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Understanding Modern Dive Computers and Operation

Protocols, Models, Tests, Data, Risk and Applications

Springer

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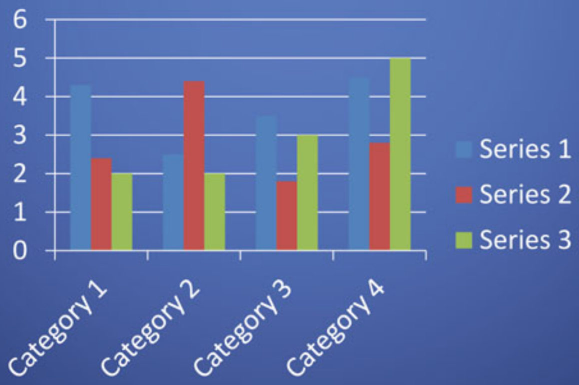
ISSN 2191-5768 ISSN 2191-5776 (electronic)
SpringerBriefs in Computer Science
ISBN 978-3-319-94053-3 ISBN 978-3-319-94054-0 (eBook)
https://doi.org/10.1007/978-3-319-94054-0

Library of Congress Control Number: 2018951058

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

UNDERSTANDING MODERN DIVE COMPUTERS AND OPERATION
Protocols, Models, Tests, Data, Risk and Applications

by B.R. Wienke and T.R. O'Leary



Cover Abstract

This short brief details dive computers, operation, protocols, models, data, tests, risk, and coupled applications. Basic diving principles are detailed with practical computer implementations. Topics are related to diving protocols and operational procedures. Tests and correlations of computer models with data are underscored. The exposition also links phase mechanics to decompression theory with equations used in computer syntheses. Happily today, we are looking at both dissolved gases and bubbles in our staging regimens and not just dissolved gas protocols. Onward through the fog. As research expands, dive computers are quick to incorporate new diving technology and science. References are both extensive and pertinent to topical developments and history. Applications focus upon and mimic dive computer operations within model implementations for added understanding. Intended audience are the computer scientist, doctor, researcher, engineer, physical and life sciences professional, chamber technician, explorer, commercial diver, diving instructor, and technical and recreational divers with a need for a concise yet thorough treatise on dive computers and applications.

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Preface

This brief focuses on dive computers, operation, protocols, models, data, tests, risk, and associated applications in working detail. Basic diving principles are framed as incorporated and implemented in dive computers. Topics are keyed to diving protocols and operational procedures. Tests and correlations of models with data are underscored. The exposition also links phase mechanics to decompression theory with equations used in computer synthesis. References are both extensive and pertinent to topical development and history. Applications focus upon and mimic dive computer operations and model implementations for added understanding. A recap with questions and answers posed to the Authors completes the brief. The intended audience are the computer scientist, doctor, researcher, engineer, physical and life sciences professional, chamber technician, explorer, commercial diver, diving instructor, and technical and recreational divers with a need for a concise yet thorough treatise on dive computers and applications.

Theory and dive computer application are, at times, more an art form than exact science. Some believe deterministic modeling is only fortuitous. Technological advance, elucidation of competing mechanisms, and resolution of model issues over the past 100 years have not been rapid. Model implementations tend to be ad hoc, tied to data fits and difficult to quantify on just first principles. Almost any description of decompression processes in tissue and blood can be disputed and possibly turned around on itself. The fact that decompression sickness occurs in metabolic and perfused matter makes it difficult to design and analyze experiments outside living matter. Yet, for application to safe diving, we need models, tests, data, and correlations to build tables and dive computers. And, regardless of biological complexity, certain coarse grain biophysics principles, some neglected in the past, are making a substantial change in diver-staging regimens, decompression theory, and coupled data analysis. Happily today, we are looking at both dissolved gases and bubbles in staging regimens and not just dissolved gas approaches of Haldane, As research expands, dive computers will be quick to reflect new diving technology and science. And that means enhanced safety.

Happy and safe diving always.

Acknowledgments

Thanks to our friends and colleagues at LANL, NAUI, C&C Dive Team Operations, DAN, Commercial Diving Industry, recreational and technical training agencies, computer manufacturers worldwide, and many collaborators at universities, national laboratories, DOE, DOD, USAF, USCG, and USN. Special thanks to my beautiful and talented wife, Luzanne Coburn, for artwork, photography, and finishing.

Author Sketches

Bruce Wienke
Bruce Wienke is a program manager in the Weapons Technology/Simulation Office at LANL. He received a BS in physics and mathematics (Northern Michigan), MS in nuclear physics (Marquette) and a PhD in particle physics (Northwestern). He has authored 250+ articles in peer-reviewed journals, media outlets, trade magazines, and workshop proceedings and has published 12 books on diving science, biophysics, and decompression theory. He heads up the C& C Dive Team vested with worldwide underwater search, assessment, and disablement of nuclear, chemical, and biological WMDs. He is a fellow of the APS, technical committee member of the ANS, and member of the UHMS and serves as a consultant to the EPA, DHS, ADA, US military, and dive industry. Bruce is an editor/reviewer for CBM, PR, TTSP, NSE, and JQSRT, and CEO of Southwest Enterprises Consulting. He is the developer of the Reduced Gradient Bubble Model (RGBM) implemented in decompression meters, tables, and dive software worldwide. Bruce has dived all over the world on OC and RB systems in military, scientific, exploration, testing, and training activities. He is a NAUI Tec/Rec instructor trainer and course director. Interests include USSA masters ski racing, USTA seniors tennis, golf, and windsurfing. Bruce is a certified ski instructor (PSIA) and racing coach (USSCA). He has won masters national titles in SL, GS, SG, and DH and quarterbacked the Northern Michigan Wildcats to a NCAA II Title in the Hickory Bowl.

Tim O'Leary
Tim O'Leary heads up NAUI Technical Diving Operations having developed and co-authored training manuals, support material, tech dive tables, monographs and related media along with tech course standards. He is a practicing commercial diver and CEO of American Diving & Marine Salvage on the Texas Gulf Coast. Tim received a BS in zoology (Texas A&M) and a DMT and CHT from Jo Ellen Smith Medical Center at the Baromedical Research Institute. He was a commercial diving and hyperbaric chamber instructor at the Ocean Corporation. Tim is a member of the UHMS, SNAME, and NADMT. He is an admiral in the Texas Navy, a USCG 100 Ton Vessel Master, and a consultant to Texas Parks & Wildlife, Canadian

Corporation, Rimkus Group, and Offshore Oil Industry. His diving experience is global on OC and RB systems in commercial, exploration, training, and testing activities. He is a NAUI Tec/Rec instructor trainer, course director, and workshop director. Other interests include skiing, deep wreck diving, and dive travel. Tim and NAUI Dive Team are credited with the discovery and exploration of the USS Perry in approximately 250 fsw off Anguar and diving it for a week on RBs.

Units and Fundamental Constants

Note so-called diving units are employed herein, that is, standard SI units for depth and pressure are not used. Instead, pressures and depths are both measured in feet-of-seawater (fsw) or meters-of-seawater (msw). The conversion is standard,

$$10\ msw = 33.28\ fsw = 1\ atm$$

Specific densities, η (dimensionless) in pressure relationships, are normalized to sea water density with freshwater-specific density equal to 0.975.

Breathing mixtures, such as nitrox (nitrogen and oxygen), heliox (helium and oxygen), and trimix (helium, nitrogen and oxygen), carry standardized notation. If the fraction of oxygen is greater than 21%, the mixture is termed enriched. Enriched nitrox mixtures are denoted EANx; enriched heliox mixtures are denoted EAHx. For other mixtures of nitrox and heliox, the convention is to name them with inert gas percentage first and then oxygen percentage, such as 85/15 nitrox or 85/15 heliox. For trimix, notation is shortened to list the oxygen percentage first and then only the helium percentage, such as 15/45 trimix, meaning 15% oxygen, 45% helium, and 40% nitrogen. Or TMX 15/45 is used. Air is sometimes noted EAN21 or 79/21 nitrox even though not enriched.

Unit Conversion Table

Time

$$1\ sec = 10^3\ msec = 10^6\ \mu sec = 10^9\ nsec$$

$$1\ megahertz = 10^6\ hertz = 10^6\ sec^{-1}$$

Length

$$1\ m = 3.28\ ft = 1.09\ yd = 39.37\ in$$

$$1\ \mu m = 10^4\ angstrom = 10^3\ nm = 10^{-6}\ m$$

$$1\ km = 0.62\ mile$$

$$1\ fathom = 6\ ft$$

$$1\ nautical\ mile = 6,080\ ft = 1.15\ mile = 1.85\ km$$

$$1\ light\ year = 9.46 \times 10^{12}\ km = 5.88 \times 10^{12}\ mile$$

$$1\ parsec = 3.086 \times 10^{16}\ m = 3.262\ light\ year$$

Speed

$$1\ km/hr = 27.77\ cm/sec$$
$$1\ mile/hr = 5280\ ft/sec$$
$$1\ knot = 1.15\ mi/hr = 51.48\ cm/sec$$

Volume

$$1\ cm^3 = 0.06\ in^3$$
$$1\ m^3 = 35.32\ ft^3 = 1.31\ yd^3$$
$$1\ l = 10^3\ cm^3 = .04\ ft^3 = 1.05\ qt$$

Mass, Density, and Viscosity

$$1\ kg = 32.27\ oz = 2.20\ lb$$
$$1\ g/cm^3 = 0.57\ oz/in^3$$
$$1\ kg/m^3 = 0.06\ lb/ft^3$$
$$1\ dyne\ sec/cm^2 = 1\ poise = 0.10\ pascal\ sec = 0.01\ poiseuille$$

Force and Pressure

$$1\ newton = 10^5\ dyne = 0.22\ lb$$
$$1\ g/cm^2 = 0.23\ oz/in^2$$
$$1\ kg/m^2 = 0.20\ lb/ft^2$$
$$1\ atm = 32.56\ fsw = 10\ msw = 1.03\ kg/cm^2 = 14.69\ lbs/in^2$$

Energy and Power

$$1\ cal = 4.19\ joule = 3.96 \times 10^{-3}\ btu = 3.09\ ft\ lb$$
$$1\ joule = 10^7\ ergs = 0.74 ft\ lb$$
$$1\ keV = 10^3\ eV = 1.60 \times 10^{-16}\ joule$$
$$1\ amu = 931.1\ MeV$$
$$1\ watt = 3.41\ btu/hr = 1.34 \times 10^{-3}\ hp$$

Electricity and Magnetism

$$1\ coul = 2.99 \times 10^9\ esu$$
$$1\ amp = 1\ coul/sec = 1\ volt/ohm$$
$$1\ volt = 1\ newton\ coul\ m = 1\ joule/coul$$
$$1\ gauss = 10^{-4}\ weber/m^2 = 10^{-4}\ newton/amp\ m$$
$$1\ f = 1\ coul/volt$$

Fundamental constants are listed next.

Fundamental Constants

$$g_0 = 9.80\ m/sec^2 \quad (Sea\ Level\ Acceleration\ Of\ Gravity)$$
$$G_0 = 6.67 \times 10^{-11}\ newton\ m^2/kg^2 \quad (Gravitational\ Constant)$$
$$M_0 = 5.98 \times 10^{24}\ kg \quad (Mass\ of\ the\ Earth)$$
$$\Gamma_0 = 1.98\ cal/min\ cm^2 \quad (Solar\ Constant)$$
$$c = 2.998 \times 10^8\ m/sec \quad (Speed\ of\ Light)$$
$$h = 6.625 \times 10^{-34}\ joule\ sec \quad (Planck\ Constant)$$
$$R = 8.317\ joule/gmole\ ^\circ K \quad (Universal\ Gas\ Constant)$$

$$k = 1.38 \times 10^{-23}\ joule/gmole\ {}^\circ K \quad (Boltzmann\ Constant)$$
$$N_0 = 6.025 \times 10^{23}\ atoms/gmole \quad (Avogadro\ Number)$$
$$m_0 = 9.108 \times 10^{-31}\ kg \quad (Electron\ Mass)$$
$$e_0 = 1.609 \times 10^{-19}\ coulomb \quad (Electron\ Charge)$$
$$r_0 = 0.528\ angstrom \quad (First\ Bohr\ Orbit)$$
$$\epsilon_0 = (4\pi)^{-1} \times 1.11 \times 10^{-10}\ f/m \quad (Vacuum\ Permittivity)$$
$$\mu_0 = 4\pi \times 10^{-7}\ h/m \quad (Vacuum\ Permeability)$$
$$\kappa_0 = (4\pi\epsilon_0)^{-1} = 8.91 \times 10^{9}\ m/f \quad (Coulomb\ Constant)$$
$$\alpha_0 = \mu_0/4\pi = 1 \times 10^{-7}\ h/m \quad (Ampere\ Constant)$$
$$\sigma_0 = 5.67 \times 10^{-8}\ watt/m^2\ K^\circ 4 \quad (Stefan - Boltzmann\ Constant)$$

Metrology is the science of measurement and broadly construed encompasses the bulk of experimental science. In the more restricted sense, metrology refers to maintenance and dissemination of a consistent set of units, support for enforcement of equity in trade by weights, and measure laws and process control for manufacturing.

A measurement is a series of manipulations of physical objects or systems according to experimental protocols producing a number. The objects or systems involved are test objects, measuring devices, or computational operations. The objects and devices exist in and are influenced by some environment. The number relates to the some unique feature of the object, such as the magnitude, or the intensity, or the weight or time duration. The number is acquired to form the basis of decisions effecting some human feature or goal depending on the test object.

In order to solidify metrics for useful decision, metrology requires that any number obtained is functionally identical whenever and wherever the measurement process is performed. Such a universally reproducible measurement is called a *proper measurement* and leads to describing *proper quantities*. The equivalences above relate *proper quantities* to the fundamental constants following and permit closure of physical laws. Unit conversion follows via the chain rule, where the unit identities in the table define equivalence ratios that work like simple arithmetic fractions. Units cancel just like numbers. For instance, from the first table,

$$10\,l = \frac{10^3\ cm^3}{1\,l} \times 10\,l = 10^4\ cm^3$$

Acronyms and Definitions

Acronyms are useful and standard throughout the dive community and are employed herein:

ANDI: Association of Nitrox Diving Instructors
BM: Bubble phase model dividing the body into tissue compartments with halftimes that are coupled to inert gas diffusion across bubble film surfaces of exponential size distribution constrained in cumulative growth by a volume limit point
Bubble broadening: Noted laboratory effect that small bubbles increase and large bubbles decrease in number in liquid and solid systems due to concentration gradients that drive material from smaller bubbles to larger bubbles over time spans of hours to days
Bubble regeneration: Noted laboratory effect that pressurized distributions of bubbles in aqueous systems return to their original non-pressurized distributions in time spans of hours to days
CCR: Closed-circuit rebreather, a special RB system that allows the diver to fix the oxygen partial pressure in the breathing loop (setpoint)
CMAS: Confederation Mondiale des Activites Subaquatiques
Critical radius: Temporary bubble radius at equilibrium, that is, pressure inside the bubble just equals the sum of external ambient pressure and film surface tension
DB: Data bank storing downloaded computer profiles in 5–10 sec time-depth intervals
DCS: Crippling malady resulting from bubble formation and tissue damage in divers breathing compressed gases at depth and ascending too rapidly
Decompression stop: Necessary pause in a diver ascent strategy to eliminate dissolved gas and/or bubbles safely and is model based with stops usually made in 10 fsw increments
Deep stop: Decompression stop made in the deep zone to control bubble growth
DAN: Divers Alert Network
Diveware: Diver staging software package usually based on USN, ZHL, VPM, and RGBM algorithms mainly

Diluent: Any mixed gas combination used with pure oxygen in the breathing loop of RBs
Diving algorithm: Combination of a gas transport and/or bubble model with coupled diver ascent strategy
DOD: Department of Defense
DOE: Department of Energy
Doppler: A device for counting bubbles in flowing blood that bounces acoustical signals off bubbles and measures change in frequency
DSAT: Diving Science and Technology, a research arm of PADI
DSL: Diving Safety Laboratory, the European arm of DAN
EAHx: Enriched air helium breathing mixture with oxygen fraction, x, above 21% often called helitrox
EANx: Enriched air nitrox breathing mixture with oxygen fraction, x, above 21%
EOD: End of dive risk estimator computed after finishing dive and surfacing
ERDI: Emergency Response Diving International
FDF: Finnish Diving Federation
GF: Gradient factor, multiplier of USN and ZHL critical gradients, G and H, that try to mimic BMs
GM: Dissolved gas model dividing the body into tissue compartments with arbitrary half times for uptake and elimination of inert gases with tissue tensions constrained by limit points
GUE: Global Underwater Explorers
Heliox: Breathing gas mixture of helium and oxygen used in deep and decompression diving
IANTD: International Association of Nitrox and Technical Divers
ICD: Isobaric counter diffusion, inert dissolved gases (helium, nitrogen) moving in opposite directions in tissue and blood
IDF: Irish Diving Federation
LSW theory: Lifschitz-Slyasov-Wagner Ostwald bubble ripening theory and model
M-values: Set of limiting tensions for dissolved gas buildup in tissue compartments at depth
Mixed gases: Combination of oxygen, nitrogen, and helium gas mixtures breathed underwater
NAUI: National Association of Underwater Instructors
NDL: No decompression limit, maximum allowable time at given depth permitting direct ascent to the surface
NEDU: Naval Experimental Diving Unit, diver testing arm of the USN in Panama City
Nitrox: Breathing gas mixture of nitrogen and oxygen used in recreational diving
OC: Open circuit, underwater breathing system using mixed gases from a tank exhausted upon exhalation
Ostwald ripening: Large bubble growth at the expense of small bubbles in liquid and solid systems
OT: Oxtox, pulmonary and/or central nervous system oxygen toxicity resulting from over exposure to oxygen at depth or high pressure

PADI: Professional Association of Diving Instructors
PDE: Project Dive Exploration, a computer dive profile collection project at DAN
Phase volume: Surfacing limit point for bubble growth under decompression
RB: Rebreather, underwater breathing system using mixed gases from a cannister that are recirculated after carbon dioxide is scrubbed with oxygen from another cannister injected into the breathing loop
Recreational diving: Air and nitrox nonstop diving
RGBM algorithm: An American bubble staging model correlated with DCS computer outcomes by Wienke
RN: Royal Navy
SDI: Scuba Diving International
Shallow stop: Decompression stop made in the shallow zone to eliminate dissolved gas
SI: Surface interval, time between dives
SSI: Scuba Schools International
TDI: Technical Diving International
Technical diving: Mixed gas (nitrogen, helium, oxygen), OC and RB, deep and decompression diving
TMX x/y: Trimix with oxygen fraction, x, helium fraction, y, and the rest nitrogen
Trimix: Breathing gas mixture of helium, nitrogen, and oxygen used in deep and decompression diving
USAF: United States Air Force
USCG: United States Coast Guard
USN: United States Navy
USN algorithm: An American dissolved gas staging model developed by Workman of the US Navy
UTC: United Technologies Center, an Israeli company marketing a message sending-receiving underwater computer system (UDI) using sonar, GPS, and underwater communications with range about 2 $miles$
VPM algorithm: An American bubble staging model based on gels by Yount
Z-values: Another set of limiting tensions extended to altitude and similar to M-values
ZHL algorithm: A Swiss dissolved gas staging model developed and tested at altitude by Buhlmann

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