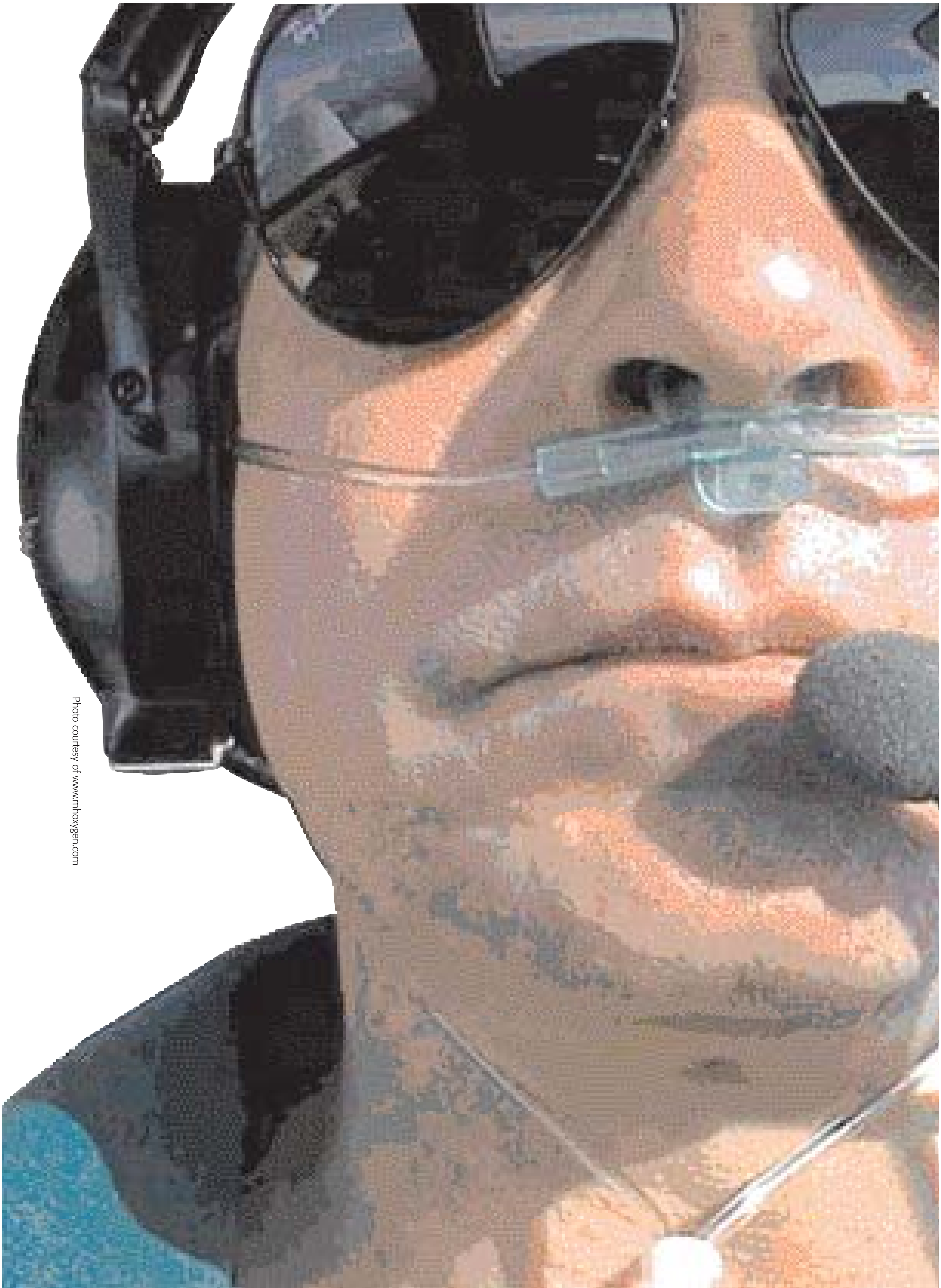


Photo courtesy of www.mhoxygen.com

Oxygen systems

Following on from Tom Vaughan's piece in the December issue of *FLYER* on the advantages of flying high, Gus Cabre explains hypoxia and offers a guide to oxygen systems in light aircraft

After reading aviation reports of accidents caused by hypoxia, like that of the famous golfer, Payne Stewart, whose Learjet 35 crashed in 1999, or the Helios Airways Flight 522 in August 2005, killing all 121 people on board, it is still surprising to hear about pilots who decide to fly above 10,000ft with no extra oxygen.

If you are lucky to fly an aircraft that is able to cruise above that height, then there will be advantages like a greater true airspeed for the same indicated speed, shorter trips with stronger tailwinds and the ability to fly above a range of mountains and bad weather, all money-saving, as well, exciting flying. However, there is a price to consider: you either pay money for that extra oxygen or risk entering hypoxia territory with possibly dire consequences.

The main gas in air is nitrogen (around 78%), oxygen (O_2) being only 21%. At ground level, that is more than enough oxygen for our organs to work normally. That is because haemoglobin (Hb), the protein found in our red blood cells, has great affinity for O_2 and will transport it to where it is needed, which is mainly to the brain and muscles. Most (99.7%) of all the Hb passing through our lungs will become saturated with O_2.

As we start climbing, the atmospheric pressure decreases and, even though the percentage of ▸

oxygen remains the same, its partial pressure (in other words, the amount available) diminishes. Our body has mechanisms that will compensate for this relative lack of oxygen (mainly chemical changes and hyperventilation) to the extent that most of us will cope with being up at a few thousand feet with barely any consequence. The magic height is 10,000ft, as it is here where, in medical terms, hypoxia really starts to affect many of us.

The science is complex, but basically, from that height the higher we go, Hb will carry even less O_2. Look up on the internet the 'oxygen-haemoglobin saturation curve' and you will see it is sigmoid in shape. A saturation of 91% coincides with 10,000ft and most of us can cope with that level, but going any higher without extra oxygen will result sooner than expected in 'hypoxia' – in medicine, there are four main types of hypoxia, but we shall concentrate on the type that relates to the lack of oxygen in the air.

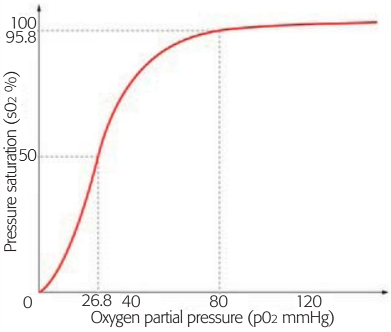
Hypoxia can manifest itself in many different ways and very few people have experienced it in a controlled environment. Military aircrew in the UK are trained in the hypobaric chambers at the RAF Centre of Aviation Medicine, Henlow, in order that that they become familiar with its symptoms and do something about it when exposed to it. It has been proven that training in these chambers has saved lives as time after time there have been reported incidents in which aircrew were under the effects of hypoxia, recognised the symptoms and managed to descend quickly to a safe height.

The symptoms vary from person to person, and even the same pilot can be affected by external factors like stress, fatigue, illness, smoking and age, as well as the rate of ascent and the height flown to. Again, if you search the internet for videos, you'll find Jeremy Clarkson extremely hypoxic after two to three minutes at 25,000ft (go to *www.youtube.com* and type in 'Jeremy Clarkson Fighter Pilot Training').

Hypoxia can manifest itself as low as 5,000ft, where we have seen night vision impaired. At around 8,000 feet, and that is the cabin height of most airliners, reaction times can be slow. It is rare to suffer greatly below 14,000 feet, but there have been numerous cases of headache and poorly-executed manoeuvres. Above those heights, the commonest symptoms are light-headedness and slowed thinking, lack of muscular co-ordination, personality changes (euphoria tends to be the commonest manifestation but sometimes getting angry for the simplest of the mistakes can be present), tunnel vision, memory loss, hyperventilation, convulsions and death.

Many who experience hypoxia actually feel fine, so do nothing about it until it is too late. That is when we talk about time of useful consciousness (TUC), the time it takes between the moment hypoxia kicks in and when we realise it and manage to correct the situation. This can be in the region of 30 minutes (or possibly much less, if affected by the external factors mentioned above) at 18,000ft and between two and five minutes around 25,000ft.

Hb Saturation



Because of the sigmoid shape of the curve, flying above 10,000ft means a much greater reduction of oxygen available

Portable oxygen equipment

So, how do we obtain more oxygen? Airliners, bizjets and some piston-engined aircraft have the capability of cabin pressurisation; they 'compress' the air in the cabin to the equivalent of 8,000ft. This way there is no need to wear masks and the temperature can also be maintained at a more comfortable level. Fast jets benefit from carrying molecular sieve oxygen concentrators (MSOC), apparatus that separates oxygen from nitrogen and concentrates the former. They all use regulators for the administration of O_2 but also carry emergency bottles, separate from the on-board oxygen system, in case of fumes in the cockpit.

For General Aviation, the easiest and cheapest way is portable oxygen. But before we look into what is available, we must look at the law. Until March 2007, there was no legislation in the UK regarding supplemental oxygen in private flights. Then, the CAA amended the *Air Navigation Order – CAP 393 Air Navigation: The Order and the Regulations* see *www.caa.co.uk/docs/33/CAP393.pdf*

The rules can be summarised as: all aircrew in private flights are to use supplementary oxygen when flying above FL130, or above FL100 if flying for 30 minutes or more. They also recommend that passengers be on oxygen above FL130.

Photo courtesy of www.Aerox.com

Masks ensure that all oxygen delivered is used by the pilot. They can be fatiguing in long flights

Interestingly, there is no requirement for Type Approval, so any type of portable oxygen system is allowed!

All basic oxygen equipment available for General Aviation will be made up of the following three systems:

- storage, in bottles or cylinders, with an open/close valve and content indicator
- a delivery mechanism, with a flow indicator and connectors
- a receiving device.

Storage. Oxygen can be stored in three forms: gas, liquid or solid. Gas is the most economical form of storage as it has the advantage of being compressible in low-pressure or high-pressure (up to 2,000psi) cylinders. The disadvantage is the bulk and weight of these containers. They can be made of steel, aluminium or Kevlar, the latter being much lighter but also more expensive. All cylinders have to be inspected at determined periods and are lifed, i.e. will need to be discarded after several years or refillings. They need to be refilled with aviation oxygen, which is purer and drier than 'medical' oxygen. This is because at cold temperatures moisture could freeze in the delivery system, severely restricting its flow.

Another problem is finding firms that will refill them for you. Small airfields do not have the facilities, scuba diving shops will not touch them the moment you mention aviation, and companies dealing with bigger aircraft usually connect their hose to the fixed cylinder system on the aircraft. A fourth option is to do it yourself – cheaper in the long run but training and the correct equipment is required.

Liquid oxygen (LOX) has great advantages but also disadvantages (it can cause severe frostbite if touched) and is only used in big aircraft or fast jets. Solid oxygen is what we find in large passenger aircraft for passenger emergency supply. By pulling the mask when cabin depressurises, these sodium chlorate candles ignite, causing a thermal reaction which releases oxygen. They are very economical, light and small but once ignited they cannot be stopped. Unfortunately, they only last a few minutes and can be a fire hazard as they become extremely hot. In summary, for General Aviation, we will be looking at oxygen cylinders.

Delivery mechanisms basically come in two major forms, continuous flow and demand regulators. A third variant, pressure demand, delivers oxygen to the lungs at increased pressure and is mainly used in aircraft flying at cabin heights greater than 40,000 feet where 100% oxygen is not sufficient. In certain fast jet aircraft, positive pressure breathing is also used when performing high g manoeuvres, as the positive pressure (up to 60 mmHg) can help to maintain blood pressure and reduce the risk of loss of consciousness (G-LOC).

The continuous flow system is a simple form of administration. As its name indicates, you just turn the key on and it will deliver oxygen continuously. The advantage is that there is no need for complicated regulators. The disadvantage is that it will waste oxygen at a high rate as it will deliver the gas independently if we are inhaling or ▸

exhaling, sneezing or holding our breath. Some of the more basic systems need you to open the valve more and more the higher you go, in order to provide you with enough oxygen to function. This could be dangerous, as relying on one's symptoms to release more oxygen is a high-risk strategy. More modern systems have been simplified with specific switch positions or settings for different brackets of heights. In any case, continuous flow systems are indicated for flights below 28,000 feet but to save oxygen they can be connected to an 'oxysaver' cannula (see receiving devices below).

Demand regulators, such as fitted to Mountain High's O2D2 oxygen delivery system, release a flow of gas from the cylinder when they sense a negative pressure like during inspiration, so 'on-demand'. In military aircraft, and emergency oxygen systems in commercial aircraft, this delivers a complete lungful of oxygen (usually via a mask) on each breath. Once it senses positive pressure (i.e. expiration), a diaphragm closes the system, hence reducing the waste to zero. Systems developed for General Aviation follow the same principle, but rather than giving you a full lungful of oxygen, a short pulse of oxygen is delivered at the beginning of inspiration, sometimes called 'pulsed dose' system. This has the advantage of using less oxygen than the conventional demand system, but it does not deliver as much oxygen, as the remainder of what you inspire is cabin air. Some companies claim to save up to four times the amount of oxygen you would consume on a continuous flow. There are different makes, mechanical or electrical, depending on the manufacturer, but the principle is the same. They can be connected to nasal cannulas or tight-fitting masks, the former being the commonest found in GA. Regulators can have ports for one, two or four people, providing the same amount of oxygen to all. There are more complex and expensive system that can release oxygen at different rates for the different users.

Receiving devices. There are two main ways of receiving a gas: by cannula or by mask. Nasal cannulas are those soft, moulded, plastic prongs that insert into the nose. They are cheap and have the advantage of delivering oxygen directly into the respiratory system, being more comfortable than wearing a mask and allowing speech using a boom mike, rather than needing a more expensive mask with built-in microphone. In the USA, they are limited to 18,000ft or below. A variant of cannula is the 'oxymiser' or 'oxysaver'. There are variants on the theme but the commonest is a cannula with a reservoir on the upper lip, like a moustache. It is used in the continuous flow system as it accumulates oxygen in the reservoir which is then delivered during inspiration. It is claimed that these systems can extend the endurance of oxygen twofold, but these tests were carried out on clinical patients at ground level, and the reservoir performance may be less efficient at height.

A disadvantage of nasal cannulas is that the quantity of oxygen delivered will be much less if speaking or breathing through the mouth, as there will be increased dilution of oxygen by cabin air and they are useless for those suffering from congestions, colds or anatomical deformity within the nasal airways. Another inconvenience is that the tubing usually goes over the ears, which may break the seal between the ear cup and scalp, affecting the quality of audio. Some manufacturers have now changed it and clip the tubes outside to the ear cups.

Masks come in three main types, again with their own variants: the oronasal rebreather, the airline drop-down type cup and a proper facial mask. The oronasal breather is commonly used and is the cheapest. It covers the nose and mouth and has a plastic bag attached. There is still good oxygen in the air we breathe out, so it is mixed with 100% oxygen in the bag. The system is safe as long as we remain below 25,000ft. The airline drop-down type is similar but there is 100% oxygen and cabin air in the bag, with exhaled air vented into the cabin. Because of the higher content of oxygen, they are certified for usage up to 40,000ft.

The last option is a proper mask, over the nose and mouth, with straps, with or without a microphone. This system must be supplied by a conventional demand regulator (not pulsed dose) as described above. The advantage is obvious: we will be breathing oxygen directly from the supply and exhaling it out to the cabin.

It can become fatiguing to wear any mask for the whole flight, and to eat and drink it has to be removed, with the danger of suffering from hypoxia if left off for too long.

So, what to buy?

It all depends on how long and high our flights are going to be, the number of people needing to use it, weight and balance, preference for cannulas or masks and eventually, the depth of our pockets.

The choice of oxygen cylinders depends on how much space and weight you can afford. Looking at what the different companies have, I have found that Sky Ox offers seven models with bottle volumes ranging from 170lt to 1,416lt.

Sky Ox	SK 12-6 Aluminium	SK 12-50 Steel
Cylinder capacity	170 litre	1,416 litre
Oxymizer duration	05:28 hours	46:21hours
Mask duration	01:49 hours	15:27 hours
Size DxL	3.25 x 18.5in	7 x 26in
Weight	2.7kg	16.4kg
Price: 2-place full	£429.49	£544.95
Price: 4-place full	£487.49	£603.95

Photo courtesy of www.Aerox.com

Pets will hyperventilate and probably lose consciousness very soon when flying high

If affordable, it would be cheaper to buy a 1,416lt bottle as it gives nine times the endurance of a 170lt (see panel below).

Consumption of oxygen will differ, depending on the system we are using, as already explained. Using the oxymizer cannula, Sky Ox recommends between 0.3 litres/minute at 10,000 feet to twice that amount up to 18,000 feet.

Depending on how frequently you fly in hypoxia territory, it may be worth spending that little bit more on a demand system or, perhaps, for a pulsed dose system rather than a continuous flow.

What else?

Other considerations are alarms like Mountain High's audio warning when the system is about to become depleted or the tubing has disconnected. Also, if you stop breathing for more than 45 seconds, a warning light and/or horn (apnoea alarm) will go off. Unfortunately, should the ceasing of breathing be due to hypoxia, it would be too late.

Before ending this article, I would like to mention pulse oxymeters. These are small medical devices that fit at the end of a finger. They indirectly measure the oxygen-haemoglobin saturation and are extremely good in warm conditions. Many GA pilots will rely on them when flying with supplemental oxygen. Unfortunately, some will use them to consume less oxygen than recommended, believing that they are safe as long as the pulse oxymeter indicates normality. Regrettably, it is not 100% reliable as it can give false readings when, for instance, blood supply has decreased to the finger tips (like in a cold environment), in severe motion (like in a turbulent flight) or with sweaty or greasy fingers (poor readings).

It gets even worse. Some pilots have found that by breathing hard (hyperventilating) they can make their oxygen saturation rise without turning up the oxygen. This is an easy trap to fall into. Although hyperventilation may increase oxygen saturation in the blood, it can reduce blood flow to the brain due to changes in carbon dioxide levels. This is why some people faint when they hyperventilate, and it can be very dangerous in the aviation setting when you are already hypoxic. The utmost care must be taken when changing the oxygen flow based on symptoms or readings of the pulse oxymeter. It is best to rely on the settings by the manufacturers as theirs will provide an extra bit more of oxygen, in the safe mode. ■

Further information

Transair sells Sky Ox and AFE is selling Mountain High, while the oxygen providers have their websites with a wealth of information:
Aerox: *www.aerox.com*
Mountain High: *www.mhoxygen.com*
Precise Flight: *http://preciseflight.com*
Sky Ox: *www.skyox.com/oxygensystems*