rover (bottom) scale compared to Apollo era Lunar Rover (top)

Small Pressurized Rover – EVA Physiology and Performance Project
Exercise Countermeasures for Constellation

Exercise hardware systems for the Constellation Program based on the current resource specifications and spacecraft constraints must be capable of providing exercise that mitigates deconditioning effects related to space flight to preserve crew health, performance and safety.

New exercise devices are required for the Crew Exploration Vehicle (CEV) and/or Lunar Surface Access Module (LSAM) during lunar missions greater than 8 days in duration to allow aerobic and resistive training for 30 continuous minutes per crewmember each day, per the Human Systems Interface Requirements.
Research Collaborations examples
NASA GRC / Cleveland Clinic

- Human Research Program / National Space Biomedical Research Institute
  - Foot Reaction Forces During Simulated ISS Exercise Countermeasures
  - Bed Rest – Daily Bone Loading Stimulus Study
  - Monitoring Bone Health by Daily Load Stimulus Measurement During Lunar Missions

- A New Harness For Use With Exercise Countermeasures – Validation of Improved Comfort and Loading with the Center for Space Medicine Harness
Research Opportunities Areas

- International Space Station as a research platform for evaluating exercise countermeasures systems, physiological monitoring, exercise prescription efficacy
- Flight Analogs – ground-based analog development, lunar bed rest, EVA simulation
- Exercise Countermeasures Advanced Concept hardware / protocol development for space exploration
- NASA Research Announcements