Diving Performance – Beyond Drag

Part 1 of 4

By Ron Evan Smith, March 2015

There are several ways to quantify diving performance. Metrics can include an achieved swimming speed at a specific RMV or metabolic rate, or an achieved depth and time interval, or other metric. In this 4 part mini-series, we will be focusing on performance metrics associated with swimming speeds and effort. Although the past decade has seen many improvemants to diver performance at depth through the introduction of rebreathers to the diving market, rebreathers achieve this performance at great cost, both in money and complexity. This means that most recreational divers will never get to exploit the benefits of these performance advantages in diving technology made possible by these rebreathers. Most divers still dive the same open circuit diving technology that we saw being used in Jacque Cousteau's underwater documentary films from the late 1960s and early 1970s.

Indeed, little has changed since then. Some might say that is a sign of a good design, that like the shark, it is so good that it does not need to evolve. However, I see a significant problem that has been patched over with stopgap measures. Furthermore, I think there are some fairly simple things that can be done to better plug the holes in the basic technology format laid out by Mr. Cousteau. My intention is to define the problem and then show that there are effective things that can be done to mitigate the situation.

This article will come in four parts. In this first part, I will define "the problem"; the performance gap that I think exists in the technology. I will show why I think it is important and why nothing has been done to solve it. In part 2, I will take a look at the engineering to get a better look at what will likely be required to solve the problem. Finally, in Parts 3 and 4, I will show some solutions that I have been working on to prime the work queue and, hopefully, get things moving in the right direction, and also cover some things that you can do now to improve your own diving performance.

The Performance Gap

Engineering a system begins with defining system requirements. In this case, we want to engineer a system for placing humans below the surface of the ocean to operate independently of the surface for a specified amount of time. If that specified amount of time is low enough and the depths below the surface are shallow enough, open circuit scuba equipment is a reasonable technology to use on the mission. For this series, I will restrict my discussion to this scope. For most divers, open circuit scuba is the limit of complexity with which they will likely engage.

Given this limited scope of ocean exploration, our first sets of requirements are to put a buddy team of divers underwater at depths not greater than 40 meters and for times not exceeding the no-decompression limits for the gas mixture being breathed (specifically, the common definition of recreational scuba diving).

The second set of requirements has to do with the fact that we are placing humans in the ocean to act independently of surface support for the duration of the dive. The ocean is a dynamic environment that is constantly changing and moving. Ocean currents commonly move at speeds beyond 2 knots. For example, the Gulf Stream has average current speeds of 3.5 knots and resides alongside the most heavily dived locations in the USA. Several popular Florida wreck dives reside at the edge of the Gulf Stream and are periodically enveloped in its currents. The humans that we want to place within this environment must be able to cope with the dynamics of this environment.

As an engineer, I would recommend that any system we design to operate independently in the open ocean needs to be able to cruise at sustained speeds of at least 3 knots and be capable of non-sustained periods of speeds at 5 or more knots. Some people may want argue about these particular values for a diver speed requirement. Some will say this is faster than needed, that they have dived for many years with much lower capability. Others may say this has too little margin and the required swimming speeds need to be higher. According to NOAA, the maximum surface currents in the Gulf Stream are 5 knots. The proposed sprint requirement has no margin to this maximum current of the Gulf Stream. However, 5 knots is a maximum surface current speed and divers typically operate below the surface and typically try to avoid maximum current conditions. For this discussion, let's just assume the requirement as I have defined it, and see what that means to scuba technology and its evolution. If our diving technology fails to meet this requirement, we will need to place increasing restrictions on how, where and when the divers are permitted to operate.

This is where the patchwork of stopgap measures come into the scene, as the system pioneered by Mr. Cousteau falls far short of these requirements. There are many stopgap measures used in the diving industry, including limiting diving activities to small time windows around local slack tides, altogether avoiding many locations with persistent strong currents, using boats to deliver divers to locations such that divers can use the anchor line to traverse the current zone and conduct the dive in the boundary layer of the sea floor (a method that is logistically analogous to overhead diving and considered technical in nature), using boats to follow the divers as they drift helplessly with the currents (requires a float line to the surface) and even in some cases using diver propulsion vehicles (DPVs) to come closer to achieving the speed requirements that I defined above.

It is worth noting that according to the most recent Tahoe Benchmark DPV tests (a large scale independent testing of DPVs from many manufacturers that was last conducted in 2011); the fastest scooters tested produced maximum speeds below 3 knots,

with the single tank diver configuration. The long range cruise speed was only 1.5 knots. The fastest DPV tested, the Cuda Fury 1150, produced a maximum speed in testing of 2.9 knots. At over $7k, this DPV is likely about four times more expensive than what most recreational divers are going to spend on all their dive gear combined, let alone what they will be willing to spend on a single item purchase. Furthermore, the Cuda Fury can't easily be used if you need to get on an airliner to get to your dive destination. The large lithium ion batteries are not allowed on the plane and would need to be shipped separately by ground or by boat. For recreational diving, simply throwing more power at the problem is not an economically viable solution.

Normalization of Deviance

Things have not improved much in the past 50 years regarding swimming performance, and performance has arguably gotten worse instead of better with the normalized use of Buoyancy Compensators (BCs) and popularization of the "tech" look for dive gear. The tech look has grought an abundance of 'D' rings to harness systems that allow a diver to clip on an abundance of accessories, many of which may not actually be used on a dive. Today we can expect a strong diver with a typical recreational scuba kit to be able to maintain 1 knot and sprint at about 1.5 knots. This is a long way from my recommended minimum performance requirements of 3 knots sustained and 5 knots sprint.

Why has nothing been done to address this basic performance deficit in the last 50 years? In short, the answer is '*normalization of deviance'*. Normalization of deviance is the gradual process through which unacceptable practices or standards become acceptable. As the deviant behavior (in this case, diving in the ocean with a severe deficit in swimming performance) is repeated without catastrophic results, it becomes the social norm and is simply accepted.

The entire scuba industry has basically evolved to accommodate this large deviance from these basic system requirements. Personally, I feel that this is one of the reasons that the scuba industry is languishing economically while the sport of freediving is growing rapidly. A freediver in streamline form with a monofin can cruise at 3 knots and sprint at 5 knots. Freediving technology does a much better job of meeting the speed requirements imposed by the ocean environment. Therefore, it is a more appropriate technology to use in the ocean than is the 70's era scuba equipment. Can the technology of scuba catch up?

Freediver in streamline form with monofin, capable of efficient cruising at 3 knots.

Conclusion of Part 1

Ocean conditions are driving swimming speed requirements for divers that are well beyond the speeds that current scuba gear and diving techniques can deliver. Whereas most divers can achieve sustained speeds of about 1 knot and sprint at about 1.5 knots, the ocean conditions require speeds more along the lines of 3 knots sustained and 5 knots in a sprint. While the deviance is very large, it has become normalized within the diving culture, and as a result, little has been done to rectify the situation.

In the next installment, we will take a look at closing this performance gap. We will look at the physics of power, thrust and drag, and see if it is even possible to meet the requirements imposed by the ocean, or if there is no choice other than to continue trying to plan our dives around good ocean currents and conditions and then trying it to see of our planning was ‘good enough’.

About The Author: Ron Evan Smith

Ron is the CEO and Chief Engineer at Smith Aerospace Corp. where he designs, developes and markets hydrofoil based monofins for freediving and scuba diving applications. He holds an Aeronautical & Astronautical Engineering degree from the University of Washington (B.S. 1995).

Ron is an award winning aerospace engineer and inventor with more than a decade of professional experience, specializing in fluid dynamics, control systems design, simulation development and system performance prediction.

Ron forged a passion for freediving at a young age that has only intensified over the years. He has been a certified diver for over 20 years and holds several advanced diving certificates through IANTD.

Diving Performance – Beyond Drag

Part 2 of 4

By Ron Evan Smith

In part 1 of "Diving Performance – Beyond Drag", we identified that ocean conditions are driving swimming speed requirements for divers that are well beyond the speeds that current scuba gear and diving techniques can deliver. Whereas most divers can achieve sustained speeds of about 1 knot and sprint at about 1.5 knots, the ocean conditions require speeds more along the lines of 3 knots sustained and 5 knots in a sprint. We also noted that while the deviance between required and realized swimming performance is very large, it has become normalized within the diving culture, and as a result, little has been done to rectify the situation.

In this instalment of "Diving Performance – Beyond Drag" we will take a look at how this performance gap can be closed and get an idea of the technology that might make it possible.

Closing the Performance Gap

What does it take to close this swimming speed performance gap? First, it requires identifying that the problem exists and committing to doing something about it. Then you need to look at the physics. It may not be as hard to solve as you think, and in fact, I believe the solutions can be far less imposing to recreational diving logistics than the adoption of rebreather technology.

I do not expect the performance gap to be closed in one step. I'm proposing 3 knots sustained and 5 knots in a sprint as a long term goal for the scuba diving industry. Falling short of the requirement is not necessarily the end of the world. We've been operating at a severe deviance of the requirement for decades. However, new incident reports are published every year recording diver emergencies that precipitated, at least initially, from divers not being able to cope with the ocean currents and conditions that they find themselves in. People have died because of this. It is high time the diving industry start making some efforts toward solving this problem of inadequate swimming performance in the ocean.

The Physics

To simplify the discussion, let's just focus on the cruise part of the requirement. I am proposing to go from a 1 knot cruise to a 3 knots cruise, a three fold increase in speed. All things remaining equal, the power required goes up with the cube of the speed, so the increased power delivered to the water needs to increase by 3 cubed, or 27 times. Obviously, this is not going to be done physically just by kicking the fins harder, but maybe the fins can be more efficient at converting work into forward thrust.

If the average scuba fin is 12% efficient (poor, but this is about the efficiency of many popular scuba fins), simply using fins that are more efficient to close the performance gap requires fins with an efficiency factor of (12%)*27, or fins operating with efficiency of about 324%. This is not possible. In practice, achieving more than 80% is very difficult and achieving more than 100% would be creating a perpetual motion machine (it violates the laws of physics and is impossible).

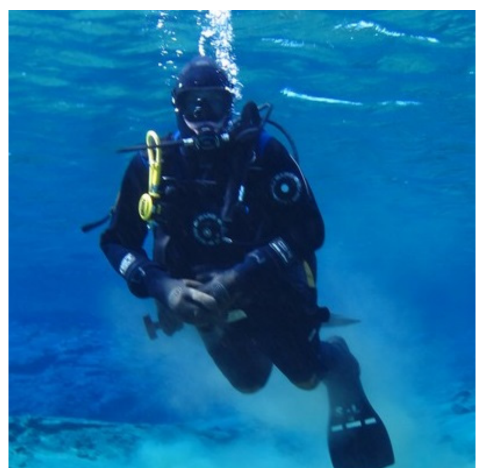
A diving fin that's over 70% thrust efficient
https://youtu.be/I4MKdazfEVM

To be realistic, let's not assume we are going to get all the way to 80%. However, if we assume we can get propulsion that is at least 70% efficient at converting body power to net forward thrust, the jump from 12% to 70% can get us from 1 knot to 1.8 knots. That's certainly a useful step in the right direction, but it closes less than half the gap to our cruise requirement.

The next place to look for more performance is to cut the drag of the diver. To get from 1.8 knots to 3 knots, a speed factor increase of 1.67, the diver's overall drag coefficient will have to be reduced to less than 22% of its typical value. That's a little more than a reduction factor of 4 in overall diver drag.

Can it be done?

In theory, Yes! A recreational scuba diver is very draggy. The difference between where we are starting from and a streamlined fusiform body shape like that of a dolphin is more than factor of 10 drag reduction. So, a factor of 4 is certainly within the realm of possible. The real question is *'how can we get there from a technology standpoint'*?



We're starting with enormous drag

From drag tests that I have done, comparing a diver wearing typical recreational scuba equipment to a freediver shows an approximate doubling of the diver's drag. So, even if we could magically make the scuba equipment disappear, we have only gotten halfway to our goal of a factor 4 drag reduction. From this, we can see that the technology will have to streamline the diver as well as streamline the scuba equipment in order to achieve the performance goal.

However, every bit helps. Better efficiency means less work and easier more relaxed diving. Even if we don't fully realize the speed requirement, the less deviant from it we operate, the more enjoyable diving will be.

This analysis shows us that a diver who can meet this proposed speed requirement will look very different from today's diver. They must be streamlined and may look more like the fusiform shape of cetaceans than a 4 limed person. They may even be using a monofin like a competitive freediver instead of the bi-fins ubiquitous with scuba diving today as it will be difficult to get 70% thrust efficiency from bi-fins. The important thing to know is that a solution for meeting the performance requirement is possible. The industry just needs to work on developing the technologies to get there.

Baby Steps

Many divers will be resistant to any change in diving technology that they are not comfortable with. Psychologically, it will be easier to accept technology that looks familiar. It is okay to reach the speed requirement over time. My goal is to get divers to realize that there should be a swimming speed goal and that we should be actively trying to move toward that goal.

It is possible to make a scuba kit that looks and functions similar to contemporary scuba equipment, but that greatly expands the swimming performance of the diver beyond the usual status quo for the industry. By making swimming performance a priority, we can adopt better performing diving fins and actively look to reduce the drag of our scuba equipment. I recently did this myself just to show an example of what can be done without making radical changes to the familiar scuba architecture. In the next installment of "Diving Performance – Beyond Drag" we will take a look at my experiment and the performance results I have been able to achieve. I think you may be impressed.

Conclusion Part 2

We have shown that it is physically possible for a scuba diver to achieve a sustained cruise speed of 3 knots. This requirement can be met if we can incorporate a diving fin system that is at least 70% efficient at converting leg energy into net forward thrust and also reduce the diver's overall drag to less than 22% of the normal drag of a recreational scuba diver. In theory, these are things that can physically be done if the technologies to achieve these goals are pursued.

In the next instalment, we will take a look at some real world hardware that attempts to partially close the performance gap to get us closer to conquering the oceans.

Diving Performance – Beyond Drag

Part 3 of 4

By Ron Evan Smith

In part 1, we identified that ocean conditions are driving swimming speed requirements for divers that are well beyond the speeds that current scuba gear and diving techniques can deliver. Whereas healthy fit divers can achieve sustained speeds of about 1 knot and sprint at about 1.5 knots, the ocean conditions require speeds more along the lines of 3 knots sustained and 5 knots in a sprint. We also noted that while the deviance between required and realized swimming performance is very large, it has become normalized within the diving culture, and as a result, little has been done to rectify the situation.

In Part 2, we were able to show that it is possible for a diver to achieve a sustained cruise speed of 3 knots. We identified that this requirement can be met if we can incorporate a diving fin system that is at least 70% efficient at converting leg energy into net forward thrust and also reduce the diver's overall drag to less than 22% of the normal drag for a recreational scuba diver. Both of these things are technically possible, but it will require developing gear that streamlines the diver as well as the scuba equipment, and the completed system may look more like the fusiform shape of a cetacean than a 4 limbed person.

Underwater Orienteering Equipment

Sadly, in part 3 we will not be showing scuba hardware that actually meets the proposed requirement. The technology for this has not been developed yet. Although the underwater orienteering equipment used in CMAS competitions is pretty close in performance, it is far from the equipment utility and versatility required of recreational diving equipment. Instead, we will take a look at some basic technology to move the swimming performance of a recreational scuba diver in the right direction and show how easy it can be to achieve some pretty impressive results without completely changing the look and feel of the traditional recreational scuba kit. Hopefully, these experiments will inspire other divers to take a close look at what they can do to improve their own swimming performance.

My Experiment

We'll look at what we can do without changing this basic diver configuration.

I recently conducted an experiment to see how much the performance gap can be closed while keeping the basic equipment layout of a contemporary scuba diver intact. At the heart of this experiment is optimizing the dive fins for swimming efficiency. I made some very efficient fiberglass and plastic composite fins that build on the technology of freediving fins and then take it a step further in evolution for propelling a scuba diver. These are technically stereo-fins as opposed to bi-fins. There are designated right and left fins that are not interchangeable. They fit the foot ergonomically and provide excellent power transfer to the fin without waste energy going into a sloppy and crudely designed foot pocket. The prototypes are called Pilot-SR1 fins, and they are proving to be very effective fins to use for scuba diving. There will be more information on the Pilot-SR1 fins provided in part 4 of "Diving Performance – Beyond Drag".

Improving the thrust efficiency of the diving fins is critical, but cutting drag is also important, so I didn't stop with the fins. I also built a prototype recreational scuba rig that incorporates some basic streamlining of the scuba equipment to better conform it to the diver's body and make it as low drag as possible while keeping the individual parts simple and portable.

I decided to use a single standard aluminum 80 scuba tank for my experiment. High pressure steel tanks are smaller and would be better, but I wanted to see what could be done with the standard tank that I would most likely end up with if I were traveling someplace exotic and remote and rented a tank to go diving. I wanted to keep it simple, only adding a conformal nosecone and a tailcone to the tank. I kept the parts relatively small and light for traveling convenience.

From the beginning, the math told me that this design had no chance of actually meeting my ultimate goal of 3 knots sustained cruise, the speed requirement that I feel should be the standard for diving in the ocean, but I thought it was a worthwhile exercise to build and test this nonetheless. Learn to walk before attempting to run, so to speak. Plus, this technology will feel more familiar to many divers and be more acceptable than something more radical.

The prototype kit consists of a backplate that incorporates an attached nosecone that covers the front end of the tank and conforms to the back of the diver's head. This closes the gap between the diver's head and the tank to minimize losses due to flow momentum exchanges in the wake zone between the head and tank. It also makes a comfortable interface for the diver's head that is much nicer than the first stage regulator that usually makes first contact with the back of the head on a standard scuba kit. I added a tailcone to the tank to recover some of the tank's profile drag. The tailcone is larger than the nosecone, but it is a hollow part that other dive gear can be packed inside of when traveling with dive gear, and the tailcone is still small enough to fit in a scuba gear bag. The kit also has 2 flat side panels that attach to close the interference gap between the diver's body and the sides of the scuba tank. Being flat, these parts also fit easily into a gear bag.

My initial prototype does not incorporate a BC. For most of the diving I do, it isn't necessary and I don't want it. However, incorporating a BC should only require exchanging the side panels for panels that are cut to accommodate a BC mini-wing. I will probably try that at some point when I get my hands on an appropriate mini-wing to use with this kit. I'm hoping I won't need to make a custom BC.

Achieved Performance: (Video of First In-Water Test: https://youtu.be/s3xaERQ8bJA)

In pool testing, I was able to cruise efficiently at sustainable speeds of about 2 knots. That is double the speeds that are typically sustainable for recreational scuba diving. Without any changes, if a diver that normally had a cruise limit of 1 knot wanted to keep up with me at 2 knots, that diver would have to increase their power output 2 cubed, or by a factor of 8 in order to keep up. This would certainly not be sustainable, if it can even be done at all.

At a speed of 2.5 knots (~2.9 mph), my regulator began to freeflow a lot and I had to limited my speed to prevent a massive waste of my air supply. I'll need to tweek the regulator to increase its cracking pressure if I want to go faster than this and find out what my actual sprint speed is with this kit. Presently, I expect it will be below 3 knots at max effort.

Experimental Kit at 2.5 knots

This kit is efficient enough that traveling at 1 knot is metabolically about equivalent to resting on the bottom and not swimming at all. It can make for some very easy and relaxed diving when in good diving conditions.

Below is a link to a video of swimming with a pod of dolphins. When resting these spinner dolphins orbit the bay at about 2 knots. The video is uncut to illustrate how I have no trouble keeping up with them while maintaining a comfortable breathing rate and workload. The shark is faster, but I could still keep up and follow it. However, I had to limit my pursuit as it was near the end of my dive and the shark was fastly heading away from my exit point.

- Diving and swimming with a pod of dolphins: https://youtu.be/I7ec3MUb67o
- Reef diving with a green sea turtle and a white tip shark: https://youtu.be/vfeJ7kiNkTU

The biggest problem presently is that the kit as shown in the video is fairly tail heavy. When I stop swimming, my feet drop. I'm only wearing the top half of a wetsuit which exaggerates the tail heavy condition of the rig. All the lead I was wearing was up around my head, but there was not much of it to get the total buoyancy right (only 3 pounds). In the future, I will need to work on solutions to get the trim balanced better for floating horizontal. Getting the trim right will make this experimental kit even more streamlined and faster in the water than what is shown in these videos.

Adopting Changes

I hope that my experiment will get scuba divers thinking and talking about swimming performance. The swimming performance of scuba divers is important to the ease and enjoyment of diving and, therefore, the popularity of diving and the health of the diving industry's economics. It is also important to the in-water safety of scuba divers. What I have done here is easily achieved and there is really no reason that the industry can't be supporting these types of designs.

Overall these changes are not prohibitively expensive to incorporate in the scope of costs associated with scuba diving. Even in low volume production, the fins that I made could probably be reproduced for prices in the range of $500 to $700. That might sound like a lot compared to traditional mass-produced scuba fins, but it is a small fraction of what most scuba divers will usually spend overall on their gear and their diving. Many scuba divers will spend over $1k on dive computers that do little to expand the capabilities of the diver or improve the comfort of their dives, whereas freedivers have been known to spend over $1k on high performance fins that make a big impact on diving performance. Which large expenditure makes more sense?

Worst case, the nosecone and tailcone for the tank can probably be reproduced for a few hundred dollars each. Low volume and prototype hardware is inherently expensive to make. In high volume production typical of mainstream diving equipment, these prices could get quite a bit better across the board and including the fins. Low volume or high volume manufacturing, either way, this technology will be far less costly and far more practical for recreational diving than getting a $4k to $7k DPV for improving diver speeds.

If enough divers demand diving gear that supports good swimming performance, we can always band together to crowdfund the development of this equipment. Are you onboard?

Conclusion Part 3

Through some basic hardware and technique changes, recreational open circuit scuba diving can achieve a significant improvement in diving performance. An efficient cruising speed of about 2 knots can be achieved without changing the basic scuba architecture. It can be done just by reducing drag with some simple fairing elements and using good diving fins and wetsuits. These performance advantages may be experienced by just about any recreational scuba diver and can make dives more fun, relaxing and safe. There is little reason for not making such changes the new normal in recreational scuba diving.

To achieve a sustained cruise speed of 3 knots will require adopting a more radical approach to streamlining and maybe even propulsion. These technologies should still be pursued, but we will get there over time in many steps of incremental developments in diving technology.

In part 4 of "Diving Performance – Beyond Drag", we will look at some things you can do now to improve your swimming performance in the ocean.

Diving Performance – Beyond Drag

Part 4 of 4

By Ron Evan Smith

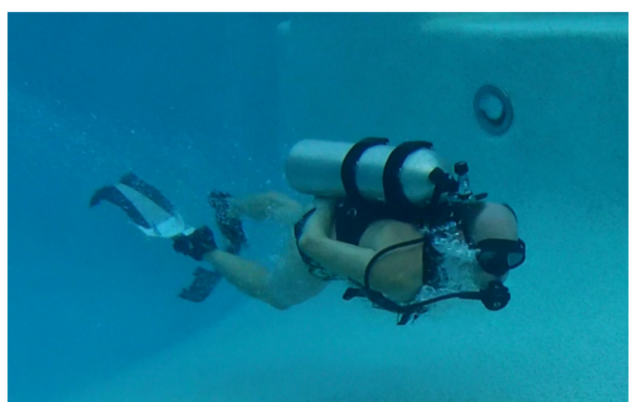
In part 1, we identified that ocean conditions are driving swimming speed requirements for divers that are well beyond the speeds that current scuba gear and diving techniques can deliver. Whereas most divers can achieve sustained speeds of about 1 knot and sprint at about 1.5 knots, the ocean conditions require speeds more along the lines of 3 knots sustained and 5 knots in a sprint. We also noted that while the deviance between required and realized swimming performance is very large, it has become normalized within the diving culture, and as a result, little has been done to rectify the situation.

In Part 2, we were able to show that it is possible for a diver to achieve a sustained cruise speed of 3 knots. We identified that this requirement can be met if we can incorporate a diving fin system that is at least 70% efficient at converting leg energy into net forward thrust and also reduce the diver's overall drag to less than 22% of the normal drag of a recreational scuba diver. Both of these things are technically possible, but it will require developing gear that streamlines the diver as well as the scuba equipment, and the completed system may look more like the fusiform shape of a cetacean than a 4 limbed person.

In part 3 we saw an example of how easy it can be to achieve some pretty impressive results without completely changing the look and feel of the traditional scuba kit. Hopefully, this experiment will inspire you to take a close look at what you can do now to improve your own swimming performance.

What You Can Do Now

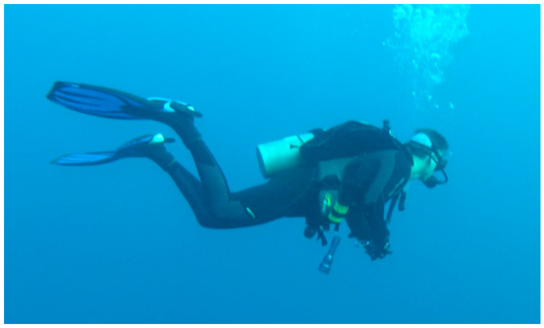
The technology to meet the 3 and 5 knot speed requirements doesn't exist for recreational sport diving. To date, no one has bothered to make it. The deviance has been normalized. However, scuba divers have the power to change this. All it requires is to denormalize the deviance. Say that it is not okay, and start demanding solutions that move in the direction of meeting the speed requirements of the oceans we want to dive in. The industry will follow the money. So, if you start buying and using swimming optimized gear, the manufacturers will follow suit and start finding ways of earning your business. They must, if they want to survive.



Good Fins and a Simple Kit Can Go a Long Way
https://youtu.be/QKuq0kHnREU

The equipment you use is important, but you can start with training and techniques. Remember that every pound of drag you can eliminate is a pound of thrust your legs don't need to generate.

- The common recommendation that you cross your arms in front of your body while diving is counterproductive to any recreational diving that involves swimming. It adds a lot of drag for no reason. If your hands are not otherwise occupied, put your hands at your side and out of the slipstream when you are swimming.
- Learn a proper kicking technique. Many divers have adopted a swimming technique that places the lower half of the leg up and near perpendicular to the swimming direction. This technique is useful for using fins with poor thrust efficiency in silting conditions as it gets the off-axis waste momentum from the fin's stroke away from the silt resting on the bottom. Efficient fins will necessarily have very little off-axis waste momentum which makes silting with them much less of an issue. If you are swimming in open water and are using efficient fins, this strange swimming technique has no benefit and kills swimming efficiency. Your legs should be straight, and there should be only limited knee bending allowed in the kick cycle. The kick amplitude should be relatively small. Large kick amplitudes will break your body's streamline position and create increased in drag.



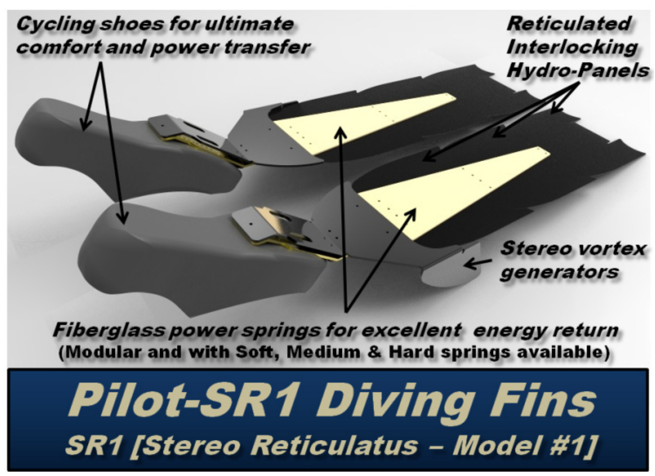
- Learn to weight yourself properly for both weight and trim. Poor weight management is one of the most common sources of unnecessary diver drag. If your feet are too heavy and pulling you out of trim, your drag profile will be increased. You may need to use a neck weight to get your trim right. Note the diver in the picture below. Her trim is off causing her to swim with her feet hanging low. Low hanging feet cause the thrust from the fins to be directed down, which will cause her to rise unless she also carries extra weight to counteract the lift. Thrust directed down can also cause silting problems in certain conditions. Too much weight overall will require inflating your BC, and an inflated BC creates more drag than an empty one. If you are not wearing more than 3 mm of neoprene, you probably don't even need a BC. One of the most bulletproof ways to learn proper weighting is to dive minimalist with no BC. This will force you to learn how to get your weight right. If you try it, you may find you really like it. I do!

Equipment Considerations:

- Instead of spending $500 on a jacket BC or a spiky "Tech" looking BC, consider diving with a basic single tank backplate, or harness. They are cheap and streamlined. Favor backplate designs that are low profile and keep the tank close to your body for reduced drag. If a BC is needed, you can still add a small narrow profile wing BC for those dives that require it. Also consider if buddy breathing is okay for your style of diving. You can potentially eliminate the octopus regulator and the BC inflator hose and the BC, along with all the drag they produce. More is not necessarily better when it comes to diving equipment. Shown here is an example of a DiveRite harness with a nice low-drag hose arrangement. The harness's D-rings are counterproductive to streamlining, but the harness itself is a good design. This setup uses a 48" hose to the second stage. Notice how all the hoses extend down from the first stage and hug the body to keep them in the flows boundary layer. This is a good hydrodynamic hose arrangement.

Good Hose Arrangement with 48" 2nd Stage

- Consider putting that $500 normally spent on a BC toward a good pair of fiberglass long blade fins with the right stiffness to match your leg strength. Good fins are not a one size fits all solution and you will need to do a little research to figure out what will work best for you. Just because a fin feels more powerful, that doesn't mean that it is more powerful. I made my Pilot-SR1 fins with three different blade stiffnesses to accommodate divers with different leg strengths. The stiffest fin feels more powerful to me than the medium stiffness. However, pool testing has confirmed that I am actually faster with the medium stiffness because I can kick it more rapidly. It is a better match for my leg strength. It also feels better to me when I'm swimming slowly. A dive buddy of mine prefers the hard fin blade. He is a cyclist and he has stronger legs. Against the stiffer fin blade, he can kick more effectively than me.
    - Swim by with Pilot-SR1 prototypes: https://youtu.be/bfCcEuCwnbQ
    - Pilot-SR1 prototype fins with standard scuba equipment: https://youtu.be/QKuq0kHnREU



- Use low profile gauges and keep them close to your body. I like using a wrist mount dive computer and a mini tank pressure gauge on a high pressure line that I keep tucked into my tank harness when I'm not looking at it.

- Dive wet. Wetsuits have much less drag than a drysuit, and they are also much cheaper (usually about 1/3 to 1/4 the cost). If you need a good warm suit, I recommend using a freediving two piece suit with a built in hood, and that has open cell neoprene against the skin. You will need to use a suit lubricant to put the suit on, but that makes it really easy to put on even if the suit is still wet from a previous dive. This style of suit design is very comfortable and very warm with basically no water transfer making it about equivalent to a basic neoprene drysuit for warmth. There are no zippers in this design to leak cold water into the suit when you move. I can dive my wetsuit for hours and still have suit lube inside the suit at the end of the dive; there is that little water transfer. (FYI: Suit lube is just hair conditioner mixed with water)
- If you must dive dry, consider using a drysuit with a stretch fit over-layer like the Fusion One, or a neoprene drysuit. To get the best swimming performance, avoid baggy dry suits like tri-lams that form a lot of creases and wrinkles unless there is a good reason that your diving requires that type of material.

If you want to do better than can be achieved with currently available gear and want to support efforts to either bring some of the technology to market from my experiment shown in part 3 of this series, or to develop gear that will make a real effort of getting that speed capability of a 3 knot cruise and a 5 knot sprint, please contact me and let me know. If there is enough interest, we can crowdfund hardware development ourselves and not rely on the likes of Aqualung, Scuba Pro, or Mares to make what we need. Sometimes, these things are better when developed by independent divers rather than large corporations anyway, and I have already shown that I can develop designs that will work. The only missing ingredient at this point is commitment.

Conclusion

In the early days, rebreathers killed a lot of their users, or maybe it is more appropriate to say that many divers managed to kill themselves with their rebreathers. While today's rebreathers are significantly safer than the early systems, rebreather diving is still generally considered to be about 10 times more dangerous than open circuit diving for conducting recreational dives. While they have a lot of performance capabilities beyond that of open circuit scuba, those capabilities come with costs, both technically and logistically. Due to the costs and complexities of rebreathers, most divers will never use them or benefit from the performance advantages a rebreather can bring to their diving.

However, basic hardware changes and some simple technique changes to recreational open circuit scuba diving can also result in a significant advancement in diving performance. These performance advantages may be experienced by just about any recreational scuba diver and can make dives more fun, relaxing and safe. There is little reason for not making such changes the new normal in recreational scuba diving.

Building scuba equipment that will make scuba divers true nektons, capable of navigating the oceans currents is also within the realm of possible. We should be striving to make these technologies a reality. A sustained cruising speed of 3 knots and sprint speeds of 5 knots is possible and within reach. To achieve this, we must be open to some new ideas and concepts that will be very different from the equipment we are accustomed to seeing. Think about what it would be like to cruise at three knots, speeds that are faster than the fastest DPV tested in the last Tahoe Benchmark. Think about easily cruising at 3 knots with no noise, no batteries and no heavy DPV either. This technology could make it easy to keep up with whale sharks, cetaceans and other nektons of the open ocean, such that we can actually swim with them for extended periods of time. The idea is simple elegance, and the changes will be disruptive to the way scuba dives are conducted and what dives are even possible to attempt.

I hope I have gotten you to think about diving differently from the way you thought about it before reading this series. I see a large disconnect between requirements for swimming performance and what has become accepted performance, and I hope that you can see that disconnect as well. These problems are solvable. Contact me if my experimental hardware is something you may want to support, or if you may be interested in supporting a crowdfunding campaign to develop equipment to attempt to reach a 3 knot cruising speed.

About The Author: Ron Evan Smith

Ron is the CEO and Chief Engineer at Smith Aerospace Corp. where he designs, developes and markets hydrofoil based monofins for freediving and scuba diving applications. He holds an Aeronautical & Astronautical Engineering degree from the University of Washington (B.S. 1995).

Ron is an award winning aerospace engineer and inventor with more than a decade of professional experience, specializing in fluid dynamics, control systems design, simulation development and system performance prediction.

Ron forged a passion for freediving at a young age that has only intensified over the years. He has been a certified diver for over 20 years and holds several advanced diving certificates through IANTD.

DRAG PERFORMANCE ADDENDUM

Since this article series was first written, I have had the time to do more in-water tests to better define the impact of equipment configuration choices. The drag of a freediver with mask, fins, wetsuit and weightbelt is the baseline for the comparisons. This diver, swimming with arms at side and looking forward in a standard recreational swimming posture, is the normalized baseline with a drag coeficient defined as 1.0.

This baseline was compared against the experimental streamlined kit from Part 3; a DiveRite Transpack 2 harness without a BC wing, configured with a 48" hose on a single regulator with the hose routed in a low drag configuration as shown in part 4 under "Equipment Considerations"; and an OMS backplate and wing (BP/Wing) with a single regulator on a standard length hose. The OMS wing is a 45 pound lift wing, banded to tuck it in as small as possible when deflated, and it was completely deflated and at neutral buoyancy for the test.

All scuba configurations used a standard AL80 scuba tank and a tank pressure gauge mounted on a high pressure hose tucked cleanly into the harness. Octopuss regulators were not used and would add additional drag beyond what was measured in these tests.

Normalizing the data to that of the freediver, here is how the drag coefficients (Cd)s breaks down:

Cd Freediver = 1.0
Cd Diver with Al80 in experimental streamlined kit = 1.15
Cd Diver with Al80 in DR Harness with no BC = 1.6
Cd Diver with Al80 in OMS BP/Wing = 2.0

As a kit and compared to the OMS BP/Wing:
Ditching the wing cuts the drag of the scuba kit by 40%.
The streamlined kit cuts the drag of the scuba kit by 85%

For the whole diver system:
Ditching the BCD wing saves 20% in total diver drag.
Using the experimental streamlined kit saves over 40% in total diver drag.

For a typical diver, adding scuba equipment doubles their drag in water. Adding more equipment will increase it further still. Contemporary scuba divers are basically swimming for two, but as has been shown here, that does not need to be the case. The lack of industry focus on streamlining scuba equipment is forcing divers to work harder underwater than necessary. Streamlining gear works and can make a really big difference in the overall diver's performance, level of relaxation and efficiency of air use. The pursuit of better hydrodynamics for scuba divers should be the next big industry priority for equipment manufacturers.

I have measured a solid 2.9 knots in sprint performance tests with this streamlined kit. This is on par with the maximum performance of high-end DPV systems, and this is accomplished without heavy and expensive batteries.

Another development: While the experimental streamline kit does not have a BC, I now know how a BC can be incorporated into the design without adding any drag to the system. I don't know if I will build this system, but I'm sure that I could do it if I wanted to. This would likely be a necessary step to move forward with commercializing this technology for recreational diving.