OXYGEN TALK

Given at the

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Welcome ladies and gentlemen. You've come to hear about one of my favorite subjects and I know it's yours also, but you don't realize it because without oxygen we and most of the earth's species couldn't exist.

JUDGMENT COMES FROM EXPERIENCE

BUT

EXPERIENCE COMES FROM POOR JUDGMENT

OR

EXPERIENCE IS SOMETHING YOU DON'T GET UNTIL JUST AFTER YOU NEED IT.

First of all, I know the statement on the left is true and if you think about it rationally you will agree with me. If you doubt me just look back on your early days of soaring.

Unfortunately, this is a never ending circle for there are numerous times in our lives when we close our eyes and blindly go where we have never before trod.

This talk will be divided into three phases: physiology, physics, and experiences and data.

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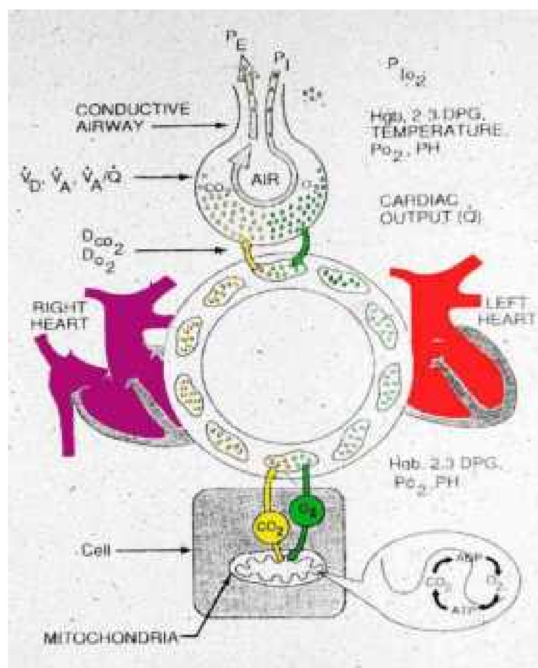
Oxygen and its use while at altitude is one of those areas that was called witchcraft many years ago but is based soundly on physiologic principles.

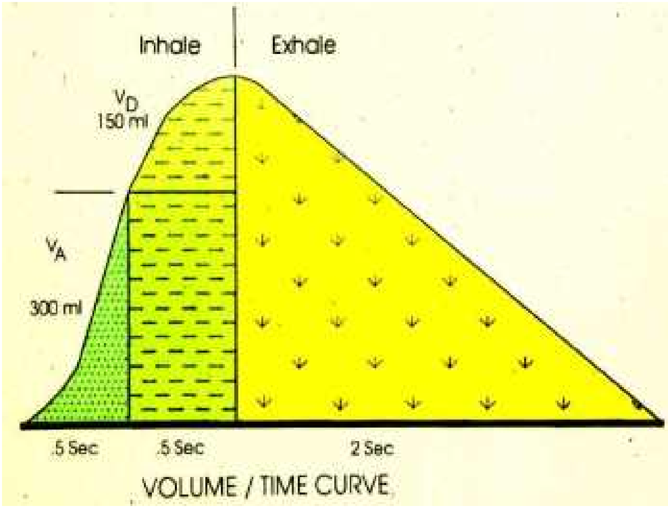
Now why do we need oxygen? Our bodies metabolize nutrients, for instance, the peanut butter and jelly sandwich you may have eaten during your last lunch provides the energy our cells need to function, our muscles to push the rudder pedals and manipulate the stick, our hearts to circulate the blood (which is the freight system of our bodies), and our brains so that we can think and make decisions. Making decisions is all what soaring is about and without sufficient oxygen, our brains will make sloppy (poor) decisions or none at all.



GAS EXCHANGE MODEL

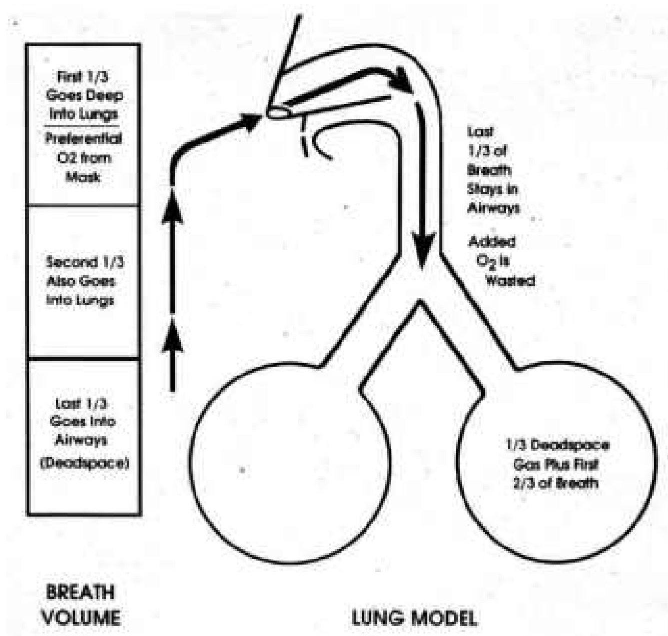
The illustration to the right crudely represents the respiratory (breathing) and circulatory systems of our bodies. Oxygen is drawn into our lungs and crosses the alveolar membrane into the blood stream where it is carried as part of the hemoglobin molecule to very distant capillaries. There, the oxygen transverses other tissues and eventually enters the cell. Within the cell, it finally enters the mitochondria where it is used to oxidize sugars, thus producing the energy we use. At many points along this system, the process of oxygenation may be interrupted or embarrassed.

Concentrating more heavily on breathing and how we get the oxygen into our bodies may get a little bit complicated for some, but I'm sure that you will get the general idea of what I'm trying to accomplish. The three color drawing (right) while looking like a

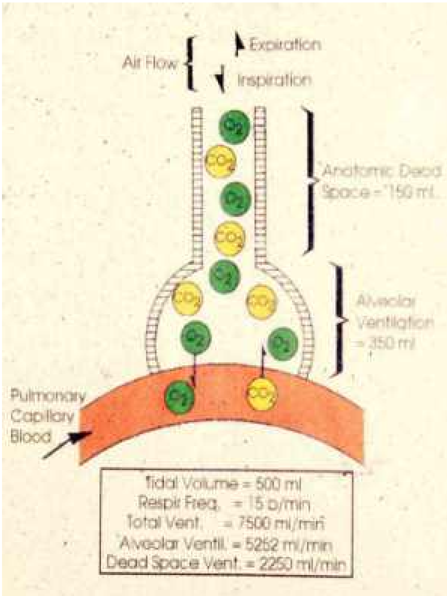


bell shaped curve represents the normal person's breathing pattern. On the left side the darker stippled area represents the first portion of each breath we take. I have colored it dark green because that portion of the breath goes deepest into the lungs, right out to the alveolar walls where the air-blood interchange takes place. This represents approximately 1/3 of our breath. The second portion, colored lighter with dashes, represents the volume of air that we breathe in that follows the first third, but generally speaking, does not take part in air-blood exchange. The lightest area (right) is the exhaled gases which plotted against time, bring us back again to the next breath after a compensatory pause.

To reinforce the idea that the first portion of the breath represents the majority of our oxygen delivery, let's use the model on the right. On the left is a column of air, which represents a breath and is divided into thirds. On the right is the nose, wind pipe, and lung system. What I want you to picture is that there already is a volume of air in the wind pipe and lungs equal to the last 1/3 of the previous breath, which contains carbon dioxide, water vapor, and less oxygen. The left column represents the next breath and the arrows show how I want you to visualize the air flow. During the first third of the breath, the top portion of the column is sucked in and chases the residual volume deeper into the lungs. The volume, now out in the lungs at the air-blood interface is the residual portion of the last breath. It will end up diluting the first portion of this new breath. The second third of the breath on the left is now sucked in and pushes the residual volume and the first third deeper into the lungs. The last third is what we might call the chaser because it only fills the larger spaces like the major wind pipes. Thus, the residual air left over from the previous breath and the first third of this new breath are deepest in the lungs and are at the air-blood interface. The second third is not as deep and doesn't really participate much in gas exchange.

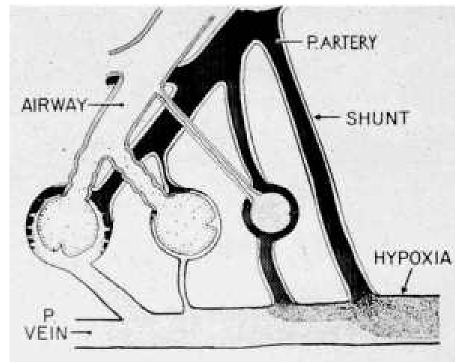


The last third is air which is known as "wasted" because it doesn't participate at all in gas exchange. Based on this model where would you expect to add additional oxygen? Where would it do the most good and not be wasted? The first third is the place because it goes the deepest into the lungs and participates in gas exchange.



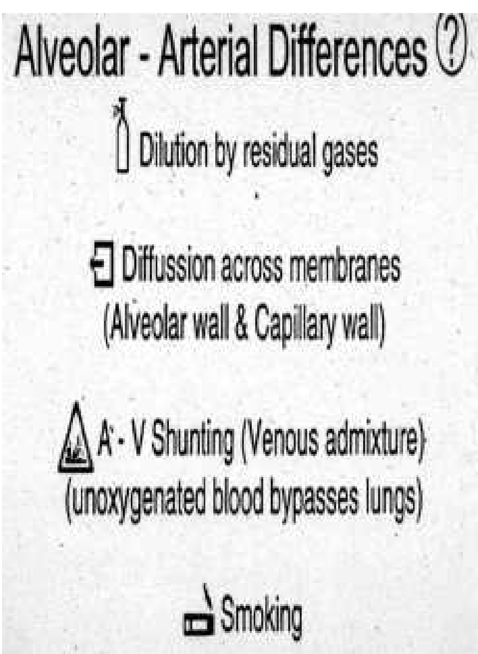
Here you see a model of the alveolus (air blood exchange unit of the lung), it's capillaries, and gases as represented by green for oxygen molecules and yellow for carbon dioxide. Of all the air that enters the lung only the air adjacent to the alveolar-capillary wall participates in gas exchange.

Unfortunately, the lung and pulmonary circulation are not perfect. There are differences in the amount of blood and air going to different areas of the lung as seen on the left. These may be physiologic, meaning normal or pathologic (due to disease). As an example, while you are sitting in your seats, more blood is going to the bases of your lungs and more air is going to the tops or apices just because of gravity. This produces a relative mismatch of air and blood. But on the average it works out fine. Shown are four variations of a constant spectrum. From left to right are normal, lots of air and very little blood, very little air and finally lots of blood, and no air at all where the blood already somewhat depleted of oxygen, and darker red which essentially bypasses the lung. This is called a shunt.



NORMAL & ABNORMAL LUNG UNITS

Various disease states, including the more common ones of asthma and smoking, cause such changes. What has to be considered is that the lung is an inefficient organ at best, but is wonderfully efficient in that it keeps us living for many years. In essence, it does a job of self regulation providing oxygen to the blood stream to nourish our bodies. Compared to the concentration of oxygen we breathe, the concentration of oxygen in the blood stream lags that in the lungs by approximately 10%. Some of the factors causing this are listed in the right hand panel.



The residual gas left in the lungs and airway before the next breath causes some oxygen dilution as does humidification (addition of water vapor), and carbon dioxide excretion. For oxygen to get into the bloodstream, it has to cross several membranes. That is not particularly easy for an insoluble gas. Certain diseases increase the amount of shunting (bypassing); that is, allowing unoxygenated blood to bypass the lung. Lastly, smoking has a tremendous effect upon the normal lung by causing constriction of the airways, destruction of alveolar, walls and gas exchange surface drastically increasing the shunting mentioned before.

Let's now leave physiology and investigate some of the physical world around us.

I'm sorry for the busy chart below. But first turn your attention to the atmosphere in which we fly. Depicted on the left, are altitude and the percent of the atmosphere remaining above our heads.

Altitude vs. Blood Oxygen

Altitude	Atmosphere Above	Barometric Pressure	Water Tension at Body Temp	Carbon Dioxide Tension	Remainder	Oxygen Tension	Arterial Oxygen in Air	Blood Saturation "Tension"
Sea Level	100%	760	47	40	673	140	100	96%
12,000 ft	75%	570	47	40	483	100	75	94%
18,000 ft	50%	380	47	40	300	62	46	80%
24,000 ft	40%	300	47	40	210	45	33	65%
36,000 ft	25%	190	47	40	103	21	16	20%

All Pressures are in Torr or millimeters of mercury

For instance at 18,000 feet (5,500m) only 50% of the atmosphere is left, thus we are above 50% of the earth's atmospheric blanket. At 36,000 feet (11,000m) only 25% of the atmosphere remains above our heads and the remaining 75% is below our feet. The next column represents the atmospheric pressure (barometric pressure) at each altitude in mm of Hg. We automatically humidify the air we breathe in and the vapor pressure of water at body temperature is 47 mm of Hg. You can see this when you breath out against a cold mirror. In addition when we, as warm bodies, breath we excrete carbon dioxide as a metabolic waste product. This is virtually constant, regulated by our brains, to 40 mm of Hg. Thus, the air we breathe in is diluted by water (humidification) and carbon dioxide excreted into it. This adds to the dilution from the residual air from the previous breath. After the 87 mm of Hg is subtracted from the atmospheric pressure, column 5, oxygen is calculated at 21%, column 6. The process of getting the oxygen into the blood stream further lowers the oxygen tension, column 7. At altitude, oxygenation can be significantly lower than we desire without supplemental oxygen. For example, compared to sea level only one third the amount of blood oxygen should be available at 24,000 feet (7250m). For the time being, please disregard the last column, oxygen saturation. It is a measure of the percent of blood cells carrying oxygen. As you can see the relationship is not linear.

The aviation community established, around the late 30s or early 1940s, obtained data upon which a guide specifying the amount of oxygen which is needed to be added for altitude has been developed. Roughly speaking it is:

OXYGEN NEEDED

1 L/MIN/10,000 ft to 35,000 ft (3.5 L/MIN) FULL FACE (SIERRA) MASK	TIGHT FITTING PRESSURE MASK TO 44,000 ft (A-14 REGULATOR)	EXTERNAL PRESSURE NEEDED ABOVE 44,000 FT i.e. PRESSURE SUIT OR PRESSURIZED CABIN.

Since very few of us will go above 35,000 feet (10,000m) or yet above 44,000 feet (13,500m) simple systems of oxygen delivery will suffice. There is only one pressurized sailplane known to me, it is in the Boeing Museum in Seattle, WA

Oxygen systems their use and results

A while ago, high over Minden in wave, I saw another glider nearby so I whipped out my telescopic camera and took this picture as we passed.

After landing I asked her to pose for me so I could take some pictures of various oxygen systems.

Basically, the present day oxygen systems fall into the five categories listed below:

Mouth tube or nasal prongs

Oxygen conserving cannula

Sierra mask and reservoir bag

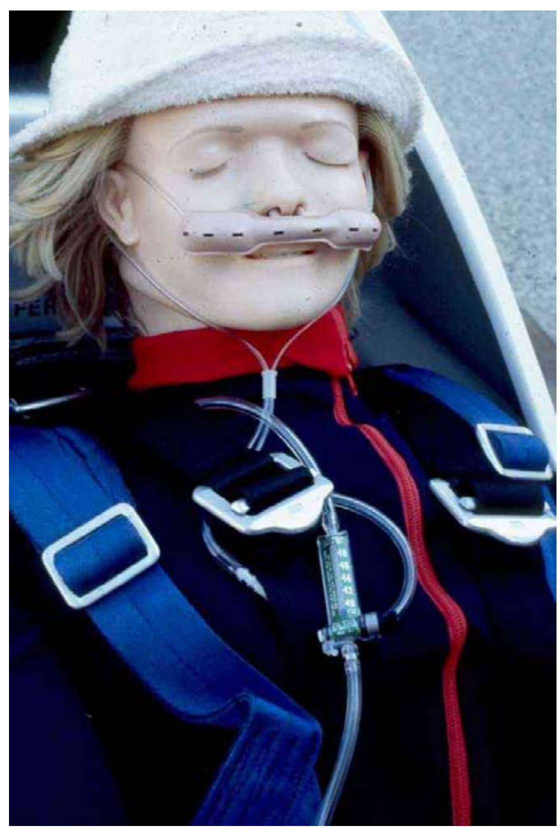
A-14 regulator and mask (100% Oxygen and pressure breathing)

Pressure suit or pressurized cabin

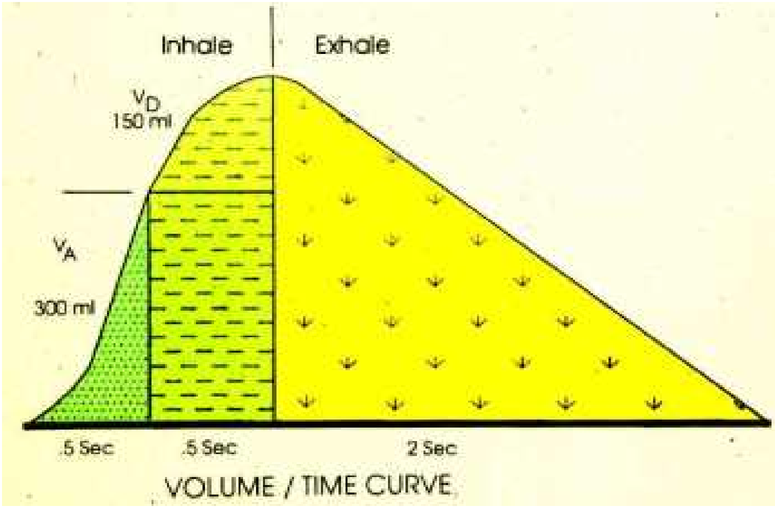
I enlisted my helper, probably familiar to many of you as Resussi Annie, (a CPR manikin) to demonstrate the various systems.

Here you see Annie sitting in the cockpit with a simple tube in her mouth and a ball flow regulator on her chest. This simple system is fairly good at levels below 18,000 (5,500m) feet but should use flows of 1 l/min/10,000 feet (3,000m) or almost 2 l/min at the maximum legal altitude of 18,000 feet (5,500m).

The other extreme, available to us is an A14 system. A14's are overhauled used Air Force surplus. It is a system which will blend oxygen based upon altitude and then begin to increase pressure against exhalation (breathing out) in order to maintain sufficient oxygen pressure in the lungs. It is not automatic. Here the regulator is located above Annie's right shoulder.

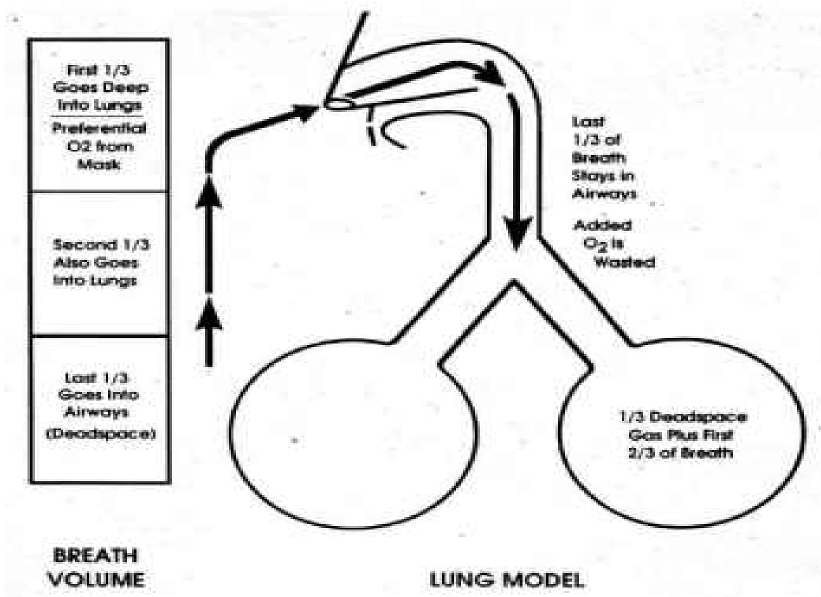


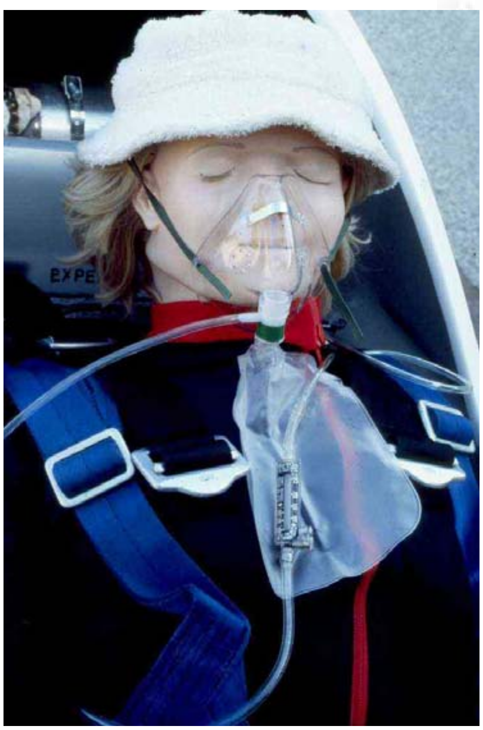
In my experience, the conservation cannula, is the most commonly used oxygen unit that my friends and I have used. It is approved by the FAA to use oxygen flows of only 30-50% of that required by other systems up to an altitude of 18,000 feet (5,500m). Its magic will be discussed shortly



Now let's return to the breath-time diagram that we talked about a little while ago. If we want added oxygen to be used most efficiently, we should add it to the very first portion of the breath so that it reaches the furthest into the lungs, into the alveolar air sacks, next to the capillaries. Any added oxygen added in late inhalation or exhalation will not reach the capillaries and will be exhaled and wasted.

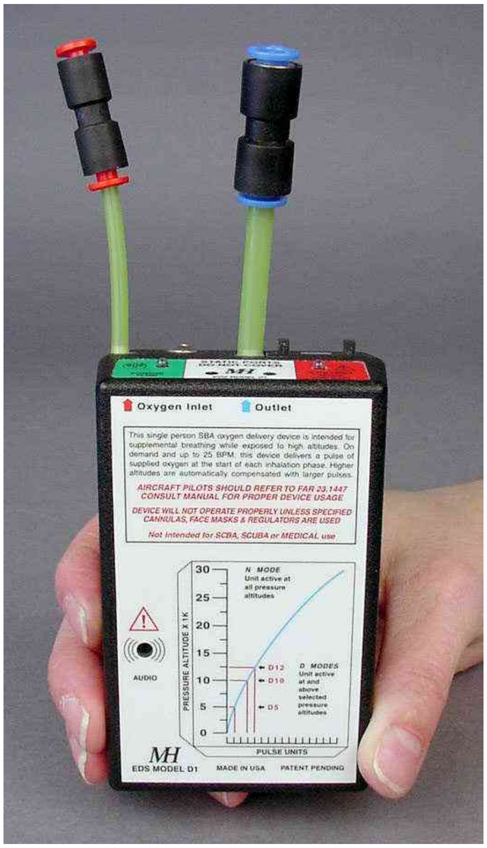
Let's reconfirm that idea using the nose-windpipe model also seen earlier. If we add oxygen to the first third of the breath it will go deeper into the lung, whereas any oxygen added to the middle and especially the last thirds will again be wasted.





Here is a mask and bag, it is much cheaper than a Sierra mask system. But, while Carl Maulden says in his American Express commercial, "don't leave home without it," I'll tell you don't even think about using it! In the cold of altitude the bag will be so stiff it won't fill because there is no valve on it. The mask fits very poorly and the holes in the sides effectively make this system very inefficient. This mask is designed for hospital use where flows of 10-15 l/min can be given without much thought of cost or availability, its maximum oxygen concentration is near 50% unless flows of 20 l/min or higher are used.

Now lets go back and revisit the standard cannula. This is a very inexpensive item which can be obtained very easily. In order to be effective it needs an oxygen flow of 1 l/min/10,000 (3,000m) feet in order to provide adequate oxygenation up to 18,000 feet. Refer back to the respiratory volume time curve a few slides before and imagine the waste of oxygen when given during the later part of the inspiratory (breathing in) phase and the exhalation (breathing out) phase of breathing.

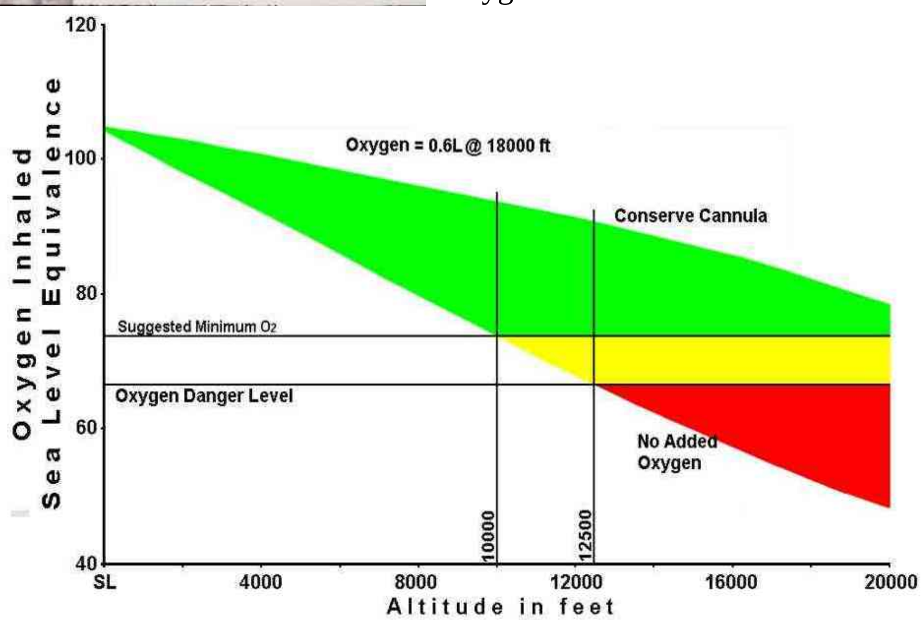


Mountain High of Salt Lake City to the rescue. Patrick McLaughlin has developed this handy dandy EDS (Electronic Delivery system) oxygen regulator for use with the standard cannula. Basically, it monitors your breathing by measuring pressure changes at your nostril and when it determines the beginning of inspiration, gives a blast of oxygen, the volume determined by an altitude sensor. It is quite efficient according to reports I have received.

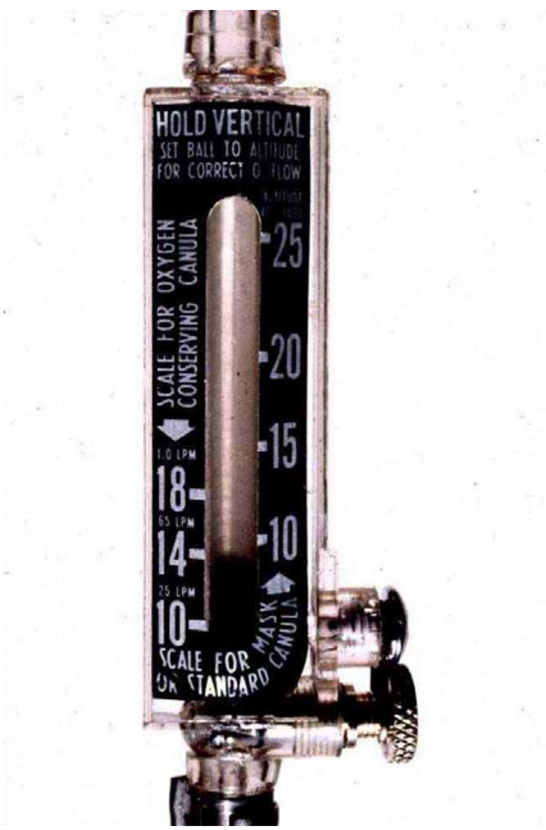
The conserving cannula, as I said, has been quite popular around here. In essence, it has two small reservoirs totaling about 15 ml in the cheek pouches that fill during exhalation from a constant flow of oxygen. Please notice that the nasal prongs are larger than those of the standard cannula. This effectively acts as a valve so the first portion of the inspiratory (breathing in) phase empties the reservoirs before entraining much ambient air. Thus, compared to the standard cannula, its effect has been tested up to 18,000 (5,500m) feet at significantly lower oxygen flows resulting in adequate oxygenation.

The flow meter on Annie's chest produces flows of about 500 ml/min/10,000 feet (3,000m), and is calibrated up to 18,000 feet (5,500m) as determined by the numbers on the right side.

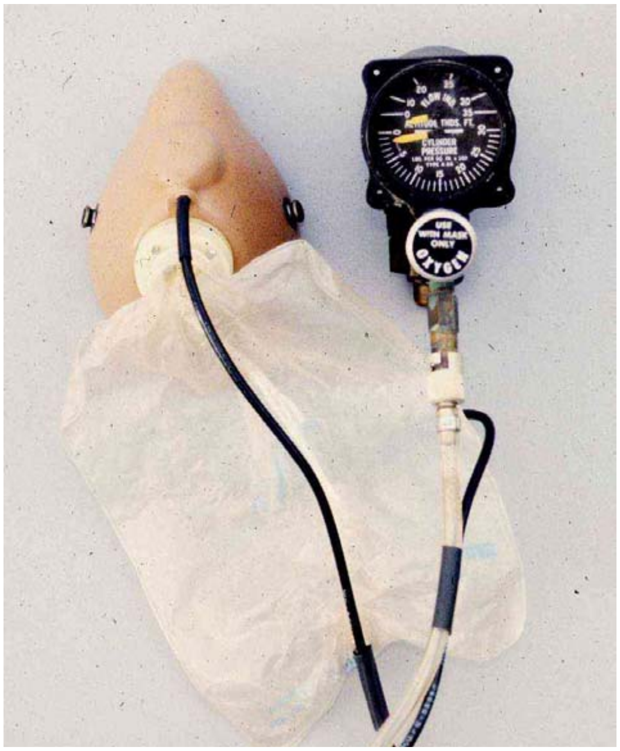
This graph below, colored for good (green), caution (yellow) and danger (red) represents the mathematically derived blood oxygen delivered at altitude from ambient air and from a conserve cannula. The ordinate is essentially the percentage of sea level oxygen delivered at respective altitudes. Without extra oxygen your oxygenation would be marginal at 9-10,000 feet (2,700-3,000m) and dangerous above 12,500 feet (3,750m). While using the conservation cannula the safe zone is above 20,000 feet (6,000m).



The next step up in efficiency is the Sierra mask system. This is a tight fitting mask with a head strap and a reservoir bag. Notice the pale rings at the mask bag juncture. Located there are valves that require the deflation of the bag prior to entrainment (adding in) of outside air. Additionally, exhaled air is prevented from filling the bag and there is slight resistance to venting exhaled air. One note of caution, don't expect the bag to fill visibly. Below 20,000 feet (6,000m) the oxygen flow does not seem to expand the bag. At higher altitudes, 30,000 feet (9,000m) and above, it becomes quite obvious that the bag is filling. This mask system is useful up to the high 30 thousands.

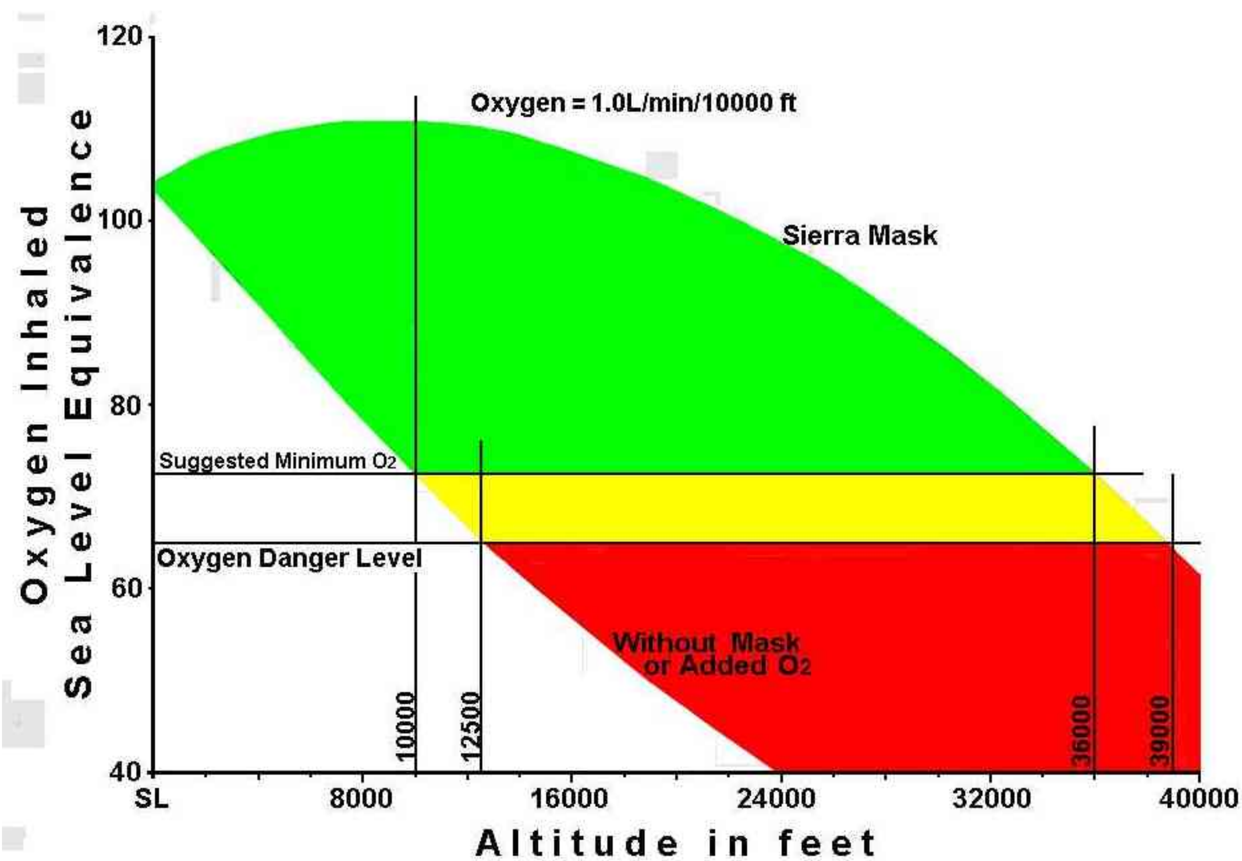


This picture shows the Nelson A4 flow regulator. Notice the two scales, the right is 0-25 or 25,000 feet (7,500m) and is calibrated for a flow of 1 l/min/10,000 feet (3,000m). The left scale is similar to that used with the conservation cannula. The sierra mask system is as efficient as the conservation cannula, probably even more so, but is designed to be used above 18,000 feet (5,500m).

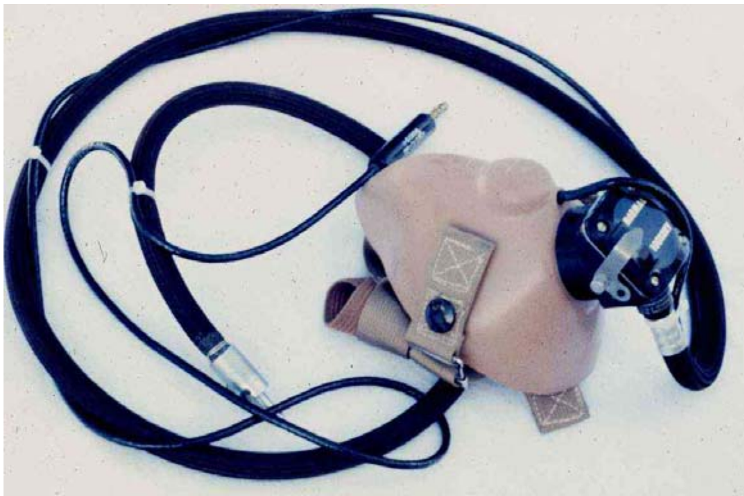


Another frequently used method of regulating the oxygen flow is the A8 regulator. Also an Air Force hand me down, these regulators are very susceptible to mal adjustment and flow errors. Frequently, these units are red tagged by a maintenance shops, thus becoming paper weights. Their advantage is that they are easily adjustable with a readout in thousands of feet.

Here is a similar curve this time based on the sierra mask system. Again it is a mathematically calculated curve. Again the no oxygen curve enters the caution range at 9-



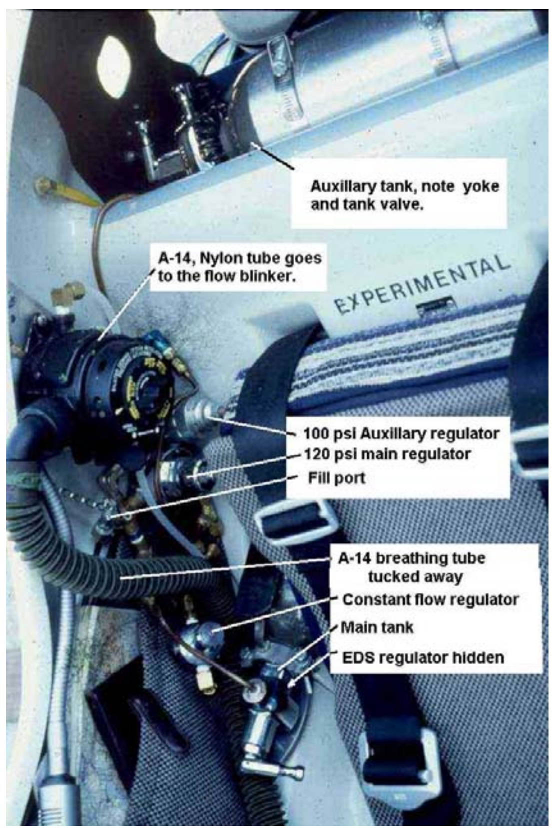
10,000 feet (2,700-3,000m) and the red range at 12,500 feet (3,750m). In contrast, the sierra mask when used correctly, enters the caution range about 36,000 feet (11,000m) and the danger area at about 39,000 feet (12,000m). I have personally used this system over 37,000 feet (11,500m).



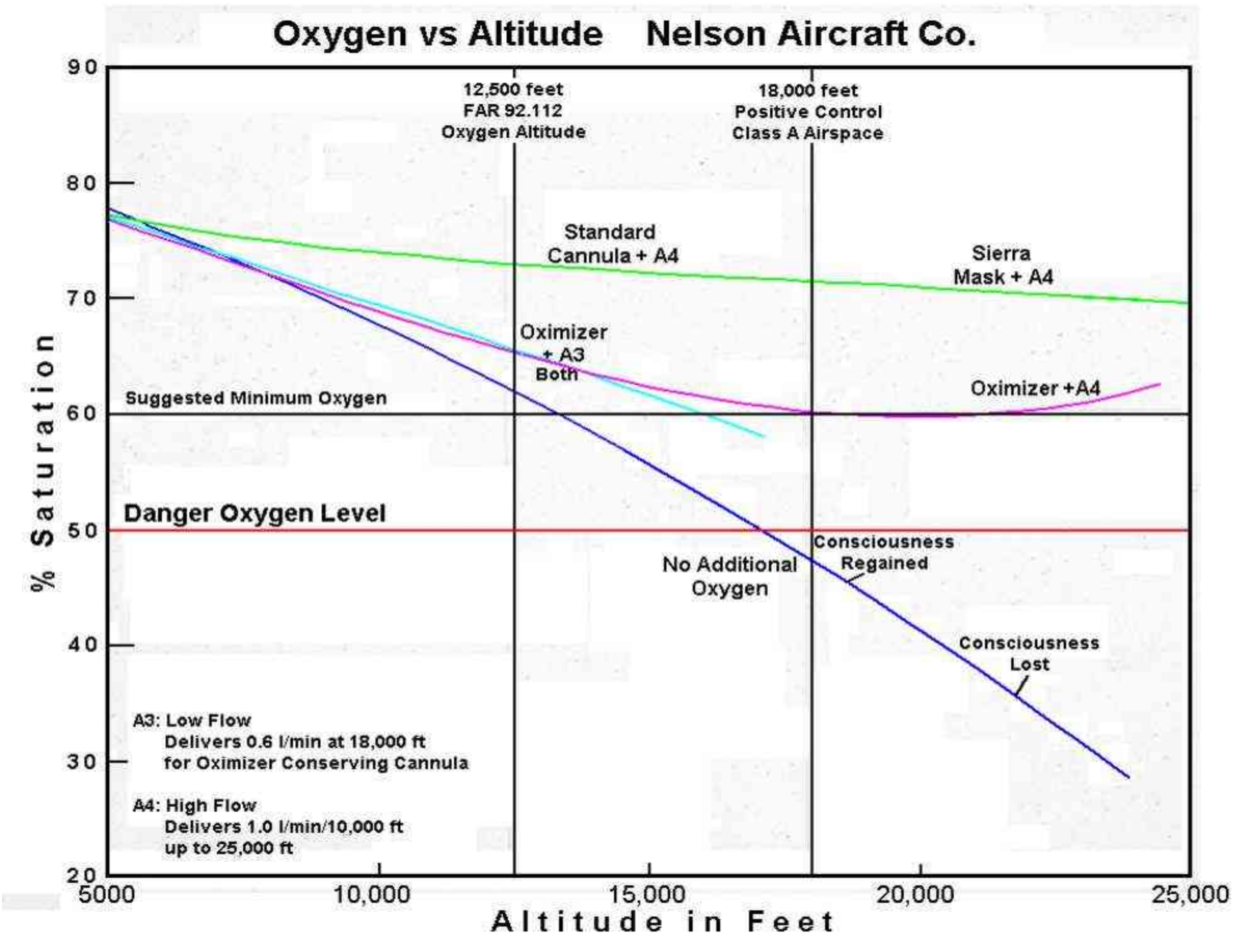
This interesting system is called the Altox system. It uses a pressurized supply between 20 and 60 pounds per square inch. The black body attached to the nose of the mask is a regulator which is sensitive to mask pressures produced by breathing. It is not very efficient in that it requires constant oxygen except for a small blend hole on the side by the silver lever. I am interested in paperwork and documentation on this unit. Unfortunately, to this date I have not been able to locate any. If any one has the documentation I would appreciate meeting you after the talk.

This is the venerable A14 system. As I mentioned before, surplus military units. On the face is a dial to change the oxygen concentration and back pressures so that it can be used to 44-45,000 feet (13,500m). Above 39,000 feet (12,000m) the unit produces resistance to exhalation so that in the low 40 thousands it is somewhat difficult to breath. It is like trying to breath with an air compressor in one's mouth.

For those of you who know the insides of gliders this is a Glaser-Dirks model 600 which has been equipped with a dual oxygen system. There are two bottles and each has its primary regulator adjusted so that they will work in a cascade system. In addition, there are secondary regulators for constant flow systems, regulators for higher pressure systems such as the Altox and EDS from mountain high and an A14 system. Essentially each system can work off of either tank automatically. I have been using this as my fun ship and test bed. See the end of the article for a schematic of this oxygen system.

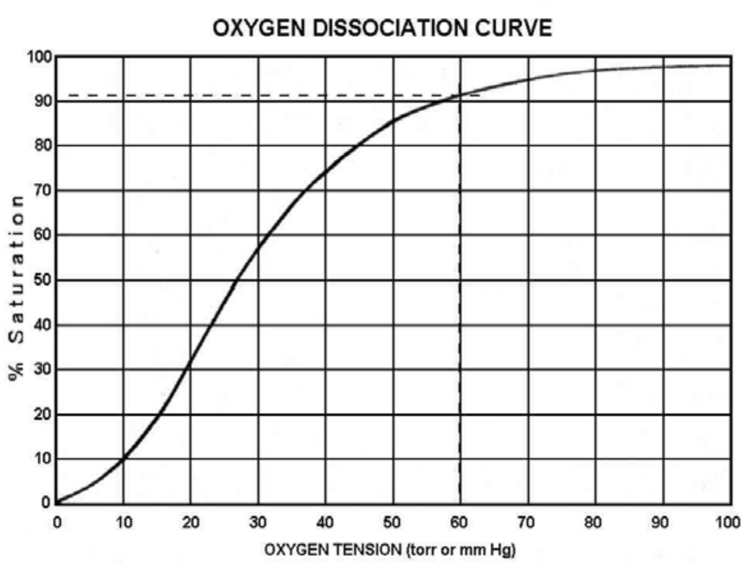


Several years ago during the development of the Nelson A3 low flow regulator, I accompanied Ted Nelson and his son Jerry and a pilot on a data gathering flight to 24,000 feet (7,250m). Several systems were evaluated as are shown in this chart. The measurements were accomplished by an oximeter, a device which uses photocells to measure the color of the capillary blood by spectral absorption at 600 and 630 mili-microns. Altitude was called out by the pilot. Ted Nelson was the recorder and Jerry was my safe keeper. Obviously, I was the guinea pig. The first climb to 24,000 feet (7,250m) was done as a control, without added oxygen.



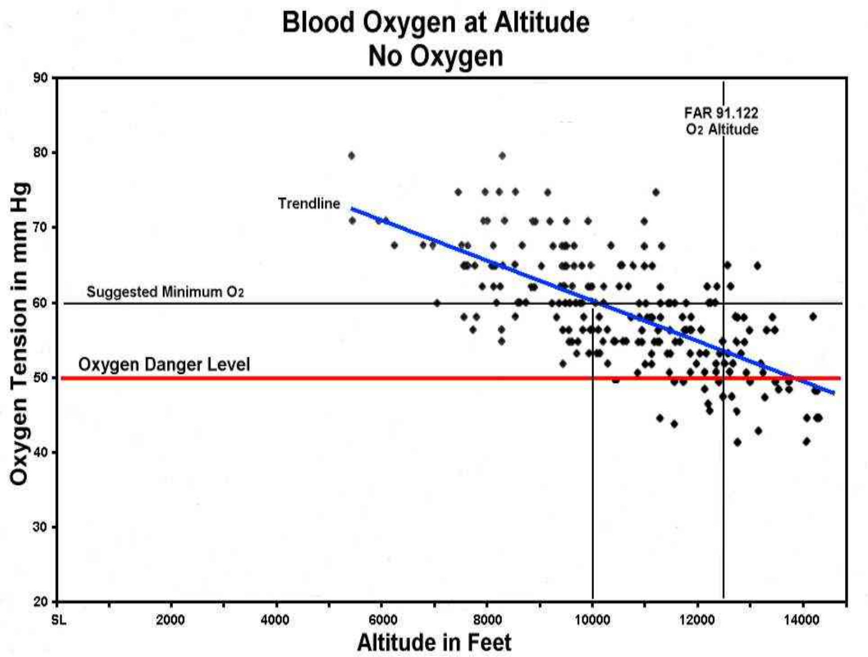
This resulted in my loss of consciousness. Previously I had been to 24,000 (7,250m) feet without added oxygen in altitude chambers without effect. The last event I remember was 22,000 feet(6,750m). After reaching 24,000 feet (7,250m) the pilot started down and I woke up at about 19,000 feet(5,750m). According to Jerry Nelson, I still acted normally, although my speech was a little slurred. Maybe this is why I accepted the RENO95 job I did (chairman of exhibits). I was a little slow to say no! The middle curve was accomplished using a conserve cannula and an early A3 flow regulator to 18,000 (5,500m) and then switching to an A4 regulator above that. The top curve was a standard cannula using an A4 regulator to 18,000 (5,500m) and then a Sierra mask above that. Obviously the top curve is best. It was felt the middle curve was marginal. Based on this data, the A3 flow regulator was modified to increase delivery volume at higher altitudes about 25% before it was put on the market.

Today the measurement of oxygen saturation and altitude is much easier. This little oximeter on the left can be put in a pocket and the barograph on the right is of similar size. Each will record into memory the flight data. The data only needs to be down loaded and matched for time



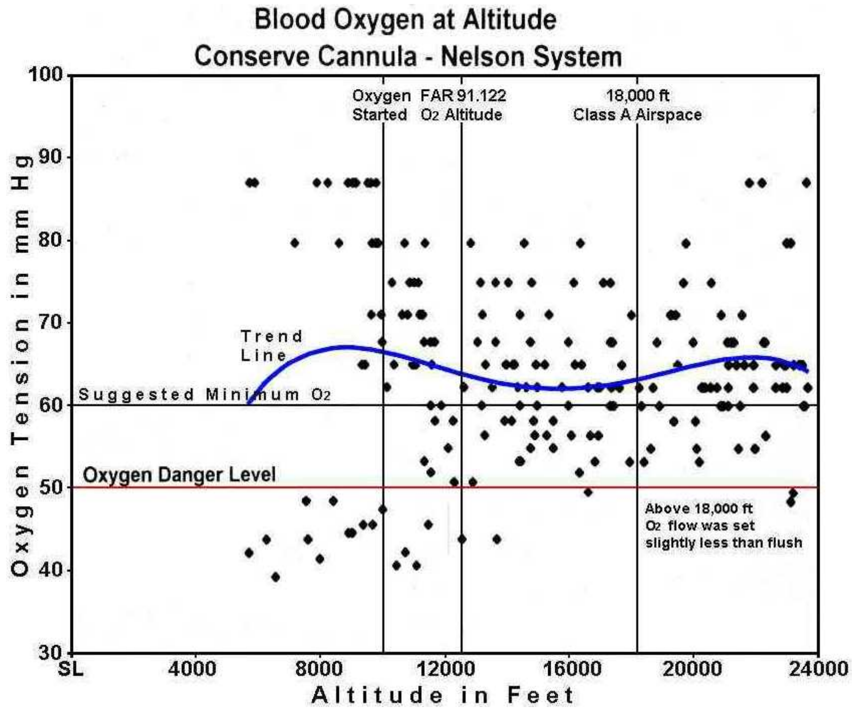
As mentioned before oxygen saturation is not linearly related to oxygen tension but instead represents directly the amount of oxygen that is carried by the blood cells. This is because the hemoglobin molecule has a changing affinity for oxygen. The equipment I use to measure oxygen, measures saturation. This needs to be converted into oxygen tension for the use you will see shortly. Essentially, the steepness of the curve corresponds to hemoglobin's changing ability to release oxygen. For instance, between the oxygen tensions of 20 and 30 more oxygen is released than between 60 and 70. Incidentally, contrary to advertised opinion, at sea level, the use of 100% oxygen only increases oxygen carried by the blood three tenths of one percent. At altitude when our saturation is lower extra oxygen is very beneficial.

Here I have plotted several flights below 18,000 feet (5,500m) using the ordinate for blood oxygen tension and the abscissa for altitude. Included is a trend analysis line. Please note the relationship of the trend line to altitude. It crosses the danger level, that level where thought and decision processes begin to be compromised, about 12,500 feet (3,000m). Also the line crosses what I consider to be the top of the yellow caution area about 10,000 feet (3,000m). This data is in support of the mathematical model without oxygen.

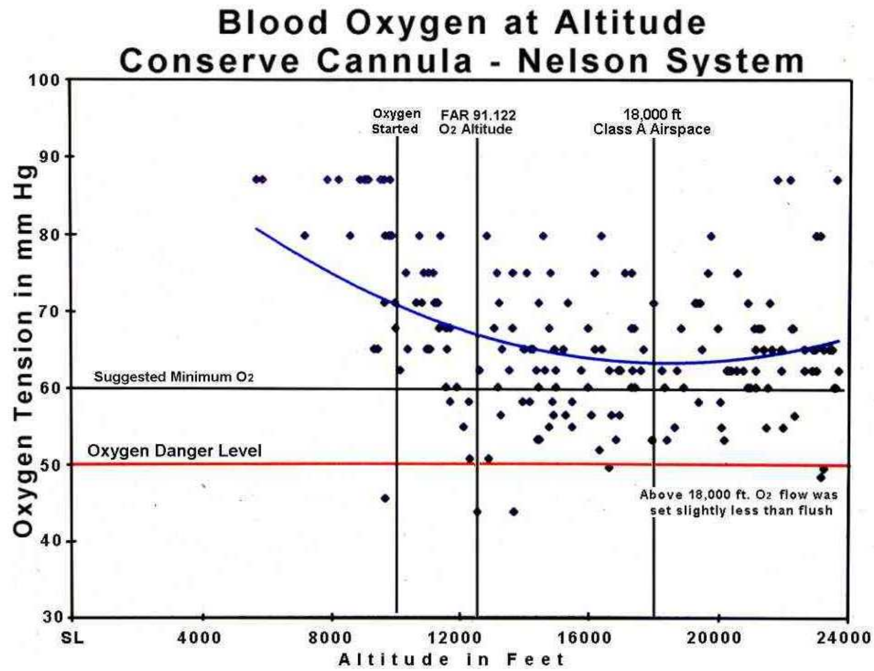


This next graph also shows oxygen vs. altitude but this time I used a nasal cannula and a nelson A3, flow regulator to 24,000 feet (6,000m). The trend line shows a bimodal curve which distressed me when I first saw it. This data was collected during a 3 1/2 hour flight from Truckee, CA and into wave just west of Minden, NV.

The wave provided three separate climbs from 10,000 feet to 24,000 feet (3,000-7,600m) before I returned to Truckee. The A3 flow regulator was set according to the altitude except above 18,000 feet (5,500m) when it was set to just less than flush. Notice that the system behaves very similarly to the mathematical model for the conserve cannula showing it is effective to the middle 20 thousand foot (6,000m) level. As I mentioned before, I was bothered by the bimodal trend line. A little investigation revealed that all 16 points in the lower left group were made during the last 16 minutes of the flight. You will also notice that they are all below 12,500 feet (3,750m) in altitude. For one reason or another I had removed the oxygen system passing through 12,500 feet (3,750m) while returning to home base.

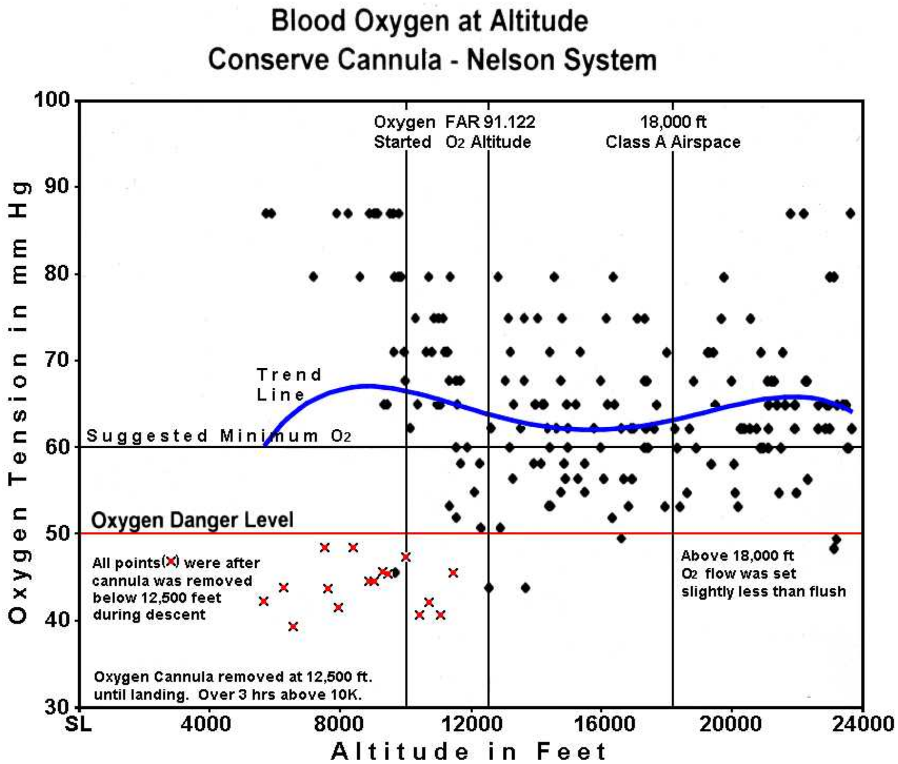


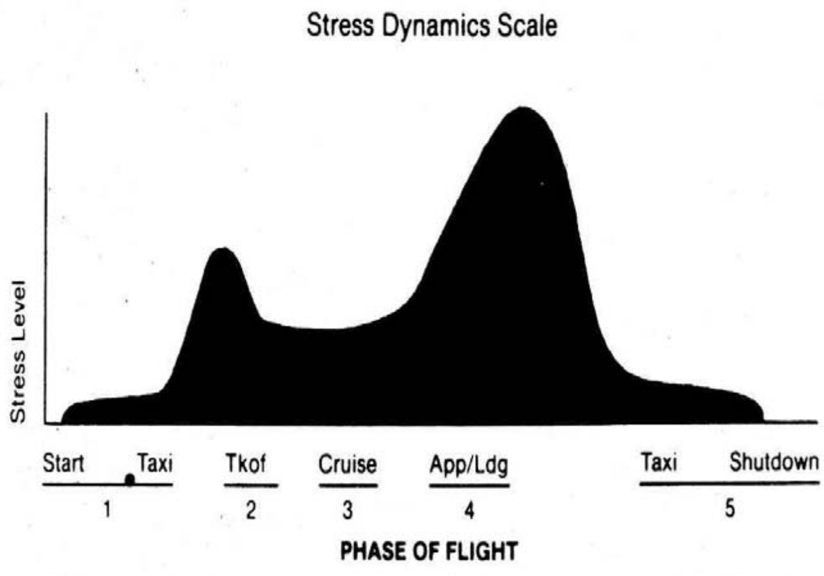
When these points are removed the new trend line is now of a much different character. It starts high at lower altitudes and curves down to around 16,000-24,000 feet (4,900-7,600m) as would be expected.



In the following diagram the offending last 16 points, all below 12,500 (3,750m) are marked with red centers. As I said these points represent all the data during the final 16 minutes of the flight, during which the altitude was less than 12,500, feet (3,750m) and during which time I was entering the traffic pattern making my approach to landing. I do not remember feeling different, although I am usually quite aware of my individual hypoxic symptoms.

The real question arises, had I known of my relative hypoxia should I have been on added oxygen? The answer is a definite YES! But the question still remains, why are all these data, without exception, aberrant, when for all rightful purposes they should not have been? My only explanation is that although I was apparently well oxygenated at altitude, might my bodily oxygen stores have been compromised? Did the removal of extra oxygen passing through 12,500 feet (3,750m) suddenly expose me to the decreased stores and allow my arterial oxygen to fall to what I consider a dangerous level. The only caveat is to do what was advocated many years ago, that is, once using oxygen continue it until roll out stops.





Source: Adapted from Richardson, J. (1978) "CFIT: A Human Factors Problem." *Aerospace Safety, 2*, 3

Don't forget you are tired, probably dehydrated, entering the airport traffic area and proceeding to a landing, all actions together, probably, the most dangerous part of the flight and possibly hypoxic as well. At this time our thought processes and judgment patterns need to be the sharpest since we took off.

Now I'll finish with a thought philosophers have pondered for years. If nobody is around to hear a meteor crash in the forest, does it really make noise. To put that in glider terms; does it really hurt when you hit the ground if you are asleep.

And lastly, I'll finish with a favorite saying of mine that matches to some degree the opening slide.

Experience is a Wonderful thing

It allows you to recognize a mistake When you make it again!

Belowt is a schematic of the oxygen system that I have used to develop the data and test the apparatus described in this article. This is the one pictured in my DG-600 earlier.