Potomac Institute for Policy Studies

Science for Policy, Policy for Science

AEROSPACE MEDICINE CORE COMPETENCIES
Final Report

June 2024

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EXECUTIVE SUMMARY

With an increase in human spaceflight, driven by planned exploration of the Moon and Mars alongside expanding commercial ventures, there is a growing demand for doctors trained to provide effective care for individuals venturing into space. The National Aeronautics and Space Administration (NASA) Office of Chief Health and Medical Officer (OCHMO) is focused on researching and mitigating human health and performance risks of spaceflight. This is furthered through the efforts of NASA flight surgeons and other aerospace medicine providers, who offer medical care to astronauts and commercial spaceflight participants. As one of the largest employers in this field, NASA has a vested interest in ensuring that aerospace medicine providers receive effective training and are equipped with the skills and knowledge needed to care for increasing numbers and diversity of humans exploring space.

The Potomac Institute for Policy Studies conducted research to determine the training, skills, knowledge, and core competencies necessary for aerospace medicine providers, particularly in the space medicine domain. The Potomac Institute interviewed 43 aerospace medicine experts, including current and former NASA flight surgeons as well as providers from military, academia, and industry.

From interviews with aerospace medicine providers, four high-level core competency areas were identified which highlight the necessary skills and knowledge to perform duties associated with the role of aerospace medicine provider:

- Clinical Expertise,
- Knowledge of the Aerospace Environment,
- Professional Skills, and
- Operational Skills.

Further second- and third-level core competencies were identified within each of the four high-level core competencies. This is not an exhaustive glossary list of every skill and technique necessary, but organizes sub-skills or examples of additional skills and techniques identified by experts and research.

Based on the findings and analysis of this study, the Potomac Institute developed the following recommendations regarding aerospace medicine training, skills, and knowledge:

1. Frequently re-evaluate and document all aerospace medicine training program requirements, including informal and practical experience components.
2. Incorporate input from individuals with experience in working with commercial spaceflight companies as well as NASA in the evaluation process.
3. Ensure continued skill development for aerospace medicine providers after training programs are completed.

INTRODUCTION

Aerospace medicine has existed as a medical specialty since the early 1900s[1] and originated alongside the development of the aviation industry. According to the Aerospace Medicine Association, aerospace medicine involves determining and maintaining the health, safety, and performance of humans involved in air and space travel.[2] This encompasses both aviation medicine (i.e., involving airplane pilots and air flight) and space medicine (i.e., involving astronauts and spaceflight). Flight surgeons can be broadly defined as expert aerospace medicine providers, and individual organizations may use the term differently. For the purposes of this report, we have used the terms "aerospace medicine practitioner" or "aerospace medicine provider" to refer to individuals who are trained in aerospace medicine and provide medical care to aviators, astronauts, or other spaceflight participants.

Historically, space medicine was combined with aviation medicine in part because few space medicine physicians were required for a limited number of human spaceflight missions from the National Aeronautics and Space Administration (NASA) or a handful of other government space agencies. Today, the reinvigoration of NASA's space campaign with the Artemis Program, the recent boom in commercial spaceflight companies, the establishment of the United States Space Force (USSF), and increasing involvement from other nations are rapidly expanding the astronaut workforce and participation in human spaceflight. However, many aerospace medicine providers will point out that getting to the space environment requires passing through the air environment, and many of the concerns of aviation medicine also apply to space medicine. As such, separating out these two types into separate medical domains is not entirely sensible.

Similarities between aviation medicine and space medicine are due in part to the fact that many of the hazardous and/or unusual elements in the aviation environment are also present in the space environment. For example, isolation and enclosure are factors that can affect both physical and mental health of both astronauts and pilots. Similarly, both astronauts and aviators are exposed to extended periods of vibration and noise; astronauts on the International Space Station (ISS) are exposed to this for a more extended period of time, but the change is a matter of degree, not of essential difference. Radiation exposure is present in both the aviation and space environments, although to a greater extent in the space environment. Conversely, the main factor that characterizes the space environment but not the aviation environment is microgravity.

Aerospace medicine providers working in space medicine are responsible for many aspects of patient care throughout the mission duration. At NASA, care begins when aerospace medicine providers conduct comprehensive medical evaluations as part of the astronaut selection

[1] *History*. (n.d.). Aerospace Medical Association. https://www.asma.org/about-asma/history

[2] *Aerospace Medicine*. (n.d.). Aerospace Medical Association. https://www.asma.org/about-asma/careers/aerospace-medicine

campaign. This entails screening astronaut candidates for their general health status and evaluating them for any disqualifying medical conditions. As our knowledge of the impacts of the aerospace environment on human physiology evolves, these medical standards are evaluated and adjusted. NASA is currently in such an evaluation process and is soliciting public comments to revise the current astronaut medical standards, requirements, and clinical procedures used to medically evaluate astronauts.[3]

Following astronaut selection and certification, NASA aerospace medicine providers become the primary care physicians for the astronaut team members. They provide care and support through training, launch, flight, and landing, and continue with longitudinal care throughout the astronauts' lifespans. These aspects are unique to aerospace medicine compared to other medical specialties. Aerospace medicine providers need to possess a wide range of medical knowledge to inform care throughout each astronaut's mission and lifespan. Each phase brings unique risks and physiological changes that the provider should be able to recognize, diagnose, and treat.

GROWTH OF COMMERCIAL SPACEFLIGHT AND RAPIDLY CHANGING SPACE ECOSYSTEM

Recent years have been characterized by a rapid increase in commercial spaceflight, which may precipitate an increased need for individuals trained in space medicine. Further, commercial spaceflight companies have different criteria for who can go to space compared to historical standards set by NASA and other international spaceflight agencies. Currently, there are no official medical standards for US spaceflight participants; because of this, commercial space companies are in the process of developing those individually, and they will likely not be the same across companies without federal government input.[4] This means that older and/or less healthy individuals may be flying, which could alter the medical conditions that will need to be treated in space or post-flight. Further, there are some medical conditions for which the impact of spaceflight is entirely unknown. For example, there has never been a spaceflight by a person with known diabetes.

The rapidly changing environment of spaceflight will likely result in many unprecedented cases of passengers flying with unique medical conditions, which will in turn necessitate medical practitioners who have the skills, knowledge, and experience to make informed decisions. Developing a robust understanding of core medical competencies and data-driven health

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[3] *Aerospace Medical Certification Standards.* (2024, May 16). Office of the Chief Medical Officer (OCHMO)/NASA. https://www.nasa.gov/organizations/ochmo/aerospace-medical-certification-standard/

[4] NASA has recently put out a request for comments regarding the provisional addition of private astronaut and NASA suborbital research specialist medical standards to OHCMO-STD-100.1, *NASA Spaceflight Medical Selection, Recertification, and Mission Evaluation Standards,* available through 7 June 2024. https://www.nasa.gov/organizations/ochmo/aerospace-medical-certification-standard/

practices underpins a safe and successful continued development in the human spaceflight endeavor.

CENTRAL RESEARCH QUESTION

The Potomac Institute for Policy Studies undertook the current study at the request of the Office of the Chief Health and Medical Officer (OCHMO). The purpose of the study is to understand the central research question: "What core competencies do aerospace medicine practitioners require to perform their duties?[5]" Although aerospace medicine includes aviation medicine, for this study's purposes, the study team focused on space medicine and astronaut care. The following report identifies and assesses the necessary core competencies—knowledge, skills, and expertise—for aerospace medical providers based on the culmination of internal research and SME interviews, review groups, and discussions with current and former aerospace flight surgeons.

METHODOLOGY

Below is a summary of the data collection and analysis approach to underscore the validity of the findings. A more detailed look at the methodology can be found in Appendix II.

To develop findings and recommendations on aerospace medicine training and core competencies, the Potomac Institute conducted a literature review and interviews with stakeholders and subject matter experts (SMEs). The literature review included reviewing official medical requirements (i.e., the Accreditation Council for Graduate Medical Education [ACGME] and the American Board of Preventive Medicine [ABPM] board certification requirements), current residency curriculums, and other information regarding current and former aerospace medicine training programs. Informational interviews with 43 SMEs, primarily current and former NASA flight surgeons, were used to develop findings and recommendations on aerospace medicine training and core competencies. Data on the interviewee's background and experience was collected and cataloged to aid in data analysis (Figure 1).

[5] Core competencies, as defined in this report, are the consensus set of knowledge and skills necessary for the practice of aerospace medicine.

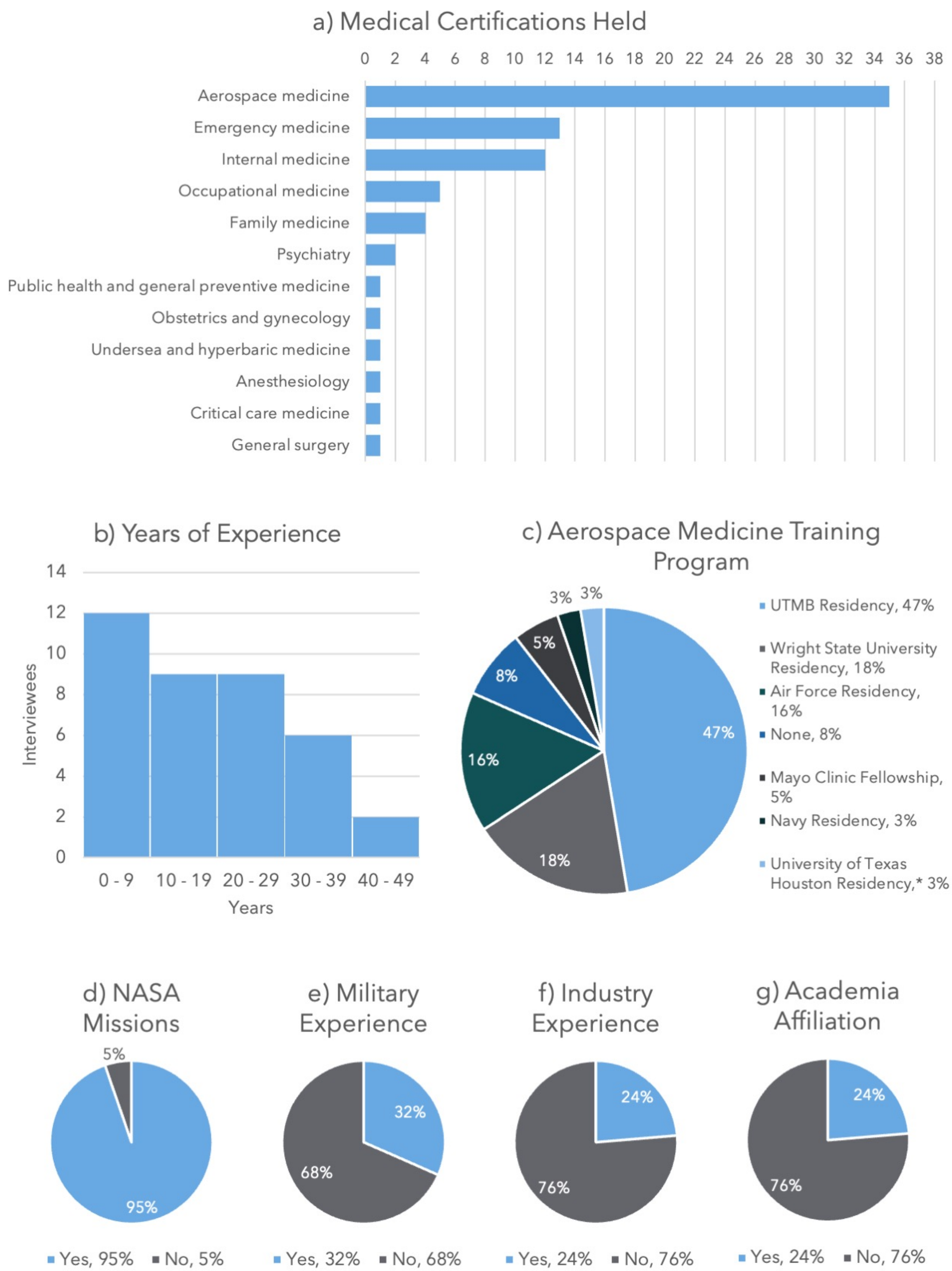

*Figure 1. Key features of aerospace medicine providers interviewed. a) Medical board certifications held (categories not exclusive). b) Years of experience in aerospace medicine. c) Aerospace medicine training program completed. d) Experience as a flight surgeon on NASA missions. e) Experience as a military aerospace medicine provider. f) Experience as an industry aerospace medicine provider. g) Academic affiliation with training programs. *Residency ultimately not approved*

Interviewee responses were analyzed using an internally developed coding scheme to identify common themes, skills, or components of the knowledge base (see Appendix II for more details and coding definitions). This analysis identified several commonly mentioned themes, skills, and components, which were integrated with knowledge from the literature review, to create an initial list of core competencies. This initial list was re-evaluated by SMEs during a closed-door roundtable discussion and additional individual interviews to inform a second iteration of aerospace medicine core competencies, which are discussed in detail below.

The skills and knowledge identified were categorized hierarchically into three levels of core competencies. The four first-level core competencies identify the overarching themes supported by second-level competencies, which are general skills and knowledge areas. Below are third-level competencies, which are examples of specific skills or abilities needed to carry out the responsibilities associated with providing care as an aerospace medicine practitioner.

Additionally, each third level skill or knowledge area was categorized using the following indicators of the level of expertise required and applicability to specific settings (Figure 2):

- 1=basic understanding or limited working proficiency; 2=skill mastery; significant expertise
- G=general medical core competency; S=Specific competency is applied in a way to space medicine that might deviate from or expand on general competency; C=Commercial spaceflight competency that may be more relevant for commercial spaceflight

This categorization method was developed based on expert interviews: several SMEs identified competency areas that required more or less mastery to operate independently as an aerospace medicine provider, or that are viewed as unique to the practice of aerospace medicine. This initial feedback was expanded upon to assign relevant ratings to each of the third level competencies. The ratings were then reviewed and iterated on again by a subset of interviewees.

Note that each aerospace medicine provider may require mastery of different skills dependent on their organization and specific duties. For example, while all will need some familiarity with Human Systems Integration to promote crew health and safety during missions, some providers may have additional training and experience in this area such as providing expertise and input into a vehicle design process. Ratings are intended to provide a general baseline needed for an aerospace medicine provider working independently (i.e., completed residency and on the job training under supervision) to provide care for patients partaking in spaceflight.

APPLICABILITY	
G	General medical core competency *applicable to a wide variety of medical practices*
S	Specific competency *applicable to space medicine in a way that might deviate from or expand on general competency*
C	Commercial competency *may be more applicable to commercial spaceflight*

EXPERTISE	
1	Basic understanding or limited working proficiency
2	Skill mastery or significant expertise

Figure 2. Ratings for competency areas based on applicability to specific settings and level of expertise required.

AEROSPACE MEDICAL EDUCATION AND TRAINING TODAY

Five aerospace medicine training programs accredited by the ACGME are currently active in the United States. Each leads to ABPM board certification. The training programs include military programs at U.S. Air Force School of Aerospace Medicine, Naval Aerospace Medical Institute, and U.S. Army School of Aviation Medicine. Two civilian programs are run by the University of Texas Medical Branch (UTMB) and the Rochester, Minnesota Mayo Clinic. Additionally, two similar but discontinued civilian programs existed at Wright State University and at the University of Texas Houston Medical Center in partnership with Johnson Space Center (JSC). Each of these aerospace medicine training programs require an existing medical degree and clinical experience for admission.[6] All programs divide participants' time between classroom education, which often incorporates a Master of Public Health degree, and practical experience, which can include field rotations with NASA, the military, and commercial companies.

Aerospace medicine residency programs require external funding sources in order to train those taking part in the program, unlike fellowships, which produce revenue through fellows' work hours in medical facilities.[7] Most medical residencies receive federal funding through the Department of Health and Human Services.[8] However, aerospace medicine residencies do not

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[6] *Residency programs & related courses.* (n.d.). Aerospace Medical Association. https://www.asma.org/about-asma/careers/aerospace-medicine/residency-programs-related-courses
[7] Interview #22, personal communication, September 8, 2023.
[8] Government Accountability Office. (2018, March). *Physician workforce: HHS needs better information to comprehensively evaluate graduate medical education funding (GAO-18-240).* https://www.gao.gov/assets/gao-18-240.pdf

receive this funding. Instead, aerospace medicine residencies are typically funded by NASA or the military, resulting in limited numbers of programs and residency slots.[9]

Terminology for aerospace medicine provider roles varies depending on the organization. At NASA, aerospace medicine providers have various experiences and job titles ranging from flight surgeon to leadership roles such as chief medical officer. Typically, NASA flight surgeons have been trained and are board certified in aerospace medicine and another medical specialty, representing over four years of academic specialty education and experience prior to starting their position. In the Air Force, however, providers who have completed an aerospace medicine residency typically work as aerospace medicine specialists. This is a higher-level role than an Air Force flight surgeon, as specialists are qualified to contribute to policy and other advanced decisions. Air Force flight surgeons must be a licensed physician and have completed the 6-to-10-week Air Force course on aerospace medicine fundamentals. For Air Force flight surgeons to qualify for the residency program and become aerospace medicine specialists, they must spend two years on the job as a flight surgeon. Roles in other organizations include aviation medical examiners in the Federal Aviation Administration (FAA), and contractor, flight surgeon, or chief medical officer in the commercial sector.

The Air Force, Navy, and Army each have aerospace medicine residency programs. The Air Force Residency in Aerospace Medicine is a two-year program and is the largest residency program with 20 residents per year.[10] This program produces Aerospace Medicine Specialists. The Air Force also has a short primary course covering the basics needed to act as an Air Force flight surgeon. In the past, this training was referred to as the Aerospace Medicine Primary course and typically took 6 to 8 weeks to complete. Currently, the Air Force uses a 10-week primary program comprised of five 2-week long courses. A medical degree is needed, among other requirements, to take part in the current program. Applicants for the Air Force Residency must complete the 10-week program followed by two years of experience as a flight surgeon.[11] The Naval Aerospace Medical Institute Residency in Aerospace Medicine is a two-year program. The residency includes a Master of Public Health degree.[12] The School of Army Aviation Medicine combined Aerospace and Occupational Medicine Residency is a three-year program. Applicants must have

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[9] Interview #11, personal communication, August 18, 2023.

[10] Dunn, J. (2023, February 13). *Aerospace medicine program fills needed flight surgeon positions*. The Air Force Research Laboratory. https://www.afrl.af.mil/News/Article-Display/Article/3296765/aerospace-medicine-program-fills-needed-flight-surgeon-positions/

[11] Interview #33, personal communication, October 19, 2023.

[12] *Department 53AR - Residency in aerospace medicine*. (n.d.). Navy Medicine. https://www.med.navy.mil/Navy-Medicine-Operational-Training-Command/Naval-Aerospace-Medical-Institute/Department-53AR-Residency-in-Aerospace-Medicine/

previously completed an accredited internship. The combined residency includes a Master of Public Health degree.[13]

The largest civilian program is UTMB's Aerospace Medicine Residency with two to four residents per year.[14] In addition to the 2-year aerospace medicine residency program, UTMB has two 4-year pathways that combine the aerospace medicine residency with a preceding 2-year residency in either internal medicine or, as of 2023, emergency medicine. The 2-year program requires applicants to have prior residency training in another field, while the 4-year pathways include this additional training.[15] The Aerospace Medicine Residency includes a Master of Science in Aerospace Medicine degree as of 2023, replacing a Master of Public Health. Mayo Clinic has a 2-year Aerospace Medicine Fellowship with one fellow every one to two years.[16] Applicants must have previously completed a 3-year residency in another medical specialty and be medical board-certified or board-eligible.[17] The fellowship includes an online Master of Public Health degree. The Wright State University Residency Program was a 2-year ACGME aerospace medicine residency active from 1978 until 2015.[18] The residency included a Master of Science in Aerospace Medicine degree. Two residents were trained through a partnership between the University of Texas Houston Medical Center and JSC beginning in 1980. The program did not receive ACGME accreditation and was discontinued.[19]

CURRENT ACCREDITATION STANDARDS

The ACGME Program Requirements[20] note six competencies for aerospace medicine programs: patient care and procedural skills, medical knowledge, practice-based learning and improvement, systems-based practice, professionalism, and interpersonal and communication

[13] *Graduate medical education army aerospace medicine training: Aerospace medicine & occupational medicine*. (n.d.). U.S. Army Medical Center of Excellence. https://medcoe.army.mil/saam-rams
[14] *Our residents*. (2023). The University of Texas Medical Branch. https://www.utmb.edu/spph/aerospace-medicine/residency-program/our-residents
[15] *Aerospace medicine residency*. (n.d.). The University of Texas Medical Branch. https://www.utmb.edu/spph/aerospace-medicine/residency-program/residency
[16] Interview #39, personal communication, November 7, 2023.
[17] *Application process—Aerospace medicine fellowship (Minnesota)*. (2023). Mayo Clinic College of Medicine and Science. https://college.mayo.edu/academics/residencies-and-fellowships/aerospace-medicine-fellowship-minnesota/application-process/
[18] *Division of aerospace medicine*. (2015, June 17). Wright State University Boonshoft School of Medicine. https://web.archive.org/web/20150617044951/http:/medicine.wright.edu/aerospace-medicine
[19] Interview #18, personal communication, August 29, 2023.
[20] *ACGME Program Requirements for Graduate Medical Education in Aerospace Medicine.* (2023, July 01). ACGME https://www.acgme.org/globalassets/pfassets/programrequirements/383_aerospacemedicine_2023.pdf

skills. Similarly, the ABPM[21] has four core content areas: the flight environment, clinical aerospace medicine, operational aerospace medicine, and management and administration. The list of aerospace medicine core competencies in this study highlights many similar skills identified in both the ABPM and ACGME lists. The ABPM list is similar in categorization, but does not include many of the professional skills included within this study. The ACGME list is broken down into more first-level categories and includes more detail on individual skills than the ABPM list. The core competencies in this study integrate the core competencies identified by the ABPM and ACGME with data collected from interviews and is explained in detail below.

UNIQUE ASPECTS OF AEROSPACE MEDICINE

One of the most essential philosophical distinctions that sets apart the field of aerospace medicine is the aspect of preventive care. Aerospace medicine providers point out that about 90% of an aerospace medicine provider's job is prevention. So far, this approach has prevented most serious medical problems from manifesting during flight. To date, it has never been necessary to bring an astronaut home for a medical problem. Many of the unique aspects of aerospace medicine relate to this focus on preventive care, whether by screening candidates to ensure that those flying can do so safely, or by contributing to the design of spacecraft to safeguard astronaut health and safety.

An important part of an aerospace medicine provider's role is the flight certification process that takes place pre-flight. It is the aerospace medicine provider's primary duty to ensure that their patient does not pose too high a risk to fly, for their own safety, the crew's, and the mission's success. The waiver process, during which candidates with potentially disqualifying medical conditions can be allowed to fly, is an important component of the certification process. To complete this process requires an intimate understanding of the environment of flight and the particular mission, risk quantification and potential mitigation strategies, and an understanding of the organization's policies and procedures.

Aerospace medicine providers emphasize the importance of training in preparing for this process. This includes both the background knowledge necessary to evaluate an individual's specific health concerns and the potential impact of the aerospace environment on that individual, as well as risk management and mitigation strategies. Soft skills also play an important role in the aerospace medicine practitioner's job, as it is necessary to build rapport and trust with a patient so that the patient will feel comfortable disclosing all relevant information.

Another role that the aerospace medicine provider plays in preparation for flight is working with engineers and researchers. NASA has previously explored the dynamics between engineering,

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[21] *Aerospace Medicine Content Outline* (n.d.). ABPM. https://www.theabpm.org/become-certified/exam-content/aerospace-medicine-content-outline/

life sciences, and health/medical disciplines with the 2017 Rosetta Stone Project.[22] Two-way communication here is essential. The engineering team must understand the human systems integration considerations in the design; that is, they must understand the potential impact that their choices will make on the crew. Likewise, the aerospace medicine providers must have a sufficient understanding of the vehicle, particularly the life support systems, so that they will be prepared to advise and/or treat the crew in anomalous circumstances.

As an example, if the atmospheric controls of a vehicle malfunctions and results in higher-than-normal levels of carbon dioxide, the engineering team and the medical team must be able to communicate adequately to fully understand the impact of the malfunction on the crew, and the aerospace medicine providers must be able to judge if there will be other effects on the crew's health, safety, and/or performance.

The specific skills involved in this include a basic familiarity with the design of the vehicle and the ability to "speak engineer." It is not necessary for an aerospace medicine provider to be able to do the engineering themselves; rather, they should be able to understand the system at a high-level and understand the relevant terminology to be able to discuss it. It is also important to consider that each vehicle is unique, and it is unrealistic for an individual to train on all of them. For this reason, this training has historically taken place on the job, and will likely continue to do so in the future.

IDENTIFYING THE AEROSPACE MEDICINE PATIENT

For this report, the study team has defined the typical patient for the aerospace medical provider as an individual who will and/or has been exposed to the space environment. Depending on the astronauts' organizational affiliation, exposure duration may vary widely from minutes to months. NASA identifies five hazards during spaceflight that pose a risk to human health: space radiation, isolation and confinement, distance from Earth, gravity, and closed or hostile environments.[23] Importantly, these hazards do not exist alone; they interact with each other to create unique effects on human physiology in a way that is not typically seen terrestrially. While the physiologic systems themselves do not change, their ability to and efficacy of function can drastically change. These hazards also impact each individual differently and changes may not manifest in the same way. Therefore, aerospace medicine practitioners must be aware of the different physical

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[22] Francisco, D. R. The NASA Human System Risk Mitigation Cycle: Standards to Requirements to Deliverables. In Williams R. S. and Doarn C. R. (Eds.), *Engineering, Life Sciences, and Health/Medicine Synergy In Aerospace Human Systems Integration: The Rosetta Stone Project* (NASA SP-2017-633, pp. 53–64). (Library of Congress, Washington, D.C., 2017).

[23] *5 Hazards of Human Spaceflight*. (2024, January 03). NASA. https://www.nasa.gov/hrp/hazards

manifestations and be able to identify these changes and develop an appropriate treatment plan if necessary.

CHANGES IN AEROSPACE MEDICINE PRACTICE: FROM SHUTTLE TO ISS AND BEYOND

Aerospace medicine providers have identified several significant changes to the field over the course of their careers. Changes included the advent of commercial human spaceflight, new mission types, types of medical care provided, and aerospace medicine training needs and processes. These changes affect the skills and knowledge needed to practice aerospace medicine effectively, especially as available roles grow and diversify. Further changes can be expected. As training programs typically take two to four years to complete, programs will need to adapt in anticipation of changes in human spaceflight and the field of aerospace medicine.

The growth of commercial spaceflight is one of the most prominent changes that aerospace medicine providers have witnessed. Specific changes include the advent of viable commercial space travel, NASA increasingly contracting out to commercial industry, increased job opportunities in industry for aerospace medicine practitioners, expansion of the types of people and those with medical conditions that are able to fly, and greater collaboration between industry and aerospace medicine training programs.

New types of spaceflight missions and vehicles for both government and commercial industry have also been major changes. As the ISS program began in 1993, missions focused on reaching Earth orbit. Human spaceflight vehicles were also limited. Between 2011 and 2020, the Russian Soyuz program was the only avenue for astronauts to get to the ISS. Interviewees noted a shift toward longer mission durations and more vehicles. Planned missions, such as Artemis, intend to send astronauts beyond low earth orbit to the Moon and eventually Mars. Longer missions require aerospace medicine providers to emphasize preventative care to keep astronauts healthy for as long as possible while in space.

Companies are contributing to new vehicles and missions, both for government and commercial customers. For example, SpaceX's Crew Dragon took astronauts to the ISS using a commercial vehicle for the first time in 2020 and Virgin Galactic has launched passengers on suborbital flights. Different missions and vehicles provide different medical resources and environments for astronauts and spaceflight passengers that aerospace medicine providers must consider.

The roles and focus of aerospace medicine providers' work has also shifted. Today, aerospace medicine providers are more likely to support less healthy individuals with a greater variety of health conditions. There is also more specialization and more diversity in the specialties of aerospace medicine providers than in the past.

Aerospace medicine providers note that their workload has increased over time and that there is a greater need for more well-trained providers, both to fill NASA roles and to support the growing commercial industry. For example, one flight surgeon observed that there are now more trainees relative to the hands-on training opportunities available.

Other changes include the development of new standards and requirements, increased scientific and medical knowledge about the effects of spaceflight, greater access to spaceflight, and increased international partnerships.

AEROSPACE MEDICINE CORE COMPETENCIES: SKILLS, KNOWLEDGE, AND EXPERTISE

Data collected from interviews was evaluated in the context of accredited standards published by the ACGME and the ABPM to develop a list of aerospace medicine core competencies that are vital to practice as an independent aerospace medicine provider. This list is not intended to replace existing published standards but rather to highlight the skills and knowledge needed to provide care from the perspective of current and former flight surgeons. Four high-level core competencies are identified, which are supported by second-level core competencies (Figure 3). The first- and second-level core competencies are discussed in detail below.

Clinical Expertise	Knowledge of the Aerospace Environment	Professional Skills	Operational Skills
• Fundamental Clinical Skills • Care for Patient in Emergency Setting • Provide Care in an Austere Environment • Telemedicine • Preventive Medicine • Occupational Medicine • Behavioral Health	• Human Health Risks of Spaceflight • Risk Evaluation • Mission-Specific Knowledge • Human Systems Integration	• Bedside Manner and Communication • Interact and Collaborate with Engineers • Interact and Collaborate with Scientific Researchers • Interact and Collaborate with Non-Technical Stakeholders • Teamwork • Continuing Education and Learning	• Medical Certification and Evaluation Process • Operations and Mission Control • Work with Organizational Partners • Mishap Prevention, Investigation, and Response • Policy, Regulations, and Procedures

Figure 3. First-level aerospace medicine core competencies with their associated second-level competencies.

1. *Clinical Expertise*

To provide care for the astronauts under their care, aerospace medicine practitioners must have a demonstrated ability to provide routine clinical care. This includes "being a good doctor," possessing general diagnostic skills, and having specific medical expertise for areas that are relevant to astronaut care. Second-level core competencies that contribute to clinical expertise are detailed below.

1.1. Fundamental Clinical Skills

Fundamental clinical skills include the ability to evaluate, diagnose, and decide on clinical treatment plans. The aerospace medicine provider must then execute this treatment plan. Specific skills required include the ability to gather a comprehensive patient history, administer a physical examination, diagnose any present conditions, and develop treatment plans for identified conditions. Clinical competency also includes various procedural skills, to create organized documentation, and mastery of communication with patients.

1.2. Care for Patient in Emergency Setting

Caring for a patient in an emergency setting includes the ability to provide emergent care for illness or injury. The aerospace medicine provider may have to provide care to patients for unforeseen medical conditions, such as life-threatening cardiovascular events or following a trauma. As spacecraft launch and landing can be extremely dangerous, the provider may have to provide care during a contingency launch or landing, including medically evacuating patients under certain circumstances. The provider may have to provide point-of-injury care and, due to the variability in conditions the astronauts face, the provider may have to treat and stabilize patients using limited resources.

1.3. Provide Care in a Terrestrial Austere Environment

Providing care in an austere environment includes the ability to anticipate health risks, implement countermeasures, and perform medical care in austere and/or hostile settings. Due to the variability in landing geographic locations, aerospace medicine providers need an understanding of travel medicine to evaluate if astronauts need any preemptive treatment to be protected from unique environmental exposures. Some locations may be remote, requiring providers to be able to administer care with limited resources, prioritize competing needs, and work through environmental stressors. To prepare for austere environments, aerospace medicine providers may need to design, maintain, and use field medical kits.

1.4. Telemedicine

Telemedicine is a vital aspect of aerospace medicine as providers may need to direct astronaut care while the astronaut is in flight. Telemedicine includes remotely communicating with the astronaut and directing patients through self-examination, diagnosing, and guiding patients through the treatment plans. During this process, aerospace medicine providers may have access to video and/or voice calls and, therefore, must be able to manage communication delays. Even with the physical distance and virtual communication platforms, the provider must be able to communicate empathy despite not being in the physical presence of the patient.

1.5. Preventive Medicine

Preventive medicine includes maintaining the health and well-being of astronauts, treating them in an abnormal environment, mitigating the impact of co-morbidities, and understanding the principles and implementation of relevant countermeasures. Aerospace medicine providers must know general health and disease maintenance protocols through the body systems (e.g., cardiovascular, neurological, respiratory, musculoskeletal, and metabolic) and must be able to assess health risks and implement countermeasures. Aerospace medicine providers must understand epidemiology and biostatistics to inform risk assessments. Similar to providing care in austere environments, aerospace medicine providers must apply infectious disease, tropical, and global health knowledge to proactively assess and treat astronauts.

1.6. Occupational Medicine

Occupational medicine includes the ability to predict, mitigate, evaluate, treat, and monitor injury and illness resulting from exposure to occupational hazards, both in terrestrial and aerospace environments. Aerospace medicine providers must be able to assess and manage risks associated with the astronauts' environment. This includes knowledge of occupational hazards and regulations during ground operations (e.g., Occupational Safety and Health Administration, Environmental Protection Agency) toxicology, and the development and implementation of organizational habitability and exposure standards. The aerospace medicine provider should be familiar with managing astronaut fatigue during the mission. Following astronaut return to Earth, the aerospace medicine provider is responsible for post-flight rehabilitation, clearance for return to normal life, and providing longitudinal healthcare and health surveillance.

1.7. Behavioral Health

Behavioral health includes the ability to diagnose and/or treat mental health, stress, cognitive decline, and related issues. Aerospace medicine providers should have an understanding of the unique behavioral health stressors of spaceflight, such as isolation and confinement, that impact astronaut behavioral health. Aerospace medicine providers may need to provide psychological support to crew, staff, and family members. Aerospace medicine providers should recognize the bio-psycho-social foundation of behavioral health issues to inform screening for risk factors and identification of early behavioral deviations.

2. *Knowledge of the Aerospace Environment*

Aerospace medicine providers must understand relevant scientific concepts relating to the aerospace environment and the impact of the space environment on physiology. They must apply evidence-based principles and leverage their understanding of the medical literature to inform patient care decisions. Second-level core competencies that contribute to knowledge of the aerospace environment are detailed below.

2.1. Human Health Risks of Spaceflight

Aerospace medicine providers should have a deep understanding of the human health risks associated with altered physiology in an altered environment. From this, they should be aware of the possible countermeasures used to mitigate or treat manifestations of altered physiology. Astronauts are exposed to many environmental stressors, such as acceleration, gravitational changes (e.g., hypergravity during launch, reduced gravity during mission), pressure changes (e.g., hyper- and hypobaria), and radiation. These unique stressors cause many changes to physiologic systems, such as cardiovascular deconditioning and fluid shifts.

2.2. Risk Evaluation

Aerospace medicine providers must be able to assess and quantify the risk to the individual, crew, and mission, during all mission phases to inform decision-making. As the risks are variable during different phases of the mission (launch, flight, extravehicular activities, landing), aerospace medicine providers must quantify the unique risks and prepare astronauts during pre-flight training. Aerospace medicine providers must understand the risks associated with emergency egress, either during launch or landing, and prepare for that scenario. They must also be able to understand the risk individual crew members bring to the mission and best prepare the astronaut to mitigate those risks.

2.3. Mission-Specific Knowledge

Aerospace medicine providers should have a basic understanding of the organization-specific technologies, systems, and mission designs and their potential impacts on crew health. Each mission may have unique ground support, vehicles, or phases of flight, and aerospace medicine providers should be informed and aware of these specific components.

2.4. Human Systems Integration

Aerospace medicine providers need to be familiar with human-centered design principles, including at least a limited ability to provide design guidance for the medical system, habitat, and vehicle. Aerospace medicine providers may need to consider human factors, specifically how humans interface with the technology, and any automated or robotic systems onboard.

3. *Professional Skills*

Aerospace medicine providers must have experience and expertise in "soft skills," such as effective communication (including risk communication), leadership abilities, teamwork, and management capabilities. Second-level core competencies that contribute to professional skills are detailed below.

3.1. Bedside Manner and Communication

Aerospace medicine providers must be able to effectively communicate with patients, crew, and their families. This requires fostering a trusting relationship and rapport with patients, crew, and their family members. This requires a high level of emotional intelligence and an innate understanding of the job-specific pressures and the impact of those pressures on the patients. Aerospace medicine providers may have to interact with high-profile individuals, so they must be able to adapt and connect emotionally with a wide variety of individuals. As they provide care, aerospace medicine providers must also be able to communicate policy and procedures to crew members and foster understanding to protect patient health.

3.2. Interact and Collaborate with Engineers

Aerospace medicine providers often communicate medical concepts to engineers and provide medical-related inputs to the engineering process. To facilitate this communication, they would benefit from an understanding of the specific terminology, requirements, and processes used by the engineering team to effectively provide input and guidance. Aerospace medicine providers must be able to quantify and effectively communicate medical risks to inform the design of the vehicle and other engineering products. During this design process, aerospace medicine providers may need to advocate for a human-centered and human-integrated design.

3.3. Interact and Collaborate with Scientific Researchers

Aerospace medicine providers must be able to communicate with scientific researchers to promote scientific research. Participating in health studies is an important part of spaceflight, as it informs our understanding of the physiological changes that occur during spaceflight. Aerospace medicine providers may act as the liaison between scientific researchers and astronauts. They may have to advocate for astronaut well-being by advising investigators on astronaut health risks associated with participation to help inform research protocol design. Conversely, they may have to communicate the risks and benefits to the astronaut to help guide them to decide on their participation.

3.4. Interact and Collaborate with Non-Technical Stakeholders

Aerospace medicine providers must be able to communicate scientific and medical concepts and risks to non-crew and non-engineer stakeholders in a way that distills technical problems into an understandable and actionable decision. They must be able to adapt their language and communication approach to the audience present.

3.5. Teamwork

Aerospace medicine providers must be able to work as part of a cohesive team and to be able to lead or follow as the situation dictates. They must be able to effectively function and collaborate within an interdisciplinary team, of which they may be a leader or member. Even when holding a leadership position, they must be able to identify when their knowledge base is insufficient and when to consult with an expert in that specialty area. In some cases, aerospace medicine providers may need to manage projects, ranging from inception to completion.

3.6. Continuing Education and Learning

Aerospace medicine providers must be able to research relevant scientific concepts, stay up to date on literature, and appraise scientific merit by critically evaluating research design and findings. This requires the desire and active participation to continue education and improve knowledge and skills as scientific and medical fields advance. Aerospace medicine providers must consistently upkeep their clinical skills and continue their education in the medical practice.

4. *Operational Skills*

Aerospace medicine providers must have the ability to work with human spaceflight missions and have experience with spaceflight-specific operational procedures. Second-level core competencies that contribute to Operational Skills are detailed below.

4.1. Medical Certification and Evaluation Process

Aerospace medicine providers must conduct aeromedical evaluations and understand, develop, update, and/or apply medical standards. This includes determining fitness for duty parameters, providing medical waivers, and understanding relevant certification and/or qualification processes. These processes and evaluations inform the selection and retention medical certification standards and determine if astronauts meet those standards and are, therefore, cleared for duty. During the medical evaluation processes, aerospace medicine providers must be able to contextualize the findings into risk assessements, which they then need to communicate to the decision makers and patients as needed.

4.2. Operations and Mission Control

Aerospace medicine providers will work on spaceflight missions, adapting to changes as they arise, work at a console, and operate as a member of the Flight Control Team in the Mission Control Center. Aerospace medicine providers must know the standard processes, procedures, flight rules, and technology in mission control to be an effective team member. They must be able to communicate with Flight Control in an effectively and timely manner, especially during nominal launch and landing responses. Aerospace medicine providers may also need to coordinate medical transport with the Flight Control Team.

4.3. Work with Organizational Partners

Aerospace medicine providers may need to function jointly with partner government, military, commercial, or international entities in some cases. This includes working with different cultures and diverse teams.

4.4. Mishap Prevention, Investigation, and Response

Aerospace medicine providers may have to apply specialty medical and human factor expertise to develop spacecraft requirements, and respond to and investigate spacecraft mishaps. They must be able to develop preventive plans and incident management procedures, especially for contingency launch and landing responses. During a mishap, they may have to coordinate with mishap response agencies or work with crowd management. Following the incident, they must be able to complete post-incident safety reviews to inform the refinement of preventive and management procedures.

4.5. Policy, Regulations, and Procedures

Aerospace medicine providers must understand the current and evolving regulations and procedures, whether they be federal, political, organizational, and regulatory restraints. Aerospace medicine providers must be able to interpret policy documents and apply medical standards. In some cases, aerospace medicine providers need to be aware of and adhere to regulations and limitations surrounding data sharing.

INTERVIEWEE-IDENTIFIED CRITICAL SKILLS

This section discusses the skills and knowledge attributes that were identified as critically important skills for aerospace medicine providers dealing with human spaceflight, according to the number of experts who discussed the respective attributes in interviews conducted for this study. Figure 4 depicts the results of that analysis, with the number of interviewees (among 38) who emphasized the listed skills and knowledge areas. As noted in the Methodology, the 22 interviewee-identified skills were developed by reviewing interviews for key themes, then creating and applying a coding scheme to the interviews to quantify the most commonly mentioned themes, skills, or components of the knowledge base.

The study team notes that the following results stemmed from the initial interviews based on open-ended, semi-structured questions. This allowed each SME to arrive at their skill and knowledge attributes with minimal prompting and reduced bias. The commonly identified skills below do not imply prioritization of one skill over the other nor does the lack of a skill being discussed indicate it is not a core competency for aerospace medical practitioners. Rather, this highlights the most commonly mentioned and considered skill and knowledge attributes.

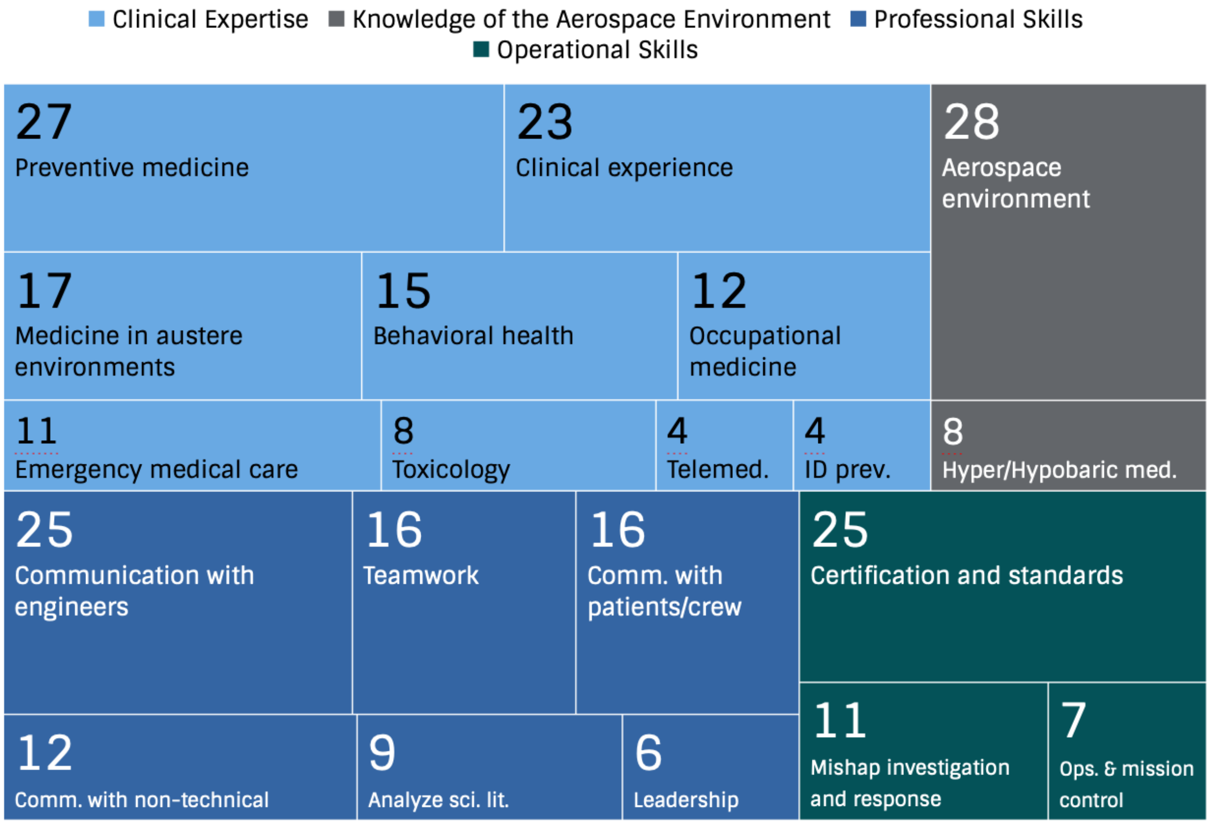

Figure 4. Most commonly identified skills and knowledge during informational interviews with SMEs. Numbers in each box indicate the number of interviewees (out of 38) who highlighted the importance of that competency.

The most common attribute identified by all experts contributing to this study was a comprehensive understanding of the aerospace environment and its impact on human physiology, which 28 of 38 interviewees (74%) highlighted. Closely following this was an emphasis on the importance of preventive medicine and related training and principles, which 27 interviewees (71%) pointed out as essential. The next most common attributes, both noted by 25 interviewees (66%), were knowledge of aeromedical certification processes and medical standards, as well as effectively communicating with engineers and providing input during the engineering process. Following this, 23 interviewees (61%) stated a need for direct clinical knowledge and experience, often noting that aerospace medicine providers should first and foremost be a good doctor. In addition to the areas shown in *Figure 4*, nine interviewees (24%) identified NASA-specific skills (e.g., work within a bureaucracy, work with international partners) and eight (21%) identified commercial spaceflight specific skills (e.g., understand company policies and procedures, work with high-net-worth individuals).

To further understand the distribution of core competencies suggested by experts, one can examine the backgrounds of the experts who recommended each attribute.

The largest portion of interviewees completed their residencies at UTMB and other programs represented a minority of interviewees. Figure 5 shows the breakdown for each recommended attribute according to whether the recommender had been educated by means of a UTMB residency, or other educational background. Differences in responses were notable for Wright State University residency attendees and Air Force residency attendees. Wright State University and the Air Force attendees identified behavioral health and patients/crew communications respectively as important skills more often than attendees of other training programs.

	UTMB Residency (n=18)	Wright State University Residency (n=7)	Air Force Residency (n=6)	None (n=3)	Mayo Clinic Fellowship (n=2)	Navy Residency (n=1)	University of Texas Houston Residency (n=1)
Aerospace environment	83%	86%	83%	33%	0%	0%	100%
Preventive medicine	67%	100%	67%	33%	100%	0%	100%
Certification and standards	56%	71%	83%	67%	50%	100%	100%
Engineer communications	83%	43%	50%	33%	50%	100%	100%
Clinical experience	61%	71%	67%	33%	50%	0%	100%
Medicine in austere environments	50%	43%	50%	33%	0%	100%	0%
Teamwork	56%	29%	33%	0%	50%	0%	100%
Patients/crew communication	28%	43%	100%	67%	0%	0%	0%
Behavioral health	22%	86%	33%	33%	50%	100%	0%
Occupational medicine	28%	29%	33%	67%	0%	100%	0%
Non-technical communications	28%	14%	33%	33%	100%	0%	100%
Mishap investigation and response	28%	43%	33%	0%	50%	0%	0%
Emergency medical care	33%	43%	0%	33%	50%	0%	0%
NASA-specific skills	28%	29%	17%	0%	0%	100%	0%
Analyze scientific literature	22%	29%	17%	0%	100%	0%	0%
Hypobaric/Hyperbaric medicine	17%	29%	33%	33%	0%	0%	0%
Toxicology	22%	29%	33%	0%	0%	0%	0%
Commercial spaceflight-specific skills	28%	29%	0%	0%	50%	0%	0%
Operations and mission control	22%	29%	17%	0%	0%	0%	0%
Leadership skills	22%	14%	17%	0%	0%	0%	0%
Infectious disease prevention	11%	29%	0%	0%	0%	0%	0%
Telemedicine	17%	0%	0%	0%	50%	0%	0%

Figure 5. Important skills and knowledge identified by attendees of each aerospace medicine training program.

Interview data was also analyzed according to whether the interviewees had previous experience with NASA missions, working in commercial spaceflight, in the military, or as instructors in academic programs relating to aerospace medicine, with results shown in Figure 6.

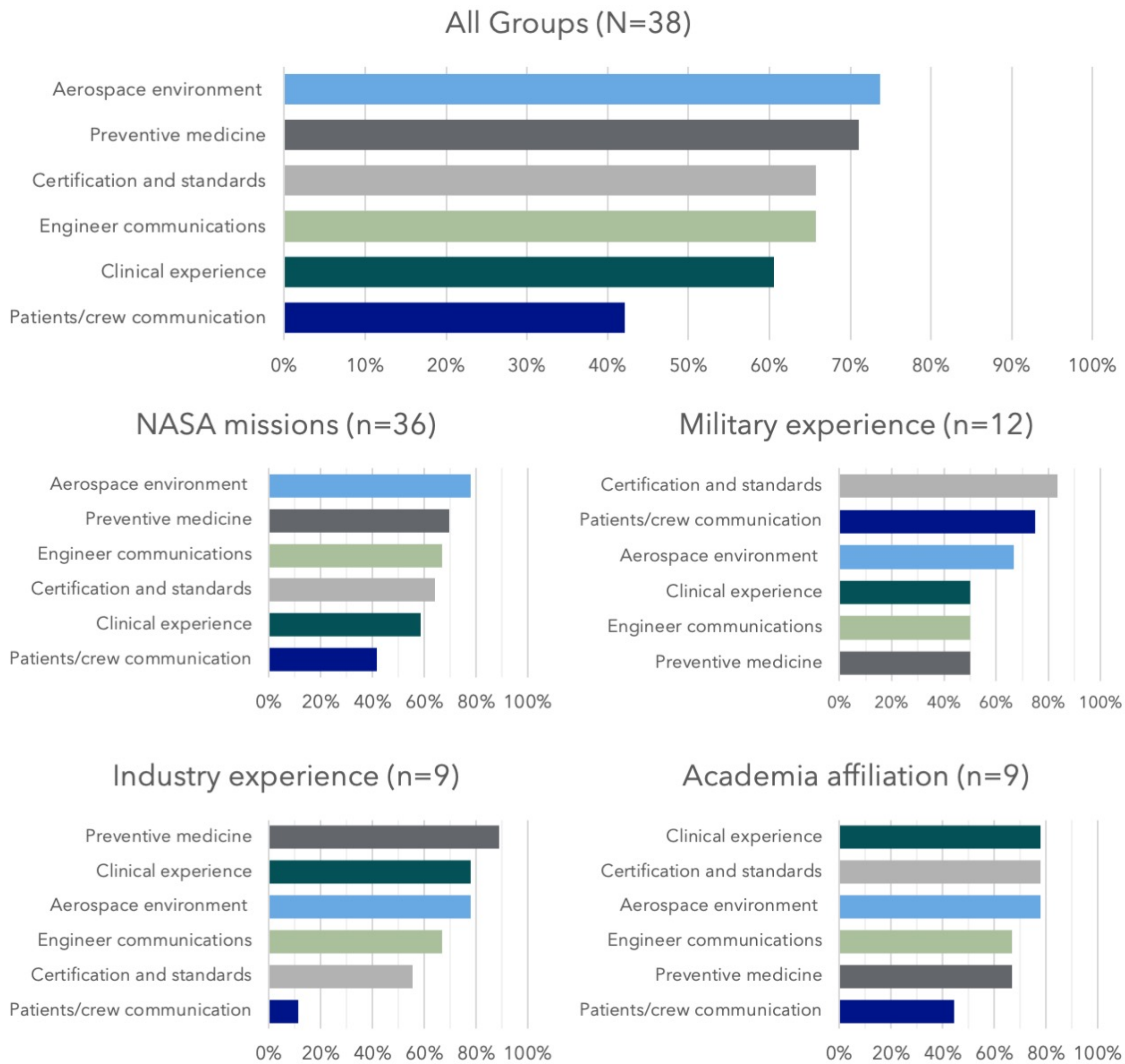

Figure 6. Important skills and knowledge most commonly identified by interviewees with experience working as aerospace medicine providers with NASA, military, industry, or academia.

Finally, interviews were analyzed according to the years of experience of the interviewee (Figure 7). For the purposes of this analysis, years of experience were binned by decade into four groups: 0-9 years of experience, 10-19 years of experience, 20-29 years of experience, 30-39 years of experience, and 40-49 years of experience.

All groups frequently identified knowledge of the aerospace environment as an important skill or knowledge area for aerospace medicine providers. All but the 40-49 years of experience group mentioned preventative medicine frequently. Certifications and standards was also frequently identified as an important area by all but the 10-19 years of experience group. Experts with fewer years of experience (0-9 and 10-19) identified the skill of communicating with engineers much more often than those with more years of experience.

	Years of Experience				
	0 - 9 (n=12)	10 - 19 (n=9)	20 -29 (n=9)	30 - 39 (n=6)	40 - 49 (n=2)
Aerospace environment	67%	67%	78%	83%	100%
Preventive medicine	75%	67%	67%	83%	50%
Certification and standards	67%	44%	78%	67%	100%
Engineer communications	83%	78%	44%	50%	50%
Clinical experience	50%	78%	56%	50%	100%
Medicine in austere environments	50%	67%	11%	50%	50%
Teamwork	58%	56%	11%	33%	50%
Patients/crew communication	25%	33%	67%	50%	50%
Behavioral health	25%	22%	67%	50%	50%
Occupational medicine	33%	22%	56%	17%	0%
Non-technical communications	42%	22%	22%	33%	50%
Mishap investigation and response	25%	44%	11%	50%	0%
Emergency medical care	17%	56%	22%	33%	0%
NASA-specific skills	33%	22%	22%	17%	0%
Analyze scientific literature	33%	33%	11%	17%	0%
Hypobaric/Hyperbaric medicine	17%	33%	22%	17%	0%
Toxicology	25%	22%	22%	17%	0%
Commercial spaceflight-specific skills	25%	33%	0%	33%	0%
Operations and mission control	42%	0%	11%	17%	0%
Leadership skills	8%	33%	0%	33%	0%
Infectious disease prevention	8%	11%	0%	33%	0%
Telemedicine	33%	0%	0%	0%	0%

Figure 7. Important skills and knowledge identified by those with 0-9, 10-19, 20-29, 30-29, or 40-49 years of experience working in aerospace medicine.

CONCLUSIONS AND RECOMMENDATIONS

The landscape of spaceflight is changing swiftly, as recent years have seen a rapid increase in commercial spaceflight, the introduction of the USSF, increased involvement from other nations, and NASA's increased focus on its Moon to Mars architecture. Therefore, there is a concomitant increase in the need for aerospace medicine providers to protect the health and well-being of these astronauts and spaceflight participants. The changing patient population underscores the need for re-evaluating the training aerospace medicine providers receive to ensure they are prepared and able to provide appropriate care.

The Potomac Institute for Policy Studies was tasked by OCHMO to determine the training, skills, knowledge, and core competencies necessary for aerospace medicine providers, particularly in the space medicine domain. Using data integrated from literature review and iterative interviews with SMEs, the Institute identified four high-level core competency areas an aerospace medicine provider needs training in to ensure they are prepared to provide the necessary care:

- Clinical Expertise,
- Knowledge of the Aerospace Environment,
- Professional Skills, and
- Operational Skills.

Each of these four high-level core competency areas is supported by second- and third-level competencies. While this list is not exhaustive for every organization, it identifies the necessary skills and knowledge necessary to practice as an aerospace medicine provider. It is important to note that not all skills and knowledge are mastered during residency training; on-the-job training and exposure to experienced aerospace medicine practitioners supplement residency training to create well-rounded, well-informed providers. Further, not every aerospace medicine provider will need the same set of skills and knowledge. Aerospace medicine providers who support NASA missions may need different skills than those who support commercial missions.

Based on findings and analysis of this report, the Potomac Institute developed the following recommendations regarding aerospace medicine training, skills, and knowledge:

1. **Frequently re-evaluate and document all aerospace medicine training program requirements, including informal and practical experience components.** The rapidly changing field of human spaceflight and the corresponding expansion of the duties of aerospace medicine providers necessitates equally flexible training programs.
2. **Incorporate input from individuals with experience in working with commercial spaceflight companies as well as NASA in the evaluation process.** The expanded role that commercial spaceflight companies play in human spaceflight should be acknowledged and incorporated into the training process. Where possible, trainees should be given the opportunity to learn from aerospace medicine providers from a wide range of experiences to better prepare them for future collaborations and cooperative efforts.
3. **Ensure continued skill development for aerospace medicine providers after training programs are completed.** Continuing Medical Education is an important component of maintaining medical licensure. As residency programs in aerospace medicine continue to develop and improve training opportunities, currently licensed providers should also be allotted time and funding with which to participate in those opportunities.

The Aerospace Medicine discipline is unique among medical fields in that providers must be equipped to identify, diagnose, and treat physiological changes not typically encountered in terrestrial medicine training and practice. Astronauts and spaceflight participants are exposed to unique hazards, which can cause unexpected physiologic changes and manifestations. Historically, astronauts exposed to the spaceflight environment were of the highest standards of health. Because of this, the adage was to "keep healthy people healthy." However, this no longer holds true, as the diversity of individuals with varying health statuses can reach the space environment through a variety of means. Therefore, the adage may now adapt to "keep people with co-morbidities or health risk factors from degrading or deconditioning to a critical point." This requires a new approach to training because aerospace medicine practitioners are encountering manifestations that have not been seen before because individuals with these risk factors have not been sent to space before. As the patient population changes, the training required to provide the standard of care evolves, too.

Practitioners must develop and apply standards to individuals to reduce the risk of adverse medical events, and review those standards over time, as additional data is collected and as flight capabilities improve and change. The fundamental skills and knowledge required by aerospace medicine specialists reflect these tasks, with an understanding of the aerospace environment being cited as the most important requirement for practitioners.

The mindset of preventive medicine is also fundamental to the practice. The resources available during spaceflight are severely limited by the mass and volume of materials and equipment that can be brought to space. It is therefore far more important and efficient to prevent adverse medical events before they occur, rather than attempting to treat them.

Communication skills are also essential, both with the crew (or spaceflight participants, as in the case of commercial space flights) and with all other individuals involved in designing and carrying out missions. The flight surgeon serves as the advocate for their patients, and bears the responsibility of looking out for their health and safety. Building trust and rapport between the patient and the practitioner will be especially important for long-duration exploration spaceflight, where crew members could be years away from definitive care.

APPENDIX I. ACRONYMS AND ABBREVIATIONS

ABPM	American Board of Preventive Medicine
ACGME	Accreditation Council for Graduate Medical Education
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
ISS	International Space Station
JSC	Johnson Space Center
NASA	National Aeronautics and Space Administration
OCHMO	Office of the Chief Health and Medical Officer
OSHA	Occupational Safety and Health Administration
SME	Subject Matter Expert
US	United States
USSF	United States Space Force
UTMB	University of Texas Medical Branch

APPENDIX II. DETAILED METHODOLOGY

DATA COLLECTION

To develop findings and recommendations on aerospace medicine training and core competencies, the Potomac Institute conducted interviews with stakeholders and SMEs, and conducted a literature review.

The literature review included reviewing official medical requirements, current residency curriculums, and other information regarding current and former aerospace medicine training programs.

Interviews included representatives from academia, industry, military, and NASA. OCHMO provided the Potomac Institute with a list of current and former NASA flight surgeons, representing the majority of the interviewees. Additional interview subjects were identified based on recommendations from interviewees in response to the question "Who else would you recommend that we talk to for this study?"

The Potomac Institute conducted informational interviews with 43 SMEs, primarily current and former NASA flight surgeons. Of the 61 flight surgeon contacts provided by OCHMO, 34 were interviewed. In addition, interviews were conducted with 4 individuals with aerospace medicine experience recommended by other interviewees, and 3 other SMEs with relevant experience identified through other Institute contacts. Data on interviewee background and experience was collected and cataloged to aid in data analysis. This data is summarized above in Figure 1.

DATA ANALYSIS

Responses to interview questions were summarized qualitatively and quantitatively to determine key takeaways, features of interviewees, and common themes.

Direct answers to interview questions and other relevant information were summarized into key takeaways. Additionally, features of the interviewees and specific answers to the interview questions were organized, categorized into topics, and further analyzed to identify common themes. Specifically, information on residency training processes, critical skills and knowledge, significant changes over time, and the impact of commercial spaceflight was collected. Descriptions of residency training processes included estimates on the proportion of time spent on didactic or classroom learning vs hands-on or practical experience. Based on the ACGME and ABPM core areas, interviews, and literature review, the Institute team initially categorized critical skills and knowledge identified by SMEs into groups as follows: clinical, technical, and scientific skills, "soft" skills, and other skills.

To further analyze interview findings related to the specific skills and knowledge that are most essential for aerospace medicine providers, a coding scheme was developed to quantify interview data on the most commonly interviewee-mentioned themes, skills, or components of the knowledge base (See Table 1 for coding definitions). The coding scheme was initially developed based on team discussion of recurrent themes in interviews, and was iteratively refined. After development of the coding scheme, all interviews were reviewed to determine which themes could be identified in each interview.

Table 1. Definitions of the skills, knowledge, and themes that were systematically identified in interviews.

Necessary Skill or Knowledge	Definition
Aerospace Environment	Understanding of relevant scientific concepts relating to the aerospace environment and impact of that environment on physiology; five human health risks of spaceflight
Preventive Medicine	Ability to provide preventative care and keep healthy people healthy; includes treating healthy people in abnormal/unhealthy environment and understanding of epidemiology, biostatistics
Certification and standards	Ability to conduct aeromedical certification exams and understand medical standards; includes determining fitness for duty, providing medical waivers, updating standards, understanding relevant certification processes
Communication with engineers	Ability to communicate medical concepts to engineers and provide medical-related inputs to the engineering process; includes communicating with engineers, quantifying medical risks, providing input on vehicle design and other engineering products
Clinical experience	Ability to provide (general/non aerospace medicine) clinical care; includes "be a good doctor," general diagnostic skills
Medicine in austere environments	Exposure to and/or understanding of environments analogous to the spaceflight environment; includes working in uncomfortable environments, Antarctica expeditions, flight experience, providing care in remote and low resource locations
Teamwork	Ability to work as part of a cohesive team and not hold the lead role or have the final say in decisions

Communication with patients/crew	Ability to effectively communicate with patients and crew; includes building trust and rapport with crew members; advocating for crew/patients
Behavioral health	Understanding of and ability to treat mental health, stress, and related issues; includes understanding of isolation and confinement, substance abuse, recognizing behavioral health issues, knowledge of associated physical symptoms, ability to provide coping mechanisms
Occupational Medicine	Ability to practice medicine in an occupational setting; understanding prevention and treatment of medical conditions in the workplace
Communication with non-technical stakeholders	Ability to communicate medical concepts to non-crew and non-engineer stakeholders in a non-technical manner
Mishap investigation and response	Ability to respond to and aid in investigating accidents; includes communicating bad news to colleagues and families
Emergency medical care	Ability to provide care for unforeseen injuries and illnesses requiring immediate medical attention; includes advanced cardiac support, advanced trauma life support
NASA-specific skills	Skills particular to working for NASA; includes ability to work within bureaucracy, work with international partners
Analyze scientific literature	Ability to research relevant scientific concepts and stay up to date on literature
Hypobaric/Hyperbaric medicine	Understanding and ability to treat medical conditions resulting from exposure to abnormally high- or low-pressure environments
Toxicology	Ability to evaluate, treat, and monitor injury and illness resulting from exposure to hazardous chemicals
Commercial spaceflight-specific skills	Skills particular to working for commercial spaceflight companies; includes interacting with high profile and high net worth individuals, concierge medical care, understanding of policies and procedures of company

Operations and mission control	Ability to work on spaceflight missions and sit console
Leadership skills	Ability to lead groups and organizations
Infectious disease prevention	Knowledge of and ability to reduce the spread of contagious diseases; includes knowledge of quarantining
Telemedicine	Ability to remotely diagnose and treat patients; includes performing provider-directed self-examination, communicating empathy without a physical presence

These 22 commonly mentioned skills, knowledge areas, and knowledge gained from the literature review were used to draft an initial set of core aerospace medicine competencies. This list was then recirculated to the original interviewees for critique and feedback.

APPENDIX III: FULL LIST OF CORE COMPETENCIES

Based on interviews with aerospace medicine providers, the Institute identified four high level core competency areas, which highlight the necessary skills and knowledge to perform duties associated with the role of aerospace medicine:

- Clinical Expertise,
- Knowledge of the Aerospace Environment,
- Professional Skills, and
- Operational Skills.

Further sub-categories for each of these areas have been identified and are detailed below, including second and third level core competencies. This is not an exhaustive list of every skill and technique necessary, but highlights sub-skills or examples additional skills and techniques identified by SME interviews and internal research. It should be noted that this study placed particular emphasis on emphasis on space medicine, albeit with the recognition that space medicine and aviation medicine are deeply intertwined. Therefore, some competencies described here apply to both aviation and space medicine, and others are primarily or only applicable to space medicine. Further, competency requirements for specific jobs may have additional requirements, or may not require all of the skills described here.

Each skill or knowledge area has also been categorized with the following indicators of the level of expertise required and applicability to specific settings (Figure 2):

- 1= basic understanding or limited working proficiency; 2=skill mastery; significant expertise
- G=general medical core competency; S=Specific competency is applied in a way to space medicine that might deviate from or expand on general competency; C=Commercial spaceflight competency that may be more relevant for commercial spaceflight

1. **Clinical Expertise**: Demonstrated ability to provide routine clinical care to a patient; includes "be a good doctor," general diagnostic skills, and specific medical expertise areas relevant for astronaut care. Clinical expertise includes the following sub-categories:
    1.1. Fundamental Clinical Skills: Evaluate, diagnose, and decide on clinical treatment plans and execute treatment plans
        1.1.1. Patient History and Physical Examination (G2)
        1.1.2. Diagnosis and Treatment of Medical Conditions (G2)
        1.1.3. Procedural Skills (G2)
        1.1.4. Patient Documentation (G2)
        1.1.5. Patient Communication (G2)
    1.2. Care for Patient in Emergency Setting: Provide emergent care for illness or injury; includes interventions for unforeseen medical conditions such as life-threatening cardiovascular events or trauma

- 1.2.1. Disaster/Emergency Response in the Field (S1)
- 1.2.2. Contingency Launch and Landing Response (S1)
- 1.2.3. Medical Evacuation (S1)
- 1.2.4. Point of Injury Care (G1)
- 1.2.5. Provide Care with Limited Resources (G2)

1.3. Provide Care in a Terrestrial Austere Environment: Anticipate health risks, implement countermeasures, and perform medical care in austere and/or hostile settings

- 1.3.1. Travel Medicine (G1)
- 1.3.2. Provide Care with Limited Resources or Constraints (S2)
- 1.3.3. Prioritize Competing Needs (G2)
- 1.3.4. Work Through Environmental Stressors (G2)
- 1.3.5 Design, Maintenance, and Use of Medical Kits (S1 - C1)

1.4. Telemedicine: Remotely diagnose and guide patient treatment; includes directing self-examination, provide anticipatory guidance, and communicating empathy without a physical presence

- 1.4.1. Communicate Via Video or Voice Call (G2)
- 1.4.2. Manage Communication Delays (S2)
- 1.4.3. Effectively Communicate to Non-Medical Provider (G2)
- 1.4.4. Direct Patients in Self-Examination (G2)

1.5. Preventive Medicine: Provide preventive care and maintain health and well-being; includes treating people in an abnormal environment and mitigating impact of co-morbidities; understanding of principles and implementation of relevant countermeasures

- 1.5.1. General Health and Disease Maintenance (e.g., cardiovascular, neurological, respiratory, musculoskeletal, metabolic) (G2)
- 1.5.2. Risk Assessment and Countermeasure Implementation (S2)
- 1.5.3. Epidemiology and Biostatistics (S2)
- 1.5.4. Infectious Disease Prevention and Management (G2)
- 1.5.5. Tropical and Global Health Medicine (S2)
- 1.5.6. Environmental Disease Prevention and Management (S2)

1.6. Occupational Medicine: Predict, mitigate, evaluate, treat, and monitor injury and illness resulting from exposure to occupational hazards (terrestrial and aerospace environment)

- 1.6.1. Risk Assessment and Management (S2)
- 1.6.2. Chronobiology and Fatigue Management (S1)
- 1.6.3. Post-Flight Rehabilitation and Return to Normal Life (S2)
- 1.6.4. Longitudinal Health Surveillance (S2)
- 1.6.5. Occupation Hazards and Regulations During Ground Operations (S2)
- 1.6.6. Development and Implementation of Organizational Habitability and Exposure Standards (S2 – C2)
- 1.6.7. Toxicology (S1)

1.7. Behavioral Health: Diagnose and/or treat mental health, stress, and related issues; includes understanding of isolation and confinement, recognizing the bio-psycho-social foundation of behavioral health issues, knowledge of associated physical symptoms, and supporting the use of coping mechanisms

1.7.1. Provide Psychological Support to Crew (S1)
1.7.2. Support Staff and Crew Family Support (S1)
1.7.3. Psychiatry Management (S1)
1.7.4. Screen for Risk Factors (S2)
1.7.5. Early Identification of Behavioral Deviations (S2)

2. **Knowledge of the Aerospace Environment:** Understand relevant scientific concepts relating to the aerospace environment and impact of that environment on physiology. Apply evidence-based principles and leverage understanding of the medical literature to inform patient care decisions. Knowledge of the aerospace environment includes the following sub-categories:

2.1. Human Health Risks of Spaceflight: Understand and mitigate the human health risks associated with altered physiology in an altered environment

2.1.1. Acceleration and Gravitational Effects Including Microgravity (S2)
2.1.2. Cardiovascular (S2)
2.1.3. Neurological and Cognitive Changes (S2)
2.1.4. Ocular (S2)
2.1.5. Fluid Shifts (S2)
2.1.6. Hypoxia (S2)
2.1.7. Pressure (Hyper and Hypobaric) Effects (S2)
2.1.8. Radiation Exposure (S2)
2.1.9. Musculoskeletal (S2)

2.2 Risk Evaluation: Assess and quantify risk (individual, crew, and mission) during all mission phases to inform decision-making

2.2.1 Pre-Flight Training and Preparation (S2)
2.2.2 Launch (S2)
2.2.3 Flight (S2)
2.2.4 Extravehicular Activities (S2)
2.2.5 Landing (S2)
2.2.6 Emergency Egress (Launch or Landing) (S2)
2.2.7 Post-Landing Rehabilitation (S2)
2.2.8 Risk Human Brings to the Mission (S2)

2.3 Mission-Specific Knowledge: Awareness of organization-specific technologies, systems, and mission design and their potential impact on crew health

2.3.1 Ground Support (S1)
2.3.2 Vehicles (S1)
2.3.3 Phases of Flight (S1)

2.4 Human Systems Integration: Apply human-centered design principles, including medical system design, habitat, lighting, task analysis, and vehicle design

2.4.1 Human Factors (S1)
2.4.2 Human Technology Interfacing (S1)
2.4.3 Human Automation/Robotic Systems (S1)

3. **Professional Skills**: Experience and expertise in "soft skills," such as effective communication (including risk communication), leadership abilities, demonstrated teamwork, and management capabilities. Professional Skills includes the following sub-categories:
   3.1. Bedside Manner and Communication: Effectively communicate with patients and crew; includes building trust with crew members and advocating for crew/patients
      3.1.1. Emotional Intelligence (G2)
      3.1.2. Build Trust and Rapport with Crew and Families (G2)
      3.1.3. Understand Specific Pressures of the Job and Impact on Patients (S2)
      3.1.4. Interact with High-Profile Individuals (S2)
      3.1.5. Communicate Policy and Procedures (G2)
   3.2. Interact and Collaborate with Engineers: Communicate medical concepts to engineers and provide medical-related inputs to the engineering process; includes quantifying medical risks and providing input on vehicle design and other engineering products
      3.2.1. Engineering Terminology, Requirements, and Processes (S1)
      3.2.2. Quantify and Communicate Risk (S2)
      3.2.3. Communicate Human Systems Integration and Human Factors Design (S1)
   3.3. Interact and Collaborate with Scientific Researchers: Communicate medical concepts and research with scientific community and advise investigators on astronaut health risks to inform research protocol design
      3.3.1. Advocate for Astronaut Well-Being (S2)
      3.3.2. Communicate Risk Associated with Study Participation (S2)
      3.3.3. Communicate Research Impact (S2)
   3.4. Interact and Collaborate with Non-Technical Stakeholders: Communicate concepts to non-crew and non-engineer stakeholders in a way that distills technical problems into an understandable and actionable decision
      3.4.1. Quantify and Communicate Risk (S2)
      3.4.2. Explain Scientific and Medical Concepts with Language and Concepts Appropriate for the Audience (G2)
   3.5. Teamwork: Work as part of a cohesive team and to be able to lead or follow as the situation dictates
      3.5.1. Collaborate Within an Interdisciplinary Team (G2)
      3.5.2. Team Leadership (G2)
      3.5.3. Consult with Other Experts When Necessary (G2)
      3.5.4. Project Management (S1 – C1)
   3.6. Continuing Education and Learning: Research relevant scientific concepts, stay up to date on literature, and appraise scientific merit; desire and active participation to continue education and improvement of knowledge and skills as scientific and medical fields advance
      3.6.1. Stay Current on Scientific Literature (G2)
      3.6.2. Critically Evaluate Research Design and Findings (G2)
      3.6.3. Upkeep of Clinical Skills (S2)
      3.6.4. Continuing Education in Medical Practice (G2)

4. **Operational Skills**: Ability to work human spaceflight missions and experience with spaceflight-specific operational procedures. Operational Skills includes the following sub-categories:
    4.1. Medical Certification and Evaluation Process: Conduct aeromedical evaluations and understand, develop, update, and/or apply medical standards; includes determining fitness for duty parameters, providing medical waivers, understanding relevant certification and/or qualification processes
        4.1.1. Selection and Retention Medical Certification Standards (S2)
        4.1.2. Medical Waiver Process (S2)
        4.1.3. Develop Medical Waiver Rationale as Needed (S2)
        4.1.4. Communicate Risk-Assessment to Decision Makers (S2)
    4.2. Operations and Mission Control: Work on and adapt to changes in spaceflight missions, and work console; includes operating as a member of the Flight Control Team in the Mission Control Center
        4.2.1. Standard Processes, Procedures, Flight Rules, and Technology in Mission Control (S2)
        4.2.2. Effective and Timely Communication with Flight Control (S2)
        4.2.3. Nominal Launch and Landing Response (S2)
        4.2.4. Medical Transport (S2)
    4.3. Work with Organizational Partners: Function effectively within home organization and jointly with partner government, commercial, or international entities; includes working with different cultures and diverse teams
        4.3.1. Military (S1)
        4.3.2. International Partners (S1)
        4.3.3. Government Agency Interactions (S1)
        4.3.4. Commercial Companies (S1)
    4.4. Mishap Prevention, Investigation, and Response: Apply specialty medical and human factor expertise to develop spacecraft requirements, and respond to and investigate spacecraft mishaps
        4.4.1. Develop Preventive Plans and Incident Management Procedures (S2)
        4.4.2. Contingency Launch and Landing Response (S2)
        4.4.3. Coordinate with Mishap Response Agencies (S1)
        4.4.4. Post-Incident Safety Reviews (S2)
        4.4.5. Crowd Management (S1)
    4.5. Policy, Regulations, and Procedures: Understand current and evolving regulations and procedures; includes working within federal, political, organizational, and regulatory restraints
        4.5.1. Regulations and limitations of data sharing (S1)
        4.5.2. Interpret policy documents and apply medical standards (S2)

Table 2. First, second, and third-level aerospace medicine core competencies.

1ST	2ND LEVEL COMPETENCY	3RD LEVEL COMPETENCY	RATING
1. Clinical Expertise	1.1 Fundamental Clinical Skills	1.1.1 Patient History and Physical Examination	G2
		1.1.2 Diagnosis and Treatment of Medical Conditions	G2
		1.1.3 Procedural Skills	G2
		1.1.4 Patient Documentation	G2
		1.1.5 Patient Communication	G2
	1.2 Care for Patient in Emergency Setting	1.2.1 Disaster/Emergency Response in the Field	S1
		1.2.2 Contingency Launch and Landing Response	S1
		1.2.3 Medical Evacuation	S1
		1.2.4 Point of Injury Care	G1
		1.2.5 Provide Care with Limited Resources	G2
	1.3 Provide Care in a Terrestrial Austere Environment	1.3.1 Travel Medicine	G1
		1.3.2 Provide Care with Limited Resources or Constraints	S2
		1.3.3 Prioritize Competing Needs	G2
		1.3.4 Work Through Environmental Stressors	G2
		1.3.5 Design, Maintenance, and Use of Medical Kits	S1 – C1
	1.4 Telemedicine	1.4.1 Communicate Via Video or Voice Call	G2
		1.4.2 Manage Communication Delays	S2
		1.4.3 Effectively Communicate to Non-Medical Provider	G2
		1.4.4 Direct Patients in Self-Examination	G2
	1.5 Preventive Medicine	1.5.1 General Health and Disease Maintenance	G2
		1.5.2 Risk Assessment and Countermeasure Implementation	S2
		1.5.3 Epidemiology and Biostatistics	S2
		1.5.4 Infectious Disease Prevention and Management	G2
		1.5.5 Tropical and Global Health Medicine	S2
		1.5.6 Environmental Disease Prevention and Management	S2
	1.6 Occupational Medicine	1.6.1 Risk Assessment and Management	S2
		1.6.2 Chronobiology and Fatigue Management	S1
		1.6.3 Post-Flight Rehabilitation and Return to Normal Life	S2
		1.6.4 Longitudinal Health Surveillance	S2
		1.6.5 Occupation Hazards and Regulations During Ground Operations	S2
		1.6.6 Development and Implementation of Organizational Habitability and Exposure Standards	S2 – C2
		1.6.7 Toxicology	S1
	1.7 Behavioral Health	1.7.1 Provide Psychological Support to Crew	S1
		1.7.2 Support Staff and Crew Family Support	S1
		1.7.3 Psychiatry Management	S1
		1.7.4 Screen for Risk Factors	S2
		1.7.5 Early Identification of Behavioral Deviations	S2

2. Knowledge of the Aerospace Environment	2.1 Human Health Risks of Spaceflight	2.1.1 Acceleration and Gravitational Effects Including Microgravity	S2
		2.1.2 Cardiovascular	S2
		2.1.3 Neurological and Cognitive Changes	S2
		2.1.4 Ocular	S2
		2.1.5 Fluid Shifts	S2
		2.1.6 Hypoxia	S2
		2.1.7 Pressure (Hyper and Hypobaric) Effects	S2
		2.1.8 Radiation Exposure	S2
		2.1.9 Musculoskeletal	S2
	2.2 Risk Evaluation	2.2.1 Pre-Flight Training and Preparation	S2
		2.2.2 Launch	S2
		2.2.3 Flight	S2
		2.2.4 Extravehicular Activities	S2
		2.2.5 Landing	S2
		2.2.6 Emergency Egress (Launch or Landing	S2
		2.2.7 Post-Landing Rehabilitation	S2
		2.2.8 Risk Human Brings to the Mission	S2
	2.3 Mission-Specific Knowledge	2.3.1 Ground Support	S1
		2.3.2 Vehicles	S1
		2.3.3 Phases of Flight	S1
	2.4 Human Systems Integration	2.4.1 Human Factors	S1
		2.4.2 Human Technology Interfacing	S1
		2.4.3 Human Automation/Robotic Systems	S1
3. Professional Skills	3.1 Bedside Manner and Communication	3.1.1 Emotional Intelligence	G2
		3.1.2 Build Trust and Rapport with Crew and Families	G2
		3.1.3 Understand Specific Pressures of the Job and Impact on Patients	S2
		3.1.4 Interact with High-Profile Individuals	S2
		3.1.5 Communicate Policy and Procedures	G2
	3.2 Interact and Collaborate with Engineers	3.2.1 Engineering Terminology, Requirements, and Processes	S1
		3.2.2 Quantify and Communicate Risk	S2
		3.2.3 Communicate Human Systems Integration and Human Factors Design	S1
	3.3 Interact and Collaborate with Scientific Researchers	3.3.1 Advocate for Astronaut Well-Being	S2
		3.3.2 Communicate Risk Associated with Study Participation	S2
		3.3.3 Communicate Research Impact	S2
	3.4 Interact and Collaborate with Non-Technical Stakeholders	3.4.1 Quantify and Communicate Risk	S2
		3.4.2 Explain Scientific and Medical Concepts with Language and Concepts Appropriate for the Audience	G2
	3.5 Teamwork	3.5.1 Collaborate Within an Interdisciplinary Team	G2
		3.5.2 Team Leadership	G2
		3.5.3 Consult with Other Experts When Necessary	G2
		3.5.4 Project Management	S1 – C1

	3.6 Continuing Education and Learning	3.6.1 Stay Current on Scientific Literature	G2
		3.6.2 Critically Evaluate Research Design and Findings	G2
		3.6.3 Upkeep of Clinical Skills	S2
		3.6.4 Continuing Education in Medical Practice	G2
4. Operational Skills	4.1 Medical Certification and Evaluation Process	4.1.1 Selection and Retention Medical Certification Standards	S2
		4.1.2 Medical Waiver Process	S2
		4.1.3 Develop Medical Waiver Rationale as Needed	S2
		4.1.4 Communicate Risk-Assessment to Decision Makers	S2
	4.2 Operations and Mission Control	4.2.1 Standard Processes, Procedures, Flight Rules, and Technology in Mission Control	S2
		4.2.2 Effective and Timely Communication with Flight Control	S2
		4.2.3 Nominal Launch and Landing Response	S2
		4.2.4 Medical Transport	S2
	4.3 Work with Organizational Partner	4.3.1 Military	S1
		4.3.2 International Partners	S1
		4.3.3 Government Agency Interactions	S1
		4.3.4 Commercial Companies	S1
	4.4 Mishap Prevention, Investigation, and Response	4.4.1 Develop Preventive Plans and Incident Management Procedures	S2
		4.4.2 Contingency Launch and Landing Response	S2
		4.4.3 Coordinate with Mishap Response Agencies	S1
		4.4.4 Post-Incident Safety Reviews	S2
		4.4.5 Crowd Management	S1
	4.5 Policy, Regulations, and Procedures	4.5.1 Regulations and Limitations of Data Sharing	S1
		4.5.2 Interpret Policy Documents and Apply Medical Standards	S2