Human Research Program

National Academies, Space Studies Board Committee on a Midterm Assessment of Implementation of the Decadal Survey on Life and Physical Sciences Research

Steve Davison
7 February 2017
Human Research Program (HRP)

HRP mission is to enable space exploration beyond Low Earth Orbit by reducing the risks to human health & performance through a focused program of:

- Basic, applied, and operational research

Leading to the development and delivery of the following:

- Countermeasures and risk mitigation solutions
- Advanced habitability and medical support technologies
- Human health, performance, and habitability standards
ISS Research: Critical to Mitigating Mars Mission Human Health and Performance Risks

HRP is a high priority for NASA science payloads aboard ISS. Each USOS crewmember participates in 10-15 separate experiments.
Compare Going to Mars to Where We Are Today with ISS

~ 1 – 2 days transit time

Communications (near real-time)

Crew exchanges

Crew supplies and logistics

Crew and atmosphere samples

Modified hardware

Emergency Crew Return

Trash

390 kilometers

“extreme car camping in space”

~1 – 1.5 years transit time, ~2 – 3 years mission time

Communications (up to 42 minutes)

228,000,000 kilometers

“recreate living on Earth capability”
Astronauts on a Mars mission will experience unprecedented physiological, environmental, and psychosocial challenges that could lead to significant health and performance decrements in the absence of effective mitigation strategies.
## HRP Research Elements: Align with Crew Stressors and Associated Human Risks

<table>
<thead>
<tr>
<th>Category</th>
<th>Stressor/Issue</th>
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<tbody>
<tr>
<td><strong>Human Health Countermeasures (HHC)</strong></td>
<td>Altered Gravity Fields: Balance Disorders, Visual Alterations, Immune Function, Muscle Atrophy, Bone Loss, Nutrition, Food, Cardiovascular, Microbiome, Countermeasures</td>
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<tr>
<td><strong>Behavioral Health &amp; Performance (BHP)</strong></td>
<td>Isolation/Confinement &amp; Altered Light-Dark Cycles: Neurobehavioral and psychosocial aspects, Sleep disorders, Monitoring/intervention tools</td>
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<tr>
<td><strong>Space Human Factors &amp; Habitability (SHFH)</strong></td>
<td>Hostile/Closed Environment: Vehicle Design, Human system interface design (lighting, display/control, ergonomics, anthropometry, robotic interfaces), Occupant protection</td>
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<td><strong>Space Radiation (SR)</strong></td>
<td>Space Radiation: Acute In-flight effects, Long-term cancer risk, CNS and Cardiovascular, Permissible exposure limits</td>
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<tr>
<td><strong>Exploration Medical Capabilities (ExMC)</strong></td>
<td>Distance from Earth: Autonomous medical care capability (monitoring, diagnostic, treatment), Medical data management, Probabilistic risk assessment</td>
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*Note that effect severity generally increases with mission duration (i.e., time of exposure to stressor)*
External Research Community

- **Strategic Planning**
  - National Academies (IOM, NRC)
    - Risk Reduction Strategy for Human Exploration of Space
    - Review of HRP Evidence Base and Merit Review Process
  - National Council on Radiation Protection (NCRP)
  - NASA Advisory Committee (NAC)

- **Science Planning**
  - Standing Review Panels (SRP)
  - Research and Clinical Advisory Panels for Visual Impairment, Space Radiation Health, Bone Health
  - Lunar Atmospheric Dust Toxicity Assessment Group
  - Decompression Risk Review, Dental Working Group
  - Habitable Volume Workshop

- **Research Implementation**
  - National Research Solicitations
    - Human Exploration Research Opportunities (HERO): Crew Health and Performance, Space Radiobiology
  - Graduate Student and Post-Doctoral Programs
External Interfaces/Collaborations

- NIH: Physiological Research
- DOE: NASA Space Radiation Lab
- Int’l Partners: Collaborative Research, ISS utilization, ISLSWG, JWG
- National Academies: Research Recommendations
- NSF: Antarctic Stations
- DOD: Army, AFRL, ONR
- External Research Community
- NSBRI/TRI
- HRP: External Interfaces
International Research Coordination

- International Space Life Sciences Working Group (ISLSWG)
  - NASA, ESA, JAXA, CSA, DLR, CNES, ASI
  - International Life Science Research Announcement

- Multilateral Human Research Panel for Exploration (MHRPE)
  - CSA, ESA, JAXA, NASA, Roscosmos
  - ISS exploration fly-off plan for multilateral biomedical research
  - ISS One-year missions

- US/Russian Joint Working Group (JWG) on Space Biomedical and Biological Sciences
  - Joint sub-groups: (i) Biomedical (ii) Crew Health and Medical Support (iii) Biological Sciences
Inter-Agency Collaboration

- NASA/NIH Memorandum of Understanding (Recently Signed)
  - MOU sets forth a framework of cooperation between NIH/NASA on space and Earth related biomedical research that benefits health on Earth & enables space exploration

- NASA/Department of Energy (DOE) on NASA Space Radiation Laboratory (NSRL)
  - NSRL provides charged particles for space radiation research on carcinogenesis, CNS, and degenerative tissue effects; shielding materials, radiation sensitivity of electronics and nuclear physics

- NASA/National Science Foundation (NSF) on Polar Biomedical Research
  - Human performance research in Antarctic Polar Stations provides extreme environment operational experience and research data with stressors similar to those found in spaceflight

- NASA/Naval Submarine Medical Research (NSMRL) Laboratory Agreement
  - High performance operational teams, like those on U.S. submarines and NASA flight crews, face common issues including maintaining effective operational team performance during prolonged stressful missions.

- NASA/Department of Defense (DoD)-Natick on Advanced Food Technology
  - NASA and DOD (U.S. Army Soldier Systems Center- Natick) are working on a common goal to produce nutritionally balanced, high-calorie meal bars that reduces volume while providing longer shelf life

- NASA/DOD/VA Collaboration (In Development)
  - NASA, DoD, and the VA Medical S&T are discussing medical research, technologies and practices focused on deployable medical capabilities and behavioral research
Internal Integration and Coordination

OCHMO and OCS
- Medical and Science Policies

Advanced Exploration Systems
- Space Radiation Shielding/MSL RAD
- NASA Space Radiation Lab. Upgrade
- Crew Mobility Systems & EVA Surface Suit
- Habitat Testing: volume, Ops concepts, design
- Interface Display & Control Unit Studies
- HERA Mission Tasks/Fidelity: Flight Simulator

Crew Health & Safety (ISS Med Ops)
- VIIP, CO2 levels, Exercise Studies
- Astronaut Occupational Surveillance
- Crew Health Risk Assessment
- Cognitive Function and Measures
- Space Radiation Protection (SRAG)
- LSAH Database

Science Mission Directorate
- Solar System Explor. Rsrch. Virtual Inst. (SSERVI)
- Space Radiation Environment
  - LRO-CRaTER radiation measurements
  - SEP monitoring/characterization
  - MSL-RAD measurements of radiation during transit & on the surface of Mars

ISS Program
- MHRPE: ISS One-year Mission
- Russian collaborations (Field Test, Fluid Shifts)
- MARES Research (ESA/US/Roscosmos)
- Advanced Exercise Device
- ARED Platform
- Technology Demonstrations

Orion
- EM2 objectives in work
- Vibration validation assessments (EM1)
- E-Procedure Validation (EM2)
- Food System Mass Reduction
- Exercise hardware
- Human Testing using Orion seat and suit prototypes

Space Technology Mission Directorate
- SBIR (Integral part of HRP’s R&T Plan)
- Thick Radiation Shielding Project
- NASA Space Radiation Lab. Upgrade

Space Biology
- Advanced Food: Pick & Eat Veggies
- Microbial Assessment/Observatory
- Translational Research Roadmap
- Bioinformatics
- Artificial Gravity Studies
- LSDA Database
HRP Approach Summary

• Enable NASA human exploration goals by conducting flight and ground research to mitigate highest risks to human health and performance on current and future exploration missions

• Fully utilize ISS research and operational capabilities to mitigate human health space exploration risks to an acceptable level

• Establish research priorities consistent with guidance from the National Academies, other external independent reviews, and NASA Health and Medical Technical Authority (HMTA) assessments

• Implement an open competitive solicitation process and independent, external scientific peer review to ensure highest quality research

• Leverage resources and expertise through collaborative research with other NASA programs, international partners, and other US agencies

• Review portfolio regularly to rebalance work and ensure ISS research subjects are efficiently utilized to mitigate highest risks to human health
Program Planning and
Path to Risk Reduction
Integrated Risk Planning Framework

“Human space flight remains an endeavor with substantial risks, and these risks must be identified, managed, and mitigated appropriately to achieve the nation’s goals in space.”

HRP works within an integrated framework to mitigate human health & performance risks

- Office of the Chief Health and Medical Officer
- Crew Health and Safety
- Human Research Program
Human Risks of Spaceflight Grouped by Hazards – 30 Risks

**Altered Gravity Field**

1. Spaceflight-Induced Intracranial Hypertension/Vision Alterations
2. Renal Stone Formation
3. Impaired Control of Spacecraft/Associated Systems and Decreased Mobility Due to Vestibular/Sensorimotor Alterations Associated with Space Flight
4. Bone Fracture due to spaceflight-induced changes to bone
5. Impaired Performance Due to Reduced Muscle Mass, Strength & Endurance
6. Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity
7. Adverse Health Effects Due to Host-Microorganism Interactions
8. Urinary Retention
9. Orthostatic Intolerance During Re-exposure to Gravity
10. Cardiac Rhythm Problems
11. Space Adaptation Back Pain

**Radiation**

1. Adverse Health Outcomes and Performance Decrement resulting from Space Radiation Exposure (cancer, cardio & CNS)

**Distance from Earth**

1. Adverse Health Outcomes & Decrement in Performance due to Inflight Medical Conditions
2. Ineffective or Toxic Medications due to Long Term Storage

**Isolation**

1. Adverse Cognitive or Behavioral Conditions & Psychiatric Disorders
2. Performance & Behavioral Health Decrement Due to Inadequate Cooperation, Coordination, Communication, & Psychosocial Adaptation within a Team

**Hostile/Closed Environment-Spacecraft Design**

1. Acute and Chronic Carbon Dioxide Exposure
2. Performance decrement and crew illness due to inadequate food and nutrition
3. Reduced Crew Performance and Injury Due to Inadequate Human-System Interaction Design (HSID)
4. Injury from Dynamic Loads
5. Injury and Compromised Performance due to EVA Operations
6. Adverse Health & Performance Effects of Celestial Dust Exposure
7. Adverse Health Event Due to Altered Immune Response
8. Reduced Crew Health and Performance Due to Hypobaric Hypoxia
9. Performance Decrement & Adverse Health Outcomes Resulting from Sleep Loss, Circadian Desynchronization, & Work Overload
10. Decompression Sickness
11. Toxic Exposure
12. Hearing Loss Related to Spaceflight
13. Injury from Sunlight Exposure
14. Crew Health Due to Electrical Shock

**Concerns**

1. Clinically Relevant Unpredicted Effects of Meds
2. Intervertebral Disc Damage upon re-exposure to μg
3. Health/Performance impacts of White Matter Hyperintensities
Human System Risk Board (HSRB)

HMTA*
Implement strategies to:
• define acceptable risk
• control/monitor human risks
• validate standards & req’ts
• transition to medical practice

HSRB
evidence
approaches
research
requirements

HRP
Perform research to:
• understand and quantify risk
• develop countermeasures
• develop standards
• develop mitigation technologies

*NASA Health & Medical Technical Authority

Human System Risk Board
- HMTA/Space Medicine (chair)
- HRP/Human Research
- Environmental Science
- Human Factors Engineering
- Space Flight Operations
- Crew Office
Human Risks Disposition for all Design Reference Missions

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<td>Electrical shock</td>
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A – Accepted  RM- Requires Mitigation  Green – low/very low consequence  Yellow – low to medium consequence  Red – high consequence
Research Planning Cycle

Evidence Base – Flight and Ground
• Research
• Clinical
• Operational experience

Reviewed by IOM

Human Health & Performance Risks

HSRB Dispositioned Risks

Reviewed by Standing Review Panels

Research Gaps

Prioritization/Implementation Constrained by
• Customer need dates
• Budgets
• Research platform availability

Integrated Research Plan

Results and Deliverables
• Mitigate Risks
• Inform Standards
• Countermeasures
• Medical Technologies

Exploration Missions & Architectures

NASA Spaceflight Human System Standards

Solicitations & Directed Research

Customer Review

Peer Review
HRP Solicitations, Tasks, and Publications

Human Exploration Research Opportunities (HERO)

NNJ16ZSA001N-FLAGSHIP1

Appendix B

NASA Research and Technology Development to Support Crew Health and Performance in Space Exploration Missions

Step-1 Response Period: September 1, 2016 – October 3, 2016
Step-1 Proposals Due: October 3, 2016, 5 PM Eastern Time
Step-2 Proposals Due: December 16, 2016, 5 PM Eastern Time
Estimated Step-2 Selection Announcement: April 2017

Human Exploration Research Opportunities (HERO) Solicitation

FY 2016

307 Tasks, 255 PIs, 118 Institutions

Number of Publications

Total Pubs | Annual Reports | Final Reports
### HRP Integrated Path to Risk Reduction (Mars)

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<tr>
<th>Planetary DRM (Mars)</th>
<th>FY15</th>
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<td>Team Performance Decrement (Team)</td>
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<td>Concern of Intervertebral Disc Damage (IVD)</td>
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</tbody>
</table>

- **ISS Required**
- **ISS Not Required**
- **Milestone Requires ISS**
- **ISS Mission Milestone**
- **Anticipated Milestone Shift**
- **Ground-based Milestone**
- **Mission Milestone**

**Concerns**
- **High LxC**
- **Mid LxC: Requires Mitigation**
- **Mid LxC: Accepted**
- **Low LxC**
- **Optimized**
- **Insufficient Data**

**End ISS**

10/14/2016
HRP R&D Investment by Risk

Radiation Exposure on Human Health total $26M
Radiation Exposure Sept. Obligations $22.8M

Space Radiation Exposure (Radiation)
Cognitive or Behavioral Conditions (BMed)
Medications Long Term Storage (Stability)
Vision Impairment/Intracranial Pressure (VIIP)
Inadequate Food and Nutrition (Food)
Team Performance Decrement (Team)
Inflight Medical Conditions (Medical)
Human-System Interaction Design (HSID)
Bone Fracture (Fracture)
Renal Stone Formation (Renal)
Sensorimotor Alterations (SM)
Injury from Dynamic Loads (OP)
Altered Immune Response (Immune)
Host-Microorganism Interactions (Microhost)
Injury Due to EVA Operations (EVA)
Hypobaric Hypoxia (ExAtm)
Sleep Loss (Sleep)
Reduced Muscle Mass, Strength (Muscle)
Reduced Aerobic Capacity (Aerobic)
Celestial Dust Exposure (Dust)
Decompression Sickness (DCS)
Orthostatic Intolerance (OI)
Cardiac Rhythm Problems (Arrhythmia)
Concern of Intervertebral Disc Damage (IVD)
Concern of Effects on Medication (PK/PD)

* Cross-Cutting
**HRP Risk Mitigation Maturation Plan**

**Now–2024 (+/-)**
Develop/test mitigation approaches
- ISS
- Spaceflight analog facilities
- Ground-based laboratories
Inform deep-space hab designs

**~2021–2030**
Validate mitigation approaches
- Orion
- Deep-space hab
- Lunar surface (?)
Inform exploration system designs

**~2035–20nn**
Fine-tune mitigation approaches
- Exploration vehicles
- Planetary surfaces
Research Activities
ONE YEAR in SPACE
THREE YEARS of SCIENCE

Through research on astronaut Scott Kelly in seven major areas, we will improve our understanding of how the human body reacts to long-duration spaceflight. Testing began one year before his launch, intensified during his 340 days in space, and will continue for a year — or longer — after his return to Earth. Each line below represents one of the investigations for the Year in Space, and the circles indicate data collection points such as blood draws, ultrasound scans and cognition tests. The results of this research will help prepare us for future voyages beyond low-Earth orbit.
U.S./Russian Field Test Studies
Twins Study (Scott and Mark Kelly)

Begin to examine next generation genomics solutions to mitigating crew health and performance risks: Personalized countermeasures

**National Research Team**
- Genome, telomeres, epigenome, transcriptome, epitranscriptome
- Proteome, Metabolome, Microbiome
- Physiology and Cognition

**Significant Privacy and Ethics Issues**

NASA developed a new genomics policy (modeled after NIH policy) that addresses informed consent, data privacy approaches, and genetic counseling on consequences of discovery (individual, family)

**Preliminary Results Presented at HRP IWS** (January 2017)
- RNA sequencing showed more than 200,000 RNA molecules that were expressed differently between the twins
- Scott’s telomeres on the ends of chromosomes in his white blood cells increased in length while in space (shortened again on return)
- Microbiome shift in microbial species included a change in ratio of two dominant bacterial groups (i.e., Firmicutes/Bacteroidetes) present in Scott’s GI tract
- Flu vaccines: T cell receptors were created and increased in both twins which was the expected immune response
Circadian Regulation via Lighting

- Astronaut Kate Rubins recently installed new lighting in the ISS that emits light in wavelengths that can be tuned to help astronauts get a better night’s sleep.
- Solid-state lighting assembly (SSLA) is an example of the ISS testing underway to prepare for eventual human travel to Mars.

Solid State Lighting Assembly (SSLA)

- Energy efficient, longer life span, no toxic mercury vapor.
- Excellent, bright light for visual performance and color discrimination.
- Suppresses melatonin to better manage circadian rhythms.
- Provides spectral adjustments to aid sleep and circadian disruption.
  - Blue shifts for the morning
  - Red shifts for the evening

Delivery and Testing Aboard ISS

- 7/16: 1st 4 SSLAs launched on SpX-9
- 10/16: Kate Rubins installed 3 SSLAs in Crew Quarters
- 11/16 Lighting Effects Flight Study begins on 49S
- 12/16: Next 11 SSLAs launch on HTV6
Began testing GCR simulator during Fall 2016 run.

- Simulates the space radiation environment: high energy ion beams (H⁺, Fe, Si, C, O, Cl, Ti, etc.) individually or together.
- Beam line, target area, dosimetry, biology labs, animal care, scientific, logistic and administrative support.
- 3 experimental campaigns per year
- Space Radiation Summer School

NSRL Beam Line
Images Courtesy of Brookhaven National Laboratory (BNL)
# Space Radiation Health Risks

## Health Risk Areas

<table>
<thead>
<tr>
<th>Carcinogenesis</th>
<th>Status</th>
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<tbody>
<tr>
<td>Space radiation exposure may cause increased cancer morbidity or mortality risk in astronauts</td>
<td>- Cancer risk model developed for mission risk assessment</td>
</tr>
<tr>
<td></td>
<td>- Model is being refined through research at NASA Space Radiation Laboratory (NSRL)</td>
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<tr>
<td></td>
<td>- Health standard established</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Acute Radiation Syndromes from SPEs</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute (in-flight) radiation syndromes, which may be clinically severe, may occur due to occupational radiation exposure</td>
<td>- Acute radiation health model has been developed and is mature</td>
</tr>
<tr>
<td></td>
<td>- Health standards established</td>
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<tr>
<td></td>
<td>- Risk area is controlled with operational space radiation monitoring &amp; shielding mitigations</td>
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</table>

<table>
<thead>
<tr>
<th>Degenerative Tissue Effects</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>Radiation exposure may result in effects to cardiovascular system, as well as cataracts</td>
<td>- Non-cancer risks (<strong>Cardiovascular and CNS</strong>) are currently being defined</td>
</tr>
<tr>
<td></td>
<td>- Research is underway at NSRL and on ISS to address these areas</td>
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<tr>
<td></td>
<td>- Appropriate animal models needed to assess clinical significance</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Central Nervous System Risks (CNS)</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>Acute and late radiation damage to the central CNS may lead to changes in cognition or neurological disorders</td>
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</table>
Central Nervous System (CNS) Effects from Space Radiation

- Research with animal models shows changes to the CNS at exposure levels in range of concern to NASA
- Current research is focused on establishing significance, mechanistic basis, and of dose thresholds for these effects
- Major uncertainty in how to extrapolate results from animals to humans
- NCRP Committee (Radiation Exposures in Space and the Potential of Central Nervous System Effects) will provide guidance on future research

Cardiovascular Effects from Space Radiation

- Current research is focused on understanding and quantifying the risk of cardiovascular effects at space-relevant exposures
- Establish whether a dose threshold exists, influence of dose-rate, and establish individual sensitivity
- Necessity for life span studies in appropriate animal models
Isolation and Confinement Analogs

NASA HERA:
3-4 Missions/yr
4 Crew
14, 30, 45 d

NASA/NSF:
Multiple Stations winter overs

US/Russian (IMBP/NEK):
4 (2018), 8, 12 month

NSF/ South Pole Station
Joint NASA/ESA AG-Bedrest Solicitation

Physiological and Behavioral Responses in Humans to Intermittent Artificial Gravity during Bed Rest

*Research to be carried out during two 60-day bedrest campaigns at the DLR’s :enviHab facility in Cologne, Germany (2017, 2018).*

- Coordinated solicitations
- Common peer review (NRESS)
- Coordinated selections to maximize scientific gain
- Shared facility costs
- International Investigator Working Group: data sharing and coordinated publications

### Physiological and Behavioral Responses in Humans to Intermittent Artificial Gravity during Bed Rest

<table>
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<tr>
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<th>SM1</th>
<th>CV3</th>
<th>ViIP1</th>
<th>M23</th>
<th>Osteo4</th>
<th>AG Gap 1</th>
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<th>AG Gap 4</th>
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<td>Standard Measures</td>
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</table>
MPCV Exercise Device (ROCKY*) Status

Design/Capabilities

- Servo-motor controlled, single cable exercise system
- Provides resistive loads up to 400 lbf at velocities up to 2 m/s
- Software-modifiable exercise loading profiles
  - Inertial characteristics of free weights for resistive training
  - Oar/boat loading dynamics for aerobic (rowing) training
  - Custom profiles for eccentric overloading, weight racks, etc.
- Capacitor bank allows unpowered operation in rowing mode

Status

- 10/18/16: SRR held at GRC
- 11/22/16: RID Review Board

*Resistive Overload Combined with Kinetic Yo-yo
Deep Space Exercise Device (ATLAS*) Status

Objectives:
- Develop exercise hardware for exploration
- Base on ISS exercise CM hardware suite
- Minimize mass, power, volume and highly
- Maximize reliability, versatility, effectiveness

Development Approach:
- Leverage the MPCV/ROCKY efforts
- Demonstrate/validate on ISS (NET 2019)
- Augment/replace ARED after initial valid

Design Goal: ATLAS will exceed ARED capabilities at 1/10 of its mass and volume

Design Specification Goals:

<table>
<thead>
<tr>
<th>Accommodation (carrier)</th>
<th>ISS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up-mass (lbm)</td>
<td>200 lbm target</td>
</tr>
<tr>
<td>Stowed Volume (ft³)</td>
<td>3.0 ft³ target</td>
</tr>
<tr>
<td>Peak Power (W)</td>
<td>480 W target</td>
</tr>
<tr>
<td>Life Cycle Count</td>
<td>750,000 cycles / year</td>
</tr>
<tr>
<td>Launch / Increment</td>
<td>Year 2019</td>
</tr>
</tbody>
</table>

*Advanced Twin Lifting and Aerobic System
Renal Stone Formation Risk Mitigation

Risk of renal stone formation/development is elevated during and early after flight
  • Fluid redistribution, bone loss, muscle atrophy, diet

Current Risk Mitigation Strategy:
  • Preflight ultrasound screening
  • In-flight prevention: increased fluid intake, diet
  • Oral Calcium citrate

Future Risk Mitigation Research Goals:
  • Flexible Ultrasound System (FUS) to provide clinical grade imaging of asymptomatic stones.
  • FUS to provide therapeutic modalities:
    - Moving a kidney stone away from the ureters
    - Moving a kidney stone lodged in the ureter
    - Non-invasively breaking-up a kidney stone.
Engagement and Communications

Train Like an Astronaut /Mission X

- **Mission X 2016 (MX16) International Fitness Challenge**
  - MX16 Walk To The Moon Challenge closed with **30 countries**, **four observing countries**, and **nearly 60K participants**

- **ISS Twins Study: Omics Exploring Space Through You Series**
  - Conclusion video 8 of 8 in the series were posted in conjunction with Twins Day, Aug 5.
  - [http://www.nasa.gov/content/exploring-space-through-you-omics](http://www.nasa.gov/content/exploring-space-through-you-omics)

Growth of participants each year in returning countries, MX12 – MX16
- 2.5 x growth countries
- 14 x growth participants
Human Research Roadmap: A Risk Reduction Strategy for Human Space Exploration

• HRP uses an Integrated Research Plan to identify the approach and research activities planned to address these risks
• http://humanresearchroadmap.nasa.gov/