Investigating the use of EM to model SCUBA diving

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Abstract

This paper describes the need for care while SCUBA diving into water . It describes and explains the risks involved, and how they avoided. It accompanies a decompression model, an implementation of Buhlmann ZH-L16 model , written in DASM script for the Cadence tool. Its purpose is to educate divers how DCI ('the bends') can form anywhere within the body, and to highlight the risks of Nitrogen Narcosis and Oxygen Toxicity.

1. Introduction

SCUBA Diving can be a dangerous activity if one is not aware of the risks and how they may be mitigated. Even in a safe, known, closed environment (such as a swimming pool), there are dangers.

A large area of concern to the diving community is the need for breathing gas under great pressure for periods of time, and then returning to breathing lower pressures. This puts the body in an unusual state, for which the symptoms for activity outside usual limits may not be immediately apparent.

It is very important for training divers to be made aware of how to calculate their limits, and the subsequent risks for exceeding them. It is also very important for experienced divers to be able to accurately calculate limits for more strenuous diving.

1.1 Breathing gas at pressure

The need for breathing great pressure comes for being at depth. Below water surface, pressure increases with water depth. "We must breathe compressed air, or some other compressed breathing gas, in order to counteract the pressure of the water and allow out lungs to expand" (Powell, 2008). Diver's equipment provides the gas at the ambient pressure from a tank containing a gas mix at very high pressure.

Divers breathe a pressure of gas that is more than the pressure of air at the surface. During descent, an increased pressure of nitrogen results in more nitrogen being absorbed by tissues of the body. The longer the diver stays at depth, the more nitrogen is absorbed into the tissues, until they are finally in equilibrium and fully saturated with the current pressure of the breathing gas. Only then does nitrogen stop being absorbed. Further descent again increases pressure, and the tissues begin to absorb again.

Ascending reverses the situation. The ambient pressure around the diver decreases during ascent. The diver's tissues are potentially higher in pressure than the gas in which they are breathing. In this case, the tissues are supersaturated. The nitrogen comes out of the tissues, and breathed out by the diver.

2. Dangers in Breathing

There are a number of conditions that can effect divers while they are diving, and for a period when they return to the surface. Decompression Illness and Oxygen Toxicity are dangerous in themselves. They can cause harm to the body, where as Nitrogen Narcosis makes the situation more dangerous initially (such as impaired concentration) , followed by symptoms which are dangerous to life.

2.1 Decompression Illness (DCI)

Ascending without regard to the pressures of gases saturated in body tissue is dangerous. The body needs time to release gases from tissues that are supersaturated, or there will become a point where the difference is so great that the gas becomes un saturated within the tissue. Bubbles will form in the tissues and DCI symptoms ('the bends') will occur. Symptoms are different from case to case.

This can be avoided by slow ascents and by making "safety stops" during ascent while the tissues have time to become less super saturated.

2.2 Nitrogen Narcosis

Breathing high pressure of nitrogen results in symptoms that may present a hazard to a diver's health. Nitrogen "narcosis typically decreases the accuracy of responding as well as increasing response time on a variety of cognitive, perceptual-motor and manual dexterity tasks." (Fowler, n.d.) The effect on concentration is also well known. "Divers have to focus on the task at hand but perceptual narrowing can cause them to be unaware of any potential dangers outside the field of concentration" (Stanley, 1995)

2.3 Oxygen Toxicity

Like Nitrogen Narcosis, breathing a too high pressure of Oxygen is dangerous. Oxygen becomes poisonous at high pressures. Symptoms of Oxygen toxicity include Dazzle, Constriction of visual field, Tinnitus and auditory hallucinations, Vertigo, Respiratory changes, Nausea, Spasmodic vomiting, Fibrillation of lips, Twitching of lips, cheeks, nose or eyelids, Syncope (fainting) and Convulsions. (Bonnier Corporation, 2011)

3. Avoiding the dangers

3.1 Limits

Usual limits are given in the form of dive tables, for which there are many varieties, or dive computers, which make a good attempt at modelling the diver's body. Diving is safe if these are adhered to, but there are health risks attached to exceeding them.

Dive tables can be simply understood as a depth to maximum time (at given depth) function. Typically they provide additional information, such as depth and duration of safety stops for a given depth and dive time.

3.2 Gas mixes

As we cannot breathe underwater, a diver carries their gas supply with them. Oxygen is the gas which is essential to us as it is the gas that supports life.

The gas mix a diver breaths could be identical to air; air contains about 21% oxygen, or an 'enriched' mix containing a different percentage of oxygen and possibly other gases in part replacement of nitrogen. For this reason, we refer to the gas mix the diver is breathing as gas, rather than air.

Gas mixes with less nitrogen make the diver less susceptible to Nitrogen Narcosis (than a gas with more nitrogen, at the same pressure). Gases with less oxygen make the diver susceptible to Oxygen toxicity (with the same comparison). However, It is not easy (and inexpensive) to achieve both.

3.3 Decompression Model

Divers can avoid Nitrogen Narcosis and Oxygen Toxicity by planning depths and gas mixes as discussed above. Avoiding DCI is a little more complex, and a model of the body is required to decide on depth and length of safety stops.

Dive computers and planning software use a model and an algorithm to track gas saturation within the body. They will typically warn the wearer when continued activity might cause them harm.

4. Brief History of Deco theory

In researching the mathematics in decompression, the author discovered an interest in decompression history. This is relevant in the study for this model as it explains the origins of the ZH-L16 model, which was chosen to be implemented in EM.

The need for decompression was discovered in the early 19th century. Early diving took place in Caissons, French for "big box", a pressurised container with an air-lock. A "French mining engineer named Tiger" (Powell, 2008) first used the term "Caisson's Disease" to describe the pains and cramps we now know as DCI.

John Scott Haldane was approached by the Royal Navy's Deep Diving Committee to establish a method to avoid "Caissons Disease". "Haldane introduced the concept of half times to model the uptake and release of nitrogen into the blood" (Powell, 2008) and suggested separating tissues into five compartments.

We move forward to the work of Professor Albert Buhlmann, but in so acknowledge the work of the US Navy and Robert Workman. Buhlmann worked on decompression for 30 years from 1959. He extended the number of compartments to 16, and looked at diving to depths of 300 metres. He created the "Buhlmann algorithm" which "became the basis for most of the world's in-water decompression computers" (Powell, 2008) and the model behind "the standard diving tables for a number of sport diving associations" (Powell, 2008). His model, and the model that was subsequently implemented in EM is based in history, and trusted by many diving organisations.

5. The EM Study

The author decided the theory behind DCI, Nitrogen Narcosis & Oxygen Toxicity could be better explained to people in dive training using a graphical model. The same model can be used to describe all three, the theory of dive computers and the purposes of different gas mixes.

Optimally, a diver will take a dive computer with them on a dive, as this will provide the greatest accuracy based on the dive they are doing, rather than the one they plan to do. However, training divers should be taught why there use is good practise. "Blindly following a set of tables, PC planning program or any other form of decompression planning without understanding some of the principles of decompression theory can be highly dangerous" (Powell, 2008)

Greater understanding of the body, and how DCI can occur anywhere within the body could result from training using a model which visually displays the calculations of a basic dive computer.

With this thinking, the author began modelling for the purposes of diver education, rather than an application to directly influence dive plans.

5.1 Use of EM

The use of EM for this purpose seemed ideal. Dive computers and decompression software are only models - models which are themselves a set of formulas and routines, created by researchers in history by observing divers. The challenge was to entirely adapt the model so that it could do the entire calculation with formulas alone.

Decompression models are essentially a number of continually changing variables over time - in this case, the pressures of the tissue compartments. It seemed ideal to model these in EM and allow rapid recalculation at a regular, short time intervals, and re-calculate all dependent formulas.

5.2 ZH-L16

The model chosen for the EM model is the Buhlmann ZH-L16 model. It is freely available and "very well tested" (Morrison, 2000). Specifically, the EM model this paper accompanies uses the ZH-L16C variant, as this is "intended for incorporation into dive computers" (Morrison, 2000), for which this model is in some regard.

The model splits up the body into 16 "compartments". Each body's tissue, organ, joint (etc) are assumed to roughly fit into one of them. All sixteen have different nitrogen half times - times for the difference between the nitrogen partial pressure (pressure of gas mix, multiplied by percentage) in the lungs and the nitrogen partial pressure in the compartment, to halve. They range from a half time of four minutes for the 'fastest' tissue, to six hundred and thirty five minutes for the 'slowest' tissue. (Chapman, n.d.)

Each tissue has a different partial pressure of each gas saturated within it, and each can become super-saturated and start to form bubbles if the pressure difference is too great.

Subsequently the partial pressure of each compartment must be tracked independently. Each must be monitored for potential super saturation, and action taken (for example, halting ascent) until the situation becomes less severe.

The Buhlmann ZH-L16C model also includes numbers for working out depth ceilings for each compartment. A depth ceiling is a minimum depth a diver should stay at to not develop DCI.

5.3 Cadence

The author decided to use Cadence to model the algorithm, ascent alarms, nitrogen narcosis, and oxygen toxicity alarms. This was based on the belief that many cyclic formulas would be required to calculate the gas contents of tissues over time.

A decision was made to entirely separate the model from the user interface. The ZH-L16C model is implemented in DASM script, away from all display and input based script. This hopefully makes this clearer, and easier to change or expand the model - maybe even switched if a 'better' one if it is published.

The model has been designed to make it easier for any future modeller to extend the model to add additional gases for more technical mixes involving gases such as helium, or maybe additional compartments. It could be easily extended to train technical or commercial divers.

The Cadence tool is now well developed, but does lack mathematical operations other than addition, subtraction, multiplication, division, and trigonometry. The ZH-L16 model requires the use of an of Exponential function, for which Cadence does not provide for. The author was lucky in that Tim Monks had been recently experimenting with the tool, and contributed a module to provide it with thinks functionality. Many thanks goes to him.

The author created a user interface using the Warwick Games Design library, a native module to Cadence. The functionality here was unexpected extensive, and so the UI was given more design work than was intended. It is hoped the reader will find it beautiful and clean as a result.

Additionally impressed with the clone and %deep notation - functionality that allows copying of whole observable trees, or simply creating references to them - effort was made to use these where possible. As a result, there is no unnecessary duplication within the model scripts.

6. Model Description

To experience the model, the user is shown a diving simulation screen. All outputs are clearly identified. To begin a descent, they may simply use the down arrow key on a typical keyboard. The up key conversely causes the diver to ascend. The user chooses a target depth with these keys, and the virtual diver will make their way toward it.

The model allows time speed to be increased and decreased by the way of the front and back arrows.

Finally, for further experience for later in trainee diver education, is the ability to switch gases. This can be done at any time, as is the case in recreational diving. There are three choices and selection can be made by using the 1,2 or 3 keys on the keyboard.

At any point, if the user is doing anything which may be at harm to their health, the issue will be highlighted in yellow. Continued action may result in red highlighting. Red is intended only if the model predicts you need, or shortly will need medical attention. It is up for the user to understand the issue and the consequences to their health from this paper or from dive training material.

The reader may experience this by descending all the way to 60 metres on air, waiting approximately 30 minutes for the fast tissues to saturate, and then ascending to the surface. This will result in many warnings, and should subsequently not be attempted in the physical world.

7. Acknowledgements

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The work of Stuart Morrison (Morrison, 2000) should be cited for his excellent DIY Decompression paper which has been a great help in establishing the formulae's and the model's data.

8. References

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