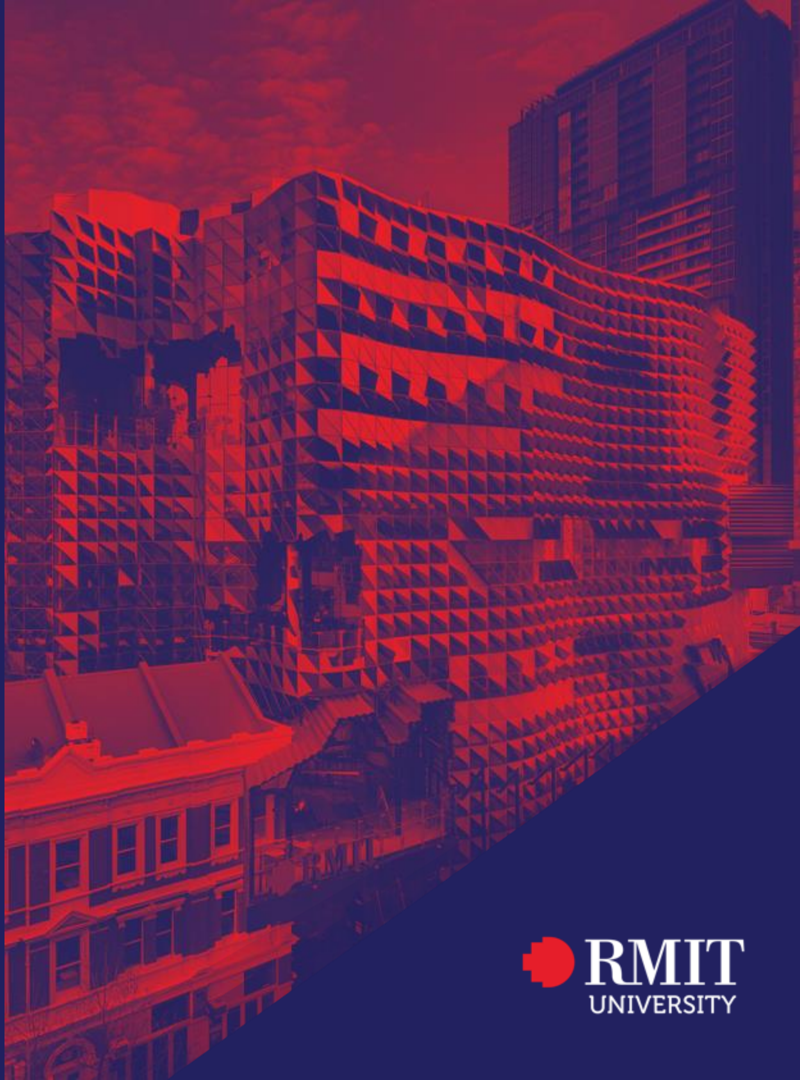
Human Performance challenges in future space operations: A student perspective

PACDEFF 2023

Associate Professor Selina Fothergill, PhD

School of Aerospace Engineering and Aviation, RMIT University



Bio in pictures

Qualifications and Licenses

BPsySc(Hons1), MOrgPsy, PhD — The University Of Queensland, Australia

Advanced Diploma of Management — Canberra Institute of Technology

Graduate Certificate Transport Safety Investigation — RMIT University

Supervisor Organisational Psychologist — Psychology Board of Australia | AHPRA

Remote Pilot Licence Multirotor sub-25kgs — Australian Civil Aviation Safety Authority CASA

Employment

airservices

A/Manager Human Factors & Analysis

Australian Civil Aviation Safety Authority CASA

Human Performance Lead, Certificate Team Manager and A/Manager Safety Systems

Australian Government
Australian Transport Safety Bureau

Transport Safety Investigator
Investigator In Charge

ICAO • OACI • ИКАО

CASA rep FRMS SARP for Regulators
RPAS study group

QueenslandRail

A/Manager Human Factors
Manager Traincrew Diagnostic & Support Program

RMIT University
School of Engineering
STEM College

Associate Professor

Space at RMIT

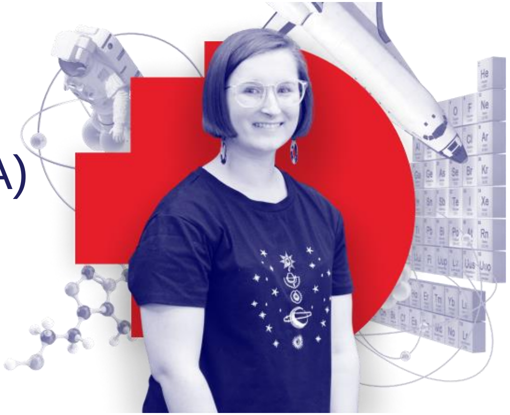
Space Industry Hub

- Advanced Manufacturing Precinct
- Centre for Cyber Security Research and Innovation
- Centre for Additive Manufacturing
- Satellite Position for Atmosphere, Climate and Environment (SPACE)

Bachelor of Space Science (BP330) 3 year FT

Aviation Discipline is joined with Aerospace Engineering (AE&A)

- Universal Payload Racking System Flight Qualification and Demonstration
- Australian Lunar Experiment Promoting Horticulture (ALEPH)



AE&A Aviation Industry Projects

- Students showcase aviation knowledge and demonstrate skills (analysis, communication, problem-solving, critical thinking, teamwork) to tackle a real-world aviation problem
- Teamwork with guidance from/topic provided by an academic supervisor
- Offshore AERO2488 and Onshore AERO2431 (Sem 3)

Learning goals:

- What is a research proposal?
- What is a literature review?
- Research design and research protocols
- Structuring the report and planning research activities
- Quantitative and qualitative data
- Workshops
- How to present research?

Context

Humans' creativity, adaptability, and problem-solving capabilities are key to resilient operations across aerospace application but there are still numerous outstanding questions about the psychosocial implications of long-duration missions; human robotic teaming for exploration and the analysis of macro-ergonomic issues such as organizational culture, safety culture and process complexity. The future could use improved methods and tools for human factors data acquisition and analysis; more complete integrated models of human performance that span the physiological, psychological, social, and task performance aspects of human behaviour and performance; improvements in human-centered design methods and tools; and better human-systems integration throughout the lifecycle

(Jones & Fiedler, 2010).

With human space exploration various human performance challenges exist: cognitive functions and human error, physiological performance and capabilities, system safety and accident prevention, habitability and habitat design, human-system interfaces design, workload and fatigue and selection and training. Starting with Skylab, then Space Shuttle, and later the International Space Station, human factors standards have been levied on the design, while selection and training policies have evolved away from physical resilience and toward scientific and professional skills. In this evolution, safety and human factors design requirements and processes have coalesced around human performance as precondition for and enhancer of system safety. In the early time of human spaceflight, the integration of man and machine was essentially a matter of ergonomics and physical resilience. In future long-duration missions, it will deal with cognitive human-machine integration and psychological resilience.

(Kanki, Clervoy & Sandal, 2017).

Space safety and human performance

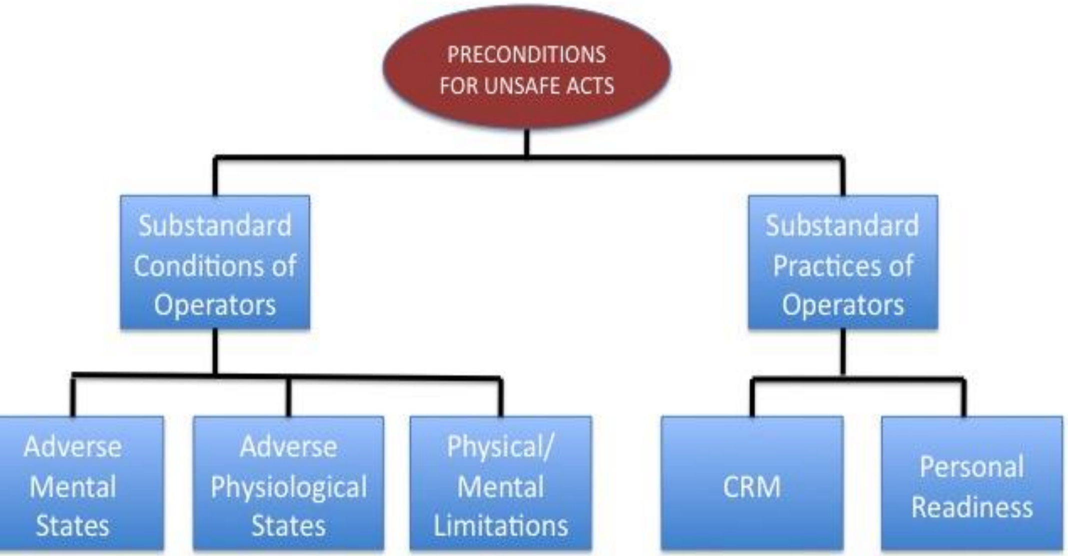
Engineering psychology applied to human spaceflight and the relationship with safety.

(Kanki, Clervoy & Sandal, 2017).

Challenges

- Cognitive functions and human error
- Workload and fatigue
- Space flight environment
- Physiological performance and capabilities
- Psychological resilience
- Human factors research tools and methods
- System safety and accident prevention
- Human-system interfaces design
- Human-automation interaction
- Human factors and safety in extravehicular activities
- Human reliability analysis methods and tools
- Human factors in mission control centres
- Organisational factors and safety culture
- Habitability and habitat design
- Selection and training
- Medical and psychological mission support
- Human factors in mishap investigation

Human error in space



(Shappell & Wiegmann, 2000).

Close calls due to human error

- Mercury MA-7 (1962): Overconsumption of RCS Fuel
- Apollo 10 LM (1969): Wrong Abort Guidance System Command
- Skylab 4 (1972): Wrong Circuit Breakers Opened for Re-Entry
- Apollo ASTP (1975): Inadvertent Manoeuvre After Docking
- Apollo ASTP (1975): Crew Exposure to Toxic Gases
- STS 3 (1982): Shuttle Almost Crashed at Landing
- Mir (1997): Progress-Mir Collision

Source: NASA-JSC Flight Safety Office database of Significant Incidents and Close Calls in Human Spaceflight

Topic

What are the human performance challenges that will need to be integrated into astronaut/space traveller crew training in the future?

This project requires students to consider how aviation/space regulators in the future may provide Human Performance guidance for operators. Currently, there is specific Australian regulatory Human Performance guidance and training requirements for manned flight operations, rotary operations, RPAS operations and Night Vision Goggles operations. What will regulators need to consider in order to provide Human Performance guidance for space/sub-orbital operations? Students will also need to decide what format this could be in (e.g., Manual of Standards, Advisory Circular, CASR etc) and provide a draft of what it might look like.

You will need to conduct a literature review on Human Performance challenges specific to space operations/sub-orbital flight and then interview policy makers and regulators (e.g., CASA, Australian Space Agency) to determine how a future regulation/guidance document might look. Students will need access the scientific literature and use interview skills.
Compare and contrast human factors/non-technical skills training topics that we have for aviation today versus what should be included for future space operations.

Group 5 (2022)
“Developing Future Operator Guidance to Manage Human Performance Risks for Space Operations”

Group 15 (2023)
“Human Performance Challenges in Space Operations”

Group 5

Research Questions

1. What is the optimal method for Australian policymakers to provide guidance on how operators can manage the human performance safety risks of space/suborbital operations?
2. What should be included in the human factors guidance and training requirements template for Australian operators?
3. How will human performance guidance and training requirements differ from existing aviation requirements due to the unique environmental risks of space/suborbital operations?
4. How will this guidance be delivered and who will be responsible for delivering and enforcing it?

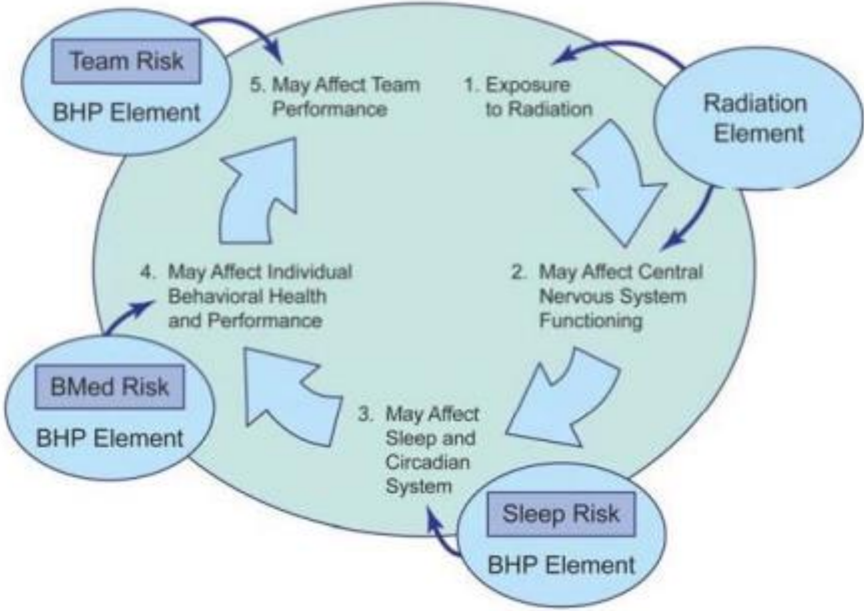
Literature Review

- Behavioural health and performance
- Space radiation
- Exploration medical capabilities
- Space Human Factors and habitability

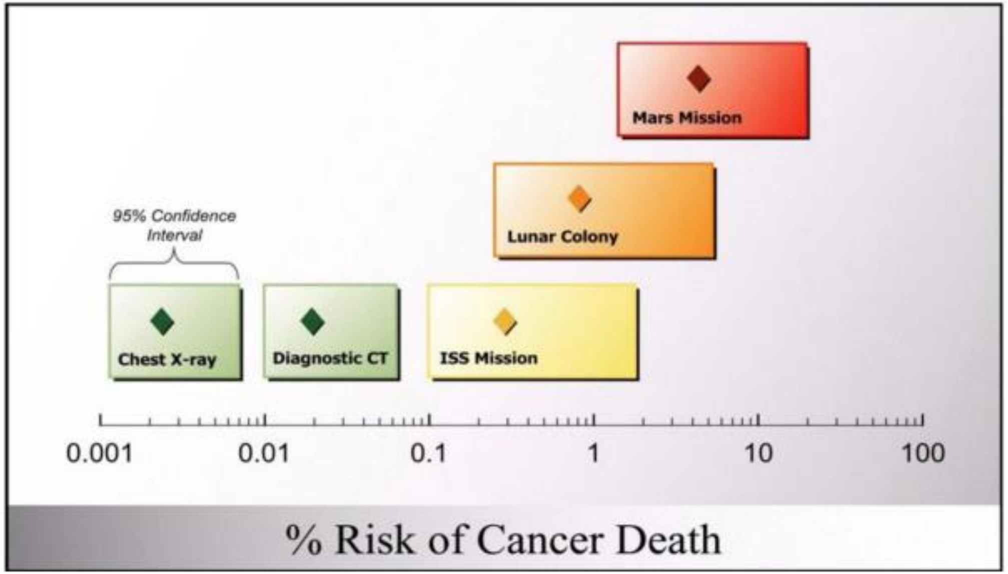
Methodology

- Questionnaire and literature review
- Content Analysis using NVivo

Group 5



Integration and interaction between BHP components (adapted from Whitmire et al. 2009)



Uncertainties in risk projection for terrestrial and space exposures (adapted from Cucinotta and Durante 2009)

Group 5

Results

Six categories were identified: Environment, Cognition, Medical care, Physiology, Workload and Fatigue, Psychology

A comprehensive content analysis table was created through using auto coding and manual filtering.

In the table:
F: the count of specific files that mentioned the point
R: the count of specific references from all the files
%: the percentage of specific reference count to total reference count

Framework components/categories											
	F	*R*	*%*		*F*	*R*	*%*		*F*	*R*	*%*
Environment	26	2320	34.46%	*Cognition*	28	1274	18.92%	*Medical care*	28	868	12.89%
Pressure	22	628	9.33%	Cognitive test	8	61	0.91%	**Medical standards**	13	231	3.43%
Radiation	14	390	5.79%	Perception	12	247	3.67%	**Preflight preparation**	9	129	1.92%
Temperature	18	335	4.98%	**Attention**	17	339	5.04%	**In-mission care**	17	321	4.77%
Vibration	9	269	4.00%	particular attention	12	69	1.02%	research & technology	10	100	1.49%
Acceleration	14	244	3.62%	sustained attention	10	44	0.65%	nutrition and sleep support	8	86	1.28%
Acoustics	5	155	2.30%	attention failure	9	29	0.43%	psychological and family support	7	49	0.73%
Humidity	7	94	1.40%	**Memory**	14	301	4.47%	environmental care	13	44	0.65%
Microbial Contamination	4	67	1.00%	working memory	9	99	1.47%	physiologic countermeasures	7	42	0.62%
Microgravity	6	65	0.97%	long-term memory	3	29	0.43%	Rehabilitation	20	107	1.59%
Lighting	5	51	0.76%	short-term memory	4	29	0.43%	Medical emergency	10	80	1.19%
Closed environment	5	22	0.33%	**Analysis and judgement**	16	241	3.58%				
				Brain injury	7	85	1.26%				

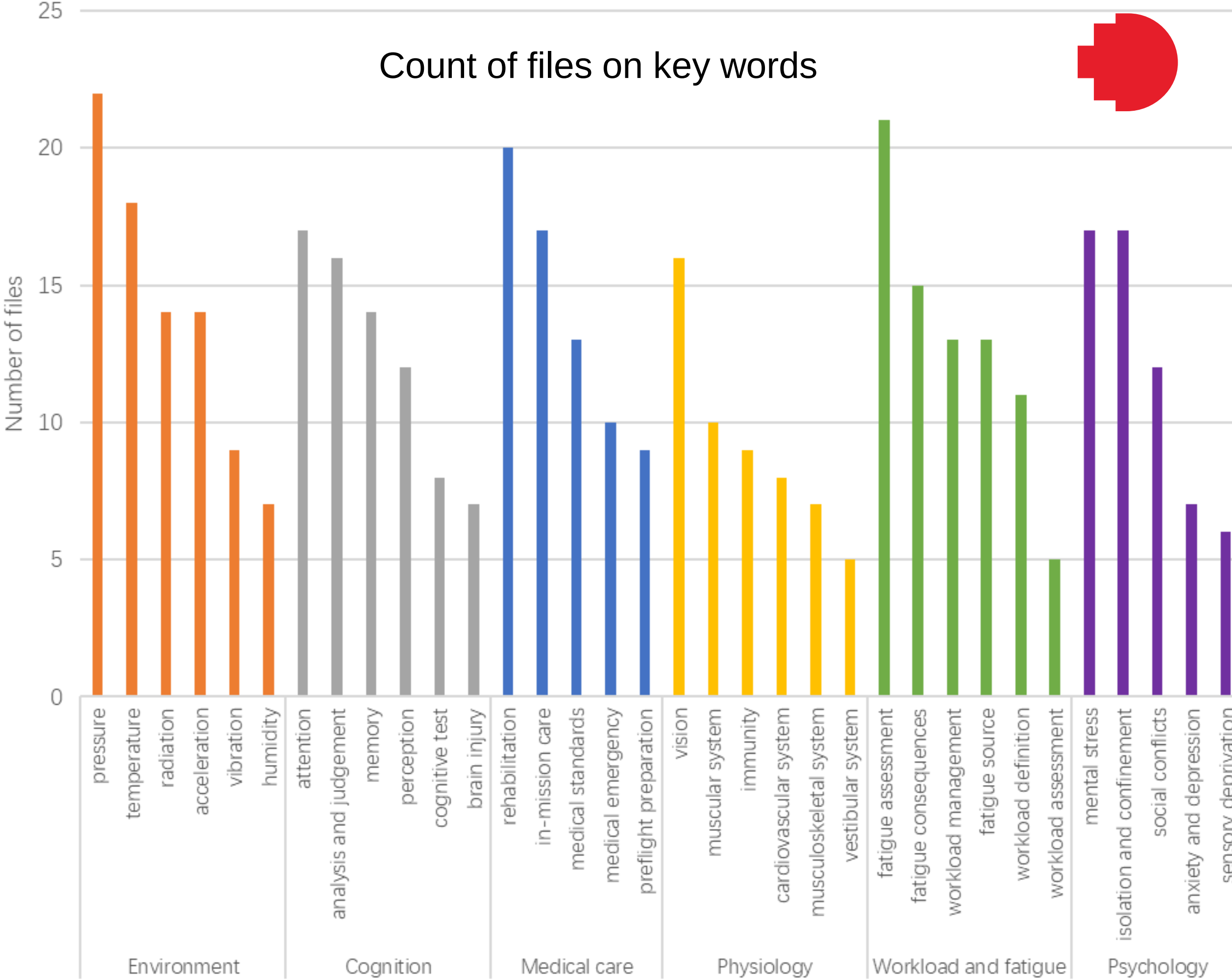
Framework components/categories/recording units											
	F	*R*	*%*		*F*	*R*	*%*		*F*	*R*	*%*
Physiology	21	816	12.12%	*Workload and fatigue*	26	783	11.63%	*Psychology*	24	671	9.97%
Vision	16	315	4.68%	**Workload**	17	350	5.20%	**Mental stress**	17	379	5.63%
Cardiovascular system	8	158	2.35%	definition and effects	11	47	0.70%	**Isolation and confinement**	17	164	2.44%
Muscular system	10	131	1.95%	assessment and prediction	5	208	3.09%	**Social conflicts**	12	70	1.04%
Musculoskeletal system	7	106	1.57%	management	13	75	1.11%	Anxiety and depression	7	37	0.55%
Vestibular system	5	63	0.94%	**Workplace fatigue**	22	433	6.43%	Sensory deprivation	6	21	0.31%
Immunity	9	43	0.64%	assessment and countermeasures	21	181	2.69%				
				source	13	137	2.04%				
				consequences	15	115	1.71%				

Group 5

Discussion

Key issues that regulators should consider when making guidelines:

- Factors specific to spaceflight need more focus. These factors are mentioned less often due to the inclusion of civil aviation files.
- Habitability factors are largely overlooked by certain authorities, despite their impact on astronauts' mental health and long-duration flights.
- Cognitive tests and creative thinking are not given sufficient emphasis. There is a need to update cognitive test models to meet the requirements of AI and robotics interfaces.
- Factors related to long-duration flights need more focus, including immunology and nutrition.
- Unique medical concerns like crew fertility and death need more attention in the future.
- The impact of automation on workload assessment standards should be considered scientifically.
- Countermeasures to social conflict is critical in the closed environment of a spaceship in future commercial space travel.



Group 5

Proposed Regulations

- We argue that the optimal method for Australian policymakers to provide guidance on how operators can manage the human performance safety risks of space/suborbital operations is a mix of new mandatory regulations issued under the Australian Space Act supported by non-mandatory guidance material issued by the Australian Space Agency.
- After the administrative changes discussed above have been introduced, the Australian Space Act should be amended to include a new division under Part 3 (Regulations of space activities and high-power rockets) called Division 10 Human Performance and HF Training. This new division would include requirements for human performance standards and human factors training to be mandatory for Australian space operators to receive permits, licenses, or approvals.
- The format of the human performance guidance template will be an advisory circular issued by the Australian Space Agency.

Group 5

Interview questions and responses

Sandra Whitmire - NASA Human Research Program's lead scientist for the Human Factors & Behavioural Performance Element

Q: What do you think are the major human performance problems associated with long-duration space and interplanetary space travel?
A: With future missions beyond low earth orbit, the crew will be forced to function more independently than they do today. In current spaceflight, crew work in tandem with mission control on the ground. That partnership has been very successful and allows for a large team of experts on the ground to work with spaceflight crew in real time. In future missions, crew will travel beyond low earth orbit, which will lead to communication delays and inherently in-mission crew will increasingly function more autonomously. They will have large teams to support in real time during an off-nominal situation, for example. So ensuring we can support crews in mission in these future missions is a new challenge. We also know that prolonged isolation and confinement can cause additional stress to behavioural health, even in high performing individuals. We are working to ensure we can provide the right support system to these future crews to help manage conflict and offset other negative effects of prolonged separation from home.

Q: What training do astronauts undertake to prepare for the psychological and mental well-being challenges of extended space missions?
A: There is a strong team at JSC that works with crewmembers prior to their mission to help them train and prepare. In the future, we hope to augment the training to ensure the stressors of future spaceflight (e.g. communication delays, small volume, distributed teams) are further addressed

Jennifer Bailey - Horizontal Operations Branch Manager in the Safety Authorization Division of the FAA's Office of Commercial Space Transportation and NASA delegation to the Interagency Space Debris Coordination Committee (IADC) Member.

Q: What developments in human factors research and technology do you foresee having the greatest impact on space regulations in the near future?
A: AST is currently focused on public safety—keeping the crew alive and functional so they can control the vehicle. We may get further authority in the near future to expand our occupant safety regulations. In the short term, AST is focused on the human factors of emergency egress, SFPs being able to get themselves in and out of their seats, and training for SFPs and crew. We're also considering whether our current medical requirements for crew are still appropriate and if there should be medical

Q: With the increasing privatization of space flight, how do you think space regulations should adapt to address the unique human factors risks associated with commercial space travel?
A: AST is currently conducting an Aerospace Rulemaking Committee (SpARC) with industry to discuss how to amend our HSF regulations (part 460). We will be discussing in the SpARC how to adjust the framework of our regulations for future HSF. Right now, commercial HSF is conducted under an informed consent regime. SFPs and crew sign an acknowledgement that the FAA has not certified the vehicle for passenger safety. FAA's focus is on public safety—we allow failures to happen and keep the public out of the way so they don't get hurt. The SFPs on commercial launches acknowledge that risk. One possibility that the SpARC could identify is how to work towards eventual certification of commercial launch and reentry vehicles. Then their operation would be more like air travel with certified vehicles and a high emphasis on passenger safety. And also, at that time, human factors risk could be incorporated into the regulations. But we have more work to do to identify specific human factors issues that could or should be regulated for HSF.

Q: How is the international community working together to develop human factors standards and share best practices for space regulations?
A: There is a committee led by the ASTM organization that brings together representatives from industry and government to develop human factors standards and other standards. These standards may not go directly into regulations, but they are consensus standards that the industry can follow to guide their designs and operations for human spaceflight. Another standard organization, ISO, does similar work, and they are more internationally focused. I recommend visiting our website, faa.gov/space. We have a human spaceflight page there with additional information and links to our current part 460 HSF regulations

Group 15

Research Questions

1. Identify and understand the major human performance challenges that arise from the impact of weightlessness on the human body, space tourism operations, sub-orbital flight and launching payloads. How do they impact human performance?
2. How can a roadmap be developed to modernise industry wide regulations to address the current regulatory gap? What are the key steps, stakeholders and resources required for successful implementation?

Methodology

- Qualitative exploratory research
- In-depth interviews with professionals specialised in relevant fields (NASA, EASA, CASA, SpaceX, spacecraft manufacturers, RMIT, Swinburne, UNSW, ANU)
- Thematic analysis will involve subjecting transcripts from interviews (NVIVO or DELVE)
- Interviewing: RMIT, Swinburne, San Jose State, CASA, Australian Space Agency, SpaceX, Virgin galactic, National Committee for Space and Radio Science, Australian International Aerospace Congress, European Space Agency, ISU, space conference organisers

Group 15

Literature Review

Mission control centres

- Operators being able to predict and anticipate potential issues to reduce the stress on the crew and prevent incidents from occurring and evolving into disasters
- Operators that are well trained and in environments where they can make decisions in a complex environment

Selection and training of passengers and crew

- FAA Human Space Flight Requirements for Crew and Space Flight participants
- All passengers be trained in emergencies beyond that of a commercial aviation flight and complete training on how to carry out role on board or on the ground so that the vehicle will not harm the public

Safety concerns for the human body in space

- Weightlessness on astronauts and physiological and cognitive well-being during extended missions
- Exposure to galactic cosmic rays, solar particle events, lightning-generated X-rays from thunderstorms (health threat increasing lifetime risk of cancers)
- The selective application of technical requirements and safety standards demonstrates the importance of a flexible approach that can adapt to various subsystems and hazardous conditions

Human-centred design

- Cockpit interfaces that are intuitive and adaptable to account for negative effects even when astronauts' performance is compromised

Group 15

Interview Questions

- What lessons from past long-duration space missions, such as the International Space Station, can be applied to enhance human performance in future commercial space operations?
- In the context of more extended spaceflights, what psychological and social considerations are essential for maintaining crew cohesion and mental well-being, and how might they differ from current practices?
- With the potential for non-professional astronauts to participate in commercial space activities, how should training programs be adapted to ensure optimal human performance in this changing demographic?
- Given the communication delays between Earth and deep-space missions, how can real-time decision-making and troubleshooting strategies be developed to address unexpected human performance issues?
- Space missions involve confined environments with limited sensory stimuli. How can sensory deprivation and monotony impact human performance, and what measures can be taken to mitigate their effects?
- As commercial space travel becomes more prevalent, what strategies can address potential individual differences in adaptation to microgravity and other space-related physiological factors?
- With the increasing involvement of private companies in space missions, how might commercial pressures impact crew selection, training, and overall human performance management?
- What advancements in wearable technologies and biofeedback systems can contribute to real-time monitoring of astronaut performance during space missions?
- When medical emergencies arise during space missions, how can crew members be trained to manage these scenarios effectively, considering the limitations of emergency equipment and expertise?
- As commercial space activities expand, how do you anticipate the regulatory landscape evolving to ensure both safety and innovation facilitation in the industry?
- What are the potential challenges and benefits of balancing government oversight and industry self-regulation in commercial space operations?
- How might international collaborations and agreements influence the regulatory frameworks for commercial space operations, especially when different countries have varying approaches to regulation?
- In space tourism, what role should governments play in certifying such endeavours' safety and ethical compliance?
- As commercial ventures push the boundaries of space exploration, how can governments collaborate with private organisations to create effective contingency plans for potential accidents or emergencies?
- With new technologies and space activities emerging, what challenges might arise in adapting existing space laws and treaties to effectively regulate commercial endeavours beyond Earth's orbit
- What potential conflicts might arise between differing national regulatory frameworks, and how can international coordination be fostered to ensure a coherent approach to commercial space activities?
- In space traffic management, what methods can be implemented for effective coordination and collision avoidance among a growing number of satellites and spacecraft from various private and government entities?
- Private space businesses frequently work with stricter financial and scheduling constraints compared to government organisations. How do these constraints influence the design and development of human-centred systems, and what measures are in place to prevent compromising crew safety and mission success?
- With the increasing frequency of sub-orbital flights and payload launches, how do you see the industry addressing issues related to space debris and its impact on space tourism operations and satellite deployments?
- How are businesses putting training programmes and standards into place given the variety of backgrounds and skill sets among those working in the private space industry, to ensure high competency and safety across multiple roles?
- Launching payloads into space requires precision and reliability. What strategies are being employed to optimise the efficiency of payload launches while maintaining high safety standards?
- How do you anticipate dealing with potential legal and ethical difficulties related to liability, informed consent, and passenger safety in emergencies?
- What measures are being taken to accommodate individuals with disabilities, ensuring they can participate in these experiences safely and comfortably?

Group 15

Proposed Regulations

- A government agency for space that could significantly enhance safety and standardisation in the commercial human spaceflight industry, independent of trade organisations
- Standardisation and safety certification services aligned with safety policies issued by relevant national regulatory bodies
- Agency functions would encompass standardisation planning, safety review panels for certification, safety program auditing, and coordination of research and education in space safety engineering
- Collaborate with regulatory bodies to ensure compliance with safety goals, policies, and requirements

Summary

With human space exploration various human performance challenges exist:

- Cognitive functions
- Human error
- Physiological performance and capabilities
- System safety and accident prevention
- Habitability and habitat design
- Human-system interfaces design
- Workload and Fatigue
- Selection and Training
- Investigations

Students identified future human performance risks

Students offered various regulatory solutions

There is much human factors work to do!

Thank you!

Safety sign

E: Selina.Fothergill2@rmit.edu.au

RMIT Investigation Programs

RMIT has formed a strategic partnership with the ATSB to offer a suite of Transport Safety Investigation higher education programs

- GC165 Graduate Certificate in Transport Safety Investigation (2019)
- Graduate Diploma of Transport Safety Investigation (2023)
- Master of Transport Safety Investigation (coming soon!)