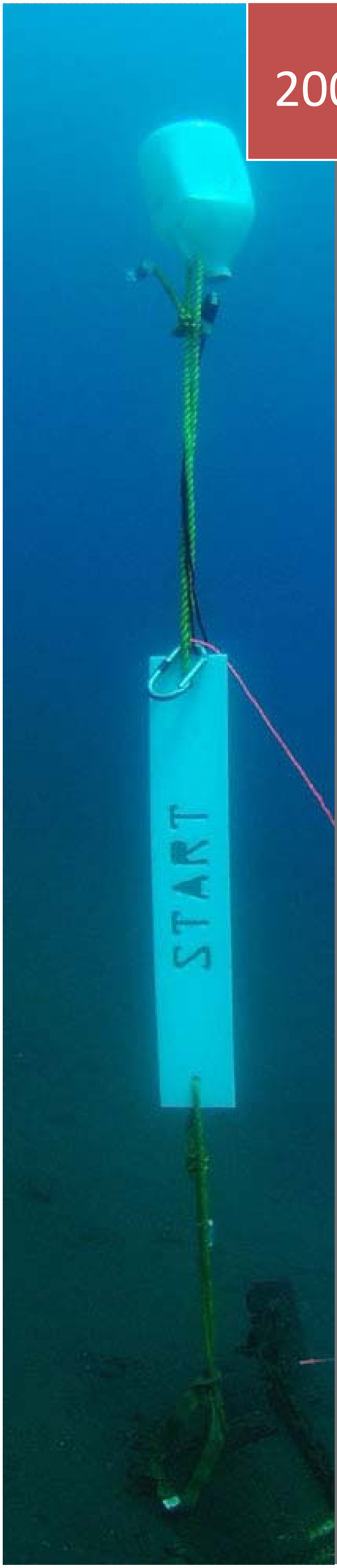

2009

The Tahoe Benchmark

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12/22/2009

The Tahoe Benchmark

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Contents

Dedicated to those who explore

and

Those who laugh with joy

Underwater

Introduction

The 2008 Tahoe Benchmark introduced the first empirical, in-the-water test of Diver Propulsion Vehicles (scooters) for the recreational diver. With over 5200 downloads, the 2008 paper[(1)] more than met its goals of giving divers the information needed to allow better dive planning and to understand differences between models more clearly.

Morning setup: as volunteers set up the shade at the race track, the test articles receive their assignment stickers.
Photo by Chuck Weber

The Tahoe Benchmark has always been intended to be a living test, with improvements made as needed, and tests included as requested. Thus the 2009 testing schedule was more ambitious, with many additional tests.

Some of the most requested data included:

- range in a technical configuration
- speed in a technical configuration

In addition, the Benchmark research team has been investigating other aspects of scooter performance, including:

- bollard thrust
- thrust vs speed
- drag change from recreational to technical configuration
- predicting speed and range change(s) from recreational to technical configuration

Thus the 2009 Benchmark not only performed the 2008 tests, but included many other new tests in a “rollup” of data gathering, all related to scooter performance.

Controversy

The 2008 Benchmark produced many results that contradicted commonly-held beliefs. Although the 2008 paper was placed through peer review, and the researchers made every attempt to make the test as egalitarian as possible, it was felt that additional efforts should be made this year to assure impartiality.

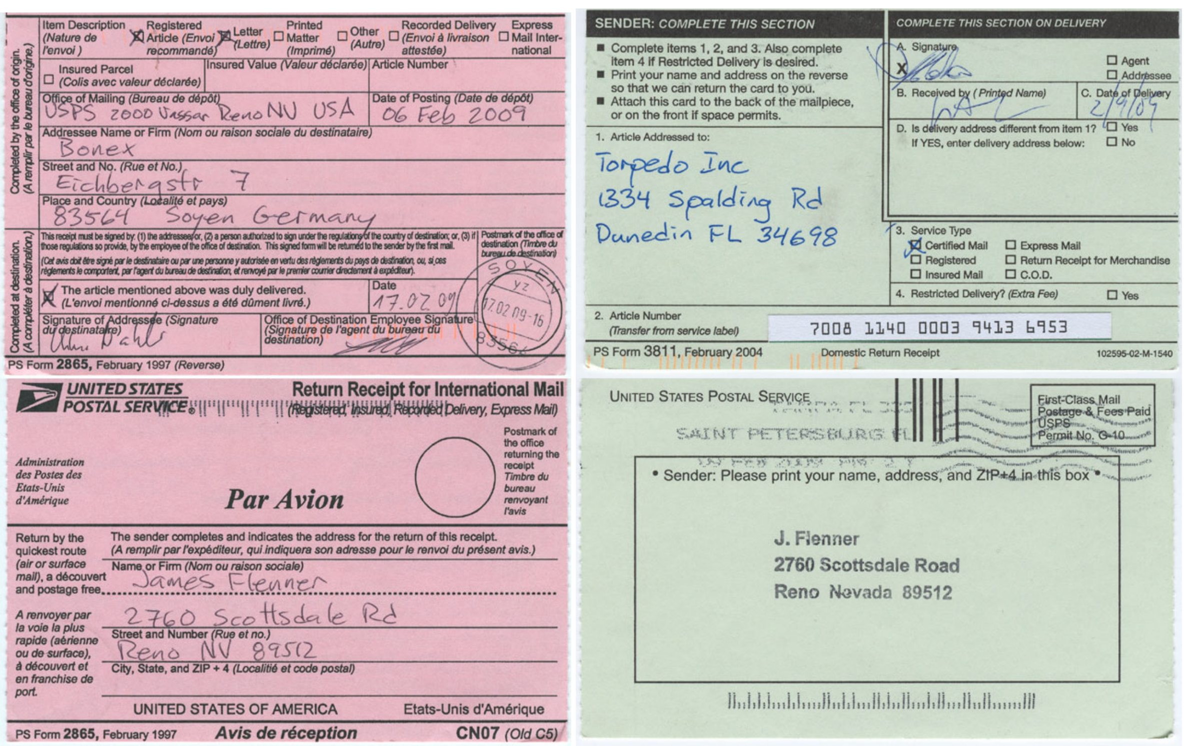
To address this, three august members of the diving community were invited to be placed as an Oversight Committee;[(2)] these impartial divers reviewed correspondence, gave direction in conduct of the Benchmark, and occasionally directed changes in the tests and test articles.

The value of the Oversight Committee was judged significant enough that any further testing will include this body.

The Scooters

In 2008, the time frame for manufacturers to provide test units was very short. This was a burden for the manufacturers, so the time frame was lengthened in 2009.

The initial requests for test articles were made to the manufacturers 6 months prior to the Benchmark. These invitations were made via registered, certified mail with delivery confirmation.



International (L) and USA (R) delivery confirmation. Some manufacturers had multiple invitations sent to accommodate mail returned as undeliverable.

Those that did not reply were contacted via telephone or via email/forums. Interestingly, manufacturer participation was not as widespread as expected, given the interest generated by the 2008 testing, and potential to have empirical data not only from their own scooters, but the competition's as well.

	Invitation Sent	Invitation Delivered	Follow-up contact	Declined participation	Agreed to participate	Manufacturer supplied	Private Ownership	Tested
Apollo	green	green	green	1				
Aquazepp	green	green	green	yellow				
Bonex	green	green	green	yellow				
Cayago	green		3					
Deep Sea Supply	green	green	green		green	green		green
Dive-Xtras	green	green	green		green	green		green
Farallon	green		green	yellow				
Gavin	green	green					yellow	green
Hollis/Oceanic	green	green	green		green		yellow	green
Jet Boots	green	green	green	yellow				
Pegasus	green	green	green		green	4		
Sea Doo	green	green	green		green		yellow	green
Stidd	green	green	green	yellow				
Submerge	green	green	green	yellow			yellow	green
Suex	green	green	green	yellow				
Torpedo	green	green	green		green	green		green
Tusa	green	green	2					

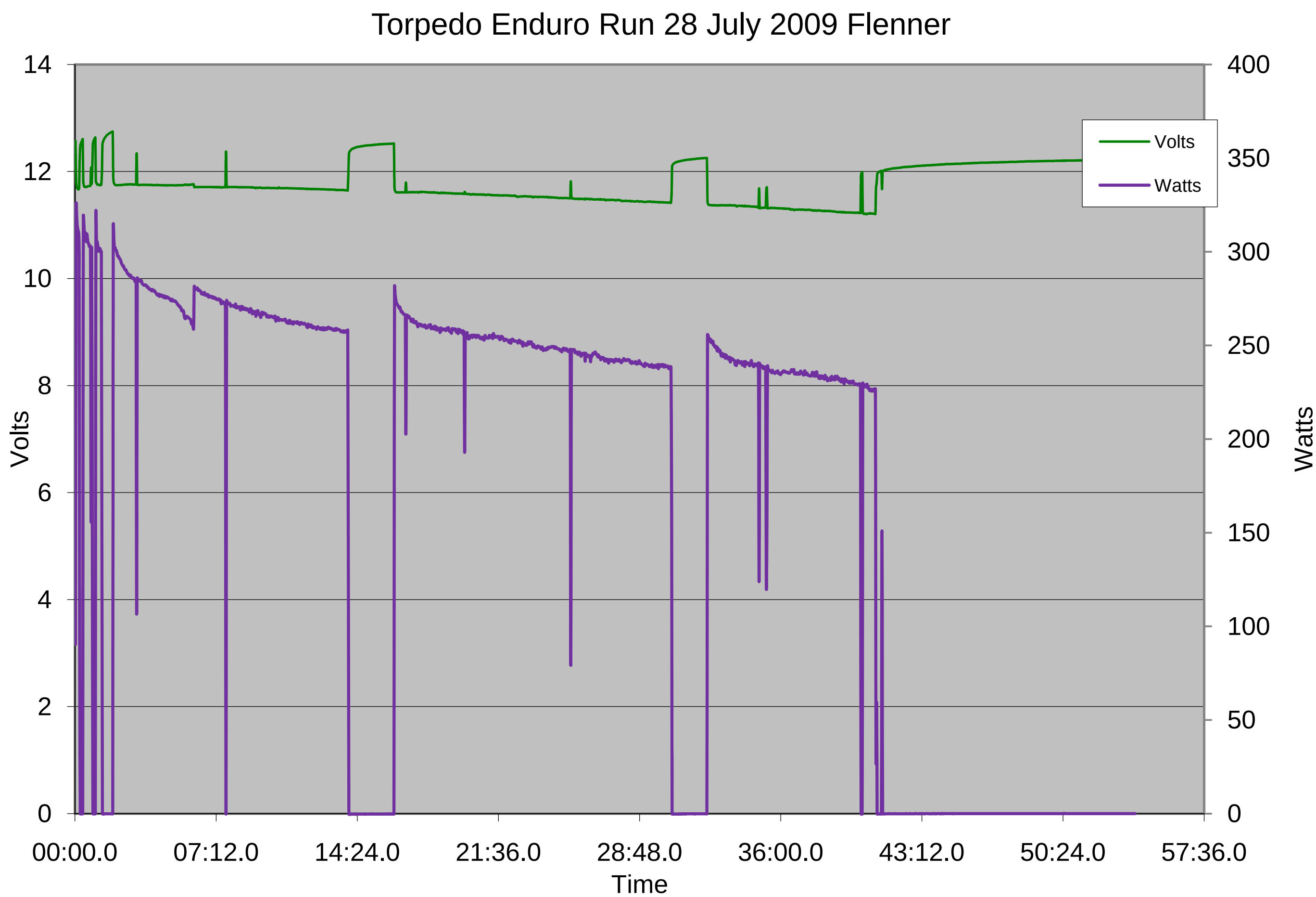
(1) Politely referred participation to US distributor, Tusa
(2) Unable to contact in person, multiple phone calls
(3) Unable to contact at listed email, address & phone
(4) Working sample not available at test date

After 4 months of soliciting manufacturers, the call was made to the diving public for scooters to loan. In fact, 5 of the test units were from private ownership.[3]

Two of the private scooters – the N-19 and Gavin Short – wait for testing in the water. The private scooters received better treatment than even our own personal scooters, being placed on rubber mats to avoid scratching, and being covered against the sun. Photo by Janet Flenner

To better serve the cave diving community, the Oversight Committee was consulted for specific models which would be most representative. Recommended were the lead acid-powered 18 Ah and 26 Ah scooters; efforts were made to place these in the test stable, and in fact, one of each were tested.

As in 2008, participating manufacturers were offered copies of all the raw data downloaded from the data recorders during testing. These files were provided to Torpedo, Deep Sea Supply, and Dive-Xtras.



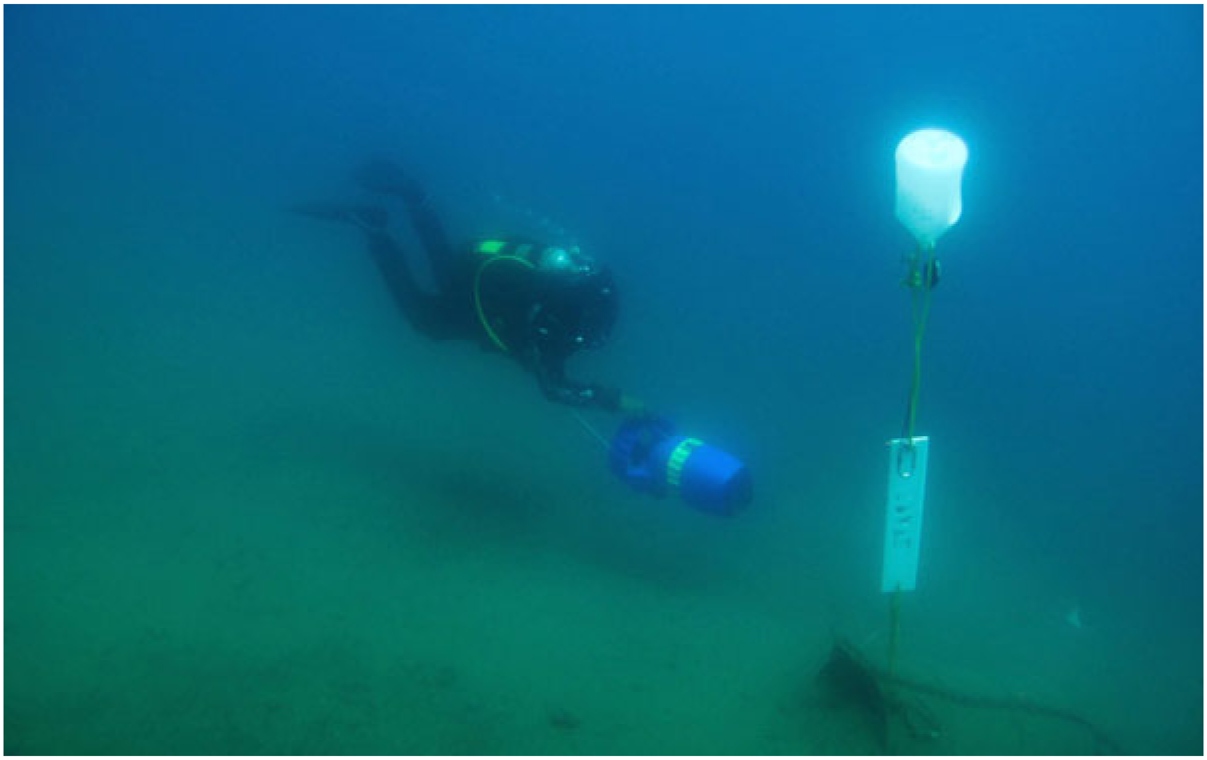
Example of data downloaded from a test dive.

The Test Track

Having been firmly surveyed, the Tahoe Benchmark dives continue to be held at what the test divers refer to as “The Race Track.” Located in Lake Tahoe, California, USA, this freshwater lake has been very well-suited to these tests.

In dye studies earlier this year, the maximum current observed at test depth (36’ fresh water) was ~2 fpm. Typical temperatures are 59˚F.

The track has been repeatedly surveyed at a length of 1325.5’; this year, Vic Erickson, one of the test divers and a professional surveyor, conducted a re-survey and found that the track measured 1325.25’, a distance variation attributed to bottom erosion.



Home again: A test diver ends a ½ mile run on the track. The start and finish are marked with polyethylene markers, and flags are placed every 100’ along the track. Photo by Chuck Weber

In the week preceding the test, during the re-survey, new flags were installed at 100’ intervals along the track. These are commonly pilfered by recreational divers. However, they are vital for accurate total distance results in the Enduro event.

It is worth noting that the track is in place all year; it is available for scooter pilots who wish to calibrate their DPV’s or get a better handle on their true performance. It can be found at what locals call “Hurricane Bay,” on the west shore of Lake Tahoe. The start marker can be found at 36’ depth, at 39˚ 07’ 16.19” N / 120˚ 09’ 38.25” W.

The Testing Categories

The testing spanned 6 days. All of the 2008 tests were retained, and several new ones added. This meant the scooters were all tested in four basic criteria:

- thrust
- maximum speed
- range at maximum speed
- range at cruise speed

In addition, those which were classified as technical scooters, were tested in a technical configuration for:

- maximum Speed
- range at maximum speed
- range at Cruise speed

In the three years of testing scooters intensively, our research team has come to believe that one of the most important characteristics of a scooter is range. However, the number most often quoted (and occasionally, disingenuously used) is speed.

The testing criteria used for ***Speed*** is two consecutive ¼ mile runs. This totals ½ mile. Speed is the average of these two runs, expressed in feet per minute. Our experience is that most divers, even experienced scooter pilots, will mistakenly believe their underwater speeds are much higher than they are in reality.

As mentioned, the next value observed is range. Range certainly is not as exciting as speed, but a scooter with range to spare is capable of generating a nice “warm fuzzy” feeling, especially when you are ½ mile off shore or otherwise extended.

Range is tested under worst-case conditions: maximum speed, with greatest battery draw, until the scooter dies.

However, most scooter pilots rarely seem to intentionally run at maximum speed, and instead, select a speed setting somewhat slower than maximum available. This behavior is seen both in recreational & technical divers. In 2008, in an attempt to elute a “cruise speed”, we interviewed a few experienced scooter pilots. A consensus speed emerged at 150 fpm.

It should be noted that our staff has access to a carefully measured track, and the ability to run with data recorders; the vast majority of scooter owners really have no such frame of reference, either of distance or time. Hence we have consistently seen divers sincerely believe their speeds are 50% to 30% faster than what they actually perform. Since the 2008 Benchmark, we have been quietly observing other divers, and their speed habits when underwater. This has shown the 150 fpm cruise speed to actually be a good match.

Because this is a beneficial data point, the 2009 Benchmark retained the ***range at cruise speed*** test, unchanged at 150 feet per minute.

A new addition is the ***bollard thrust*** test. Preliminary research had been done in early 2009 on a limited set of scooters. We took the opportunity to test all the scooters, widening our database considerably.

Scooter types & Weight

Scooters were divided into two categories, based on their depth rating:

- technical (depth rated 200' or more)
- recreational (depth rated shallower than 200')

Recreational scooters were tested for thrust, max speed, and cruise range. The technical scooters were tested for the same, and added a max speed test and cruise range test in a technical gear configuration.

One scooter, the Oceanic Mako, is classified as a recreational scooter. However, it is often found in common use by technical divers, pulling heavily loaded divers with doubles and stages, and so was included in the technical test battery for informational purposes.

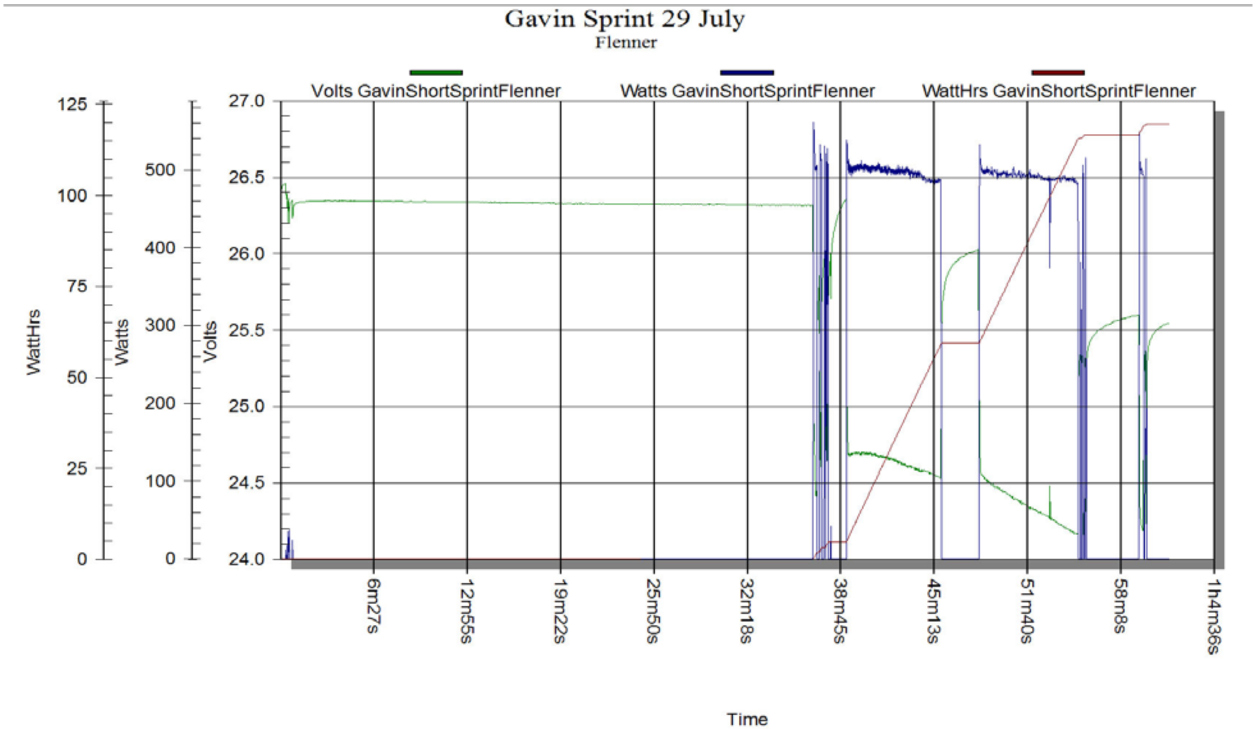
Each scooter was weighed during the test, prior to diving for the day. It was measured in a ready-to-dive configuration, weighted for neutral in fresh water, without an instrument package.

Test Conduct

The 2009 testing used a similar methodology as in 2008. This allowed the greatest variable- the divers- to be removed, along with their variance in physique, trim, body position, and equipment.

Each diver made similar runs on each scooter. Then, that diver's results were ranked as percentages of their fastest speed. At the conclusion of testing, all percentages were averaged, with results exceeding 2 sigma discarded.

Data collection was via Medusa Oracle power recorders[(4)] , which harvested volts, amps, watts, watt-hours, and time from each run. The recorders were downloaded to a laptop, then cleared, after every dive. These recorders worked flawlessly throughout the test.



An example of the raw data download.

All divers were configured with drysuits, undergarments for the 59˚F water, and a backplate/wing. Gas was provided free by Adventure Scuba of Reno, a sponsor of the Benchmark, and was provided in steel 72's. Due to the altitude and repetitive nature of the dives, all dives were done with EAN32.

A portion of the daily gas needs. Given the long hours at Lake Tahoe, logistics of transporting (and filling) cylinders became a task in itself, handled admirably by the volunteers. Photo by James Flenner

Selection of a single tank & drysuit as the “Tahoe Benchmark Standard” was primarily to allow results to be used for both recreational divers, as well as technical ones.

Prior to testing for the day, all scooters were given a full, complete overnight charge. During transport and set-up, the scooters had at least 4 hours for the batteries to cool after charging.

Two manufacturers, Dive-Xtras and Deep Sea Supply, sent representatives. They were there to support their scooters; the Benchmark staff did nothing to prep, transport, charge or maintain these test units. Before diving, the scooter was presented to staff to have the data recorder attached, then sealed by the rep and placed in the water.

Manufacturer-provided items without a rep (Torpedo) and private-owned scooters were maintained by staff following the owner’s manual.

Maximum Speed

Also known as “the Sprint” by the test divers, every scooter started a track run with this test.

The scooter was run north on the test track, at maximum pitch and, if equipped with a speed control, at maximum speed setting. After reaching the course end marker, the trigger was released. This imprints the start and end time on the data recorder[16].

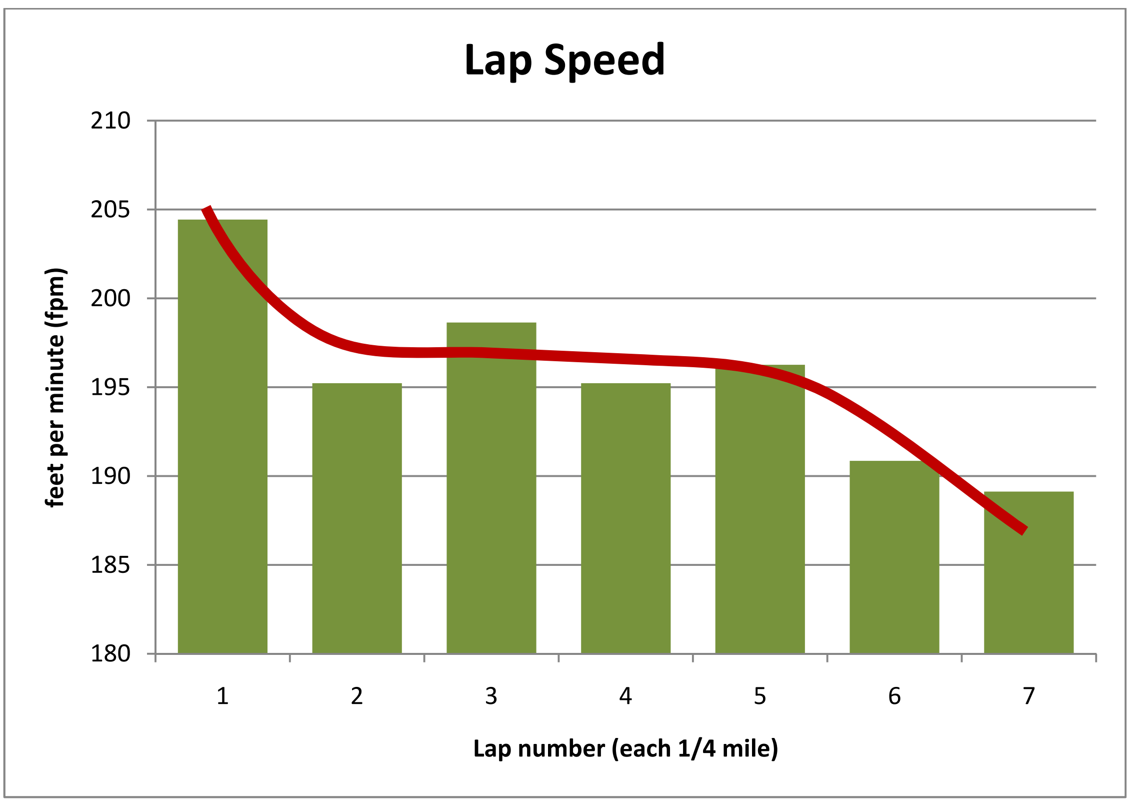
After reaching the end marker, each scooter was given a 2-minute rest. This simulates the average ratio of trigger time used by divers: 68% on the trigger[(5)]. After the 2 minutes were up, the test diver similarly repeated the speed run south.

A question that has been raised occasionally, since the publication of the 2008 paper, is how the selection of the track length and speed runs came about.

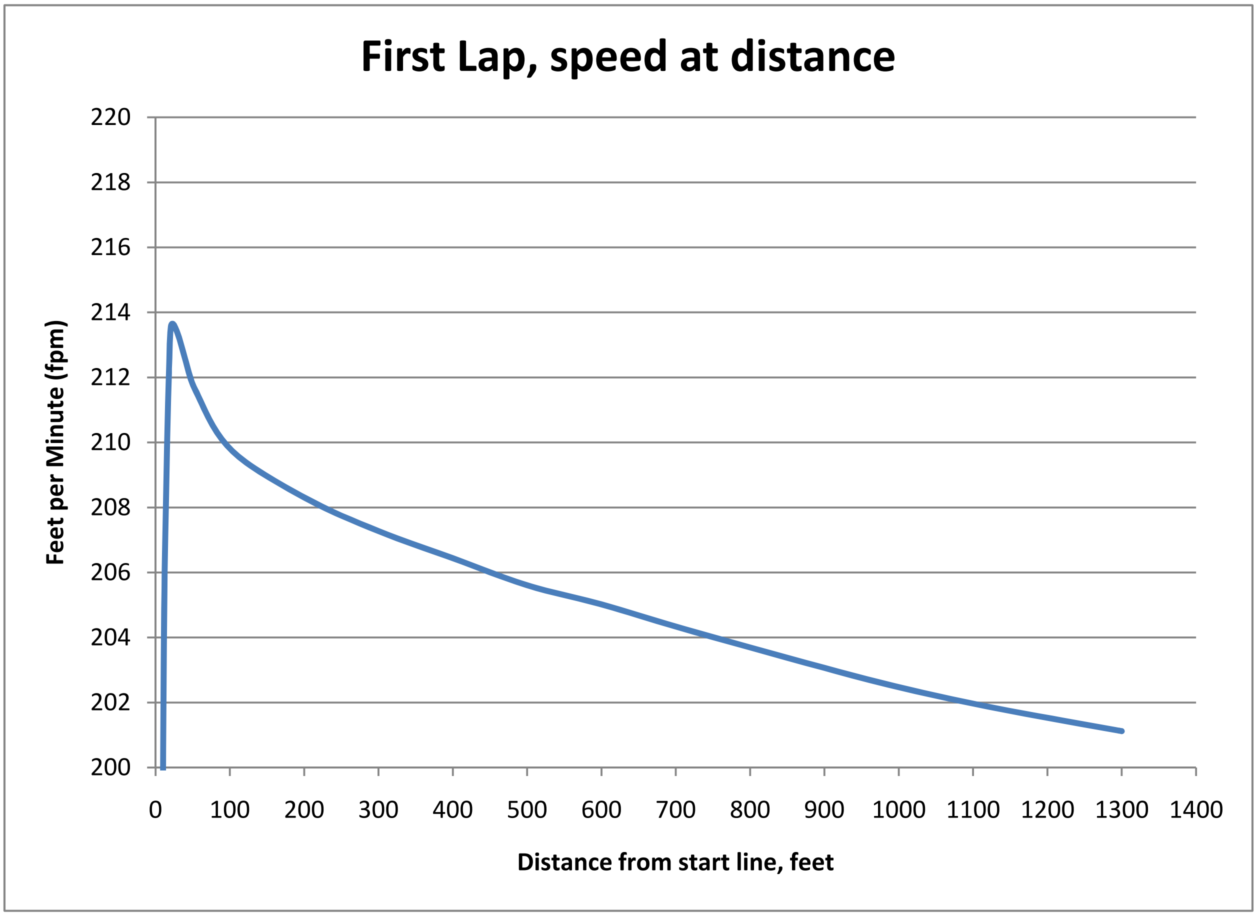
The Tahoe Benchmark began as attempts to gather data for ourselves; we wanted numbers that could translate to mission planning and performance. The selection of the test track length, ¼ mile, came from initial testing in 2007.

First attempts were over a very short measured course, initially 100', then, 300'. All we had been able to discern was very uneven, non-repeatable results. With the initial data, we were able to see trends that pointed us to two ¼ mile runs.

Our data have shown that scooters will start their first ¼ mile lap with significant speed. This is due to the higher voltage of a freshly-charged battery. This quickly attenuates to the speed which will be seen for the majority of the run; then as the battery becomes discharged, speed quickly falls.



In addition, when data were analyzed for the first, initial lap, it has been repeatedly seen that there is a dramatic initial spike of speed, as the battery voltage is high, which then declines. The short time frame of this speed peak makes it unsuitable as a determination of overall performance.



The choice, then, became: rating maximum speed at what point? If one was simply interested in bragging rights, one would select the speeds seen in the first several hundred feet.

Because these tests are intended for real-world applicability, one would choose the speed seen in the working portion of the test run. This is possible with the higher-capacity scooters, but some scooters tested have a relatively short range, and thus do not have a steady-state portion. Averaging the fast first lap with the steady state second lap has thus been chosen, and for consistency, is applied throughout the testing procedure.

Range

“The Enduro,” or, range at maximum speed, was a continuation of the maximum speed run. Here, the scooter is run at maximum speed (with a 2-minute pause at the end of every quarter mile), letting the laps pile up, until the scooter died.

Divers were changed out every mile.

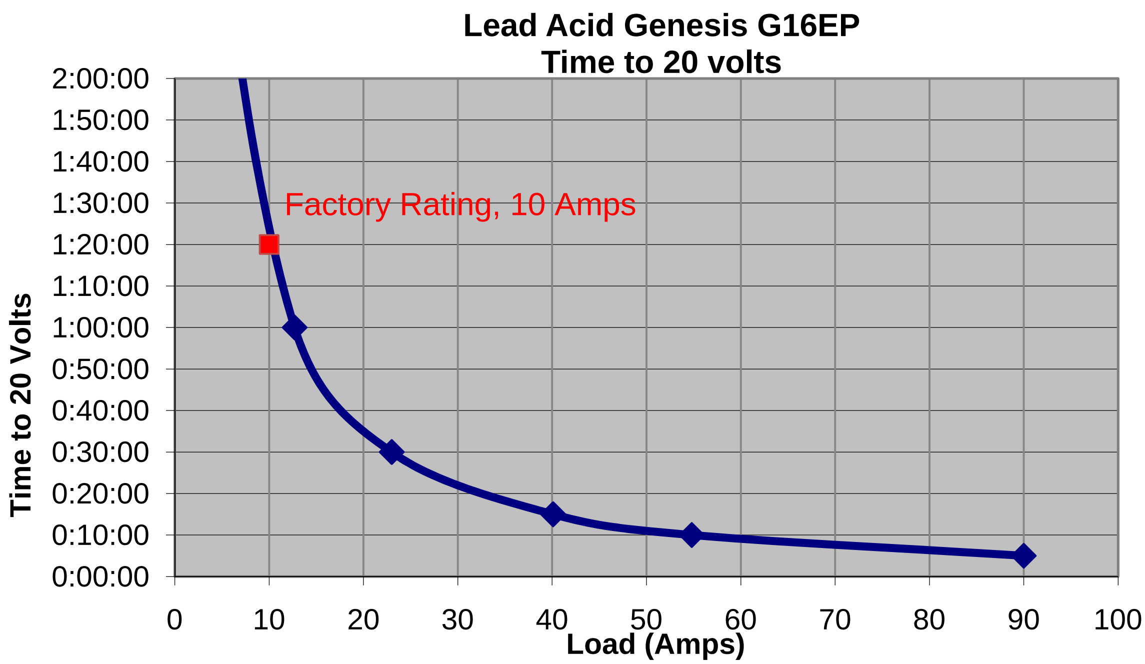
Dead was defined as the first low-voltage cutout, or when a scooter slowed to 100 fpm (technical) or 50 fpm (recreational). Last year, the dead point was chosen at 67 fpm; in analysis of the data, we observed that this permitted battery voltages to dip dangerously low, so we adjusted the endpoint speed.

After the 2008 Benchmark, considerable controversy was stirred by the (relatively) low performance, in the enduro, by lead-acid powered scooters. This year we were especially careful to generate good data for this type, and performed additional tests.

Range for a scooter is not simply the capacity of the battery, usually expressed in amp-hours or watt-hours. The draw rate, or amps that is being demanded of the battery, has significant influence.

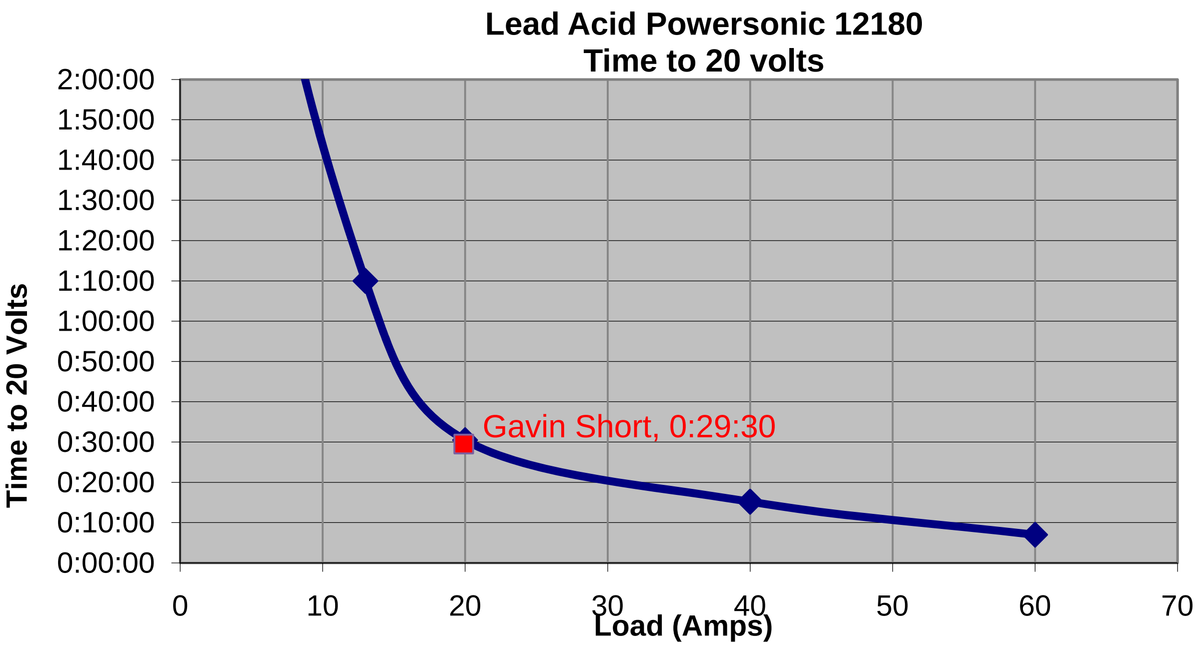
Typical lead-acid batteries are tested by the manufacturer at a low draw rate. For example, an excellent lead-acid battery, the Genesis G16EP, is rated by the manufacturer to produce 16 amp-hours at a load of 10 amps.

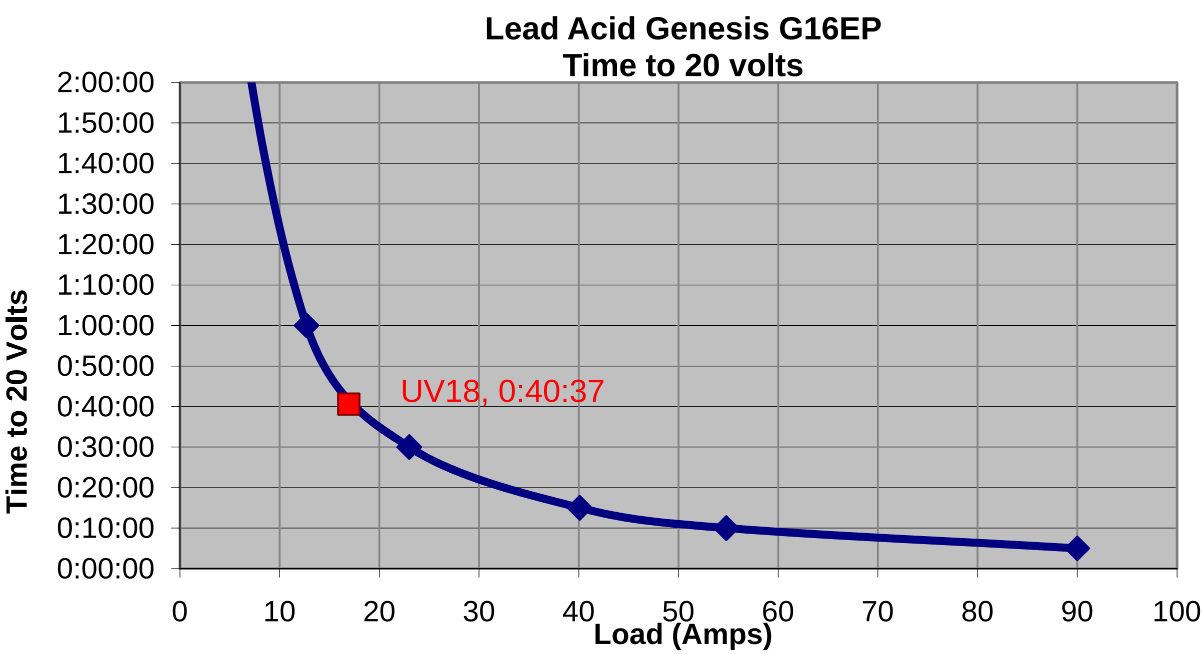
As the draw rate increases, the amount of electricity that can be delivered decreases significantly. The graph below is taken from published specifications(6) by EnerSys, the maker of the Genesis G16EP:



As can be seen, as load increases, delivery decreases non-linearly. Thus Short bodies, in the enduro test, will deliver significantly less than the factory rating for the battery.

When last year's performance by the UV-18, and this year's performance by the Gavin Short[7] are plotted on the factory discharge curves, we see that their performance is as would be expected:

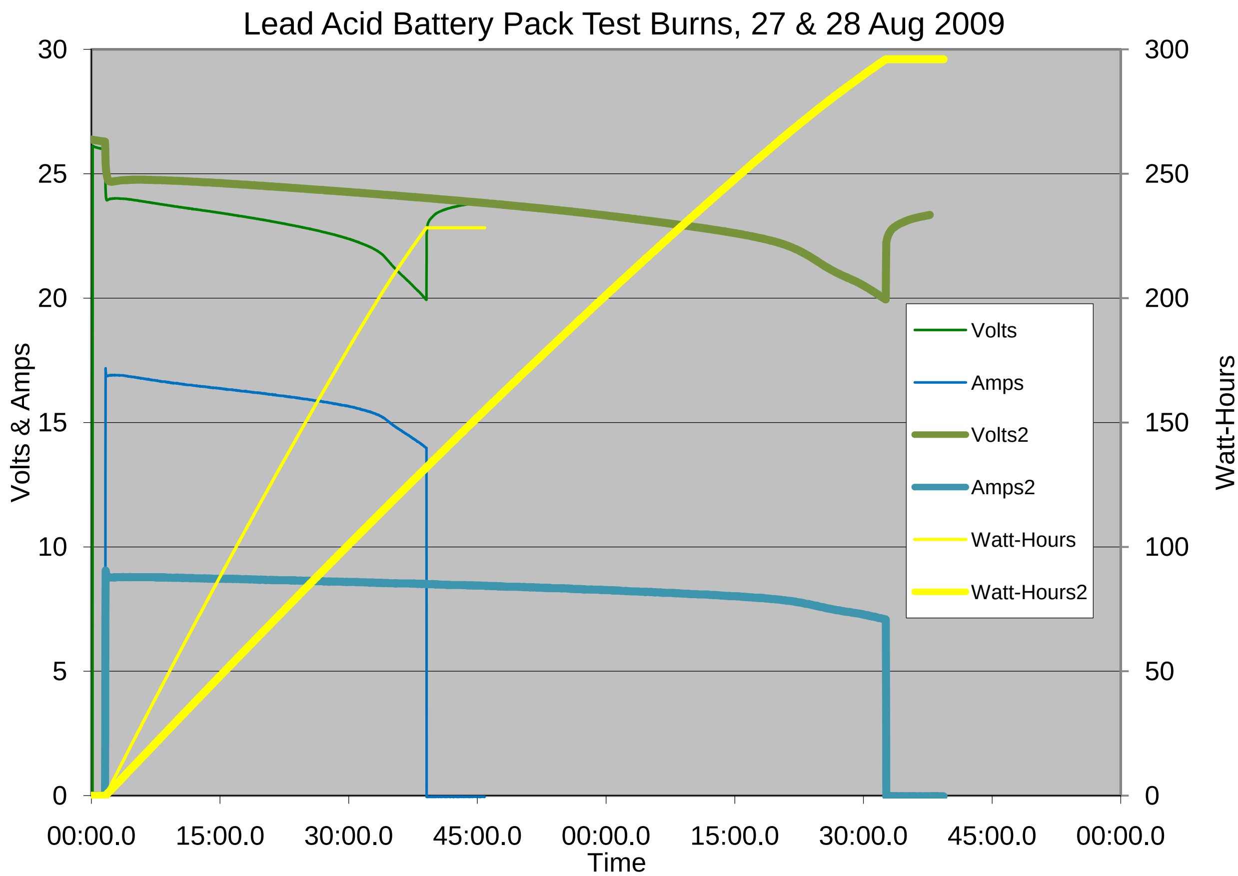




Draw rate has implications beyond just the short body scooters, however; long body lead-acid scooters use the draw rate effect to their advantage. For example, this year we tested a long body lead-acid scooter, and found that unlike the short bodies, the two 26 Ah batteries in the long body delivered their full rated capacity. This is because each battery experiences half the draw.

The UV-26 test article. Because the draw was distributed over two battery packs, this model extracted the rated capacity from its battery packs. Photo by Chuck Weber

To confirm this, we instrumented a battery pack and burn-tested it at the rate that would be expected for both high and low draw rates.



Here we can see that when the pack was discharged at a 16 amp rate, that it produced 228 watt-hours over 38 minutes.

When the same pack was discharged using an 8 amp rate, it produced 296 watt-hours over an hour and 32 minutes, a considerable improvement in output.

Cruise Speed

Cruise speed, as previously mentioned, was set at 150 fpm. After a scooter had been put through a max speed test, the test diver would return to the start line, where a stopwatch was hung. Then, the scooter was adjusted to run at 150 fpm (2 minutes over 300'). The scooter was then run for ½ mile with a 2-minute pause at the north end marker.

Running by the clock: Stopwatch in hand, test diver Vic Erickson begins calibrating a scooter for the cruise speed test. Photo by Chuck Weber

Technical Configuration

Those scooters determined to be "technical" also were tested for maximum speed and cruise speed in a technical gear configuration.

The technical configuration was chosen to be a midpoint of sorts. Adding multiple stage bottles increases drag dramatically, and not all divers use this configuration.

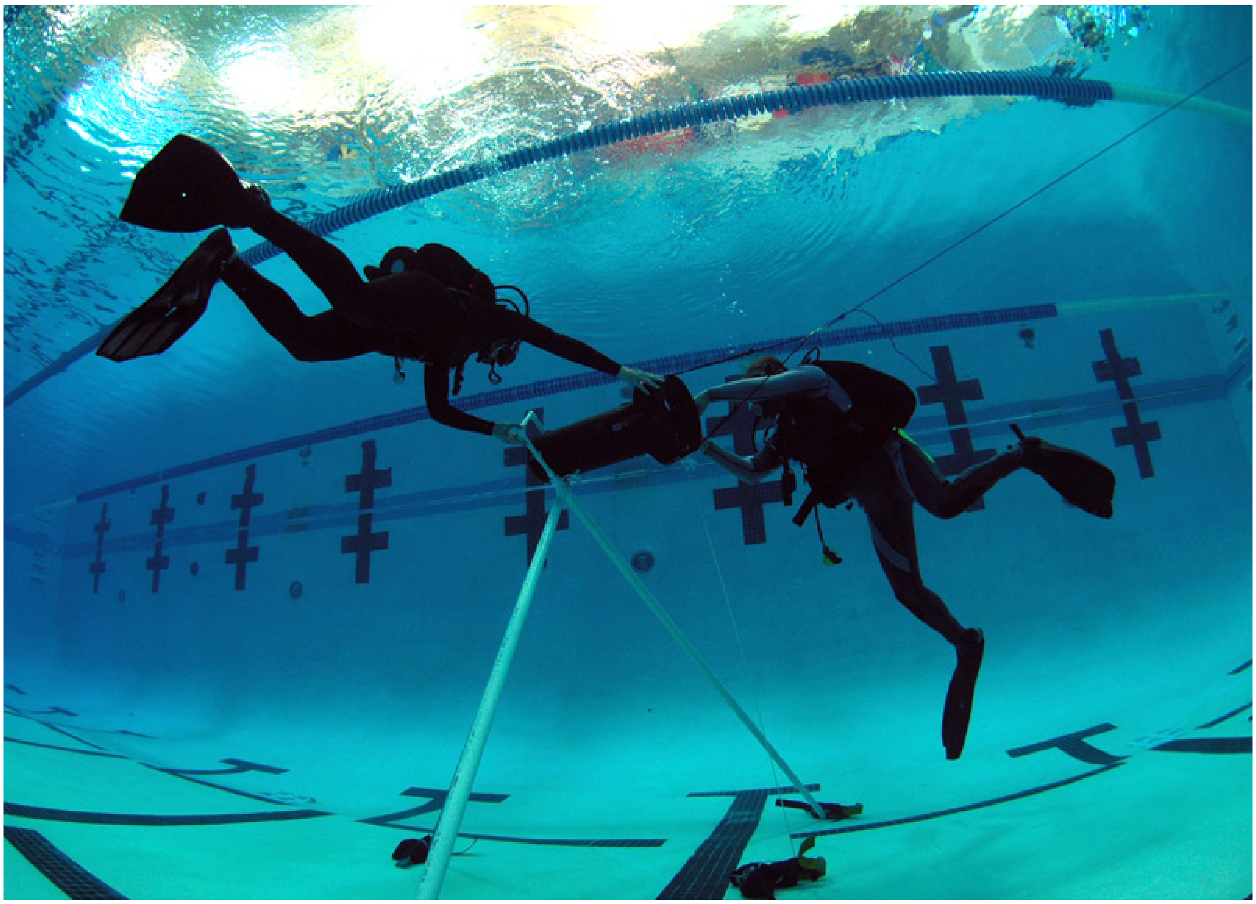
The configuration chosen was:

- open circuit steel doubles
- drysuit
- aluminum Luxfer 80 stage, EAN32, 3000 psi

The selection of stage cylinder was done after preliminary testing. A full stage was found to “hang”, whereas a half full stage would float and tuck into the armpit. The hanging cylinder was found to be the lowest-drag configuration of the two; simply having a floating stage would increase the diver’s drag by an additional 12%.

Thrust

Also a new addition to the Tahoe Benchmark, we added thrust testing of all the test units in 2009. Thrust testing is detailed in the 2009 publication, DPV Bollard Pull Test.[8]

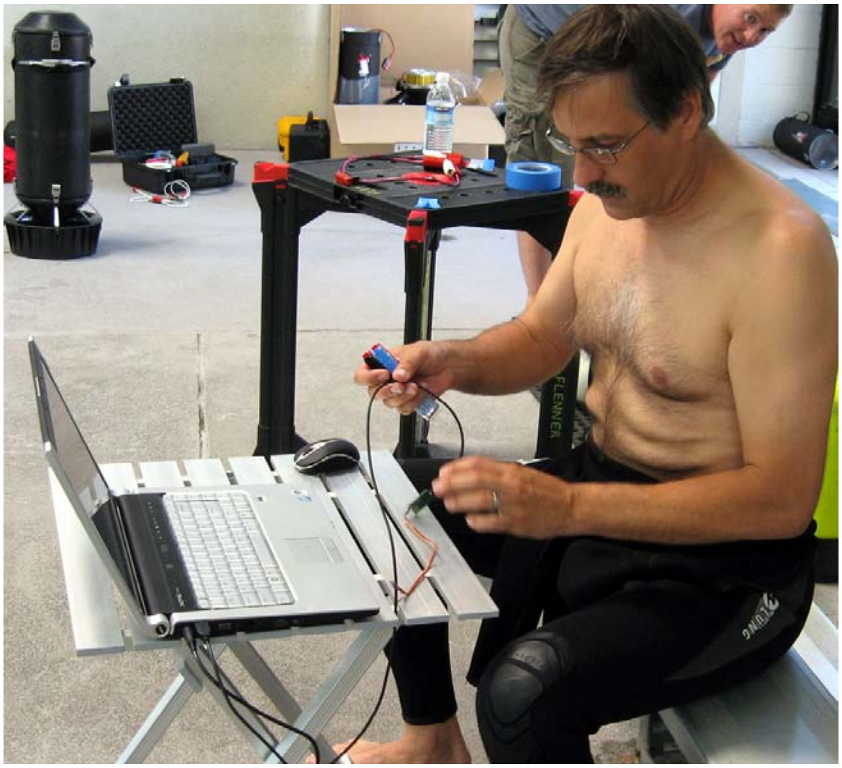


Bollard thrust: An N-19 is loaded into the test stand during thrust testing. Photo by Chuck Weber

Thrust testing was conducted in the immaculately maintained Carson City Aquatic Facility pool[9]. A restraint frame was placed in the pool, carefully placed to avoid recirculation issues that would skew the thrust results; then, the test divers would place the scooters in the water. The scooters were then run at maximum thrust while attached to a load cell. The scooters were run for 3 minutes, with thrust data gathered from the last 2 minutes.

The Test Week

The staff, volunteers, test divers and participating manufacturers met for a mixer and briefing Sunday, 26 July 2009. Here we discussed scheduling and testing procedures, and clarified responsibilities.



Testing began in earnest on Monday, 27 July 2009, as thrust testing was conducted at the pool. Testing began at 10:00 AM and ended at 3:00 PM

Testing at the Lake Tahoe track was Tuesday, Wednesday and Thursday for the single-tank configuration, and Friday for the technical configuration. Typical days began with set-up and briefing at 9:00 AM, with the last diver emerging from the water around 6:00 PM.

One problem we had in 2008 was a lack of support personnel. We didn't even have any food. This year, with the help of the Northern Nevada Dive Club, 14 volunteers assisted with carrying gear to and from the water, tank fills and transport, and <gasp> food. There was no food to be had in 2008; this year, thanks to the generous donation of time and food by John and Mary Ryczkowski, we actually had fresh-cooked food for the week.

No starving this year: John Ryczkowski (R), serves up lunch. Photo by Chuck Weber.

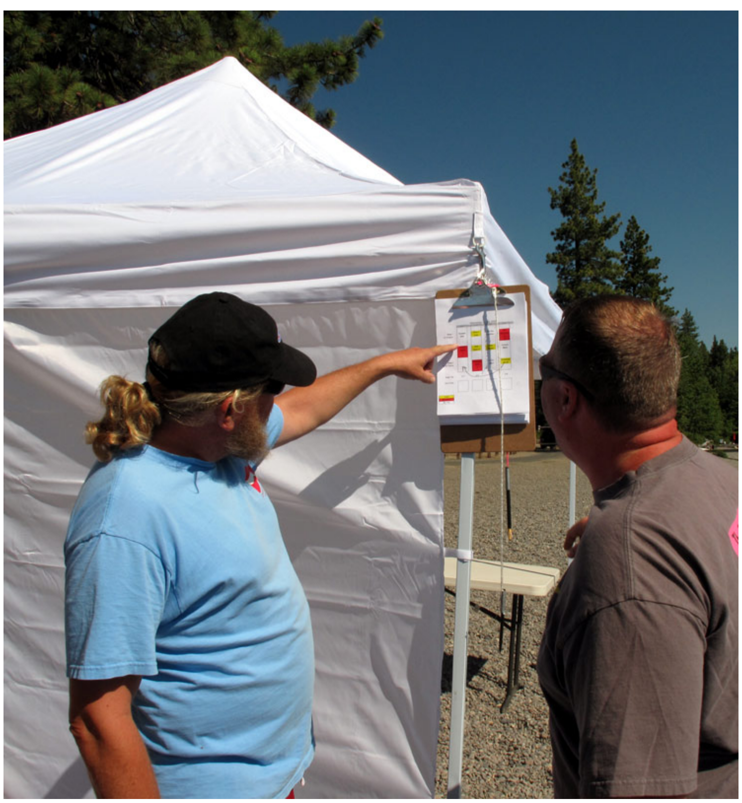
Because the 2009 schedule was twice as task-filled as the previous year, we would have been unable to complete it this year without the selfless efforts of our volunteers.

Another benefit was that the test divers were able to get into the water fresh, and concentrate on their job of producing consistent results.

The test divers were chosen for scootering experience, with a minimum of 200 scooter dives. As originally selected, the test divers were: Vic Erickson, returning from 2008; Harry Wong, from the Bay Area; and Claudette Dorsey, from Hermosa Beach. Harry Wong was unable to attend, so the alternate, James Flenner (also from the 2008 test) stepped in.

Contrary to common perception, the scooter pilots were not directed to simply “go fast.” Instead, they were directed to be clean, but more importantly, consistent – ride every scooter in the same fashion, with identical trim & body position.

Also, in this year's events, there was an outside participant in the form of John Nellis. John had made a homebuilt scooter with several new features, and had requested the use of the testing venue. He fit in his scooter during slack time periods in the thrust tests, and was his own test diver during the race track testing. Not being a manufacturer, this was felt to be in the spirit of the Tahoe Benchmark, With his own data recorders and other engineering equipment, John fit right in.



A concern was that scooters would receive uneven rest periods. For example, the enduro had diver changes every mile; having a diver waiting at the start line was critical. To assure that diver changes were well coordinated, a daily schedule[10] was published, that included diver changes and scooter order throughout the day. This also balanced surface intervals. The schedule was posted, and a daily "master timekeeper" was appointed that would time the diver exchanges, and keep the test flowing.

The Results

The following table details the results[17] obtained from the 2009 testing. The reader is strongly cautioned, however, to peruse the ***Events of Note*** section that follows.

		Tahoe Standard (Single Cylinder)						Tahoe Tech (Doubles + Stage)				
		Max Speed			Cruise			Max Speed		Cruise		
Make	Model	fpm	Watts	Range	Watts	Range	Thrust	fpm	Range	Watts	Range	Weight
Dive-X	Cuda 650	266	928	1.7	190	4.8	71	238	1.5	253	3.7	53.8
Dive-X	Sierra 16	179	454	1.2	242	1.8	35	160	1.1	330	1.3	37.4
DSS	LithiumCuda	258	1005	1.6	185	4.9	76	230	1.3	277	3.5	50
DSS	MiniCuda	268	1082	1.8	219	5.6	78	239	1.7	322	3.7	42.4
DSS	SuperSierra	182	514	5.0	250	7.5	35	163	3.9	304	6.0	37.6
Gavin	Short	192	500	1.1	342	1.2	39	172	1.0	376	1.1	70.2
Oceanic	Mako	144	222	1.9	221	1.9	25	129	1.5			54.8
SeaDoo	GTI	97		0.5			8					19.8
Submerge	N19	203	465	1.9	305	2.2	43	182	1.7	351	2.0	49.2
Submerge	UV26 (rebuilt)	154	364	2.8	360	3.0	28	137	2.4			93.8
Torpedo	2000	104	265	0.9			8					39.2

Events of note

Gavin Short

There were 3 Gavins available for us to test. We thrust tested all 3 and used the strongest one for the remainder of the testing. It's worth noting that the other two showed similar performance to the Gavin tested last year, which was criticized as being a slow example.

Our experience with the type is one of great variability (between units) in performance, which points to the need for periodic maintenance and tuning for best speed and efficiency.

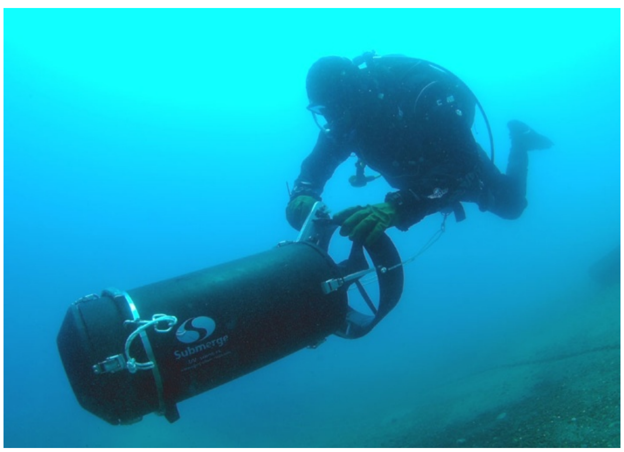
Deep Sea Supply Lithium Cuda Battery

This aftermarket battery for the Cuda was very new to the market, and with a large capacity, the test team prepared for a lot of miles when the unit ran the enduro. However, at roughly half the predicted range, the scooter died. That range is reported here.

The enduro is the most demanding test we run; we would routinely open the scooters, of all makes, to find the wiring hot to the touch.

In this case, when the manufacturer analyzed the data, it was traced to a thermal switch in the battery controller, which tripped early. Deep Sea Supply has since told us[11] that the controller's thermal switch has been replaced. Here, the testing process has made for a better product.

Submerge UV-26 (rebuilt)



The test article was donated from a private owner[3]. There were no other UV-26's offered. It's worth pointing out that the owner takes impeccable care of his gear, so we were pleased to have this example.

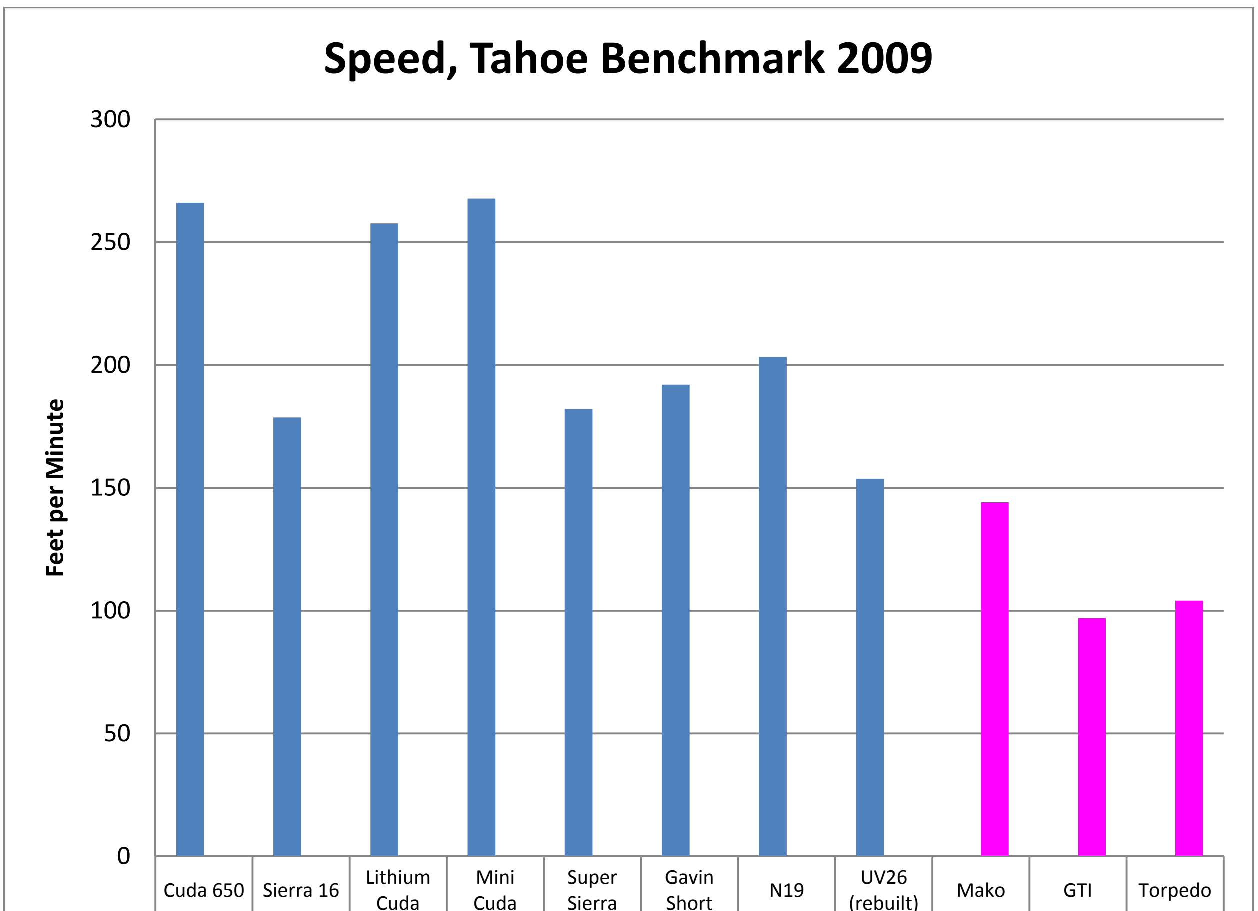
During the initial testing, all the test divers noted that it felt slower than expected – in fact, it appeared similar to the unused Gavins in performance. However, there appeared to be nothing mechanically or electrically unsound, so we elected to keep it in the testing process. That performance is reported here.

In inquiries after the testing, it has come to light that the scooter has had two prior owners, and been rebuilt once, including replacement of the motor with an Oceanic piece. The owner has confirmed it has a Submerge back end, approx. 7 years old. Although not representative of a new manufacture UV-26, this points to the performance variation that can be encountered in the used scooter market.

Maximum Speed Results

Using the Tahoe Benchmark standard configuration (drysuit, single steel 72, BP/W), all of the scooters were tested for speed over ½ mile, with a 2-minute pause at ¼ mile.

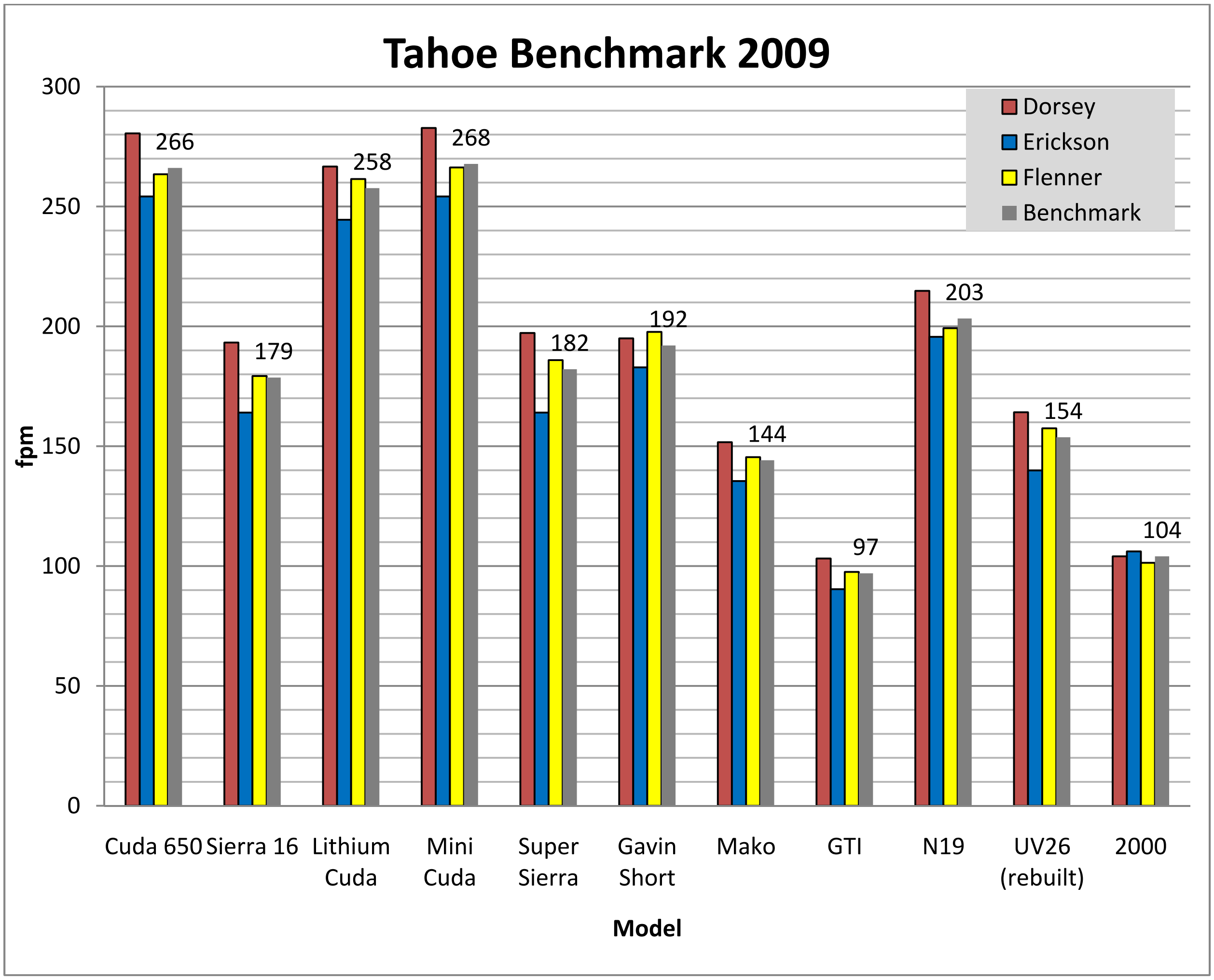
Tahoe Benchmark standard configuration.
Photo by Chuck Weber



	Cuda 650	Sierra 16	Lithium Cuda	Mini Cuda	Super Sierra	Gavin Short	N19	UV26 (rebuilt)	Mako	GTI	Torpedo
Tech	266	179	258	268	182	192	203	154			
Rec									144	97	104

To place the speeds in perspective, each 50 fpm increase represents a significant speed step, both in perception, and performance requirements.

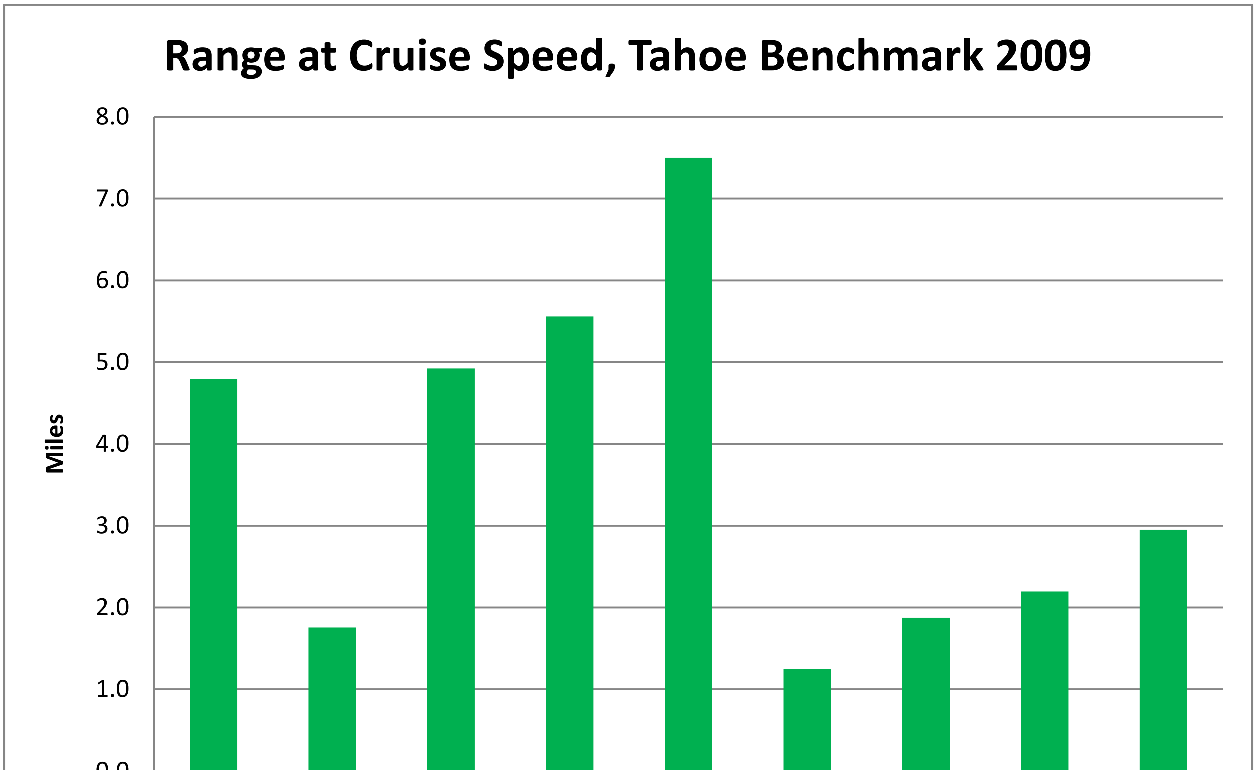
As part of QC for the test, we looked at all the divers' performance scores, checking for abnormally fast (or slow) times.



Overall speed results.

Range at Cruise

As last year, this was a test that everyone felt was important; it is one of the few where it is not only applicable in the real world, but, since all the scooters were tested at the same speed, direct comparisons are valid.



	Cuda 650	Sierra 16	Lithium Cuda	Mini Cuda	Super Sierra	Gavin Short	Mako	N19	UV26 (rebuilt)
Cruise	4.8	1.8	4.9	5.6	7.5	1.2	1.9	2.2	3.0

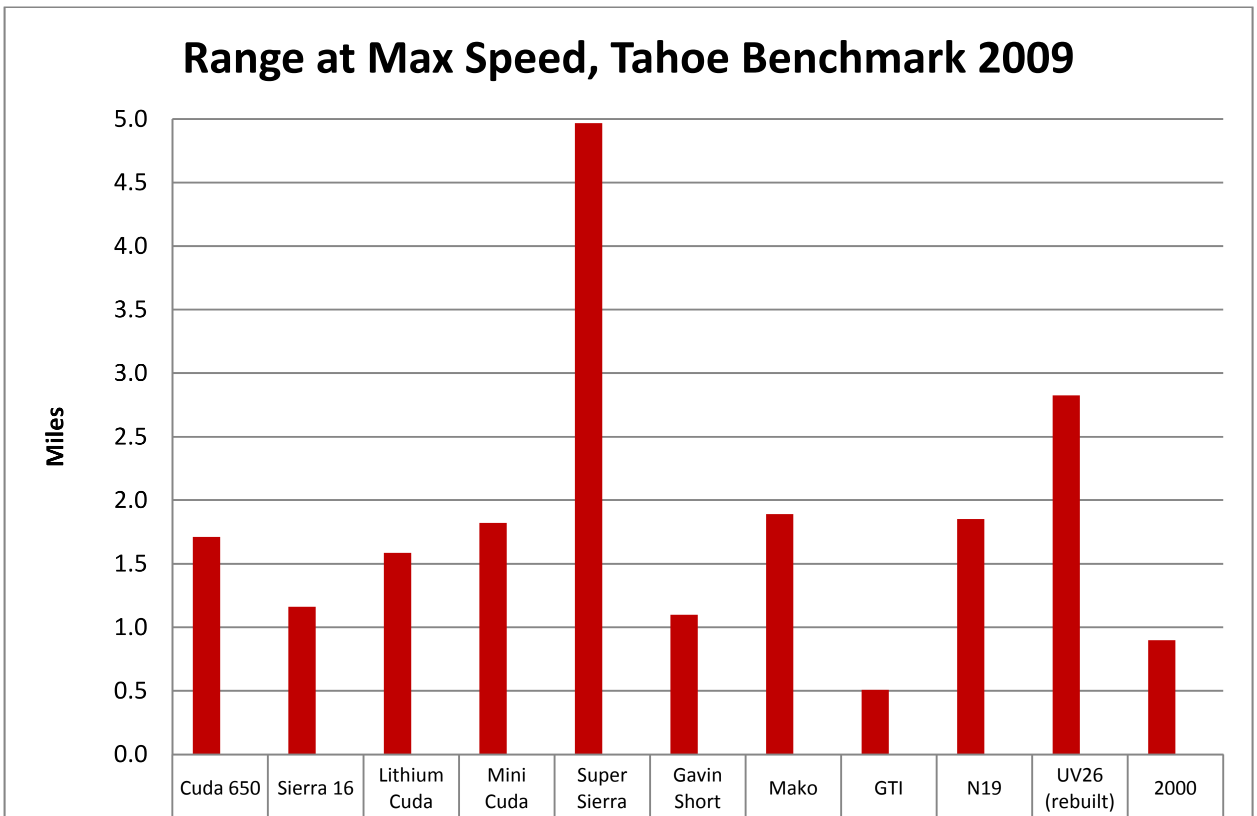
Each scooter was run ½ mile (including the 2 minute pause at ¼ mile) after being calibrated to run at 150 fpm. For the single-speed models, prop pitch was used to set speed; those with variable-speed electronic control used the electronics to set speed.

From the data recorders, the power consumption in watts was extracted. The battery's power capacity was found in the enduro, admittedly, the worst-case for capacity. These were combined to yield the cruise range. In the 2008 test, this methodology was verified by running a scooter until dead at cruise speed. The actual matched the theoretical within 6%.

Range at Maximum Speed

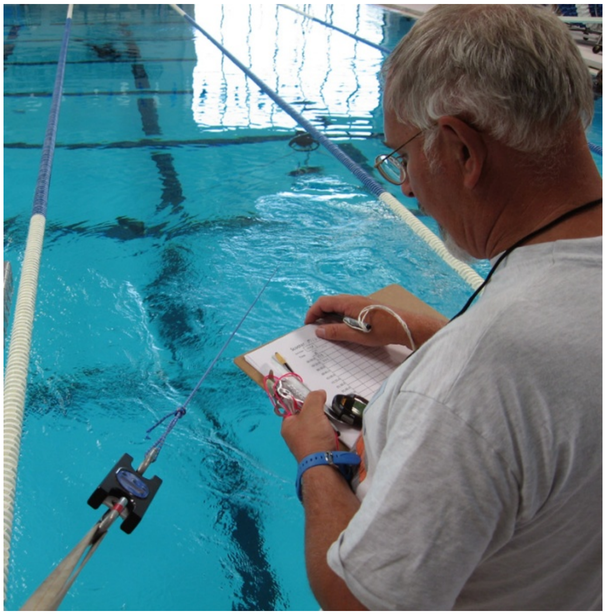
This was the enduro, the hardest test for the scooters, as they ran the track at maximum draw and drained their batteries the fastest.

Here, a scooter's speed works against it; power requirements vary as the cube of speed, so a scooter with twice the speed will have 8 times the draw in watts. Thus slower scooters will have greater range. However, the data are useful and are presented here for planning purposes.



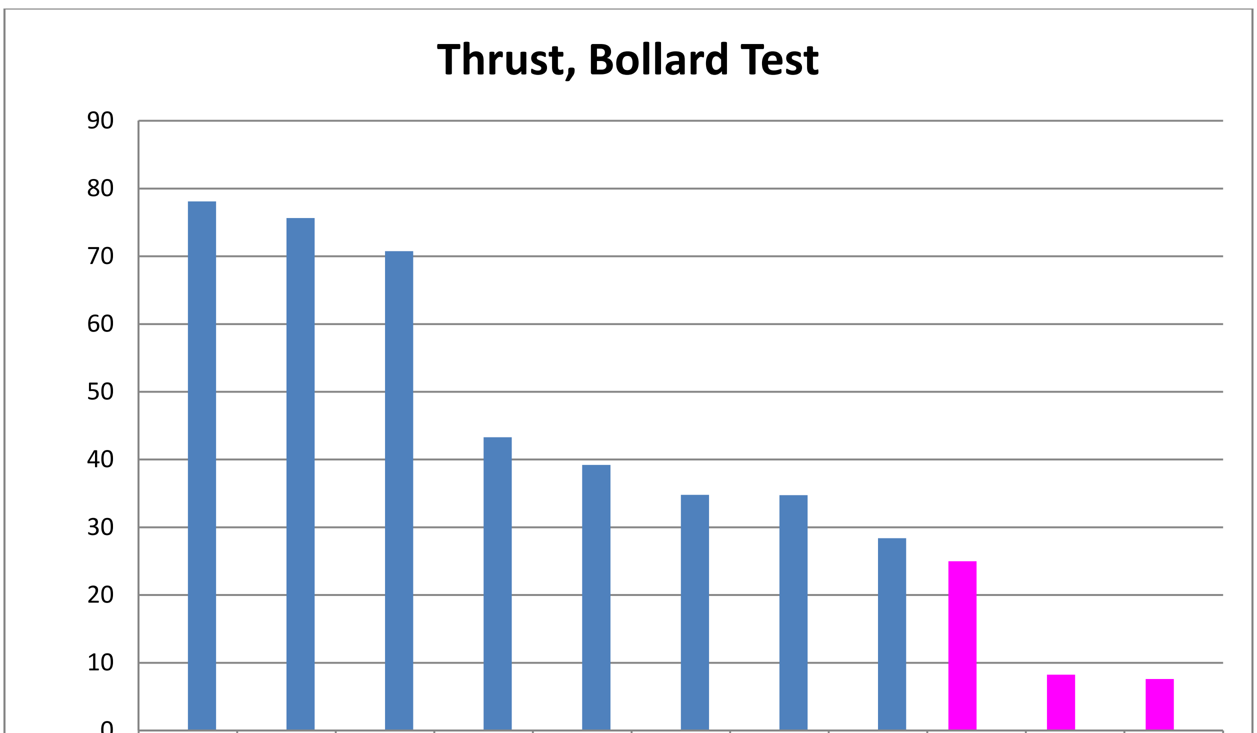
	Cuda 650	Sierra 16	Lithium Cuda	Mini Cuda	Super Sierra	Gavin Short	Mako	GTI	N19	UV26 (rebuilt)	2000
MaxSpeed	1.7	1.2	1.6	1.8	5.0	1.1	1.9	0.5	1.9	2.8	0.9
Speed	266	179	258	268	182	192	144	97	203	154	104

Thrust



New for 2009, this observes the static bollard thrust of each scooter in controlled conditions. Using the methodology outlined in DPV Bollard Pull Test,[8] a test stand were placed in a large test tank, and data was gathered via a load cell.

Scooters were configured, then run at maximum thrust. The first minute of run is unrecorded, to allow some battery designs to burn off their high-voltage initial peak. Then, two minutes of data is recorded.



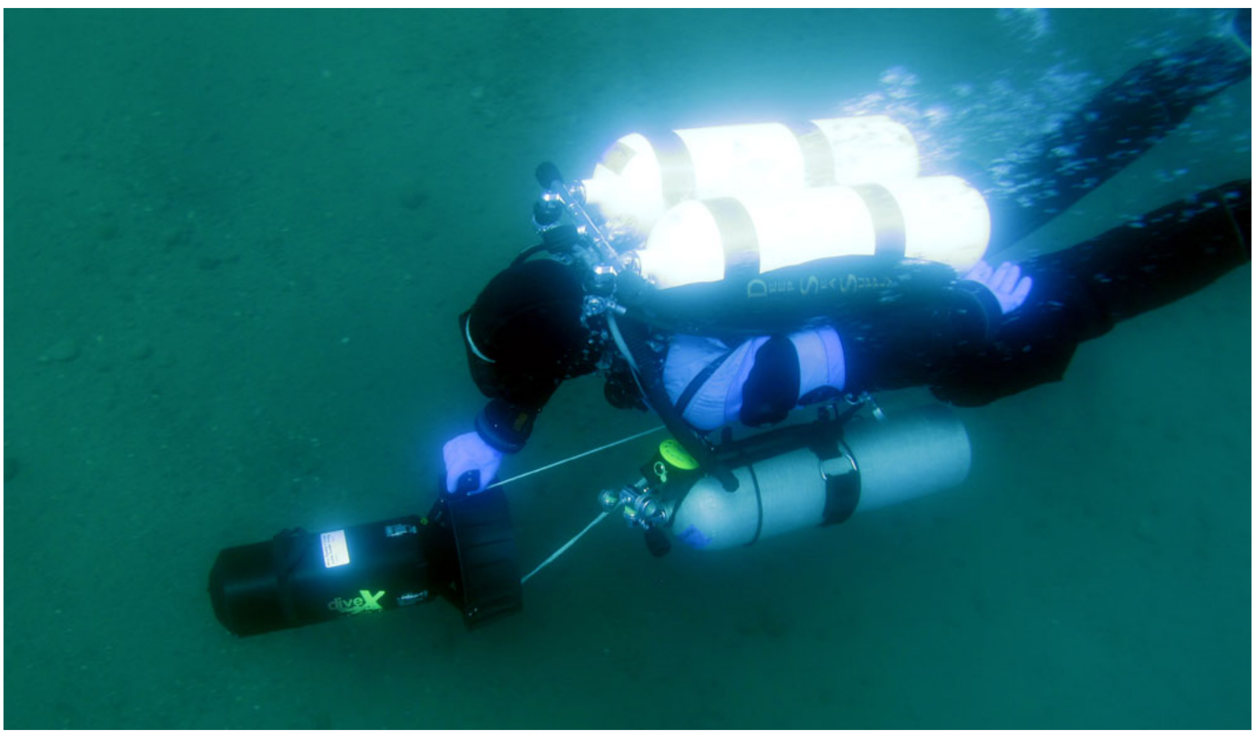
	Mini Cuda	Lithium Cuda	Cuda 650	N19	Gavin Short	Super Sierra	Sierra 16	UV26 (rebuilt)	Mako	Torpedo	GTI
Rec									25	8	8
Tech	78	76	71	43	39	35	35	28			

Thrust has been seen to be an excellent predictor of speed and load-pulling ability. However, it falls short when predicting range, as the variables of load, draw rate, battery capacity and others combine in ways that exceed what can be extracted from a single data point.

Technical Gear – Maximum Speed

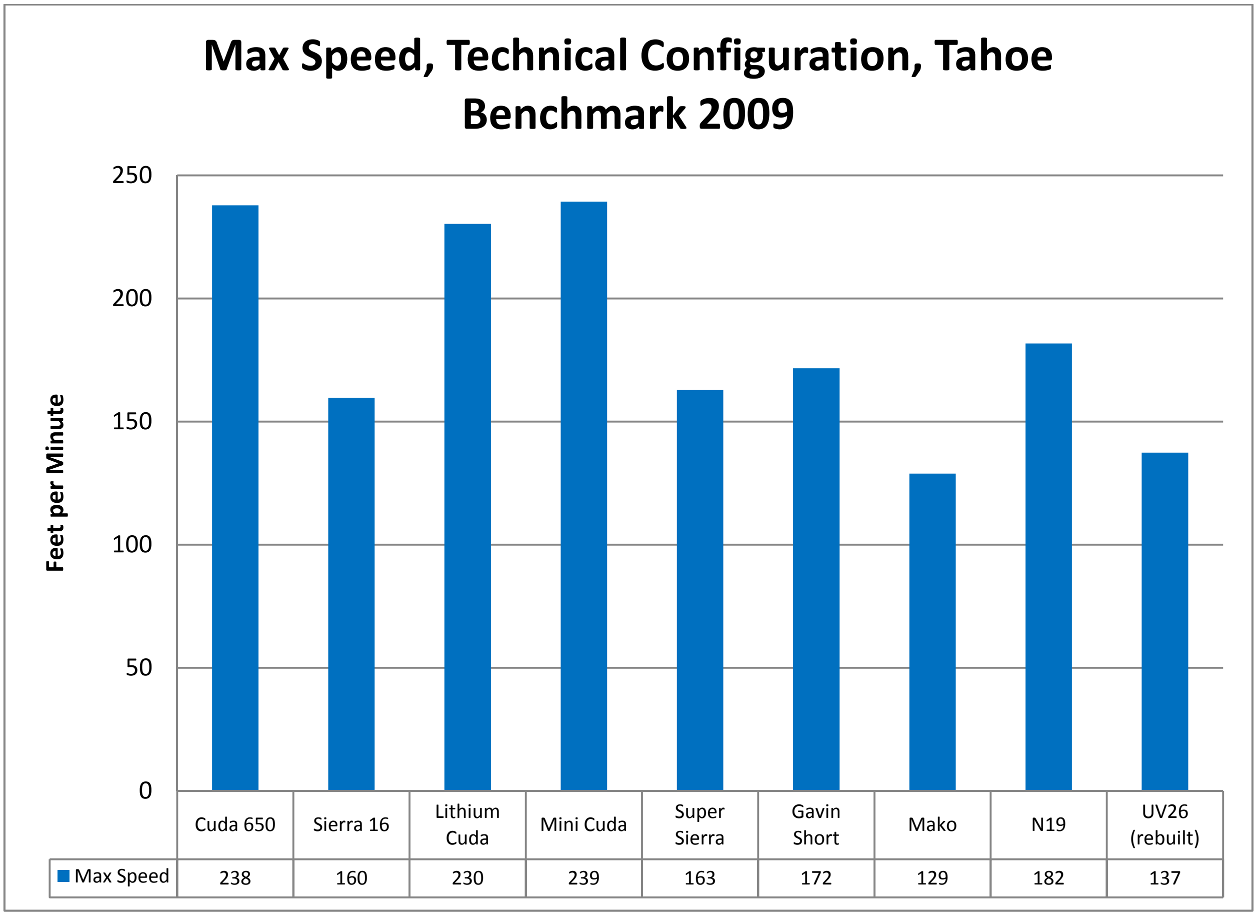
This, one of the most anticipated portions of the testing, came from user requests(12) . As some prior research had shown, the results could be anticipated. However, the data were gathered in what has become the Tahoe Benchmark Technical Configuration:

- drysuit
- doubles
- BP/W
- aluminum Luxfer 80 Stage @ 3000 psi of 32%



Test diver Dorsey runs the track in the technical configuration. This body & stage position was found to be the lowest drag. Photo by Chuck Weber.

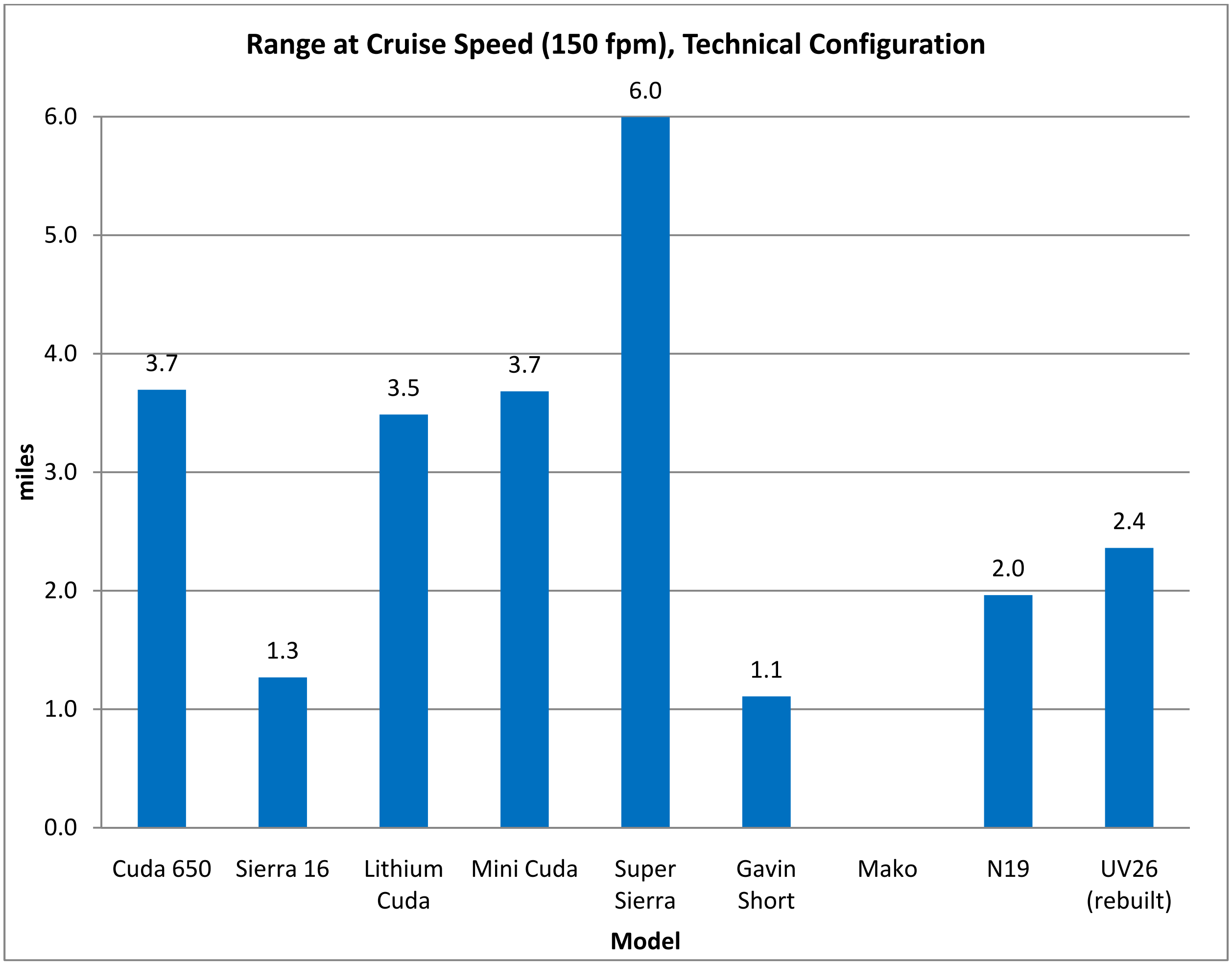
As with the standard configuration, the max speed (sprint) consists of two ¼ mile runs, one north, then south, with a 2-minute pause between.



	Cuda 650	Sierra 16	Lithium Cuda	Mini Cuda	Super Sierra	Gavin Short	Mako	N19	UV26 (rebuilt)
Max Speed	238	160	230	239	163	172	129	182	137

Technical Gear – Cruise Range

As with the standard configuration, at the conclusion of the sprint, each scooter was configured for 150 fpm, then run an additional ½ mile. The data from this were used to generate the cruise range.



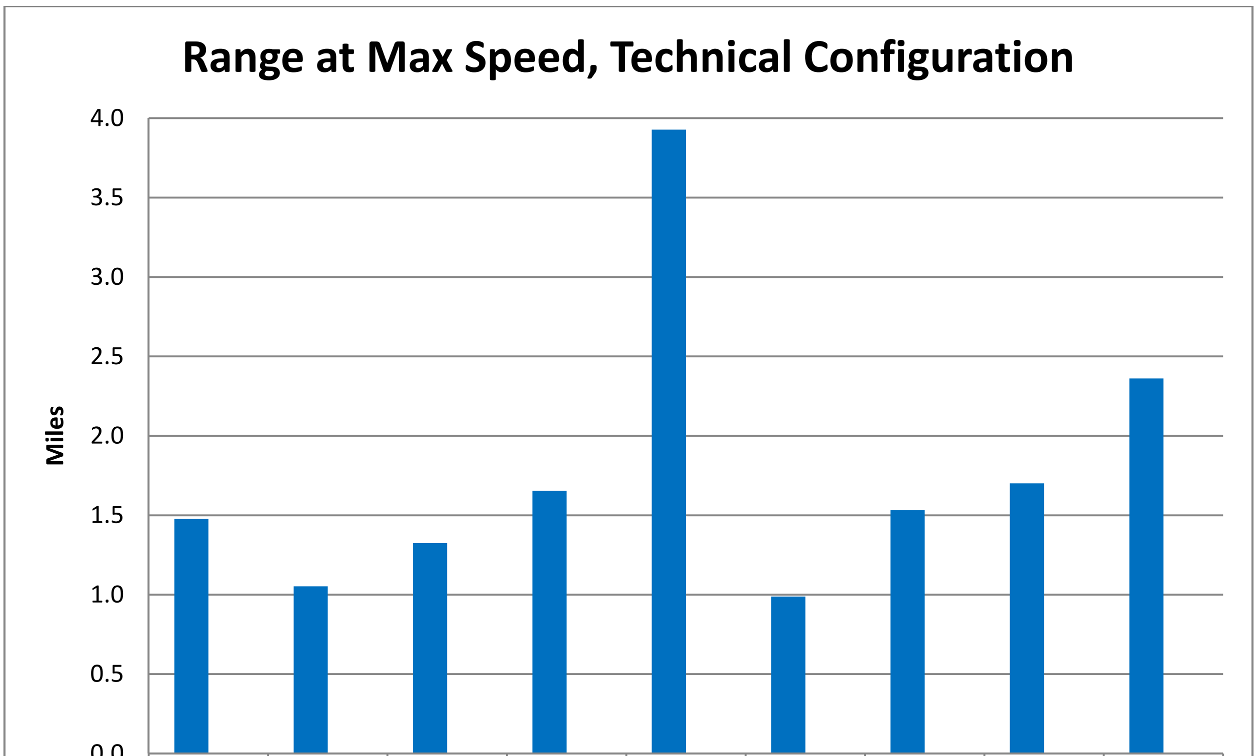
Note: UV-26 results included for informational purposes; its max speed in tech configuration was 137 fpm.

Technical Gear – Max Speed Range

This can be effectively considered the enduro for technical gear. As before, here a scooter's speed works against it, as the faster scooters experience higher draw rates, and thus, shorter burn times.

The test units were not tested as the standard configuration; this time constraints moved this to a calculation of observed capacity, and speed & draw rate in the technical configuration.

A verification test was done with one scooter, where it was run until dead. That distance exceeded the prediction by 8%.[13] Hence the data presented are conservative, which in an overhead environment is not a bad thing.

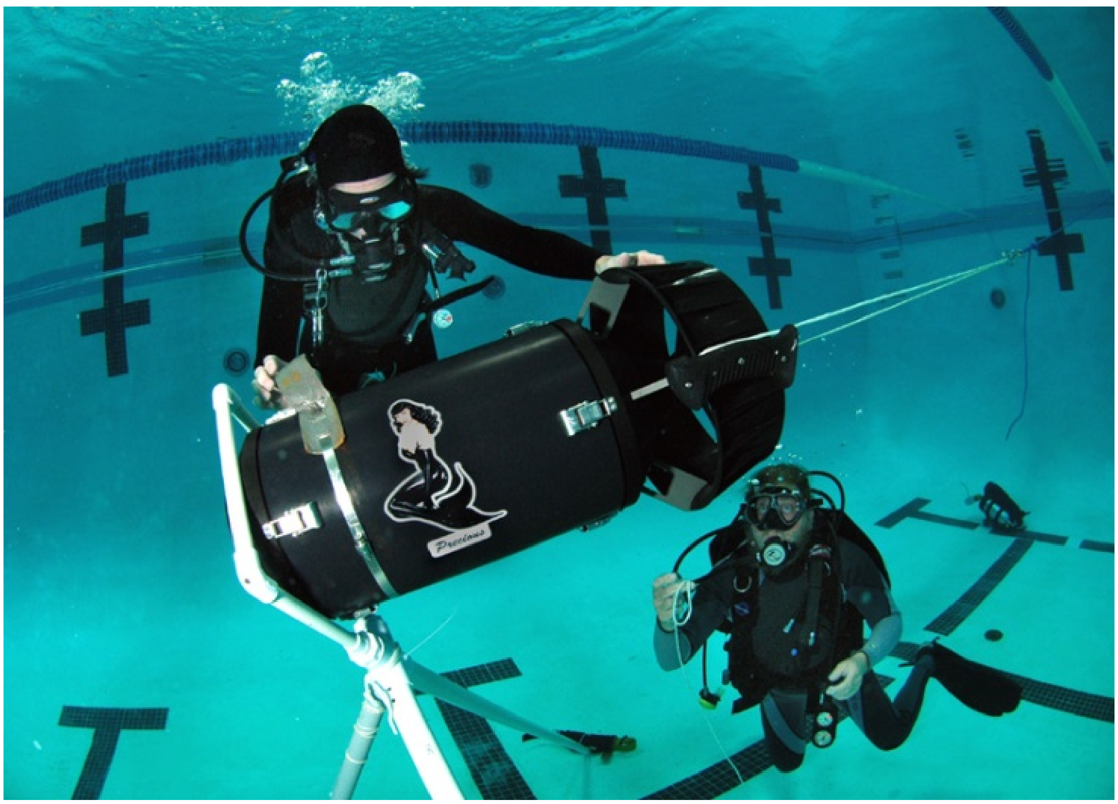


	Cuda 650	Sierra 16	Lithium Cuda	Mini Cuda	Super Sierra	Gavin Short	Mako	N19	UV26 (rebuilt)
Range	1.5	1.1	1.3	1.7	3.9	1.0	1.5	1.7	2.4
Speed	238	160	230	239	163	172	129	182	137

Additional Research

The Thrust-Speed Connection

Of great interest to the researchers has been the connection between thrust and speed. Drag is the component that has to be overcome by thrust; with some knowledge of the drag factors involved, it should be possible to model, and hence predict, the resulting speed from a given thrust.

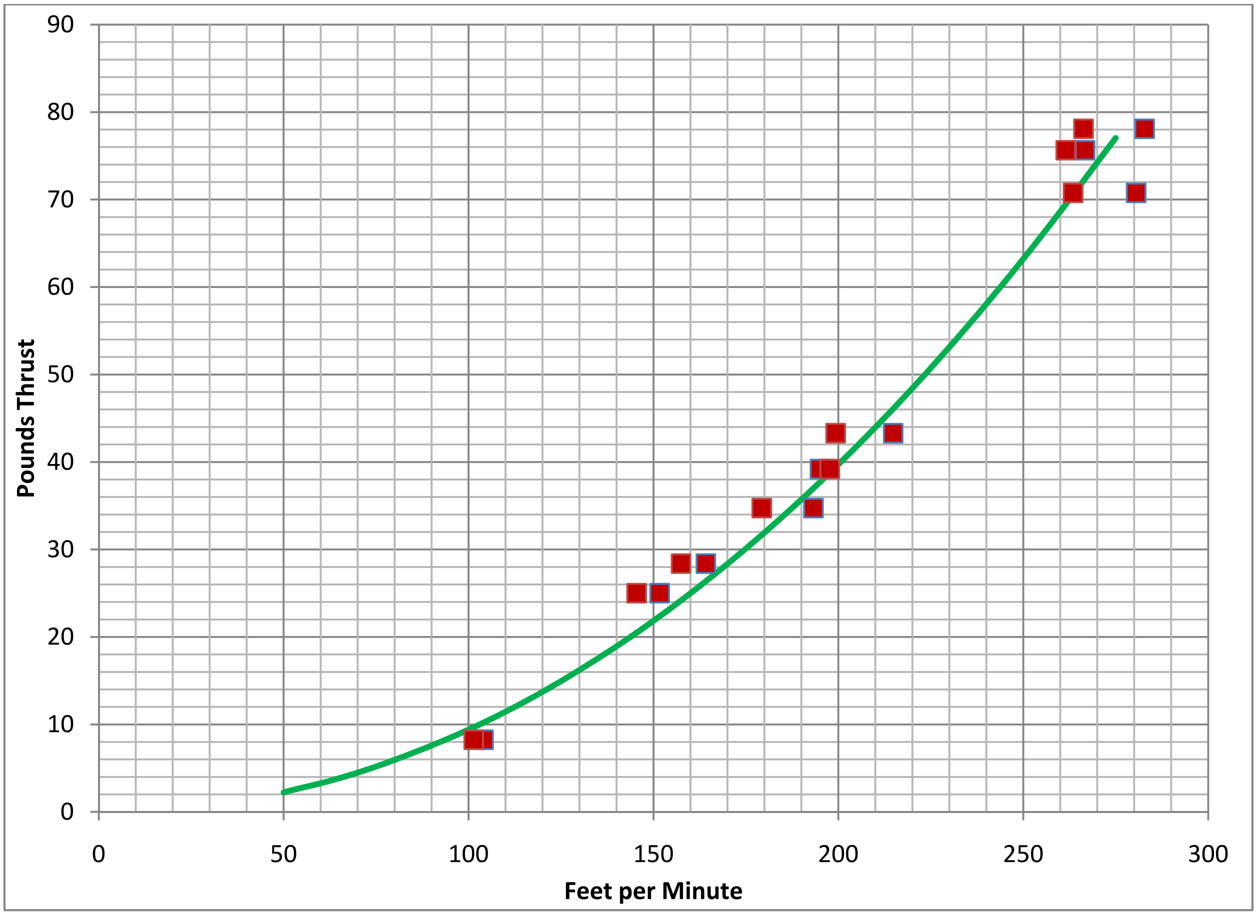


The Gavin Short is loaded into the test stand for thrust testing. Photo by Chuck Weber

The 2009 test was an opportunity to harvest more data to apply to this investigation. The result: an applicable model, and good confirmation of the veracity of the model.

Because drag rises dramatically in relation to speed,[14] it explains how an 8-pound thrust scooter will perform at 104 fpm, yet more than tripling the thrust only results in a 40 fpm advantage.

The following is a graph of observed results (data points) versus the model (solid line).



The (simplified) model has been found to be:

$$fpm = \sqrt[2.08]{\frac{lbs\ Thrust}{0.00065}}$$

Application: not all divers have a test track (or a location suitable to install one). As we have seen, some models are susceptible to variance from one article to the next. Use of a fairly simple bollard thrust test will allow a diver to elute the speed of their DPV in the Tahoe Benchmark Standard configuration; comparison with test data can also show if a scooter is under/over performing.

Note that this does not infer ranges or burn time; these are functions that involve capacity of the battery and motor efficiency.

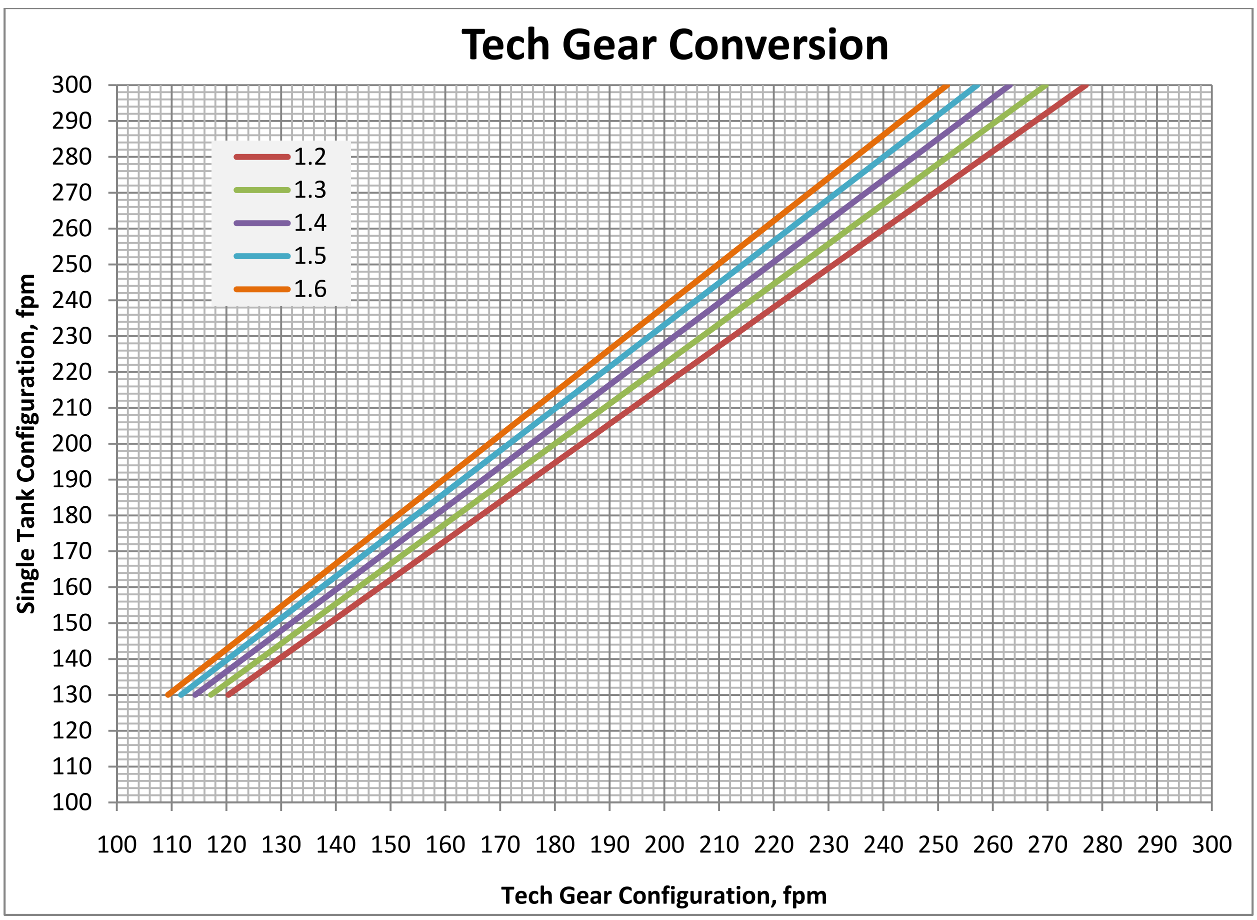
The Single-Double connection

This investigation has delved into the “brass ring” of scooter questions: it is obvious that the same diver, on the same scooter, will travel slower wearing doubles than in a single. But, *how much* slower?

The research into this has generated a conversion factor. It assumes a baseline for the drag of a diver in a single tank to be 1 (one). This unitless factor represents the drag of a diver in the Tahoe Benchmark Standard configuration.

Thus, if a diver (for example) had double the drag in doubles, than in a single, they would have a conversion factor of 2 (two).

Our initial investigations used a limited sample of divers and several scooters. From this, we moved on to the thrust/speed conversion, and using the 2009 Benchmark data, as well as many other investigation dives over the year, the following conversion chart[15] was produced:



Our data show that the typical technical diver will have a Conversion Factor (CF) of 1.4. This means they have 1.4 times the drag they would have in a single. So, if a diver had, for example, a speed on a scooter of 200 fpm in a single, they could consult the chart, and starting on the left, read across to the 1.4 line. Following the chart down, they would see they could expect a speed of 176 fpm in technical gear.

Note the caveat of “typical technical diver”. A CF of 1.4 is a bit “dirty,” in aviation terms. This is usually because of a combination of poor trim, a buoyant stage bottle, and resting the left hand on the valve of the stage. We have seen that very experienced scooter pilots will have as low of a CF as 1.2 in the Tahoe Tech configuration.

Adding an additional stage bottle has been seen to result in an extra 0.10 in CF. And, not changing the bottle count, but simply switching from a hanging bottle to a floaty one (with the attendant arm position induced) increases CF by 0.12.

The results published in this paper (in the Tahoe Benchmark Technical Configuration) are the experimentally found results. Analysis of these results shows the average CF (as related to the Tahoe Standard “single”) to be 1.3. If a scooter does not have published technical configuration data, the CF of 1.3 could be used to generate a speed to be used in comparison with other scooters,

Of interest is that each test diver had a personal CF. When comparing their singles runs vs. their technical runs, that CF was found to be applicable for virtually all scooters that diver tested. This was found to be contrary to the “urban myth” that certain types of scooters perform better when heavily loaded. In all cases, switching to technical gear resulted in a simple reduction in speed as predicted by the CF. This implies that thrust has more importance than previously given.

The schedule had “penciled in” a test run with an Inspiration rebreather, anticipating generating a CF for that configuration. Unfortunately the schedule was packed, and ran over into Saturday, and we did not have time to generate this. Our apologies.

Application

If a diver accurately knows their speed on both a single and in technical gear, they can find the intersection point; this is their personal CF. This can be used when switching scooters to determine speed on the new scooter.

Also, if one knows their personal CF, they can then begin to see speed differences by adding or subtracting bottles, a benefit for planning.

Even if one does not know their personal CF, one can use the “average CF” to compare published speed data for scooter types. Here, one would use the chart to extract the speeds which will be expected in various configurations.

Final Thoughts

It is entirely appropriate to mention here the long hours of selfless effort placed into this research by the volunteers – truly, this could not have been done without them. A sincere thank you to you all, and the thanks of the diving community.

Volunteers transfer stages and scooters out of the water during the tests. Photo by James Flenner

As before, it is very tempting to place too much emphasis on the numbers presented here. Although these tests indeed reveal speed and range differences between models, each scooter is a gestalt of weight, handling, maintenance requirements, speed and range. The knowledgeable diver will generate a set of their own requirements, and use the data to match their needs best.

As with last year, all the test divers remarked on how different each scooter felt in handling and ergonomics. A scooter that some would love, others would be ambivalent about. Again, these aspects are beyond the scope of this test, so, try before you buy.

In regards to the UV-26 (rebuilt) results: if the reader is overly concerned that the motor in this particular test unit was not built and installed by Silent Submersion, and that its performance is not typical of other UV-26s, then he/she should dismiss all statistics generated by this particular scooter.

It has been very gratifying over the last year to see the impact of the 2008 Benchmark. Divers have become more knowledgeable, openly quizzing manufacturers about their testing methodology when advertising speed numbers. We've seen a more common presentation of performance in manufacturer advertising. And, divers have been seen to use realistic performance numbers in mission planning, and equip themselves appropriately.

All these things are why the Tahoe Benchmark has been authored, and it is a gift of many to the community.

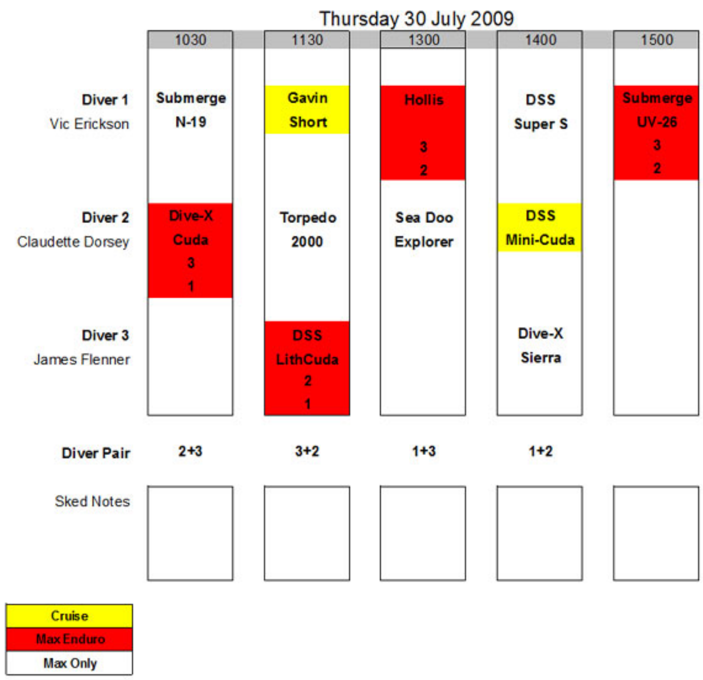
Last one out of the pool: Test diver Claudette Dorsey celebrates after the last dive Saturday. Photo by James Flenner

And as before, the racetrack is always open for divers. The bar's been raised: the time to beat in the standing quarter mile is 4 minutes 43.5 seconds…set by a girl!

References

1. The Tahoe Benchmark 2008 is available as a download from http://tahoebenchmark.com .
2. The Oversight Committee consists of Brian Armstrong, John Sampson, and Kevin Jones. All were selected for their diversity of personal scooters, experience, and position in the community.
3. Private ownership scooters included:
    a. N-19, in beautiful condition with less than ten dives, from Chris Pechacek
    b. UV-26 from Andy Huber
    c. Gavin Short body from Ray Ridout
    d. SeaDoo GTI from Mike Revty
    e. Oceanic Mako from Marcus Ollom
4. Medusa Products is no longer in business.
5. Throughout 2009 the Benchmark staff has been instrumenting the scooters of volunteers at dive sites, being used for typical recreational & technical dives.
6. EnerSys, pdf entitled US-EP-RS-001, April 2006
7. PowerSonic, pdf entitled PS-12180H, Aug. 2004
8. DPV Bollard Pull Test is available from http://tahoebenchmark.com
9. Use of the Carson City Aquatic Facility courtesy of Kurt Meyer.

10. An example of the daily schedule. Because the schedule was drawn up in advance, some scooters were promised that did not appear in the test.



11. From an email by the manufacturer: "DSS Lithium Batteries have internal protection electronics. These electronics are protected against over temperature. During the "Enduro" portion of the testing the sustained high currents the Cuda Lithium Battery is capable of delivering exceeded the thermo switch setting. This caused the battery to shutdown without damage.

    This thermo switch auto reset within minutes, but the test protocol calls for terminating the test at the first "cut out". Substantially less than full battery capacity was delivered during the test. Fitting of a thermal switch of slightly higher rating now allows for full discharge."

12. Multiple requests via email and forums were received for this testing.
13. James Flenner and Vic Erickson researchers, June 2009
14. $$\mathbf{F}_d = -\frac{1}{2}\rho v^2 A C_d \hat{\mathbf{v}}$$
15. Conversion Chart available for download at http://tahoebenchmark.com
16. Due to space constraints in the battery compartment, the SeaDoo was run without a data recorder. Times were gathered with a diver-worn stopwatch.

17. The results in total. Includes run times for those that use dive time to monitor scooter reserve.

Tahoe Benchmark 2009

		Tahoe Standard (Single Cylinder)								Tahoe Technical (OC Doubles + Stage)						
		Max Speed				Cruise				Max Speed			Cruise			
Make	Model	fpm	Watts	Range	Run Time	Watts	Range	Run Time	Thrust	fpm	Range	Run Time	Watts	Range	Run Time	Weight
Dive-X	Cuda 650	266	928	1.7	0:35:17	190	4.8	2:46:01	71	238	1.5	0:32:48	253	3.7	2:04:15	53.8
Dive-X	Sierra 16	179	454	1.2	0:36:52	242	1.8	1:05:37	35	160	1.1	0:34:48	330	1.3	0:48:01	37.4
DSS	LithiumCuda	258	1005	1.6	0:33:58	185	4.9	2:54:22	76	230	1.3	0:30:23	277	3.5	1:56:49	50
DSS	MiniCuda	268	1082	1.8	0:36:16	219	5.6	3:04:22	78	239	1.7	0:36:29	322	3.7	2:05:23	42.4
DSS	SuperSierra	182	514	5.0	2:26:41	250	7.5	4:06:42	35	163	3.9	2:07:25	304	6.0	3:36:46	37.6
Gavin	Short	192	500	1.1	0:29:30	342	1.2	0:49:26	39	172	1.0	0:30:24	376	1.1	0:39:53	70.2
Oceanic	Mako	144	222	1.9	1:07:51	221	1.9	1:08:05	25	129	1.5	1:02:47				54.8
SeaDoo	GTI	97		0.5	0:28:42				8							19.8
Submerge	N19	203	465	1.9	0:53:34	305	2.2	1:15:42	43	182	1.7	0:49:27	351	2.0	1:05:53	49.2
Submerge	UV26 (rebuilt)	154	364	2.8	1:40:53	360	3.0	1:44:27	28	137	2.4	1:30:45				93.8
Torpedo	2000	104	265	0.9	0:41:32				8							39.2