DPV Bollard Pull Test

Tahoe Benchmark Research Series

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Methodology and equipment for DPV thrust testing

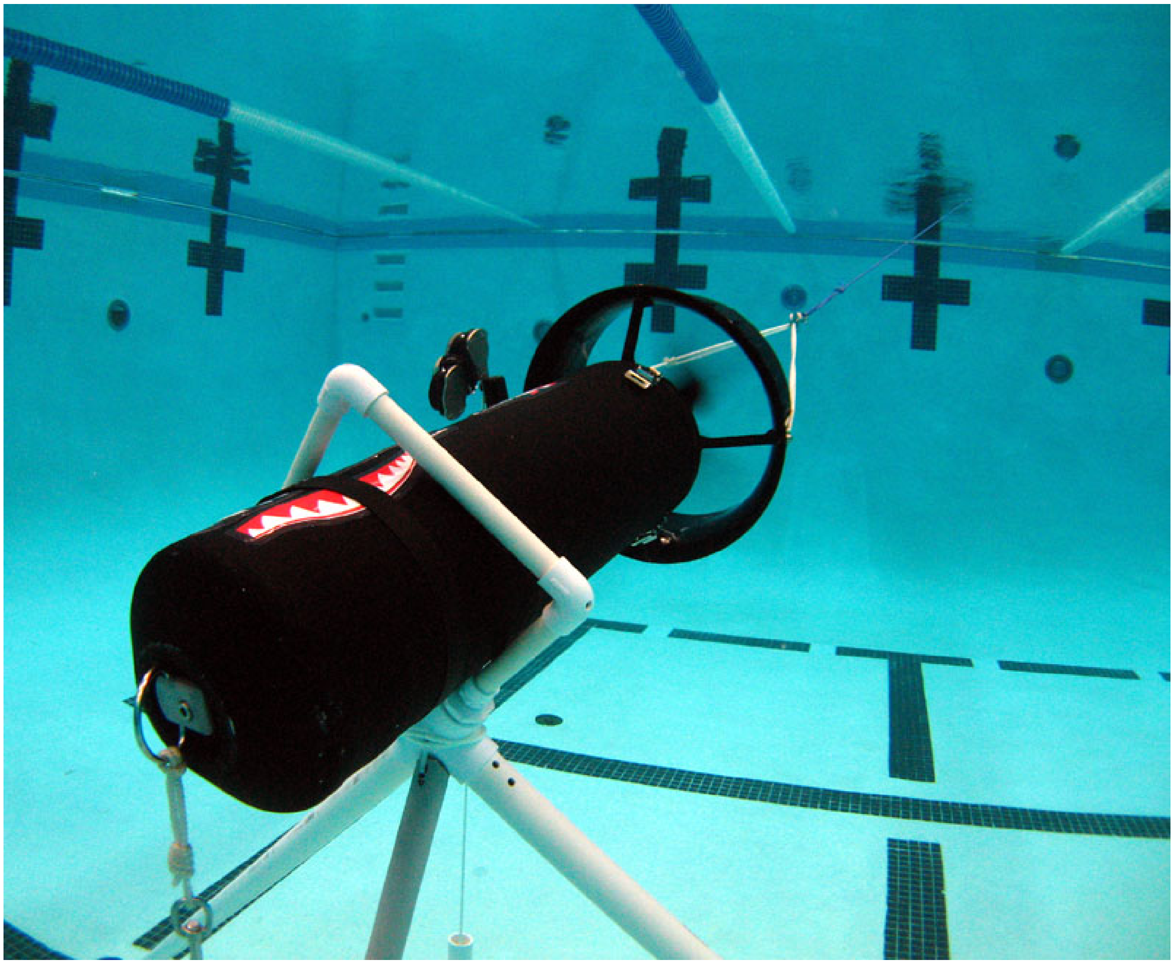
DPV Bollard Pull Test

James Flenner, Primary Researcher, Tahoe Benchmark 2009

Abstract

Diver Propulsion Vehicle (DPV or scooter) thrust has been traditionally difficult to compare. This document outlines the method adopted by the Tahoe Benchmark to allow repeatable and comparable thrust results from different DPV's regardless of location tested.

This static thrust test is adopted in part from the static Bollard Pull test used in the Maritime industry, specifically in Lloyd's Register of Shipping(1) and the American Bureau of Shipping(2). These tests are used to determine the static pull that a vessel can perform and are used as one point of baseline comparison.



DPV undergoing bollard pull thrust test. Note disturbed water where towline passes through water surface, and undisturbed water on surface to left.

Generally, the Bollard test consists of placing the DPV into the water; it is attached to a bollard on shore with a non-stretching line. The scooter is run and the thrust generated is measured with a load cell or scale. This test will become part of the testing schedule at the 2009 Tahoe Benchmark.

Expansion

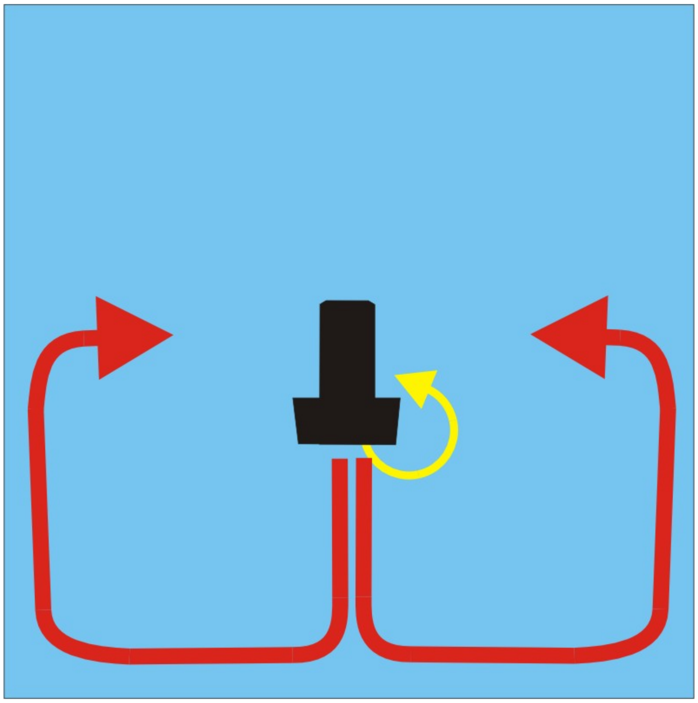
The DPV Bollard Test is performed under optimum conditions, and attempts to give every advantage to the DPV test article through manipulation of propeller slip conditions. Propeller thrust is directly influenced by propeller slip; when the propeller assembly has zero advance velocity, the propeller blade slip is 100%, and thus, thrust is 100%(3). As an unrestrained DPV gains forward speed, advance velocity increases, and propeller slip decreases, seen as reduced thrust. Generally, a speed increase of 101 fpm (30 mpm) results in a ~6% thrust reduction (4). Therefore, the Bollard Test holds the test article stationary in the water to achieve the highest slip values, and thus the highest thrust.

Upon activation of the DPV, the propeller spins in dead water, and thrust is 100%. As the Bollard test proceeds, water flow will begin to establish through the propeller disc, and thrust will begin to fall as the assembly is bathed in moving water that provides advance velocity. This is commonly seen as falling thrust as the test proceeds.

If nearby surfaces, such as the bottom of the test tank or the surface of the water, are too close, they will restrict the cross section of available water flow, and thus the speed of the water flow through the propeller increases. This is a further increase in advance velocity, and thrust will decrease accordingly (4). Such close proximity is to be avoided.

Test Tank

Although it may be tempting to perform the test in open water, this should be avoided. Due to the relatively low thrust output of DPV's, results from open water have not been found to be repeatable, due to environmental influence(5). Only results from a large volume test tank (swimming pool) have been found to be acceptable.



Water recirculation caused by too small of a test tank (red) and Vortex Ring State (yellow)

Objects and surfaces in the immediate vicinity of an operating DPV influence the water flow both into, and out of, the propeller. These objects can exhibit influence from a surprising distance. Placing a hand on the scooter shroud has caused thrust to vary by as much as 12%, and shallow (1.5 meters) depth test tanks have produced 1% to 3% less thrust(5).

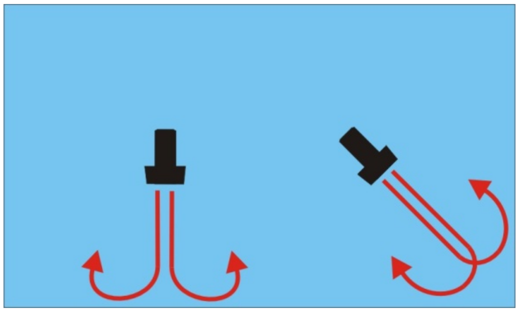
In addition, any recirculation of water will produce a marked reduction of thrust. Generally, water recirculation can be caused by a small tank (see illustration), nearby objects that allow a vortex ring state to develop, or directing thrust at a test tank wall placed too closely.

To reduce these influences, the minimum tank size is:

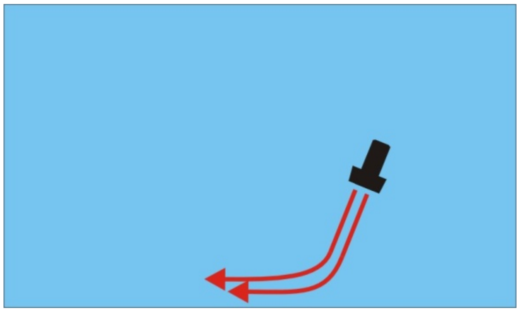
- Depth: 4 meters
- Width: (side to side with respect to the DPV) 15 meters minimum
- Length: (fore and aft with respect to the DPV) 25 meters minimum

Placement of DPV

Our tests have shown the best position of the DPV is at mid water, or at a depth of 2 meters in a 4 meter deep tank. The orientation of the scooter (in relation to the walls of the tank) is important, as well. A slight angle (75˚) in addition to a bias to one side of the tank helps reduce recirculation.

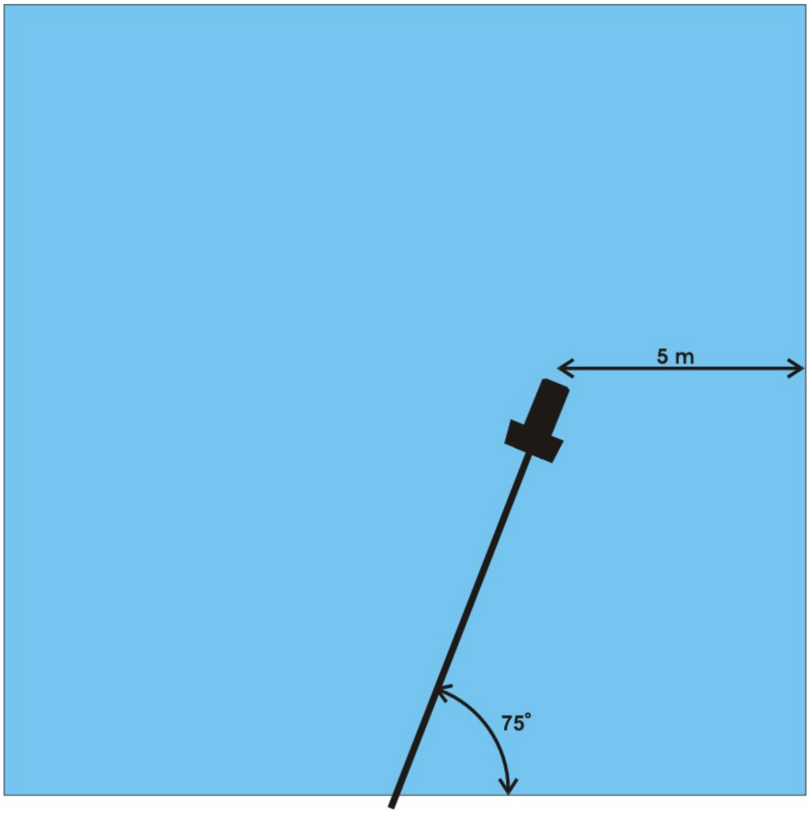


Poor placement choices



Good placement – little recirculation

The scooter should be placed no closer than 5 meters to any one wall of the tank.

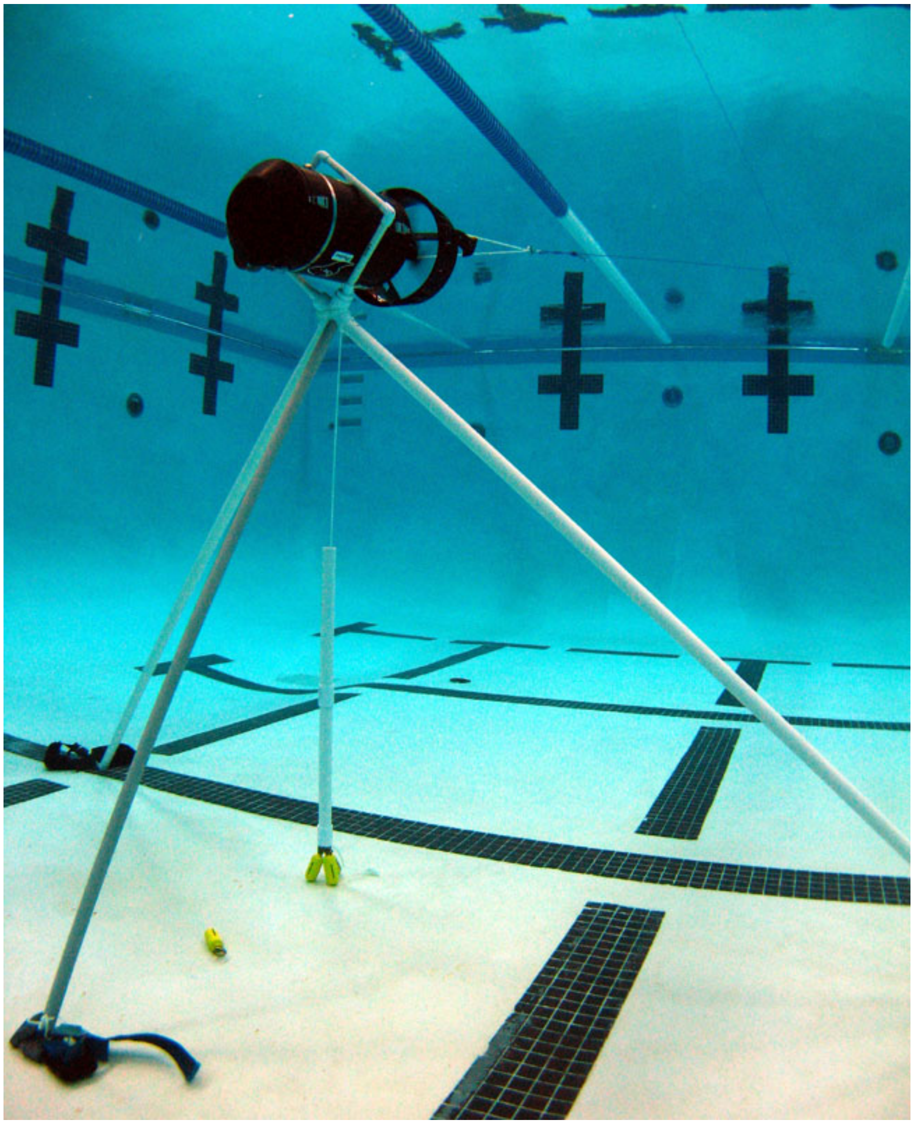


Restraining the DPV

The bollard, or immovable object outside of the tank, should be close to the edge of the tank and be unyielding at stresses of up to 150kg. The attachment of the towline is nominally placed at 1 meter above the surface of the water. This allows the load cell, which usually cannot withstand exposure to water, to be placed between the towline and the anchor, and remain above possible damage.

Towline length used is 10 meters.

Several materials have been experimented with for towline construction. Thin diameter is a requirement, since the towline is in the prop wash. Initial tests with 3.8mm Polyester braid, with 0.8% stretch at loads imposed with by the DPV, were good. However, best results came from 1/8" (3mm) Spectra braid, at 0.2% stretch. The Spectra cordage effectively anchored the scooters in place, allowing only 2cm of variation in position as the line stretched under load, versus 8-10cm for the polyester.

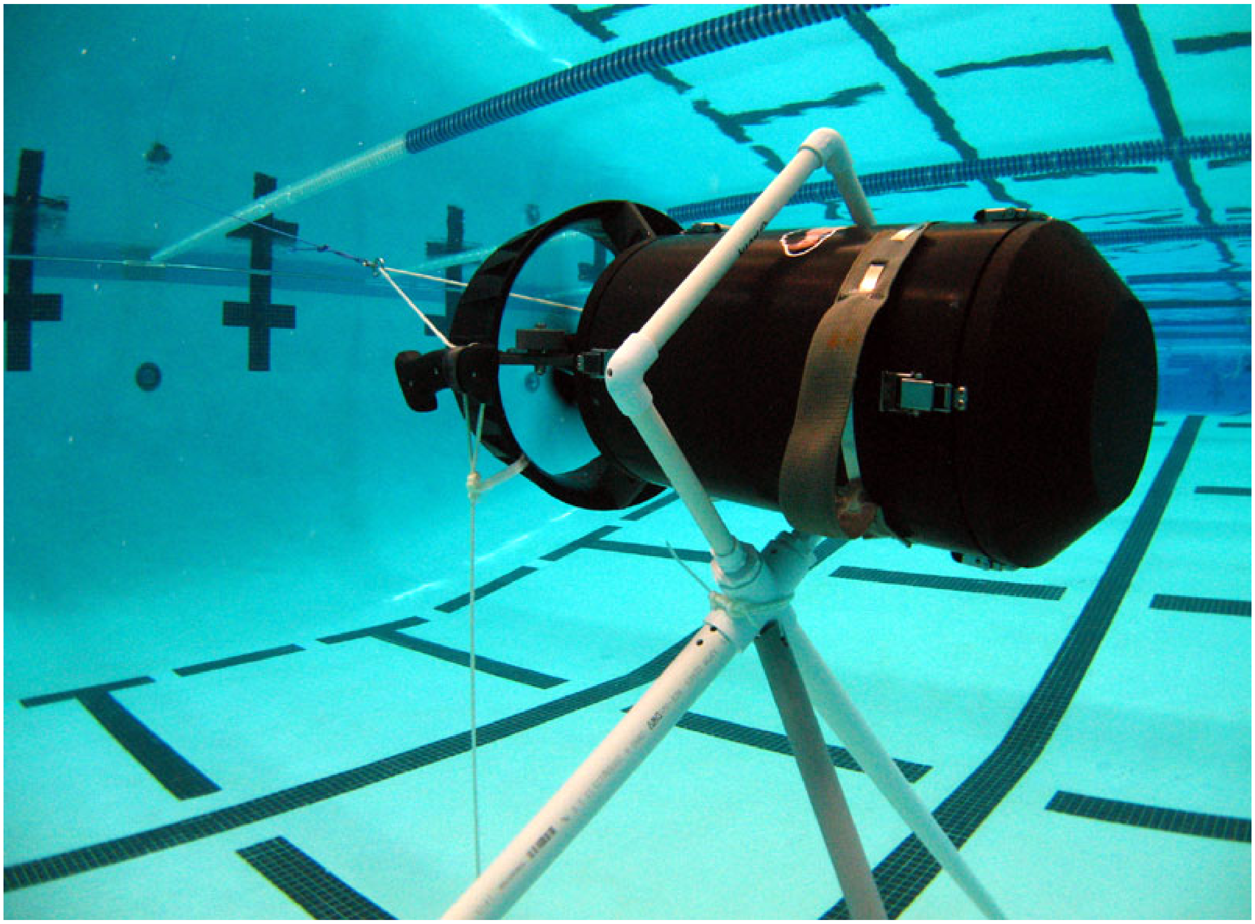


The DPV should be restrained in position underwater, lest it wander willy-nilly throughout the test tank. However, this restraint cannot alter the thrust of the DPV.

The apparatus used has been designed to avoid imparting any resistance to the fore-and-aft motion of the DPV; such resistance is seen as a thrust variation. To accomplish this, the nose of the scooter is placed inside a restraint square; this square is built oversized, such that it is roughly 1.5" (4 cm) larger than the nose diameter of the DPV test article.

This restraint square has to be rigidly supported, as flexation from side-to-side is also seen as a thrust variation. This support, or “test stand”, is constructed of 1.5” PVC and sized to hold the DPV at midwater.

The size of the restraint square may be varied, by using different length tubing sections, for different scooter bodies.



While running, the scooter will exhibit torque, or rotation around the long axis of the scooter. This means the handle will need to be restrained; this is performed by placing a length of non-stretching line from the handle to the bottom of the tank. Weights are applied as needed to hold the handle from rotating. Generally, depending on scooter performance, the weight required will vary from 3 to 8 lbs.

Configuring the DPV

The DPV should have a fully-charged battery. If possible, the charge should be the night prior, to allow batteries to return to room temperature.

The DPV will also need to be neutral in the water, and efforts should be made to assure this. Neutral in this case does NOT include the bolt snap commonly attached to the diver's crotch strap. A scooter which is not neutral will sag, or float, in the test stand and produce incorrect results.

The scooter will have the prop set to maximum pitch, and a test diver will enter the tank with the scooter. After positioning the scooter in the test stand and connecting the towline and the anti-rotation torque line, the scooter is activated. Scooters not equipped with a trigger lock may be held "on" with a simple rubber band.

At this point, the towline should be adjusted such that the restraining square is over the forward portion of the scooter hull; the ideal placement is 1/3 of the overall scooter length from the tip of the nose. Adjust the anti-torque line by adding more weight if needed, and assure the scooter is in line with the towline. Stop the scooter and allow the water to settle for 3 minutes.

Data gathering

The DPV and apparatus should now be correctly configured for the test. The data is gathered from a load cell or mechanical scale place in line with the towline. Regardless of type, the instrument should be calibrated for the expected pull, 13 to 35 kg (30 to 75 lbs), and capable of reading in divisions of 0.1 kg (0.2 lbs).

Tare the load cell, and signal to the test diver to start the DPV. Immediately after starting the scooter, the diver should retreat to a distance of at least 5 meters or more.

With the appearance of load on the instrument, a topside researcher should begin observing data. When the observed thrust data becomes steady, data recording should begin. The preferred method is a load cell that exports data to a computer; however, manually recording readings at 15 second intervals is appropriate. At the conclusion of a 3 minute data run, the diver is signaled to end the test.

If another test is contemplated, the water should be allowed to settle for at least 3 minutes without the scooter running. All testing runs and set-up test runs should have this 3 minute settle time.

A typical load cell in the 150 kg range

Categorization of Data

Data is categorized as follows:

- Sustained Thrust: the arithmetic average of all values recorded during the 3 minutes run.
- Peak Thrust: Highest single value recorded during the 3 minutes run.

When Bollard results are reported, the one that should be most correctly referred to is the Sustained Thrust figure(4). This is the one that is most consistently repeatable with equal results, where Peak Thrust is often the result of an outside influence and should not be reported.

Although most correctly reported using N (Newtons) as units, Bollard results here will be reported in either pounds, or kilograms, for easy understanding by the diving audience.

Gavin 1

Run Order					
Time	Prop	Prop	Prop	Prop	Prop
00:00.0					
00:15.0					
00:30.0					
00:45.0					
01:00.0					
01:15.0					
01:30.0					
01:45.0					
02:00.0					
02:15.0					
02:30.0					
02:45.0					
03:00.0					

All Thrust in
Pounds

Example recording sheet used during the Bollard test

Observations

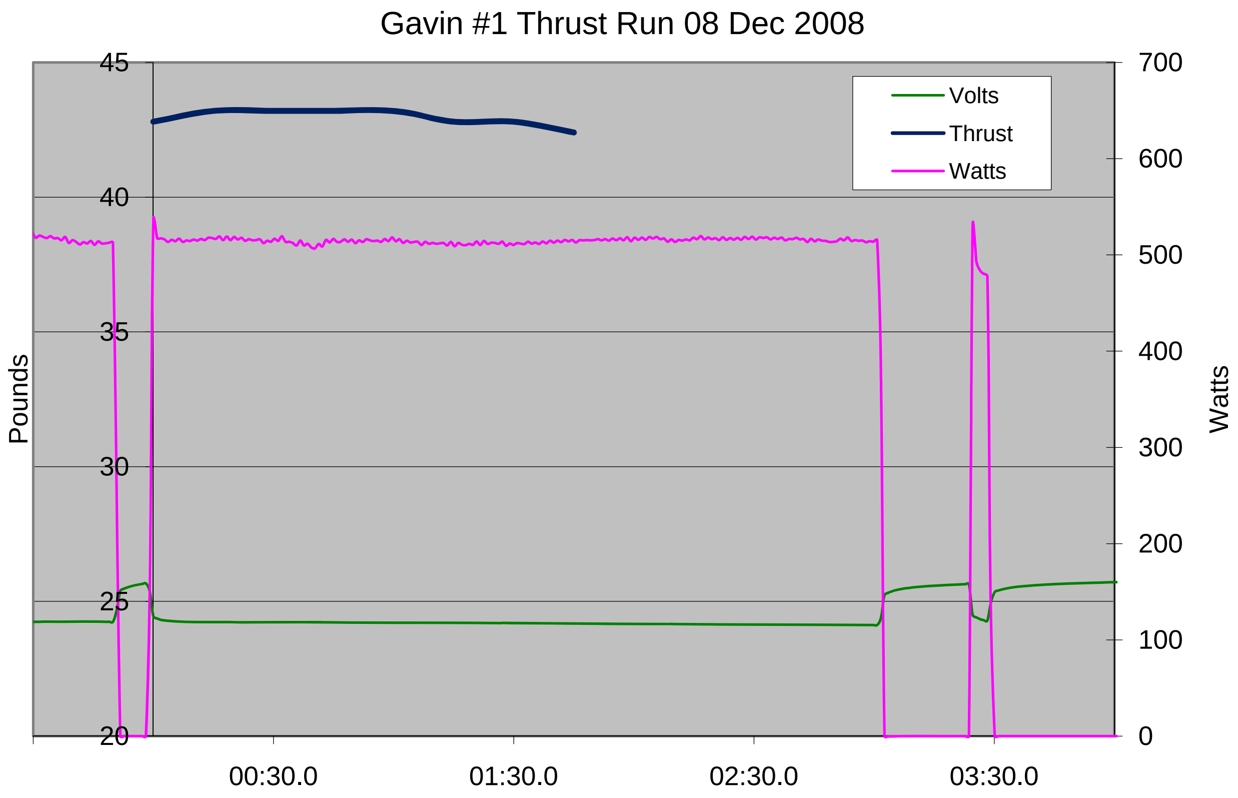
Some limited data has been gathered to date. Peak Thrust is reported here in the interests of educational comparison.

Bollard Pull Thrust

		Thrust (lbs)	
Manufacturer	Model	Sustained	Peak
Gavin	Short #1	43.0	43.2
Gavin	Short #2	32.9	33.2
Dive-Xtras	Sierra	42.3	46.0
Dive-Xtras	Cuda	72.8	75.6
Oceanic	Mako	25.0	25.2

These static bollard pull runs were noted to have an increase in power consumption (Watts), when compared to running freely through the water with a diver. Generally this is attributable to the decrease in slip caused by advance velocity(3). This highlights that although static bollard pulls have value in comparing relative performance, they are not necessarily applicable in computing burn time or in-the-water range.

		Watts	
Manufacturer	Model	Bollard	Free Water
Gavin	Short #1	493	444
Gavin	Short #2	n/a	399
Dive-Xtras	Sierra	524	439
Dive-Xtras	Cuda	1075	943
Oceanic	Mako	245	224



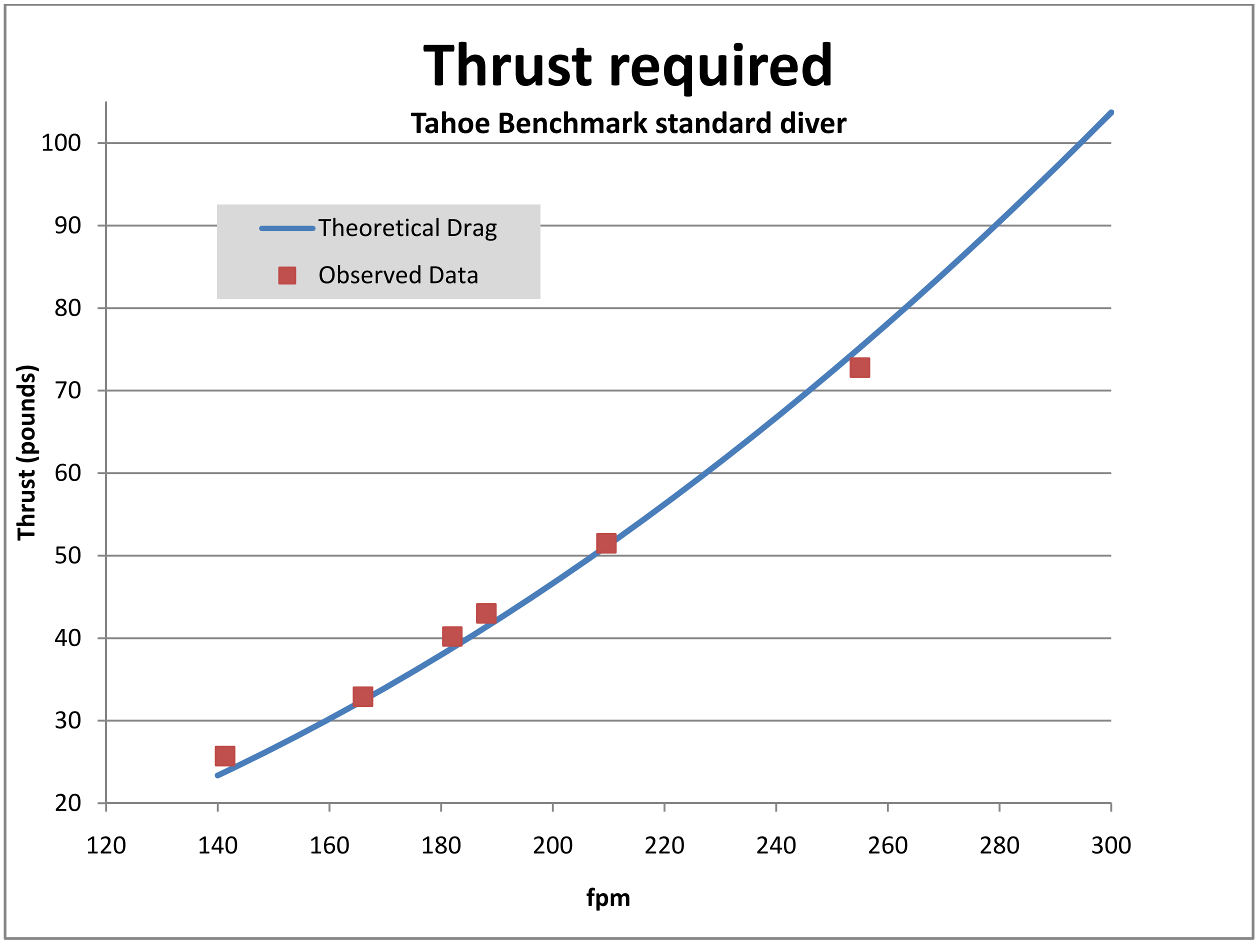
Example of data recorder results from a Bollard Pull test. Note decline in thrust as the test progresses.

Application

Drag varies as the square of velocity, as seen in the drag equation:

$$\mathbf{F}_d = -\frac{1}{2}\rho v^2 A C_d \hat{\mathbf{v}}$$

Assuming that Bollard Pull thrust is equivalent to thrust required while free-running in the water is a supposition that does not take into account losses due to decrease in propellor slip as influenced by advance velocity, or, nozzle efficiencies. However, it is possible to generate a projection of speed which may be expected from a given thrust. When the experimental observations are cross referenced with known speed results, the following is seen:



Furthermore, technical divers display more drag than they would if in a single cylinder. If a diver knows their personal conversion ratio (most divers display 1.25 to 1.45 times more drag in a technical configuration than the Tahoe Benchmark standard) they can divide Bollard Thrust by their Tech ratio. The result can be followed across the graph to yield a rough expected speed in tech gear.

References

1. Lloyd's Register of Shipping, Guidance Information, ***Bollard Pull Certification Procedures*** October 1992
2. American Bureau of Shipping, ***Rules for Building and Classing Steel Vessels Under 90 Meters (295 Feet) in Length 2001,*** Part 5, chapter 8, appendix 2, Guidelines for Bollard Pull Test, 2001
3. Man B&W, ***Basic Principles of Ship Propulsion,*** 2004
4. Hannu Jukola and Anders Skogman, ***Bollard Pull,*** 2002
5. James Flenner, John Ryczkowski, et al, Tahoe Benchmark research series, Nov 2008-March 2009