Aviation Medicine: global historical perspectives and the development of Aviation Medicine alongside the growth of Singapore's aviation landscape

Gan W H, Low R, Singh J

ABSTRACT
Aviation Medicine traces its roots to high altitude physiology more than 400 years ago. Since then, great strides have been made in this medical specialty, initially catalysed by the need to reduce pilot medical attrition during the World Wars, and more recently, fuelled by the explosive growth in globalised commercial air travel. This paper traces the historical milestones in Aviation Medicine, and maps its development in Singapore since the 1960s. Advancements in military aviation platforms and technology as well as the establishment of Singapore as an international aviation hub have propelled Aviation Medicine in Singapore to the forefront of many domains. These span Aviation Physiology training, selection medical standards, performance maximisation, as well as crew and passenger protection against communicable diseases arising from air travel. The year 2011 marks the centennial milestone of the first manned flight in Singapore, paving the way for further growth of Aviation Medicine as a mature specialty in Singapore.

Keywords: air travel, Aviation Medicine, Aviation Physiology, historical perspectives

Singapore Med J 2011;52(5):324-329

INTRODUCTION
Most people would remember the first motorised flight by the Wright brothers (American brothers, Wilbur and Orville Wright) on December 17, 1903 as a significant milestone in the history of aviation. It was the harbinger of commercial air travel, which saw an explosive growth globally in the 20th century. The stratospheric limit was surpassed on April 12, 1961, when the former Union of Soviet Socialist Republics launched Russian military pilot Yuri Alexeyevich Gagarin into space. This landmark event marked the beginning of an era in manned space flight. The significance and implication of sending terrestrial Man into the skies is not lost to medical practitioners around the world. In the last hundred years, major strides have been made in the domains of Aviation and Space Medicine to support military operations and the ever-growing civil aviation industry. In Singapore, the nation's relatively short history in the engagement of Aviation Medicine belies the contributions to the field by local Aviation Medicine physicians, and the recognition accorded to them from practitioners in the region and beyond.

HISTORICAL PERSPECTIVES
No one appreciated the perils of flying more than the pioneers of aviation. Yet since time immemorial, Man had always had an impassioned desire to take to the skies. From mythical winged man-creatures to guardian angels, this ability to fly was worshipped through every age and era, permeating many diverse cultures in geographical regions across the world.

The legend of Daedalus and Icarus is familiar to all in aerospace medicine. Daedalus, imprisoned in a tower with his son Icarus by King Minos of Crete, made wings out of bird feathers and wax, and both of them escaped by taking off in flight. Icarus, ignoring warnings by Daedalus, flew too near to the sun, causing the wax to melt and his wings to come apart. He fell into the sea and drowned. Some say the hypoxia at high altitudes could have affected Icarus' better judgement! Leonardo da Vinci, the famous Italian artist, scientist and inventor, sketched pictures of parachutes, human-powered aircrafts and ornithopter flying machines long before these concepts were translated into practical applications.

Aviation Medicine traces its roots to high altitude physiology, when in the early 16th century, discomfort with mountain travel was already documented in the Spanish army during wars to conquer Mexico and neighbouring territories in the New World.[1] 'Mountain sickness' was particularly well described and coined by the Jesuit priest Jose de Acosta in the later part of the century, when he described hypoxic symptoms of anorexia, nausea, vomiting, dizziness and panting during his stay in the Andes, and how

Republic of Singapore Air Force Medical Service, RSAF Aeromedical Centre, 492 Airport Road, Singapore 539945

Gan WH, MBBS, DAvMed, MRCP
Aviation Medical Officer

Low R, MBBS, DAvMed, MMed
Chief Air Force Medical Officer

Civil Aviation Medical Board, Civil Aviation Authority of Singapore, Singapore Changi Airport, PO Box 1, Singapore 918141

Singh J, DAvMed, MSc, FAMS
Chairman

Correspondence to: Dr Gan Wee Hoe
Tel: (65) 6210 0506
Fax: (65) 6285 3032
Email: gan_wee_hoe@yahoo.com.sg

these symptoms resolved shortly upon descending to lower altitudes.[2]

Throughout the 17th and 18th centuries, scientists experimented and made discoveries that were to form the fundamentals of Aviation Physiology today. Notably, Otto von Guericke (1602–1686) developed the air pump that allowed the creation of a vacuum, and demonstrated how two hemispheres joined together by a vacuum core could not be pulled apart by horses. Robert Boyle (1627–1691), using von Guericke's invention of the pneumatic pump, studied air bubble formation in the eye of a viper following decompression in a chamber, and formulated the famous Boyle's Law.

The first untethered manned flight by two French men, a physicist and an army officer, who ascended with a balloon to an altitude of 2,700 ft, took place on November 1, 1783. This date marked the birth of aviation.[2] With further advancements in balloon technology, such as the use of hydrogen to create greater lift, higher altitudes were achieved. Jacques Alexandre Cesar Charles (1746–1823), the discoverer of Charles' Law, made a balloon flight on December 1, 1783 up to 10,000 ft and described the first case of otitic and sinus barotrauma in himself. During the 19th century, Paul Bert (1833–1886), acknowledged by some to be the Father of Aviation Medicine, performed hundreds of experiments to study the physiological effects of pressure change in an altitude chamber, many of which with himself as the subject.

Into the 20th century, the first powered flight by the Wright brothers in 1903 paved the way for rapid growth in the aviation industry. Developments in aviation were further fuelled by World Wars (WW) I and II, as militaries discovered the importance of air superiority in delivering the first salvo and in achieving strategic and tactical advantage in the overall war campaign. However, fatalities from aviation accidents were exceedingly high. 90% of British military pilot deaths in the first year of WWI resulted from human factors, of which two-thirds were reportedly due to physical defects in pilots.[3] This prompted the Royal Flying Corps to institute selection medical standards for pilots,[4] which contributed to the purported drastic reduction in deaths from physical defects to "20% during the second year and 12% during the third".[5]

Wars catalysed the growth of Aviation Medicine in Europe and the United States (US). Apart from improved physical standards and examinations for aviator selection, research facilities were set up to conduct studies in aspects of Aviation Physiology, particularly in areas faced by aircrew flying the early generation aircraft with rudimentary oxygen and navigation systems. Such research was aimed at developing better equipment and training to protect the aviators from potentially fatal physiological threats such as hypoxia and spatial disorientation. The Barany chair, the first-generation spatial disorientation trainer developed by the United States Air Force (USAF), has been described as "the greatest contribution of medicine to the technical advancement of aviation".[6]

Professional training was recognised in the early 1900s as a key factor in upholding consistency and medical standards in aircrew selection and training. New aeromedical examiners had to undergo training in concepts of Aviation Physiology and Medicine before being allowed to conduct examinations on aircrew. One such programme at the Air Service Medical Research Laboratory in the US recommended that these examiners fly regularly so as to understand the physiological challenges facing aviators. This led Eugene R Lewis, an otolaryngologist at the laboratory, to coin the term 'flight surgeon' for these specially trained aeromedical examiners.[7] This term is still being used for Aviation Medicine practitioners in the USAF today.

The concept of aeromedical evacuation (AME) also evolved over the years of WWI and II. From primarily transporting flight surgeons to casualty holding areas in the frontline, this *modus operandi* was soon replaced with air transportation of the seriously wounded from the frontline to hospitals in the rear through the use of aircraft customised to accommodate stretchers.[8] AME remained an important mode of rapid casualty evacuation to higher echelons of medical care, saving the lives and limbs of hundreds of thousands of soldiers through the major battles, from the World Wars to the Korean and Vietnam Wars. Today's AME is executed by both military air forces and civilian air ambulances using modern air platforms with sophisticated environmental control systems (such as temperature and cabin pressurisation controls). This stands in stark contrast to the old days of evacuating casualties with a small air plane with an open cockpit. The complement of pressurised cabin, advanced air-certified medical monitoring and life-saving equipment, as well as medical personnel trained in the principles of critical care in the aviation environment have enabled the success rate of AME missions to continue to improve into the 21st century.

MILITARY AVIATION MEDICINE IN SINGAPORE

According to the Dictionary of Military and Associated Terms by the US Department of Defense (2005), Aviation Medicine is a special field of medicine that is related to the biological and psychological problems of flight. This definition connotes the physiologically challenging flight environment and operating conditions for aviators, as well as the mental and cognitive workload associated with aviation, an occupation where even minor errors can potentially result in catastrophic consequences. It also encapsulates the breadth and depth of the different human systems that need to be addressed for the optimisation of health, safety and performance of those in aviation. In the US and Europe, Aviation Medicine, also known as Aerospace Medicine (encompassing Space Medicine) or Flight Medicine, is a mature medical specialty serving the large population of military aviators, civilian airline pilots, flight deck crew and air traffic controllers.

Aviation Medicine is not a new specialty in Singapore, with the foundation of its development having been laid at the time of the formation of the then-Singapore Air Defence Command (SADC) in 1968. The first medical centre supporting the SADC in catering to the unique healthcare needs of aircrew and air traffic controllers was set up in Seletar West Camp in the same year. Realising the need to have doctors trained in Aviation Medicine, the few doctors in military service at that time were successively sent to the Institute of Aviation Medicine in the Royal Air Force (RAF), United Kingdom (UK) for specialist training in Aviation Medicine. This paved the way for the medical service of the Republic of Singapore Air Force (RSAF) to gradually expand its focus from merely primary healthcare for the aviators, to embark on Aviation Physiology Training (APT).

The vision to create a specialist centre to house aeromedical services and physiology training for the fledgling air force's pilots was conceptualised at the start of the 1980s. At that time, the air force had already taken delivery of the A-4 Skyhawk jet fighters, and there was an urgent need to enhance pilot safety and effectiveness in flying these agile fighters. In justifying his case for the setting up of an aeromedical centre, the then MAJ(Dr) Lim Meng Kin, RSAF's Senior Medical Officer said, "*If the proposed centre's core functions of aeromedical training, research and clinical services prevented just one aircraft accident, the savings in cost, not to mention the pilot's life, would more than pay for the entire investment*".[9] And so its approval heralded an epochal chapter for Aviation Medicine in Singapore, not only in the significance of the creation of a centre of excellence in Aviation Medicine, but also as the germination bed and breeding ground that trains and qualifies all Aviation Medicine specialists in Singapore today.

The capability build-up for the RSAF Aeromedical Centre (ARMC) was, at the very beginning, piecemeal, but rapidly gained momentum in the 1980s. The first piece of training equipment was a Mark III Decompression Chamber used for altitude and hypoxia training. This was purchased from the RAF in 1968 for a princely sum of 50 cents as a token of goodwill and friendship, just before the British pulled out from Singapore. Over the next two decades, the RSAF progressively added new APT Trainers to its suite of equipment to train pilots in aviation-related physiological threats. Programmes for aviators were developed to help pilots understand and recognise spatial disorientation and the physiological limitations associated with night vision and the use of night vision goggles. An oxygen systems training facility was set up in the centre, and it was here that trainee aviators would be first introduced to positive pressure breathing for altitude protection, exposed to realistic simulations of oxygen systems failures 'in-flight' and systematic checklist procedures and taught emergency drills in the event of such failures. Ejection drills for fighter pilots also naturally came under the ambit of the centre's training responsibilities, incorporating the theory of the physics and physiology of high G (gravitational) and Q (windblast) forces with practical training in an ejection simulator. However, the crown jewel of the ARMC was the human training centrifuge. Often described by pilots as somewhat akin to a torture chamber, the centrifuge, which had its first operational run in March 1995, was iconic and the only advanced high-G trainer of its kind in the region at that time. It enabled trainee pilots to get accustomed to G forces before flying a trainer aircraft, and honed fighter pilots in their anti-G straining manoeuvre, a skill crucial to prevent G-induced loss of consciousness (G-LOC) and ensure survivability of both man and machine during air combat.

Studies and reports have consistently documented the importance of APT in minimising aviation incidents and accidents. Cable performed a retrospective study of aircraft safety occurrence reports listing hypoxia as a factor in the Australian Defence Force, and found that 75.8% of these hypoxic episodes were recognised by the aircrew themselves due to prior aviation physiology training, thereby enabling them to take corrective measures and avert any potentially fatal accidents.[10] The USAF demonstrated a reduction in G-LOC crashes from 4.4 per million flight sorties to 1.6 after the implementation of anti-G-LOC training programmes in 1985.[11] Spatial disorientation, another major contributing factor in aircraft mishaps, accounted for 11% of USAF crashes between the period 1990 and 2004, giving an overall rate of 2.9 per million sorties and a crash fatality rate of 69%.[12] These facts and figures present the evidence to convince the aviation industry of the need to train aviators in awareness and recognition of, and countermeasures against physiological threats of the flight environment, and form the driving force in the continual research and development of high-fidelity, mission-oriented trainers. Today, APT is accepted globally as an integral component of pilot training, and is a key contributor toward the safety record of aviation.

The other major accomplishment for military Aviation Medicine in Singapore is in the domain of medical and psychological selection. Although this may seem reminiscent of the undertakings by the medical specialty's forefathers during WWI, what distinguished the ARMC's work was its focus on interventional measures to maximise the employability and deployability of the air force's aviation vocationalists. Unlike many other countries, Singapore has a very small human resource pool from which to select its military elites, especially pilots, owing to its rigorous but necessary medical entry requirements. Apart from formulating a set of selection standards that fulfils the stringent medical requirements for an aviator, the ARMC also identified conditions that resulted in high medical attrition for pilot applicants, such as myopia, for active intervention. Operational evaluation was performed on the effects of hypoxia and the arid conditions of flight on the quality of vision for candidates who underwent photorefractive keratectomy (PRK) and laser-assisted *in situ* keratomileusis (LASIK). Additionally, those with PRK were assessed for the effects of high G-forces on their visual correction procedure. Currently, only PRK is considered compatible locally in military aviators. The results proved PRK to be safe and effective in pilots operating under austere flight conditions. PRK was employed as an intervention tool to widen the selection pool for myopic and astigmatic pilot trainees in the RSAF from 2005, and it is one of the first air forces to do so outside of the US. This underlying impetus drives military Aviation Medicine in Singapore to continually examine, research and evaluate interventional modalities to optimise our human capital.

Psychological selection of pilots is traditionally steeped in psychomotor and cognitive testing to select applicants with an innate good 'stick sense' and the appropriate cognitive skills required for flying. Over the years, thousands of applicants have been put through the computerised pilot aptitude selection test battery, and the data validated to successful completion of pilot training. This large and comprehensive set of data sets the stage for the next frontier of development in selection tests by the Aviation Psychologists at the ARMC.

CIVIL AVIATION MEDICINE IN SINGAPORE

In the early days, medical regulation for flight crew in the civil aviation industry came under the charge of the then Government Medical Department (now Ministry of Health [MOH]). Initially located in Alexandra Hospital, it moved to Tan Tock Seng Hospital in the 1980s, where the late Dr James MJ Subramaniam became the first Chairman of the Civil Aviation Medical Board (CAMB).

Between 1993 and 1994, local pilots approached the Ministry of Health to seek a more structured framework governing the medical certification of flight crew. This led to a reorganisation of the CAMB. Among other changes, two Aviation Medicine specialists from the RSAF took over the helm of the CAMB. Dr Lim Meng Kin was appointed Chairman of CAMB, and Dr Jarnail Singh seconded from the RSAF to the Civil Aviation Authority of Singapore (CAAS) as full-time Deputy Chairman. The support from MOH continued unabated and alongside notable clinical specialists such as Prof Chee Yam Cheng, A/Prof Chew Chin Hin and Prof Feng Pao Hsii, and a multidisciplinary team and expertise was brought to the Board.

In 1997, CAAS formed a task force to look into the optimal location of the clinical functions of the CAMB, keeping in view that the pilots were not keen to be part of a hospital's patient population when presenting themselves for licensing medical assessment boards. It was opportunistic that the RSAF had just expanded its ARMC in view of the larger footprint needed to accommodate new APT equipment. The centre was also working on outsourcing its routine clinical and training functions to a new government-affiliated medical agency, the latter of which would continue to operate out of the ARMC. This would serve the RSAF's intent for the ARMC to be a one-stop aeromedical services centre for its military aircrew, and pave the way to achieve its goal of being a regional centre of excellence in Aviation Medicine. The co-location of CAMB within the ARMC was a natural choice, and one that was welcomed by the RSAF. This co-existence of military flight-surgeons, civil aviation medical regulators and an aeromedical services provider would bring military and civil Aviation Medicine practitioners under one roof, and concentrate the pool of Singapore's Aviation Medicine expertise within a single locality. CAMB moved to its present clinical office within the ARMC in 1997.

Singapore has played a key role in spearheading several global initiatives with the International Civil Aviation Organisation (ICAO). The Medical Provisions Study Group (MPSG) was started in 2004 to review the Standards and Recommended Practices (SARPs) governing medical provisions for international civil aviation. Dr Jarnail Singh, the current Chairman of CAMB, has chaired the MPSG, which reviewed current medical best practice and brought it in line with all the regulatory standards governing the assessment of flight crew and air traffic controllers. The MPSG is currently reviewing the area of training and qualification of Designated Medical Examiners (DMEs), which will result in the adoption of a competency-based training framework and an update to the ICAO's SARPs. Singapore has teamed up with the International Academy of Aviation and Space Medicine to provide training to DMEs at the Singapore Aviation Academy.

Public Health Emergency Contingency Planning for international airports after Severe Acute Respiratory Syndrome was another major initiative seeded by Singapore to ICAO. From its first international working group meeting in Singapore in June 2003, comprising representatives from ICAO, World Health Organisation (WHO), International Air Transport Association, Airports Council International, CAAS, MOH Singapore and Prof Chee Yam Cheng, Tan Tock Seng Hospital, public health emergency preparedness measures have evolved to a wider framework (after the alert raised in 2005 by WHO with regard to a possible outbreak of the H5N1 Avian Influenza) known as the Cooperative Arrangement for the Prevention of Spread of Communicable Disease through Air Travel.[13] This gave the aviation sector, in collaboration with the public health sector, a set of guidelines and criteria on preventive measures to fulfil in order to curb the spread of infectious diseases of pandemic potential through confluence of people in airports and airlines, ultimately making air travel safer for passengers.

AVIATION MEDICINE – GOING FORWARD

The force modernisation and inauguration of new capabilities by the RSAF over the last four years have seen the air force operating new platforms such as the F-15SG fighter aircraft. These machines are specifically designed to gain tactical advantage in a fast-paced and complex environment. Operating such highly effective, manoeuvrable and long-endurance fighters require the pilot and his weapon systems operator to be optimally prepared—physically resilient and psychologically agile, alert and aware at all times—in order to successfully accomplish the mission. More new-generation fighters will be developed and fielded in the near horizon, testing the physiological and mental limits of the man-in-the-loop. The challenge is not only for the pilot to not be the limiting factor in the man-machine system, but to be able to extract the maximum capability out of the aircraft they fly. Aviation Medicine, specifically focusing on human performance maximisation through pharmacological means, cognitive and behavioural processes and biotechnological enablers will gain even greater importance, contributing to the decisive edge in operational success.

Unmanned aerial vehicles, or UAV, have been rising in prominence over the last few decades. UAV pilots are ground-based operators but nevertheless fall under the purview of Aviation Medicine specialists as part of the overall medical management of aviation vocationalists and operations. UAV operations pose unique cognitive challenges. UAV operators fly the aircraft remotely based on flight information displayed on the console of the crew station. Unlike pilots in manned aircraft, they do not have the benefit of three-dimensional spatial orientation cues and are therefore relatively deprived of important visual and proprioceptive input important for keeping the aircraft on the desired course, altitude and attitude. From a human-systems perspective, this results in complex man-machine interactions between the environmental, crew station and cognitive domains for the UAV operator. New UAV platforms are also long-endurance systems. As such, alertness strategies and fatigue countermeasures become areas for translational research and operational evaluation.

In the realm of civil Aviation Medicine, the way forward is to better manage risk among pilots and air traffic controllers of different age groups by leveraging on advancements in epidemiology, preventive and therapeutic medicine; this will continue to compel a rethink of the medical assessment standards. Aviation Medicine practitioners are the logical link between public health the aviation sector for developing and promulgating requirements and guidelines for public health emergencies of international concern, especially keeping in mind that air travel does result in the rapid movement of people and the diseases they carry globally. UAV platforms are entering the civil sector as well and will require the same measures outlined above for safe integration with traditional manned aeroplanes. Fatigue risk management is another area that Aviation Medicine will increasingly delve into. Airline medical departments will have to rethink their role within the airline, as supervisory oversight, afforded by the medical regulations of civil aviation authorities, is progressively minimising that aspect of their responsibilities.

Human factors, long recognised as a contributory factor in the aircraft incidents and accidents, should be integrated in the aeromedical training of both civil and military pilots. This can be taught in a highly realistic and applicable manner through the use of case studies and possibly, in- flight simulators, thereby bringing about a holistic approach in aeromedical training together with the traditional components of Aviation Physiology. In this regard, Aviation Medicine physicians will have to be knowledgeable and skilled in this domain, partnering human factors experts and psychologists in this training.

CONCLUSION

Aviation Medicine continues to evolve with the advancements in airplane and systems technology, the operationalisation of leading-edge military manned and unmanned aircraft, and the boom in the commercial air travel industry. It has a hallowed history, tradition and practice that dates back more than 400 years, yet finds new relevance everyday in addressing the human physiological and psychological adaptation, whether crew or passenger, for flying operations, especially with the rapid developments in military aviation technology and the ever-growing consumerism in air travel. It is little wonder that Aviation Medicine is a well-established medical specialty in its own right in the US and Europe, alongside the multitude of traditional disciplines such as Internal Medicine and Surgery.

In 2011, as we mark the centennial milestone of the first manned flight in Singapore, it is also time to recognise Aviation Medicine and its *raison d'etre* in ensuring our military airmen and civil aviation aircrew fly safely and effectively, and in enabling our complex air navigation operations to run smoothly by minimising the prejudice of human failure. Both past accomplishments and future promises will continue to inspire and uphold the excellence in the practice of Aviation Medicine in Singapore.

REFERENCES

1. Dille JR, Mohler SR. The beginnings: past and present. In: Davis JR, Johnson R, Stepanek J, Fogarty JA, eds. Fundamentals of Aerospace Medicine. Philadelphia: Lippincott Williams & Wilkins, 2008: 1-19.
2. Harsch V. The history and development of Aviation Medicine. In: Curdt-Christiansen C, Draeger J, Kriebel J, eds. Principles and Practice of Aviation Medicine. Singapore: World Scientific, 2009: 3-28.
3. Jones DR. Flying and dying in WWI: British aircrew losses and the origins of US military aviation medicine. Aviat Space Environ Med 2008; 79:139-46.
4. Gibson TM, Harrison MH. Aviation medicine in the United Kingdom: Early years, 1911-1918. Aviat Space Environ Med 2005; 76:599-600.
5. Wilmer WH. Plane News. Newsletter of Issoudun Army Air Field, AEF, France. 1918. Volume unknown.
6. Armstrong HG, ed. Aerospace Med. Baltimore: Williams & Wilkins, 1961.
7. Alford BR, Atkins JH Jr. Historical ties between otolaryngology-head and neck surgery and aviation and space medicine. Otolaryngol Head Neck Surg 1998; 118:S2-4.
8. Vanderburg K. Aeromedical evacuation: A historical perspective. In: Hurd WW, Jernigan JG, eds. Aeromedical Evacuation – Management of Acute and Stabilized Patients. New York: Springer-Verlag, 2003: 6-12.
9. Ooi A, ed. RSAF Aeromedical Centre – For Man, For Mission: 25 years of excellence. A MINDEF Publication, 2008.
10. Cable GG. In-flight hypoxia incidents in military aircraft: causes and implications for training. Aviat Space Environ Med 2003; 74:169-72.
11. Lyons TJ, Davenport C, Copley GB, et al. Preventing G-induced loss of consciousness: 20 years of operational experience. Aviat Space Environ Med 2004; 75:150-3.
12. Lyons TJ, Ercoline W, O'Toole K, Grayson K. Aircraft and related factors in crashes involving spatial disorientation: 15 years of U.S. Air Force data. Aviat Space Environ Med 2006; 77:720-3.
13. International Civil Aviation Organisation. In: Cooperative Arrangement for the Prevention of Spread of Communicable Disease through Air Travel (CAPSCA) [Online]. Available at: www.icao.int/icao/en/med/CAPSCA. Assessed August 1, 2010.