Tech Diving Mag

Research - Development - Exploration

Yet Another Benchmark - Part I

Stage Bottles

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Continuous Gas Blending Using Double Oxygen Analyzer

Diving Pioneers & Innovators: A Series of In Depth Interviews (Bob Ballard)

Issue 11 – June 2013

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Editorial

Welcome to the eleventh issue of Tech Diving Mag.

A wealth of information along with some interesting stories and first-hand experiences are brought together by our generous contributors for this issue: world renowned industry professional Bret Gilliam, technical diving instructor Albrecht Salm (PhD), expert diver and research enthusiast Jurij Zelic and accomplished diver, instructor trainer and book author Steve Lewis. Get to know more about them and read their bio at www.techdivingmag.com/contributors.html.

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Asser Salama
Editor, Tech Diving Mag

Yet Another Benchmark - Part I

By Albrecht Salm

We wanted to compare a couple of dive computers, diving tables and desktop deco software products with our notorious 42 m, 25 min dive on air. This, as such, isprobably not a real tec dive to talk about for this magazine but a dive an ambitious recreational diver could do as well as a one tank dive. As well we want to lay in Part I the foundation to get the idea what is going on in Part II.

Part II will cover the same dive and basically the same procedure but with a somewhat non-standard mixture of Heliox20 (20 % Oxygen, balance Helium). The rationale for this we will cover in part II, appearing in this magazine by the end of 2013.

But our diver will readily get a good feeling concerning the variability in outcomes, if she wants to: the extreme positions in TTS (time-to-surface) in Table I for this dive are:

- 16 or 17 min for a Standard RGBM model via
- 85 min (from my friend Dr. Max Hahn, who calculated a conservative table for recreational diving with a tolerated constant inertgas overpressure of 0.4 Bar([1], [4]) up to
- 102 min with another bubble model software at the very other end.

But before we go into details of Table I, we found out that there is no real standard definition of TTS to which everybody would adhere to. We found various ways to calculate the TTS:

A) TTS = BT + TST + AT
B) TTS = TST + AT
C) TTS = TST = TDT

Legend:
TTS = time-to-surface
BT = Bottom Time (effective time at bottom, normally including descend time)
AT = Ascend Time (normally maximum geometric depth divided by the ascend rate)
TST = Total Stop Time, basically the sum of all stop times
TDT = Total Decompression Time, in principal: TST + AT, but sometimes as well:
TDT = Total Dive Time = BT + TST + AT

Most software products and tables are using definition B) for TTS. Well, but not everybody and not always ...

To make comparability even worse we had to fiddle with a couple of parameters in the dive computers or the PC software: our goal was that the dose of absorbed inert gas should be the same for all outcomes!

Our definition of the "absorbed inert gas dose" is straightforward: it is the time-integral (the area) under the dive profile (i.e. depth vs. dive time). For a rectangular box profile from a table it is just:

depth * time

Thus we had to fiddle about with:

- ascend and descend rates
- barometric air pressure at begin of dive
- temperature
- water density
- pre-defined gradient factors
- set of coefficients for calculation of the allowed / tolerated supersaturation.

Even worse for this comparison are the intrinsic gradient factors of, say a couple of, RGBM implementations. These run internally a straight-forward ZH-L ("RGBM folded over ZH-L" as Bruce Wienke would have it) but had modified the original so-called a- and b-coefficients from the ZH-L mother via gradient factors, called "f-factors" in these frame works.

Products for professional use (i.e. construction & repair diving or saturation diving) could allow for:

- workload (oxygen consumption)
- skin temperature and even the
- respiratory coefficient (volume ratio of carbon dioxide production to oxygen consumption).

If the product was based on the notorious ZH-L 16 system from Albert Alois Buehlmann [2], we tried to force it to use the "ZH-L 16 C" set of coefficients. The ZH-L 16 C is a somewhat little bit more conservative set than the ZH-L 16 A used for the ZH-86 dive table, and is said to accomodate for the peculiarities of an on-line dive computer produced schedule [l.c.: p. 158].

If we lost this battle, say for a fixed and printed table, we put a remark in the right-most column. And, finally: we are not talking about variations, say, in the "sub-5-minute" or "Modulo 2 minute domaine" but rather when it comes to a factor of 2 oreven more!

But our test-diver could have fun when she calculates the arithmetic mean and the standard deviation of all these TTSs …

The basic, primary variation in the TTS, especially within a group of same computers, results of the statistical error in measureing the basic parameters (pressure, temperature, time and the fO_2 via an analyzer). These errors in physical measurement can easily sum up to 10 to 20 % of the calculated TTS. This is why we won't splitt hairs here about smaller variations in the TTS: these could readily be masked by random behaviour of mother nature.

To breath a little bit more life into this: have a look at the title picture. There you see 3 dive computers after a common dive from one diver (me! I took this one a couple of weeks ago here, 'round the corner in El Qusier, Red Sea ...) , exactly on the same depth but with 3 different depth readings and, for sure: with 3 different "NDL"s (= "no decompression limits", which I put in inverted commas: because there is no such thing like a no decompression dive …) respectively 3 different stop times. Let's put these readings in a little table for a clear overview:

Computer: brand & type	**depth reading [m]**	**„NDL" / stop time [min.] (*)**
COCHRAN: EMC-20 H	**16,4**	**+ 5**
VR Tech.: NHeO3	**16,8**	**- 3 (1'/ 3 + 2'/ 17)**
UWATEC: Aladin TEC 2G	**16,9**	**+ 10**

(*) 1st. dive of the day, i.e. no repetitive dive, max. depth ca. 31 m, topical run time ca. 42 min for all boxes: <u>no special features</u> (conservativisms, level stops etc. ...) <u>activated</u>.

Here, Cochran's EMC-20 H (left most box) gives the minimum depth with he shortest NDL: it is sporting an automatic adaption to water density via conductivity measurement. The longest NDL is given by Uwatec's / Scubapro's TEC 2G (box on top), programmed to fresh water density. Our little friend from UK (right most box) forced me already to do a “micro bubble avoidance stop” around 17 m for 2 min and wanted to do as well a real deco stop for 1 min @ 3 m. This is the reason that the right part of its display changed to red and gave me the 2 min break for making this little photography.

So, in this picture we have everything in common:

- ➢ deviations of the measurements
- ➢ deviations of the outcomes

The real bad message here is: the longer and deeper the dive, the more the deviations. This is probably not so interesting for recreational air diving: but this one will hit the TEC diver, wanting to do a little bit longer and deeper than usual.

And there is another bad message which you learned already from another past issue of this magazine (Tech Diving Mag, Issue 5 – December 2011, p. 41 - 53): the more Helium you put in your mix the more pronounced are these deviations for bad or negligent software implementations, be it in a dive computer or in a piece of desktop deco-software.

Table I: Test Dive on Air, depth: 42 m, bottom time: 25 min

depth of stop → / stop times	24 m	21 m	18 m	15 m	12 m	9 m	6 m	3 m	**TTS min**	Remarks
RGBM				1	2	3	3	7	**16**	Table (pls. cf. legend)
GAP				1	3	3	3	7	**17**	RGBM -2
EMC					2	2	3	8	**19**	Conservative = 0
USN old							2	14	**20**	
MDv 450/1							5	15	**20**	+ ca. 4.2 !
Deco Trainer						1	5	13	**24**	V 3.01
OSTC 470							6	14	**25**	TDT = 50
Ultimate Planner 1.2							6	15	**25**	TDT = 50
IANTD Air					1	4	3	18	**26**	Table
BGV C23						3	7	17	**30**	only „total deco time“
DIVE 3_0						1	6	16	**27**	TDT = 52 (*)
OSTC Planner v 434						1	6	16	**28**	TDT = 53
DIVE 2_905						2	6	16	**29**	TDT = 54
USN 2008							26		**31**	140 feet
USN 09-03							28		**33**	140 feet
ZH-86						4	7	19	**33**	42 m / 27 min
DECO 2000					1	4	8	16	**33**	
Trust 2.2.17						4	7	19	**34**	TDT = 59
DCIEM						7	8	17	**36**	

NHeO3	26/2		2			1	8	21	**36**	Version 11/2011
TEC						3	k. A.	k. A.	**36**	L0 (Level Stop)
DP			1	1	3	4	9	19	**37**	GF: 45 / 90
GAP		1	1	1	2	4	9	19	**37**	GF: 45 / 90
VPM		2	2	3	4	6	8	14	**39**	138 feet
VR3	2	-	2	-	-	2	8	22	**40**	3 m -> 4.5 m
TEC					1	k. A.	k. A.	k. A.	**40**	L1
GAP		2	2	4	4	6	10	12	**40**	RGBM recreational
HLP 1.x			2	3	4	6	9	16	**40**	Default
EMC			2	1	3	4	8	19	**41**	Conservative = 50
VPM	1	2	3	3	5	6	9	14	**43**	Buehlmann safety factor = 145.4 feet
TEC					3	k. A.	k. A.	k. A.	**45**	L2
DP (**)		1	2	2	4	6	11	19	**46**	VPM Rel 3.1.4
Hahn DC-12					5	5	9	25	**47**	24 min BT
TEC				1	k. A.	k. A.	k. A.	k. A.	**50**	L3
TEC				3	k. A.	k. A.	k. A.	k. A.	**57**	L4
HLP		2	3	4	6	8	13	24	**60**	VPM 10 % Safety factor
TEC			2	k. A.	k. A.	k. A.	k. A.	k. A.	**65**	L5
NHeO3	27/2	20/2			1	8	13	39	**69**	Cons.: 50
SDP	1			1					**73**	P2 / A0
Hahn									**85+**	
HLP 1.x	2	3	4	6	8	13	22	44	**102**	VPM 30 % Safety factor

Legend (in alphabetic order):
BGV C23 = (replaced the old VBG 39), means the german legal/safety procedures for commercial in-land diving with air from 01.04.2001
DC-12 = UWATEC / Scubapro dive computer with the P-6 set of coefficients from Dr. Max Hahn; pls. cf. at: www.divetable.info/kap4_e.htm
DCIEM = Defence & Civil Institute of Environmental Medicine) since 01.04.2002: Defence R & D Canada - Toronto, DRDC Toronto, Air Table in the "Diving Manual" DCIEM No. 86-R-35 March 1992, p. 1B-14
DECO 2000 = table from Max Hahn for rec/air diving, released 2000; used in europe, especially by CMAS. Tables, as well for EAN and mountain lake diving, available at: www.vdst-shop.de
Decotrainer: www.decotrainer.de
DP = DecoPlanner Version 2.0.40 resp.:
DP(**)=DecoPlanner Version 3.1.4, www.globalunderwaterexplorers.org
EMC = Cochran EMC-20 H, Version j, www.divecochran.com
GAP = GasAbsorptionProgram Version 2.3.1665
Hahn = custom table with inertgas overpressure 0,4 Bar, [4]
IANTD = Intl. Assoc. of Nitrox & Tec Divers;Technical Diver Encyclopedia, May 1998, p. 233; www.iantd.com
HLP 1.x = HL Planner Version 1.0.2314, www.hlplanner.com/
MDv = Marine Dienstvorschrift 450/1 Anlage 6 (matches the old DRÄGER Table 210, last version from 1970 and 1984), this is the

table used for german military diving; classified information.
NHeO3 = successor of the VR3 computer from DeltaP technologies, which was withdrawn from the market due to a many a lot of problems, now: www.techsupport.technologyindepth.com, somewhat strangely modified ZH-L (****)
OSTC = Open Source Tauchcomputer / Planner; www.ostc-planner.net
RGBM = Reduced Gradient Bubble Model, table bought in 2003 from rgbmdiving.com (***),
SDP = Suunto Dive Planner 1.0.0.3, www.suunto.com
TEC = Uwatec / Scubapro Aladin TEC 2G computer, which allows for user adjustable level stops (L0 → L5)
Trust : www.keimes.de which is a freeware, but requires Java (☹), which is also free
TTS = time-to-surface (after end of BT)
Ultimate Planner: www.techdivingmag.com/ultimateplanner.html
USN = United States Navy; the NEDU (Naval Experimental Diving Unit) is taking care about these things. The topical diving manual Rev. 6 with all the tables is available at NAVSEA: www.supsalv.org ; resp.: www.supsalv.org/pdf/Dive%20Manual%20Rev%206%20with%20Chg%20A.pdf
VPM = Varying Permeability Model, here an Excel Version from Eric Baker (for XP or older OS, so no longer available)
VR3 = mix gas computer from DeltaP with up to 10 mixes, ZH-L based, once it was king of the road ... ; see above at NHeO3
ZH-86 = Zuerich air table from 1986, [2, p. 225]
(*) DIVE 3_0 with full blown numerical solution, no rounding up; whereas DIVE 2_9x is not …
(***) this company went bankrupt ca. 2004, as well there have been a couple of rumours after the dcs treatments of Mark Elyatt after his various record-dives with RGBM schedules ... a specimen copy is available at: www.divetable.info/skripte/ntable.pdf
(****) have a look at: www.divetable.info/kap8_e.htm

What was a little bit disturbing for us where two things:

1) The variation of TTS with a factor of ca. 6 (102 / 16)
2) The variations of different versions from a given software, especially prominent with the Heliox20 dive (Table II in Part II)

Nota Bene: the difference from the multiple USN entries is not "just another version", but instead is a complete change of mindset within the decompression paradigm. It changed from the old Workman 1965 work horse to the VVAL 18 LEM model from Ed Thalmann. The old work horse from Bob Workman was a modified Haldane-model, embellished with a couple of more compartments and his famous "M-Values". Haldane himself put the constraints of his table #1 very clearly: less than 50 m, less than 30 min TTS, no repetitive dives, not for old (>40 years) and men inclined to obesity! [3]. As well he pointed out, that his table is only for "uneventful decompression", i.e. NO BUBBLES! His argument was, that bubbles would mechanically hinder the perfusion, i.e.: the blood flow. But an unhindered blood flow is essential for the de-saturation with inertgas. This is why Ed Thalmann said:

"... at NEDU our exponential uptake on off-gassing led us into a brick wall. I injected the V-VAL 18 into it, the exponential uptake and linear off-gassing model."Captn. Dr. Edward D. Thalmann, Naval Forces under the Sea: The Rest of the Story, p. 293.

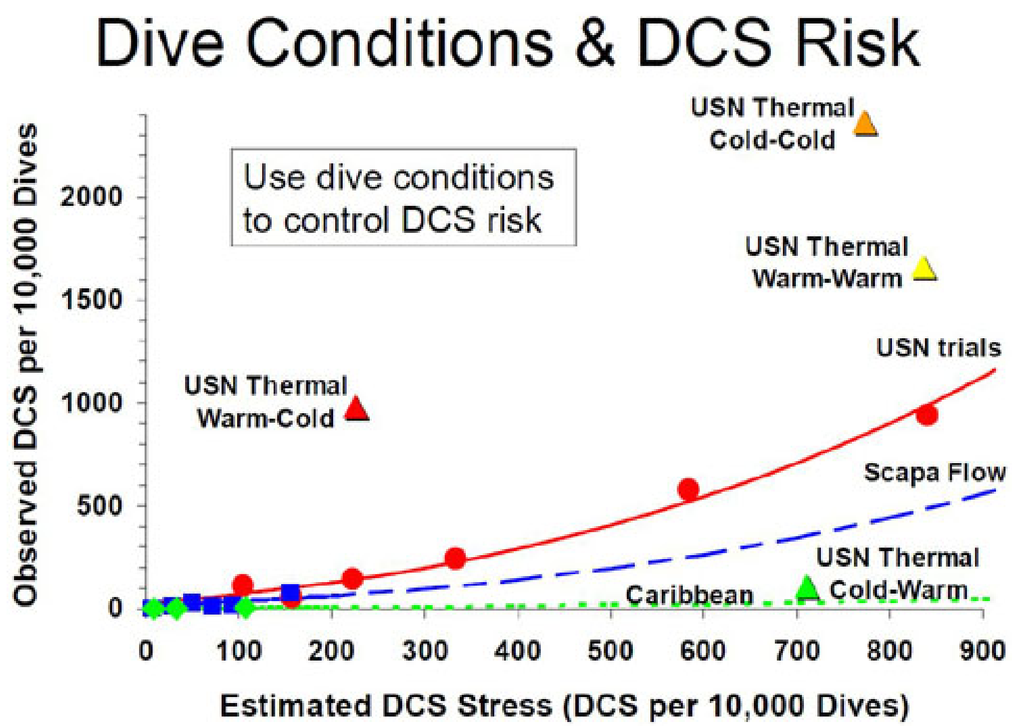
Thus the new USN table (Rev. 6, 2008) prolonged all the deco stops and as well shifted all the 10 feet (3 m) stops down to 20 feet (6m)!

The standard question on looking at this table of TTSs is the following:

Is the longer TTS safer?

I.e.: is a TTS of 100 min+ really "6 times" safer than the shortest RGBM schedule? Well, probably not so:decompression sickness is a relatively seldom event. It appears ca. 1 – 2 times in 100.000 scientific dives, in 10.000 recreational dives, ca. 3 times in approx. 10.000 military dives (normal operation), 1 – 2 times in 1.000 to 2.000 commercial dives and, appeared exactly 338 times in 7.755 USN experimental dives done by the NEDU.

There is another nice result from Dick Vann (UHMS, ASM 2008, p. 251) covering these topics:



Basically it's not only depth, time and fO_2: but as well workload and skin temperature (besides a very lot of other stuff and: de-hydration, fitness and age ☺).

And we shall not forget, how Michael Powell put it in the past issue of this magazine:

"No tables have been tested with subjects haling tanks on the surface." [Tech Diving Mag, Issue 10, 2013], p. 26.

A couple of weeks ago I gave a lecture on these topics during a GTUEM meeting (www.gtuem.org) on the occasion of an anniversary celebration for a recompression chamber facility in the frankfurt area (germany). We discussed these things with the doctores Arne Sieber (www. seabear-diving.com) and Adel Taher (who is running the deco chamber in SSH): one argument was, that despite the great variation in TTS, theP(DCS), the statistical probability of getting hit with adecompression sickness, would be more or less the same for the whole bunch of these TTS's. Mathematically speaking, this is quite true but these are just numbers which would not help for our real world diving.As well the true discrimination of a 1% P(DCS) margin from one TTS to anotherwith zero or only one or 2 hits of DCS within reasonable statistical accuracywould require something like additionally 300 controlled dives [private communication, 02. Feb. 2013, 15th. anniversary of HBO-RMT, Wiesbaden, after a couple of beers …].Or, to put this one into your perspective of real diving: if you made one DCS-free mix gas dive the last weekend and would like to question if the next one, absolutely identical dive, will be as well DCS free the next weekend then your confidence intervall ranges from almost nearly 0 % (unknown) to ca. 90% (relatively sure).

So the simple take-home message is:
none of these models (inert gas book keepers, tables, dive computers, …) have a lease on the ultimate truth. NONE!

(to be continued with: Heliox20 and a little bit about bubble models) …

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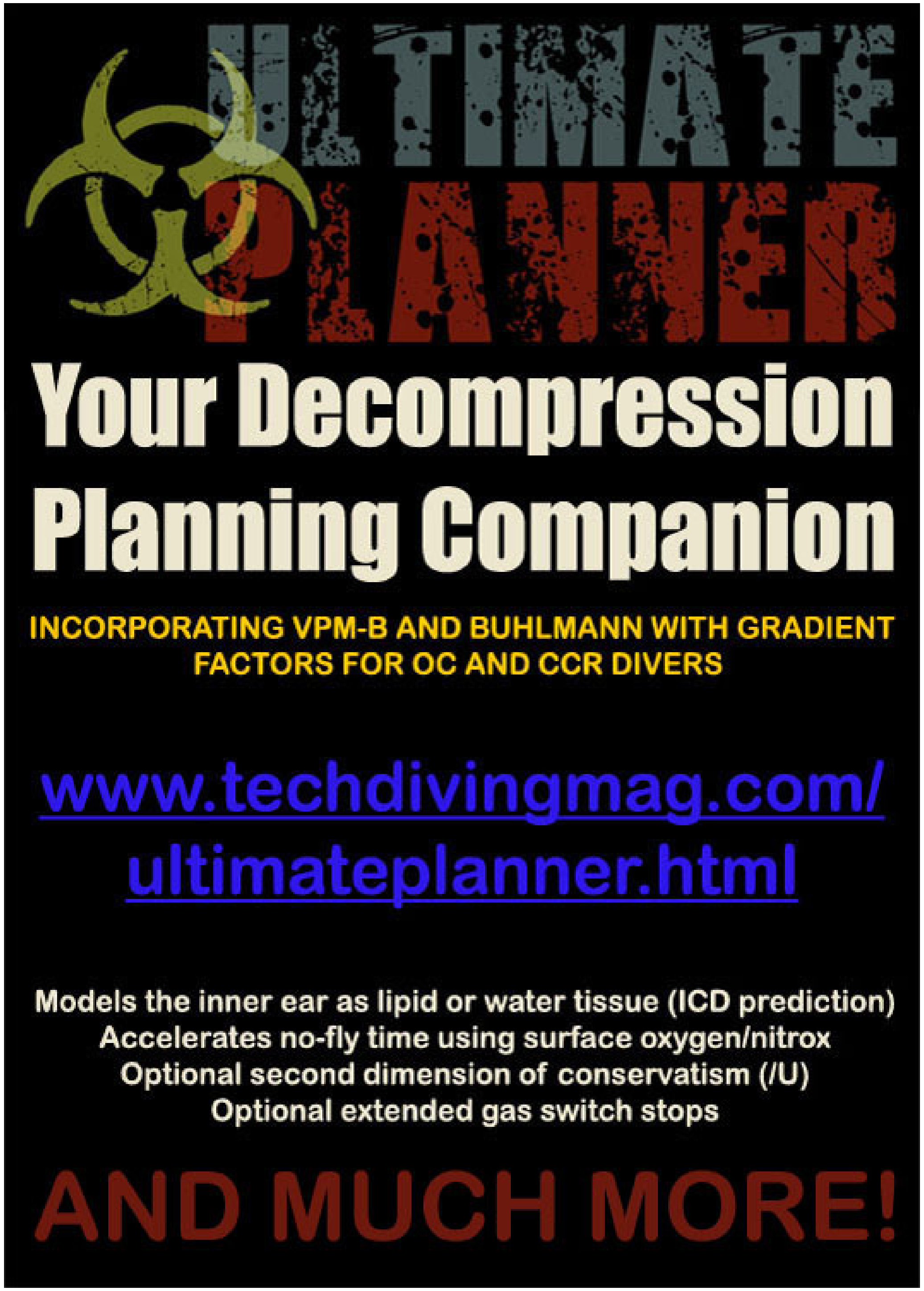


Stage Bottles

By Steve Lewis

A good place to start outlining what works for me or Doing What Works (DW^2) or whatever you wish to call it, is with stage bottles. These are as close to ubiquitous as any other piece of kit—even closed-circuit divers use them – and rigging a stage bottle in a preferred way (or as close as possible to DW^2) is not as easy as companies selling the "store-bought" accessories for rigging them would have us believe.

First though, a definition: the term stage bottle describes an independent scuba cylinder filled with "breathing medium" and fitted with at very least a regulator first and second stage. Its exact configuration and intended use goes a long way to dictating what else the bottle has attached to it and what it contains.

The list of names and uses for this "additional" gas source include:

- Deco bottle: a cylinder filled with decompression gas to help optimize off-gassing during the diver's ascent. Fitted with regulator first and second, and an SPG on a short hose.
- Sling bottle: any scuba cylinder carried at a diver's side and often rigged in the traditional North Florida Cave Diver's fashion (see diagram below) as opposed to side-mounted.
- Stage bottle/stage cylinder: a cylinder usually containing bottom mix which can be "staged" (left at a strategic point) for use in either an emergency or to extend bottom time/cave penetration.Fitted with regulator first and second, an SPG on a short hose, and occasionally a LP inflator hose with a universal Schrader connection.
- Buddy bottle: a cylinder of bottom mix used as a redundant gas source to be used in the case of an Out of Air Emergency or primary regulator failure, situations traditionally dealt with by signaling "share air" to a buddy. Required kit in the case of recreational solo divers. Fitted with regulator first and second, and an SPG on a short hose.
- Bailout Cylinder or Cylinders: typically an open-circuit alternative for rebreather divers in the event of a catastrophic unit failure such as a completely flooded loop or carbon-dioxide break-through. Fitted with regulator first stage and often connected directly to the diver's bailout regulator. Sometimes fitted with a standard second stage on a medium-length or long hose, and an SPG on a short hose or a button SPG.
- Contingency bottle/cylinder: Usually a staged cylinder used in the event of system failure, and typically employed in complex ascents requiring multiple gas chances. Often attached to a decompression station and possibly fitted with more than one second stage.
- Redundant gas source: Another name for a Buddy Bottle, Bailout Cylinder, and Contingency Bottle.

There are probably others but this list presents the most common variants that you are likely to come across.

One additional note (and apologies to those of us who use SI units primarily): Many divers believe aluminum (or aluminium) alloy cylinders make great stage, bailout, deco, etc. bottles. The reasoning behind this is the buoyancy characteristics of aluminum bottles compared to steel.

The classic aluminum 80 (nominally holding 80 cubic feet of "ideal gas" at its working pressure of 3000 psi), weighs roughly 32 pounds on the surface when empty; but in the water in the same state has a buoyant lift of three and a quarter pounds (in other words, it floats when empty, and can do so even taking into account the effect of an attached regulator). When filled, the same tank has an apparent in-water weight of almost two pounds, due to the mass of the gas it is filled with.

A steel cylinder with an imperial volume of 80 cubic feet is more compact, which lends it very different characteristics in and out of the water. For example, it has thinner walls and surprisingly perhaps, less mass. A steel 80 weighs approximately 28 pounds on the surface when empty. In the water its smaller dimensions mean it displaces less water, and when empty has an apparent in-water weight of about three pounds. When full, that apparent weight is around nine pounds. The difference between an aluminum and a similar capacity steel cylinders' buoyant shift appeals to those of us who intend to carry a bottle throughout the whole dive. Steel bottles are popular when the practice or environment suggests dumping it (staging it) at the beginning of a dive. Typically, this is what the majority of cave divers do with their decompression gas: leaving it staged somewhere near the cave entrance at the beginning of the dive: although not all cave divers use steel decompression cylinders!

In the vast majority of diving undertaken by open-circuit technical divers, the most common uses of additional cylinders are to carry decompression gas(es) (deco bottles) and to help extend bottom time or penetration in caves (stage bottles). These can be rigged and configured in very much the same way; and the same methods and technique works for their buddies diving closed-circuit equipment, and needing to carry bailout cylinders.

The traditional North Florida rigged stage bottle looks like this:

The advantage of this simple design is that it is easy to find rigging kits, which are available from various mainstream equipment manufacturers. Many dive stores, even those who do not "cater" to technical divers, seem to have one or two kits in stock or on display. Less expensive, and with access to some equipment line, stainless steel bolt-snaps and a pipe-clamp, fitting this type of rigging on a stage bottle is the work of a few minutes and it effectively and quickly attaches the stage bottle reasonably close to the diver when she clips the top bolt-snap to a D ring on her shoulder harness and the bottom snap to another D ring on her hip. There is one modification to a store-bought a stage-bottle kit that will help with clipping and unclipping the bottle, as well as help it to sit as close as possible to the diver. This is to make the distance from the clip on the bottle's neck to the anchor point of the tail clip, correspond to the distance between the diver's shoulder and left hip D rings.

However, there is one issue that a growing number of divers have with this technique: even when rigged according to Hoyle, the orientation of the stage bottle is awkward. When the diver assumes a horizontal trim, the tanks nose points down and its bum sticks in the air. A concern with this orientation particularly in tight spots, is that the business-end of the tank – the part with the valve and gas supply system attached – is likely to drag in silt or get tangled in line. But this orientation also creates unnecessary drag and can actually influence a diver's passage through the water… especially in a strong current.

Grey is diver's body, red is orientation of bottle that we want to avoid.

Another, better option is to sidemount stage bottles.

Here's a snap of a diver in horizontal trim carrying an 80 cubic foot aluminum bottle sidemount style. Notice that the rig is more streamlined and offers fewer options for entanglement and less water resistance than the traditional North Florida rig.

Aluminum bailout cylinder oriented at diver's side. Tail is a little high but acceptable.

Rigging a stage for sidemount carry requires a little more planning, and the following list of accessories:

- A CAM band with steel bolt snap
- A short loop of heavy-duty bungee cord and a second steel bolt snap (a size or two smaller than the one on the CAM band)
- A plastic or silicon (preferred) snorkel keeper
- Some bungee loops or inner-tube loops for stuffing regulator hoses (the techniques for which we will discuss later)

Let's look first at preparing the bottle itself.

Before we run through how to attach the rigging for a sidemounted stage, we need to decide on which side of our body the bottle will sit. Most divers who wish to carry a single stage, hang it on their left side. The convention for this has its genesis in old-school cave diving because of the routing of a diver's long hose from his manifold (behind his head and connecting a set of twin tanks) down the right side of his body and across his chest. That being the case, here's a step-by-step guide on how to rig a stage that will sit on the diver's left flank.

Step one: You will need a tank fitted with a valve with the orientation of the hand-wheel to the mouth of the valve the opposite of "normal." With the valve opening of a conventional valve facing away from the viewer, its hand-wheel (the on-off knob) points to the viewer's left. The majority of single tanks are fitted with left valves regardless of whether they are DIN, Yoke or Convertible. The reason usually given for this – apocryphal or otherwise – is that a right-handed diver using this valve on her back-mounted single cylinder can reach the valve behind her head [and operate it] with her right hand. In any event, for this application, you want the other one!

Step two: Stand the tank on the floor, and look at it from above imagining an analog clock face superimposed over it. Now with the hand-wheel at 12 o'clock, the valve's mouth will point to your right a full 90 degrees from the hand-wheel, or to three o'clock. When the tank is being carried, we want to have the regulator first and second stages pointing away from our body. This is the orientation we want. Step three: Slip the CAM band over the top of the cylinder and orient the anchor point for its bolt snap to seven o'clock. This is a starting point and will probably need slight adjustment to make sure that when the bottle is carried, the hand wheel points away from the diver's bottle.

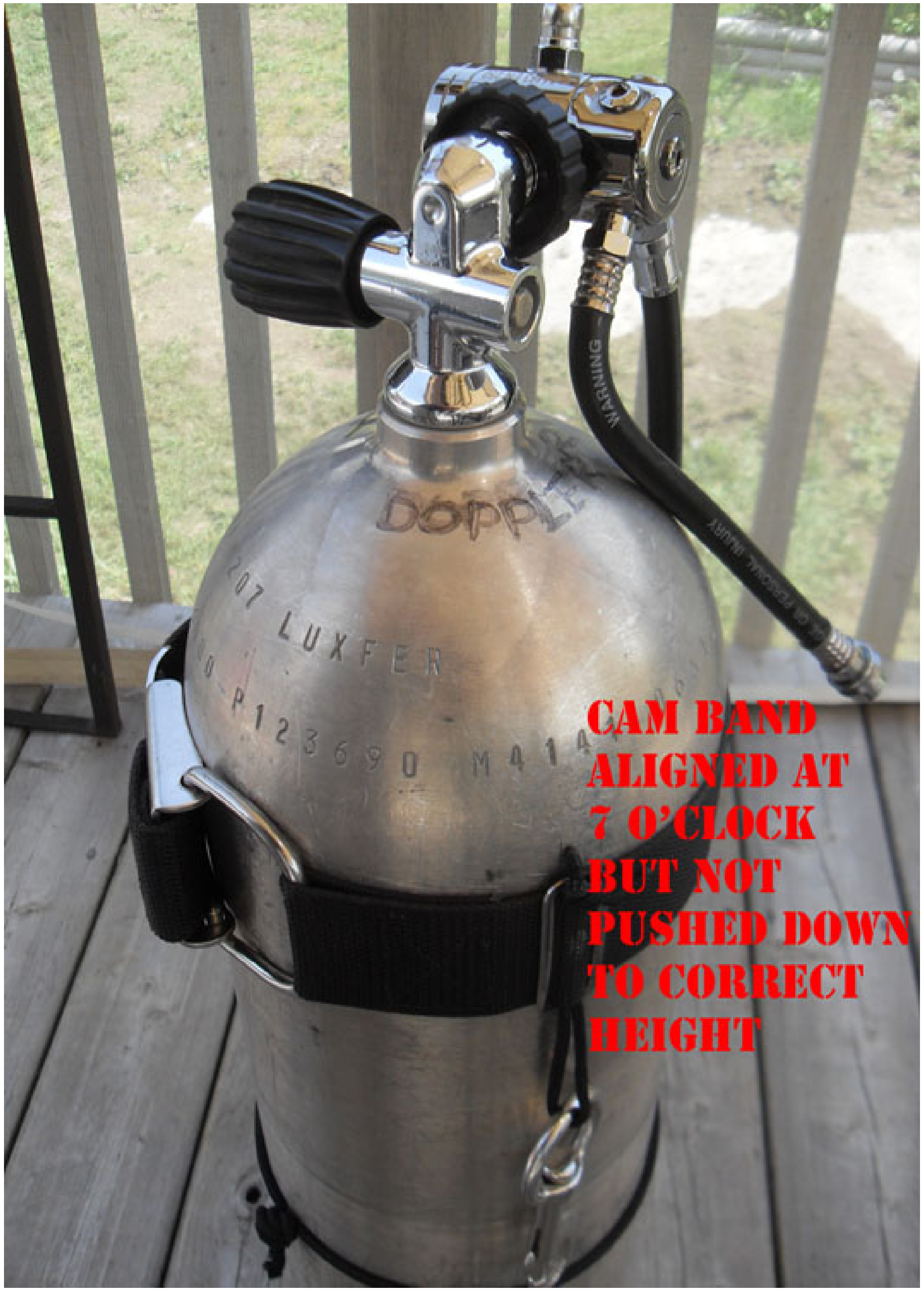
Step three: Now slide the CAM band down until its bottom is a few centimeters from the floor. (On an aluminum 80, the CAM band may need a small ballast weight to help orient the bottle horizontally in the water.)

Step four: Pull one loop of the silicon snorkel keeper over the valve so that it lays flat against the top of the cylinder with the other loop in a position that allows for the regulator mouthpiece to be stuffed into it.

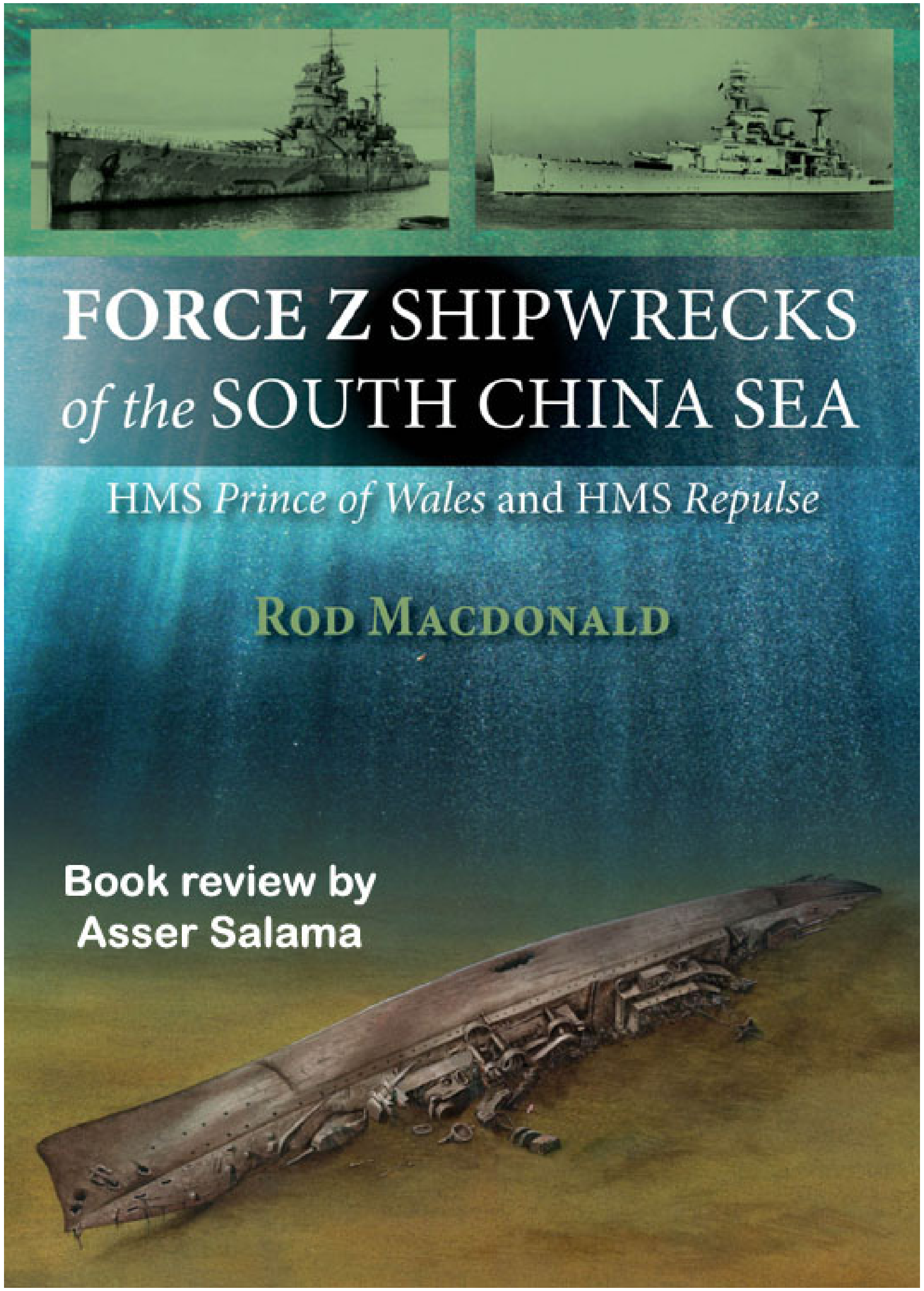
Step five: Pull the small loop of equipment line with the bolt snap over the valve making sure it cannot slip off easily. This bolt snap is not the primary thing keeping the top of the stage bottle in place – that's the bungee loop that's going to be fitted to the diver's harness (more on this later). This bolt snap is a backup and therefore, can have some slop without effecting how tightly the tank sits to the diver's side.

Step six: Add a couple of inner-tube rubber bands to the tank to hold regulator hoses in place.

Step seven: Make fine adjustments to the "height" of the CAM band in the water with the help of a friend. The aim is to adjust the anchor point until the bottle sits parallel to the body's centerline with the business end not restricting the diver's arm movement. It may not be intuitive, but decreasing the distance from the anchor point of the bottom bolt snap and the bottom of the cylinder (moving the CAM band away from the valve), will push the top of the cylinder into the diver's armpit, which may not be a comfortable feeling!



Notice the silicon snorkel keeper.



Book review by
Asser Salama

History! The world of ultimate fascination, and what's better than the accounts of two mighty dreadnoughts!

In 1941, Force Z including the two top-notch Royal Navy battleships HMS *Repulse* and HMS *Prince of Wales*, along with their supporting fleet sailed out to Singapore. The *Repulse* was 242 meter (794 foot) long, while the *Prince of Wales* was 227 meter (745 foot) long.

December the same year, exactly on the tenth, the two beauties were destroyed by the Japanese air power. 85 bombers pounded them leading to their demise. They both sunk with a huge number of casualties. Three days earlier, the Japanese attacked Pearl Harbor, Hawaii, causing huge damage to the US Navy fleet and thousands of casualties. After these two events, it became clear that air force, which was then a recent innovation in warfare, is the way to go.

WWII has put the battleship era to an end.

Internationally acclaimed author and wreck diver Rod Macdonald divides this volume, *Force Z Shipwrecks of the South China Sea*, into three "books", or simply sections. The first comes in three chapters and is all about the construction, commissioning and sea career of the two dreadnoughts. The specifics of each battleship are described in details, along with some terrific black and white photographs.

The second section comes in nine chapters and is a historic research on the Japanese aims and steps that led eventually to the siege of Singapore. This is explored in details with some outstanding photographs are illustrations.

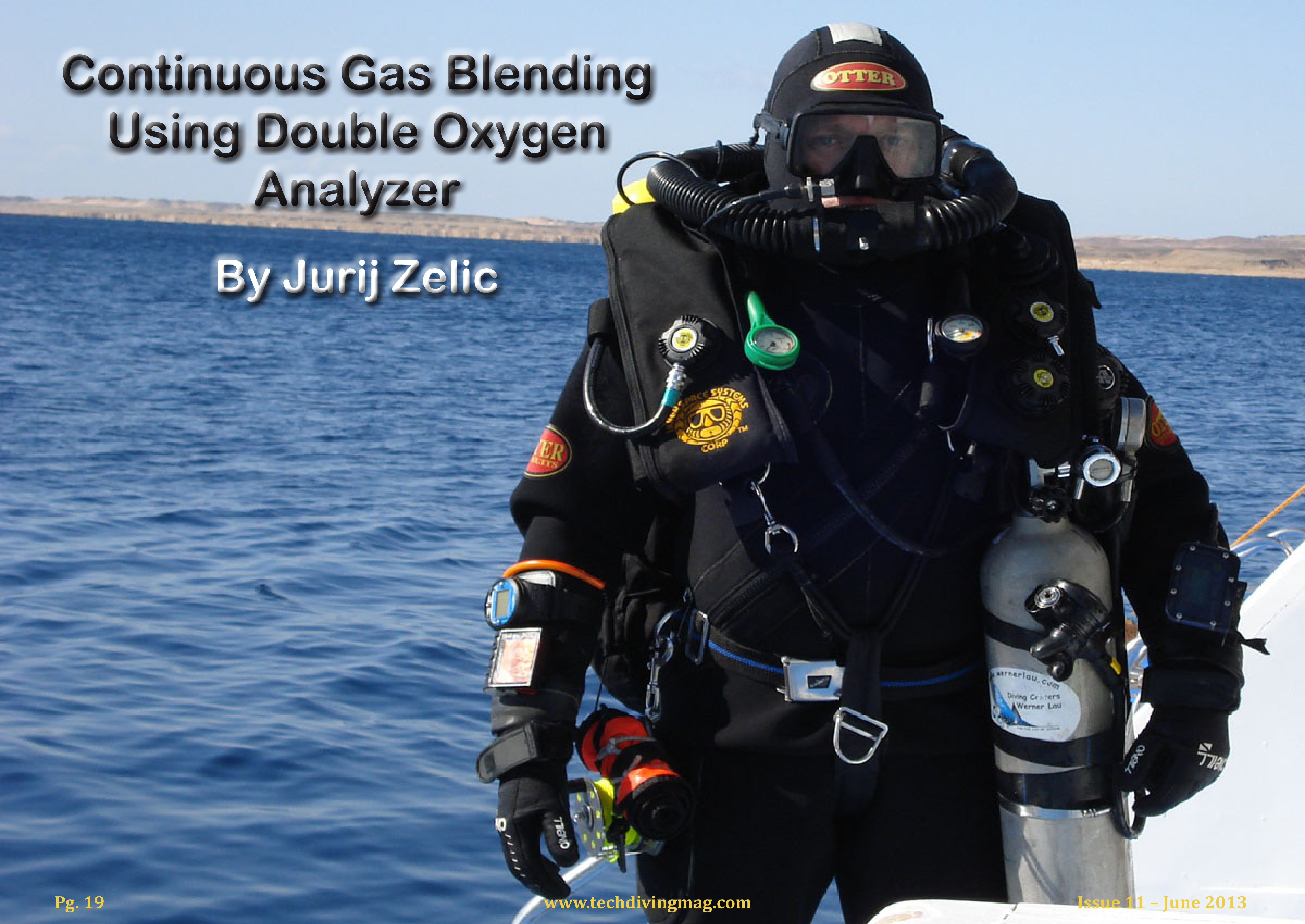
And finally, the third section comes in two chapters and deals with diving! Both wrecks are covered in details in terms of bow, stern and what's in between. The *Repulse* lies on her side, while the *Prince of Wales* lies inverted. This is clearly illustrated via detailed paintings. Finally there are some underwater photographs towards the end of this section.

***Force Z Shipwrecks of the South China Sea* comes in 166 pages and is published by Whittles Publishing. It is available at: www.whittlespublishing.com/Force_Z_Shipwrecks_of_the_South_China_Sea**

This book is also available in North America from NBN Books (www.nbnbooks.com).

Continuous Gas Blending Using Double Oxygen Analyzer

By Jurij Zelic



This article does not contain enough information one needs to neither start blending his own gas mixes safely nor build his own continuous gas blender. It just suggests a different approach to blenders who already use home-built continuous blenders. I suggest to read *Oxygen Hacker's Companion* published by Airspeed Press or to attend an appropriate gas blending course.

Continuous gas blending

Continues trimix blending has some advantages compared to more traditional methods. Better gas usage and less equipment exposed to high-pressure pure oxygen are just two of them.

The main disadvantage for sure is the high price of commercially available gas blending units. This disadvantage along with the fact that continuous blending units are very simple devices, are the main reasons many divers build their own gas blending units.

Most of the continuous gas blenders use the same principle of operation. The air is mixed with the low pressure gas in a first mixing stage, analyzed for oxygen share, mixed with second gas and analyzed for oxygen again. First and second gases are pure oxygen and pure helium in any order, based on personal preference and desired mix. Desired oxygen and helium flow is adjusted using needle valves (blue buttons in fig 1) that are fed from gas regulators.

There is no need for an expensive helium analyzer in this process. Anything about the end mix can be calculated from the two readings of oxygen share.

Gas mix is then compressed using any diving compressor and filled into the scuba tank.

Fig 1 – commercial gas blending unit

Based on which gas (oxygen or helium) is mixed with air in the first mixing stage and which gas is added in a second mixing stage, two flavors of procedure can be used; oxygen first procedure versus helium first procedure.

The choice of which procedure to use is made based on few criteria:

- Avoiding oxygen rich readings (more than 40%) for safety reasons – oxygen first procedure produces higher readings on first sensor. Mix richer than 40% must never be fed into compressor inlet.
- Avoiding oxygen low readings (less than 10%) for accuracy reasons – helium first procedure produces lower readings on the first sensor.
- Personal preference.

The mix being filled can be calculated through the readings of the first and a second oxygen sensor. Commercial blending units use a microprocessor unit to calculate the mix in real time (plus they can provide some safety features like shutting off the oxygen supply in case of too rich oxygen concentration being feed into the compressor inlet). In fact the processor unit is by far the most expensive part of commercial blender and that is why most home-built blending units will use double nitrox analyzer instead.

Determining the readings of both oxygen analyzers that correspond to the desired mix is pretty easy math. In fact if "oxygen first" procedure is used the fist analyzer always reads the same value (that depends on MOD of the mix being filled), the reading of the second analyzer is the same as the oxygen share of the mix being filled.

Fig 2 – home-built double oxygen analyzer

The tricky part is setting both needle valves to set the desired oxygen readings for both analyzers. On oxygen first procedure opening oxygen valve will increase oxygen reading on both analyzers, opening helium valve will decrease reading on second analyzer and increase reading on the first. The situation is similar on helium first procedure.

Knowing that typical response time of oxygen sensor is 5 seconds, one can imagine that setting correct flows of oxygen and helium is long iterative process of applying small changes on both needle valves.

Gas blending using VpmMixer program

The idea behind VpmMixer program is to separately adjust oxygen flow and helium flow reducing the problem to same level as mixing nitrox. That reduces the time needed to set correct oxygen and helium flows and increases the mixing accuracy and saves the expensive helium.

VpmMixer will do topping up calculations for all three cases and all the necessary calculations for topping up mix; necessary flows of each gas, helium cost calculation and filling time.

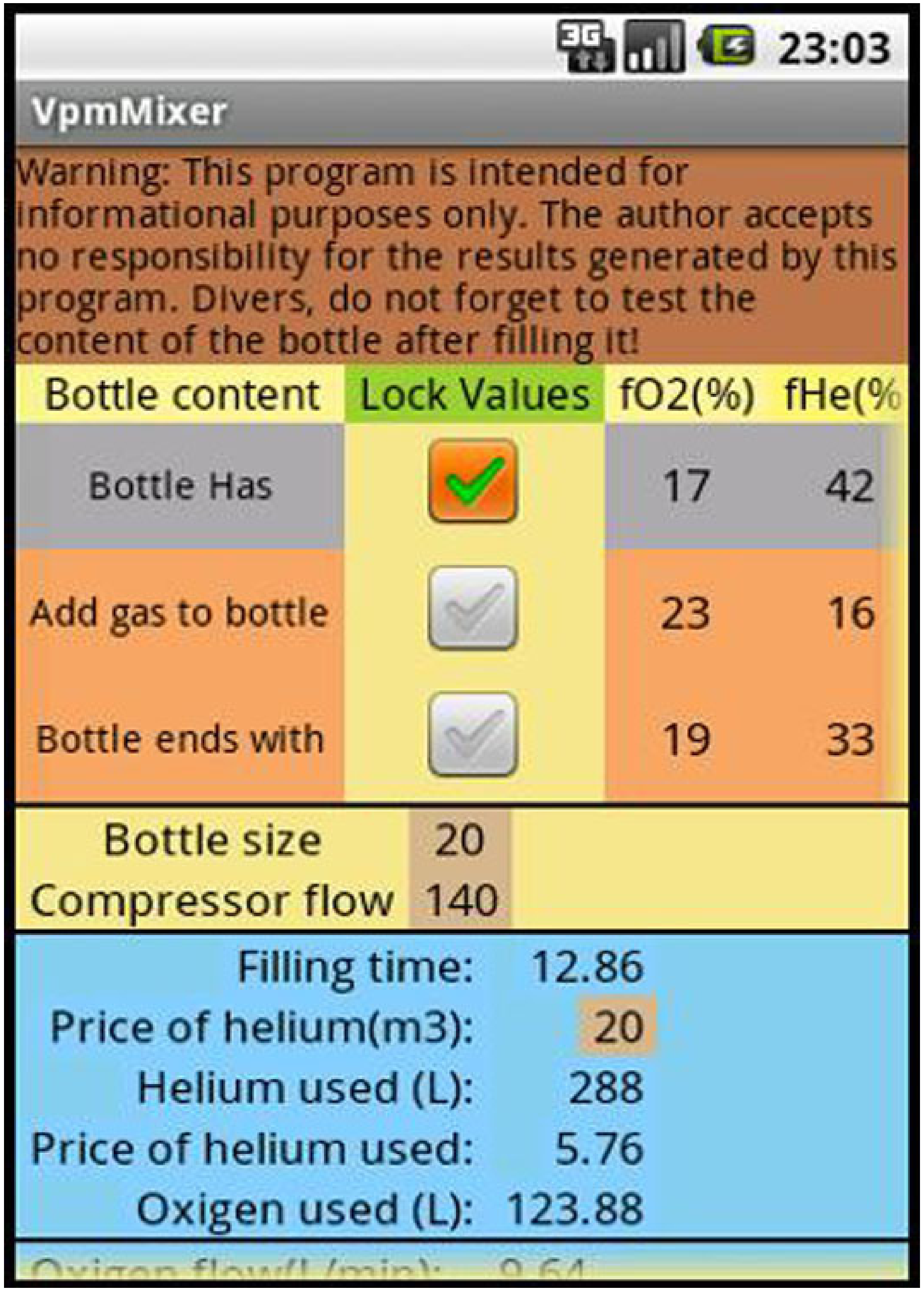
On the bottom of the screen there are all the necessary calculations for three stage process of setting the correct gas flows for both “oxygen first” and “helium first” procedures.

1. Start the compressor.
2. Keep the oxygen and helium banks closed and calibrate both oxygen analyzers.
3. Open the oxygen bank and set the correct oxygen flow by setting the oxygen needle valve until the correct readings on both analyzers are reached (not the same as any of the end readings).
4. Open the helium bank and set the helium flow by setting the helium needle valve until the correct readings on both analyzers are reached.

After that you can open the scuba tanks and start filling them, while doing just some minor adjustments on both needle valves during the process.

The oxygen tank must always be shut before shutting down the compressor (that is why the automatic compressor is not the best choice for continuous gas blending and the blending unit should never be left unattended during the filling process).

After letting the mix to settle down for a few hours and analyzing the mix, the tank is ready to use.



Bob Ballard

DEEP OCEAN EXPLORER

BY BRET GILLIAM

Most of the previous interview subjects have been with pure divers who made their mark in film, manufacturing, writing and photography. This interview however, is with famed oceanographer Dr. Bob Ballard, discoverer of the *Titanic* and *Bismarck* wrecks and leader of over a hundred other memorable expeditions.

Ballard's offices are located at the Institute For Exploration (IFE) at the Mystic Aquarium in Mystic, Connecticut. As summer crowds of eager visitors thronged through the turnstiles of the IFE exhibits at the rate of nearly a 1,000 an hour, I navigated my way past a full-sized replica of a support ship with a full-scale submersible on its aft deck "floating" in its own massive water basin. I then rendezvoused with an eager staff member who shuttled me into a private elevator and up to Ballard's inner sanctum.

Catching up with Dr. Bob Ballard, probably the world's apex ocean explorer, is roughly akin to attempting to lasso a tornado. The man moves at the manic pace of a Jack Russell terrier that had way too many cups of coffee. It's not hard to see how he maintains an athletic frame well into late middle age. Since both of us were on a tight schedule that day (he was off for a horseback riding vacation in Jackson Hole, Wyoming and I had to depart for Cocos Island to ride sharks), I outlined what I needed for some photo opportunities before settling down for the interview Q&A. Before the last words were out of my mouth, Ballard was off with the urgent stride of an Omaha insurance salesman late for his first lap dance at a Las Vegas convention.

I streamed behind in the turbulence of his wake as we set up shots in his office, by the submersible exhibits, at a control console for some of his many remote video streams from cameras in the wild, and on a sprinting slalom course through the fascinating museum of oceanography he has put together. In less than 20 minutes, I'd seen the entire Institute For Exploration, burned four rolls of film, met about a dozen staff and assistants, climbed over the exhibits including re-created models of *Titanic*'s radio room, *PT-109*'s bridge, and probably lost five pounds through perspiration alone.

We ended up in Ballard's spacious office suite dominated on one wall by a 30-ft. long map of the world and an opposite wall of glass overlooking the outside exhibits. As he sat at his desk politely answering my questions and reflecting on his unique career, a large plasma TV screen streamed a live video from a rocky kelp bed off California where two kayakers were ogling a sea lion colony. Aside from being a fascinating intellect, Ballard is perhaps the premier "gadget guy" I've ever met. He views advances in imaging technology as the ultimate tools for exploration. He's also a font of insightful quotes that help the layperson find some perspective between hype and science.

"Exploration is a discipline," explains Ballard. "Look at Charles Darwin, Christopher Columbus, and one of my heroes, Capt. James Cook. They were sent forth as disciplined observers. Adventure is bungee jumping off a bridge; exploring is mapping the canyon under the water of that bridge."

This perspective dovetails nicely with the IFE's mission statement: "To inspire people everywhere to care about and protect our ocean by exploring and sharing their biological, ecological, and cultural treasures."

Ballard's just the guy to make all that happen. He has a Ph.D. in marine geology and geophysics from the University of Rhode Island. He spent three decades at Woods Hole Oceanographic Institute where he helped refine and develop the use of manned submersibles and remotely operated vehicles (ROVs) for marine exploration. With 13 honorary degrees, the rank of commander in the Naval Reserves, and a litany of cutting edge research expeditions that have rightly established him as “da man” in the niche of modern ocean exploration, Ballard had already made a career’s worth of marks when he made himself a household name with the discovery of *Titanic*’s wreck over two miles deep in 1985.

He notes ruefully, “After I found the ship, I got some 16,000 letters from children.” This may have been the richest treasure he has discovered: the imagination of a whole new generation of potential scientists, explorers, ecologists, etc. that is growing up in a new age of information and access.

Ballard has been involved in over 110 expeditions that included break-through research in proving the theory of plate tectonics, the discovery of hydrothermal hot water vents, the pioneering use of submersibles and ROVs as scientific tools, and a host of other pure science accomplishments that should have left a footprint in the public’s consciousness along the way.

“No child had ever said to me, ‘that’s cool!’ about my work,” he reflects. “But as soon as I find an old rusty ship, I’m inundated.”

Go figure. Ballard’s Jason project now allows nearly two million students and 33,000 teachers to join him in his work through the modern miracle of telepresence... each year! His new facility in Mystic carries that educational mission a notch farther and his imagination continues to grow.

“When I first arrived in 1967, the best way of getting to work was submarines. So I was a pioneer in using submarines to explore the deep sea. During the course of that work, it became glaringly obvious that physically going to the ocean floor was not going to work. With the average depth of the ocean at 12,000 feet, it used to take me two and a half hours just to do the descents. That’s a five hour commute round trip! My average bottom time was three and half hours and I could only explore about a mile. It was ludicrous.

“Since 71 percent of the planet is under water, and there are only five submarines in the world that can go to that depth, and each of them can only carry three people... this means that on a really good day, you might have 15 people exploring. So I got out of submarines after decades of diving, and went to Stanford, circa 1979, and taught geophysics.”

While there teaching, Ballard saw the acorn of a technology advance that would grow into Silicon Valley. The rest would prove to be historic for him and the ocean science community. He was on a roll and I let him go.

“What I was most interested in was fiber optics. You know in the movie *The Graduate* where the guy whispers to Dustin Hoffman’s character: ‘It’s plastics.’ Well, I’ll tell you, it’s fiber optics! I could see the logical breakthrough in my world because of fiber optics.”

This forever relieved explorers of the need to physically dive the depths of the ocean and deal with the limitations of time, not to mention the associated hazards. Physically, he could be relieved of the need to travel to the work site if an underwater robot observer could communicate what it was ‘seeing’ effectively. This led to the development of the *Argo-Jason* concept.

With *Titanic* model

"*Argo-Jason* was named in honor of Jason and the Argonauts, the first explorers of western civilization. This allowed us to put robots under the ocean and leave them there, around the clock. Instead of three hours, we now had 24 hours, and could do 10 times the work. Instead of three people crammed into this little metal ball, freezing to death with the angst of 'we could all die down here,' the idea was to build a control center and do it all by telepresence. Now I can turn on a monitor, and I'm under the ocean, the TV monitors are my windows. More importantly, I can have 20 other people with me. So when something swims by, there is all this mental intellect gathered together, plus a satellite link. Say the world's expert on something is fishing in Montana, we can go get them online, then ask, hey, take a look at this!"

With that opener, we began talking about what got him started along this path.

You began as a geologist in physical sciences then went on a career path to becoming a classic scientist. Did you perceive a change to oceanography when you did graduate work at the University of Hawaii?» The change came much later when I was asked by the Navy to survey the sunken remains of the *U.S.S. Thresher* and *Scorpion*, followed then by my search for and investigation of the *RMS Titanic*. That changed my career direction from geological oceanography to archaeological and historical oceanography.

When and where did you learn to scuba dive?» I learned to scuba dive in Southern California in 1958-59. I was certified by the L.A. County Fire Department, if I recall correctly, since back then that was the only organization that could certify divers.

You spent time in Hawaii as a dolphin trainer and later commented that you felt the dolphins were training you.» It was interesting working with an intelligent animal. I discovered that kindness and affection was as powerful a motivator as food.

You earned an ROTC commission as an Army officer but ended up being transferred to the Navy. How did that come about?» I was a graduate student pursuing a Ph.D. in Oceanography at the University of Hawaii and went down to the Navy Recruiting Office at Pearl Harbor to inquire about transferring. The Navy needed oceanographers so they took me.

Tell us about your first experience with deep submersibles at the Ocean Systems Group in 1966.» I was working for Dr. Andy Rechnitzer and Dr. Richard Terry. They were designing and building the *Beaver Mark IV* lock-in, lock-out submersible for Mobile Oil and wanted to use it for scientific as well as commercial purposes. My job was to dream up operational requirements for geological exploration and observe how that translated into the design.

What was it like to work with Dr. Rechnitzer?» Great. He and Dr. Terry were both dreamers.

The Navy threw a wrench in your academic path when they suddenly called you up for duty. What was that like being uprooted from sunny California and landing in the snowy northeast?» I loathed it at first, it was quite a culture shock but it proved to be a critical turning point in my career.

The Navy assignment was your first introduction to Woods Hole Oceanographic Institution (WHOI). How did you fit in?» I had helped in the original design of *Alvin* while working for Rechnitzer and Terry, therefore knew a lot about similar submersibles. I was also going to graduate school at USC and working for the Oceans Systems Group. The head of the Geology Group at Woods Hole was Dr. K.O. Emery who founded the Graduate School of Marine Geology at USC, so both groups accepted me and I was quickly put to work. Later it was Dr. Emery and Bill Rainnie who made it possible for me to return to graduate school at Rhode Island to receive my Ph.D. while making a living with the *Alvin Group*.

Was this your first experience with intense competition between various academics for funding?» That came later. At first I worked for the *Alvin Group* with the Office of Naval Research (ONR) funding.

Originally it was the WHOI that brought you and the Alvin deep submersible together. What was *Alvin*'s history and mission at that time?» There was quite the buzz when I arrived at WHOI in March of 1967. *Alvin* had just found the H-bomb off Spain. As submersibles were still considered scientifically untested, the science community did not take them seriously. *Alvin* was also unable to dive deeper than 6,000 feet; therefore it was confined to dives on the continental margin while many other findings were happening in the deeper mid-ocean ridge.

What projects had *Alvin* participated in?» Besides the bomb search, *Alvin* was doing dives for geologists and biologists but nothing earth shaking.

Can you share with us some of the first research projects you were involved in at WHOI?» At first, I went to sea with K.O. Emery and one of his previous graduate students from USC, Dr. Al Uchupi. They taught me a great deal about continental margin geology, submarine canyons, and the complex geology of the Gulf of Maine and its relationship to the newly emerging science of plate tectonics.

Full-scale model at the Mystic Aquarium in Connecticut

You had to deal with some raging egos that infiltrated some of your cruises and affected morale. What did you learn from those Ph.D. types that seemed to lack leadership?» Intelligence is not a substitute for leadership. In fact, the scientific community tends to produce poor leaders.

***Alvin* and the *NR-1* represented different approaches to submersible design, compared to older craft like *Trieste*. Did you see the exploration potential right away?»** Not so much an exploration potential in the case of *Alvin* as it can only cover a limited amount of terrain, but what made it unique was its ability to go to complex geologic settings and figure out the science associated with it. The *NR-1* had exploration potential but it was highly classified, very expensive, and very uncomfortable to use.

***Alvin* sank in 1968. What happened?»** They were lowering the sub in its cradle with the hatch open when the forward cables snapped, throwing the sub into the water with enough force to send it underwater and flood the pressure sphere. They were lucky to get out alive before she sank.

What was your first dive in *Alvin* like?» I had dove in *Ben Franklin* the previous year. The *Franklin* was very comfortable and could stay down for three-to-five days. My first dive in *Alvin* was in the Gulf of Maine and it was very frustrating because visibility was so poor.

While you were in New England you hooked up with the Boston Sea Rovers.» I was a young Ensign in the Navy when I went to my first Sea Rovers Clinic. Cousteau, Waterman, Giddings, and many others were there. It was the greatest collection of diving egos you could ever hope to meet. The annual gathering was full of energy and excitement, but as I would later learn, the focus of these clinics was not necessarily about the science of the sea, but rather the art of diving.

I understand that one of your first discussions about *Titanic* originated at a lobster bake with the Sea Rovers. Did you envision then that such a dive in a submersible was possible?» Yes. The project was named *Titanius*, not far off from *Titanic*. *Alvin*'s steel hull was about to be replaced with one made of titanium. The new hull would allow for an increase in diving depth. This meant *Alvin* could now reach the *Titanic* for the first time.

Eventually you were forced to make a decision between a Navy career and pursuing your Ph.D. as a scientist. Was that a difficult choice for you?» No, I knew I had to pursue a Ph.D. Without one you can't lead. You have to work under someone else and always play second fiddle.

How did you become the designated fundraiser for the *Alvin* projects?» In 1970, ONR told Bill Rainnie he had three years to replace ONR's funding with new, non-military funding sources. I was convinced it could be done so Bill hired me to do it and I did.

Describe your feelings upon first viewing the deep water Jonah crabs from a submersible.» It was on my first *Ben Franklin* dive. We had dropped a bait can to attract life and when I saw the 55-gallon drum completely covered by hundreds if not thousands of feeding crabs… I decided never to be buried at sea.

Later you became embroiled in the debate among scientists over the theory of "continental drift." These differing opinions sparked heated and sometimes rancorous discussion, didn't they?» That was a very exciting and heady time which truly demonstrated how exciting science really is and that diving should be more than just a great story at a Sea Rover clinic.

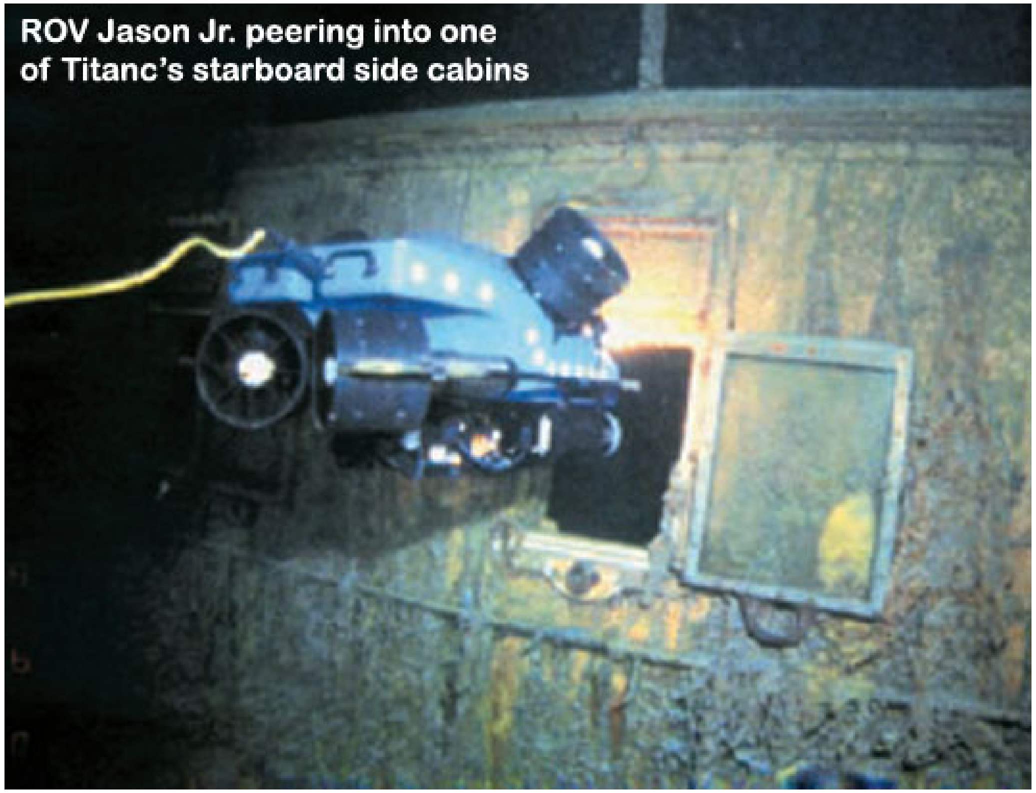
Didn't *Alvin* help to confirm your theory about continental drift?» Yes, but only in a supporting role to a lot of other tools.

You changed the way *Alvin* and other submersibles were utilized by trying to pinpoint their focus on specific marine areas.» During *Project Famous*, *Alvin* demonstrated that having human eyes and hands on the bottom of the ocean was the ultimate final step in underwater science.

On one of your earlier *Alvin* dives you were nearly crushed by a huge boulder? How deep were you and how did that happen?» It was 1976 and we were diving in the Cayman Trough. We were working at the base of a giant cliff pulling rocks out of the rock face. As we moved up the face, we realized that the rocks we were trying to pry loose were holding up a massive boulder just above us. That was a scary moment. Thank God we were unsuccessful in prying them loose!

***Alvin* was originally only designed to go to 6,000 feet. You pushed for the submersible to be certified to twice that depth. How did you accomplish that?»** The Navy wanted to build and test a new titanium sphere so we convinced them to use *Alvin* as a test bed for that program.

Tell us about the pioneering work you did on *Famous*?» *Famous* was the turning point in deep submergence science. We were under scrutiny by the entire oceanographic community and they were convinced it would fail. Fortunately, the critical science could be done over a very small area, ideally suited for *Alvin*. The rift valley of the mid-ocean ridge along the plate boundary was rugged and complex, yet less than one mile across.


ROV Jason Jr. peering into one of Titanc's starboard side cabins

You also had a narrow escape when a fire started on a deep dive. What caused that and how did you deal with it?» I was diving in the French bathyscaph *Archimede* in 1973, a year before we used *Alvin*, on a series of preliminary dives in the *Famous* area. We were on the bottom at 9,000 feet when an electrical fire broke out inside the pressure sphere. The sphere quickly filled with toxic black insulation smoke. Our eyes and lungs were burning as we dropped out weights and headed up. It took one and a half hours to surface. I was sick with strep throat, which only compounded my misery, but it was a historic dive.

Did you feel vindicated when finally earning your Ph.D. after all the challenges to your work?» Getting my Ph.D. was the end of one phase in my life and beginning of a new one. Without it, too many doors were locked.

How did *Angus* come about?» *Angus* was developed by Dr. Bill Bryan and Dr. Joe Phillips at WHOI for *Famous* to conduct a series of film runs across the rift valley floor. I went on to perfect it as a search tool for *Alvin*. We used it in 1977 to find the first active hydrothermal vents and in 1979 to find the first "Black Smokers."

You discovered publicity aided funding for your exploration projects. But this also brought criticism from the old school academics. How did you deal with that element?» Working for *National Geographic* was a blessing and a curse. Every Sea Rover loved *National Geographic* while most oceanographers thought doing anything with them was a waste of time. I later discovered it was much more complex than that. The fact was most oceanographers were doing things that the public and *National Geographic* had no interest in. To make matters more difficult, the press, *National Geographic* included, portrayed science as an "I" profession when in reality, it's an "us" (it's a collective scientific effort). The press would single out an individual and make them a hero. This made some rightfully angry and others wrongly jealous.

The discovery of the hydrothermal vents off the Galapagos was another landmark.» It was a great expedition and it was clearly the result of much hard work by many great scientists.

Didn't you also nearly have an accident by approaching a hot water chimney vent?» We didn't realize at the time how hot the vent water was until *Alvin* returned to the surface and we saw the heat damage. It had melted down to the foam, close to the viewport on the port side of the sub. We then became very careful when working around black smokers on future dives. It could have been a disaster had we let the hot fluid hit our view ports inches away.

Although you were a huge advocate of deep submersibles, you eventually favored a different means of observation in deep ocean zones by utilizing unmanned vehicles. Did this cause a rift between your ideas and the manned submersible factions?» My conversion to remotely operated vehicles made me a traitor in the eyes of the deep submergence community. It was a fraternity that felt I had deserted them. The physical act of diving was such a part of deep submergence that not doing it, or worse yet, replacing it with robots threatened to emasculate those who utilized remotely operated submersibles. I was more interested in why I was diving as opposed to the pure act of diving. Diving was becoming "old hat" for me and I saw so many people continuing to "pound their chests" about the dangers of diving when in reality air travel took more lives. People would return from a dive then talk about it but never tell me anything interesting about what they saw. It was too macho a world for me to live up to the rest of my life – a Sea Rovers Clinic gone to the extreme.

You were left to conceive, design and build the *Argo-Jason* system.» In 1979, we returned from the Galapagos Rift with the first biologists to see the exotic marine life living around the vents. We mounted a new digital color camera on *Alvin*'s arm to test. I had my back turned to the view ports and was looking at a TV monitor when I noticed the biologist was doing the same. A light went off in my mind. Why were we down here if the biologist thought the view on the screen was better than looking out of the sub's viewport? That year, I took a sabbatical to Stanford and began to dream up the *Argo/Jason* system. The idea was to use the newly emerging technology of fiber optics to move the sub's window to the surface so we could achieve more bottom time. Bottom time is so short in a submersible, particularly when you make a deep dive. It takes too long to get down, surface, and then recharge the batteries. With an ROV, our bottom time could be 24-hours a day. Again I was more interested in why I was diving than the act itself. I was willing to give up the chest-pounding heroics to get more time on the bottom and learn more about the wonders of the underwater world.

In searching for the wreck of the submarine *Thresher* you had an epiphany about the trajectory and trace debris left on the bottom that changed your methodology for looking for wrecks. Can you explain how you changed the accepted theories and why?» Prior to that experience, the standard way to look for something on the bottom was to use a side-scan sonar. But in complex bottom terrain with many targets, deep canyons and narrow ridges, a side-scan sonar can quickly become difficult to use. In such terrain, only the largest of targets can be seen and then you have to be on top of them before they're detected. The *Thresher* was destroyed by a powerful implosion creating a vast debris field that stretched out over several square kilometers. A side-scan was unable to tell the difference between debris and the millions of glacial stones (erratics) dropped by melting icebergs years before, but a camera could.

The discovery of the *Titanic*, sunk to a depth of more than 12,000 feet, etched your reputation for all time.» Finding the *Titanic* was a mixed bag. It made me famous, it made me enemies for life and it totally changed my life and career. I often wonder where I would be today had I not found the *Titanic*. I am very happy where I am today, thanks in a large degree to the *Titanic*. I'm doing things that never would have been possible. Clearly, however, finding the *Titanic* was not the most important project I have ever done. My biggest disappointment concerning the *Titanic* project was the conflict that erupted between the French and Woods Hole over credit for the discovery, as well as the subsequent salvaging of the *Titanic* by the French after the discovery. I'm convinced that had there been a diplomatic solution, both sides would have protected the *Titanic*, and she would look just like she did when we first found her.

Diver inspects Alvin's ascent and descent weights

Although many artifacts of the *Titanic* are nearly perfectly preserved, there are no traces of human remains. Why?» Remember the Jonah crabs? People are eaten and their bones are exposed. The deep sea is undersaturated in calcium carbonates that make up bones. As a result, bones dissolve quickly leaving only the inedible shoes behind. Inside wrecks you'll find bodies and skeletons, but not outside unless you are in the Black Sea, which has no oxygen.

What are your thoughts on the practice of taking laypersons on submersible dives to the *Titanic* if they ante up the fee?» I think visiting the *Titanic* by lay people is wonderful. It's no different from going to see the *Arizona* in Pearl Harbor. My concern is for the damage to her decks that will result from the subs that land there and leave things behind. I'll give you an update next summer when I go back for the first time since finding her.

Did you like Jim Cameron's movie *Titanic*?» Yes. Great movie!

You and I are both members of the prestigious Explorers Club. Cameron was just inducted and given a special award, how does this sit with you?» I think Jim is a great moviemaker and an innovator of filming technology. I wish I had his cameras, lights and his budgets.

You've had a long relationship with the National Geographic Society and produced some great articles and films for them. You've had your differences along the way including a ruckus over the first press conferences following *Titanic*'s discovery in 1985. How do you balance the relationship with sponsors?» I have a wonderful relationship with the National Geographic Society. I am one of their Explorers-in-Residence and receive more support from them now than I have ever received in the past. I hope it goes on forever. National Geographic management stood with me during the *Titanic* press flap with the French and our sub-sequent return to the *Titanic* the following year, others didn't.

Please enlighten us on the discovery of the *Bismarck*. Was it a similar project to *Titanic*?» Same visual-search strategy just a larger area and with another sunken ship close by that threw us off the first year, we recovered the second year and found her. Before one can explore a ship, one needs to find it, and that is the hard part. Exploring a wreck site is the reward one is given after the hunt ends. And finding the German battleship *Bismarck* was not easy. In fact, it was the most difficult hunt I have ever conducted, and that includes finding the *RMS Titanic*, the *USS Yorktown*, and *PT-109*.

What made the search for *Bismarck* difficult was the depth at which the ship lies–more than 14,500 feet of water–the uncertainty of its location, the terrain in which it had come to rest, and the avalanche it set off on impact with the seafloor. Unlike other seekers of shipwrecks, I adopted a hunt strategy for finding shipwrecks in the deep that involved constant visual contact with the bottom. My colleagues questioned this strategy, relying instead upon the age-old technique of using a side-scan sonar to search. Operating in total darkness, video cameras can only see a short distance, 30 meters at best, while 100 kHz side-scan sonars can reach out more than 400 meters to a side. Why would I want to search with a camera?

Back in 1984, the U.S. Navy was thinking about disposing of the nuclear containment vessel that housed the reactors in retired nuclear submarines. We were concerned about the adverse affects the reactors might have on the deep benthic environment. For that reason, the Navy wanted to investigate the nuclear reactors of the *USS Thresher* and *USS Scorpion* that have been lost and still never found, in the 1960s. I was called in to see if I could find them using my new camera sled *Argo*.

While mapping the wreck sites, I made a fundamental discovery. Shortly after sinking, both subs imploded catastrophically thousands of feet above the sea floor, creating a mass of debris of all weights and sizes. As this material sank, underwater currents carried the lighter debris more than one mile away from the heavier objects, creating a long trail of wreckage. More importantly, side-scan sonars were unable to detect these light objects while a camera could.

1. Alvin's divers communicate with support ship A-II before the sub begins a dive on Titanic

2. Artist's rendering of "black smoker" being investigated by Alvin

Both *Titanic* and *Bismarck* released a tremendous quantity of debris into the water at their moment of sinking. Knowing the currents in the area, I could predict the direction in which the debris would have drifted and lay out search patterns that crossed the debris field at one-mile intervals. This made it possible to move through the area very quickly. For *Titanic*, this strategy worked fantastically. Once I located the debris field, I was able to follow it to the shipwreck. For *Bismarck*, however, the method proved more difficult. During the 1988 search, I picked up a debris trail that led to another ship, a larger wooden schooner that had sunk years before. The summer search window was lost.

The following year, I picked up another debris field but it led to a large depression with nothing in it. Had *Bismarck* been buried by its own impact? No, *Bismarck*'s impact with the seafloor had set off a giant landslide, carrying the ship downslope, requiring more time to finally locate her. As I got close, I saw its skid marks on the bottom, surrounded by hundreds of German boots.

Except for a small portion of the stern, the ship was upright, intact and in an amazing state of preservation. The swastikas on her bow and stern decks were still there. We examined the mighty armor belt looking for signs of damage. We found none. As I wrote in my 1990 book, the *Discovery of the Bismarck*, "alongside the hull we could see evidence of hits from the British secondary guns. In some cases, the shells had splattered like bugs on a windshield, seeming to leave the armor intact."

But what struck us most as we returned to port was the absence of implosive damage to her hull like that on the stern of *Titanic*, the result of a ship sinking before being fully flooded. From the integrity of the wreck, it would seem that *Bismarck* sank well after her watertight compartments had been blown open to speed her final journey to the ocean floor. The first question I was asked by the British press was, "Did we sink her or was she scuttled?" To their horror, I answered, "I believe she was scuttled." But only after further exploration would we know for sure.

You've extensively explored the shipwrecks of the Solomon Islands' Iron Bottom Sound. You later turned your attention to locating the wreckage of John Kennedy's *PT-109* off Gizo in the northern Solomons. How did that search differ from your hunt for other wrecks?» *PT-109* was a true needle in a haystack. It wasn't where everyone thought, so what's new? And we didn't have much time to find her. The bottom currents were very strong and she was mostly buried by drifting sand dunes.

How did the Kennedy family feel about your expedition?» The Kennedy family was great and fun to work with, particularly Max Kennedy who went on the expedition with us. Our strongest support came from Senator Edward Kennedy and his great staff.

You've also been conducting explorations in the Mediterranean for ancient shipwrecks.» After finding many contemporary shipwrecks like *Titanic*, *Bismarck*, *PT-109*, *Yorktown*, etc. I began to wonder about the fate of older and potentially more important ancient shipwrecks. This thought has now set me on a new path. I'm now convinced that the deep sea contains more ancient history than all of the museums in the world combined and I want to help unlock that underwater museum for the world to enjoy and learn from.

Do you believe that, as a society, we are spending too much money on space exploration and not enough on marine and ocean exploration?» I think space exploration is something our nation should do including putting humans on Mars. I simply think we, as a society, should be spending a similar amount on ocean exploration.

What's your opinion on the state of manned submersible and ROV units today and what would you like to see next?» The Ocean Science Board of the National Academy of Science has been asked by the National Science Foundation to deal with the furtherance of deep submergence technology. That study is underway and I've made a specific series of recommendations to the group but time (less than a few months) will tell. Their hearings are ongoing.

Graham Hawks' *Deep Flight* submersible has gotten a lot of press. It exudes sizzle and sex appeal but do you feel it will it prove to be a useful tool for science?» I think it will provide people, particularly the lay public, with a wonderful opportunity to fly in the underwater world. I don't think it will result in a great deal of compelling science, but that doesn't mean *Deep Flight* submersibles shouldn't be built with private money.

Since you founded *Jason* in 1989 it has greatly expanded. Bring us up to date on its current programs and where you see this going.» The Jason Foundation for Education is entering its 15th year. More than five million students and teachers have been involved in its annual educational program. This year alone, one and a half million students are doing Jason and 33,000 pre-college science teachers are using our web-based curriculum and annual "live" expedition.

Let's touch on an item of controversy. Are wrecks graveyards to be left undisturbed or are they fair game for archaeological study?» It depends. There are wrecks… and there are wrecks. Some are important and many are not. I draw a line between a recent wreck and an ancient wreck. Recent wrecks have living survivors and living

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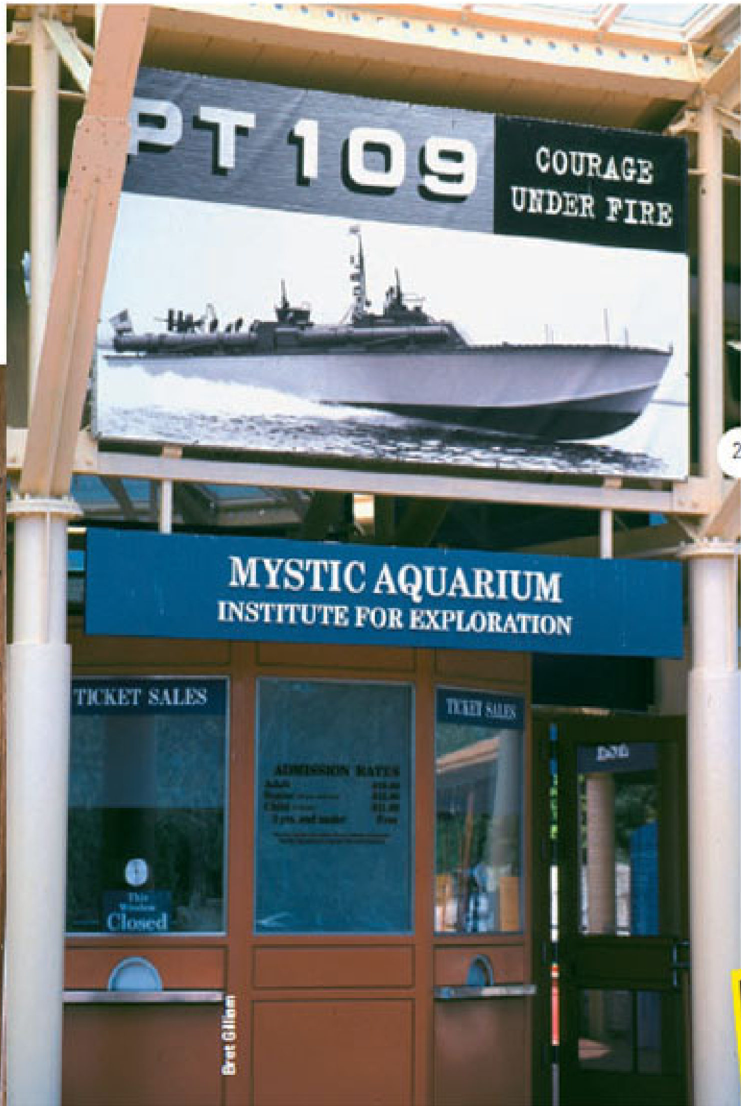

1. WWII PT boat display, Institute for Exploration, Mystic Aquarium
2. Entrance of PT-109 show, Mystic Aquarium

relatives of the dead. They need to be treated with respect for the feelings of the living individuals left behind. I draw a line between wrecks that are historical and ones that are not. I draw a line between wrecks that are fascinating and/or beautiful to visit and ones that are not. In other words, if you find a wreck that is historically or archaeologically important, a wreck that is enjoyable or beautiful to visit, what gives you the right to take something from that wreck that makes it less important, less enjoyable, or less beautiful for those who follow. Just because you can take something from a wreck does not mean you should. I think objects taken from a ship lessen the object and lessen the ship. Once found, a ship is no longer lost. Modern technology is making it easier and easier for others to visit that ship in person or with telepresence technology. Again, I think salvage is a form of macho thinking that needs to change. It demonstrates lack of integrity to rip something off a shipwreck and it proves nothing. It takes much more character to leave it as you find it.

Should artifacts be studied and left underwater or brought up and preserved?» If there is something to be learned scientifically or archaeologically, then recovery is justified. Many of the ancient shipwrecks I found were commercial carriers with large quantities of the same object and in some cases, these objects are still preserved underwater. In such cases, only a few need to be recovered. The remainder is not going anywhere and is easy to locate should scientists need another sample. I think underwater museums should be created. It's very expensive to conserve, guard and protect ancient artifacts forever. Forever is a long time!

What about the ships themselves, such as the Civil War ironclad *Monitor*?» In some cases, bringing shipwrecks to the surface, particularly small ones, is the best way to preserve them for others to enjoy and that action is justifiable. But in the case of the *Titanic*, removing artifacts, particularly artifacts that can remain underwater for thousands of years (i.e. glass, ceramics, etc.) lessens the experience of others who follow. I think technology will soon make it possible to stop further degradation, in fact, even reverse it.

What's this new project you've got going at the Mystic Aquarium?» It is the Institute For Exploration (IFE)/Mystic Aquarium and it has no endowment. Wish it did. Donations are accepted. IFE is dependent upon many sources including federal grants from the Office of Naval Research, NOAA, in particular, Office of Ocean Exploration, National Geographic Society, private donations, and 750,000 visitors that come to our exhibit center every year.

For most of your career, you've had to chase funding from the Navy, *National Geographic*, National Science Foundation, etc. Will your new Institute make your exploration projects easier now?» The need to raise funds to chase your dreams will never go away. Columbus had to do it. Lewis and Clark had to do it. Peary had to do it and I, along with other explorers, am no exception. It's a rite of passage.

You've recently embarked on a project for semi-submersible oceanic habitats. Do you see floating cities in our future? Is *Waterworld* just around the corner?» I don't think a large number of people will live beneath the sea in ambient pressure habitats. That's great for science and for industry but too expensive for the masses. I do believe that more people will move out onto the sea. They already are doing it on offshore platforms of the oil and gas industry. Tens of thousands of us do it each day. I foresee a time when families will begin to do it on vertical spar buoys like Scripps' FLIP. It's a matter of time and dropping costs.

You've managed to carve out a fascinating career as an underwater equivalent of *Indiana Jones*. What advice might you give young people who'd like to pursue a similar path in ocean exploration?» I always tell young people to follow their dreams. Not their mother's, father's, or teacher's dreams but their own. You need the passion of your dreams to get you back up on your feet when society knocks you down.

What are your new dreams?» I have always lived in two worlds. The world of deep submergence technology and the world of deep submergence science. It goes back to my upbringing by Andy Rechnitzer and Dick Terry and later by K.O. Emery and Bill Rainnie. In the world of deep submergence technology, I want to go to the next level in telepresence this summer when I begin the process of moving the diver to the beach so one can have infinite "bottom time." Just think, if you come to Mystic in July and August, for 24 hours a day for 30 days you can be underwater in the Black Sea and Eastern Mediterranean diving on a series of ancient shipwrecks, working with those at sea as if you were there. In the world of deep submergence science, I want to begin a new field of research in deep-water archaeology. Just last year, I accepted a full professorship at my alma mater, the Graduate School of Oceanography at the University of Rhode Island where I received my Ph.D. in the summer of 1974, just before going to sea on *Project Famous*.

I am now director of the Institute for Archaeological Oceanography and starting next year we begin offering a dual degree with the University's History Department. New graduate students in this program will receive a Ph.D. in Oceanography and a Masters in Marine Archaeology. Using our newly developed vehicle systems (*Echo*, *Argus*, *Little Herc*, and *Hercules*), we hope to pioneer this new field of research and uncover lost chapters of human history while the world looks on.

Editor's note: There are about 40 copies of the original book still in Bret Gilliam's personal inventory. They are available as a Signed/Numbered Limited Edition personalized to each buyer by Gilliam at $200 each, including shipping. He can be contacted for purchase at bretgilliam@gmail.com.


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