# Engineering, Life Sciences, and Health/Medicine Synergy in Aerospace Human Systems Integration: The Rosetta Stone Project—An Executive Summary

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## ABSTRACT

*The successful design, development, and operation of human-rated and human-operated systems require the combined effort of engineering, science, and human health disciplines. This is extremely important to minimize risk and ensure safe operation of complex systems. Over six decades of National Aeronautics and Space Administration (NASA's) efforts in aviation and human spaceflight, the highly trained individuals from each discipline who have worked collectively to accomplish our spaceflight programs must embrace human systems integration (HSI) with different skill sets, terminology, and approaches. The Rosetta Stone, which enabled translation of ancient Egyptian hieroglyphics, represents an appropriate analogy for communication necessary between these three distinct disciplines. A group of subject matter experts was assembled to write a text to be used within Aerospace HSI to ensure effective dialogue between engineers, life scientists, and health/medicine experts. A 10-chapter NASA special publication was produced. Each chapter provided a cogent discourse on various aspects of the subject. A series of recommendations were also developed and reported here. As a community, we are embarking on new exploration initiatives. The human will serve as a constant and essential element in the construct of systems to support these missions. Each discipline must work closely together from the beginning of the design phase to ensure HSI is successfully accomplished and the programmatic expectations and goals are safely met.*

**Keywords:** human systems integration, human spaceflight exploration, medicine, engineering, life sciences, conflict resolution

## INTRODUCTION

Over the past six decades, National Aeronautics and Space Administration (NASA) has developed a wide array of robotic and human-rated spacecraft and has been at the forefront of aviation science in aircraft design and performance. During these decades, much has been accomplished in human exploration of space and in aviation.[1,2] Although not absent of tragedy, lessons have been learned and systems have improved to ensure the health and safety of those who fly these complex systems and those who operate them from the ground.[3]

Although there are many disciplines and domains within the space program, we categorize them into three broad areas—engineering, life sciences, and space medicine.



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## MEETING A NEED FOR COMMON GROUND

Successful design, development, and operation of human-rated and human-operated systems require a multidisciplinary collaborative effort between engineers, physicians, and scientists.[4] From the early days of human spaceflight, the relationship between the various disciplines has been characterized by the challenges each mission has presented. Each of these disciplines is trained in different ways and approaches problems in unique and often altruistic ways.

In antiquity, a stone artifact, the Rosetta Stone, contained three different languages. This granodiorite stele from the Hellenistic period serves as an analogy to the three aforementioned disciplines. The goal, therefore, of our effort was to bring together a wide array of subject matter experts to develop a better understanding of the differences in culture and practice of these communities. NASA's Chief Engineer, the Chief of Safety and Mission Assurance, and the Chief Health and Medical Officer, which comprise NASA's Technical Authorities, directed that a team be formed and a series of recommendations developed for improving human systems integration (HSI) within NASA.[3]

A team of authors was established by the senior author (R.S.W.) to write a series of chapters to be published in a NASA special publication (SP). This publication (NASA-SP-2017-633), edited by Williams and Doarn,[5] provides a series of recommendations that can be applied to enable a more collaborative understanding for the various cultures and disciplines required to send humans and human-operated spacecraft into space, complete their respective missions, and return them safely back to Earth.

## A ROSETTA STONE PROJECT

The current "Rosetta Stone" project draws its inspiration from the original ancient carved rock decree, engraved in three distinct lexicons to be understood within the context of one another. With this idea in mind, this project was undertaken to examine similarities and differences in culture and practice between engineering, life sciences, and health and space medicine disciplines in the context of HSI.

The successful design, development, and operation of human-rated systems for spaceflight require the combined efforts of engineering, science, and human health disciplines.[2] Each of these disciplines contributes a different set of scientific and technical expertise in addressing the challenges of planning, designing, and operating safely and successfully in the environment of space. HSI can be defined as comprehensive multidisciplinary management and technical process that focuses on the integration of human considerations into the system acquisition and development processes to enhance human system design, reduce life-cycle ownership cost, and optimize total system performance.[3] The implementation of HSI is challenging and often fraught with problems. HSI must play an integral and active role in the development of spacecraft and high-performance aircraft. This role must address considerations related to health and safety of the operators and passengers. Complex systems that are not human rated, but operated directly or remotely by humans and maintained by humans, must also undergo the HSI process for full success.

The primary goal of the project was to identify and understand differences and to make recommendations for improving the ability of the communities to work together more effectively to improve HSI and human systems operations. Notable examples of HSI failures in aviation and space vehicles are provided throughout the book.[5–7] The complexities of human–machine interfaces are examined from behavioral health and performance, human factors engineering, and safety perspectives. Differences in the ways that engineers, life scientists, and physicians approach problem identification, evaluation, and solving are described.[8–10] In addition, an innovative approach to human health risk evaluation using sets of ethical principles and responsibilities to guide decision-making to determine acceptable risk for human space exploration missions is described in detail.

After the Space Shuttle Columbia disaster in 2003, NASA implemented engineering, safety and mission assurance, and health and medical technical authorities to provide independent checks and balances of NASA's programs and projects. The article describes some of the challenges facing technical authority implementation, especially in the field of health and medicine.[5] NASA life scientists and medical personnel recognized the imperative of effective communication with engineering program management years ago, and took steps to improve their ability to communicate with engineering colleagues.

The NASA health and medical system was reconfigured to an occupational health model (risk-based standards to requirements to deliverables) to optimize astronaut health.[11] The NASA Human Research Program (HRP) was integral to these changes, prioritizing its research agenda to address health and human performance risk requirements and using system engineering tools to communicate with NASA leadership and management. Experts in the HRP have adapted probabilistic risk assessment, a major engineering risk assessment tool, to assess health and medical risks in human spaceflight in the form of the Integrated Medical Model (IMM).

The IMM is an innovative tool that expresses medical risk in quantitative terms that are relatable to engineers and interpretable by the engineering community and may also have wide value beyond the realm of human spaceflight. Human factors experts and other experts in HSI have produced the HSI Practitioners Guide, which provides phase-by-phase guidance for HSI activities and products and has been adopted by NASA's foremost human spacecraft development projects.[3]

This article summarizes the differences in the medical/life sciences and engineering communities of practice, beginning with the substrate on which each community works, continuing through professional lexicon, risk analysis, and identification, to risk remediation and problem resolution.[5] Cultural and practical bridges need to be built between the various communities of practice responsible for the design, development, and operation of human occupied and operated systems. The following are recommendations for improving communication and understanding between engineering and medical/life sciences communities:

1. Recognize the fact that significant cultural differences between communities of practice (*i.e.*, engineering and medicine) involved in NASA system development and operations exist. These cultural differences pose a risk to effective HSI.
2. Address cultural differences, primarily between engineering and medical/life sciences communities, early in the career paths of practitioners. Given the importance of human-rated and human-operated systems, not just to NASA but also across society, these differences should be formally addressed in the early training curricula of both engineering and medical/life sciences students in their respective professional schools.
3. Develop a common lexicon and common means of communication, methods, and practices that are recognizable and understandable by all, as effective communication is imperative. In NASA, the Technical Authorities and the Mission Directorates should collaborate to produce training modules in NASA's learning management systems—System for Administration, Training, and Educational Resources (SATERN)—to promote understanding of cultural differences and improve dynamics and the working relationship between engineering and medical/life sciences communities. NASA should also establish a mandate for the Technical Authorities to emphasize effective HSI and to mediate and translate between the medical/life sciences and engineering communities. Medical/life sciences communities should leverage communication techniques used widely in systems engineering as much as possible. Medical/life sciences communities should utilize engineering risk analysis techniques when feasible. Engineering communities would be well served to formally consider specific defined ethical principles and responsibilities when evaluating overall risk assessment and acceptance. The field of human factors engineering is critically important as common ground for the intersection of all communities of practice in HSI, and can serve as an effective agent and venue for change.
4. Create an imperative that all members of these diverse and relevant communities work together in a common platform to ensure the health and safety of the crew member and the entire system that supports them from design, through construction to operation. The diversity of thought/perspectives from each of the relevant communities is a necessity to have successful systems and as such, those diverse contributions must be actively engaged, encouraged, and respected. Such a paradigm is critical in human spaceflight as it enters a new phase of deep space and planetary exploration.
5. Recognize that dynamic tension exists between Technical Authorities and program/project management. This tension is healthy in the vast majority of cases and is laudatory for its value in enhancing safety and the overall project/program success. Serious conflicts can arise, however, when differences of opinion between technical authorities and program managers potentially affect budgets and schedules. Firm organizational commitment to fully vetting of all opinions, with senior leadership cognizance of and authority over final decisions, is imperative.
6. Engage the National Academies of Engineering, Science, and Medicine to study and comment on the imperative of cross-community collaboration and communication in HSI. This study could be facilitated by the Committee on Aerospace Medicine and Medicine of Extreme Environments and the Board on Human System Integration.
7. Study the disparate ways in which human factors and HSI are organized and addressed throughout NASA. Disconnects between requirements "ownership" and workforce management from center to center and directorate to directorate might contribute to the HSI challenges currently faced. A multidisciplinary team to fully study organizational challenges to effective HSI should be chartered.
8. Inclusion of all responsible and relevant communities of practice in all phases of the project/program, from design to operations, is absolutely necessary. Inclusion of communities late in the process has demonstrably untoward and sometimes tragic effects.
9. The ethics-based decision-making framework that has been implemented for health and medical risks should also be considered for use in other risk acceptance paradigms. The same ethical principles and responsibilities

could be applied to risk analysis, mitigation, and acceptance in the safety and engineering realms as well. This would provide a broader context for risk decision-making, and result in a stronger foundation to support the acceptance of higher risk levels, particularly in situations where mitigation strategies are inadequate or not available. Incorporation of a formal role for ethical considerations in engineering and safety risk analysis and decision-making could ultimately result in more comprehensive mission planning and management.

10. Finally, stress the importance of organizational leadership in achieving successful HSI. Ultimately, effective HSI is clearly a leadership responsibility. Communication and understanding between diverse communities of practice must be inculcated as an organizational core value, repeatedly emphasized by leadership as an imperative.

The engineering, safety, life sciences, and health and medical communities have an obligation to work together as collaboratively as possible in the processes of HSI. As we move away from Earth in exploration class missions, this effort becomes even more important.[12,13] We will not have the ability to abort missions and return to Earth, and repair/remediation of systems failures will be supremely challenging to impossible. The health, well-being, and survival of our exploration crews depend on successful synergy of the engineering, life sciences, and medical communities of practice at the earliest stages of design.

## AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist.



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