Artificial Gravity Future Plans for ISS

Peter Norsk & Jeff Smith
NASA JSC & ARC
Why Use Artificial Gravity?

• NASA’s vision for space exploration include DRM\textsc{s} that would send humans beyond LEO for long duration periods.

• Artificial gravity (AG), by reproducing the normal 1G environment, has the unique feature of protecting all physiological systems in all individuals against the effects of weightlessness.

• The selection of the final health protecting countermeasure suites should include consideration for AG, not just traditional methods.

• AG is feasible from an engineering aspect, but more research is required to define the fundamental operating parameters for an AG countermeasure.
# Human Risks of Spaceflight

Grouped by Hazards – 30 Risks & 2 Concerns

<table>
<thead>
<tr>
<th>Altered Gravity Level</th>
<th>Radiation</th>
<th>Hostile/Closed Environment–Spacecraft Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Vision alterations</td>
<td>• Exposure to space radiation</td>
<td>• CO2 exposure</td>
</tr>
<tr>
<td>• Renal stone formation</td>
<td></td>
<td>• Inadequate food/nutrition</td>
</tr>
<tr>
<td>• Sensorimotor alterations</td>
<td>• Limited in-flight medical capabilities</td>
<td>• Inadequate human-system interaction design</td>
</tr>
<tr>
<td>• Bone fracture</td>
<td>• Toxic medications</td>
<td>• Injury from dynamic loads</td>
</tr>
<tr>
<td>• Impaired performance</td>
<td></td>
<td>• Injury during EVA</td>
</tr>
<tr>
<td>• Reduced aerobic capacity</td>
<td></td>
<td>• Celestial dust exposure</td>
</tr>
<tr>
<td>• Adverse health effects</td>
<td></td>
<td>• Altered immune response</td>
</tr>
<tr>
<td>• Urinary retention</td>
<td></td>
<td>• Hypobaric hypoxia</td>
</tr>
<tr>
<td>• Orthostatic intolerance</td>
<td></td>
<td>• Sleep loss &amp; work overload</td>
</tr>
<tr>
<td>• Back pain</td>
<td></td>
<td>• Decompression sickness</td>
</tr>
<tr>
<td>• Cardiac rhythm problems</td>
<td></td>
<td>• Toxic exposure</td>
</tr>
<tr>
<td>• Effects of medication</td>
<td></td>
<td>• Hearing loss</td>
</tr>
<tr>
<td>• Intervertebral disk damage</td>
<td></td>
<td>• Sunlight exposure</td>
</tr>
</tbody>
</table>

- **Distance from Earth**
  - Limited in-flight medical capabilities
  - Toxic medications

- **Isolation**
  - Adverse cognitive or behavioral conditions
  - Performance & behavioral health decrements
Human Risks of Spaceflight
Grouped by Hazards – 30 Risks & 2 Concerns

Altered Gravity Level
• Vision alterations
• Renal stone formation
• Sensorimotor alterations
• Bone fracture
• Impaired performance
• Reduced aerobic capacity
• Adverse health effects
• Urinary retention
• Orthostatic intolerance
• Back pain
• Cardiac rhythm problems
• Effects of medication
• Intervertebral disk damage

Radiation
• Exposure to space radiation

Distance from Earth
• Limited in-flight medical capabilities
• Toxic medications

Isolation
• Adverse cognitive or behavioral conditions
• Performance & behavioral health decrements

Hostile/Closed Environment–Spacecraft Design
• CO2 exposure
• Inadequate food/nutrition
• Inadequate human-system interaction design
• Injury from dynamic loads
• Injury during EVA
• Celestial dust exposure
• Altered immune response
• Hypobaric hypoxia
• Sleep loss & work overload
• Decompression sickness
• Toxic exposure
• Hearing loss
• Sunlight exposure

Risks potentially minimized by artificial gravity
Rotation of the whole vehicle
e.g. Mars NTR
$ r = 56 \text{ m} \\
\omega = 4 \text{ rpm}$

Rotation of part of the vehicle
e.g. Nautilus-X
$ r = 6 \text{ m} \\
\omega = 12 \text{ rpm}$

On-board centrifuge
e.g. AGREE
$ r = 1.6 \text{ m} \\
\omega = 24 \text{ rpm}$
### Whole vehicle rotation configurations

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Hab counterweighted by reactor/power conversion systems</th>
<th>No rotating joints, power connections, fluid connections, etc.</th>
<th>Vehicle angular momentum must be continuously vectored for TVC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Entire vehicle rotates</td>
<td>Power conversion systems operate in g-“field”</td>
<td>Thermal radiators in g-“field”</td>
</tr>
<tr>
<td>Irre Batons</td>
<td>Vehicle pointing provides majority of thrust vector control (TVC)</td>
<td></td>
<td>Crew ingress/egress</td>
</tr>
<tr>
<td>Ox Cart</td>
<td>Hab counterweighted by reactor/power conversion systems</td>
<td>Thrust vectoring decoupled from rotational angular momentum</td>
<td>Megawatt-level power, prop transfer across rotating joints</td>
</tr>
<tr>
<td></td>
<td>Thrusters, despun, gimbaled for TVC</td>
<td>Power conversion systems operate in g-“field”</td>
<td>Potential cyclical loading of rotating joints</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thermal radiators in g-“field”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Crew ingress/egress</td>
</tr>
<tr>
<td>Beanle Cap</td>
<td>Split habitation volumes for counterweights</td>
<td>Thrust vectoring decoupled from rotational angular momentum</td>
<td>Inefficiencies in duplicating habitation systems, crew transfer between them</td>
</tr>
<tr>
<td></td>
<td>Reactor/power conversion systems, thrusters in zero-g</td>
<td>Thermal radiators in zero-g</td>
<td>Potential cyclical loading of rotating joints</td>
</tr>
<tr>
<td></td>
<td>Thrusters gimbaled for TVC</td>
<td></td>
<td>Power conversion systems operate in zero-g</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kilowatt-level power transmission across rotating joints</td>
</tr>
</tbody>
</table>
NOTE: Spacecraft's front end points toward the Sun with vehicle's longitudinal/spin axis oriented perpendicular to its flight vector.
# Summary: Effectiveness of AG Prescription

<table>
<thead>
<tr>
<th></th>
<th>main hypotheses*</th>
<th>finding</th>
<th>comment</th>
</tr>
</thead>
</table>
| Bone | ↔ bone mineral density  
↑ bone homeostasis | as expected  
not supported | short duration  
insufficient loading? |
| Muscle | ↑ strength  
↑ fiber-type homeostasis  
↓ muscle atrophy | supported  
supported  
supported | |
| Cardio | ↑ orthostatic tolerance  
↑ sympathetic response  
↑ aerobic capacity | supported  
supported  
supported | |
| Neuro | ↔ CDP, OCR  
↔ SVV  
↑ proprioceptive reflexes | as expected  
not supported  
supported | no adverse response  
spatial disorientation? |
| Immuno | ↑ stress marker response | not supported | no Δ either group |
| Psych | ↔ cognitive performance | supported? | ↓ trend, but low n |

*expected outcome of Treatment Subjects when compared to Control Subjects
2014 Artificial Gravity Workshop
Chairs: William Paloski, Ph.D., and John B. Charles, Ph.D.

White Paper
Ames Research Center, February 19 – 20, 2014
Editorial Board:
Peter, Norsk, M.D., Maneesh Arya, Ph.D., LaRona Smith, RN, MSN, Ronita Cromwell, Ph.D., Justin Kugler, Charlene Gilbert, and David Baumann, M.Sc.
Conclusion and Next Steps

The workshop showed that there is a broad interest among engineers, researchers, managers and international partners to pursue AG as a countermeasure for future long duration manned deep space missions. The key conclusions and next steps are:
• A feasibility study anticipating a 1-G continuous AG-level by spinning the whole vehicle on a trip to Mars with a crew of 4 in an 8.3 m radius habitat and radius of rotation 56 m has shown to be possible.

• The physiological requirements to engineering should be defined and constitute answers to the following questions: 1) Intermittent or continuous AG? 2) if intermittent: G-levels, durations, radius of rotation? 3) if continuous: Minimum G-level, radius of rotation? These answers are pivotal for determining feasibility of AG.
• An AG peer reviewed research project should be established according to the management aspects in fig. 2 on an international basis exploiting ground based AG facilities worldwide in a coordinated fashion.

• The main physiological drivers for AG during long duration space missions should be defined (such as the VIIP syndrome) and the G-dose physiological response curve established to define thresholds etc.

• Considerations as to whether an intra-vehicular human centrifuge should be installed on ISS and/or an additional centrifuge module attached to ISS.
• The physical side effects of spinning (Coriolis force, cross coupling effects etc., motion sickness) should be determined for deciding optimal spinning radius and G-level in close cooperation with engineers.

• The critical research path based on public international solicitations should be established with parallel tracks towards 2022 involving 1) animal centrifuge research a) ground based and b) on ISS, 2) human ground based bed rest and SAHC research, 3) human ground based long arm centrifugation and long duration (days) research, 4) ground based cell culture centrifugation research, and 5) ISS cell culture centrifugation research.
Conclusions

- Broad interest to pursue AG
- Continuous whole space habitat spinning possible
- Before 2022, life science requirements should be defined
- Three scenarios: Intra-, extra-, & whole-vehicle rotation
- Critical research path (international):
  1) Animal ground and space,
  2) human ground,
  3) cell culture ground and space
AG Project Status

• **March 2014** – HRP approval to initiate the Artificial Gravity project to develop evidence-based recommendations for or against the use of AG in deep space transit vehicles by 2022.

• **September 2014** – Creation of Internat’l AG Working Group as a sub-group of the International Countermeasure Group.


• **April 2015** – HRP approval of AG Research Plan.

• **May 2015** – NASA Request for Information (RFI) on Biological & Physiological Effects of Partial Gravity.
AG Research Plan

1. AG Level
   – G dose-physiological response relationship
   – Humans, rodents, cells
   – Parabolic flight, centrifugation, suspension, bioreactor, computational models

2. AG Duration and Frequency
   – Continuous rotation
   – Intermittent rotation

3. Health Consequences of AG
   – Cross-coupled and Coriolis accelerations
   – Gravity gradient
   – Intracranial pressure

4. Validation of AG Prescription
   – Comparison between animal centrifugation on the ground and in space
   – Tests of a human centrifuge in space
Detailed Research Plan

1. **AG Level**
   - G dose-physiological response relationship
   - Humans, rats, cells, computational models
   - Ground-based studies:
     - Bioreactor
     - Centrifugation with or without unloading
     - Parabolic flight
     - Digital Astronaut Project
Detailed Research Plan (cont’d)

2. AG Duration & Frequency
   – Continuous rotation
     • Large-radius centrifuge / habitat
   – Intermittent rotation
     • Short-radius centrifugation
during bed rest / dry immersion
3. Health Consequences of AG
   – Cross-coupled & Coriolis accelerations
     • Rotating chair
     • Slow Rotation Room
   – Gravity gradient
     • Large-radius centrifuge
   – Intracranial pressure
     • Large-radius centrifuge
4. **Validation of AG Prescription**
   - Comparison between animal centrifugation on the ground and in space
   - Space operations of a human short-radius centrifuge
   - Tests of a human centrifuge in space
AG-Animal Models (Ground & Space)

Overview of Mouse Habitat Cage Unit

Features:
- 30 days ~ 6 months keeping with maintenance
- Unit: L160mm × W160mm × D115mm, < 1.5 kg
- Cage: Floor Area > 96.7 cm², Diagonal Length > 12.7 cm, 20-27 degree C, 30-70%RH, < 60dB
- LED Lighting (0-50 lux) with on/off cycle
- Cage refreshing requirement once a week
- Feed/water resupply requirement once a week
- Temperature, humidity, and concentration of CO₂ and NH₃, video images are monitored.