Another Go-Around: Revisiting the Case for Space-Based Centrifuges

Laurence R. Young¹, Erika B. Wagner¹, Joan Vernikos², Jessica E. Duda³, Charles A. Fuller⁴, Kenneth A. Souza⁵, Cynthia Martin-Brennan⁶, and Christopher P. McKay⁵

¹Massachusetts Institute of Technology; ²Thirdage, LLC; ³Aurora Flight Sciences Corp.; ⁴U. California-Davis; ⁵NASA Ames Research Center; ⁶American Society for Gravitational and Space Biology

Please note that the following paper reflects the personal opinions of the listed co-authors. These opinions and recommendations are based on our discipline expertise in the areas of gravitational biology and artificial gravity. None of the following comments are official NASA or U.S. government positions.

The need for space-based centrifuges for both research applications and astronaut countermeasures has been articulated for decades. Key reviews and reports from NASA and the space life sciences community have long identified artificial gravity (AG) facilities as a top priority for the gravitational biology and aeromedical communities:

There was unanimity of opinion that any major adverse effects of spaceflight could probably be prevented by creating an artificial gravitational field within the spacecraft... The need for a centrifuge on future flights is of the highest priority (NRC, 1979).

Variable Force Centrifuge...is the single most important facility in any life sciences program...[and] should increase the scientific return from space experiments by orders of magnitude...A VFC is an essential instrument for the future of space biology and medicine (NRC, 1987).

Whether used in the near-term to facilitate human missions to Mars, or put off until developing missions to destinations farther away, artificial gravity will eventually be required to protect humans exploring space (IAA, 2009).

The cancellation of the Centrifuge Accommodation Module planned for ISS left life sciences researchers with no rotational or glovebox facilities for flight investigations, and reopened the call for such a core capability. As recently as 2009, approximately 10 percent of the nearly 150 position papers publicly submitted to the ongoing National Academies’ Decadal Survey on Biological and Physical Sciences in Space included some mention of centrifugation or artificial gravity (National Research Council, 2010), including both a key position paper from the Aerospace Medical Association and a highly focused white paper representing the views of 18 senior investigators and engineers in the field. Together, these documents make specific recommendations for developing an effective artificial gravity regimen to protect astronaut health through a combination of ground and flight resources for studying cells, animals, and humans.

Although free-flyers, such as the Russian Bion/Biocosmos, can test some animals and provide for centrifugation, only the ISS will currently permit both animal and human testing of artificial gravity. Once the ISS ceases operation, our opportunities to explore the efficacy of AG as a human countermeasure will be limited to yet undefined opportunities on commercial or other spacecraft.

Clinical deconditioning associated with microgravity exposure is dramatic and progressive, with changes markedly faster than age-related declines and recovery in some systems incomplete after as long as a year postflight (Buckey, 2006). Serious commitment to exploration-class missions, whether or not they involve surface stays, requires more effective and efficient countermeasures, with better knowledge of gravity threshold requirements and clearer prescription of how much, how often, how long such loads must be applied. This requires understanding the role of gravity in biology and physiology, and will not be adequately met by current approaches based on ground-based trials. To do so requires the ability to test a range of living organisms, including humans, using space-based rotating facilities. Importantly, such experiments are also relevant to understanding the role of gravity in...
maintaining health on Earth, as well as the nature of life elsewhere in the Universe.

The needs of the life sciences community with respect to artificial gravity systems are not monolithic, nor is the appropriate solution likely to be. Core themes that could be addressed with flight centrifuges are enumerated below:

1. Countermeasure development and testing
   (a) Efficacy: Artificial gravity is the only known integrated countermeasure designed to address all physiological systems affected by microgravity exposures. However, while the efficacy of very large rotating vehicles operating at 1-g is generally accepted by the community, the effectiveness of short-radius intermittent exposures still needs substantial research (International Academy of Astronautics, 2009). Successful ground studies (Young and Paloski, 2007; Warren, et al., 2006) require flight validation.
   (b) Responses to rotation: Numerous studies have shown that short-radius centrifugation up to 30 rpm is acceptable on the ground (e.g. Iwasaki, et al., 2001); however, an in-flight human countermeasure feasibility test is needed, which can also answer fundamental questions about the role of gravity in vestibular function, serving the basic research community.

2. Fundamental gravitational biology
   (a) 1-g control: Among the greatest criticisms of microgravity research efforts to date has been the inability to accurately distinguish the effects of reduced gravity from other factors in the flight environment, including launch and entry loads, radiation, stress, etc. An appropriate 1-g control environment would substantially improve the quality of research conducted on ISS.
   (b) Partial-g responses: Understanding biological responses to partial gravity environments between microgravity and 1-g is a key unexplored area of both basic and applied research. Partial gravity data is vital for understanding the fundamental mechanisms of mechanosensing, and for designing potential countermeasures appropriate for Lunar and Mars exploration. Research into plant and animal response at partial gravity will be essential to planning long-term life support systems to support lunar and Mars bases, and animal results will provide an early indication of the magnitude of any problems for long-term human bases. This information is needed as early as possible in the design and planning for extended human stays on the Moon and Mars.

3. Systems architecture trades
   Despite dozens of white papers and trade studies since the earliest days of human spaceflight, the concept of a large-radius rotating vehicle has yet to be demonstrated in flight. Hardware designs abound, from deployable tethers and booms to more traditional assembled structures. If such an architecture is to be seriously considered for exploration-class missions, a successful flight with living organisms using a free-flyer platform would be a critical first step towards future crewed flights.

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Interest from Japan, ESA, Russia, and China has been growing; we have recently visited ground centrifuges and discussed AG research needs with colleagues in Nagoya, Xi’an, Toulouse, Cologne, and Moscow. Separate ESA Topical Teams are at work on flight animal centrifuges and large radius ground centrifuges. Furthermore, JAXA, ESA, and NASA are reviewing the AGREE project (Iwase, et al., 2010) studying the requirements and practicality of the placement of a short-arm human centrifuge on the ISS. All participants appear convinced of the importance of international cooperation in the further research on both the scientific and countermeasure aspects of AG. This is consistent with NASA’s renewed commitment to ISS research, transformative technology and international cooperation.

We strongly recommend that NASA fund immediate technical evaluation of the readily available flight technologies, with the aim of a rapidly deployed flight system or systems designed to deliver near-term science results that can clearly recommend for or against the development of more expensive and complex systems.
A subset of such approaches, any of which we estimate could be readied for flight in less than three years, given appropriate resources, include:

- Requalifying the Neurolab Rotator previously flown for human research on STS-98;
- Design of a small, human-powered portable centrifuge for ISS, drawing on substantial ground experience (e.g., Clément and Buckley, 2007);
- Adaptation or reflight of the Russian Biocosmos centrifuge being readied for animal flights in 2013;
- Possible salvage of elements of the Japanese CAM rotor and supporting hardware;
- Leveraging existing CAM experience and designs to prepare a double rack-scale small animal centrifuge for use on ISS or a free-flyer platform.

Depending on upmass, downmass, and volume availability, systems proposed for use on ISS could be flown in the existing Station volume, or mated to a docked transfer module such as an ATV or COTS platform. Free-flyer approaches could similarly leverage either a dedicated platform, or commercial orbital access, e.g., SpaceX DragonLab or Bigelow inflatable platforms. While it might be possible to mount biology research payloads to a human centrifuge, or even to mate a human platform to a biology centrifuge rotor, we see this added complexity as a barrier to rapid progress and support parallel evaluation of the strategic and scientific value of independent human and animal system designs.

We believe firmly that there is an engaged community, both domestically and across our ISS partner nations, ready to respond to opportunities aligned with any of the options presented above. A coordinated, collaborative approach could provide answers to pressing scientific and operational questions. Success is crucial to safe planning and execution of exploration programs, and holds substantial promise for basic research. Space agencies interested in human space exploration should not let this opportunity pass by again.

REFERENCES


