Hypoxia is a condition of reduced oxygen bio-availability caused by decreased oxygen diffusion from lung to blood, impaired oxygen transport in blood, decreased tissue perfusion or histotoxicity. Hypoxia triggers various decreased oxygen diffusion from lung to blood, impaired oxygen transport in blood, decreased tissue perfusion or histotoxicity. Hypoxia triggers various decreased oxygen diffusion from lung to blood, impaired oxygen transport in blood, decreased tissue perfusion or histotoxicity. Hypoxia triggers various decreased oxygen diffusion from lung to blood, impaired oxygen transport in blood, decreased tissue perfusion or histotoxicity. Hypoxia triggers various decreased oxygen diffusion from lung to blood, impaired oxygen transport in blood, decreased tissue perfusion or histotoxicity. Hypoxia triggers various decreased oxygen diffusion from lung to blood, impaired oxygen transport in blood, decreased tissue perfusion or histotoxicity. 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commissioned by the Australian Transport Safety Bureau (ATSB) in 2006 found that there were 517 pressurisation failure events involving aircraft on the Australian civil register between January 1975, and March 2006. One event involved multiple fatalities, and in all 10 events involved death, hypoxia or minor injury. Pressure system failures rather than rapid decompression occurred in most cases. The report concluded that there is a “high chance of surviving a pressurisation system failure, provided that the failure is recognised.” Recognition of such failures relies mostly upon warning systems, but these can go unheeded as hypoxia begins to impair neurocognitive functioning. This was graphically demonstrated in a military KingAir B200 in 1999 with three senior aircrew on board which failed to pressurise on climb. When the pilot in command lost consciousness the co-pilot recognised the emergency and treated him with oxygen but failed to doxygen himself, yet nevertheless managed to descend the aircraft to safety. The master caution for cabin altitude was never recognised. This incident involved highly experienced aircrew who had been trained in their hypoxia symptoms.

**Is there a safety benefit in training?**

Early recognition of hypoxia is important in preventing incapacitation to enable corrective actions to be taken. Explosive decompression is self-evident, but hypoxic symptoms from unrecognised depressurisation are often subtle and may be difficult to recognise without previous training. There is often very limited time for flight crew to recognise any hypoxia symptoms before consciousness is lost. Impaired cognitive ability due to hypoxia may negate the effectiveness of automated warning systems. But what do pilots think about training for this contingency? In a survey of 67 professional pilots in the USA, almost all indicated that they believed that altitude chamber hypoxia training should be conducted initially and recurrently, especially for commercial and airline transport flight crews, and most believed that the need for training should be based on the altitude capabilities of the types flown. Unfortunately there has not been any similar survey of Australian aircrew conducted. Theoretical knowledge of the effects of altitude on human physiology and performance is required by the Civil Aviation Safety Authority, but practical hypoxia training for flight crew has not been readily available.

Military forces have always recognised that practical training substantially reinforces knowledge of hypoxia and adds a further level of safety through early detection. Based on the sort of incident data presented above, most air forces have conducted hypoxia familiarisation training for aircrew for at least the last 70 years, traditionally using hyperbaric altitude chambers. Such recurrent training throughout an aviator’s career refreshes their awareness of symptoms and identifies any changes in an individual’s symptoms. Although symptoms are idiopathic to the individual, they are usually rather consistent over time for that person. There is published data that suggests such training works and saves lives. In the report of 656 USAF hypoxia incidents described above, 696 of the cases involved trained aircrew, and only 3.8% of these experienced loss of consciousness as a result. Of 50 passengers in the study, 94% experienced loss of consciousness. This study concluded that this major difference in hypoxia susceptibility between trained aircrew and untrained passengers emphasises the benefit of hypobaric chamber training in the recognition of hypoxia. Of the 520 trained aircrew who recognised their own symptoms, 26.2% stated that they were “just like the chamber”. Similar results were found in the ADF study, in which 86% of hypoxia-trained aircrew recognised symptoms in themselves or in others and took corrective actions.

**Is there a need for civilian training?**

Advancements in aircraft design have led to an ever increasing envelope of performance in aircraft that are readily accessible to the general aviation community. Light aircraft, such as Mooney’s M20TN “Acclaim” are powered by 6 cylinder dual turbocharged, dual intercooled engines allowing cruise altitudes of 25,000 feet. Other examples include the Lancair IV which can cruise at 24,000 feet and 330 kts, and comes with an optional pressurised cabin. In most cases pressurisation is not the norm, yet these aircraft can effortlessly climb and cruise at altitudes above 10,000 feet necessitating the use of constant flow oxygen systems. These systems have little redundancy and no warning systems to indicate failure.

Increasing numbers of Very Light Jets (VLJs) are already being sold and operated overseas in the General Aviation sector by high net-worth individuals and corporations. These include aircraft such as Embraer’s Phenom 100, the Eclipse 500 and the Cessna Citation Mustang, which like their larger “bizjet” counterparts such as Learjet, are pressurised and normally operate well above 40,000 feet. The need for advanced military style jet training including hypoxia recognition has been suggested. For airline operators, the Airbus A380 is already in service and carries between 555 and 840 passengers (depending on configuration) at cruise altitudes of 43,000 feet. The technological advances in materials and systems required for the A380 developments will reduce fuel and other costs, and improve environmental friendliness. However, the need for improved safety training requirements will correspondingly increase and the need for added hypoxia protection has already been realised at those higher cruise altitudes. Generally civilian aviators are unable to access practical hypoxia training, and there are very few civilian owned and operated hypobaric chambers in the world. One noteworthy exception is the FAA Civil Aeromedical Institute (CAMI) chamber in Oklahoma City which has been training engineers, airline flight crew, student pilots and flight attendants by theoretical instruction in aviation physiology and an altitude chamber flight since 1962. In addition, there are 14 other cooperating military installations throughout the U.S. In Australia the only operational hypobaric chamber is at RAAF Base Edinburgh near Adelaide, however this is not routinely available for civilian training. Despite the known risks of hypoxia and the documented aviation incidents listed above, practical hypoxia training for civilian aircrew has not been implemented in emergency procedure training yet. Because normobaric systems are now available, perhaps it is time for the civil aviation regulatory authorities to recommend that practical hypoxia training experience be included in the emergency procedures training, where practicable.

The major factors inhibiting the ability to conduct hypoxia training for civilian aircrew has been the poor availability of hypobaric chambers, their capital cost and maintenance expense, and the risk of decompression sickness. Given the perception of minimal risk of hypoxia in the industry, it is therefore not surprising that training is dismissed as impractical on the basis of cost-benefit analysis. However, if a simple, inexpensive, effective and accessible alternative was available, the financial equation may look much more favourable. Over the last 10–15 years, physiologists and aerospace medicine researchers have developed and trialled ground-based methods of training which use reduced oxygen gas mixtures to simulate the physiology of high altitude. Hypoxia can be produced by lowering inspired oxygen partial pressure either by barometric pressure reduction (hypobaric hypoxia-NH) or by lowering the fractional concentration of O2 in inspired air (normobaric hypoxia-NH). Some research suggests that there may be slight physiological differences between HH and NH, but the risks of barotrauma and decompression illness associated with the use of hypobaric chambers for hypoxia familiarisation training have made alternative methods almost obligatory.

Due to the risk of decompression illness in traditional hypobaric chamber training at altitudes up to 25,000 feet, in 2001 the Royal Australian Air
Force developed a Combined Altitude Depleted Oxygen (CADO) technique of hypoxia training which utilises a reduced oxygen gas mix delivered by mask at an altitude of 10,000 feet in a hypobaric chamber, simulating a total physiological altitude of 25,000 feet much more safely but this chamber technique is not accessible for training civilian aviators. The Canadian Forces have also adopted CADO hybrid hypobaric & reduced oxygen gas-mix system for its training. The Reduced Oxygen Breathing Device (ROBD) developed jointly by Duke University, and the US Naval Aerospace Medical Research Laboratory (NAMRL) uses a closed-loop breathing circuit with computer controlled fraction of inspired oxygen. This device has been proven effective in inducing hypoxia in subjects under normobaric conditions, and has been used effectively in military flight simulators to demonstrate physiological emergencies in a dynamic flight environment. Hypoxia induced by normobaric ROBD has been found equivalent physiologically and symptomatically to that induced by altitude hypobaria in US Navy studies. Non-rebreathing normobaric systems have also been studied and found effective in demonstrating hypoxic symptoms to students and Air Ambulance personnel at Monash University. This reduced oxygen breathing method described by Westernman uses reduced O2 gas-mix and a non-rebreathing mouthpiece to produce normobaric hypoxia, with continuous pencil and paper tests of cognitive function. This is largely a research laboratory development, and relatively inaccessible for civil aviators, although it has been used for 15 years to train mobile intensive care air ambulance personnel in Victoria and the Australian Capital Territory.

A very recent and innovative development in Australia is the GO2Altitude hypoxia training system which can provide an accessible means of hypoxia training for civilian flight crews where no facility has been previously available. GO2Altitude hypoxia training utilises a semi-permeable membrane technology to concentrate nitrogen gas from room air to produce a gas with the desired low oxygen concentration, unlike other normobaric methods. It utilises bulky gas cylinders and has higher maintenance and running costs. The GO2Altitude system has the advantage of being designed specifically for aviation training purposes, and provides detailed automated printout of physiological data, continuous cognitive test results and video-recorded behaviour. Validation of this new technology is ongoing and preliminary results of research have been published.

Conclusion
Hypoxia remains the most serious threat of high altitude flight, and this is evident by reviewing the statistics of incidence and fatalities. It is arguable that the changing nature of the general aviation industry means that perhaps civilian aviators today face an even greater threat from hypoxia than previously, which introduces new imperatives and challenges in training. Advances in hypoxia training techniques over the last decade mean that these challenges can now be met with safe, accessible and more cost effective training technologies which can only result in better safety through improved defences.

References