

Artificial Gravity Research Plan

AG Research Group

21 August 2014

Artificial Gravity Research Plan

This document describes the forward working plan to identify what countermeasure resources are needed for a vehicle with an artificial gravity module (intermittent centrifugation) and what Countermeasure Resources are needed for a rotating transit vehicle (continuous centrifugation) to minimize the effects of microgravity to Mars Exploration crewmembers.

Table of Contents

HRP Artificial Gravity Risk	4
Risk Statement	
Risk Content	
Criticality Metric	
Operational Relevance	
Mitigation Strategy	
Point of Contact	
Gaps and Tasks	
Intermittent AG1: We do not know if a Short-Radius Centrifuge (SRC) is effective for protecting against sensorimotor disturbances (SM) and orthostatic intolerance (OI) in microgravity	
Task 1 – Determine the most effective AG level	
Task 2 – Determine the most effective AG duration	
Task 3 – Determine the health consequences of cross-coupled and Coriolis accelerations	
Task 4 – Determine the health consequences of gravity gradient	
Task 5 – Assess the effects of SRC on neurocognitive functions	
Task 6 – Assess the effects of SRC on post-flight decrease in performance	
Intermittent AG2: We do not know if a SRC is effective for protecting against muscle and bone loss (MS) in microgravity	
Task 1 – Assess the protective role of SRC on MS in humans	
Task 2 – Assess the protective role of SRC on MS in animals	
Task 3 – Should additional CM be required beside a SRC?	
Task 4 – Should exercise be integrated with centrifugation?	
Intermittent AG3: We do not know if a SRC is effective for protecting against the VIIP syndrome in microgravity	
Task 1 – Effects of SRC on intracranial pressure in healthy subjects	
Task 2 – Effects of SRC on intracranial pressure in patients with VIIP syndrome	
Intermittent AG4: We do not know if AG will be required on the Martian surface	
Task 1 – Assess the effects of Martian gravity in volunteers during head-up bed rest	
Task 2 – Assess the effects of Martian gravity in ISS crewmembers immediately post-flight during head-up bed rest	
Continuous AG1: We do not know what rotation rate and radius can be used to maintain adequate crew health and performance	
Task 1 – Adaptation to Slow Rotating Room (SRR)	
Task 2 – Adaptation to Large Radius Centrifuge (LRC)	
Continuous AG2: We do not know the limits for rotation rate and radius regarding exercise, ambulation, material handling, EVA	
Task 1 – Validation of comfort zone parameters for radius up to 4 m	
Task 2 – Validation of comfort zone parameters for radius > 4 m	
Continuous AG3: We do not know the expected crew health and performance consequences during and following spin-up and spin-down of a rotating transit vehicle	
Task 1 – TBD	
Continuous AG4: We do not know the operational restrictions that should be placed on crewmembers during spin-up and spin-down of a rotating transit vehicle	
Task 1 – TBD	

Artificial Gravity Research Plan

Continuous AG5: We do not know if additional countermeasures will be required to supplement continuous AG during transit
Task 1 – TBD

HRP ARTIFICIAL GRAVITY RISK

The most serious risks to long duration flight involve radiation, behavioral stresses, and physiological deconditioning. Artificial gravity (AG), by substituting for the missing gravitational cues and loading in space, has the potential to fully mitigate the last of these risks by preventing the adaptive responses from occurring.

Risk Statement

The rotation of a Mars-bound spacecraft or an embarked human centrifuge offers significant promise as an effective, efficient multi-system countermeasure against the physiological deconditioning associated with prolonged weightlessness. Virtually all of the identified risks associated with bone loss, cardiovascular deconditioning, muscle weakening, sensorimotor disturbances, space anemia, and immune compromise might be alleviated by the appropriate application of AG.

Risk Context

Experience with AG in space has been quite limited and a human centrifuge is currently not available on board the ISS. A complete R&D program aimed at determining the requirements for gravity level, gravity gradient, rotation rate, frequency, and duration of AG exposure is warranted before deciding the best technique for implementing AG in space.

Criticality Metric

[The current criticality rating for physiological deconditioning is...](#)

Operational Relevance

During the Exploration program all crewmembers will need to perform at a high level of competence after landing on Mars. There is evidence that following a six-month stay in microgravity, bone and muscle mass are lost, the cardiovascular, pulmonary and immune systems are weakened, vision could be impaired, the vestibular system no longer senses tilt and as a result balance could be off.

Mitigation Strategy

Past efforts to mitigate physiological deconditioning have focused on countermeasures delivered in a piece-meal fashion, e.g., LBNP and fluid loading for the cardiovascular system, exercise for muscle and bone. Although the risk due to physiological deconditioning has been greatly reduced through these countermeasures, it is at the expense of significant crew time and equipment. Artificial gravity (AG) presents the advantage of reproducing Earth-like gravity and therefore affecting all the physiological systems. AG can be generated by rotating the entire spacecraft continuously, or by means on an on-board short-radius centrifuge that the crewmembers will ride intermittently. We need to determine the rotation rate, radius, and duration of exposure that are the most efficient for maintaining physiological conditioning in microgravity so that optimal decisions on the vehicle capabilities can be made early in the Exploration Program.

Point of Contact

Gilles Clement

Gaps and Tasks

Artificial gravity generated by a rotating environment is an untested area in orbit. Simulations will be performed using short and long-radius centrifugation in ambulatory subjects, patients with VIIP syndrome, during bed rest, immersion, and head-up tilt. Investigations will also be conducted in animals in ground-based simulation studies and during centrifugation on board the ISS.

The first series of gaps will address the issues with intermittent centrifugation using an onboard short-radius centrifuge (IAG). The second series of gaps will address the issues with continuous rotation of the space vehicle (CAG).

Information gained during the tasks in IAG Gap 1 will primarily determine the most effective AG level and duration during short-radius centrifugation (SRC) for protecting against sensorimotor disturbances and orthostatic intolerance in microgravity, as well as preventing from adverse health consequences, including neurocognitive impairment. The tasks in IAG Gap 2 will assess the protective role of SRC on the musculoskeletal in humans and animals, and whether additional exercise, integrated on the centrifuge or not, is required for better protection. The tasks in IAG Gap 3 will assess the effects of SRC on intracranial pressure. The tasks in IAG Gap 4 will specifically investigate the effects of Martian gravity (0.38 G) on physiological deconditioning during simulation studies or immediately after six-month stays in actual microgravity. This information will be important for determining whether AG will be needed on the Martian surface.

The tasks in CAG Gap 1 will assess crew health and performance of the various physiological systems during long-duration exposure to a rotating environment compatible with those of a rotating space vehicle. The tasks in CAG Gap 2 will validate the limits for rotation rate and radius regarding exercise, ambulation, material handling, and EVA operations. The more information gained through CAG Gaps 3 and 4 will result in a more efficient closure of CAG Gap 2 by assessing the consequences of spin-up and spin-down of a rotating transit vehicle. Finally CAG Gap 5 will determine if additional countermeasures will be required to supplement continuous AG during transit.

Intermittent AG1: We do not know if a Short-Radius Centrifuge (SRC) is effective for protecting against sensorimotor disturbances (SM) and orthostatic intolerance (OI) in microgravity

Present State: SRC have been used during 5-21 day bed rest studies for generating 1-2 G at the heart along the subjects' body axis for 30 minutes to 2 hours per day. This intermittent centrifugation has been beneficial for maintaining orthostatic tolerance, blood volume, parasympathetic activity, exercise capacity, and postural stability. However, it was not efficient

Artificial Gravity Research Plan

for preventing immune system deficiency, and the effects on cognition and muscle and bone loss were inconclusive. In addition the effects of multiple (shorter) daily centrifugation sessions vs. a single bout of centrifugation have not been systematically studied so far. In all the past studies the subject's head was immobilized so the effects of cross-coupled angular and Coriolis accelerations during head and limb movements are not known. Finally, a human factor analysis of crew acceptability and comfort is not currently available.

Target for Closure: TBD

Interim Stages:

Task	Incomplete/Complete
Determine the most effective AG level	Incomplete
Determine the most effective AG duration	Incomplete
Determine the health consequences of cross-coupled angular and Coriolis accelerations	Incomplete
Determine the health consequences of gravity gradient	Incomplete
Assess the effects of SRC on neurocognitive functions	Incomplete
Assess the effects of SRC on post-flight decrease in performance	Incomplete

Note: Closure metric = (number of tasks completed/number of tasks) x 100

Approach: A multidisciplinary AG working group including scientists, engineers, and flight surgeons will convene to determine the range of AG level and duration to be tested in these tasks, and the standard baseline core data to be measured before, during and after centrifugation.

Effectiveness of SRC against SM and OI

Short Title: Effectiveness of SRC against SM and OI
Not Completed
PI:
Responsible HRP Element/Project:
Supporting Org(s):
Solicitation Mechanism(s):
Funding Status:
Task Narrative: This ground-based effort is required to validate if AG level at the heart lower than 1 Gz and if the duration of SRC less than 1 hour still prevents sensorimotor and cardiovascular deconditioning. A slower rotation rate would induce less cross-coupled angular and Coriolis acceleration (and the associated spatial disorientation) during head and body movements, thus being more acceptable by the crew. The specific effects of the gravity gradient will also be investigated by comparing the same rotation rate between short-and long-radius centrifugation. The effects of SRC on neurocognitive function and post-flight decrease in performance will also be evaluated.
Resources:
Deliverables: