ORCA INDUSTRIES' DIVE COMPUTERS

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The ORCA Industries EDGE Dive Computer was the first model based dive computer available to recreational divers. After six years in the field, and the release of the SkinnyDipper as the second in the series, over 1.5 million dives are estimated to have been made using the ORCA decompression model. Bends incidence to date has been minimal, and less than comparable rates using the U.S. Navy tables. ORCA continues to improve hardware and software, and plans to release the third computer of the series in 1989.

ORCA Industries was formed in 1982 to develop a revolutionary element of diving technology, the EDGE Dive Computer. The EDGE was unique because it was the first of the model based dive computers. With its capability for multi-level and repetitive diving, the EDGE extended dive times and increased productivity for working divers. Its graphic tissue-tracking display has helped educate many divers about the mathematics of decompression. Since it implements a ceiling depth, instead of fixed stops, for dives requiring decompression, it allows diving flexibility which was previously unavailable.

The EDGE is a large unit, with a full range of decompression functions, many of which are unnecessary for the average recreational diver. In 1987, ORCA added the SkinnyDipper as the second computer in the series. Using the time-tested ORCA model, SkinnyDipper was designed with the recreational diver in mind. It presents an instinctive display of information, consisting of remaining no-decompression time, depth, and dive time, and doesn't have the EDGE graphics. SkinnyDipper is smaller, lighter, and less expensive than EDGE, and has proven to be very popular. Although it doesn't have the EDGE's capability for decompression information display, it does display a ceiling depth and doesn't lock up or shut down in decompression mode.

ORCA remains the leader in Dive Computers, and will present the third computer in the series at DEMA 1989. The new computer, as yet unnamed, will implement strong points of both EDGE and SkinnyDipper, and should prove to be a very capable machine.

WARRANTY DATABASE

ORCA maintains a computer database of EDGE and SkinnyDipper warranty information. Included in the database are the owner's name and address, of course, but also information about the owner's diving style and frequency. Analysis of the database shows that EDGE and SkinnyDipper owners are relatively similar people, which was not expected given the different marketing targets.
EDGE owners return warranty cards for 65% of all units sold. They are, in general, older divers who can afford the more expensive computer, with 56% over 35 years of age, and only 7% younger than 25. They report an outstanding number of dives per year, the database average is 82 for those who responded. The different age groups report different averages, with the under 25 group at 101 dives/year, the 25-35 group at 91 dives/year, and the over 35 group at 75 dives/year. This is understandable, since many EDGE owners take multiple, intensive dive trips each year, and justify the expense of the instrument by the increased diving that it provides.

SkinnyDipper owners only return warranty cards representing less than 30% of all units sold. They have a similar age distribution to EDGE owners, with 7% under 25, 33% 25-35, and 60% over 35. They report a smaller number of dives per year, with a database average of 62. The averages for the different age groups is also less than the corresponding EDGE group, with the under 25 group making 65 dives/year, the 25-35 group making 75, and the over 35 group making 54.

This information on the age distribution and diving frequency of ORCA computer owners allows us to estimate the number of dives represented by the warranty database. It is assumed that each computer only makes half the normal dives during the year that it is purchased, except for SkinnyDippers in 1987, which are only given 25% of annual dives due to late release. The individuals in the database not reporting age and dive information are assumed to have a similar distribution to those who did report. Finally, the average number of dives per year for each age group is assumed to be 50 dives/year for each EDGE, and 38 dives/year for each SkinnyDipper in the field for the full year. All assumptions are chosen to be conservative, so as to underestimate the number of dives performed.

Including only warranty data, and not dives by the entire owner population, at the end of 1987 there had been 207,000 dives on EDGE, and 12,900 dives on SkinnyDipper. At the end of 1988, only within the warranty database, EDGE will have logged 430,000, and SkinnyDipper 112,600. This data is presented in spreadsheet form in the appendix.

The analysis of cumulative dives can be extended to the entire ORCA computer owner population. Those owners not represented in the warranty database are assumed to be similarly distributed to those who returned warranty cards. In making this estimation, production records are used to represent the number of new computers in the field each year. Computers using the ORCA model made by other manufacturers are not included in this analysis. Other assumptions are identical to those made in the warranty database calculations.

Figure 1 shows the estimated cumulative dives for all ORCA computers from 1983 to the end of 1988. Contributions from the three different age groups and both computers are shown. The steady growth of EDGE dives can be seen, with cumulative totals of only 30,000 in 1984, 115,000 in 1985, 274,350 in 1986, and 584,725 by the end of 1987. By the end of 1988, EDGE dives will have reached over one million. The influence of SkinnyDipper is seen beginning in 1987, with 50,000 additional dives on the ORCA model, for a cumulative total of over 635,000. With 466,000 SkinnyDipper dives by the end of 1988, there will have been over 1.5 million dives made on the ORCA model.

Although Figure 1 also shows the breakdown of dives by age group, in addition to computer type, it is difficult to see the exact distribution of age group. Figure 2 displays this data directly, showing that, for the year-end 1988 data, 57% of the dives are made by the over-35 group, 36% by the 25-35 group, and only 6% by the under-25 group.
While it is not possible to place an exact number on the size of the ORCA decompression model diving exposure, these extremely conservative estimates can give us a general idea of the scale involved.

**Figure 1. Cumulative dives on ORCA computers**

1984–1988

BENDS INCIDENCE

At the 1988 Annual Scientific Meeting of the Undersea and Hyperbaric Medical Society, Joel Dovenbarger presented a paper prepared by Vann, Dovenbarger, Wachholz, and Bennett, discussing dive computer bends cases. There were 38 cases, effective year-end 1987, experienced by users of dive computers. Cases of obvious user error were discarded, as were inappropriate reports such as that of the person diving with a buddy who wore an EDGE. All 38 cases were not attributable to persons wearing EDGE or SkinnyDipper, as other computers are available. For the purposes of discussion, let us assume that all cases were marks against the ORCA decompression model, or the use of model based dive computers in general.

In his February 1988 Diving Medicine Column in Skin Diver Magazine, Dr. Fred Bove cites bends incidence figures for the use of the U.S. Navy Standard Air Decompression Tables. The source of his figures and the assumptions involved is not mentioned. It is not unreasonable to assume that the figures represent the gross bends incidence attributable to the Navy tables within the Navy diving population. Furthermore, we should note that these figures are based on people diving the tables in the real world, with whatever errors and fudge factors this involves. His figures are 9 cases per 100,000 dives for dives within the no-decompression limits, and 38 cases per 100,000 dives for decompression dives. The U.S. Navy makes predominantly single no-decompression dives, with single decompression dives less common. The Navy tends not to make
repetitive, multi-level, no-decompression dives over a number of consecutive diving days, which is extremely common to recreational diving vacations.

**Figure 2. Distribution of cumulative ORCA dives**

Using the cumulative dives on the ORCA model and the number of reported bends cases at year-end 1987, the gross bends incidence of the ORCA model is 6 cases per 100,000 dives. Since this is for all dives, not just no-decompression, it does not correspond directly with either of the U.S. Navy statistics. It compares favorably with the 9 cases/100,000 Navy no-decompression figure, and is one-sixth of the decompression dive figure. This is in spite of the typical computer vacation dive history of 3-5 multi-level dives per day, for five to fourteen day trips. These numbers can only provide a conservative rough estimate, given the errors of reporting and the uncertainty of the denominator, but they lead us to accept the ORCA decompression model for the depths and exposures typical for recreational divers.

**ORCA PHILOSOPHY**

ORCA is constantly alert for ways to fine-tune the hardware or the decompression model to the benefit of recreational divers. The EDGE/SkinnyDipper algorithm is not valid at altitudes above 2000 feet, as it becomes less and less conservative at increasing altitude. An altitude algorithm has been developed for use in future computers which will eliminate the problems of using ORCA computers above sea level. This algorithm will produce the time-tested ORCA model at sea level, and adjust conservatively for altitude exposures.
We listen to our computer owners, and others interested in future dive computers, and try to implement their suggestions for the improvement of the next generation of dive computers. Such features as better graphics, display lighting, dive profile logging, and more are being considered for new products.

ORCA is also seriously interested in education and training of the diving population, as we feel that the best and safest computer owner is a well educated diver and consumer. We support instructor training programs and the development of dive computer specialty courses in the scientific community, all recreational agencies, and the military. We plan on continuing as the major force in dive computers into the next decade, as well as the next millennium.

LITERATURE CITED


Vann, R.D., J. Dovenbarger, C. Wachholz and P.B. Bennett. 1988. DCS and decompression meters. Undersea Biomedical Research, Supplement to Vol. 15. Abstract page 64. Annual Scientific Meeting of the Undersea Hyperbaric and Medical Society, Bethesda, MD 20814

APPENDICES

A. ORCA EDGE Warranty Database Summary Statistics

WARRANTY CARDS ON FILE

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AVERAGE NUMBER OF DIVES PER YEAR FOR THOSE REPORTING

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B. ORCA SkinnyDipper Warranty Database Summary Statistics

WARRANTY CARDS ON FILE

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**CUMULATIVE**

**ANNUAL**

12892 112623

12892 99731
THE DATAMASTER II
A FUNDAMENTALLY DIFFERENT DIVE COMPUTER

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Rancho Palos Verdes, CALIFORNIA 90274 U.S.A.

INTRODUCTION

At the present time, there are ten or more dive computers being sold within the United States. They come in a wide variety of sizes and shapes, and each displays data that is relevant to a diver. They all incorporate state-of-the-art electronics that produce exceptionally accurate and reliable measurements of depth and time. Only one uses a table calculation, and all of the rest rely on a mathematical model or algorithm to predict the decompression status of a diver. In my judgment, the most important contribution that the dive computer has made to recreational diving is the introduction of accurately monitored multi-level diving, a concept described by Graver (1979), and more recently verified by the experiments of Huggins (1983) and Powell (1987). Since the table calculation design represents no advantage beyond a table, I will not discuss it further. Instead, I shall focus on the algorithms, wherein lies the fundamental and profound difference between the Datamaster II and all of the remaining dive computers.

DECOMPRESSION THEORY

The decompression theory originally conceived by Haldane and his co-workers (Boycott et al., 1908) and used by Workman (1965) to produce the U.S. Navy Diving Tables predicts the nitrogen loading of six hypothetical tissues or compartments. Each compartment is assigned a "half-time" and a maximum allowable surfacing value known as an "M-value". The U.S. Navy no-decompression limits and all ten foot decompression stops are derived by calculations based on these twelve numbers.

At a constant depth, the solution to the governing equations can be expressed as an exponential function of time, and the model previously described is commonly referred to as an "E-E Model". This model predicts that the uptake and elimination of nitrogen takes place at the same rate. The algorithm used by the EDGE is an E-E Model, and the term EDGE-like refers to this model and all dive computers that use it.

The U.S. Navy Repetitive Dive Tables represent a major departure from this theoretical model. Residual nitrogen times are based on the slowest (120 min) compartment (des Granges, 1956). The algorithm designed for the Datamaster II accurately replicates the residual nitrogen time of the U.S. Navy Repetitive Dive Tables. It achieves this not by a table look up, but by allowing the 120 min compartment to control repetitive diving.

On a single dive, multi-level or not, the performance of the Datamaster II and the EDGE will be difficult to distinguish. The reason for this is that multi-level diving is governed by depth dependent compartment control and not by nitrogen elimination. Since the EDGE and the Datamaster II have similar no-decompression limits, they produce very similar multi-level profiles.
Repetitive diving is an altogether different issue. The EDGE will allow significantly more bottom time than the Datamaster II for repetitive dives, with the difference most pronounced for deep dives and short surface intervals.

Ordinarily, what works is what counts. However, when it comes to decompression sickness what does not work is the more important issue, and in the next section I shall review the data base.

DATA BASE

"Remember when discoursing about water to induce first experience, then reason"...Leonardo da Vinci

Any applied mathematician confronted with Haldane's theory, Workman's M-values, and des Granges' need to construct a single table for all repetitive diving contingencies is logically lead to the conclusion that a micro-processor programmed with an E-E Model is the proper design solution for a dive computer. Thalmann (1984, 1986), while lead to this obvious conclusion, was nevertheless prudent enough to test it. The following are quotes from Thalmann's reports:

"The most significant finding of this study was the failure of the E-E Model to adequately compute safe repetitive dive profiles without seriously reducing no-decompression limits"...Thalmann (1984)

"While it appears that some increases in repetitive no-decompression times are likely, the E-L Model predicts some times that are too long"...Thalmann (1986)

The E-L Model that Thalmann refers to in the second quote has a linear elimination that is more conservative than an E-E Model, but is less conservative than the U.S. Navy Repetitive Dive Tables.

One can only conclude that repetitive diving at the U.S. Navy no-decompression limits cannot be reliably predicted using an E-E Model. However, it is important to note that both the EDGE and the Datamaster II have reduced no-decompression limits. The ultrasonic Doppler experiments of Spencer (1976) demonstrate a substantial reduction of bubble formation for reduced no-decompression limits, and it is certainly plausible that this can be expected to lead to a reduced risk of decompression sickness. The question is whether this alone is sufficient or whether a slower elimination algorithm is also necessary for repetitive dive control.

Figure 1. is an attempt to qualitatively illustrate the design envelope, those regions that have been validated, and those that have been demonstrated to fail. The vertical axis represents M-values that are directly related to the no-decompression limits for a single dive. The horizontal axis represents elimination half-times, which control repetitive diving. The E-E Model allows the 5 min. compartment to relax with a 5 min. time scale, whereas the U.S. Navy effectively uses a 120 min. time scale for all compartments when dealing with repetitive dives.

The U.S. Navy Dive Tables fall in the upper right hand corner of Figure 1., and they represent the most extensive data base that we have, namely thirty years of demonstrated reliability. If one adds to this experience the data of Spencer, one arrives at
the design of the Datamaster II that lies in the lower right hand corner. In the upper left hand corner is a region demonstrated by Thalmann to produce unacceptable DCS. In the lower left hand corner are the EDGE-like dive computers, and this is largely uncharted territory. Largely, but not entirely. Edmonds (1988) tested the EDGE against several deep (120 to 147 ft) repetitive dives that the Royal Navy had shown produced DCS after the third exposure. The EDGE not only allowed the third dive, but several thereafter.

Figure 1. Dive computer design envelope

All EDGE-like dive computers will allow repetitive dives to depths in excess of 120 ft, with surface intervals of less than 60 min., and with bottom times of the repetitive dives virtually identical to that of the first dive. These profiles are undeniably unsafe and should be avoided. Edmonds' admonition to restrict repetitive dives to 30 ft is probably overly conservative, but in the absence of further testing, it is not possible to quantify what is a safe depth for repetitive dives using these dive computers.

While the EDGE-like dive computers are unsafe for some set of repetitive dives, the Datamaster II is more conservative than is necessary for perhaps an even larger set of dives. When the Datamaster II was first designed, the U.S. Navy Dive Tables represented the only significant data base for repetitive diving. That is no longer true. In 1987, Powell presented the results of a series of experiments that were designed to produce a new set of dive tables for recreational divers (Powell, 1987). The premise was that recreational divers never reach the limits of compartments slower than 60 min, and therefore repetitive dive times could be substantially increased. Whether this hypothesis stands the test of 6 dives per day for 6 days in a row remains to be seen. Regardless, this important data set
demonstrates that there is a substantial region of intermediate depths and times for which the U.S. Navy Repetitive Dive Tables, and thus the Datamaster II, are overly conservative. Unfortunately, these data do not include repetitive deep dives nor repetitive shallow dives with long exposures. The former is a direct test of fast compartment elimination, and the latter is a test of slower compartment buildup.

A dive computer should allow what has been shown to be safe, but must not allow what has been shown to be unsafe. Further, it should not allow dive profiles that are radical departures from those that have been tested. An algorithm is not magic. It is simply a means by which one can extrapolate limited experience to new circumstances, and it is only as reliable as the data base upon which it has been tested.

SUMMARY

The Datamaster II Dive Computer utilizes a decompression algorithm that is profoundly different than other presently available dive computers. The performance of the Datamaster II and any EDGE-like dive computer will be remarkably similar for a single no-decompression multi-level dive. For repetitive diving, the Datamaster II will be considerably more conservative. Arguably, the Datamaster II is too conservative for some intermediate depth repetitive dives. Demonstrably, the Edge-like dive computers are unsafe for deep repetitive dives, and at present it is not possible to define a safe depth for their use when repetitively diving deeper than 30 ft.

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THE SUUNTO SME-ML PRESENTS
THE CONCEPT OF MULTI-LEVEL DIVING

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It is a warm clear day, the sky is cobalt blue and only scattered clouds off in the distance break up the horizon. The water is glassy calm. It is a perfect day for diving in the Western Caribbean. The kind of day that you would travel halfway around the world for. In fact, most of the divers on board the small dive boat had done just that.

This was their one week. The week they saved and planned and dreamed about for the last year. Dreams about this one week were often the only thing that made life in the hustle and bustle of the "day to day grind" bearable. Despite the perfectness of the Caribbean scene, the divemaster had a problem.

There were a dozen divers on board. Varying degrees of skill, physical condition, knowledge, and temperament. Almost half had some type of dive computer.

"OK, here is the plan" the divemaster started. "The top of the reef is at approximately 40 feet here, the maximum depth for this dive will be 100 feet. I don't want anyone to descend below me! Those of you diving with tables, be back on the boat in 20 minutes. The ones diving with computers must be back in an hour, no matter how much air you have left!" He raised his voice to make his point.

The faces of the "table divers" grew long. Why were they being penalized? the divemaster had seen this reaction before. It is a scene that plays itself out literally hundreds of times each day.

The diving industry is currently examining the way we dive, how we track those dives and how we teach decompression theory. Now, more than ever before, all diving professionals need to have a greater understanding of basic decompression theory. Like it or not, we are in the midst of a great technological revolution in recreational diving.

There is a desperate need to provide more information to those interested in applying this new technology to their diving activities. It will be up to the diving instructors to determine how the industry makes the transition to multi-level diving. It is now, and always has been, the instructor's job to educate divers about the proper use of new technology, advances in equipment, and changes in diving practices. Dive computers are no different. And we can all rest assured that this is not the last technological advance that will come along and affect our sport.

You will notice that we started this article by calling it "computer-assisted" multi-level diving, not computer controlled. The diver will always be in charge and any claims to the contrary are misleading and wrong. Both Sea Quest, Inc. and Suunto of Finland firmly believe that there is a "NEED TO TEACH" the principles that go into the design and proper
use of dive computers. Not just ours, but all such devices. No one has come up with a way to replace common sense, diving skills and the basic concepts of decompression theory.

Instruction on the proper use of multi-level diving techniques goes far beyond the typical owner's manual of our computer, or any device, including tables of all configurations. This belief led us to develop a support program designed to assist diving instructors. The "NEED TO TEACH" program includes: Instructor guides, student work books, dive planning slates, multi-level log books, and two different instructional videos.

We sought out noted diving authorities such as Dr. George Lewbel, Dr. Bruce Bassett, Dr. Sylvia Earle, Dr. Tom Neuman, Dr. Tom Rhodes, and many other specialists, to help us present this information in a way that could be used by any qualified instructor, regardless of certifying agency.

Our instructional program is designed to allow instructors to structure and teach according to their chosen diving philosophies and their student's needs. The instructors can adapt the program's aides to their diving communities' regional differences and to the practices of their certifying agency.

WHY THE SME-ML IS THE WAY IT IS

The Suunto SME-ML is a true multi-level dive computer. It takes into account all the various depth segments of a dive and the precise amount of time spent at each depth, mathematically modeling theoretical nitrogen in-gassing and out-gassing according to appropriate pressure differentials. We modified the Haldanean model, which has been the basis for almost all decompression schedules since the early 1920's, by incorporating the Doppler meter silent bubble research done by Dr. Merrill Spencer.

In designing their standard decompression schedules, the U.S. Navy constructed a mathematical model based on 6 different "tissue" compartments. When it came time to figure repetitive dives, there were so many possible combinations of dive time, maximum depths and surface intervals that the immense number of calculations required made it impractical for them to continue using all 6 compartments. As a result, repetitive diving with the Navy tables is based on a mathematical model for a single compartment. You must remember that these tables were designed before the computer age. Use of a single compartment was the easiest and most practical way to devise a repetitive schedule that was a fairly low priority, and for an organization that had a massive roster of divers to call upon.

The Suunto SME-ML calculations are always based upon a mathematical model that contains 9 compartments, the 6 compartments found in the Navy tables plus 3 additional compartments. In addition, the SME-ML produces half times ranging from 2.5 minutes to 480 minutes, in comparison with the Navy tables' 5 to 120 minute half times. This expands the range and makes more conservative the mathematical approximation of the diver's body, and still applies both to repetitive dives and to first, or single, dives.

The SME-ML's "low bubble" no-decompression limits, by design, allow less nitrogen to build up in the compartments than the U.S. Navy tables. Each compartment has a reduced Maximum Allowable Pressure (M.A.P. or "M" value) which reflects a more conservative estimate of the body's ability to hold excess nitrogen upon surfacing. An excellent example of this is the no-decompression limit for the first dive to 60 feet: the U.S. Navy tables allow 60 minutes at 60 feet and the SME-ML allows 53 minutes at 60 feet.
More importantly, the SME-ML incorporates a slower ascent rate, 33 feet per minute, to permit a more gradual release of excess nitrogen as the diver ascends.

If a diver using the SME-ML ascends faster than 33 feet per minute, the "SLOW" warning will blink on the diving display.

The diver can slow down or stop coming up until the "SLOW" warning disappears, as long as he does not ascend above 10 feet. If "SLOW" is still flashing at 10 feet, the diver must stop there until it goes off. Should the diver surface with the "SLOW" on (definitely not a recommended practice), the "SLOW" warning will remain on until the next dive, or until the unit shuts down - a reminder for the diver to adjust ascent rates (an instructor can easily see who is having problems in this area and work with those individuals).

Our number one goal in designing the SME-ML was to present the diver with all of this valuable information in a straightforward, easy-to-read display. One that would only show the information that was significant at a given moment. The Suunto SME-ML features an uncluttered screen that only displays diving information while the unit is underwater, and surface/dive planning information while it is on the surface.

Next we thought that it was very important to eliminate the need for external switches. No external switches means no holes in the housing that might cause the DC to flood. Regardless of this benefit, it was the fact that we did not want the DC to be switched off (either accidentally or in uneducated attempts to prolong battery life) while it was still calculating residual nitrogen levels between dives, that lead to the development of the rubber contacts that activate and recall the dive profiles. Simply stated, the Suunto SME-ML cannot be turned off during a repetitive dive series.

The surface interval display of the SME-ML automatically begins to show dive planning information to help plan the next dive at the end of the dive just completed. As the surface interval increases, so does the available dive time for the next dive, based on the residual nitrogen level in each of the 9 compartments the SME-ML uses as a model for its calculations.

The SME-ML continues to track residual nitrogen in all 9 compartments on the surface until they no longer affect no-decompression limits. It automatically shuts down when all 9 compartments are "clean" of residual nitrogen. It is not at all uncommon for an SME-ML to remain on much longer than the standard 12 hours the Navy tables call for, particularly if you have been diving heavily.

Sea Quest and Suunto saw the need for what is in essence an underwater flight recorder. A memory capable of recording precise data, an exact dive profile. We realized how quickly maximum depth and total dive time would become insufficient information when true multi-level diving techniques were applied. (How can you explain a maximum depth of 110 feet with a total dive time of an hour or more when only this simplistic information is available?)

The Suunto SME-ML features the ability to recall up to ten hours of dive time, and display it in 3 minute increments. This information can be easily organized into accurate dive profiles that graphically display a diver's true exposure at various depths.

Dive profiles are extremely helpful in post dive debriefings. Did the student execute the dive plan for this dive? Did a student exceed the maximum depth limit set for this dive? Did the student make a safety stop at the end of this dive? The many applications of the "underwater flight recorder" function of the SME-ML are just starting to be understood. It
is a new tool for a new era in diving. Part of the challenge and part of the excitement of introducing these new concepts into diving instruction will be the proper application of these new tools.

At this time we all must realize the changes our sport is going through and that it is up to us, as diving professionals, to master these new tools and techniques so that we can share this information with the rest of the recreational diving community. Decompression theory has always been a complex and fascinating subject. With such a multitude of new tools and techniques, computer assisted multi-level diving is a subject that you could write a book about, and, in the process of creating our support program, we have.

The Suunto SME-ML is the state of the art in dive computers. We truly believe that. We want you to learn as much as you possibly can about decompression. We are convinced that the more you know, the better we will do in the market place. The more you teach, the safer our sport will become.
MANUFACTURER'S SESSION DISCUSSION

Discussion after John Lewis

John was asked to comment on the fact that the unit did not outgas (Lewis calls this "relaxation," in reference to the mathematical exponential "decay" at a rate proportional to the difference in gas partial pressures) at the surface. John pointed out that this function does not affect the behavior of the unit in multi-level diving, where it continues to outgas in a manner about 10 fsw more conservatively than the model of the USN tables.

Discussion in manufacturer's session

[EDITOR'S NOTE: No papers were received from Al Carpenter (Beuchat), Mark Walsh (Dacor), or Chuck Locke (U.S. Divers), but since the presentations were made, we feel some discussion should be included. Chuck Locke provided the DC comparative tables in the appendix.]

Presentation by Al Carpenter

Al Carpenter is West Coast sales representative for Beuchat USA. The dive computer sold by Beuchat in the U.S. is the same as the Aladin and Black Fox. Beuchat has no design or manufacturing function, and only distributes it in the U.S. as the G.U.I.D.E. The DC was developed in Switzerland by the Uwatech Co. This unit is based on the research of Dr. Bühlmann. It uses six compartments and has four sets of parameters for four different altitudes. First is sea level to 2470 feet altitude, 2400 to 5100, 5100 to 8555, and 8555 to 13200. The unit senses the altitude.

A big problem is that people have trouble turning the unit on. You start it by dipping it in water or by wetting your fingers and touching the two contacts. It is now ready to go into the dive mode. You have ten minutes to get it into the water or the unit will shut down. If it does shut off and then you go into the water, it will flash an error and you have to go back and start over. It displays two rows of numbers and letters and six group areas. A 3.6 lithium battery gives 5 years or 800 diving hours. It has 13 functions in the readout. The first is contact activation. It will activate at 4 feet of depth and its depth is good from 4 feet to 315 fsw. It has a maximum depth indicator. You have to come up 4 fsw shallower than the maximum depth in order to get it to lock on to the maximum depth. It shows your remaining no-d time, flashing "deco warning" on a digital display. You have to stop at 10 fsw stages to 80 fsw. As soon as you clear a depth, it clicks to the next depth.

If you pass a stop coming up, it tells you to go back to that stop and it locks into that mode. It won't outgas at the surface if a stop is missed, it will just add on to the previous dive if you do another dive. It goes into a ten minute surface interval mode after a dive in which you cannot access anything or change anything. It is waiting to see if you are going to make another dive within 10 min, in which case it will calculate it as part of the previous dive. In other words, the minimum surface interval is ten minutes.

There are two probes you can contact to access the log of the last five dives. It gives you maximum depth, total dive time and surface interval time. This surface interval would not last if you made a dive yesterday. There is a low battery indicator, and the user can change the battery. You do however lose the memory when you change the battery. It is
sold as a console or as a wrist unit, at $699 and $450. There are two console models, a
two-port and a three-port, which also has a compass, and there is an instructor's model.

Presentation by Mark Walsh

Mark Walsh is the project engineer for Dacor, responsible for the MicroBrain. This
dive computer was developed with Divetronics, Switzerland. It uses the P3 model, a
modified version of the Bühlmann-Hahn P2-3, with 6 compartments, from 4 to 397
minutes. It comes in several configurations, wrist and console, and an instructor's model
with a potentiometer on it for simulating dives. There is also a simulator program that runs
on an Atari available to dealers and instructors. An IBM PC version is coming out in
January. They have a user's guide for dealers and instructors, but he mentioned that they
are not an instructor organization and would like the input of the training agencies.

The MicroBrain runs from 0 to 330 fsw, and assumes sea level to be 0.95 bar. It is
altitude adjusting, from 0 to 4920 feet and from 4920 to 6560 feet. It has a range for
equilibration, and it takes less time to equilibrate if you are already partly at altitude. Above
6560 feet it does not compute no-stop times because this is not well enough known. It then
becomes a precision depth gage and bottom timer. It records the most recent six dives in the
last 48 hour period and is considered to be a no-decompression and multi-level computer. It
scrolls no-d information before the dive from 51 to 130 fsw in 10 fsw increments. It uses
depths of 51, 61, 71, 80, 90 and so on, due to rounding off of conversions from metric. It
does no-d down to 250 fsw, where you get two minutes. While it is a no-decompression
profiler, it does give you decompression information. Ascent rate is 33 to 40 fsw per
minute. It switches from no-d time to decompression time required, with stops to as deep
as 100 fsw. It is a conservative model.

If you miss a stop, it gives you a descent warning, and takes you down to where
you need to go to do your decompression. If you do not go down, or if you omit a
decompression stop, it goes "out of range". Another out of range condition is total elapsed
time of more than 199 minutes, in which case it shuts down for 24 hours. The "bottom
time" is the total dive time.

It is encased in silicone with two three-volt batteries soldered in place inside. It is
supposed to be good for 10 years at 100 dives per year. If you need to send it back for a
new battery, they will send you another unit and then extract the electronics from the gel of
the former. It shows your diving time as bars on a triangle, which gets smaller as your
available dive time is reduced. You activate the unit to get the scrolling by touching the
contacts and then you activate it when you begin the dive by doing the same thing. You can
zero the unit with a special magnet, allowing more than one person to use the same unit. Of
course when you do this, you can't dive again until the next day because the residual gas is
lost.

Presentation by Chuck Locke

Charles E. Locke is manager of R&D for U.S. Divers, who market the Data Scan
II. The Data Scan II is functionally the same unit as Oceanic Datamaster II, but has a
slightly different display that shows the same information. In the console version there is
an algorithm for managing air usage.

Chuck mentioned development of a new unit. Their affiliate La Spirotechnique is
talking to Uwatech about a Bühlmann-based unit, the "Monitor".
A great deal more information about this unit, and the others as well, is given in a comparison prepared by Chuck Locke and included in the appendix.

The next question was for more information on the air consumption algorithm which John Lewis, designer, responded to. It keeps track of the breathing rate parameter which is consumption normalized at depth. If you double the atmospheric pressure, you double the consumption. It makes that approximation so that alterations in depth, are taken into consideration. It is a running average of your particular consumption.

Flying after diving

Most of the units have a "safe to fly" mode. Someone asked what criteria are used to be able to say this. The Suunto has to outgas to a point less than 2 psi over ambient pressure. This was challenged by Mike Emmerman, who has data on a number of divers who have developed DCS in aircraft in a wide variety of gas loading statuses, even as much as 41 hours after a dive. The message is, we probably do not have enough data to make this decision. Ralph Osterhout maintained, however, that we need some sort of criterion for this function, and this was agreed.

It was further pointed out that 12 hours is considered a safe post-dive time to go flying, but that it may take 19 to 20 hours to clear the 480 minute compartment down to 2 psi over ambient. Flying as long as 5 days after extensive diving has resulted in symptoms. One opinion is that calculations of gas loadings may have little bearing on when it is safe to fly. It is probably the bubbles and how long they persist.

Dick Vann points out that we really cannot say it is "safe to fly", that all we can do is choose an acceptable degree of risk. How do we make this decision? There is no line between "safe to fly" and "not safe to fly". All we have is a gradual reduction of risk. Divers frequently, due to contingencies like bad weather, will choose to fly after a dive. They normally get away with it. Even though there is no hard line, we feel it is necessary to set some kind of limit.

Mike Emmerman has gathered 47 cases where the diver had been a "D diver" (USN repetitive status, which is the point considered safe to fly) or better, for 7 to as many as 40 hours before flying, did not show symptoms before flying, but had symptoms in the aircraft or shortly after landing. There was not enough data to reconstruct either the dive profile or even a "body" profile of the person.

Ralph asked if DEMA might sponsor data collection, perhaps through DAN, to help get a data base together. He feels sure that researchers like those in this Workshop could make something of it.

Bill Hamilton reported a workshop held by the U.K. Diving Medical Advisory Committee convened because the helicopter pilots in the North Sea were concerned about hauling divers to shore after they had been diving. When the group was asked for data, the silence was deafening. There were very few documented cases to report. The workshop was swung by a report of 15,000 diver-trips following a rule of flying no sooner than 12 hours after diving, with no reported problems. This does not mean 15,000 divers flew 12 hours after diving, but that the rule had that data base behind it. That rule was adopted. That group would not be specific about nitrox saturation diving, but felt it should be over 48 hours.
The Workshop carried on to list the values for flying after diving of the various DC's represented here.

- **Computek:** 2 fsw over ambient
- **DigiTek:** 12 hrs after last dive
- **MicroBrain:** 0.58 bars as the ceiling
- **Skinny Dipper:** 2 fsw (1 psi) over ambient
- **Suunto:** 2 psi over ambient

The value given by Max Hahn applies to the MicroBrain. Max explained that the lowest pressure one should encounter in a commercial aircraft is 0.65 bars, and that having a ceiling of 0.58 bars should be well within this limit (this is about 8,000 feet of altitude). This is a ceiling, not the inert gas pressure in the tissue. This might take as much as 24 hours. Those DC's not mentioned do not have indicators.

John Lewis, whose DC does not have this function, suggests that to get good data this will have to be done experimentally. Glen Egstrom notes that this will take some years at best, but that it is acceptable to go on with the current criteria.

Bill Hamilton warned that this talk illustrates the hazard in making decisions of this sort, that it is easy to get narcotized by the numbers and begin to believe them.

"Lockup" mode

The discussion turned to the maximum depth allowed, with concern expressed by many that the depths allowed are too deep. The values are in the Appendix. Some of the units go "out of range" or otherwise stop working when the depth is exceeded. This led to further discussion of the matter of the DC's shutting down when they might be needed most. One reason for this is that when the diver has "violated" in certain ways, there is no good algorithm for getting him/her out of that situation with confidence. Example: When the diver omits a stop on ascent, the computer will see a faster outgassing, but what is more likely, is that the diver has provoked bubble formation and needs more time, not less, to get to the surface.

In the cases where the DC's stop computing, they usually continue to provide time and depth information and it is up to the diver to use that to get to the surface.

A number of suggestions were made about how to handle the violating diver. There seemed to be agreement that the diver in this situation cannot go unpunished. It was even suggested that the DC should shock the diver when he violates, or that it should "break" or go into a lockup mode that requires a $100 repair bill to get it going again. While there was agreement that the violation should be punished, when to do it and how to do it was not agreed upon. Another thing that was agreed by most is that we prefer the DC's to continue to compute for the diver who has violated.

There is a dilemma here, because the focus of the thinking ranged from the novice student diver to the experienced scientific diver, and the viewpoints seemed to be reflected in the part of the elephant touched by each blind man. Some wanted the units not to go deeper that 130 fsw, because that is the "limit" for recreational divers, but the realities are that the reasons they buy the units is for more aggressive diving. A major theme throughout this and other discussions is the strong belief that the recreational divers need more and better training. Whether the DC's should limit their diving was not agreed on at all.
It was pointed out that we were here with concern for the scientific diver, who may dive to as deep as 190 fsw, if qualified, and his DC should do the job. But scientific divers also operate under a much higher order of discipline and are far more diligent about obeying the rules, since there is a lot at stake. Even so, the entire diving community will note the conclusions of this Workshop.

There was of course a plea to standardize the criteria for the "lockup" mode. The Workshop did not do that, instead charged the manufacturers with providing some means of getting out of these violation situations, and to not have the DC stop computing.

Units

When the matter of units came up, Bill Hamilton pointed out that one cannot correctly use the linear conversion factors between feet and metres as units of length when pressure is the parameter involved, because the definitions are different:

One msw = 1/10 bar = 10 kPa

One fsw = 1/33 standard atmosphere = 0.030705 kPa

Therefore the conversion between the pressure units is

One msw = 3.2568 fsw

One fsw = 0.30705 msw