Aerospace Medicine: Challenges and Opportunities

Russell B. Rayman

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AS WE ENTER the early years of the 21st century, the aerospace medicine community will face many challenges, yet at the same time, be afforded many opportunities. We face these challenges and opportunities resolutely and confidently as our predecessors have done since the birth of aviation a century ago. This White Paper is not necessarily comprehensive, but rather a brief summary of some of the major issues as seen by the contributors representing the many subdisciplines of aerospace medicine. It is meant as a guide as we accept the challenges and realize the opportunities during the coming decades within our provinces of civil aviation, military aviation, and spaceflight.

Civil Aviation Medicine

As the world grows closer together through the inexorable process of globalization, civil aviation medicine has been evolving from a system of national aeromedical standards to a system of international aeromedical standards. We are seeing this regionally; for example, the Joint Aviation Authorities (JAA) and internationally through the efforts of the International Civil Aviation Organization (ICAO). This ambitious effort to achieve unified standards is called "harmonization."

Harmonization has come a very long way considering that it is fairly new to aviation medicine. Its progress thus far has been astonishing because of the initial great disparity among the nations. It might have been predicted that harmonization would be an impossibility. For example, the purpose of the periodic flight medical examination differs by national regulatory authorities. In some countries the medical examination is considered an instrument to ensure airmen health and safety *only* until the next required examination, perhaps 6–12 months later. Little or no thought is given to long-term health considerations. However, in other countries, long-term health and short-term flying safety are given equal weight. (The rationale for this divergence is beyond the scope of this paper.) As an example, there would be little justification to require a cholesterol level if flying safety for the next 6 months were the only consideration. On the other hand, it would be beneficial in the context of long-term health. This has great impact on the scope (and costs) of the medical examination when secondary prevention is considered as well as aviation safety. Nevertheless, the quest for harmonization must continue in order to reach a reasonable level of standardization.

The issue of passenger safety, health, and comfort continues to receive a great amount of attention. Despite a number of studies to the contrary, the belief that cabin air contains unacceptable levels of toxic substances and microbials is held by many. Although research is ongoing, it is anticipated that it will take many years, as well as robust funding, to bring this issue to closure. The answer probably lies in studies that include monitoring of the aircraft cabin air with simultaneous surveillance of passengers and crew for illness. If high levels of a toxic substance or pathogenic organism were detected in flight and a significant number of crew/passengers on that flight developed signs/symptoms that are plausibly and temporally related, this would constitute credible evidence of a link. Such a study has been recommended by the National Research Council in its 2002 report, "The Airliner Cabin Environment and the Health of Passengers and Crew."

Passenger safety, health, and comfort must also be given particular attention as aircraft manufacturers produce large airplanes accommodating as many as 1000 passengers as well as aircraft capable of long-haul flights up to 18 hours. Consequently, in-flight medical care capability such as the contents of emergency medical kits (EMKs), use of automated external defibrillators (AEDs), and frequency of medical diversions will require constant review with an eye toward refinement. Telemedicine systems must also be developed as part of this capability, at least on long-haul flights. Furthermore, as more passengers take to the air and in flight medical care capability becomes more sophisticated, the commercial airlines must ensure around-the-clock access to ground-based medical consultants.

With increasing numbers of passengers of all ages, in-flight medical care is becoming more and more compelling. Each airline, based upon its own experience and best judgment, has determined EMK contents, use of AEDs, extent of crew training, and the establishment of in-flight medical care procedures. If the airlines shared this information, in-flight medical care capability could be refined and to some extent standardized. This might be accomplished if the airlines of the world agreed to provide, anonymously, data on in-flight medical events to a central repository. The information could then be retrieved by the airlines to be used for their respective planning purposes.

In recent years, many parts of the world were afflicted by the severe acute respiratory syndrome (SARS) outbreak. There was particular concern regarding the transmission of the organism from person-to-person in flight (as well as transmission to the general population at the destination). We must be mindful that another SARS epidemic or an epidemic due to any one of a number of emerging infections could occur. This issue is even further compounded by the threat of biochemical, biological, or radiological terrorism. Consequently, the international aerospace medicine community must ensure that procedures that provide an effective and efficient response are in place.

Age limits for the involuntary retirement of air transport pilots is another ongoing controversy. There is a great divergence of opinion in that some countries have no age limit, while others have arbitrary retirement age limits as low as 55 years of age. Age limits are driven very much by the perception of risk of sudden incapacitation due to medical causes as well as by the assumption of significant cockpit performance decrement due to the aging process. Today it is difficult to scientifically support or refute any particular age limit. Research efforts must be directed toward establishing a methodology for determining on an individual basis when a pilot is no longer safe to operate an airplane.

Military Aviation

The major challenge in the coming decades will be in the broad area of human factors. Rapidly advancing technology has brought in its wake automation, increasingly sophisticated computerization, and futuristic control systems. Although there are great benefits from the new technology, it brings with it many complexities that could actually cause performance decrement. For example, with increasing automation, the crewmember becomes more passive rather than active in the control of the aircraft. This could lead to boredom, inattention, and complacency. Furthermore, flying skills might be degraded, particularly with an in-flight emergency, because flight is being increasingly controlled by computers rather than the aircrew. Consequently, the research community must devise these advanced systems with an eye toward a reasonable balance between active participation in aircraft control and passive observation.

It is expected that military operations will rely increasingly on uninhabited aerial vehicles (UAV) for tactical, strategic, and reconnaissance operations. Nevertheless, the UAVs must be controlled by somebody, as there is no such thing as an unmanned system. At the time of this writing, depending upon UAV type, as many as 68% of losses have been due to operator human factors. These operations will require new medical standards for selection and retention with particular attention given to hand-eye coordination skills, resistance to vigilance fatigue, and the ability to operate in three dimensions from two-dimensional data. (Although UAVs are currently in the province of military aviation, there is a growing requirement in the civil sector; e.g., for surveying land for commercial purposes.)

Military aviation medicine must also continue research efforts in the area of biochemical warfare. This would include the refinement of biochemical ensembles, the detection of biochemical agents in real time, the development of effective decontamination procedures and the implementation of effective disaster response plans. Another threat to be considered is laser weaponry, necessitating appropriate countermeasures, particularly eye protection.

Over the past decade there has been an alarming decrease in aerospace medicine basic and applied research with a number of institutions throughout the world either being closed or scaled back to a level of activity that is a fraction of previous output. In large part, this has been due to military funding cutbacks by governments. As a result, the expertise that existed is slowly dissipating, making it problematical if these research institutions were suddenly required to increase their activities. Somehow the military services must convince lawmakers of the necessity to maintain at least a minimum level of research in military aerospace medicine if we are to ensure the best crew performance as well as flying safety.

Loss of spatial awareness, spatial disorientation, and G-loss of consciousness (GLOC), continue to threaten flying safety, although notable progress in anti-G protection has reduced the incidence of GLOC accidents/incidents. Nevertheless, even though these problems have been with us since the early days of aviation and thus far have defied resolution, we must continue our research efforts. Scientists and engineers must aggressively seek innovative solutions such as the tactile situation awareness system (TSAS). One possible avenue is the installation in aircraft of ground collision avoidance systems (GCAS) and automatic collision avoidance systems (ACAS).

Space Medicine

Although the Columbia accident caused a lengthy hold on the space program, the prospect of a Mars mission or a return to the Moon will provide our greatest challenge in the coming decades. A mission to Mars will be particularly challenging because of its hostile atmosphere consisting of 95% carbon dioxide at less than 1% of Earth's sea level pressure, temperatures as low as −193°F, and potential for serious radiation exposure. Selection of habitat and pressure suit environments depend on each other and are critical to efficient conduct of exploratory activities. Design of a compatible and operationally effective habitat and pressure suit environment depends on future research activities to define their environmental parameters. In addition, the expected duration of the flight (2 - 3 yr), and the lack of capability for a quick return in event of a significant in-flight problem are formidable challenges. Nevertheless, the space-faring nations of the world are moving forward and it is possible that we will witness a manned Mars mission within the next 20 to 30 yr.

Meanwhile, the space medicine research community must be funded to pursue an aggressive program in order to determine effective countermeasures. Although the countermeasures known today are of marginal value on shorter duration flights, their efficacy on a long-duration mission of several years is highly doubtful. The physiological aberrations caused by microgravity have been well defined over the past 40 yr: bone loss, muscle atrophy, cardiovascular decompensation, neurovestibular dysfunction, and hematological changes among others; human factors, mental health, and radiation are also compelling considerations. Although astronauts fully recover within several months after return to Earth, there is a possibility that physiological changes on longer duration missions may be irreversible. If we are to have reasonable certitude of a safe flight and the prevention of long-term disabilities, the space medicine community must be innovative (and well funded) in its quest for effective countermeasures.

One promising avenue of research is artificial gravity. Full efforts are warranted to evaluate this countermeasure modality as there is the possibility it could effectively preserve cardiovascular function and prevent bone loss and muscle atrophy. Research protocols utilizing bed rest laboratories and human centrifuges could provide critical information regarding its efficacy. If it proves to be an effective countermeasure, scientists must determine an adequate prescription for astronauts—i.e., what level of G, frequency, and duration of exposure would be required.

Another concern is the paucity of in-flight research subjects. The International Space Station (ISS) crews will number 6 with each team onboard for 6 months, thereby providing only 12 subjects per year for experiments. Consequently, it would take many years to have a cohort large enough to provide acceptable statistical power. As a result, analog studies are critical, particularly bed rest studies as described above. Statistical power can be reasonably assured only if ground-based studies complement those done in flight.

Regarding in-flight medical care, weight and volume limitations will require extreme discretion in the selection of diagnostic and therapeutic modalities. Some form of imaging, such as ultrasound, which shows much promise in that the equipment is small, light weight, and easy to use, would be of distinct value. For the analysis of body fluids, standard laboratory equipment would not be acceptable. Consequently, small scanners must be developed that provide blood chemistries noninvasively, for example, by placing the scanner over a blood vessel. Possibly, nanotechnology will be developed that could provide not only diagnostic options, but therapeutic ones as well.

Regarding pharmacokinetics, there is evidence that medication taken by mouth in a weightless environment is not absorbed, distributed, or excreted as it is on Earth. This was demonstrated on a small cohort prescribed acetaminophen. Because a large pharmacopeia will most likely be taken on a Mars/Moon Mission, the pharmacokinetics of medications in microgravity must be explored, which will necessitate an extensive research program.

There is the possibility of the need to perform emergency surgery on a long-duration mission. Minor procedures have been successfully performed on small animals on ISS and the parabolic aircraft, but whether major procedures could be performed is unknown. The need to tether both patient and physician, as well as to prevent instruments, body fluids, and tissue from dispersing throughout the cabin, are formidable problems. Further, if a surgeon is part of the crew, it is likely that months or possibly 2 – 3 years could pass without the opportunity to perform a surgical procedure, which could degrade the surgeon's skills. In order to keep a surgeon's skills honed, virtual reality systems will be needed to allow the surgeon to practice various procedures during the voyage to and from, for example, Mars.

It is clear that the medical care system must be an autonomous one whereby the crew has the capability to diagnose and treat with little or no support from controllers on Earth. This is a compelling requirement in that there will be no escape and return vehicle. Furthermore, telemedicine or telerobotic surgery would be of dubious value because it would take up to 40 minutes for a signal to be transmitted roundtrip from the space vehicle to Earth and then back to the space vehicle—not very feasible, particularly with a medical emergency or surgery.

An area of particular importance for long-duration spaceflight is radiation. It is known that there are radioactive Z particles in space that could be damaging to human tissue. Because this could be a limiting factor for flight, extensive research must be directed toward their effects on human tissue as well as proper shielding to protect the crews.

And finally, because of the cultural diversity of the crews, much more research is needed in the areas of crew compatibility and conflict resolution not only among the crewmembers themselves, but also between the space vehicle crewmembers and ground control personnel. Many astronauts and cosmonauts have reported serious difficulties in this area as indicated by some missions having been jeopardized because of conflict.

In addition to spaceflights sponsored by governments, there will be a burgeoning industry in space tourism with ordinary citizens afforded the opportunity to spend days or weeks on various space platforms in the coming decades. Because many space tourists may be elderly or have pre-existing illness, medical standards that are reasonable and appropriate must be developed. Work has already begun in this area, applicable only to short-duration flights of less than an hour. Once flights become available for days, weeks or possibly months, much more will need to be done to define not only medical standards, but in-flight medical care capability and appropriate countermeasures, including their compatibility with an aging tourist or a tourist with pre-existing illness.

Miscellaneous Considerations

Because some aspects of training, human factors, safety, air evacuation, and fatigue overlap aviation and space operations, they are treated separately in this miscellaneous section.

Training: In most countries of the world, aerospace medicine or aviation medicine is not recognized as a medical specialty in its own right, but rather an added qualification. This may be a disincentive for physicians who would otherwise consider a career in aerospace medicine. In order to make aerospace medicine as attractive as possible, full efforts are needed to ensure that it is recognized as a specialty within the medical community and that there is a clearly defined, attractive career track. Likewise, to ensure a robust research community, efforts are needed to attract young scientists toward masters and doctorate programs.

Aerospace human factors: Although human factors was briefly discussed above in a military context, it is also applicable in the civil sector. Loss of situational awareness, crew resource management (CRM), and cockpit automation apply to any aircraft whether military, commercial, or private. Research must continue in the area of cockpit controls and displays with an eye toward simplification, position, and ergonomics in order to decrease the risk of overload leading to error. Ever since aircraft were first built, there has too often been a lack of input from aerospace human factors experts during the design phase. As a result, some aircraft have ergonomic flaws that hinder a pilot's cockpit performance. Clearly, human factors/ergonomic considerations must be given attention to ensure the best from pilots. This can be most efficiently accomplished if manufacturers consult with human factors experts *early on* in the design phase of new aircraft.

Safety: Because aviation, in general, has been systems safety oriented, effective procedures have been developed and refined over the years in flight as well as in the aviation workplace. Likewise, procedures for reporting accidents and incidents have been developed, as well as techniques for aircraft accident investigation and error prevention. Aviation, therefore, could provide a great service by sharing its knowledge and experience with non-aviation industries, particularly those having marginal safety programs.

Air evacuation: In past years, air evacuation was primarily a military activity. However, there has been a bourgeoning in the civil sector with hospital-based as well as private companies offering rotary-wing and fixed-wing services. The military air evacuation system in most nations is highly organized with established standards and protocols for medical operations including requirements for periodic inspections to ensure compliance with those standards and protocols. However, this is not necessarily true in the private sector.

Although some countries and regions do have enforceable standards applicable to the medical crew, including requirements for training, equipment, and treatment protocols, in many areas none exists. Consequently, private air evacuation services may be available to the public without the protection afforded by appropriate standards. This is not to say that these unregulated services pose a threat to patient safety or quality care, as many undoubtedly have an excellent system of self-regulation.

Nevertheless, since hospitals and physicians are held to strict standards, it would seem reasonable that air evacuation services also be held accountable. In the U.S., the Commission on Accreditation of Medical Transport Systems (CAMTS), a voluntary organization, established comprehensive standards for air evacuation. For a fee, CAMTS would inspect a unit and, if in compliance with its standards, would issue a certificate of compliance. Because this is entirely voluntary and the fee is substantial, only some air evacuation units have volunteered for CAMTS survey. There is the possibility that local government or insurance companies may require CAMTS certification in the future in order to qualify for payment to patients. In any event, there should be some system of enforceable standards for air evacuation operations. Perhaps the military model would be the best option.

Although the military model is exemplary, there are yet unsolved problems among some of the world's military services. For example, few nations have fully dedicated air evacuation aircraft – rather, aircraft of opportunity must be employed. This makes training of medical crews very difficult and the compatibility of equipment with the airframe problematical. Consequently, allied nations should strive to utilize similar aircraft and to establish protocols and equipment requirements that are interchangeable. International efforts should also continue in the quest for effective air evacuation supplies and equipment as well as aircraft compatibility.

Fatigue: Over the past six decades, aircrew fatigue has become a human factors issue of major concern in civil and military aviation operations. With commercial aircraft routinely flying long-haul flights over many time zones, the stresses of fatigue and circadian desynchrony are often imposed upon crews. Likewise, in military operations fatigue can be a factor not only in sustained combat operations, but also in ferrying fighter aircraft over long distances.

Because fatigue is a threat to flying safety, much research has been conducted over the years regarding countermeasures. One countermeasure that remains elusive is a universally acceptable definition of what constitutes the crew duty day and crew rest. There are clear differences of opinion among managers, regulatory authorities, and the aerospace medicine community.

The research community must continue its efforts to determine optimal crew duty day and crew rest and to explore other fatigue countermeasures such as in-flight napping and the use of medications such as short acting hypnotics and stimulants. In any event, recommendations for fatigue countermeasures must be based upon solid evidence of efficacy, if they are to be adopted.

Medications: Over the years there has been a trend toward liberalization of policy, both civil and military, regarding use of various medications while flying as a crewmember. There was a time when even relatively benign medications such as the thiazides were disqualifying. However, with decades of experience, we have learned that many medications, heretofore disqualifying, can be prescribed without compromising flying safety. Consequently, research should continue to determine compatibility of commonly prescribed medications with the aviation environment. As an example, at the time of this writing, selective serotonin reuptake inhibitors (SSRIs) as maintenance medication for depression are under consideration by some regulatory agencies.

Conclusion

About 35 years ago, a respected leader within the aerospace medicine community stated that aerospace medicine had reached its limits. This White Paper clearly puts this assumption to rest. Aerospace Medicine faces challenges today that were undreamed of in 1970. Undoubtedly, if a White Paper were to be written in another 35 years, in 2040, we would marvel at its content. Nevertheless, our concerns now are the challenges of the early 21^{st} Century. It is hoped that what is written herein will provide us with direction as we move forward in aviation and space.

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