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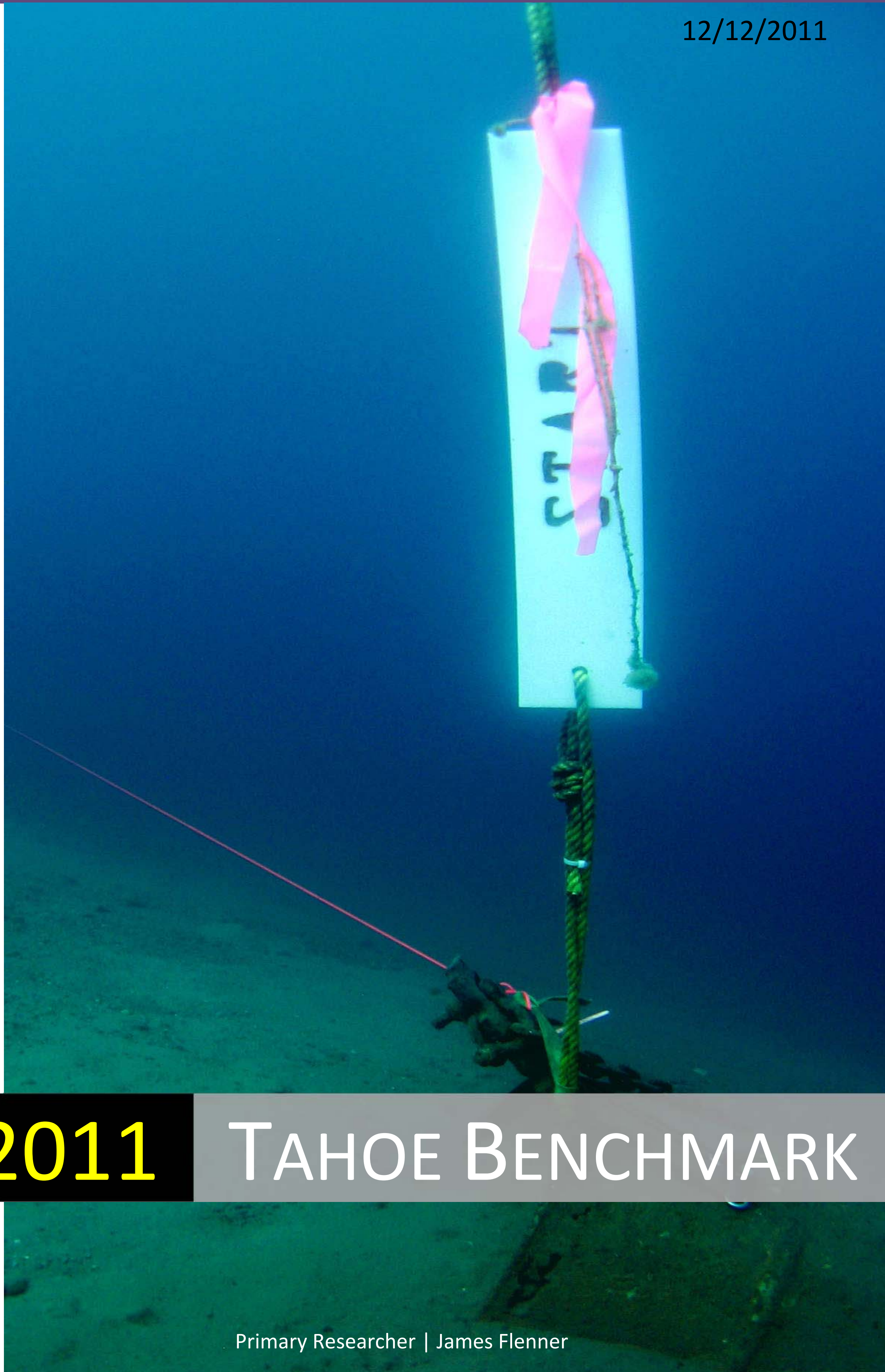


2011 Tahoe Benchmark

Primary Researcher | James Flenner

The Tahoe Benchmark

July 2011

Contents

For Ted Strong

Innovator – Lifesaver - Inspiration

Introduction

Merlin Rhoda (L) and Dani Valerio (R) plan a scooter dive at Point Lobos State Park, CA.

Late in 2010, several divers were overheard planning a dive in the parking lot of a popular dive site in California, which involved a target about ½ mile off shore. As the question of scooter range came up, one diver confidently stated that his scooter would travel 1.7 miles in his gear configuration of doubles and stages, and that he'd be traveling at 160 fpm.

Before 2008, this was a conversation that in all likelihood would not have happened. Scooter divers had only a vague idea of the real performance of their DPV's, with a dearth of reliable data on which to plan a dive safely. Owners of DPV's were (and still are) intensely partisan, thus were questionable sources of impartial information for those looking to purchase a DPV. These problems were the reason for the Tahoe Benchmark: impartial, in-the-water real world testing to find the true performance and abilities of each DPV.

With new advances in technology and DPV design breaking into the market, the 2011 Tahoe Benchmark tests have been highly anticipated, and produced participation by more manufacturers than any other test.

Testing (Abstract)

The 2008 Tahoe Benchmark DPV tests were designed to test two basic performance parameters of each scooter:

- Power
- Range

Testing was conducted again in 2011. With several new design features beginning to enter the market, such as the prevalence of lithium battery chemistry, high voltage motors and a break from the Tekna propeller, the test parameters were expanded to better assess DPV performance.

Significant for 2011 was the highest manufacturer participation to date. A disappointment was zero participation by recreational-class DPV's. (1)(2)(3)

The Tests

As the first tests in 2008 were considered, the only easy way to test for overall power of a scooter was through speed. As a generalization, the faster scooter was the more powerful, and had a greater load pulling ability. Hence, the tests primarily emphasized speed.

A critical parameter when planning a scooter dive, especially into an overhead-restricted environment, is the scooter's range. Each scooter was additionally tested for range under worst-case conditions: maximum speed.

Investigators were also interested in the overall efficiency of a scooter design. It was felt that finding these data and publishing them might make for a more even-handed comparison, as well as help prod the market into better designs. Hence, all scooters were tested at a common speed.

The 2008 tests were:

- Maximum Speed
- Range at maximum speed
- Cruise (150 feet per minute) tests

Morning setup during the 2009 Tahoe Benchmark

In 2009, an additional test was added to these three: the Bollard Thrust test. In this, each test scooter demonstrated its maximum thrust under controlled conditions. Also, by popular request, each scooter was tested in a high drag configuration, with speed and cruise tests while equipped in doubles and a stage.

In 2011, these tests remained essentially unchanged. So to summarize, the 2011 tests include:

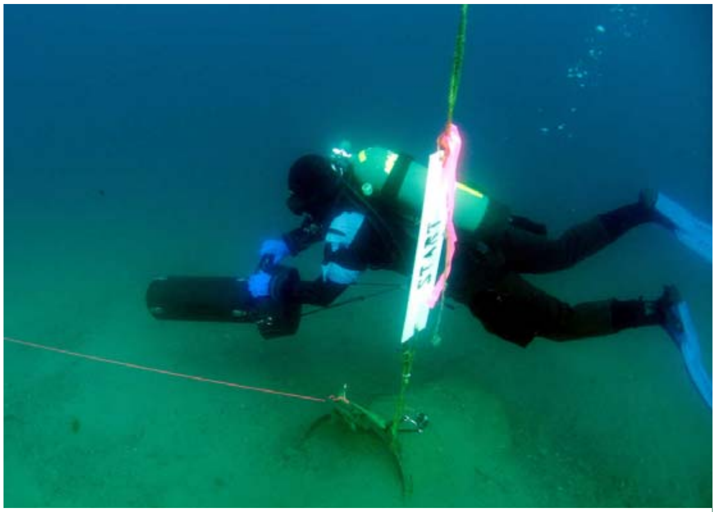
- Thrust testing
- Maximum Speed
- Range at maximum speed
- Cruise (150 feet per minute)
- High Load Maximum Speed
- High Load Cruise (150 fpm)

After the in-water tests were concluded, the data were analyzed, and the paper was authored. After examination by the Oversight Committee[19] the paper was placed through peer review[20]. Manufacturers were provided with copies of the final paper and raw data downloads prior to public release.

Methodology

Venue

Experiments prior to 2008 had shown that short-distance speed tests were wildly inaccurate. Also, currents can easily skew results. This led to the selection of the test track at Lake Tahoe, a relatively still body of fresh water.



Test diver Claudette Dorsey at the Start line of the racetrack. Note the fluorescent pink line, new for 2011.

The track runs south to north at a depth of 36 feet of fresh water. The track has been carefully measured at a distance of 1325.5 feet by one of the test divers, who is employed as a professional surveyor. Every 100', a permanent bottom marker has been installed. The start and finish lines are marked by large underwater tags which are held off the bottom by floats.

2011 was an interesting year for the ecology of Lake Tahoe. The famously clear water has been declining in visibility over the last several decades, and 2011 saw the worst vis ever observed: 20'. When the track was re-surveyed 2 weeks prior to the tests, it was decided to lay line for the test divers to follow. This line, the markers, and the start/finish tags are now permanently placed, and available for any diver who wishes to test their own scooter.

Also, a repeat of the 2009 dye studies showed that occasional currents of up to 1 (one) fpm existed on two of the days of testing. These currents were localized to the middle of the track, and found to be caused by a strong southerly breeze as a result of thunderstorms. The data were examined carefully, and this current shows to be self-cancelling by virtue of the testing method, which uses results from a north run followed by a south run.

Staff (L to R) James Flenner, Claudette Dorsey, and Vic Erickson spool up 1/3 mile of line the week prior to the test.

The Tahoe Benchmark standard

Since exposure protection and BC selection can make such a difference in the drag (and thus speed) of a diver, the Tahoe Benchmark results are all from testing in the following configuration:

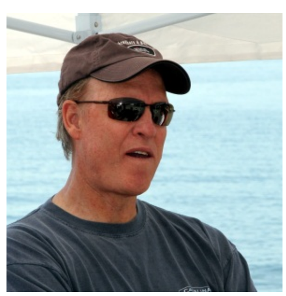
- Dry suit
- Back Plate & wing
- Single steel 72

The divers wore undergarments appropriate for 6 dives per day in 58$^{\circ F}$ water. Breathing gas was 32% nitrox, which was provided free to the test by Adventure Scuba.

Test divers wearing the Tahoe Benchmark standard configuration.

The test divers are required to have at least 200 scooter dives logged. In the case of the 2011 divers the low number is roughly 400, and the highest above 800. The three test divers have all been test pilots in the previous Benchmark studies, and include two men and one woman.

In testing such as this, the hardest variable to be removed has been the divers themselves. Here, the 2011 test continues to use the same variable reduction strategy as in the 2008 and 2009 tests. Each scooter is run once by each test diver; all of that diver's results are ranked as percentages; and at the end of testing, each scooter has its percentage scores averaged. Data that exceeded 2 sigma standard deviation is rejected. This allows the individual differences between divers, such as trim, body size, equipment, and others, to be removed from the results.



The three test divers: (L to R) Claudette Dorsey, Alan Studley, & Vic Erickson. The divers completed 66.8 miles underwater.

One scooter was tested in 2011 which does not appear in the results. This was a 2009 model scooter[4], identical in all respects to the 2009 testing, which had been tested to produce the same thrust as two years ago. This scooter became the statistical "bridge" which allowed the combining of the 2009 results with the 2011 results in a meaningful way.

Maximum Speed

The maximum speed test, also known as the "Sprint," is designed to measure the speed of the scooter over two ¼ mile runs. Previous experimentation had demonstrated that shorter distances allowed the start-up and body position variances too much influence.

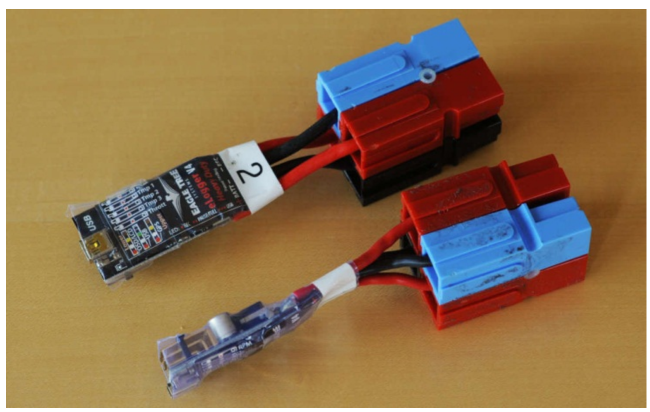
In this photo from 2009, a test diver pauses for 2 minutes at the North finish line.

The test is performed as two opposing track runs, one north, and then one south. Any current present on the track thus becomes subtractive. The runs are separated by a timed two minute "rest period" at the north finish line, allowing the scooter to best mimic the typical diver's pattern of 68% trigger activation[5].

All parameters of the scooter's performance are recorded on Eagle Tree Systems eLogger v4 Heavy Duty (150 Amp) data recorders. These are configured to record volts, amps, and watts at a 10 hertz sampling rate. Test divers would release the trigger of the test scooter as the nose crossed the finish line; thus, timing of the runs[6], and therefore the speed of the scooter, is extracted from the data recorders.

Each scooter was given a Sprint test with a fully charged battery. Batteries were allowed to charge, then cool, the night prior.

Because each scooter was Sprint tested three times – once for each test diver – the complete Sprint test took three days to complete.



The Eagle Tree Systems eLogger v4 data recorder. These are the Heavy Duty model, which will record loads as high as 150 Amps.

Range at Maximum Speed

Nicknamed the "Enduro," each scooter had to perform this once over the course of the 2011 testing.

The scooter was run at maximum speed over the length of the track, followed by a rest for 2 minutes. Then, the scooter was run in opposite direction. At the conclusion of each length the scooter was rested for 2 minutes, again, to represent the typical scooter ratio of trigger on vs. trigger off of 68%[5].

This process would continue until the scooter died. The test diver would record the closest distance marker on the track, and this would be the range of the scooter.

The endpoint ("dead") was defined as:

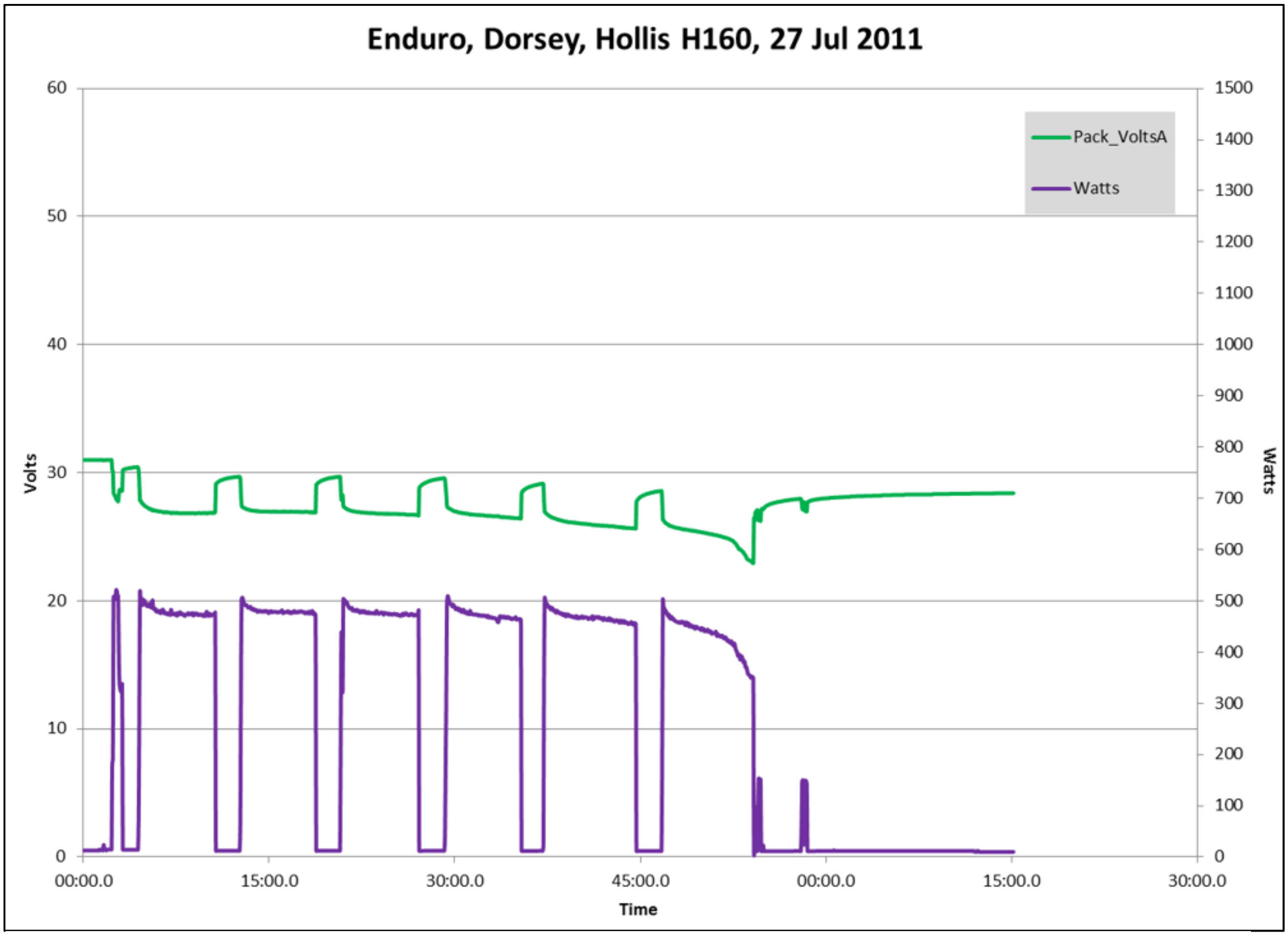
- lead-acid battery scooters: a speed of 100 fpm.
- lithium & nickel battery scooters: at the first point of electronic battery protection.

The endpoint for lead-acid battery scooters was chosen after examination of the data from 2008 & 2009.

Dorsey (R) & Studley (L) hand off the SS Magnus (far R) during the Enduro. The scooter seen on far L is a utility scooter, used to shuttle test divers to and from the track.

Typically, a lead-acid scooter will slow down as battery voltage decreases, and at 100 fpm, these scooters are seen to be at 18 volts (or 9 volts per battery). Allowing them to continue at slower speeds gains little additional distance and damages the batteries by excessively low voltages.

The endpoint for all other batteries is most influenced by the electronic speed controller. These are typically programed by the manufacturer to cut the current to the motor if battery pack voltage drops low enough to damage the pack. This is usually seen as a "cut out", and the test divers are instructed to note the distance at that point. [7]



An example of an Enduro run.

Scooters have differing cut out strategies. For example, some simply kill the motor. Others reduce the speed at which the motor runs. Either way, the first instance of battery protection is the endpoint.

A fortuitous benefit of the Enduro is that it functions as a stress test. The conditions are the most difficult for the scooter. It is being run at maximum speed, which results in the highest draw rate from the battery and the most heat buildup in the motor, electronics, and battery. Although several test articles had more theoretical range in their design, the stress of the Enduro highlighted design weaknesses by a premature failure. That range, as observed to the point of failure, is the one reported in this test and is highlighted in "*Events of Note*".

Not surprisingly, piloting a scooter at speed is actually exhausting, muscle-numbing work. The more tired a diver, the sloppier (and thus, higher drag) they become. This does not allow the scooter to perform at its best, so test divers were changed out after every mile (4 track lengths) underwater.

Cruise

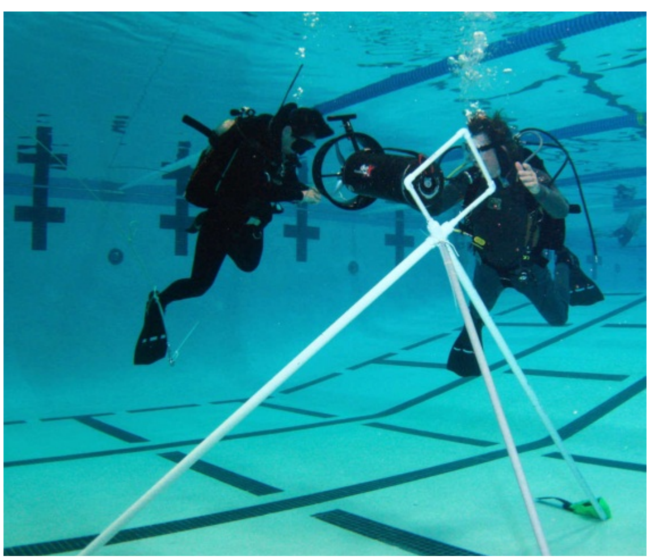
Here the intent of the test was to allow direct comparison between scooters. For example, power (watts) increases as the cube of the speed[8]. Thus, a faster scooter will drain its batteries much more quickly than a slower scooter. Range comparisons between two scooters at maximum speed would, at first blush, show the slower scooter to have an artificially inflated range.

James Flenner (L) and Larry Hanlon (R) discuss data trends and events during the water testing.

By running all the scooters at a common speed of 150 feet per minute, true differences of efficiency and battery capacity, both of which contribute to range, become apparent.

For the Cruise Test, test divers would configure the scooter for roughly 150 fpm, either via electronic speed control or propeller pitch. Then, using a stopwatch[9], they would run 300' down the track, then reverse course. Once the average became 2 minutes for each 300', the scooter was run a full length of 1325.5 feet. The scooter was allowed to rest for two minutes, then returned. The data harvested from the data recorder is then used to generate watts for comparison, and range.

Thrust



The DSS Cuda Fury 1150 is loaded into the test stand during thrust testing at the Carson City Aquatic Center.

Thrust is the static pull of the scooter as measured in pounds This is directly applicable to pulling heavy loads or speeds that can be produced. Testing was accomplished by running each scooter inside a test stand at maximum thrust, while connected to a load cell.

Each scooter experienced a test run of three minutes. The first minute allowed the battery to stabilize to normal operating voltages; the remaining two minutes of load cell data are then collected. The thrust published is the arithmetic mean.

Thrust testing was performed with the assistance of the staff at the immaculately maintained Carson City Aquatic Center[10] pool, and could not have been done without them.

Dr. Hanlon checks the load cell as the underwater test stand is assembled and aligned. A surrogate scooter was used to ensure that the apparatus was configured correctly, then thrust testing began.

To ensure direct transfer of thrust to the load cell, the 2009 Spectra tether line was replaced with ¼" Samson Braid AmSteel Dyneema cordage, rated at 8,600 lbs, which stretched ~ 2.4 mm while under load.

Rodney Nairne of Submerge Scooters explains the trigger of the Minnus prior to thrust testing.

Details of this procedure can be found in the 2009 publication, DPV Bollard Pull Test, on the www.tahoebenchmark.com website.

Technical (High Drag) configuration

First introduced in 2009, here test divers re-ran the Max Speed (Sprint) and Cruise tests while equipped with OC steel doubles, and a Luxfer 80 cubic foot stage of 50% at 3000 psi. Except for the configuration, test parameters remained the same.

Alan Studley waits in the water for a test scooter during "high drag" testing.

Several test runs were performed in a KISS GEM rebreather. Surprisingly, results were almost identical with the OC doubles configuration. Speculation had placed that a rebreather would exhibit significantly higher drag, and thus lower speed, a result which did not materialize.

The Scooters

Initial invitations to scooter manufacturers were sent via mail with a delivery confirmation. USA mail was Certified, international mail was Registered. The mail invitations were sent 02 May 2011.

Nick Hollis, of Hollis Dive Gear, preps the H320 for a track run.

Follow-up emails were sent the week after. Those that did not respond to mail or emails, or refused delivery of hand mail, were telephoned directly.

One month before the test, a call for privately owned scooters was made, with good response from the diving community.

Five manufacturers agreed to not only send test articles, but attended in person. During testing, the atmosphere on the beach was truly one of cooperation; each manufacturer not only prepped their own scooters for testing, but cheerfully carried scooters of all makes into and out of the water, assisted the test divers, and generally helped out on the beach just like the volunteers.

	Invitation Sent	Invitation Delivered	Follow-up contact	Declined participation	Agreed to participate	Manufacturer supplied	Private Ownership	Tested
Apollo				3				
Bladefish				5				
Bonex								
Deep Sea Supply								
Dive-Xtras								
Gavin								4
Halcyon								
Hollis/Oceanic								
Logic Dive Gear								
Diver Tug	1			5				
Patriot Maritime								
Pegasus					5			
Sea Doo					5			
Stidd								
Submerge								
Suex		2						
Torpedo						4		
Tusa				3				

(1) email only

(2) Non-delivery of paper mail, email received

(3) Unable to contact at listed email, address & phone

(4) There were no new models in 2011

(5) Initially indicated interest, later declined or did not participate

Manufacturers present included Deep Sea Supply, Dive-Xtras, Hollis, Logic Dive Gear, and Silent Submerge. In the case of these manufacturers, they maintained, charged, transported and prepped the scooter for a test dive. The Benchmark team did nothing for these scooters. The private ownership scooters were maintained by the research team, adhering to the manufacturer instructions in all regards.

Part of the agreement with the manufacturers was that a copy of the all raw data would be provided to those manufacturers that participated.

Jon Nellis of Logic Dive Gear works on the Genesis 600.

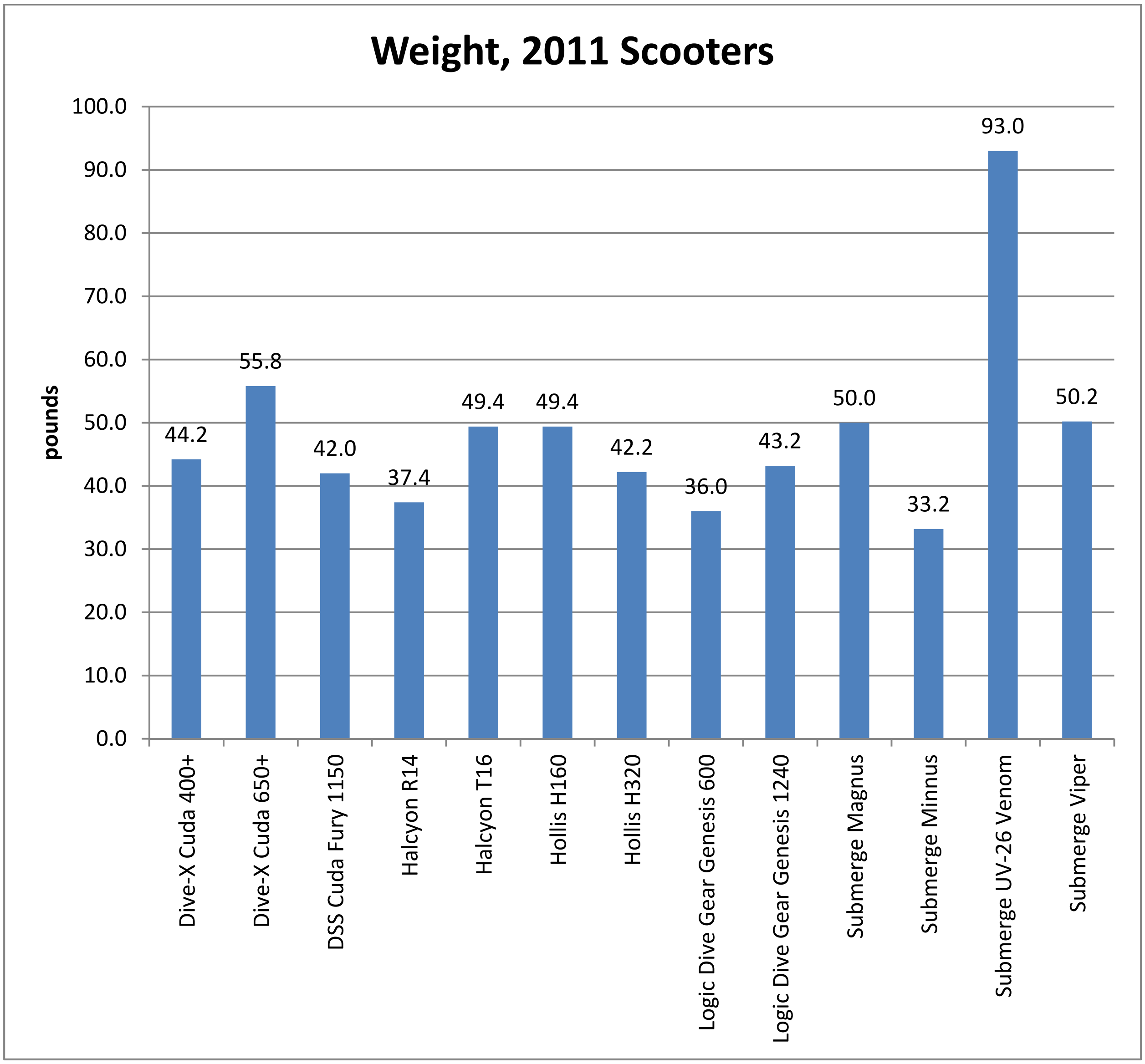
Scooter types

As before, depth rating provided the two basic categories:

- technical (200’ or more)
- recreational (shallower than 200’)

The intention was to test the recreational scooters to the same standards as the technical ones. However, there were no scooters provided by recreational manufacturers, hence, all scooters tested in 2011 were technical class scooters. *Note: Torpedo Inc. has been a stalwart participant of the Tahoe Benchmark, and simply had no new models to test in 2011.*

All scooters were configured for fresh water, weighted for neutral buoyancy, and balanced for trim, without a data recorder. They were then weighed.

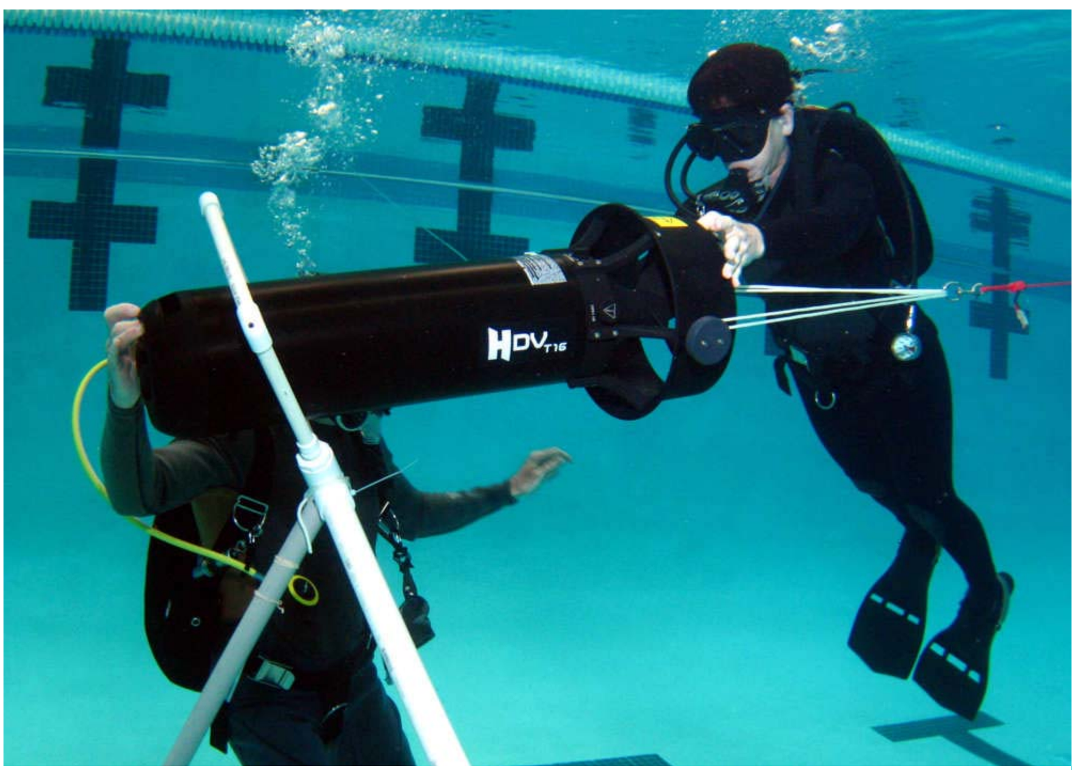


The Results

A summary of the 2011 test results is seen below. The reader is cautioned to read the following chapter, "*Exceptions*". For comparison to the 2009 scooters, see the next page.

		Tahoe Standard (Dry suit + BP/W + single							Tahoe Tech (Doubles + Stage)				
		Max Speed				Cruise			Max Speed		Cruise		
Manufacturer	**Scooter**	**Speed**	**W**	**Wh**	**Miles**	**W**	**Miles**	**Thrust**	**Speed**	**Range**	**W**	**Range**	**Weight**
Dive-X	Cuda 400+	269	1061	342	1.0	206	2.9	79	248	0.9	268	1.7	44.2
Dive-X	Cuda 650+	272	1078	439	1.1	193	3.9	80	*	*	*	*	55.8
DSS	Cuda Fury 1150	292	1075	1291	4.1	501	5.8	91	260	3.5	508	5.4	42
Halcyon	R14	161	259	302	1.9	259	1.9	31					37.4
Halcyon	T16	187	393	371	1.9	314	2.4	40	179	1.8	386	1.8	49.4
Hollis	H160	211	483	330	1.5	268	2.3	44	186	1.5	295	1.9	49.4
Hollis	H320		1881	162	0.2	200	1.4	81	*	*	*	*	42.2
Logic Dive Gear	Genesis 600	283	979	565	1.9	165	5.6	91	*	*	*	*	36
Logic Dive Gear	Genesis 1240	289	1001	789	2.2	165	7.8	89	243	2.1	241	5.7	43.2
Submerge	Magnus	259	919	746	2.4	253	5.0	64	234	2.2	387	3.6	50
Submerge	Minnus	239	652	562	2.3	309	3.3	55	218	2.1	378	2.5	33.2
Submerge	UV-26 Venom	205	489	623	3.3	278	3.9	46	*	*	*	*	93
Submerge	Viper	224	673	786	3.2	287	5.1	55	196	2.6	374	3.7	50.2

**Note: due to time constraints, not all scooters were tested in Tahoe Tech configuration. Asterisks here do not indicate a failure, simply that the scooter was not specifically tested.*



The Halcyon T16 is loaded into the test stand prior to thrust testing.

Results Compendium

The latest (2011) results were combined with the last (2009) results. This is presented here for those divers who own these prior models.

To facilitate the data combination, the 2011 test scooters included a 2009 model of the Cuda 650. This scooter tested within 0.4 lbs of thrust, and supplied the statistical bridge allowing the two years' results to be normalized. For clarity, this chart does not include this scooter which was annotated as "Calibration Cuda" during the week in the water.

		Tahoe Standard (Dry suit + BP/W + single							Tahoe Tech (Doubles + Stage)				
		Max Speed				Cruise			Max Speed		Cruise		
Manufacturer	Scooter	Speed	W	Wh	Miles	W	Miles	Thrust	Speed	Range	W	Range	Weight
Dive-X	Cuda 400+	269	1061	342	1.0	206	2.9	79	248	0.9	268	1.7	44.2
Dive-X	Cuda 650+	272	1078	439	1.1	193	3.9	80	*	*	*	*	55.8
Dive-X	Cuda 650	266	928	525	1.7	193	4.7	71	240	1.5	249	3.8	53.8
Dive-X	Sierra 16	179	454	264	1.2	245	1.7	35	161	1.1	325	1.3	37.4
DSS	Cuda Fury 1150	292	1075	1291	4.1	501	5.8	91	260	3.5	508	5.4	42
DSS	SuperSierra	182	514	1099	5.0	249	7.5	35	164	4.0	316	5.8	37.6
Gavin	Short	192	500	250	1.1	347	1.2	39	173	1.0	371	1.1	70.2
Halcyon	R14	161	259	302	1.9	259	1.9	31					37.4
Halcyon	T16	187	393	371	1.9	314	2.4	40	179	1.8	386	1.6	49.4
Hollis	H160	211	483	330	1.5	268	2.3	44	186	1.5	295	1.9	49.4
Hollis	H320		1881	162	0.2	200	1.4	81	*	*	*	*	42.2
Logic Dive Gear	Genesis 600	283	979	565	1.9	165	5.6	91	*	*	*	*	36
Logic Dive Gear	Genesis 1240	289	1001	789	2.2	165	7.8	89	243	2.1	241	5.7	43.2
Oceanic	Mako	144	222	251	1.9	219	1.9	25	130	1.5			54.8
SeaDoo	GTI	97			0.5			8					19.8
Submerge	Magnus	259	919	746	2.4	253	5.0	64	234	2.2	387	3.6	50
Submerge	Minnus	239	652	562	2.3	309	3.3	55	218	2.1	378	2.5	33.2
Submerge	N19	203	465	385	1.9	304	2.2	43	183	1.7	364	1.9	49.2
Submerge	UV26	211	513	623	3.2	324	3.7	46	190	2.5	362	3.0	92.8
Submerge	UV-26 Venom	205	489	623	3.3	278	3.9	46	*	*	*	*	93
Submerge	Viper	224	673	786	3.2	287	5.1	55	196	2.6	374	3.7	50.2
Torpedo	2000	104	265	152	0.9			8					39.2

Scooters named in neon are classified as Recreational scooters, tested in 2009.

32% nitrox was provided free to the Benchmark by Adventure Scuba of Reno, NV.
Staged nearby are scooters waiting to be tested.

Exceptions

Deep Sea Supply Cuda Fury 1150

Weighing the DSS Cuda Fury 1150.

The Cuda contains an electronic motor control, which can be configured for two different scooter designs. During the Cruise test, the Cuda Fury 1150 was intentionally configured to a 5-speed setting.

When so configured, the slowest setting performed at 207 fpm, not the 150 fpm required for the Cruise test. This higher speed reduces Cruise range.

Because this scooter was configured as intended by the manufacturer representative on-site, the results are correct.

Dive-Xtras Cuda 650+

In the day prior to the Enduro test, the Cuda 650+ was used by non-test divers who had arrived to "demo drive" scooters, and was drained more than usual. The battery did not charge to 100% that night. Therefore, this scooter died in the Enduro sooner than expected.

Because this scooter was maintained and configured by the manufacturer representative on-site, the results stand as tested.

The new propeller and shroud of the Dive-X Cuda 650+

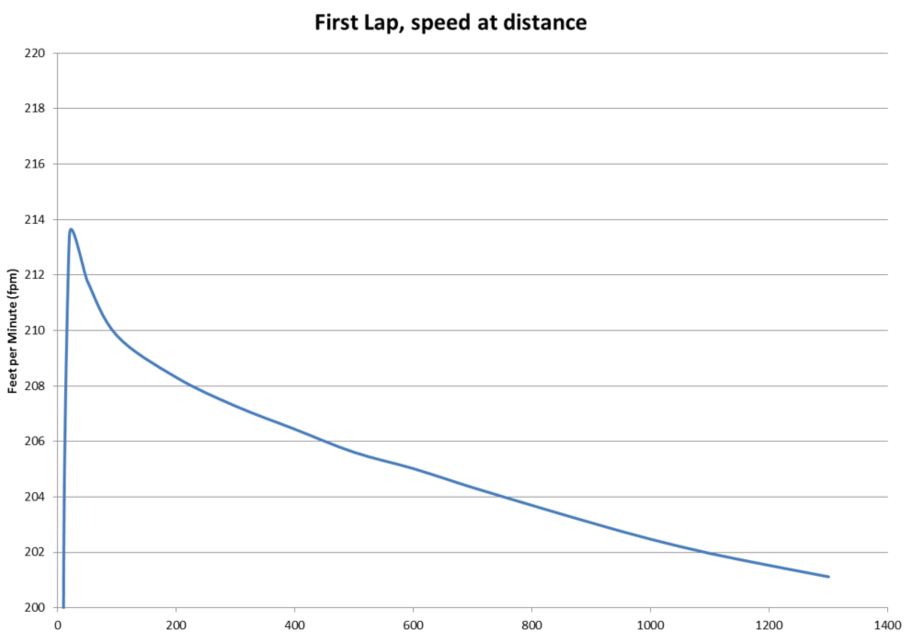
Hollis H320

The completely new design H320 (R) stands next to the H160 (L).
It is worth observing the H160 performed flawlessly.

The Hollis H320 has a completely new design motor, which draws an average of 1880 Watts from the battery. This scooter, when brought up to maximum speed, would quickly overdraw the battery system, tripping protective circuitry. The scooter would typically die within 300 to 600 feet on the track. This happened for all three test divers.

The battery would not recover in the water, and had to be connected to a charger to reset.

Because of the extreme shortness of the run(s), the speed produced was artificially higher than would have been seen over two ¼ mile runs. Therefore the results show a blank result for speed.



Speed decay as seen along the length of the track.

The speed seen during the beginning of a ¼ mile run is typically 10 to 12% higher than the overall result. The H320 exhibited 292 fpm during this high speed portion.

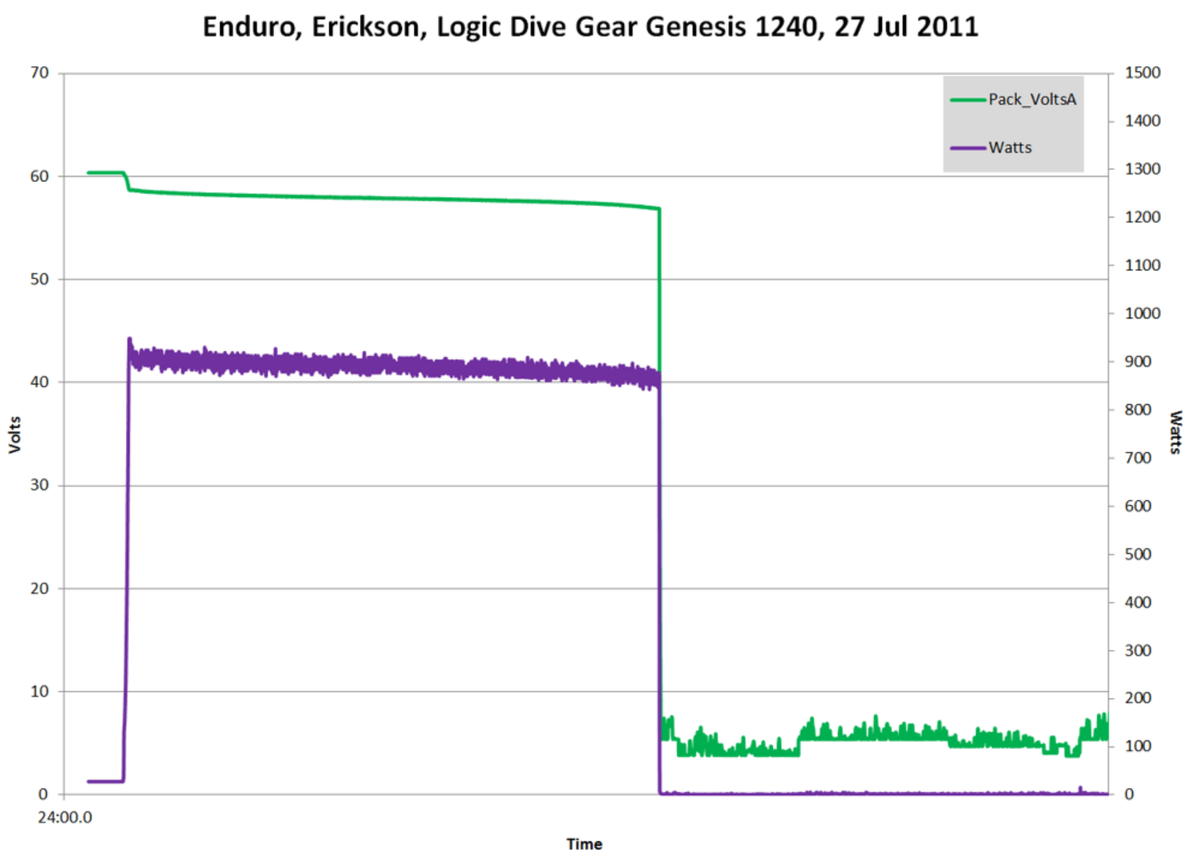
Because this scooter was configured by the manufacturer representative on-site, the results stand as tested.

Logic Dive Gear Genesis 1240

The scooter died sooner than expected and would not restart underwater. Upon opening the scooter, the manufacturer noted the battery was not latched down and a connector on the data recorder had pulled partially out of its housing. This connector was previously identified as being loose when installed in a different scooter. The data showed transient low voltage that could indicate either a battery failure or voltage drop from the high resistance of a barely mated connector caused by the shifting of the battery. The manufacturer reconnected the loose connector, the voltage returned to normal and scooter operated in air, but it was not immediately run under a load to verify whether it was a battery or connector related event.

The tail section of the Logic Dive Gear Genesis 1240.

Since the manufacturer is responsible for the battery design and also installed the battery and data recorder prior to this test, the results stand regardless of the cause.



The last lap of the Enduro for the Genesis 1240. Of interest is the sudden drop from ~58 Volts. The Genesis had the highest voltage of all the scooters tested.

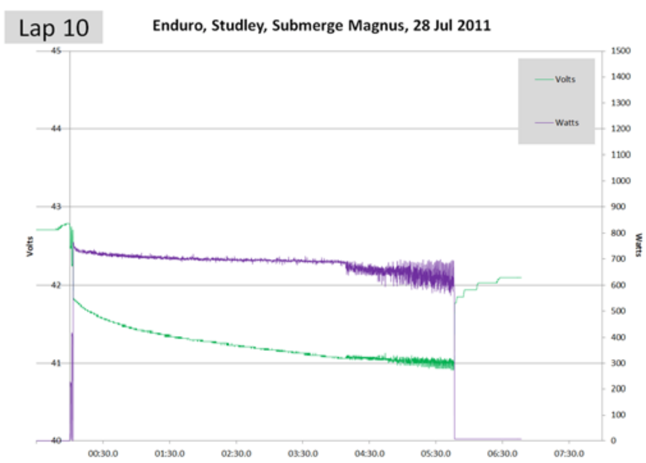
Submerge Magnus

The testing protocol calls for an end to the Enduro test when:

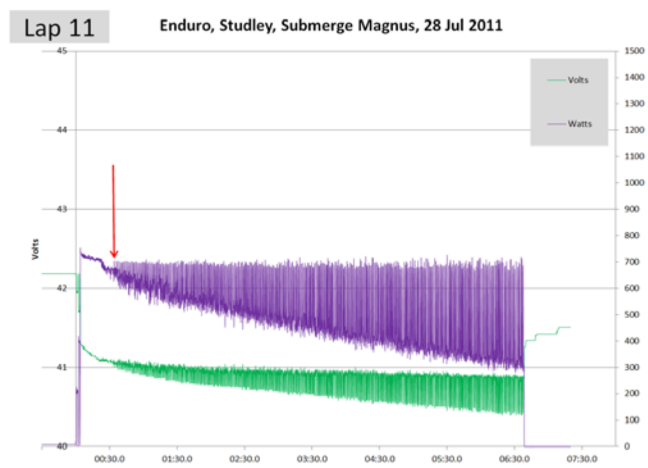
- Speed drops below 100 fpm, or
- First point of electronic battery protection

Rodney Nairne preps the factory Magnus for an electronics package.

Examination of the data showed that the electronics initiated battery voltage protection in the last third of Lap 10. However, the test diver reported a notable reduction in performance at the beginning of lap 11. This is also the point that battery protection renewed on that lap (typically battery voltage recovers somewhat during the 2 minute rest period).



As battery voltage declines to 41 Volts, battery protection can be seen to begin.

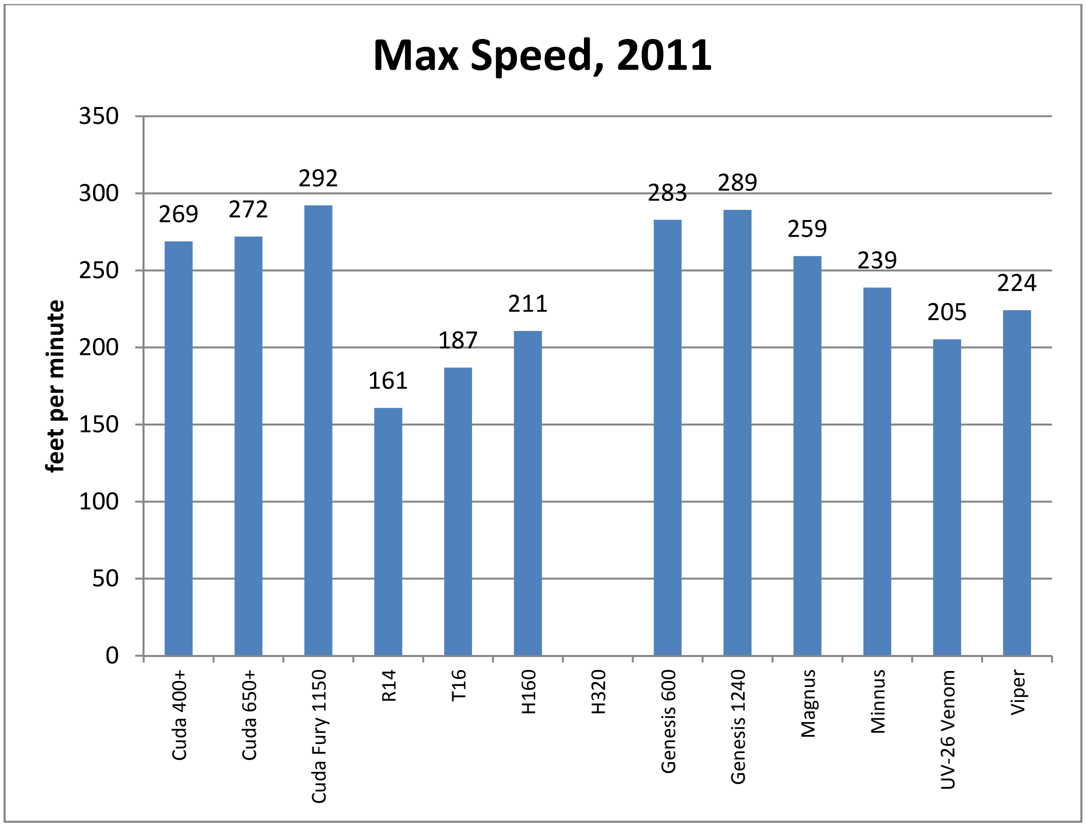


With the "bump" in Watts, the diver felt the decline in output, and the Enduro ended at this point.

Some scooters initiate their battery protection by dropping their speed to a lower setting. Since the test divers were instructed to note a sudden reduction as that point, and it coincided with the battery protection, the Magnus was deemed to have an endpoint at the 30 second mark in Lap 11, not earlier in Lap 10.

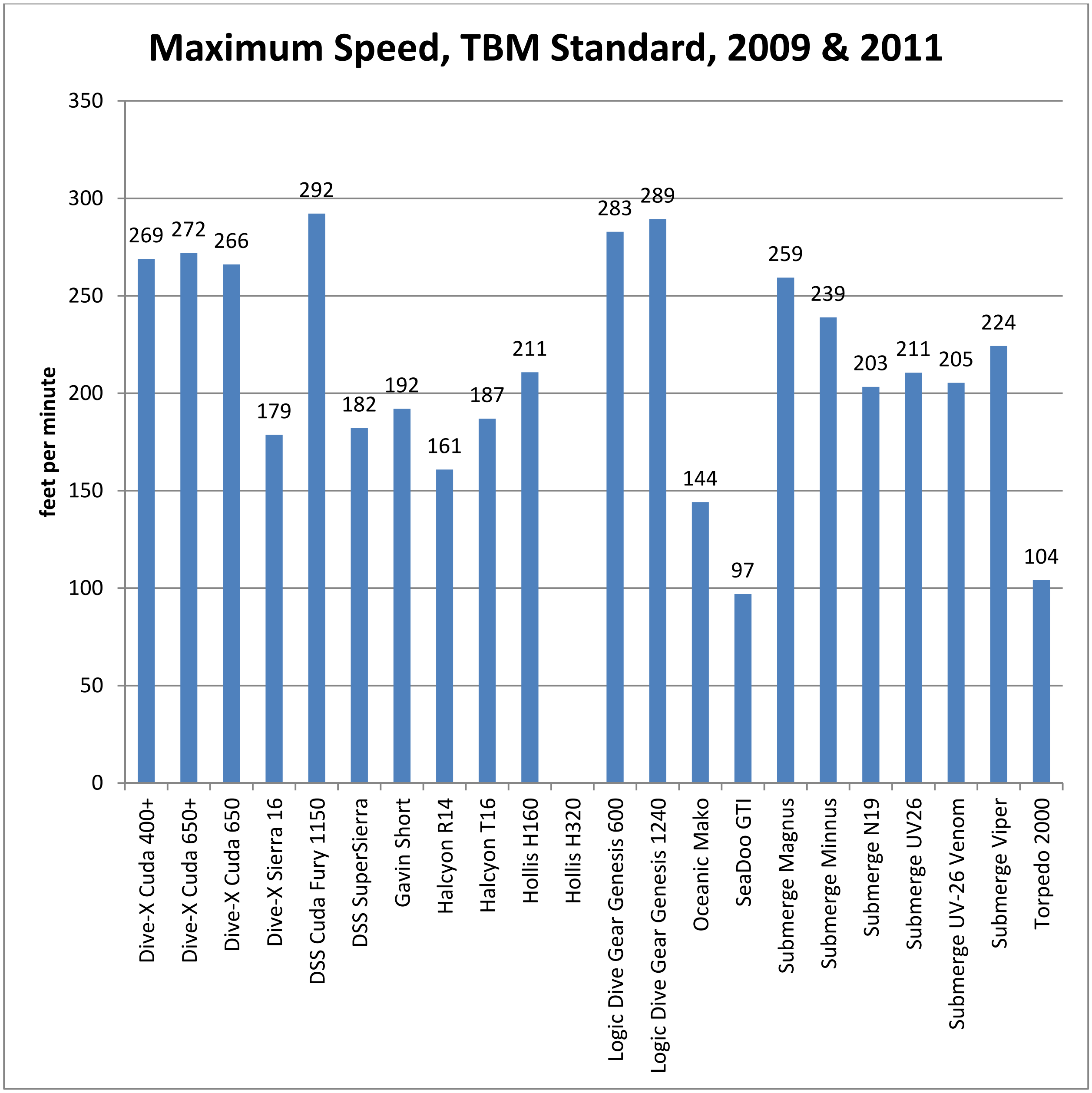
Maximum Speed Results

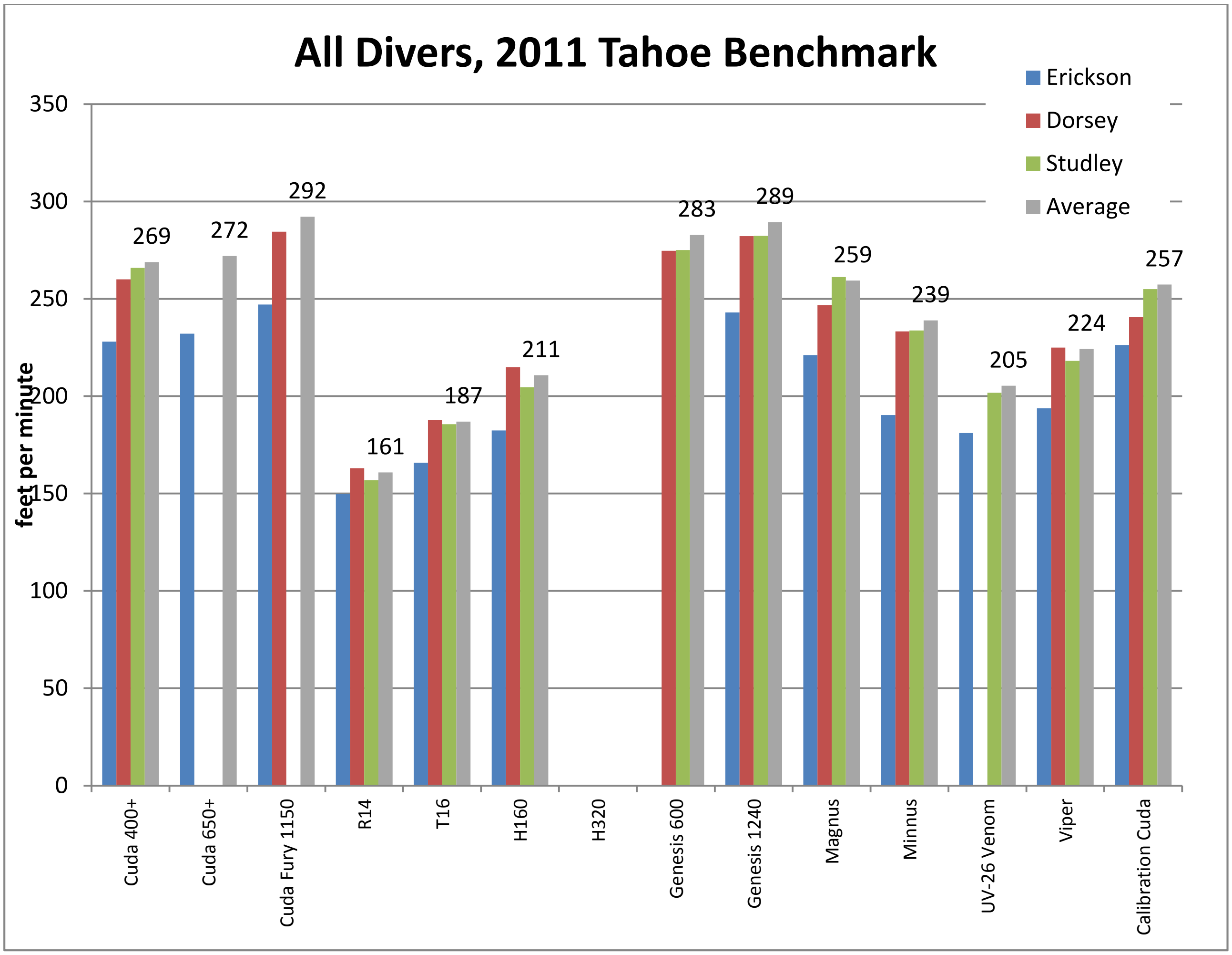
Found in the Tahoe Benchmark Standard configuration of drysuit, BP/W and a single steel 72, these are the speeds over two opposite-direction ¼ mile lengths. There is a 2 minute pause between lengths.



It is worth observing here that each 50 fpm "step" – 150 fpm, 200 fpm, 250 fpm & 300 fpm – represents an underwater performance increase that is substantial, involving significant demands on the equipment and the diver.

James Flenner (L) & "Data Boss" Larry Hanlon review the performance of test diver Claudette Dorsey (C) as Tobin George (R) of Deep Sea Supply looks on. Periodic reviews were part of the overall quality control of the project.


Maximum Speed, TBM Standard, 2009 & 2011
feet per minute
0
50
100
150
200
250
300
350
269
272
266
179
292
182
192
161
187
211
283
289
144
97
259
239
203
211
205
224
104
Dive-X Cuda 400+
Dive-X Cuda 650+
Dive-X Cuda 650
Dive-X Sierra 16
DSS Cuda Fury 1150
DSS SuperSierra
Gavin Short
Halcyon R14
Halcyon T16
Hollis H160
Hollis H320
Logic Dive Gear Genesis 600
Logic Dive Gear Genesis 1240
Oceanic Mako
SeaDoo GTI
Submerge Magnus
Submerge Minnus
Submerge N19
Submerge UV26
Submerge UV-26 Venom
Submerge Viper
Torpedo 2000



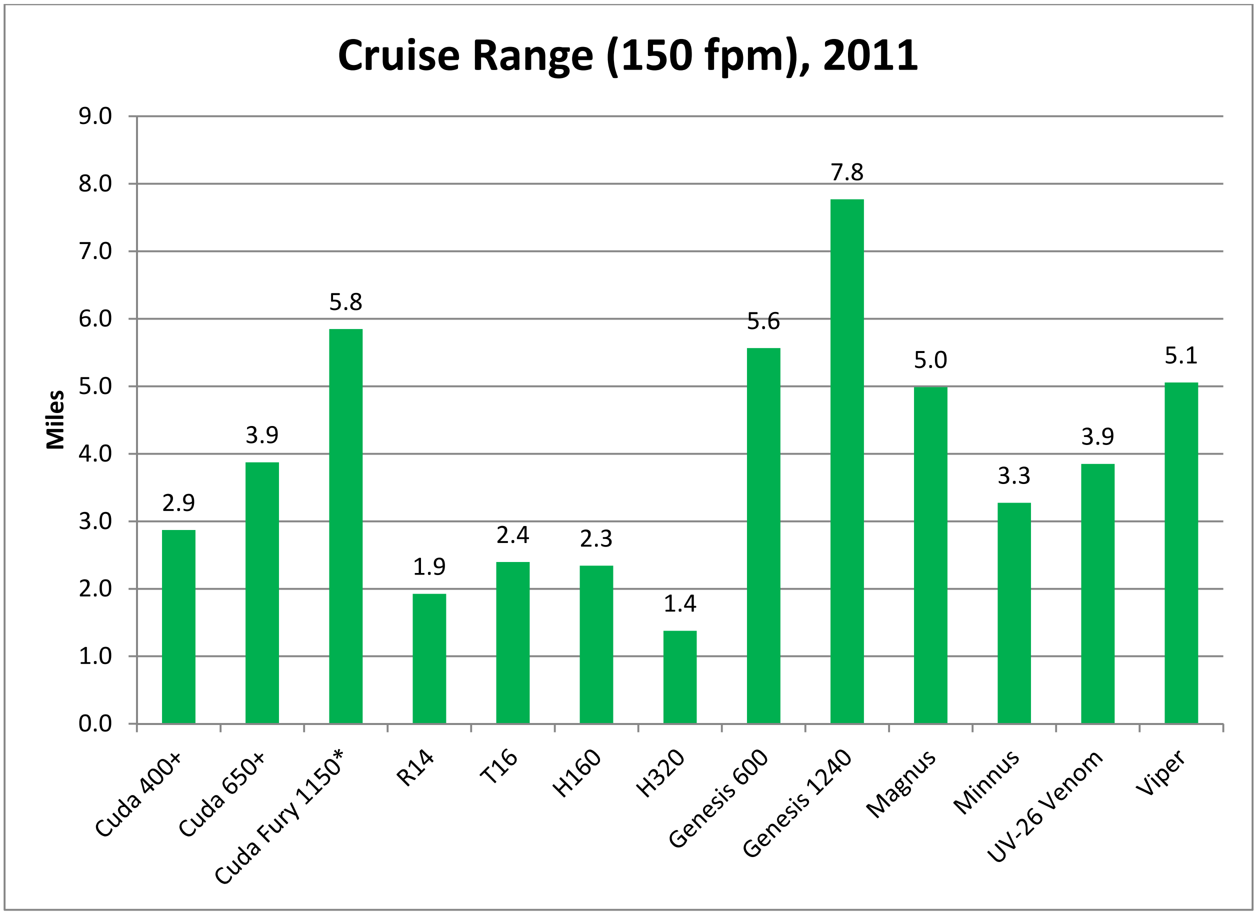
The 2011 Max Speeds. As a population, the test divers were slightly slower than the 2009 results. The Average includes the correction obtained from the Calibration Cuda (seen far R) to make these results integrable with the 2009 test.

The divers' results were scrutinized daily, looking for anomalous runs and errors. As a generalization, divers were told to run as fast as possible. However, above all, consistency was the most important quality we expected, and the test divers exhausted themselves to deliver that.

The return of the chuck wagon: Mary & John Ryczkowski donated time and food to keep the test divers, staff, volunteers and manufacturers fed during the week.

Range at Cruise

One of the few direct comparisons, this test also is an excellent reference when anticipating performance differences in teams of mixed scooter types.



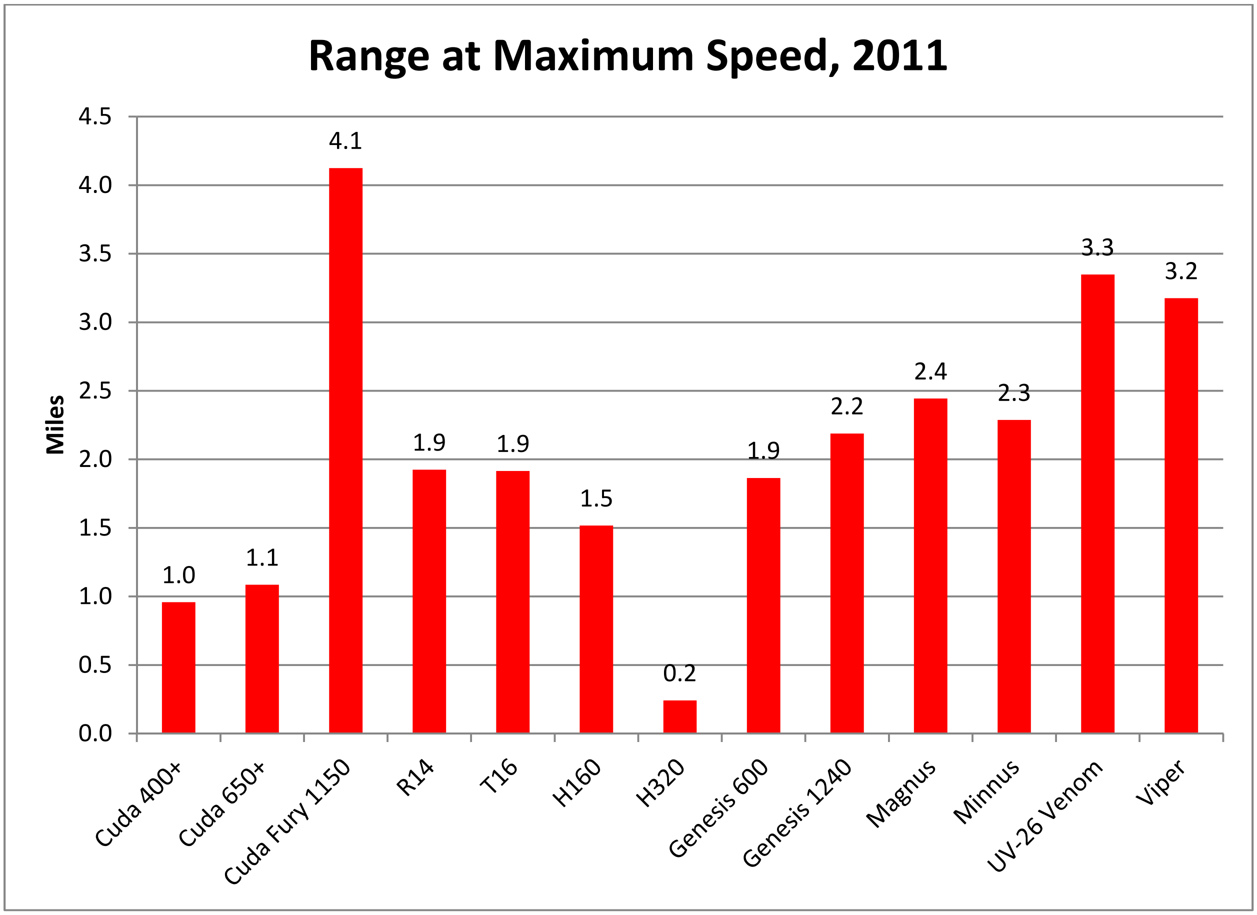
*: at 207 fpm

After each scooter was configured to run at 150 fpm[12], either via prop pitch or electronic speed control, it was run over two opposite-direction ¼ mile lengths. The performance of the scooter was harvested from the data recorders; cruise range was found by combining the battery capacity (from the Enduro) with the watts found in the Cruise test. Because the Enduro is a high-draw test, and batteries generally produce more watt-hours at lower draw rates, these results are generally conservative[13].

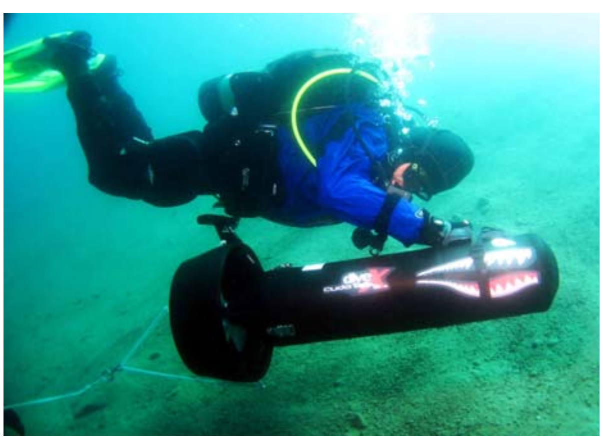
Range at Maximum Speed

Without a doubt, the Enduro is the hardest test the scooters experienced during the week.

The batteries have maximum draw in watts. The motors and electronics gain their highest temperatures. Strain on physical components is highest, and cumulative.

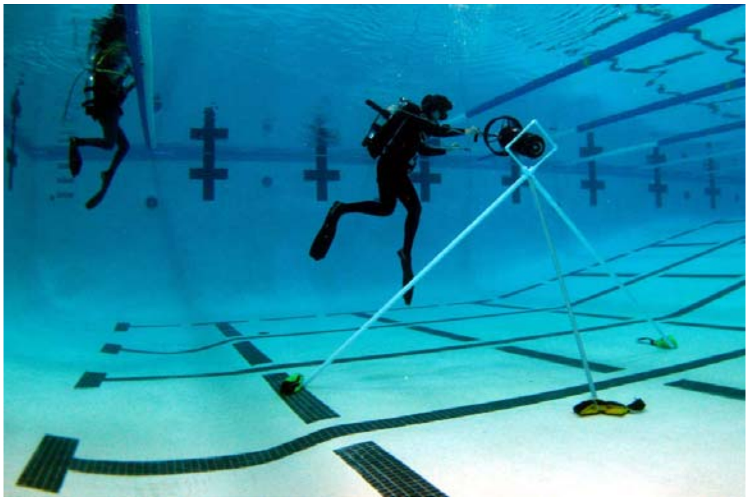


These results can be very deceiving. Faster scooters see a significant reduction in range, and slower scooters benefit. This is because power (watts) varies as the cube of speed[8]. Doubling speed results in an 8 times increase in watts required. Although these data do not allow direct comparison, they are useful from a planning perspective.

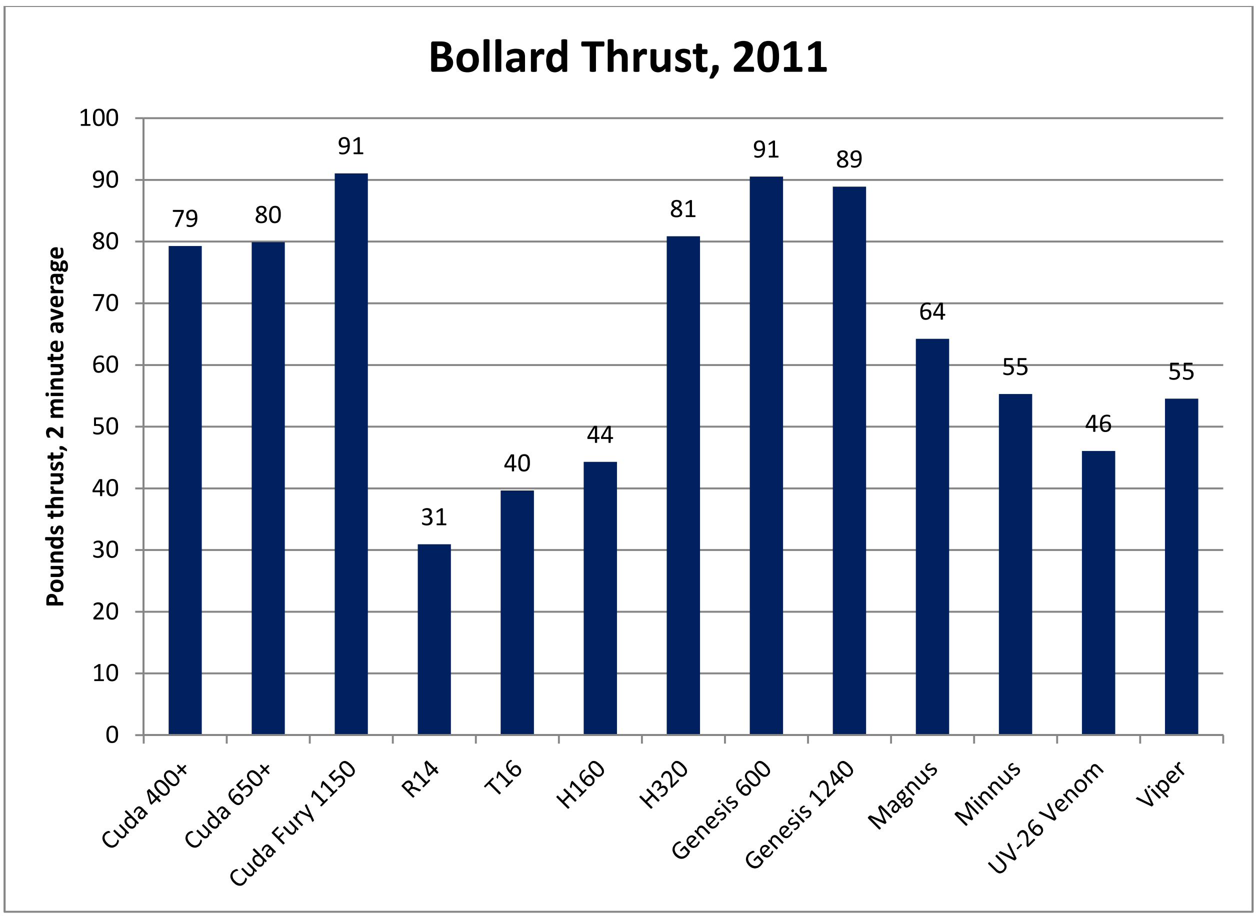


Vic Erickson swims a scooter home after being drained in the Enduro.

Thrust



The only "diverless" test performed, this involved placing each scooter in static water, restrained in a test stand, and run at maximum performance for 3 minutes.



The thrust produced has been extremely useful when predicting speed and, especially, load-pulling capacity.

Care should be taken, however, when attempting to project these data beyond those points, as other variables significantly alter the results.

Technical Results

Claudette Dorsey in the Tahoe Benchmark Technical configuration. Additional stage bottles add significantly more drag.

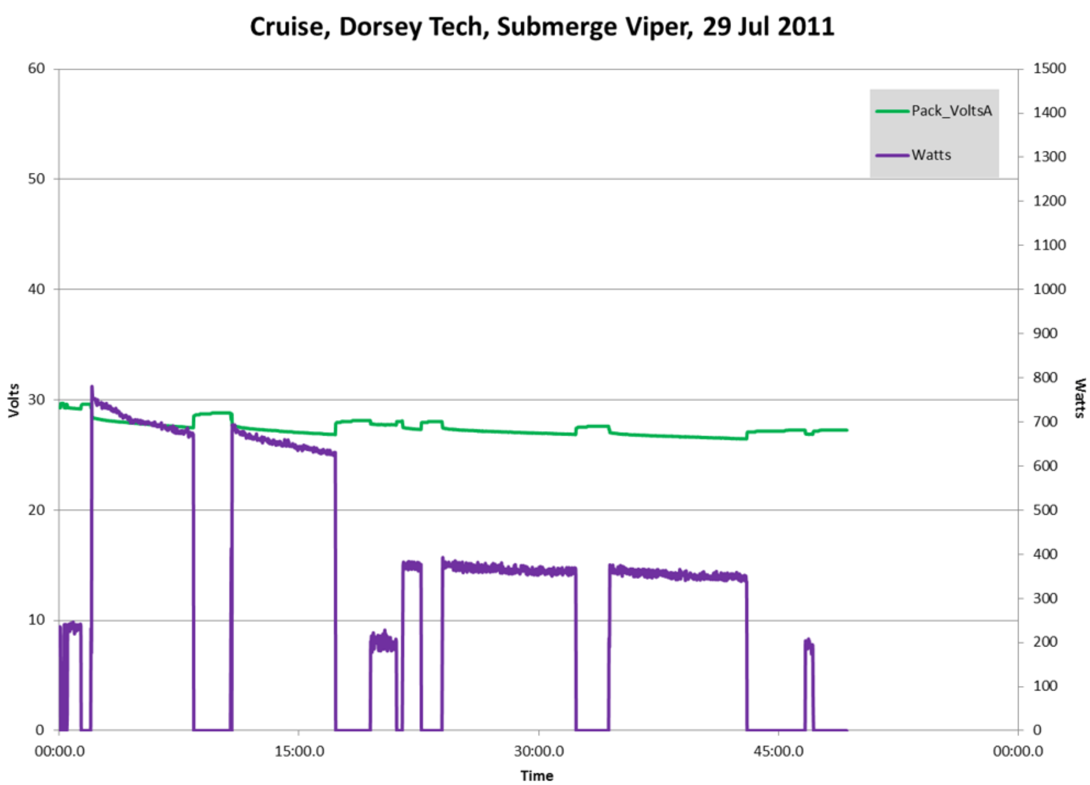
Also known as the "high drag" tests, these are essentially similar to their analogues in the TBM Standard configuration, albeit in different gear:

- Drysuit
- OC doubles
- BP/W
- Luxfer aluminum 80 stage of

50%, filled to 3000 psi

Due to time constraints, not all scooters were tested for tech. Manufacturers with roughly similar models were asked to choose one and present it for testing. Thus the Cuda 650+, the Genesis 600, and UV-26 Venom were not tested simply as a function of running out of time in the week.

The Hollis H320 was performing make-up tests and not available for the technical portion. And, the Halcyon R14 would not attain cruise speed (150 fpm) in technical gear, and was not tested.

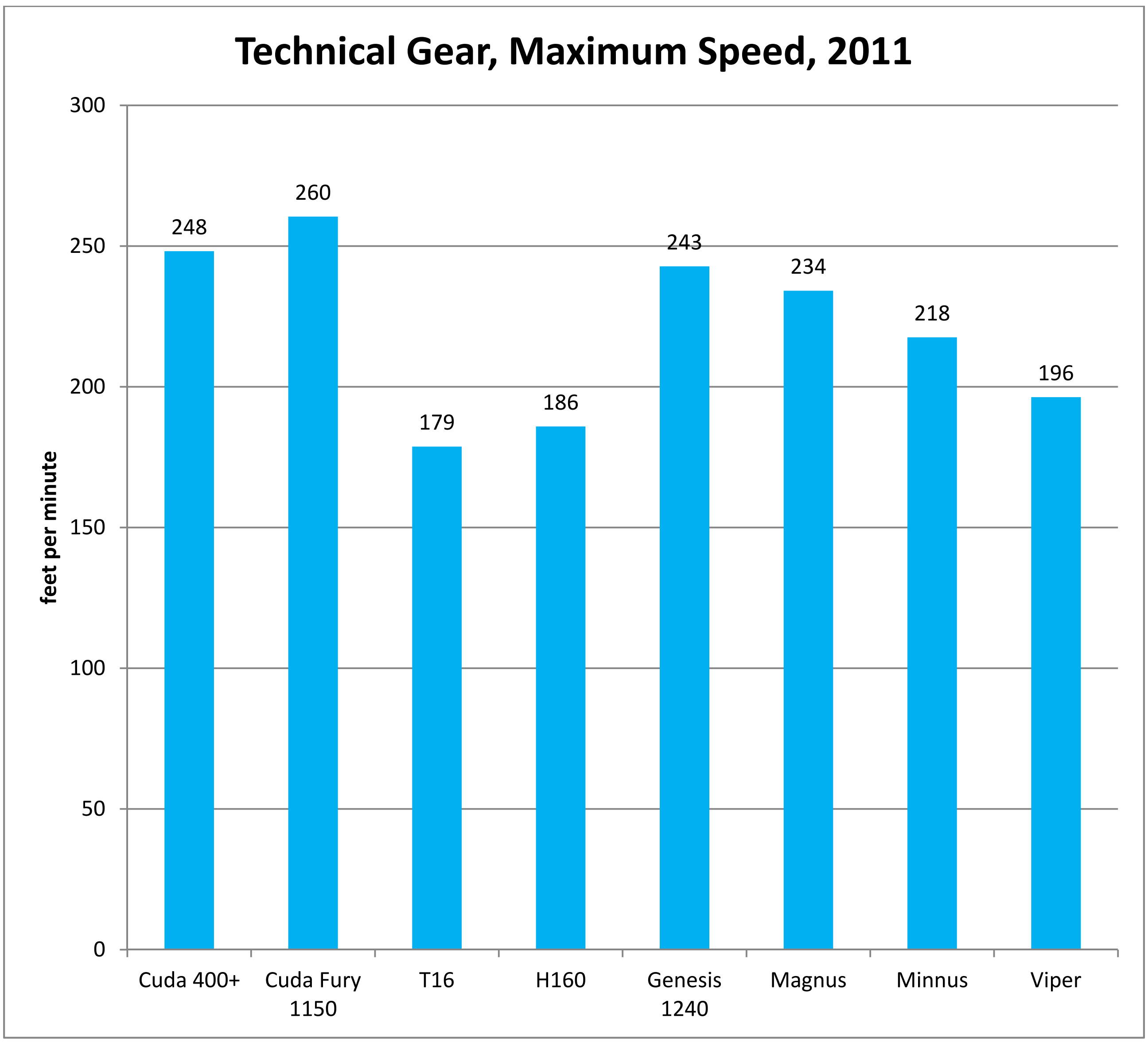


An example of a typical Tech gear test run. Note the two high speed laps, followed by short 300' lengths to set speed for 150 fpm, then, two cruise laps.

Technical – Maximum Speed

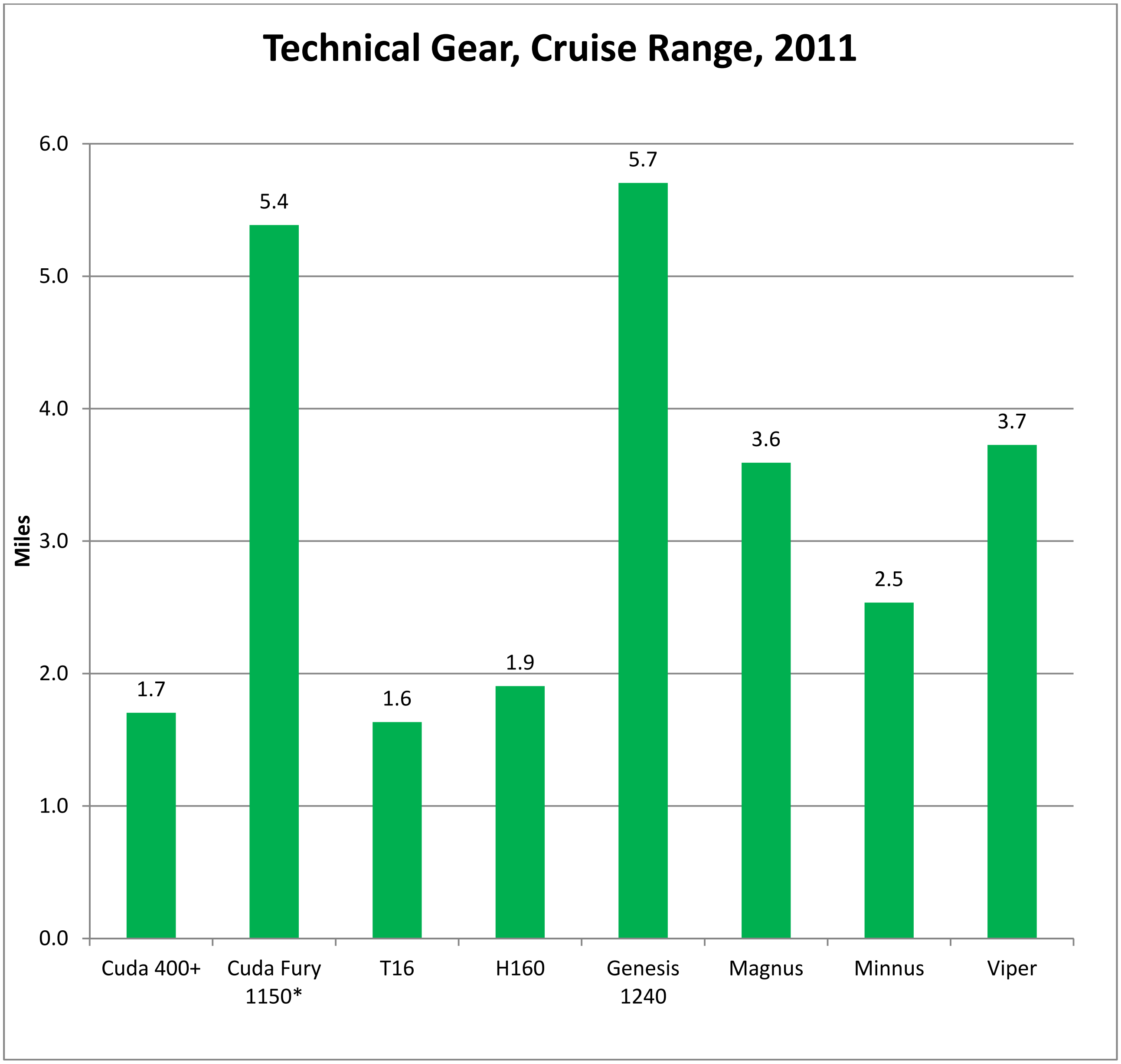
These Maximum speed results are the product of very experienced scooter pilots who had been practicing speed runs all week, with special care given to trim and buoyancy. These data represent the upper limits of speeds that should be expected. For example, adding an additional stage adds 10% drag; a “floaty” stage adds 12%. The latter is of interest, because of a pervasive urban myth that tail-light (“floaty”) stages are “more in the slipstream” and thus cleaner. Our experimentation has shown the opposite to be true.

Also, 5 degrees head-up trim (from true horizontal) will add an additional 15%. Our test divers could not even see ahead of them, as they concentrated on flat trim. Thus, all of these factors combine to produce the upper speeds possible by divers in technical gear.



Technical – Cruise Range

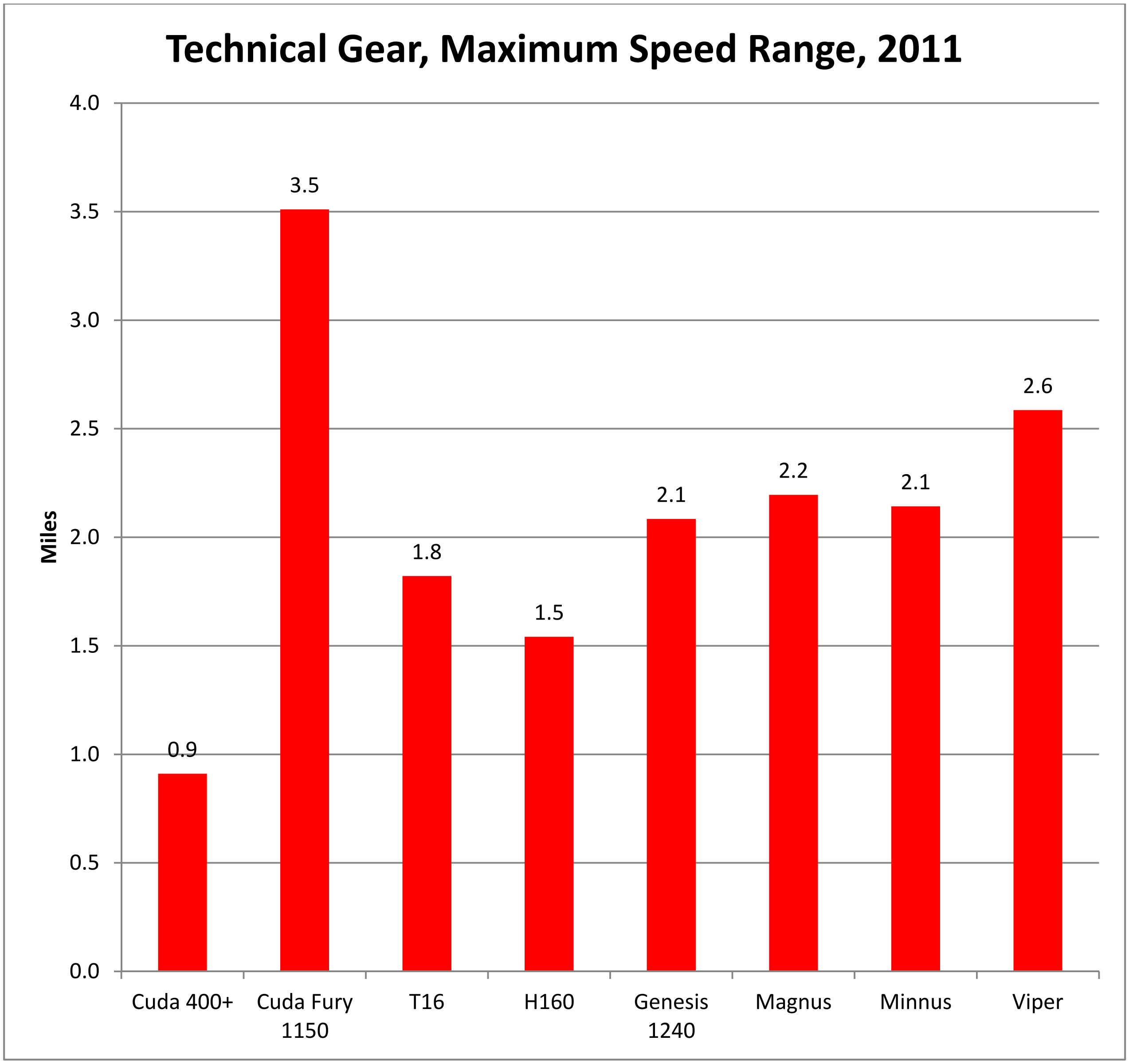
Again, this was run over two opposite ¼ mile lengths after configuring the scooter for 150 fpm.



**: at 194 fpm*

Technical – Range at Max Speed

Similar to the Enduro for the Standard configuration, this is the range to be expected if run at Maximum Speed until dead.



With only one day budgeted to testing the Technical configuration, range was extracted from the draw rate, speed exhibited, and known battery capacity from the Enduro.

Industry trend – is newer better?

One of the volunteers, Janet Flenner, walks the Hollis H320 out of the lake. The Hollis H320 is built entirely of new technology.

Manufacturers were requested to send only new models, nothing which had been tested prior[14]. It is significant that we had 13 different scooters to test.

Since 2008, the Tahoe Benchmark has been the home of new technology for scooters. This year was no exception, as we saw the highest concentration of new technology to date, in the form of motors, batteries, and propellers.

Many of the problems seen in 2011 stemmed from the maturity (or lack of it) in this new technology.

Much of the new technology has great promise. However, the integration process with current scooter design has been very compressed, timewise. Scooters were arriving to the testing with manufacturers still assembling or adding features. Two scooters were not available for testing the first day because they were still being assembled as prototypes.

As is typical in design-and-test cycles, these new features will eventually mature, and over the next year, divers will reap the benefits. Still, this year's testing showed the current lack of maturity in some of the technology.

Benefits from New Technology

1. Our experimentation has long shown that speed control by varying RPM is more efficient than adjusting prop pitch. This year, the Submerge scooters took advantage of this by adding electronic speed controllers to most models. The positive impact of this is seen by comparing the cruise range results of the UV-26 Venom (2011) vs. the UV26 (2009), with an additional ¼ mile in range.
2. The new propeller and duct design of the Dive-X Cuda 650+ resulted in 12% more thrust, when compared with the 2009 Cuda 650, while maintaining efficiency at slow speeds. The DSS Cuda Fury 1150 also had a new propeller design, which produced 20% more thrust.
3. As a general population, the 2011 scooters were smaller and lighter than any year prior, making them more user friendly.

Tobin George of DSS assembles the Cuda Fury 1150. The propeller is entirely new.

Battery capacity

A trend that became obvious in the 2011 tests is the lithium revolution. More scooters in 2011 were powered by lithium batteries than in 2008 and 2009 combined.

Two of the seven lithium packs tested at the 2011 Benchmark

Lithium battery packs have numerous advantages – light weight & excellent power density are the two biggest reasons lithium is selected as a battery chemistry. Smaller scooters that run farther, and faster, are the obvious payback – albeit, at twice the price per watt-hour of NiMH.

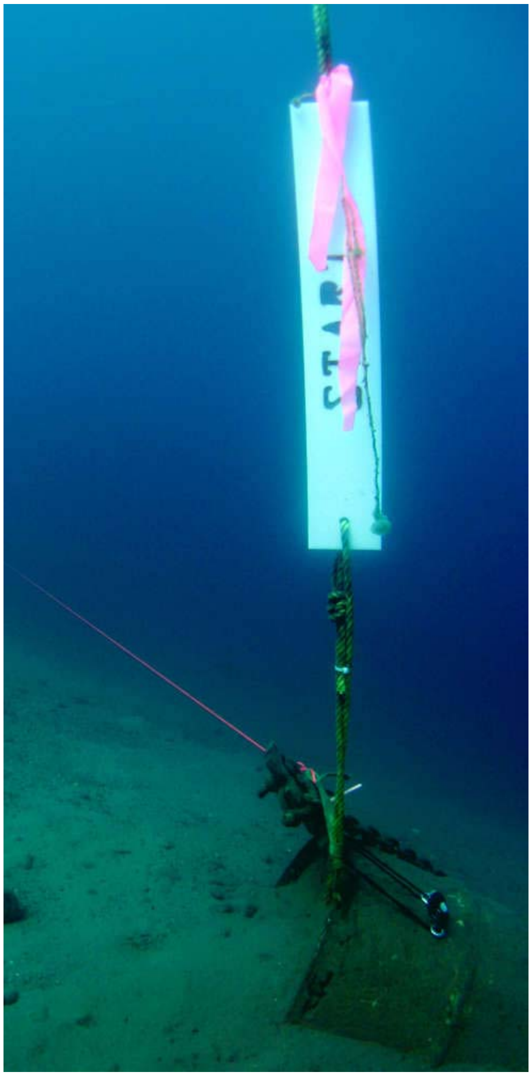
Here the lack of maturity stems not from the battery itself, but from the way the rest of the world has not figured out how to deal with the fast advance of battery technology.

Hence, we see that regulations governing the transport and shipment of battery packs made from lithium cells to be restrictive(15)(16) and difficult to fulfill, with no relief in sight. If anything, regulations have become more restrictive over time. It has become very difficult and prohibitively expensive to ***legally*** ship a production(17) lithium scooter battery by air, and simply difficult to ship by ground(18).

It is also very difficult to quantify lithium technology. There is great difference in sourcing a battery pack with extensive testing and design cycle time, versus one that is simply welded together and thrown in place, and this difference is not seen by a cursory reading of specification sheets.

The design and manufacture of very large capacity lithium battery packs is very much a new field. Again, the pace of new technology advancement obscures this, and the prudent diver will dig deep to find design maturity.

The safety of the battery charging, price of purchase, price of delivery, the complexity of the electronics – all are factors the diver must balance when considering lithium for their scooter.



The Tahoe Benchmark's role

Although pleased with the contributions of the benchmark, the researchers worry that results from past testing may have resulted in market pressures that have changed the landscape for the worse.

Prior, there was no reliable way to measure the performance of a scooter. Now, divers can look up numbers – and the number that gets thrown around the most is maximum speed. Manufacturers have been addressing this in developing new products.

What has followed is a "scooter arms race" of sorts.

Scooters have been built to be faster than others. Motor demands have reached the limits of what batteries can supply, almost making expensive Lithium batteries a necessity. One scooter exhibited a draw of 1880 Watts, enough that would trip the circuit breaker in a common household wall socket. Two new scooters had a system voltage of 66 Volts, far beyond the industry norm of 24 Volts from just a few years ago. Prices are in the range of US $6,000 – or more.

Speed, for speed's sake, is not a viable single engineering goal for a piece of life support equipment. Speeds now are at the upper limit of usability in a utility sense, and engineering compromises are being made to gain that speed.

The original intent of the Benchmark was to discover the real performance numbers of scooters we used in real diving, to allow safer dives. We intend to continue that tradition, with future testing placing more emphasis on range and efficiency, and less on pure speed.

A big word of thanks

This is a project built on the shoulders of giants. Those giants are people that don't own a scooter, are willing to work long, miserable hours at the most unglamorous jobs imaginable, and take time from their jobs to do it.

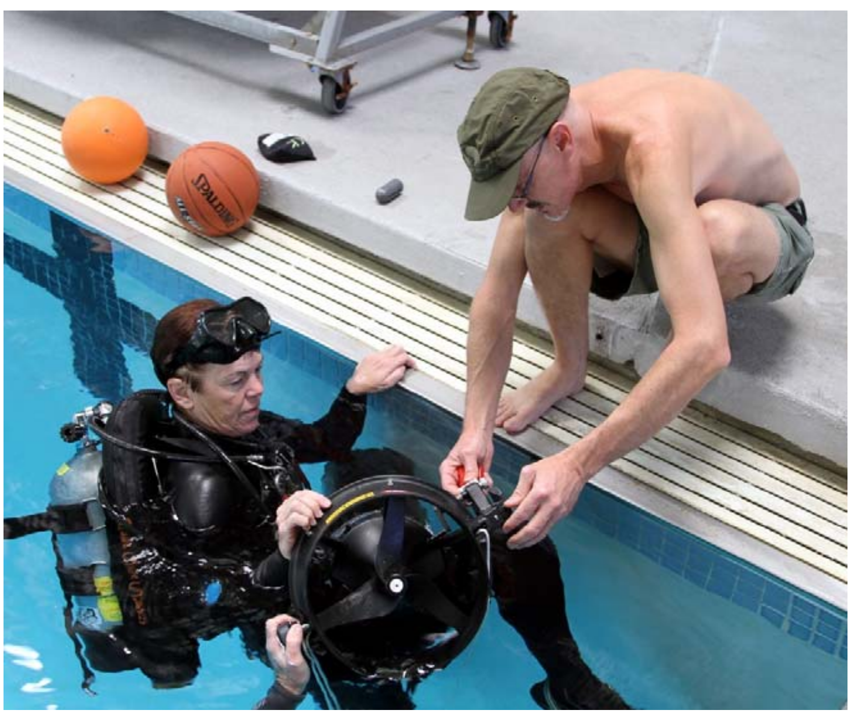
Jerry DeVore delivers a scooter to Claudette Dorsey.

We're speaking, of course, of the volunteers. Without them this project could never be. All of us owe them a debt beyond words.

From staying up until midnight – night after night – just to make sure we had nitrox fills. The folks that patiently stood by, just to snatch a test diver's fins away from them, and help them get out of their gear.

The Indy-car tank swaps when a tight schedule called for it. The complete set-up-the-circus every morning with tents, scuba tanks and tables for food. And through it all, with a genuine smile.

Steve Stokes converts a cylinder to DIN as he sets up Vic's BP/W. Simple things like this kept the divers fresh for their 4.5 miles per day.



Manufacturer Rodney Nairne of SS hands off a Halcyon scooter during the thrust testing.

This year, the Tahoe Benchmark had the help of over a dozen people over the course of the week, a number that doesn't include the staff (that drove across two states to be there), the test divers (that drove only across one), or the manufacturers (that crossed the country).

Janet Flenner checks cylinder pressures at the end of the day, allowing that night's Nitrox fills to be prioritized.

There is a new category that deserves thanks this year: you, the reader. Because of selfless donations to the Tahoe Benchmark Foundation, we had enough to cover the cost of fuel for our volunteers, and food for our people at the lake. The community is far-reaching, indeed.

No research paper is complete without comprehensive editing. We are beholden to Russell Edge for taking the time to make this paper presentable.

And finally: a heartfelt thank you to the manufacturers that attended: Tobin George, Nick Hollis, Ben McGeever, Rodney Nairne, and Jon Nellis. It was as if there wasn't any parochial divide; you were just as likely to see Nick Hollis wading in to retrieve a Dive-Xtras scooter as his own. Tobin George running to his pickup to get tools for another manufacturer, or Rodney tenderly schlepping scooters into the water as if they said "Submerge" on the side.

The sense of community – from *everyone* – was infectious, and despite the long, hard hours, everyone smiled. All the time.

Thank you just doesn't say enough. …But there it is.

Thank You.

References

1. Contact was made at DEMA 2010 with Bladefish & Sea Doo. Both indicated that they would like to participate. Letters and emails were sent with the other invitees, with no reply.
2. Torpedo made contact with staff, and indicated they had no new designs.
3. Pegasus Thruster initially indicated they would participate, and withdrew the week prior to give a demonstration on the east coast.
4. Annotated on the daily schedule sheets as the “Calibration Cuda”, this was a 2009 model owned by the staff. The scooter had the stock 2009 drivetrain, electronics, and battery. When thrust tested, it produced 70.4 lbs of thrust, vs 70.8 lbs in 2009.
5. Prior research by Tahoe Benchmark staff, 2008-2009. Data recorders were installed in ordinary scooters used for recreational (not research) diving.
6. Dropouts, caused by a test diver loosening the trigger or other causes not related to scooter design, were subtracted from the lap times.
7. Divers would note the closest 100’ marker, and write that on the scooters’ test sticker. Here is an example of a test sticker:

8. $P_d = F_d \cdot V = \frac{1}{2} p v^3 AC$
9. Two test divers used the stopwatch display of the Liquivision X1; one diver used a hand-held stopwatch.
10. The Benchmark received invaluable assistance by the Facilities Manager, Kurt Meyer.
11. The DSS Lithium Cuda cut out earlier than expected in 2009. Because the scooter was maintained and prepped by the manufacturer, these results stood. Similar treatment was given to manufacturers in 2011.
12. 150 fpm was configured over short 300’ long runs, and confirmed by timing those runs at 2 minutes. When properly configured, two complete ¼ mile runs were made in opposite directions.
13. Depending on battery chemistry and the designed C output of cells. Typically lead-acid benefits most from lower draw rates, and high-C lithium cells the least.
14. Cosmetic changes were not considered “new” models. Changes to the propeller, shroud, battery, motor controller, etc, were considered new models.
15. *Guidance Document, Transport of Lithium Metal and Lithium Ion Batteries*, IATA
16. *Lithium Battery Guidance*, ICAO
17. *UN Test Manual of Tests and Criteria, 4th Revised Edition, Lithium Battery Requirements*, part 38.3, US DOT
18. 49 CFR 172.102, Special Provision 188
19. The Oversight Committee consists of Brian Armstrong, Kevin Jones and John Sampson.
20. Peer reviewers: Tony Alba, Lynne Flaherty M.D., Peter Rothschild J.D.