

## HYPOXIA RECOGNITION TRAINING IN CIVILIAN AVIATION: A NEGLECTED AREA OF SAFETY?

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### Abstract

Since the earliest days of aviation, hypoxia at altitude has been recognised as a safety hazard, and this hazard continues to this day, such that a recent Australian Transport Safety Bureau report on hypoxia and loss of cabin pressure describes 517 incidents in Australia between 1975–2006<sup>12</sup>. The risk of hypoxia in civilian aircraft may be increasing as the performance and flight envelope of civil registered aircraft expands. There is good evidence that hypoxia training of flight personnel aids early recognition of symptoms, and this has been a routine in the military for several decades since World War II. However, there has been no easily accessible and cost-effective method of such aircrew safety training in the civilian sector in Australia. This review examines the published incidence of hypoxia events in military and civilian aviation, and presents data on the benefits of hypoxia training. New developments in hypoxia training are discussed which could provide more accessible, cost-effective and safer training to civilian aviators to offset this ever-present risk.

### Why the concern?

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 cardiovascular and respiratory adjustments to occur in the body, but despite such compensations it causes impaired function in vision, cognition, motor control, and ultimately severe incapacitation, unconsciousness and death<sup>1</sup>. Since the earliest balloon ascents, hypoxia has been recognised as a physiological threat which increases with altitude. In April 1875, two young Frenchmen, Croce-Spinelli and Sivel, became the first fatalities from aviation hypoxia during their attempt to reach 26,200 feet in an open balloon with colleague Gaston Tissandier, even though the famous physiologist Paul Bert had provided them with oxygen for the ascent<sup>2</sup>. Harding, in Ernsting's learned textbook, states that acute hypobaric hypoxia is the most serious single hazard during flight at altitude<sup>3</sup> and it continues to be a threat today. Most jurisdictions mandate theoretical training in altitude physiology and hypoxia. Now a few require practical experience including the US Federal Aviation Administration (FAA) which advertises and highly recommends hypobaric chamber training courses at the Civil Aerospace Medical Institute (CAMI) for General Aviation

pilots<sup>4</sup>. Further, the UK Civil Aviation Authority (CAA) also recommends practical training to supplement theoretical knowledge. It almost appears there has been a prevailing perception in the civil aviation industry until recently that hypoxia incidents are rare, and if they do occur, emergency oxygen systems, warning systems and rapid descent will save the situation and prevent hypoxia, with no need for symptom recognition on the part of the crew.

So how common is the problem of hypoxia in aviation? Many fatal accidents occurring as a result of hypoxia may not be immediately recognised as such, given the numerous other potential causes of fatal accidents. However, a few recent hypoxia accidents have occurred in a dramatic and sensationally publicised fashion to remind all aviators of this ever-present altitude threat. In October 1999, a Lear Jet 35 crashed near Aberdeen, South Dakota having departed Orlando, FL, four hours earlier, and flown on autopilot across the United States with an apparently incapacitated crew<sup>5</sup>. The aircraft attained an altitude of 45,000 feet before it crashed due to fuel exhaustion, killing all on board including professional golfer Payne Stewart. Cabin pressurisation failure and hypoxia have been widely mooted as the probable causes of this accident. In 2005 the crash of a Helios Airlines B737 in Greece again re-iterated the danger of undetected hypoxia leading to crew incapacitation, reminding the aviation community about the importance of altitude physiology knowledge even in airline operations.

Although fatalities due to hypoxia as seen in these high profile examples are relatively rare, hypoxia incidents are common – particularly in military aircraft. There were 656 reported incidents, including one fatality and aircraft loss in the paper by Island and Frayley<sup>6</sup> analysing USAF hypoxia incidents from January 1976 to March 1990. Rayman and McNaughton<sup>7</sup> reviewed 298 cases of in-flight hypoxia in the USAF. Of the incidents, 144 occurred in trainers, 48 in fighters, 28 in transport aircraft, 23 in bombers, and 1 in U2 reconnaissance aircraft. Therefore in total, 193 cases (64.7%) occurred in aircraft despite oxygen equipment being routinely used and a mask worn by aircrew at all times. The predominant symptoms experienced were paraesthesia, light-headedness, dizziness, decreased mentation, and visual changes, while other symptoms were extremely variable including 16 cases who described loss of consciousness. These symptoms clearly indicate the constant dangers of even mild hypoxia to the aviator. In 98 cases (33%) the cause was not determined, but 134 (45%) were due to problems or failures in oxygen mask, regulator, hose or oxygen supply. There were 58 (19%) due to cabin pressurisation failure, and 8 (3%) due to mask removal in flight. The US Navy reported 18 cases of loss of consciousness and 4 fatalities over a 21 year period<sup>8</sup>, while the Canadian Forces had no fatalities from 1963–1984<sup>9</sup>. A review of Australian Defence Force (ADF) incidents for the period 1990–2001 reported 27 hypoxia incidents involving 29 aircrew, and one fatality, the majority occurring in fighters and unpressurised training aircraft<sup>10</sup>. More recently Files, Webb and Pilmanis described the US military experience of cabin depressurisation occurring between 1981 and 2003<sup>11</sup>. Of a total of 1055 incidents found, hypoxia occurred in 221 resulting in 3 deaths. The vast majority (83%) of these incidents were slow in onset, which implies that onset of hypoxia symptoms would be more insidious. All these reports demonstrate that even today, hypoxia remains a serious threat to military aviators.

Thus hypoxia in military aircraft is widely reported. Reliable civilian data relating to hypoxia incidents and loss of cabin pressure is harder to find than military data. In the USA, National Transportation Safety Bureau (NTSB) statistics reveal 40 aircraft accidents related to hypoxia between 1965 and 1990, resulting in 67 fatalities. This data cited in Island and Frayley<sup>6</sup> suggests that on average there were more than 2 deaths per year due to hypoxia related accidents in the US prior to 1990. A report on depressurisation incidents and accidents

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<sup>12</sup>. Pressurisation 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 don oxygen himself, yet nevertheless managed to descend the aircraft to safety. The master caution for cabin altitude was never recognised<sup>13</sup>. 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<sup>1, 6</sup>. 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<sup>14</sup>. 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<sup>15, 16</sup>, 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 hypobaric altitude chambers<sup>17, 18</sup>. 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 idiosyncratic to the individual, they are usually rather consistent over time for that person<sup>19</sup>. There is published data that suggests such training works and saves lives. In the report of 656 USAF hypoxia incidents described above<sup>6</sup>, 606 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<sup>10</sup> 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<sup>20</sup>. 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<sup>21</sup>. 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<sup>21</sup>. 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<sup>22</sup>. 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<sup>22</sup>.

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<sup>18</sup>. In addition, there are 14 other cooperating military installations throughout the U.S.<sup>4</sup>. 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<sup>14</sup>. 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-HH) or by lowering the fractional concentration of O<sub>2</sub> in inspired air (normobaric hypoxia-NH). Some research suggests that there may be slight physiological differences between HH and NH<sup>23</sup>, but the risks of barotrauma and decompression illness associated with the use of hypobaric chambers for hypoxia familiarisation training<sup>17</sup> 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

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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<sup>17,24</sup>, 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<sup>25, 26</sup>. 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<sup>27</sup>. Hypoxia induced by normobaric ROBD has been found equivalent physiologically and symptomatically to that induced by altitude hypobaria in US Navy studies<sup>28</sup>. 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 Westerman<sup>29</sup> uses reduced O<sub>2</sub> 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<sup>30, 31</sup> which can provide an accessible means of hypoxia training for civilian flight crews where no facility has been previously available. GO2Altitude<sup>®</sup> 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<sup>25, 26, 29</sup> which utilise bulky gas cylinders and have 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<sup>30,31</sup>. Validation of this new technology is ongoing and preliminary results of research have been published<sup>30,31</sup>.

## 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.

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