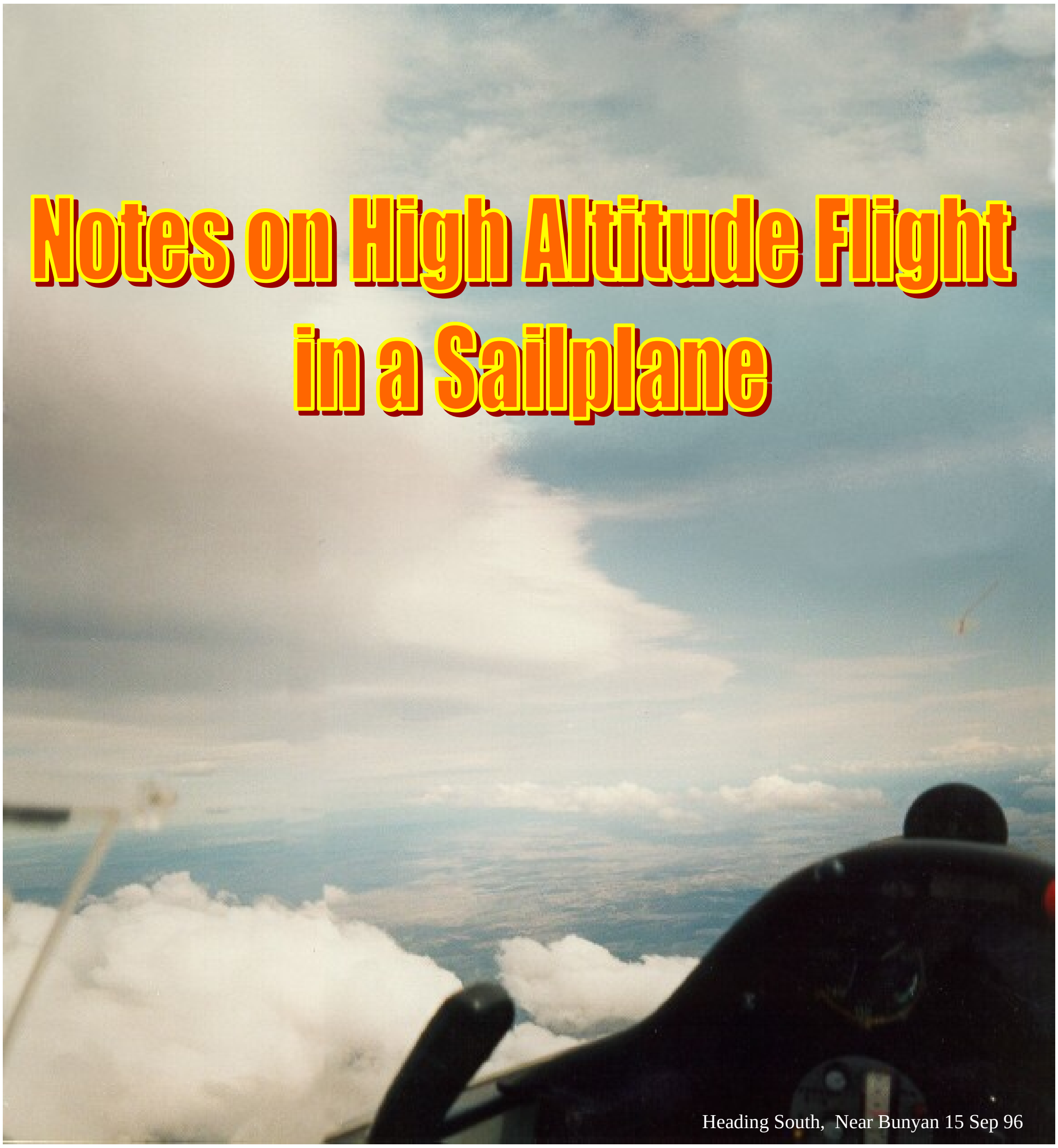
Notes on High Altitude Flight in a Sailplane



Heading South, Near Bunyan 15 Sep 96

September 2014

NOTES ON HIGH ALTITUDE FLIGHT IN A SAILPLANE

A greater understanding of the various weather phenomena within the atmosphere means that more sailplane pilots in Australia are now experiencing the challenges and rewards of high altitude flight. In Australia the exploration of mountain waves has given pilots climbs of greater than 30,000 ft[1]; shear wave has given climbs above 20,000 ft[2]; and thermals in hot arid conditions have given climbs up to at least 18,000[3].

These notes are intended to provide an introduction to physiological factors that need to be addressed when contemplating flight above 10,000 ft in a sailplane, namely:

- **The effects of increasing altitude**
- **Typical Oxygen Installations, Characteristics and Limitations**, and
- **The need to remain warm**.

These notes are provided as information only. They are only a guide and the information contained herein is not exhaustive. They are a compilation of data available in open literature and from the author's personal experiences.

Individual responses to high altitudes in a sailplane will vary widely between individuals. Accordingly, <u>Readers using these notes do so at entirely their own risk.</u>

Pilots contemplating high altitude flight are strongly encouraged to undergo aviation medicine training in a decompression chamber to determine their own responses to low atmospheric pressure

1 Australian Absolute Altitude record - 33,000 ft, near Thredbo, 26 Aug 95, Richard Agnew (World record 50,641 ft)
2 21,000 ft Narromine, 28 Dec 75 - there may have been higher climbs since, of which the author is unaware.
3 18,000 ft at Waikerie with cumulus base estimated ~ 20,000 ft.

THE EFFECTS OF INCREASING ALTITUDE

With increasing altitude, and reducing atmospheric pressure, two separate physiological issues need addressing:

- The need for additional oxygen, and
- The effects of gases in the body

The Need for Additional Oxygen

There have been occasional stories of pilots climbing to 20,000 ft for brief periods without using additional oxygen and returning safely to earth having apparently suffered no ill effects. Equally there are stories of pilots experiencing serious difficulties as low as 12,000.

Story 1.

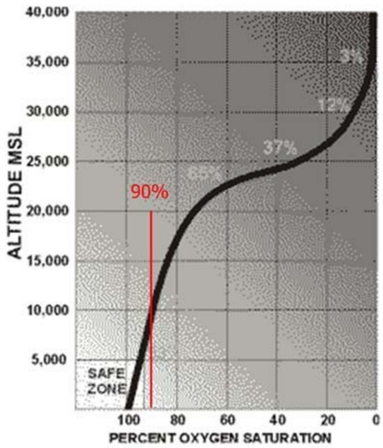
During the famous shear wave day of 28 Dec 75, immediately prior to the 14th Australian National Gliding Championships being held at Narromine, NSW, quite a number of climbs to 20,000 ft were made in clear blue conditions. A number of sailplanes were not oxygen equipped. At one stage a Libelle was observed to carry out a series of exuberant manoeuvres including at least one loop. Upon his return the pilot was elated at having achieved his diamond height, but denied knowledge of any looping manoeuvre.

Story 2.

Many years ago, at a country club an instructor was taking his son for a flight in the club's open cockpit two seater. At around 10,000 ft the father was horrified to see his son unstrapping with the intention of clambering over the side and had to be restrained.

Both the stories above are somewhat anecdotal, but they serve to illustrate some of the considerations of high altitude flight. What then, are the facts about the need for additional oxygen and what can the soaring pilot do about it?

The proportion of oxygen to nitrogen in the air remains constant at all normal flying altitudes.[4] However, pressure decreases with altitude and it is the pressure that forces oxygen through the lungs into the bloodstream. At sea level the amount of oxygen carried by the blood in a healthy fit person is about 98% of maximum saturation. As the pressure decreases the amount of oxygen carried by the blood falls. Aviation medical authorities consider the minimum saturation levels for adequate cerebral functions to be above 90%. In a healthy fit person this equates to around 10,000ft amsl. Below 87% (~ 12,000 FT) is heading into the dangerous zone Above 15,000ft the blood saturation level drops off at an exponential rate.



Accordingly, as altitude is increased, additional oxygen must be supplied to a pilot to maintain adequate oxygen saturation levels and prevent the effects of hypoxia (lack of oxygen) [5]. (For safety, some pilots carry a simple device called a pulse oximeter which is attached to a finger and provides the pilot an immediate reading of his blood oxygen saturation level.[6])

Hypoxia

[4] The air contains 78% nitrogen, 21% oxygen and 1% other gases.

[5] Technically, it is the 'partial pressure' of oxygen in the blood which must be maintained at a sufficient level for the pilot to avoid the effects of hypoxia.

[6] Pulse Oximeters are discussed a little more at page 14, in the Typical Oxygen Installations section.

Briefly the effects of sudden exposure to a lack of oxygen, such as with an oxygen system failure or a cockpit pressurisation failure, are:

- **4,000 feet** – the first evidence of hypoxia occurs when night vision deteriorates;
- **10,000 – 15,000 feet** – progressive cerebral deterioration frequently with insidious onset; headaches; visual changes; defective judgement; poor discrimination; slowing of reaction time, exhilaration. Characterised by:
    - insidious onset with deterioration in cerebral function; but
    - rarely a lapse into unconsciousness;
- **15,000 – 22,000 feet** – an extension of the above effects with weakness, cyanosis (bluish discolouration of skin and nail beds); tremors of the hands, fingers and head; loss of useful consciousness (10 – 20 minutes) and death (1 – 4 hours);
- **22,000 – 25,000** feet loss of useful consciousness in 4 – 7 minutes;
- **25,000 – 30,000** feet loss of useful consciousness in 1 – 4 minutes, with death in 8 – 10 minutes.
- **30,000,- 40,000** feet loss of useful consciousness in 30 – 60 seconds, and death in 2 – 5 minutes;
- **40,000 – 50,000** feet – loss of useful consciousness in 9 – 15 seconds; and
- **above 50,000** feet – you shouldn't be there in a glider unless wearing a pressure suit.

Remember, the times quoted above do not take into account any time spent without additional oxygen at lower altitudes, as would be is the case during a typical sailplane climb without oxygen. As stated earlier, they apply to the situation if the pilot ceased breathing additional oxygen at that altitude. **In other words, for pilots climbing without oxygen the times above are largely irrelevant since pilots may be incapacitated before reaching even 15,000ft!** Additionally, these are only average values because every person reacts differently and there can be a wide difference between individuals during oxygen deficiency. For this reason it is impossible to predict how an individual will react at a particular altitude, although for a given individual the symptoms usually remain the same. The altitude values can be typically lowered by 2,000 – 3,000 feet for persons who smoke moderately to heavily, or are in poor physical condition. Alcohol (including the hangover period) and dehydration also have a deleterious effect by reducing the body's ability to absorb oxygen from the blood, thus reducing blood saturation levels. Other factors include temperature, anxiety and physical exertion. Do not underestimate the effects of anxiety or of simple physical exertion in the cockpit such as twisting around trying to reach something behind you, both of which can dramatically reduce saturation levels when above 10,000ft easily tipping the balance between adequate and dangerously low oxygen saturation levels.

Hypoxia – Dangers and Symptoms

The dangers of hypoxia are insidious. <u>The most dangerous aspect of Hypoxia is that the pilot experiencing hypoxia does not, and cannot, detect his loss of performance</u>. It sneaks up on the victim with little or no warning and the first symptoms can easily go unnoticed. Frequently a feeling of well-being and happiness, quite similar to the first stages of intoxication, accompanies the onset of hypoxia. This feeling eventually changes to one of dullness and confusion, which can be followed by unconsciousness and finally death. Again individuals vary in their symptoms with the onset of hypoxia, with some experiencing subtle but recognisable symptoms such as tingling of the extremities, a "zinging" light headed feeling, whilst others have almost no recognisable symptoms at all. The sometimes heard folklore of checking for blue fingernails is hazardous. By the time fingernails turn blue, the pilot is hypoxic and he may not even be in a state to check his fingernails and even if he does he may not be in a state of mind to carry out an emergency descent immediately.

If in doubt, do not wait for obvious symptoms to occur (it may be too late), rather:

- **Immediately Commence VFR <u>Descent</u> with full airbrake, and Select <u>Maximum Oxygen flow</u> – (100% if your regulator allows)**
- **<u>Check security</u> of all connections**
- **<u>Control Breathing</u> at a normal rate**
- **Continue descent <u>below 10,000'</u>**.

To Repeat without apology:

The most Dangerous aspect of Hypoxia is that the pilot experiencing hypoxia <u>does not</u>, and <u>cannot</u>, detect his loss of performance and loses the ability for critical judgment.

Residual Effects of Hypoxia

Recent experience strongly suggest that pilots who have conducted flights for extended periods whilst mildly hypoxic (ie summer thermal flights where most of the flight was conducted in 12-14,000ft range) suffer residual effects after descending below 10,000ft and their judgement remains somewhat impaired all the way through the landing phase. Reason for this is unclear, but could be oxygen related, dehydration related or a combination of both.

<u>Hyperventilation</u>

Hyperventilation is caused by rapid breathing which reduces the carbon dioxide in the bloodstream. When this happens, the excessive loss of carbon dioxide leads to the blood vessels in the brain constricting and so reducing the amount of oxygen available. Anxiety, fear or excessive stress can precipitate rapid

North West of Bunyan climbing through 10,000 ft - 15 Aug 00

breathing and the resultant hyperventilation. Dizziness, light-headedness, tingling of the hands and feet, visual disturbances and the inability to think clearly - the commonest symptoms of hyperventilation - may be experienced singly or in combination. These are symptoms also commonly noted during hypoxia, and to a certain degree are produced by the same mechanism - a reduction in oxygen supply to the brain. For those of you who have tried to start a fire by repeatedly blowing hard to get those first few flickers to burst into life and then have stood up to find yourself quite dizzy and unsteady - you have just hyperventilated.

Hyperventilation, while closely resembling hypoxia is not as critical or life-endangering, and may be corrected by the application of simple measures. Since hyperventilation is frequently brought on by anxiety, it occurs more often in a tense and worried pilot when he is placed in conditions of extreme emotional stress.
To prevent or alleviate the symptoms of hyperventilation, pilots must be familiar with its cause. To correct it, the pilot consciously slows his breathing rate to normal.

Because the pilot himself may be unable to distinguish whether he is hypoxic or hyperventilated the recommended procedure is to:

- **Immediately Commence VFR Descent with full airbrake, and Select Maximum Oxygen flow – (100% if your regulator allows)**
- **Check security of all connections**
- **Control Breathing at a normal rate**
- **Continue descent below 10,000'**.

Additional reading on hypoxia, reproduced from 'Sailplane and Gliding' magazine[7] is included at the end of these notes.

FL 245 near Bredbo 20 Aug 2010

[7] Flying High – Dr Peter Saundby, 'Sailplane and Gliding' 1993 Yearbook

The Effect of Gases in the Body

This section will describe the effect of pressure changes on:

- gases **trapped** in the body, and
- **evolved** gases which give rise to decompression illness (DCI).

Trapped Gases.

Trapped gases are those which normally exist or occur in the body at ground level. As altitude increases these gases expand and, if trapped, can cause problems during a climb, or descent. There are four sites in the body where gas can be trapped; the middle ear, sinus, gut and teeth.

Middle Ear. The eardrum has no perforations in it and during ascent the volume of air in the middle ear increases and the eardrum bulges slightly. When the pressure difference across the drum reaches a certain value, air escapes down the eustachian tube into the back of the throat. Problems are not usually encountered during ascent, but during descent the ears must be actively cleared. If the middle ear cannot be adequately ventilated the drum will bulge inwards causing pain. Problems of the inner ear at altitude are usually due to the pilot flying with an upper respiratory tract infection, or with acute hay fever. If wriggling the jaw, yawning or swallowing doesn't relieve the pressure, the Valsalva manoeuvre should be used. This involves pinching the nostrils between the thumb and forefinger, and with a closed glottis or closed mouth, blowing gently to clear the Eustachian tubes. Moving the jaw at the same time might assist. Use only as much force as necessary to clear the ears. If valsalva fails some pilots have found relief by chewing Minties or similar confectionery.

Sinus. This situation is similar to that encountered with the middle ear, and usually arises for the same reasons, e.g. flying with a cold. Because the sinuses have rigid walls, differences in pressure affect them more dramatically. Pain can arise during ascent or descent, the latter being more common. Treatment is again aimed at equalising pressures, and the Valsalva manoeuvre should be used to attempt to relieve the discomfort. Use of a nasal spray such as “Drixine” can also help clear the sinus ducts.

Gut. Every intestinal tract contains some gas, the majority of it being nitrogen, which comes from swallowed air. During ascent the gas will expand and unless naturally expelled will give rise to a colicky abdominal pain increasing in intensity with gain in altitude. Problems arising from this cause are unusual below 25,000 feet, but can be experienced by some individuals at much lower altitudes. Diet plays a part in the prevention of abdominal bloating and gas pains. Prior to any intended high altitude flight avoid gas producing foods (cabbages onions and other personal food idiosyncrasies which give rise to indigestion), fizzy drinks, beer and chewing gum. In the event that you find yourself in this uncomfortable situation vigorously expel the cause of your discomfort at either or both ends, as necessary!

Teeth. Pain from the teeth, though not common, can occur. When it does, the subject has usually had dental work done in the preceding six weeks[8]. Fillings have been known to come out but fortunately this is a most rare occurrence!

The best course of action with middle ear or sinus pain during a climb is to attempt to relieve the pressure and return to a lower altitude. Be prepared for a return of the pain during the descent. If, as is

[8] If the dental procedure was carried out under anaesthetic then the likelihood of any pain is reduced.

much more likely, the pain occurs during a descent and attempting to clear the pressure does not provide immediate relief, attempt to level off or if necessary climb until the pain subsides. Then, whilst continuing with efforts to relieve the pressure commence a slow descent leveling off (if you can) each time the first signs of pain return. And after the pain subsides recommence the descent.

In the case of gut or teeth pain, usually the best answer is to descend.

Importantly, flying with a head cold or sinus problems must be avoided . Damage to the eardrum and sinuses can easily occur due to pressure changes, resulting in perforated eardrums and/or infected sinuses. It is much easier to wait a week for the cold to completely clear, rather than weeks or even months before being able to fly again.

Evolved Gases (Decompression Illness or DCI)

Evolved gases are those which come out of solution due the reduction of pressure with altitude[9] [10], causing the potentially dangerous condition known as decompression illness DCI (or …sickness DCS). It is generally accepted that the gas responsible is nitrogen, the majority of it being dissolved in simple solution in fatty tissue in the body. Therefore the fatter the pilot, the greater his susceptibility to this problem. Age is also a factor. There are four types of DCI, depending on the location of the bubbles:
Joint problems (The Bends), respiratory problems (The Chokes), skin manifestations (The Creeps) and nervous system effects (The Staggers).

Bends. Bends is thought to be due to Nitrogen bubbles in the joints causing mild to severe pain, occurring usually around the major joints (elbows, shoulders knees and ankles), but has been known in smaller joints such as fingers. Initially there is a mild ache which can progress into a severe and agonising pain. Joints which have suffered previous injury seem to be the first affected.

Chokes. The Chokes is a rare but potentially very dangerous condition where bubbles are formed in the small blood vessels in the lung. Initially there is a burning deep chest pain accompanied by a non-productive cough and progressive difficulty breathing. This dangerous situation is relieved by an immediate descent.

Skin Manifestations. Skin Manifestations include cold/warm sensations, itching tingling, gritty sensations and a mottled and diffuse rash. Skin manifestations are believed to be caused by nitrogen bubbles just below the skin surface.

Nervous System. Bubbles forming in and around the brain and spinal cord will produce symptoms related to the area of evolution. That is if your visual cortex is affected, you will have visual problems such as blind spots, blurring, flickering, tunnelling or dimming of your vision. The range of symptoms is diverse and includes headache, partial paralysis, speech difficulties, vertigo, loss of orientation, delirium or even unconsciousness and death. In fact, any conceivable symptom caused by a malfunction of your nervous system can occur.

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[9] 18,000 ft can be used as a rule of thumb as the potential minimum height for onset of this phenomenon.

[10] An analogy is the bubbles that come out of a soft drink when the pressure is relieved as the bottle-top is removed.

Factors Affecting DCI

Altitude and Duration of Exposure. Bubble formation is primarily a function of pressure change. The table below gives an indication of the likelihood of DCI at various pressure altitudes for the times quoted.

Altitude	Time of exposure	Estimated % likelihood of DCI
30,000	>4hrs	Up to 100%
25,000	1 hr	25%
22,500	1 hr	10%
20,000	1 hr	< 5%
18,000	1 hr	< 5%

As seen in the table there is an increasing risk of DCI from 18,000 to 25,000 ft. Above 25,000 ft the risk increases significantly, until at 45,000 ft virtually everyone will have problems if they stay at that pressure altitude long enough.

Age. As age increases, so does susceptibility to DCI. Over the age of 42, risk increases significantly.

Body Fat. Fat contains a lot of nitrogen, increasing the likelihood of DCI.

Gender. There is evidence that females are more susceptible than males, increasing immediately following menstruation.

Exercise. Even mild physical activity greatly increases the risk of DCI. This is similar to shaking a coke bottle – many more bubbles coming out of solution.

Individual Susceptibility. The susceptibility of an individual to DCI in changed by a variety of factors including recent injuries, the after affects of alcohol ingestion, fatigue, hypoxia and the presence of other illness, such as infections.

Recompression (i.e. descent to lower altitude) can relieve the symptoms outlined above. The symptoms can sometimes be significantly relieved if only a small descent is made, but if that altitude is then maintained, the symptoms may recur. It is important to return to ground level if any symptoms of decompression sickness occur in flight. Therefore, if DCI symptoms are experienced airborne, it should be treated as serious and pilots should:

- **Descend**
- **Select Maximum Oxygen flow – (100% if your regulator allows)**
- **Land as soon as possible**
- **Seek medical attention from a medical practitioner who is familiar with aviation medicine issues.**

Reducing the Risk of DCI

For a given climb, DCI risk can be reduced by breathing 100% pure oxygen prior to take-off and continuing to breathe 100% for the flight. Unfortunately, it is not normally practical for glider to pilots to pre-breath because most of equipment installations are not capable of providing the 100% pure oxygen required. Notwithstanding, the following is provided for interest:

Prebreathing 100% oxygen is a means to wash out Nitrogen from the body to reduce the likelihood of Nitrogen bubble formation. The time of prebreathing before take-off depends upon a range of factors including rate of climb, height climbed to and duration of flight at high altitude. As an illustration, the following table gives some idea of the prebreathing times involved.[11]

Altitude	Exposure Time	Pre-breathing time
18,000 – 25,000 ft	Up to 15 min 15 – 30 min 30 – 60 min More than 60 min	0 min 15 min 30 min 60 – 180 mins
25,000 – 35,000 ft	Up to 15 min 15 – 30 min 30 – 60 min More than 60 min	30 min 60 min 90 min 90 – 180 min

Due to the risk of DCI , except for special operational reasons, sustained flight above 25,000 ft cabin altitude is prohibited by the RAAF.

[11] Taken from Prebreathe Requirements for Research Purposes at the Armstrong Laboratory, USAF.

Extremely valuable additional information on decompression illness in the article 'The Risks of Wave Flying', reproduced from Sailplane and Gliding magazine[12], is included at the end of these notes.

The most Dangerous aspect of Hypoxia is that the pilot experiencing hypoxia <u>does not</u>, and <u>cannot</u>, detect his loss of performance and loses the ability for critical judgment.

[12] The Risks of Wave Flying – LtCol Robert Weien & Peter Harmer, 'sailplane and Gliding' Aug/Sep 1995

TYPICAL OXYGEN INSTALLATIONS, CHARACTERISTICS AND LIMITATIONS

An oxygen installation in a sailplane normally consists of four major components; a tank in which the oxygen is stored under pressure; a pressure-reducing regulator, a delivery regulator; and a breathing device to deliver the oxygen to the pilot. The systems described below are typical of systems used in sailplanes today.

Storage Tank

Oxygen is stored in a pressure tank, or 'bottle' which can be constructed from steel, aluminium or composites. Capacities vary considerably and a search of the web will reveal the various size, shapes and weights.

Most recent European gliders make provision for a 100mm dia bottle up to around 600 mm long. Intent here is to use a European manufactured bottle with max pressure capacity of 200 bar – 3,000psi.

Most US sourced bottles, which tend to be larger than European bottles, and therefore can create fitment challenges in some gliders, have a maximum pressure capacity of 1800 – 2200 psi

A bottle with capacity quoted as 20 cu ft (US) or 3L (Euro)[13] will generally be sufficient for an extended high altitude flight.

Pressure Reducing Regulator

Immediately downstream of the storage bottle is placed a pressure reducing regulator to reduce the bottle pressure to around 20 – 30 psi (this pressure varies depending on the requirement) for use by the delivery regulator..

Oxygen Delivery Regulator

Oxygen systems are usually described by the function performed by the delivery regulator: continuous flow; diluter demand; pressure demand; and a more recent development, the electronic delivery system. On some systems the pressure reducing regulator and the delivery regulator are in a single assembly usually simply referred to as the oxygen regulator.

Continuous Flow Systems. Typical continuous flow equipment fitted to sailplanes provides a continuous flow of oxygen from the bottle through the regulator to the mask. The pilot normally can adjust the flow of oxygen to the mask at the regulator (many systems use a simple flowmeter as the regulator) in accordance with his altitude to minimise waste at lower altitudes. A storage bag is fitted to the pilots mask to store oxygen whilst the pilot is exhaling which is then used during the next inhalation. When using a face mask, these systems have a maximum operating altitude of 22-25,000 ft.

[13] The Yanks normally quote their capacities in the amount of oxygen delivered at atmospheric pressure and the Europeans the capacity of the bottle. A 3 litre bottle at 200bar/3,000 psi will provide 600 litres which is 21.2 cu ft. (At 2,000 psi this will bottle will provide 411litres which is 14.5 cu ft)

Diluter Demand Systems. These systems contain a mechanism within the regulator which mixes oxygen with the ambient air, increasing the amount of oxygen in the mixture with increasing altitude. Additionally, these systems contain a very sensitive control valve in the oxygen regulator which responds to the slight decrease in pressure created in the mask at the onset of pilot inhalation, opening to permit flow into the mask. As the pilot ceases inhaling, the valve closes to shut off the flow. The regulator is normally panel/cockpit mounted, and can have a maximum operating altitude of 35,000 ft, at which altitude pure oxygen is being delivered to the pilot.

Pressure Demand Systems. These systems are similar to the diluter demand system with the additional capacity to provide a regulated over-pressure of 100% oxygen above about 27,000 feet. Above 34,000 ft, 100% oxygen at ambient pressure is insufficient to maintain oxygen at the sea level equivalent. Pressure demand systems, by providing oxygen under pressure, increase the delivery pressure in the lungs so that this system has a maximum operating altitude of around 48,000 ft.

For these systems to be effective appropriate masks which can be tightened to form a tight, almost painful, fit to prevent oxygen leaks are necessary. Pressure breathing, during which exhalation becomes increasingly difficult with altitude, is a strenuous exercise and unless practiced cannot be sustained for long periods.

Electronic Delivery System (EDS). The electronic delivery system monitors micro-pressure changes during the breathing cycle delivering a precise pulse of oxygen at the very beginning of each breathing cycle. Tests have shown that by using this technique less oxygen is needed than with a conventional constant flow system. Delivery of the oxygen to the pilot is via a cannula (discussed later) or face mask. These systems feature lower oxygen consumption rates compared with other systems and the manufacturer, Mountain High (MH), states that their *" .EDS System enables the general aviation pilot to fly at pressure altitudes up to 25,000 feet with safety and comfort."* Their O2D2 Instruction Manual implies that the system is capable of F300. (MH instruction manual requires that a mask be used above 18,000ft)

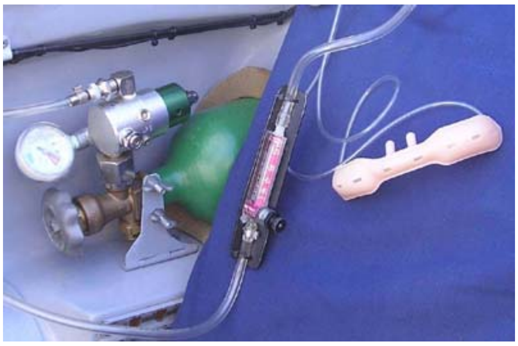
Breathing Devices

Breathing devices can be divided into two categories, cannula and face masks.

Cannula Cannula are in very common use amongst the gliding fraternity. Cannula are fitted to the nostrils and are used with constant flow and EDS systems. The type normally used in sailplanes with a constant flow system is of the Oxymiser®[14] type. The Oxymiser

[14] Oxymiser is a registered trademark of CHAD THERAPUTICS, Inc.

oxygen and then drain during inhalation to add additional oxygen



to the intake.

The Oxymiser type cannula (pictured above) are limited to 18,000 ft but are reasonably economical on oxygen use.

EDS cannula are similar to hospital type cannula and do not contain a storage bag.

Cannula practical experience.
Pilots at Bunyan have noticed that using Oxymiser cannula with constant flow systems, oxygen saturation levels can easily fall below expected levels. Use of these cannula above 15,000' sometimes need more oxygen than a properly fitting face mask to maintain correct blood oxygen saturation level. Accordingly the use of a face mask above 15,000' should be considered. Also, see comments later on shallow breathing.

Face Masks Typically, face masks can be divided into two sub-categories - the masks used with demand systems, and those used with constant flow systems. The demand system mask contains valves which allow inhalation of the air/oxygen mix direct from the regulator and exhalation to the cockpit. Constant flow masks utilising a storage bag allow the pilot to inhale the oxygen being delivered to the mask, any oxygen in the storage bag plus cockpit air which gives the air/oxygen mix. On exhalation the oxygen flows into the bag to avoid waste and is available for the next inhalation. Both types of mask can be fitted with a microphone to allow radio communications without having to remove the mask. The EDS mask is similar to the constant flow mask, but without the storage bag.

Shallow Breathing

Evidence shows that quite a few pilots reduce their respiration effort while at high altitudes thus causing a compromise in the effectiveness of an oxygen system while at moderate to high altitudes. The need to breath actually comes from the need to purge of carbon dioxide (CO2) from the blood, not the lack of oxygen (O2). At altitude the body detects lower absolute CO2 and causes ones respiration system to decrease in volume and rate because there is very little CO2 to purge. This causes you to breathe shallowly at a time you need to breath normally or greater.

Accordingly remain conscious of this fact and remember to always maintain a normal breathing depth. For some pilots this may require continuous monitoring. (*The author of this document is one of those who easily falls into a shallow breathing cycle. You may be one of them as well!!*)

Emergency Oxygen Systems

Should an oxygen system fail at high altitude it is quite possible for a pilot to have insufficient time to descend to a safe altitude before losing consciousness[15]. Accordingly, an emergency oxygen system should be carried.[16] Emergency systems fall into two categories; on board systems and bail out systems.

On Board Systems On board emergency systems usually consist of a small oxygen supply through an

[15] From 30,000 ft to say 15,000 ft in a 45 degree dive at 100 kts takes over two minutes (Rate or descent 7,500 ft/min). Useful consciousness at 30,000 ft is around 1 minute. Even if the problem were recognised quickly, the likelyhood of the pilot remaining conscious during the descent is questionable.

[16] United States wave flying practice is to carry emergency oxygen systems from as low as 14,000 amsl.

On Board Systems On board emergency systems usually consist of a small oxygen supply through an independent pressure reducing valve on top of the bottle direct to the pilot's mask. These systems are activated by the pilot, following failure of the main system and are normally intended to provide oxygen during a rapid descent to lower altitude. Some systems may include a separate mask or mouthpiece, whilst the most sophisticated systems can replicate the main oxygen system.

Bail Out Systems Bail out systems usually consist of a small oxygen supply which is attached to the pilot's parachute. This enables the pilot to receive oxygen during parachute descent from high altitude. As with the on board system, the oxygen is normally fed directly from a pressure reducing valve direct to the pilots mask. Bail out systems can be rigged to activate automatically on the pilot leaving the cockpit. Manual operation of the system in the cockpit allows the bail out system to be used as an emergency system in the event of a failure of the main oxygen system.

The Pulse Oximeter

As mentioned earlier, a very useful device is the pulse oximeter, commonly used in hospitals, which directly measures the oxygen saturation level in the blood. It fits over a finger tip and measures the blood saturation level optically using a dual source of light and some clever processing. A range of models exist in varying sizes and varying display options.

Their only downside is that they will interfere with the pilots gloves and each pilot must determine what is his preferred method of fitting the oxymiser and keeping his fingertip warm.

Note: Pulse Oxymeters require the finger to be warm and therefore receiving blood. Accordingly, as you climb and supplemental oxygen becomes progressively more important, the cockpit temperature is reducing and flow of blood to the finger can slow and the Pulse Oxymeter will simply stop indicating. This normally becomes a problem above about 15,000 ft in winter and measures need to be taken to keep the hand adequately warm. Specially modified gloves and perhaps keeping the hand inside the jacket can resolve the problem. If your hands feel cold the pulse oxymeter normally won't work.

Notwithstanding, the oxymiser is a very useful device and well worth considering for high altitude flight monitoring.

In Brief

A range of oxygen systems are available for use in sailplanes. When properly installed and maintained oxygen systems are highly reliable. Nevertheless, it is imperative that before flight you fully understand the system that you are about to use, its pre-flight checks, limitations, and normal and emergency operating procedures.

Remember, oxygen is like a parachute, when you really need it there is no substitute.

The most Dangerous aspect of Hypoxia is that the pilot experiencing hypoxia does not, and cannot, detect his loss of performance and loses the ability for critical judgment.

THE NEED TO STAY WARM

The ‘standard atmosphere’ cools at 2 degrees Celsius per 1,000 ft altitude (at the dry adiabatic lapse rate). At 15,000 ft the ‘standard atmosphere’ is -15 degrees and at 25,000 ft the temperature is nominally -35 degrees. At Cooma, wave flights into the really extreme temperatures above say 30,000 have been rare and some of the extreme effects of the cold have not been encountered. Notwithstanding, individuals react differently, or on a particular flight a pilot may simply not be adequately prepared resulting in the pilot suffering the extreme effects at lower altitudes.

Without protection at low temperatures, the human body can suffer from frostbite, hypothermia, and eventually death. In a sailplane, protection from the cold is provided by warm clothing and solar radiation[17] through the canopy. To assist in keeping the feet warm, chemical foot warmers, obtainable from outdoor activity stores, have proven to be very useful.

As the body becomes cold, its in-built safety mechanisms adjust the blood flow to keep the vital organs, including the brain, heart, lungs, etc warm. The extremities such as feet and hands are the first to be sacrificed, receiving a reduced blood flow and being the first parts of the body to feel cold.

> Frostbite Without the oxygen and warmth provided by the blood, firstly fingers and toes can begin to freeze. Frostbite shows up firstly as a tingling sensation but then feeling is lost. If caught early, circulation can be restored but in extreme circumstances, amputation can become necessary. Wriggling your fingers and toes can assist in preventing the onset of frostbite by maintaining circulation, but if you suspect the onset of frostbite your best course of action is to descend to a warmer environment.

> Hypothermia If the body is unable to keep the vital organs warm and the body’s core temperature begins to drop, hypothermia has set in. This is a very dangerous situation. Symptoms can include the body stopping shivering from the cold, drowsiness, fatigue, a feeling of well being, sleepiness, delirium and ironically a feeling of being warm. The only cure is to get warm as quickly as possible. Hypothermia can be just as subtle as hypoxia and if a pilot suspects he might be suffering from its onset he should descent immediately, drink warm fluids, bundle up and seek medical attention if necessary.

In order to avoid the effects of extreme cold and, importantly, be able to enjoy the flight, a pilot must dress accordingly. It is probably true to say that one will never ever be really warm enough if any time is spent at altitude, but if dressed appropriately reasonable comfort can normally be achieved. The general principle is that two thin layers of loose fitting clothing are better than a single thick layer. The layers will trap the air providing insulation which helps to retain body heat.

Many people successfully wear full length thermal undergarments followed by corduroy or woollen trousers, a flannelette or woollen shirt, two light woollen jumpers covered by a warm coat and/or some sort of flying suit over the lot. A thin pair of thermal or silk gloves inside a pair of heavy woollen gloves (mittens will be warmer, but are more clumsy in the cockpit) can provide good protection for the hands. A significant amount of body heat can be lost from the head so wear a warm hat over your head. Depending on

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[17] Solar heating can be particularly effective. On a clear day with continuous sunshine through the canopy the cockpit can remain surprisingly warm at high altitude. However, beneath an overcast the cockpit can become bitterly cold. If a high cloud cover exists prepare for a very cold flight.

your oxygen mask a balaclava type hat or a beanie and a lightly fitting neck choker, or scarf, to put round your neck and under your chin will add comfort. Whilst not covered here you will probably flying with the air vent fully open to minimise canopy frosting, thus covering all exposed skin is very important.

normal footwear. Remember you will need to have enough room under the panel and on the rudder pedals for whatever solution you choose.
Do not wear heavy leather hiking or working boots as these boots can conduct the heat away from your feet quite quickly.

Finally, pay particular attention to keeping the feet warm. Two layers of woollen or thermal socks inside a pair of warm boots are the minimum. They should be absolutely dry to give maximum insulation. Consider changing socks immediately prior to take off including liberal amounts of talc powder to soak up any perspiration that might have accumulated whilst carrying out the usual pre-flight chores. As mentioned earlier chemical foot warmers, obtainable from outdoor activity stores, have proven to be very useful Also, apparently electric socks, which can run for a surprisingly long time on small dry cells, can also provide relief from the cold. Various boots ranging from insulated boots, through those of the 'ug' variety or the foam plastic apres ski boots work well. Snowmobile boots apparently are also quite effective. Another method is to use insulated 'over boots' which zip up over

Notwithstanding, make sure that your boots will be retained during the opening shock phase of a parachute descent. Should bale out be necessary, loss of boots during a parachute descent in many of the regions around Cooma, particularly over the main range would be most hazardous. Further they should be sturdy enough for a walkout following an outlanding.

When considering the best form of clothing in which to keep warm, remember that you will not be undertaking any exercise in the cockpit and that some of the clothing available for cold environments, such as skiing, is designed to provide warmth during physical activity and may not be appropriate for the inactive situation.

Finally – Urination and Hydration

Of course we all know that the cold encourages urination. As we climb into a cold environment, the body cools, and as earlier discussed, shunts blood away from our extremities. Accordingly, the blood is preserved in our core and the body starts to develop a sense of "fullness". The kidneys responding by getting rid of the "fullness" and deposit "excess" fluid into the bladder. Then we will need to urinate. This process is one of volume depletion and is referred to as *cold diuresis*. There is little that we need do about it except to drink to stay just ahead of thirst. Don't overdo the drinking since the body will secrete any excess intake into the bladder. (The less that we allow ourselves to get cold, the less the effect - another reason to stay as warm as possible.) However we need to consider our descent. If/as we warm up during the descent – and this will be more relevant during the warmer months - the body goes through the reverse process and we will need to rehydrate as we warm up. We should rehydrate commensurate with the warming process so drink during the descent as dictated by warming, but ensure that you rehydrate immediately when back on the ground.

Rule is:

If you have been cool or cold, rehydrate as soon as you begin feeling warmer.

SUMMARY

High altitude wave soaring can be an exciting and rewarding experience. The beauty of the cloudscapes and the solitude of the occasion can be truly awe inspiring.

However, the previous discussion presents some of the potential dangers associated with high altitude flight. Notwithstanding, if you are in good health, know the effects of altitude on the human body and fly within your limitations you should be confident of making safe climbs to high altitude with low risk.

Know your oxygen system, and when carrying oxygen always assume that a high climb is possible and prepare accordingly.

Finally, if you have any system or physiological problems whilst climbing when above 10,000 ft, normally the best course of action is to commence rapid descend, select maximum oxygen flow, check oxygen connections, and maintain a normal breathing rate.

In addition to the articles mentioned in the earlier footnotes an Additional Reading section is provided at the back of this document for the readers interest and education.

Between Colinton and Michelago circa 1995 by Paul Wiggins

FLYING HIGH

Peter, a former RAF doctor, explains just what happens to the body during high altitude flight and warns that the great danger of hypoxia is that it is insidious

Peter is a doctor and pilot who spent most of his career in the Royal Air Force. Learning to fly in the University Air Squadron whilst a student at Bristol, he later completed his RAF wings and flew a range of military aircraft. His professional career has been in Aviation, Occupational and Public Health Medicine. Gliding since 1960, he has three Diamonds. A life member of the RAFGSA, he has been a club CFI, secretary and vice-chairman. As well as providing medical advice, he has served the BGA on the Executive Council and Instructor Panel. He was responsible for the present BGA system by which the fitness of pilots is assured. Having retired from the RAF as an Air Commodore, he now works for the NHS in Wales and flies from Talgarth.

The upper atmosphere is an inhospitable, cold, dry and rarefied place. Man evolved in the denser, warmer and moister layers and is well adapted to these conditions. Those few who have visited high mountain ranges know their bleak and hostile climate. The highest sites of human occupation are at 17 000ft and the inhabitants have had a long time to become acclimatised to the harsh conditions.

Our problem is that, given the soaring opportunity, even the simplest club glider can ascend to these unfriendly levels in less than an hour. Gold height is as far as one can safely climb without consideration, Diamonds require knowledge and equipment. To avoid danger, it is necessary to be aware of the adverse factors, and to understand and use the oxygen system. The hazards arise from low oxygen levels, low temperatures and changing pressures.

Oxygen is essential to support all animal life and the requirements of our bodies are met by the gaseous oxygen that comprises about one fifth of the air we breath. Most of the rest of the air is nitrogen, with small quantities of rare gases, water vapour and carbon dioxide. Because the atmosphere is mixed by winds and convection, the composition of the atmosphere is the same at all flyable heights and places, although cold air will carry less water vapour. Atmospheric density roughly halves every 18 000ft, and the oxygen falls proportionately.

Our lungs are the organ which exchanges carbon dioxide for oxygen; internal gases are in equilibrium with the blood. To prevent the lungs from drying out, lung gases are saturated with water vapour at body temperature and air is humidified in the nose, which is the reason our breath steams on a frosty morning. It is also why medical oxygen systems are unsuitable for use in aircraft; the warm exhaled moisture will condense and freeze in the mask.

So long as we are alive, carbon dioxide will be coming out of the blood into the airsacs of the lung, and oxygen will be transferring from the lung into the bloodstream. Compared to air, lung gases are moist, contain more carbon dioxide and less oxygen. At altitude the absolute quantities of water and carbon dioxide will remain the same, leaving even less room for oxygen.

The rate and depth of respiration is driven by the level of carbon dioxide in the bloodstream. Physical exertion increases the metabolism in the muscles, raises the carbon dioxide level in the blood, stimulates ventilation and facilitates the transfer of oxygen from the blood to the tissues, restoring equilibrium. Healthy bodies have a considerable reserve capacity for exertion, therefore when at rest, we can accept a reduction in the level of oxygen of the air that we breath. At 10 000ft atmospheric pressure is 65% of sea level pressure, but oxygen in the blood is at 90% of sea level saturation. Even at this level, a small reduction in pilot performance can be demonstrated, but under favourable conditions, ascent to 12 500ft by a fit and healthy pilot is safe. This is the limit when breathing air.

Trials in fit young military aircrew showed that between 10 000ft and 15 000ft the ability to perform skilled tasks is impaired; between 15 000ft and 20 000ft there is a marked deterioration of performance, with a loss of judgment and willpower. Above 20 000ft the symptoms become severe leading to unconsciousness. Above 25 000ft the onset of unconsciousness is so rapid the pilot has few warning symptoms. For safety, the cockpits of military fighters are pressurised to 25 000ft cabin altitude. The efficiency of the heart and lungs declines with age and fitness. Those of us who find ourselves breathless when rigging the two-seater would be well advised to subtract several thousand feet from all the altitudes quoted.

> ***"Any attempt to avoid hypoxia by deliberately over breathing will be disastrous"***

The great danger of hypoxia is that it is insidious and, as with alcohol, the sufferer fails to appreciate the degree of performance deterioration. Experience of hypoxia in a chamber is useful, but is no substitute for following the rules, and monitoring the oxygen system in flight. Any attempt to avoid hypoxia by deliberate over breathing will be disastrous, because it washes out the carbon dioxide in the bloodstream and stops oxygen from transferring to the tissues. One cannot improve on the natural biochemical mechanisms.

In a climb, the effects of hypoxia can be delayed by adding oxygen to the inspired air; this maintains the partial pressure of oxygen in the lungs at altitude by displacing nitrogen. Good demand oxygen regulators have internal capsules which control the mixture automatically. At 34 000ft they will deliver 100% oxygen to maintain sea level values. Climbing above this altitude, even when breathing 100% oxygen, will result in increasing hypoxia and at 40 000ft is equivalent to breathing air at 10 000ft. Above 40 000ft the fall in saturation is very rapid and hypoxia can only be prevented by pressure breathing. In gliding usage, masks are seldom free of leaks and it is impossible to assure 100% oxygen; 35 000ft is a prudent altitude limit without specialist support.

Shortage of oxygen in the upper atmosphere is compounded by low temperatures. On average, the temperature falls by 2°C for every 1000ft. In the UK, freezing level is rarely above oxygen level. The experiences of glider pilots resemble those of bomber crews in World War 2. They spent long periods in over ventilated, unheated aircraft at around 15 000ft. When the body is both cold and short of oxygen, it will not shiver and body temperature may fall. This hypothermia slows all mental processes and makes frost-bite more likely.

It was probably the mechanism of what used to be called "chronic anoxia". This was distinguished from "acute anoxia" by the failure of oxygen or descent to produce a rapid cure. Because body temperature is slow to rise, the pilot will not recover on the descent, and is vulnerable to flying errors on landing. Oxygen protects against the cold, but keeping the body warm also reduces the oxygen requirement and indirectly protects against lack of oxygen. These are not theoretical hazards. I have seen both frost-bite and landing accidents when on wave expeditions in Scotland. The altitude sickness suffered by mountaineers is secondary to prolonged hypoxia, and is not a problem for aviators.

One can keep warm by the use of suitable clothing; any winter sports shop stocks an excellent range of thermal garments. The practical problem is to dress after the sweaty exertion of rigging and pushing out the glider. Snow boots are cheap good insulators. I have used electrically heated socks, but these consume power. A flying helmet will keep the head warm, as well as securing the oxygen mask. Never ever fly to altitude with wet feet; frost-bite can permanently cripple your activities. The RAF pattern gloves are the best compromise between insulation and dexterity and green ones are warmer than the white.

Gliders climb relatively slowly, and those who respect their gel coats descend with caution; but even at low levels, pressure changes can cause problems. Air in the ears and sinuses escapes in the climb, and re-enters on the descent. Ventilating one's ears is a matter of practice. If one is foolish enough to fly with a cold, the mucous may block the passages to ears or sinuses leading to severe pain on the descent. If this happens, and the soaring opportunities allow, it is recommended to climb until the symptoms disappear, wait a little, and then recommence a slow descent. Gas is normally present in the gut, and there should be no social inhibitions about releasing flatus from either end!

Prolonged flight above 20 000ft brings a theoretical risk of decompression sickness. This is the same disease as can afflict divers, and is caused by nitrogen bubble formation. The older, obese and previously exposed are more vulnerable. It is a serious disease which may show itself by a variety of symptoms; coughing, pains in joints, or the skin can itch. It is cured by immediate descent; compressing the bubbles, will give an instant cure. Self diagnosis is unreliable so that if one is feeling in any way unwell at altitude, whatever the temptation, it is always wiser to descend. With the airbrakes out, few gliders will come to any harm, even with a temporarily incapable pilot.

Above the clouds, there is little attenuation of solar radiation, indeed the sun contributes to keeping warm. Sunglasses are essential but the low density orange ones, so effective in bright haze, are unsuitable for use at high altitude. Darker greener ones are more useful.

The deserts of high altitude are so near, but so hostile. To explore safely, one must dress properly, understand one's oxygen system, follow the procedures and recognise one's personal limitations. When in doubt, descend and fly again another day. In an emergency, just get the airbrakes open.

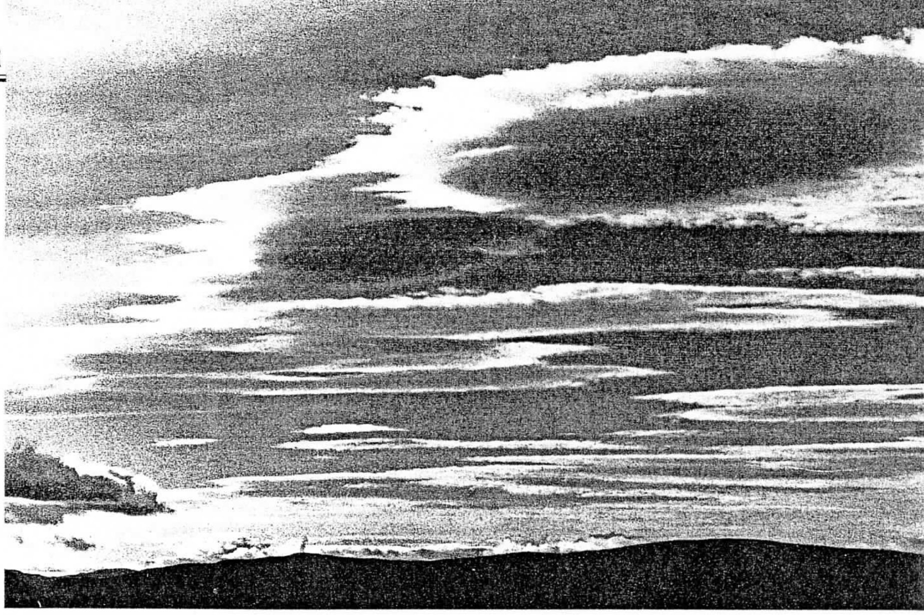


Photo: I.D.Parker.

THE RISKS OF WAVE FLYING

The photograph above looks idylic but gliding at high altitude needs to be treated with respect. This is emphasised in both the introduction by Pete Harmer and the OSTIV paper presented by Pete and Bob Weien

Grounded for three years because of ignorance - an incident described by Pete

A pilot was flying a wave cross-country and had been at high altitude for about four hours when he was suddenly attacked by a searing headache. The pain was of such ferocity that he could no longer really concentrate on flying the sailplane, but through the discomfort he thought it best to get on to the ground before something disastrous happened. During the descent the pain eased a little and he managed to fly to his home airfield.

Once on the ground the headache had gone but the pilot felt completely drained of enthusiasm for anything, except for going to bed for a long sleep.

This he did, but on waking next morning he found one arm numb and devoid of any sensation. The pilot, thinking that this was getting a little serious, decided to go to his doctor to get things sorted. The doctor diagnosed a transient ischemic attack, a transitory stroke, and immediately grounded the pilot!

It took the luckless pilot three years to convince the medical and licensing authorities that this was a wrong diagnosis and that he should be allowed to continue flying. He is flying again and representing his country at World Championships.

What was the real reason for this pilot's incapacitation?

All the evidence available suggests that the he suffered an attack of decompression sickness (DCS). It was quite obvious that with time the pilot has totally recovered, but a course of recompression therapy on the day of the event would have ensured a speedier result and he would have been able to be flying again 48hrs after the event.

It is hardly surprising that the doctor did not diagnose DCS as I doubt if he had even heard of the problem, except perhaps in association with divers rather than fliers, let alone seen a case before this one.

In my casual discussions with glider pilots about DCS the response ranges from mild confusion to total ignorance. In this article we will try to unravel the confusion and remedy the ignorance, but one fact to start off with is that decompression sickness is not hypoxia or lack of oxygen.

Flying at altitudes above, say, 15 000ft is full of danger to catch the unwary and can be divided into four areas:

1. Hypoxia, which was dealt with by Peter Saundby in his excellent article in *1993 S&G Yearbook*.
2. Trapped gas within the body, which expands with increasing height and is only unpleasant when it gets vented. Voids (sinuses and inner ear) within the head may not equalise pressure on descent and cause pain.
3. Cold, which has been written about before but basically prepare for it by wearing many thin layers of clothing. However warm it is on the airfield, it is always cold at altitude.
4. Decompression sickness, which we cover in the paper we gave at the OSTIV Congress held with the World Championships at Borlänge, Sweden in 1993 and reproduced from *Technical Soaring*.

DECOMPRESSION SICKNESS IN HIGH ALTITUDE GLIDER OPERATIONS by Robert W. Weien and Peter M. Harmer, RAF IAM, Farnborough, England.

Introduction

High altitude glider operations possess the potential for causing decompression sickness (DCS), as a consequence of the altitudes reached and the times spent at those altitudes. The risk, and therefore the incidence, should be higher in glider pilots than in military pilots, because of the general lack of preventative measures taken in soaring. This paper discusses DCS in general, the risk in glider operations, and briefly describes a study which attempted to establish the incidence of DCS in the gliding community.

DCS is the medical condition which occurs as a result of the reduction in ambient barometric pressure to such a degree that inert gas dissolved in the blood and tissues comes out of solution and forms bubbles. It is most commonly associated with diving, but also occurs in the aviation environment.

Physiology of DCS

The fluids in the body contain inert gases, in quantities consistant with Henry's Law. This states that the amount of gas that will dissolve in a liquid at a given temperature is directly proportional to the partial pressure of that gas over the liquid. All gases are absorbed and eliminated according to this law, but most gases are either metabolically active or have a partial pressure too low to be of significance.

The inert gas of primary interest in DCS is nitrogen, since it constitutes 79% of the atmosphere. It is not metabolised, thus it is absorbed and eliminated from the tissues and body fluids passively. The body tends towards saturation with nitrogen, so a diver absorbs additional nitrogen when breathing underwater under high pressure. When the diver returns to sea level pressures, the excess nitrogen must be eliminated.

Nitrogen is absorbed and eliminated through the lungs, and further dissemination through the circulatory system. Different tissues have different rates of absorbtion and elimination, complicating the issue of predicting total body nitrogen levels. This area has been extensively researched, primarily in the diving environment, as part of dive table development.

When a body has been at sea level for a prolonged period (days), it is saturated with nitrogen. An ascent to higher altitude (lower pressure) results in supersaturation, and the body begins to off-gas the excess nitrogen. The degree of supersaturation necessary for bubbles to form is defined by the critical supersaturation ratio:

$$PN2 / PB = CSR$$

in which PN2 is the partial pressure of nitrogen at the equilibrated altitude, and PB is the total barometric pressure at the altitude of interest. In aviation we are rarely concerned with mixed gas use, so only air (79% nitrogen, 20.9% oxygen) is considered here. For air the CSR is 1.58.

Bob Weien is a Lt Col and doctor in the US Army, and has been an exchange officer at Farnborough for three years. Bob has a US PPL for aircraft, helicopters and gliders and owned a Nimbus 2 when in the USA. Pete Harmer is a physicist and has worked at RAF IAM and CHS for the last 12 years on altitude life support and protection. Pete started gliding at Farnborough in 1964 and is now a Full Cat instructor with two Diamonds and 2500hrs. He, with his wife Jill, has flown their K-2B from many sites throughout Britain and several in Europe, and they have often been seen local soaring Lasham in their shared Nimbus 3DM.

When a reduction in pressure is made which exceeds this level then DCS becomes possible. For those equilibrated to sea level pressures (760 mmHg), this occurs at approximately 18 500ft. The CSR threshold is based on the assumption that the linear ascent threshold well known in the diving community extends into the altitude realm. Recent studies in the USA indicate that the altitude threshold may actually be considerably lower. Nonetheless, 18 500ft can be used as a rule of thumb in describing the potential onset threshold.

Clinical features of DCS

Once bubbles form, they can have a variety of effects ranging from simple joint pain, through to death. The degree of symptoms and their location depend on the number of bubbles, and where they travel after they have formed. Bubbles cause symptoms through two basic mechanisms; mechanical effects and surface activity effects.

Mechanical effects are those which occur as a result of the physical presence of the bubble. These include obstruction of blood vessels and tissue distortion or disruption. When a vessel is obstructed the flow of blood downstream in that vessel is restricted or eliminated, resulting in symptoms of tissue hypoxia. Tissue changes can be caused by the expansion of gas bubbles through the effect of Boyle's Law which states that as ambient pressure is reduced, a bubble will expand, and exert force on the surrounding tissues.

The surface activity effects are those resulting from the body's active response to a foreign body. The surface of a bubble is viewed as a foreign body and several systems respond to it as such, including the complement cascade and platelets.

Common presentations of altitude DCS include joint pains (the "bends"), skin symptoms (often itching), neurologic symptoms (headaches, numbness, or paralysis) and respiratory symptoms (shortness of breath, substantial chest pain).

A number of factors which influence the onset of DCS have been noted, these include:

1. Exercise. Physical exercise, especially during or in the hours immediately after an altitude exposure, increases the likelihood of DCS.
2. Cold. Low temperatures increase the risk of DCS, probably due to vasoconstriction resulting in poor perfusion of peripheral areas (poor circulation). This, in turn, leads to incomplete clearing of nitrogen from the poorly perfused tissues.
3. Age. Increasing age increases risk.
4. Obesity. Fat is a long half-time tissue: that is, it absorbs and eliminates nitrogen over a much longer time course than "fast" tissues, such as blood. This leads to localised areas of increased off-gassing gradient where bubbles can form.
5. Dehydration. This leads to reduced circulating blood volume, and poor perfusion, and can result in incomplete clearing of excess nitrogen.
6. Physical injury. Inflammation associated with an injury is a common site for DCS symptoms.
7. Flying after diving. If one has participated in diving activities and absorbed extra nitrogen, this increases the total need for nitrogen elimination and lowers the altitude at which the CSR will be exceeded.
8. Gender. Females are at significantly higher risk of DCS than males.

The onset of symptoms is usually rapid. Approximately half the cases occur while at altitude, or in the first hour after return to ground level in altitude chamber runs. The initial symptom occurs within 12 hours in 86% of cases and within 24 hours in 97%.

DCS responds well to correct treatment. Recompression therapy in a hyperbaric (diving) chamber is the standard treatment: in a recent ten year review of the USAF's experience with altitude DCS, 98.5% had complete resolution. In the absence of a hyperbaric chamber, or until a patient can be transported to one, 100% oxygen should be breathed, (this treatment is not as effective, however).

Prevention of DCS

The rate of DCS can be reduced through preventative measures. If 100% oxygen is breathed then nitrogen is cleared from the system in a process termed denitrogenation. This is somewhat of a misnomer, however, since denitrogenation results only in partial elimination of nitrogen from the body. The longer the course of denitrogenation, the higher the threshold for DCS. Symptoms are also less likely to be severe. The RAF uses a 30min denitrogenation schedule before ascent for altitude training above 30 000ft.

How big a problem is DCS in aviation? Estimates of incidence are usually made from records of military altitude chamber training. A number of these have been published in recent years. The range is from approximately 0.5 to 3 cases per 1000 exposures.

Potential for DCS in gliding

The potential for DCS in high altitude glider operations is great, for a number of reasons:

1. The altitudes reached are high enough for DCS to occur. Flights above 25 000ft are common. The British altitude record is now over 37 000ft.
2. No preventative measures are taken against DCS. Wave pilots typically do not don their oxygen masks until at 10 000ft or above.
3. Oxygen systems in gliders are not standardised, and so may not provide 100% oxygen. Denitrogenation may not occur, even when the mask is in place.
4. There is no method to alert pilots with predisposing factors, to allow them to reduce their risk.

The incidence of DCS in high altitude glider operations would therefore be expected to be higher than that experienced in military aviation. We have not been able to find any reported cases of DCS among glider pilots, in the medical literature, or in gliding publications, or *via* informal inquiries at several gliding sites known for wave prior to writing this paper. But subsequently several cases, including the one heading this article, have come to our attention although not always directly from the pilot concerned.

DCS incidence study

The Centre for Human Sciences of the Defence Research Agency (ex RAF Institute of Aviation Medicine) at Farnborough began a study to establish the incidence of DCS in glider pilots during the wave season 1993-1994, comprising a questionnaire based survey of pilots returning from wave flights.

The two possible outcomes could have shown:

1. The anecdotal evidence is correct and DCS occurs much less frequently in the glider population than in military aviation. This would be a suprising result, and would require further investigation of glider flight profiles to determine the reason. If true, then lessons learned could be applied to military aviation.
2. Glider pilots have an incidence of DCS as high or higher than military experience would suggest. This is the most likely outcome, and could be used as a basis for communicating DCS prevention techniques to wave flying pilots in an effort to enhance safety.

Pete concludes

DCS is a likely side effect of high altitude glider operations, but is a risk which can be minimised through the use of proper preventative techniques. There was a study (1993-94) to determine the size of the DCS problem in gliding but unfortunately, for many and varied reasons, it floundered fairly early on and long before any statistically correct sample had been reached. The idea behind this study was NOT to gain evidence to put any sort of restriction on altitude flying, I enjoy it as much as anyone, but to gain an insight into a previously unmentioned problem to enhance the safety of our sport.

However what I would now like to try is for pilots having read this article who think they could have suffered from DCS, to let me know - any personal details will be kept confidential. I believe there are many pilots who have suffered from mild DCS and have just thought that the joint pain was due to the cold, cramped cockpit and the headache to a heavy session the night before. Mild symptoms will invariably disappear on descent and will possibly be forgotten in the wild story telling that evening. Could anyone who has had any strange symptoms or sensations, which cannot truly be put down to hypoxia or anxiety, during or after a flight to above 10 000ft please write giving details to P. Harmer, Aeromedicine and Neurosciences, Centre for Human Sciences, Defence Research Agency, Farnborough, Hants GU14 6TD.

ADDITIONAL READING

The following reading provides further discussions on:

- Hypoxia,
  Flying Safety Spotlight 3/98
  Flight Safety Australia, July 1998
  Flight Safety Australia, Nov-Dec 2000

- Decompression Illness (DCI),
  Flying Safety Spotlight 3/98

- Depressurisation
  Flight Safety Australia, Mar-Apr 2000

HYPOXIA
ARE YOU PREPARED FOR IT?

by SQNLDR Noel Derwort CFI, CFS

I recall completing my first hypoxia training at AVMED while on my pilot's course. All the students paid the appropriate amount of attention to the lecturers. This was, after all, a 'very real issue', and although we weren't examined on the subject 'your life could depend on it'.

I was young and probably very naive. Despite all my best intentions, I wondered if those very minor symptoms of hypoxia I experienced in my first chamber run would really ever attract my attention.

By the time I conducted my first refresher training, I was well into the aircrew attitude which permeated all the boggies of the day (*'if it wasn't actual flying it wasn't important'*). I did, however, recognise that my hypoxic symptoms were still the same as experienced during my earlier training, only less noticeable. I continued to wonder if I would ever notice these seemingly minor physiological warning signs while flying.

Learning the hard way!

Several years later whilst on exchange flying T-38 Talons, I was programmed for a solo continuation sortie. The profile called for a climb to FL330 and then a transit to a nearby field for some approach work, prior to returning to base. It was a hot day in the middle of the desert on the Texas high plains and the sortie was my second for the day. I was somewhat fatigued as the work ethic in the unit at the time required instructors to be at work for an average of 60 hours per week. Normal briefing time for the day was two hours prior to sunrise so that all flying could be completed before the temperature became extreme and curtailed flying.

As I taxied out I felt a little fatigued and hot although it was great to have the opportunity for a solo, so I was keen to launch. Shortly after take-off and passing 10 000 ft I completed the climb checks – including oxygen – and noticed that I was feeling slightly apprehensive. I put down my nerves to heat and fatigue and continued. However, passing transition at 18 000 ft, I felt the hair on my neck standing on end and my skin was 'creeping'. At this point muted alarm bells were going off in the back of my mind; however, I disregarded them. Next, passing FL250 I suddenly remembered why all of these symptoms made me so uneasy – ***hypoxia***.

I gangloaded the regulator (which took two attempts), squawked emergency (it took three tries to get my hand onto the IFF), and commenced a rapid descent. All my symptoms got dramatically worse; however, I dutifully ignored it as oxygen paradox.

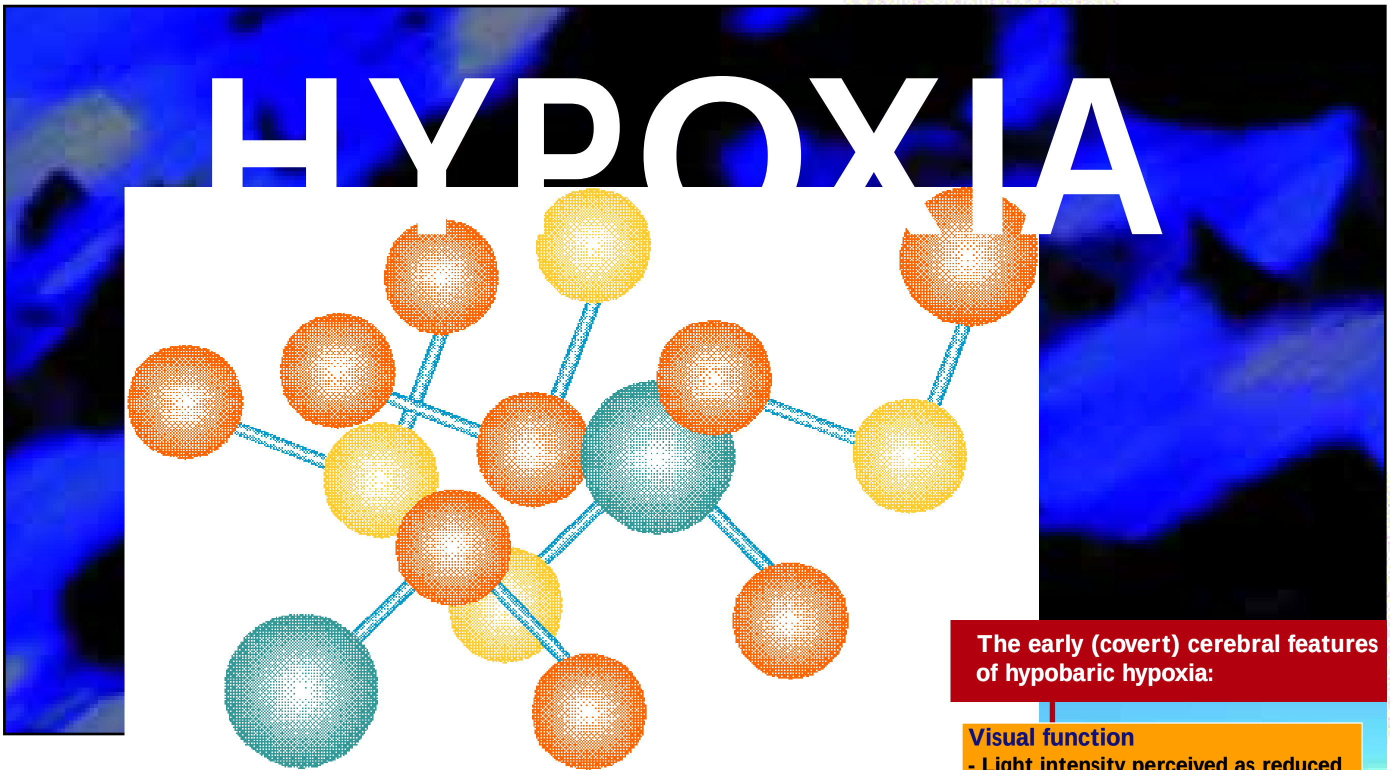
After some time, when I didn't notice any improvement, I discharged my emergency oxygen bottle and disconnected from the main system. The high oxygen pressure generated from the bottle made speaking almost impossible which, combined with my Aussie accent, did nothing for the American controllers.

During this latter period I was wondering at what point do I eject! After all, I wasn't really in control of my actions, so would I have the awareness to make that decision? I decided against an ejection and stayed with the aircraft. After landing I needed to be helped from the aircraft. The resulting investigation found the oxygen regulator to be faulty.

Several sorties later, during my pre-flight inspection, I discovered my emergency oxygen bottle was empty and I instantly thought of what could have happened.

On my next AVMED refresher I was a very keen participant, thankful for the training and the reminder of those critical symptoms for me. I learnt a lot from the sobering experience of being hypoxic whilst solo. Hopefully, you won't ever have to learn the hard way like I did. ✈

HYPOXIA



Flying fox (2)

Without oxygen the body cannot function. Reduced oxygen intake can degrade mental and physical performance – even at altitudes as low as 4,000ft.

JEFF BROCK & ROD BENCKE

"YOU OKAY, DAVE?" I WAS TALKING, but he wasn't answering. "Dave!" It was close to a shout. "Huh?" I'd woken him at last.

"Check your altitude, you're climbing like a homesick angel."

Dave was a competent pilot, but on this day he was having some trouble. He didn't seem focussed, and he was all over the sky. We'd been flying for an hour. He was fine when we started, but he seemed to be having a difficult time as the flight progressed. We were going from Jervis Bay to Wagga, and as we climbed over the Snowy mountains, Dave's condition worsened. He corrected the errant climb and I returned my attention to the open chart in front of me.

Suddenly, I had this feeling that something was wrong. I looked up to see trees in front of us on a 6,000ft ridge. And they appeared to be coming closer.

The chart flew off my lap as I grabbed the yoke. I didn't think about stalling, I just wanted to see sky again. I pulled back hard and the aircraft nosed up, a little lower than I'd have liked, but enough. Dave didn't fight me, he just let me correct him.

"I got it Dave." The trees below rustled, leaves loosened by our wake were scattered about. Dave let go as the windscreen went from green, to blue and back to half-green and half-blue on top. I looked over at him and he stared back at me, vacant but scared. "You okay?", I asked. "Uh?", he answered, still staring vacantly. I flew the rest of the way.

I later realised that Dave was suffering from hypoxia, a lack of oxygen – I knew I wasn't affected, but I should have known sooner that Dave was in trouble.

So what happened? One reason Dave was affected by hypoxia and I wasn't is that Dave smokes a packet of cigarettes a day. That means when Dave and I are lying on the beach, he is still doing flight time. Physiologically, he's at 5,000ft, while, as a non-smoker, I'm still at sea level. Smokers absorb far more carbon monoxide into their blood than non-smokers, and the carbon monoxide reduces the blood's ability to carry oxygen. The bottom line is: if you smoke you may be affected by hypoxia at a much lower altitude than a non-smoker.

There are things other than smoking that can speed up the onset of hypoxia, or worsen its severity. Alcohol and its lingering effects can leave you physiologically 2,000ft higher than someone who is not hung over. Illicit drugs, prescribed medications and even some over-the-counter cold medications can worsen the effects of hypoxia. If you have a chest infection you are already

The early (covert) cerebral features of hypobaric hypoxia:

Visual function
- Light intensity perceived as reduced
- Visual acuity diminished in poor illumination
- Light threshold increased
- Peripheral vision narrowed

Psychomotor function
- Choice reaction time impaired
- Eye-hand co-ordination impaired

Cognitive function
- Memory impaired

The overt features of acute hypobaric hypoxia:

- Personality change
- Lack of insight
- Loss of judgement
- Loss of self-criticism
- Euphoria
- Loss of memory
- Mental uncoordination
- Muscular uncoordination
- Sensory loss
- *Hyperventilation*
- Semi-consciousness
- Unconsciousness
- Death

- Dizziness
- Lightheadedness
- Feeling of unreality
- Feeling of apprehension
- Neuromuscular irritability
- Paraesthesia of face extremities
- Carpo-pedal spasm

source: Aviation Medicine. J.Ernsting, P. King, 1998

Improved performance

ANDREW THOM

The benefits of using supplemental oxygen for long flights below 10,000ft.

A PILOT'S PERFORMANCE AFTER A couple of hours at 5-8,000ft does seem to be different. How come the engineer who did 4 years of university maths can't even add up in the air?

I remember arriving at Essendon in the mid 1980s, after a flight from Adelaide in a 172. It was 2am and I had come alone, at 8,000ft and over the top from the Adelaide Hills to Bacchus Marsh. The fatigue was extreme and I would have avoided any task that required actual thought. But was it only fatigue?

Someone recently suggested to me that there are significant advantages in using oxygen below 10,000ft where it is not mandatory. So I tried it.

What a difference! The extreme fatigue was not there, and calculation did not meet the same block. Other pilots who use oxygen at low levels report similar effects.

The Australian regulations say that over 10,000ft you must use supplemental oxygen.

Rob Fox

Andrew Thom says when he uses supplemental oxygen he experiences less fatigue and improved concentration. Other pilots report similar effects.

The US Federal Aviation Administration (FAA) limits unpressurised commercial flying with no oxygen to 10,000ft, but permits private pilots to operate to 12,500ft, as a concession to their terrain.

In 1996 the FAA's Civil Aeromedical Institute studied the performance of 20 private pilots in simulator flights while breathing oxygen concentrations equivalent to sea level, 8,000ft, 10,000ft and 12,500ft. The study concluded: "Errors made by the reduced oxygen group were far more serious".

Until the 1950s and 1960s, oxygen equipment was awkward, heavy and expensive, and introduced a new set of risks and skills for the pilot, so general aviation grew up without it.

In the early 1980s, a development in an unrelated field offered to change the situation. Smoking related and other illnesses produced a large number of patients discharged from hospitals with reduced lung function. There was a need for lighter, portable equipment to allow these people some mobility. The nasal cannula went part of the way, by feeding the oxygen up the nostrils and leaving the mouth free. It still consumed the same flow of oxygen.

Then the Oxymizer nasal cannula was developed. It maintains the same blood oxygen level with only one-third of the flow needed by a mask.

Applied to aviation, these devices open some new possibilities. With cannula flow rates of only 0.7 litres per minute at FL180, as opposed to 1.8 for a mask, a 5kg portable cylinder (C size) will last for 11 hours. At 10,000ft, using only 0.3 litres per minute, the same cylinder goes for 24 hours.

Because of the large existing market, C size medical oxygen cylinders are available at over 800 distributors throughout Australia. These can be used in an Approved System to supply supplemental oxygen to aircrew.

As well as permitting operation up to 18,000ft with only simple nasal dispensers, these developments make it practical to use supplemental oxygen below 10,000ft.

Why would a pilot want to? Well, that is hard to answer for anyone who hasn't used it and experienced the difference in alertness and fatigue.

Those who have don't need convincing.

Andrew Thom is the director of Electronic Force Management and chief pilot for Melbourne Air Taxis.

starting higher than someone else.

If you have ever felt exhausted after a prolonged flight at 8,000ft or 9,000ft, wondered why you get headaches during or after these flights, or ever caught yourself fudging navigation calculations because your brain seemed a bit fuzzy, you were probably hypoxic.

So what is hypoxia, and what are its effects?

Deprived tissues: Hypoxia is a physiological state where tissues are deprived of adequate oxygen and organs such as the lungs, brain, heart, and the eye, are adversely affected.

Once you climb above sea level, the partial pressure of oxygen in the ambient air decreases and you are exposed to a degree of hypoxia. One of the earliest effects is a subtle impairment of vision.

The onset of the effects of hypoxia can therefore be very subtle. Worse still, self-checking is normally ineffective. This is because one of the body's initial responses to a decrease in ambient concentration of oxygen is a sense of well-being or mild intoxication – you can be quickly lulled into a false sense of well-being.

Increase the altitude and the time of exposure and more serious symptoms occur. General clumsiness and trembling may be noticed, breathing becomes rapid, vision is degraded further, questions and answers may be ignored, and appreciation of aircraft attitude and situation may not be noted until after some delay.

You can expect mood changes which can take the form of hilarity, pugnacity or drowsy apathy. In extreme cases and at higher altitudes, you will lose consciousness.

Vision, judgement and lung function: Because the retina uses more oxygen than other tissues, vision is the first function to be impaired by hypoxia (especially night vision). A reduction in the ability to see dimly-lit objects – particularly during twilight – can be detected as low as 4,000ft.

When you fly in twilight, you are using your mesopic vision – a time when your vision receptors in the retina are working in truly adverse circumstances – the rods for night vision, and the cones for colour. In conditions of dim light, the retina uses the last remnants of colour from the cones and is only beginning to utilise the rods, which are not truly effective yet.

If you are hypoxic and flying during this twilight-time, your vision will be compromised. If you climb to a higher altitude, the effects will worsen.

If you are flying at night above 4,000ft, it is wise to turn up the intensity of the light

HOW HYPOXIA STARTS

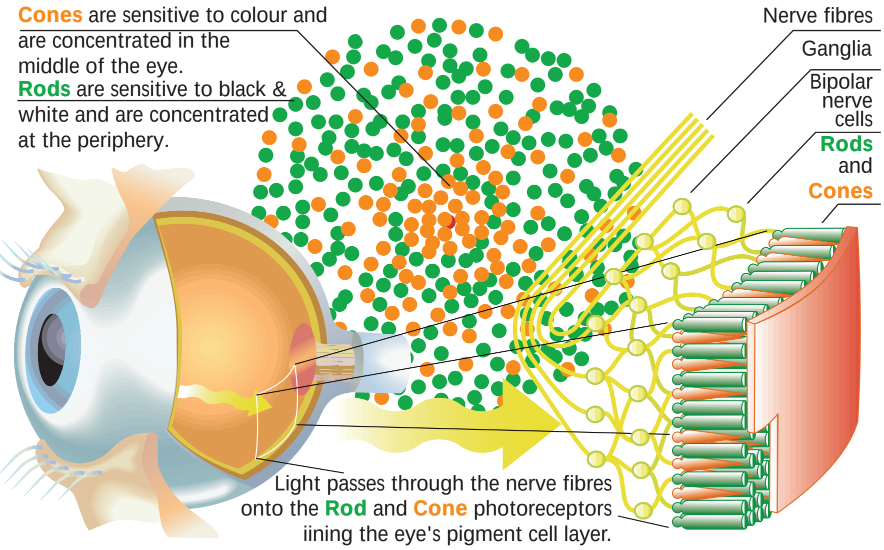
HYPOXIA AFFECTS THE GASEOUS exchange of carbon dioxide and oxygen in the body. At sea level, healthy people may have a 97-99 per cent oxygen saturation in their blood haemoglobin.

The body is a little like a heat machine. Just like an engine, it takes in fuel (food) and burns it to create energy. The burning process requires oxygen, and the correct amount of oxygen.

Oxygen from the air enters the bloodstream by passing across the surface of the lungs. Gaseous waste products, such as carbon dioxide, travel in the opposite direction – from blood to the atmosphere. The passage of oxygen into the bloodstream is governed by the partial pressure exerted by that gas in the lungs (approximately 21 per cent atmospheric pressure). While the proportion of oxygen in the atmosphere remains the same as one gains altitude, the total atmospheric pressure falls. Therefore the partial pressure of oxygen falls and so less pressure is exerted to achieve the transfer from lungs to blood. The blood receives less oxygen, which means the body is unable to burn its fuel properly and so starts to function less well.

To overcome this reduction in the partial pressure of oxygen, flight crew can increase the proportion of oxygen they breath by the use of an appropriate oxygen system.

EYES NEED OXYGEN



Peter Breis

The photo receptors in the eye's retina – the rods and cones – require extraordinary amounts of oxygen when compared with other tissues in the body. Rods are used for night vision, and are not colour sensitive. Cones are used for day and colour vision. Below: night vision is affected by even low-level hypoxia, which can make instrument lighting look dull.

in the cabin to help compensate for the impairment in your visual performance. You should use supplemental oxygen if available.

After vision, the tissues most affected by hypoxia are those areas of the brain associated with judgement, self-criticism and the accurate performance of mental tasks. This occurs at around 10,000ft in fit people with good lungs and at a lower altitude for smokers and others with certain medical conditions.

While 10,000ft is the ceiling above which oxygen must be used by flight crew members in unpressurised aircraft, some individuals with reduced lung function will become hypoxic well below that level and should consult their designated aviation medical examiner about the benefits of using supplemental oxygen. This includes people with chest problems such as asthma, chronic obstructive airways disease (emphysema), industrial lung disease, certain forms of anaemia, ischaemic heart disease or even mild degrees of heart failure.

Prevention: If you smoke more than 10 cigarettes a day, you have already rendered your oxygen intake deficient by 10 per cent or more. Smokers should avoid smoking before and during flight as it may degrade the ability to absorb oxygen.

Be wary of self-medication for a cold or hayfever, as these can aggravate the effects of hypoxia. You should be cautious about any medication which can induce drowsiness, as this will be increased by hypoxia – watch out for antihistamines and analgaesics containing a narcotic component (for example, codeine).

Hypoxia is aggravated by the cold, so keep a comfortable cabin temperature.

To ward off the effects of drowsiness, hang over, or lack of sleep, many pilots take stimulants, such as coffee, to keep awake. Caffeine may reduce drowsiness, but it will

PM Photography (2)

Impairment of night vision is one of the first effect of mild hypoxia. Instrument lighting looks dull (left), and greatly improves in clarity and brightness with only a little supplemental oxygen (right).

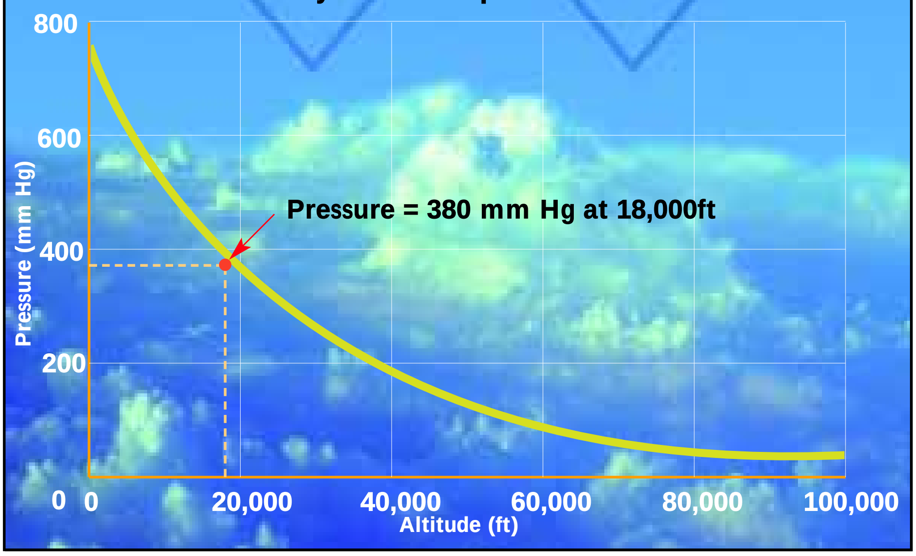
TIME OF USEFUL CONSCIOUSNESS

Altitude (ft)	Consciousness
15,000	30 minutes or more
18,000	20–30 minutes
22,000	5–10 minutes
25,000	3–5 minutes
28,000	2.5–3 minutes
30,000	1–3 minutes
35,000	30–60 seconds
40,000	15–20 seconds
45,000	9–15 seconds
50,000	6–9 seconds

PRESSURE AND ALTITUDE

Altitude ft	Altitude m	Pressure hPa	Pressure lb/in²	Temperature °C
0	0	1,013.25	14.70	+15.0
5,000	1,525	843.1	12.23	+5.1
10,000	3,048	696.8	10.11	-4.8
15,000	4,572	571.8	8.29	-14.7
20,000	6,096	465.6	6.75	-24.6
25,000	7,620	376.0	5.45	-34.5
30,000	9,144	300.9	4.36	-44.4
35,000	10,668	238.4	3.46	-54.2
40,000	12,192	147.5	2.72	-56.5

The exponential relationship between the pressure exerted by the atmosphere and altitude



Flying fox

not improve your tolerance to the effects of hypoxia.

Supplemental oxygen or descending to a lower altitude, if it is safe to do so, are the only ways of treating hypoxia.

CAO 108.26 was amended in January 1996 to enable the use of oxygen canula systems, which deliver oxygen through "nose prongs". This portable system is relatively inexpensive and is very flexible and economical.

If you fly regularly on extended unpressurised flights at or around 10,000ft you should seriously consider the use of supplemental oxygen. Oxygen use also frees the pilot from the 10,000ft altitude limitation, opening up the possibility of superior weather avoidance, particularly in the winter months, and offering greater fuel efficiency and therefore greater range.

Fire danger: When using supplemental oxygen, remember that pure oxygen is a fire danger. You need to make sure that your oxygen cylinder is approved, stowed, serviced, and maintained properly. You should avoid any sources of ignition inside the cabin, such as cigarette lighters. Do not use petroleum-based products – such as vaseline or lipstick – on your face when using supplemental oxygen as these can react adversely when in contact with 100 per cent oxygen. Burns to the lips and mouth have been reported.

Single pilots are most at risk from hypoxia because there is no-one to notice the subtle changes that indicate its presence.

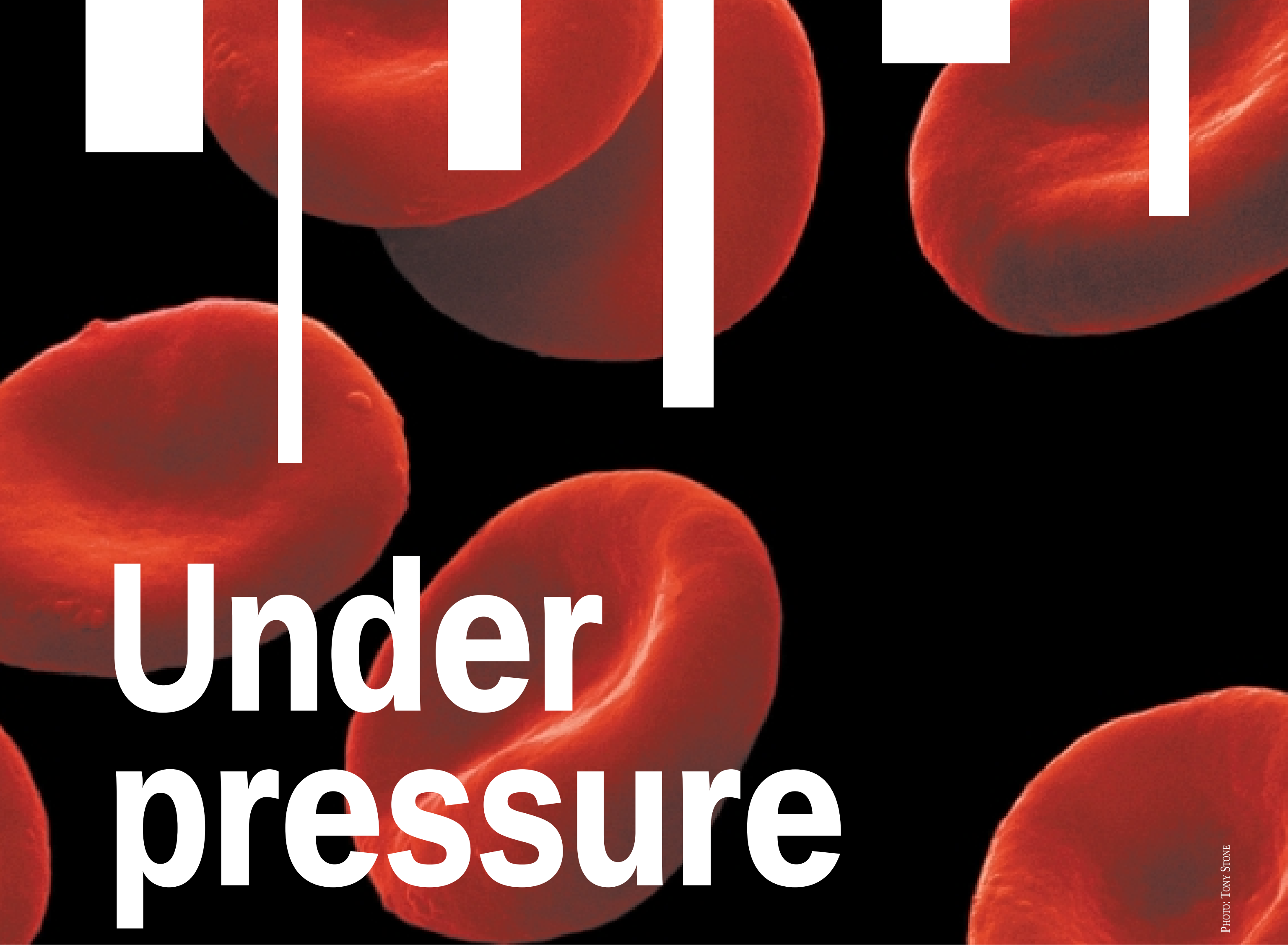
"Single pilots are most at risk from hypoxia because there is no-one to notice the subtle changes that indicate its presence."

It is unlikely to be a large problem below 10,000ft except on long flights, particularly at night, or when the you are fatigued or unwell.

There are a number of unexplained accidents which have occurred on long night flights which are believed to have hypoxia as a cause. Night freight pilots should be particularly vigilant.

The safety message is simple – if you have the opportunity to use supplemental oxygen, then use it.

Rod Bencke is a CASA flying operations inspector. Jeff Brock is the acting director of aviation medicine for CASA. Research by Sophia Kalogeropoulos.



Under pressure

PHOTO: TONY STONE

Hypoxia can leave you with very few options.

Mark Wolff

At the hypobaric chamber at the RAAF base in Edinburgh several hundred air force pilots each year get to check out their reactions to depressurisation and the effects of hypoxia.

The chamber is set to an altitude of 25,000ft, which gives a time of useful consciousness of around three to five minutes.

Up to ten pilots at a time sit in the chamber tensely waiting for the depressurisation, which starts at 8,000ft and moves to 25,000ft in just 10 seconds. Each clutches a checklist of tasks they are to perform. Each is determined to remain conscious and capable for as long as possible.

After about two minutes one of the subjects is asked to repeat back a number. Inevitably the subject is unable to do so. In fact, most don't remember being asked.

Trying to go through the checklist the pilots tend to exhibit one of two kinds of behaviour: they are either "page flickers" or "fixators". The page flickers will just sit there mindlessly flipping through the checklists; the fixators will just stare at one page. They are "passengers in their own bodies".

These two quite different behavioural responses to rapid depressurisation hint at a variation in individual responses to a lack of oxygen, or hypoxia.

Hypoxia is a threat to safety for all pilots operating pressurised aircraft and for unpressurised aircraft that fly at an altitude of 10,000ft or above– the legal ceiling above which oxygen must be used by flight crew members in unpressurised aircraft.

Some individuals with reduced lung function will become hypoxic well below this level. This includes people with emphysema, industrial lung disease, certain forms of anaemia, ischaemic heart disease and even mild degrees of heart failure.

If you smoke, you may have already reduced your oxygen intake by a significant factor. Avoid smoking before and during flight.

The nature of hypoxia: The term hypoxia translates from the Latin to mean insufficient (hypo) oxygen (oxia). It is a physiological state in which tissues are deprived of adequate oxygen, and organs such as the brain, eyes, ears, lungs and heart are adversely affected.

When an aircraft undergoes rapid decompression above around 35,000ft, the time of useful consciousness for crew may be 30 seconds or less, depending on the altitude (see table). At lower altitudes the time of useful consciousness may be longer, but subtle effects may still impair your functioning. The more rapid the decompression, the faster symptoms of hypoxia will appear.

Crew surprise and perhaps lack of familiarity with decompression can contribute to dangerous delays in appropriate response. Research by the US Air Force shows 80 per cent

Carriers of Oxygen: Human red blood cells.

of pilots with no experience of decompression wait as long as 15 seconds to respond correctly to a loss of cabin pressure.

Because of the insidious effects of hypoxia on judgement and reasoning, the correct response to loss of cabin pressure is always to don the oxygen mask – immediately. That's the only way you can be sure that you will make the right choices.

The death of US golfer Payne Stewart in October 1999 and two recent Australian incidents – one in a RAAF King Air and the other in a civilian King Air – have put the spotlight on the issue of hypoxia. While the RAAF incident is known to have involved hypoxia, we may never know the contributing factors to the civilian accidents.

In the RAAF incident, shortly after the aircraft was levelled at the planned cruising level of FL250, the right-hand seat passenger noticed that the pilot was acting erratically while manipulating the Global Positioning System (GPS). Soon after, the pilot slumped over the controls and turned a curious shade of blue.

Fortunately the passenger (who was a pilot but was not endorsed on type) was able to take control of the aircraft. He descended and, after having some trouble locating the communications panel, declared an emergency. He was extremely lucky – he should first have donned his own oxygen mask to ensure he was able to function correctly.

Preliminary reports from US investigators reveal the cockpit voice recorder on Payne Stewart's aircraft contained no voices, but that there were sounds consistent with various alarms (cabin altitude/low pressure, stall warnings). Speculation is that the accident may have been related to decompression early in the flight and that the pilots and passengers may have been incapacitated by the low level of oxygen. Pilots of military aircraft assigned to follow the Learjet after it failed to respond to ATC transmissions and climbed above its assigned altitude said the windows were covered with ice and that there was no sign of flight control movement.

The flight ended when the aircraft dived into the ground at the time that the Learjet's fuel supply would have been exhausted.

Symptoms and signs: The symptoms of hypoxia are similar to alcohol. Like alcohol, there can be a personality change.

The first signs include both mental and physical effects. Mentally there can be a loss of judgement, self-criticism and short-term memory. This can be accompanied by an increase in reaction time and a kind of mental "tunnel vision" similar to the fixation on the GPS unit experienced by the RAAF King Air pilot. You may even become euphoric.

"There is a high degree of individual variation in the response to hypoxia: some people may hyperventilate and turn blue immediately; others may not. In a small number of individuals unconsciousness may occur before any other symptom."

The physical effects include muscular incoordination and an impairment of colour, night and peripheral vision. Hearing also deteriorates.

You may experience hot flushes and turn blueish at the extremeties (cyanosis).

Rapid breathing or hyperventilation is one of the early physical signs.

But because hypoxia impairs judgement, you may not notice loss of vision and hearing or other physical or mental signs. It's the opposite of "You don't know what you've got until you lose it". More like, "You don't know what you've lost until you get it back".

Simple tasks become extraordinarily difficult and performance fails.

As hypoxia continues, you become semi-conscious. After you lose consciousness entirely, you have only minutes to live, depending on the altitude.

There are many factors which affect tolerance to hypoxia. The faster the rate of ascent, the quicker the onset.

Apart from smoking and lung disease, you may be more susceptible if you are ill, stressed, unfit, fatigued, under the influence of drugs or are suffering from a hangover.

There is a high degree of individual variation in the response to hypoxia: some people may hyperventilate and turn blue immediately; others may not. In a small number of individuals, unconsciousness may occur before any other symptom.

Recovery procedures: Don your oxygen mask immediately, select 100 per cent oxygen if you have differential settings, then descend to 10,000ft or below, terrain permitting. You may find that you feel worse immediately after putting your oxygen mask on. Do not take it off. This is called the oxygen paradox and you will feel better after about one minute.

Breathe at a normal rate and depth. Declare an emergency, and land as soon as possible.

After recovery from an episode of hypoxia, some symptoms may persist. These include headache, fatigue and lethargy.

Note that if you have been in an aircraft

TIME OF USEFUL CONSCIOUSNESS

Altitude (ft)	Consciousness
15,000	30 minutes or more
18,000	20–30 minutes
22,000	5–10 minutes
25,000	3–5 minutes
28,000	2.5–3 minutes
30,000	1–3 minutes
35,000	30–60 seconds
40,000	15–20 seconds
45,000	9–15 seconds
50,000	6–9 seconds

PRESSURE AND ALTITUDE

Altitude		Pressure	Temperature	
ft	m	hPa	lb/in²	°C
0	0	1,013.25	14.70	+15.0
5,000	1,525	843.1	12.23	+5.1
10,000	3,048	696.8	10.11	-4.8
15,000	4,572	571.8	8.29	-14.7
20,000	6,096	465.6	6.75	-24.6
25,000	7,620	376.0	5.45	-34.5
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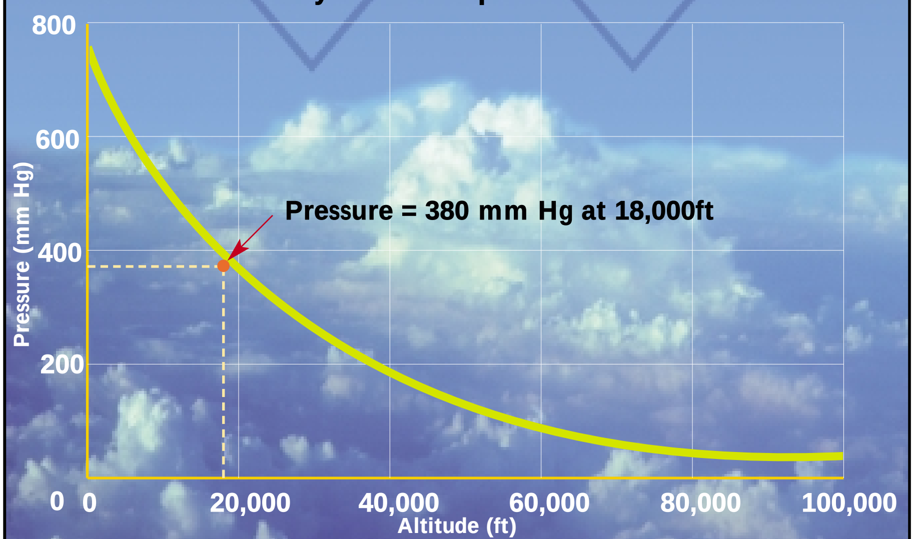
The exponential relationship between the pressure exerted by the atmosphere and altitude



Flying fox

which has been decompressed, you should not fly again the same day because you will increase your risk of decompression illness. Decompression illness (or the bends) can be incapacitating, particularly if nitrogen bubbles enter the brain.

You should also use oxygen if you detect fumes or smoke. Again, set the oxygen at 100 per cent in order to prevent any toxins from the fumes or smoke entering the system.

Prevention: The key to prevention is two-fold. First, you need to follow your flight manual prompts to accurately set and monitor cabin pressure.

As soon as the cabin pressure drops below recommended levels you should take preventative action.

If warning systems indicate problems with cabin pressure, you must immediately don your oxygen mask and descend if terrain permits.

It pays to know your equipment, because it can take some time to put the oxygen mask on. Make sure you know how to use the masks, practise using them, and time yourself in putting them on.

There are traps with checklists which you must guard against. You should understand your pressurisation and oxygen systems, and fill in the gaps in your checklists so that you are sure of what to do in an emergency.

For example, if you are over ocean and have an uncontained engine failure which leads to depressurisation, you will want 20,000ft or so to retain range. But do you have enough oxygen? Do you know how to calculate that?

Sixty per cent of corporate jet depressurisations are caused by uncontained engine failures. Most others are caused by doors or windows departing the aeroplane.

Even if you set up and use checklists properly, things can still go wrong.

A checklist is a skill based action which means it is a stored pattern of preprogrammed activity. The greater the skill level, the greater the chance of “strong, but wrong” error. All it takes is a change to a well practised routine and a missed attentional check. The intention may be correct, but the action may be wrong.

You could get it wrong through inattention, distraction or pre-occupation. That’s why checklists needs to be monitored carefully: they are the last line of defence.

If you are halfway through a checklist, and are interrupted, go back to the beginning and start again. Be sure, however, not to introduce new errors by operating things like switches which have already been activated correctly.

The one thing that you should not do first is to start working out what's gone wrong. That is, you should not be problem solving and planning on line.

This is hard to do. If you know the aircraft well and you have a pressurisation warning going off, but the cabin pressure indicator seems OK, you should not be trying to work out which is correct. You must immediately put on the oxygen mask, descend and *then* look to problem solve.

The reason you should not work the problem early is that hypoxia interferes with your ability to solve problems and limits your time of useful consciousness. Get the oxygen right first, then ponder your situation.

> **"If you have a pressurisation warning, but the cabin pressure indicator seems OK, you should not be trying to work out which is correct. You must immediately put on the oxygen mask, descend and *then* look to problem solve."**

If you go into problem solving mode you will lose valuable time. You should take the course of least regret.

From a human factors point of view, once you notice a pressurisation warning, you need to quickly don your oxygen mask. So your well-practised rule should always be: pressurisation warning, don mask, descend (terrain permitting), solve the problem.

Based on CASA safety promotion presentations by: Dr David Newman, Director, Flight Medicine Systems; Michael Rodgers, Manager, Human Factors and System Safety, CASA; Al Bridges, Manager, Program Delivery, CASA; and Squadron Leader Shane Thompson, RAAF.

Variability of symptoms

Larger aircraft are not immune. Cabin alerts are fallible and hypoxia symptoms are insidious and variable.

Even if cabin altitude alerts function correctly, time of useful consciousness may be less than expected for a given altitude. In 1995, a US Navy P3C departing Japan suffered a rapid decompression to cabin altitude of 24,000ft in 10 seconds.

Despite the captain's immediate directions, it took the flying pilot some time to don oxygen equipment and initiate descent. He then had difficulty remembering the emergency descent procedure. The non-flying pilot made several radio calls without response, before others realised she had not replaced her headset after donning her smoke mask.

The flight engineer became fixated with the uncorrectable pressurisation problem and the captain placed his mask on him.

The captain, sitting behind the flying pilot, noticed that his fingernails were blue and decided to check the crew aft. They had differing symptoms:

- One member felt light-headed, experienced tingling, started to walk aft but had to sit down.
- A spare pilot noticed the pressure change, discussed rapid decompression and hypoxia with another member, felt light headed and lost colour vision. He felt nervous as he had no oxygen mask.
- The navigator felt tingling and was disoriented. He noticed misting in the cabin, became claustrophobic, hyperventilated and fixated on his station.
- Another crewman felt his ears pop, felt cold, dizzy, confused, disoriented and sat down until another member administered oxygen.
- Another felt cold, short of breath and suffered an upset stomach.
- Another attempted to grab a walk-around oxygen bottle but became confused and remembers searching for a toolbox key for a ratchet to unfasten the wall bracket.
- One passenger became nervous, laid down, began shaking and had blurred vision.
- Another passenger saw the misting, thought there was a fire, turned blue, had ear pain and noticed everything in slow motion.
- The spare flight engineer was fascinated when the coffee pot lid exploded and coffee sprayed everywhere. He walked to the flight station, became exhausted, disoriented, saw bright flashing lights and had to be administered oxygen.
- Another passenger started cleaning the spilled coffee, felt ill, couldn't figure out how to open the toilet door and vomited on himself.

Following this incident, the US Navy recommended "don oxygen mask" as the first item in the Rapid Decompression and Cabin Press Light On emergency checklists.

Courtesy Flying Safety Spotlight, *3/00.*

SUSPECTED DECOMPRESSION ILLNESS

THE PC9 was to undergo an investigative test flight as part of an ongoing engine acceleration problem. The test flight necessitated diagnostic procedures to be carried out at 25 000ft. Oxygen prebreathing requirements were carried out in accordance with HQTC SI (OPS) 3-7. On completing the investigative action at 25 000ft, the pilot felt a tingling sensation in his left hand accompanied with a dull numbness. This sensation was not of significant intensity; however, the pilot did consider the possibility of decompression illness (DCI). Up to this time the aircraft had been at altitude for nine minutes. The pilot remained on 100 per cent oxygen for the recovery and the aircraft landed five minutes later.

Due to the subtlety of the symptoms, the pilot had difficulty in determining if sufficient doubt existed as to the possibility of DCI, but on return to the squadron lines he elected to go to medical section.

The SMO commented that the pilot presented at 1605 hrs with symptoms of tingling of the left hand and forearm, which had started at 25 000 ft and had persisted after landing. There were no other symptoms of DCI. A full neurological including mini-mental examination was normal. He was treated with oxygen, oral fluids and rest and was observed. Symptoms subsided gradually, being minimal after 40 minutes and gone by a further 15 minutes. The pilot was maintained on oxygen until 2030 hrs and discharged home at 2100 hrs. A review the following day revealed no recurrence of symptoms nor the development of any new symptoms of DCI. Following consultation with AVMED and a specialist from the [Melbourne] Alfred Hospital Hyperbaric Medicine Unit, it is considered that the pilot's symptoms were due to DCI. Accordingly, he was prohibited from flying (or scuba diving) for 72 hrs, to be reviewed before resuming flying duties.

During this incident the pilot had doubts about the cause of his symptoms. A preferable course of action would have been for him to have alerted medical services airborne so that oxygen could have been available on landing. The pilot is an experienced Unit Maintenance Test Pilot who has regularly flown to 25 000 ft and is extremely diligent in his conduct of pre-breathing and oxygen checks. On the sortie immediately prior to the incident sortie (less than one hour previous), the pilot had been at 15 000ft. Discussions with AVMED indicate this could have increased the chance of DCI.

Pending further action the unit has restricted all flights 24 hrs prior to a climb to 25 000ft, to 10 000 ft. Additionally, the unit has made the following recommendations:

- the SI be reviewed, with AVMED consultation;
- AVMED include this incident in their DCI training for PC9 operators;
- all PC9 operators be briefed on this incident with emphasis to UMTPs; and
- AVMED review DI(AF) OPS with respect to operations above a cabin altitude of 25 000ft, to ensure sufficient guidance is available to all ADF aircrew. ✈

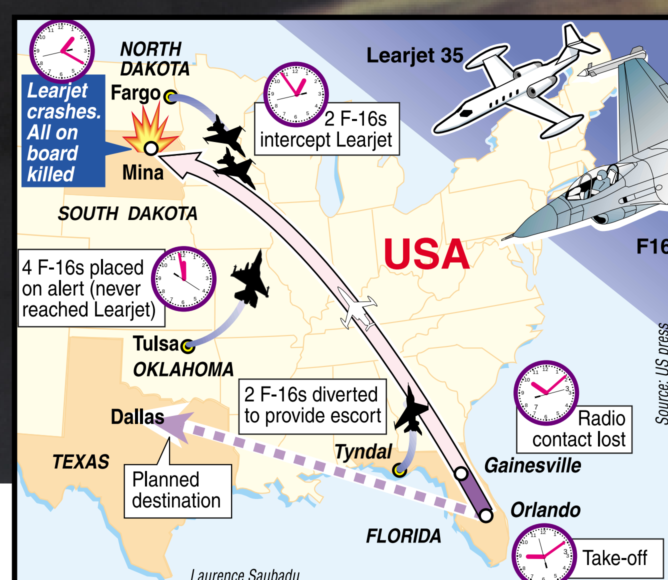
Many receive advice, only the wise profit by it.

RUNAWAY PLANE

HOW TO MANAGE A DEPRESSURISATION EMERGENCY

PRESSLINK

The crash of a runaway Lear Jet 35 carrying US golfer Payne Stewart and five others has raised questions about the best ways to handle loss of cabin pressure.



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David Newman

When a Lear Jet 35 aircraft operated by Sun Jet Aviation crashed on October 25, 1999, in a grassy field near Aberdeen in South Dakota, America watched in horror. On board were six people, including professional golfer Payne Stewart. All were killed. But it wasn't just its famous passenger which saw this flight make headlines – the Lear had just spent nearly four hours crossing the USA on autopilot with an incapacitated crew.

The aircraft had departed Orlando, Florida with its four passengers and two-pilot crew at around 9.19am enroute for Dallas, Texas. The planned flight time was two hours, but the aircraft carried four hours and 45 minutes worth of fuel.

Less than 30 minutes later, the aircraft was northwest of Gainesville, Florida. It had been cleared to 39,000ft and was passing through 37,000ft when radio contact with air traffic control was lost. Radar plots showed the aircraft continuing on a north-westerly heading.

Five military aircraft (F-16 fighters) were sent to intercept the Lear Jet at an altitude of approximately 45,000 feet, following the aircraft until it crashed due to fuel exhaustion, after crossing half a dozen US states and travelling almost 2,500 kilometres.

The fighter pilots were unable to find any sign of structural damage to the aircraft, but they reported that the windows of the Lear were misted over, and they couldn't discern any signs of life inside.

The investigation by the NTSB is ongoing. The cockpit voice recorder recovered from the accident site contains no voices, but there are sounds which the NTSB feel are consistent with various alarms such as cabin altitude warnings and stall warnings.

So what went wrong? What led to the crew and passengers apparently becoming incapacitated and unresponsive, with the aircraft deviating significantly from its planned flight path and exhausting all of its fuel? While the NTSB plans to conclude its investigation and release a final report in the next few months, early indications point to a failure of the cabin pressurisation system.

The risks of cabin decompression are fortunately not tremendously high. However, these risks are still present, and when a decompression event happens to you the effects will be dramatic. It is worth knowing what to expect, whether you fly a pressurised aircraft for business or pleasure, or fly just as a passenger in a pressurised aircraft. The old saying, “it’ll never happen to me” is not enough protection.

Cabin pressurisation: Pressurisation of an aircraft cabin to a lower altitude than the one it is flying at offers significant advantages. The typical passenger aircraft has a cabin altitude of 6000-8000ft, while the outside altitude may be 40,000ft. The differential pressure is therefore high (in the order of 55-62kPa [8-9psi], depending on aircraft type). The advantages of this arrangement are that the passengers and crew can operate in “shirt-sleeves” comfort, with little danger of hypoxia or decompression illness at this altitude. There are some disadvantages, though, such as the additional weight of the pressurisation equipment and the performance penalty in generating the pressure differential. However, in most operations the advantages outweigh the disadvantages by a long way.

Air for pressurising and conditioning an aircraft cabin is taken from outside air which is compressed via engine-driven compressors. In jet aircraft such as the Lear Jet, the air is bled directly from the compressor stages of the engines, upstream of the combustion chambers. The air is then directed through the heat exchanger and refrigeration circuits to pressurise, heat and/or cool the aircraft cabin as required.

The pressurisation system typically involves a series of control valves to ensure the maintenance of a given cabin altitude. A pressure controller compares cabin altitude with ambient aircraft altitude, and uses pneumatic or electric signals to control the opening of a series of discharge valves, which allow air to flow out of the cabin. In this way, the desired cabin differential pressure is maintained. The flow of air into the cabin depends on the size of the cabin and the thermal conditions desired by the occupants. Pressurisation demands are generally much less than the thermal conditioning demands. Typical mass flow requirements for a large passenger aircraft are in the order of 200-400 litres of air/passenger/minute.

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US golfing celebrity Payne Stewart won 18 professional titles, including the 1989 PGA and the 1991 and 1999 US Opens. He is remembered for his outgoing personality and flashy clothes.

Failure of the pressurisation system can be slow or rapid. Slow decompression results in a gentle climb in cabin altitude, whereas rapid decompression involves a sudden loss of cabin pressure. Decompression can be explosive, implying an almost instantaneous change in cabin altitude. Slow decompressions are generally due to engine or pressurisation system problems, whereas rapid or explosive decompressions reflect major structural problems with the aircraft. Here we are considering only rapid or explosive decompression.

Physical effects of decompression: So what happens when the window of your aircraft suddenly disappears in-flight? Consider the BAC-111 in which one of the cockpit windows had been improperly installed after maintenance. The window disappeared, and along with it the captain. He was extremely fortunate in that he was grabbed by one of the crew before he was fully through the window. Other structural failures have occurred, such as in the Aloha Airlines 737 that had the upper fuselage just aft of the cockpit detach from the rest of the aircraft.

There are a number of possible causes of loss of pressurisation. System malfunctions can lead to a slow loss of pressurisation, most of which should be detected by built-in warnings. The most serious cause is some form of structural failure which can lead to rapid or explosive decompression.

In the event of a sudden cabin decompression, several things will happen, largely simultaneously. There will be a lot of noise immediately, along with a significant mass flow of air throughout the cabin towards the breach in the fuselage. These effects are due to the high pressure differential, which can no longer be maintained. The mass flow of air blows dust and debris around the cabin, which may reduce visibility. A cloud of mist may form in the air due to the rapid pressure changes and differences in relative humidity. The air flowing out of the fuselage can approach the local speed of sound, so it is little surprise that objects as large as people and suitcases are blown out of the cabin, provided the hole is large enough. It is actually a misnomer that things are “sucked” out of the aircraft: what happens is that the mass exodus of air simply blows them out. Smaller items such as food trays and cutlery can become lethal projectiles during a rapid or explosive decompression.

The time taken to decompress the cabin completely depends on a number of factors. Two of the most critical are the volume of the cabin and the size of the defect in the hull. A large cabin with a small defect (for example a 747-400 with a window missing) will take longer to fully decompress than a small cabin with a relatively large defect (for example a Lear Jet with a door missing). Another factor important in the time to decompress is the ratio of cabin pressure to ambient pressure. The larger this ratio the more time is required to decompress the cabin.

Once the pressure inside the cabin is effectively the same as that outside the aircraft, mass movement of air ceases and the occupants are then exposed to the other hazards of being at altitude without the protection of a pressurised cabin.

Physiological effects of decompression: A pressurised cabin protects the occupants of the aircraft from the physiological hazards of being at significant altitude. Once cabin decompression occurs, the occupants are no longer protected. They are all at risk from a number of important factors, such as hypoxia, cold, the effects of pressure change and decompression illness.

The single biggest problem with cabin depressurisation is that there is no longer any protection against hypoxia. While the air at 40,000 feet still contains 21 per cent oxygen, it is 21 per cent of not very much. Hypoxia is a very real threat.

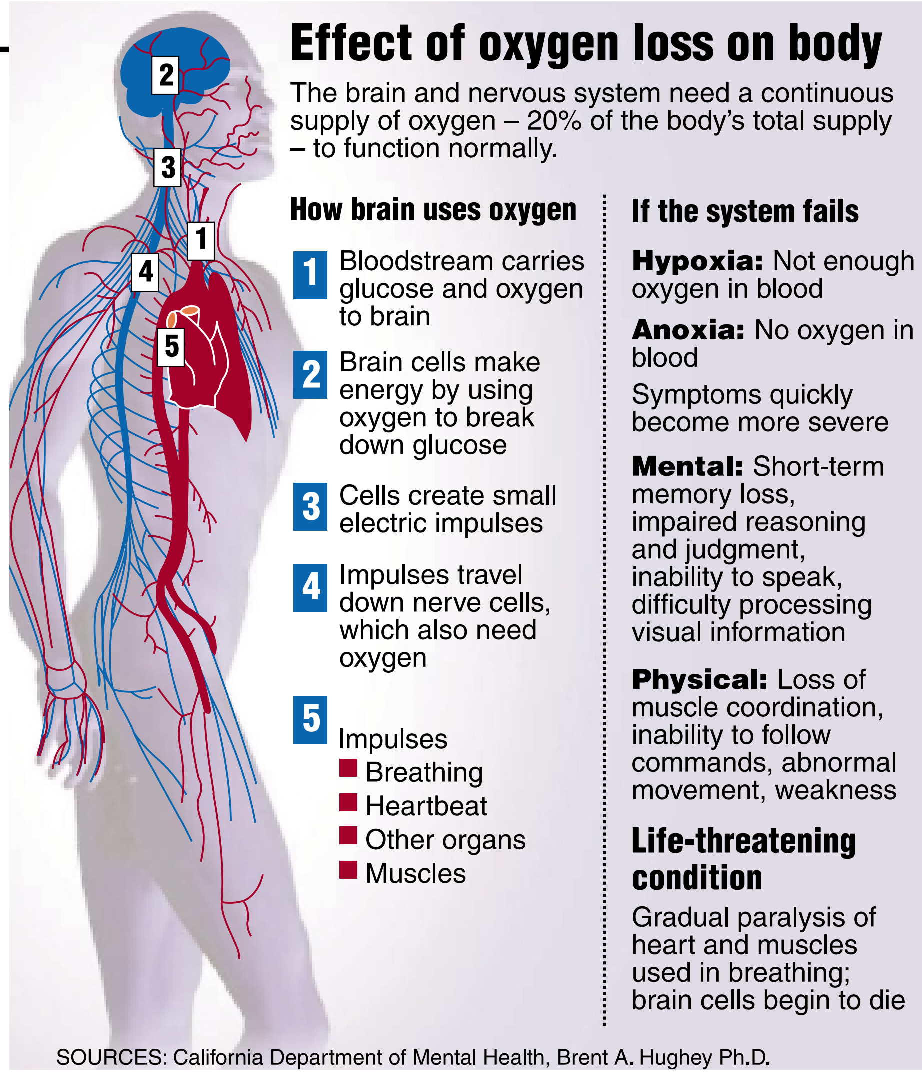
The time of useful consciousness is the time interval between onset of an oxygen supply problem (in this case a loss of cabin pressurisation) and the point at which a person is no longer able to do anything about it. With a rapid decompression to 40,000ft, the time of useful consciousness is in the order of 12 to 15 seconds for most fit and well people. Unless supplemental oxygen is supplied, complete unconsciousness and then death will progressively occur over a few minutes.

During a rapid decompression, a person may actually have more oxygen in their bodies (due to being at 8,000ft) than there is in the atmosphere at 40,000ft, with the result that oxygen will leave their bodies and enter the atmosphere in order to even the score. This off-gassing of oxygen is unhelpful to the person, and will reduce their time of useful consciousness significantly.

However, the aircraft's immediate descent will help all those on board as they descend into "thicker" air. Unfortunately, it would appear that the crew of the Payne Stewart Lear Jet were unable to initiate a descent, presumably due to them all being unconscious as a result of very rapid hypoxia.

At 40,000ft, the outside air temperature will be in the order of -56°C. This may well cause problems for those near the defect in the hull, and those dressed for summer conditions! The rapid pressure change may lead to trapped gas in the body (middle ear, gut, lungs, teeth) expanding which could cause discomfort or injury. At 40,000ft an amount of trapped gas in the bowel could increase its volume roughly four times, causing considerable abdominal discomfort.

Exposure to altitudes above 18,000 feet carries with it the risk of decompression illness. This is a possibility, but due to the short time generally spent at altitude after a decompression event, and the fact that the descent into greater atmospheric pressure will tend to help treat any nitrogen bubbles that might form, this is not a huge risk.



What to do: In the event of a decompression, the use of supplemental oxygen is critically important. Any delay in donning the oxygen mask will increase the chances of hypoxia occurring. Flight-deck crew need to don their masks as a matter of absolute priority. This needs to be done as quickly and efficiently as possible, before anything else. Protection against hypoxia is the fundamental survival aspect in this situation – remember that there are only a few seconds of time available before unconsciousness occurs.

Training in the use of whatever oxygen equipment is carried on your aircraft and the procedures to be followed if decompression occurs cannot be overstated. As a pilot, you should be very familiar with the oxygen equipment you carry. Getting this on your head as soon as possible requires practice.

Once you have your mask on and are breathing oxygen, you must control the rate and depth of your breathing. Hyperventilation will not help you much!

Immediate descent to a lower altitude and communication with air traffic agencies are also extremely important. The old adage of "aviate, navigate, communicate" can be modified a little during a decompression to read "ventilate, aviate, navigate, communicate". The limiting factor during a decompression is the need for humans to breathe sufficient oxygen – you must ventilate your lungs with enough oxygen to prevent yourself from losing consciousness.

Cabin attendants need to ensure that they are also using oxygen masks. If possible, they should ensure that passengers have fitted their masks and are all seated during the descent. Both cabin attendants and passengers must ensure that they have their own masks on before assisting others with theirs. This prevents a situation where two people are unconscious with neither wearing a mask. Remember that time is very short at altitude during a decompression.

If you travel as a passenger in a pressurised aircraft, keep your seat-belt on whenever seated and pay attention to the safety brief. This brief is given for a reason! Although aircraft decompressions are rare, they still happen and without much warning. Being prepared is your best chance of a positive outcome.

Dr David G. Newman is an aviation medicine consultant.