Preface

William H. Gerstenmaier

Associate Administrator,
Human Explorations and Operations Directorate,
NASA Headquarters,
Washington DC, USA
Email: william.h.gerstenmaier@nasa.gov

Michael R. Barratt*

Astronaut Office,
NASA Johnson Space Center,
Houston, TX, USA
Email: michael.r.barratt@nasa.gov
*Corresponding author

Biographical notes: William H. Gerstenmaier is the Associate Administrator for Human Exploration and Operations at NASA Headquarters in Washington, DC. In this position, Gerstenmaier directs NASA's human exploration of space. He has programmatic oversight for the International Space Station, Orion deep space vehicle, Space Launch System, commercial crew transportation development, space communications and space launch vehicles. He began his NASA career in 1977 at NASA Lewis (now Glenn Research Center) performing aeronautical research. Throughout his career he has held many key positions in human spaceflight in both the Space Shuttle and Space Station programs. He holds a Bachelor's degree in Aerospace and Astronomical Engineering from the Purdue University (1977) and a Master's in Mechanical Engineering from the University of Toledo (1986).

Michael R. Barratt is a NASA Astronaut and Physician specialising in Space Medicine. He currently works to apply spaceflight medical standards and principles to new spacecraft design while maintaining proficiency as an active astronaut. He came to the NASA Johnson Space Center in 1991, and worked as a medical officer supporting Space Shuttle and Mir station missions until being selected to the astronaut program in 2000. He has flown twice to the International Space Station, serving as Flight Engineer for expeditions 19 and 20, and aboard the Space Shuttle Discovery for its final flight in 2011, accumulating 212 days in space. He has served leadership positions in the astronaut office and in the medical operations and research arenas. He also serves as an Associate Editor for Space Medicine for the journal *Aerospace Medicine and Human Performance*, and is a Senior Editor of the text book *Principles of Clinical Medicine for Space Flight*.

Human performance modelling has long played a role in the aviation world, among other things to inform systems design and operational guidelines and to predict risk of untoward events. Identification and closure of significant risk gaps by predictive modelling is a high value capability. Although modelling processes are constantly maturing in step with advances in aircraft and avionics capabilities, the human in the aviation environment is fairly well characterised. Spaceflight introduces a new set of physical, environmental, and physiologic factors that are less understood and not well known to the human performance community. This issue of *IJHFMS* with its focus on human factors modelling in the aerospace environment affords us a welcome opportunity to share some of these unique aspects of the human in spaceflight.

As with aviation and other venues requiring control of vehicles and systems, the human operator in space must accumulate and process multiple sources of sensory information associated with the vehicle and the environment. The integrated outputs of this information are the motor actions associated with direct vehicle and systems control and decisions that influence more highly automated processes. This sensory-motor loop applies to diverse activities associated with a space mission. Astronauts conduct manual control of spacecraft during free orbital flight, rendezvous and docking, and landing, operate large robotic manipulators, control airlocks and berthing systems, perform highly complicated space walks, and execute complex payload operations. The backdrops for these activities are the dynamic acceleration environments with multiple G loads on ascent and entry, and that most novel of all conditions, weightlessness.

Almost all sensory cues that serve to inform one's sense of position and locomotion are radically altered in the weightless environment. Visual inputs become even more dominant, but without a gravitational axis, the visual up or down has no standard reference; it can be changed instantly at the subject's convenience. The multi-channel neurovestibular system, the classic balance organs residing in the inner ear along with their neural input and control channels, are uncoupled from gravity and send information to the brain that conflicts with the visual and other sensory inputs. This leads to a process of neurosensory adaptation that includes space motion sickness and potential spatial disorientation, both in one's own position sense and that of external objects. The loss of gravitational loading also nullifies proprioceptive inputs – pressure sensations in the joints along the body axis that also serve to identify the direction of gravitational force. Haptic cues that define the sense of touch must be reinterpreted to account for an arm and hand that now lack background weight.

In addition to the neurosensory changes noted, there is a constellation of physiologic changes and processes that begin immediately upon arrival into weightlessness that we only briefly summarise here. Anthropometric changes include increased chest diameter and decreased abdominal girth, and upward displacement of internal organs and diaphragm. Spinal lengthening occurs that may drive a seated height increase of 6%. Fluids shift from the lower half of the body to the chest and central circulation, and over a period of several days circulating blood volume and red blood cell mass decrease by roughly 15%. The cardiovascular system changes significantly to increase cardiac output but decrease vascular resistance, resulting in a new stable but poorly understood equilibrium that appears to support optimal human performance in this new environment. Bone and muscle tissue begin to atrophy, more pronounced from the postural regions most involved in countering gravity in day to day movement, such as the heels, hips, pelvis, and lumbar spine. This must be countered by rigorous daily exercise to ensure fitness and function on returning to Earth. There are significant changes in metabolism, fluid regulation, and the immune system as well.

Fortunately the human gradually adapts to the weightless environment and astronauts become very effective workers for long periods. The average duty tour on the

International Space Station (ISS) is roughly six months in duration, and the current expectation is for high productivity during this time carrying out science and maintenance activities. But there remain gaps in our understanding of human adaptation that may influence human health and performance, and G transitions remain a particularly hazardous phase of spaceflight. Past lunar activities and future exploration missions back to the moon (0.17 of Earth's gravity), to Mars (0.38 of Earth's gravity) and asteroids will involve piloting and surface activities in fractional gravity fields, where even less is known about human performance.

To add to the neurosensory and physiologic changes, the spacecraft environment itself introduces other factors that may influence human performance. Spacecraft are inherently small and confined, a particular challenge with multiple crewmembers. Due to the absence of gravity for guiding and containing fluids and buoyancy driven convection for mixing gases, continual operation of fans and pumps creates a noise environment. In low Earth orbit where the vast majority of human spaceflight experience has accumulated, at an orbital velocity of roughly 28,164 km/hr and about 90 minutes per orbit, there are roughly 16 sunrises and sunsets per day. Without natural day and night cues, circadian desynchrony may combine with stressful work schedules to create a fatigue risk. The cabin atmosphere is critically dependent on life support systems, and cabin carbon dioxide levels typically run 10–15 times higher than in the natural Earth atmosphere. Although there is essentially real time communication, monitoring, and control links with ground support teams in Earth orbit, an interesting aspect of future exploration missions will be delayed communications due to the distances involved. Radio signals experience a nearly three second round trip to and from the moon, and this could balloon to as much as 44 minutes both ways for a Mars expedition.

It is worth mentioning that hardware and systems themselves may be equally challenged in the spaceflight environment. Due to severe constraints on launch weight, hardware must be as light as possible. This basic fact along with the formidable acceleration and vibration loads associated with launch and landing means that mechanical systems are often operating at the upper limit of performance specifications. Once in orbit or deep space cruise, there are extreme temperature fluctuations and direct effects of solar electromagnetic radiation on materials, and the constant bombardment of ionising radiation from solar and deep space sources.

A final aspect of the character of human spaceflight involves its international nature, formulated and cemented largely over the last two decades. Both crewmembers and systems come together across lines of language, culture, and technical standards, exemplified in the five agencies and 15 nations participating in the ISS. Although this best combines global resources to enable the scale of large, high value projects such as the ISS and near term exploration missions, there are added trip points compared with a single national program.

As we look holistically at the environment in which crews must operate these complex machines, several natural factors that can influence human performance, particularly at the human-machine interface, become apparent. Deliberate training and exposure to these extreme environments can help crews adapt and perform optimally during the mission. Astronauts preparing for spaceflight typically spend hundreds and even thousands of hours learning to operate in these conditions. For example, Space Shuttle flight crews spent hundreds of hours in high fidelity motion based simulators training for the ascent phase and for landing the Shuttle. These training events included multiple failures to allow the crews to learn to operate in a time constrained and stressful environment, both individually and as a coordinated team. Typical training events included simulated failures at a cadence and magnitude higher than ever expected in actual flight. This was done to improve task performance under nominal return from space landing conditions.

Some of the physiologic conditions noted above such as returning to the 1 G environment (Earth's gravity) and its effects on motor sensory input cannot be simulated. The goals of the training have been to solidify task familiarity and over-stress in problem resolution to compensate for the conditions that could not be simulated. Spaceflight crews also fly high performance T-38 aircraft, which helps astronauts learn to operate smoothly and reflexively in a dynamic and physiological stressful environment. The piloting skills required in the T-38 are not the same as a Space Shuttle, but the environment has many similarities to a Shuttle entry. Lastly the Shuttle crews also flew a modified Gulfstream aircraft that mimicked the Shuttle flying characteristics on final approach. This aircraft provided many real world cues to the crew and facilitated retained handling skills, critical following transition from a spacecraft in weightlessness to a complex atmospheric vehicle. In preparing crewmembers for the highly demanding task of Shuttle landing, each simulation venue attempted to train for a particular aspect of the return environment, since no individual simulator could mimic the actual entry conditions in complete sequence. Exposure to these conditions individually under extreme loading prepared the crews for the real task of return where all conditions occurred simultaneously under less demanding circumstances.

With all of these factors at work in a high stakes-high cost endeavour, the need for effective predictive modelling is obvious. It is not difficult to envision the negative effects of task saturation or a contingency event against this novel physiologic, environmental and cultural milieu. Identifying risks and predicting outcomes enables concentration of resources and planning toward their mitigation; this applies equally to complex systems, individual hardware items, and of course the human operator. Equally obvious are the concerns with uncertainties. As of this writing, about 560 people have flown in space over the past nearly 50 years. However for any given investigation or rigorous assessment of adaptation and performance, only a tiny fraction have participated.

To narrow these uncertainties and provide high level inputs for predictive modelling, several actions are needed. These include methodical formulation of performance metrics in standard spaceflight activities, standardisation of modelling methods, and availability of results and findings to communities with sufficient expertise. Combined with analogous information on hardware and systems performance, it is expected that predictive models can mature in step to inform high level decisions on mission architecture, vehicle design, provisioning, and vehicle operation. Effective modelling will also identify where risks and uncertainties remain, to which more conservative solutions may be applied. New approaches that use mental work load models and human capability factors to predict failures are particularly interesting in that these factors are naturally evident as we prepare crews to operate in these extreme environments. The difficulty will be in obtaining sufficient quality data for the specific cases to build sound models.

This issue's focus on human factors modelling in the aerospace environment comes at a time unique to the human spaceflight world. The ISS has been permanently occupied for 17 years, sustaining resident and visiting crews of astronauts and cosmonauts in assembly, maintenance, and science activities. Two new spacecraft are under construction and on the verge of operational (Space Exploration Technologies Dragon and Boeing Starliner), soon to carry human crews to the ISS. The Orion spacecraft and Space Launch System heavy lift booster is also under design and construction, destined to carry crews out of low Earth orbit to outward destinations such as near lunar space, support eventual lunar landings, and further ventures. At the same time commercial enterprises such as Virgin Galactic and Blue Origin are actively test flying suborbital carriers that will soon enable a spaceflight experience to a wide range of paying customers. Simply put, there has never been a time in history when so many human carrying spacecraft were under construction and in test flight phases. Although these endeavours may suggest a robust understanding of the spaceflight environment, to the community involved in informing design and operational requirements there remain many areas of uncertainties and concern.

We appreciate the opportunity to share some of the unique factors that influence human performance in spaceflight, and look forward to continual closure of our uncertainties and further enhancement of predictive models to inform this activity.