Figure 1: Typical PWC

Personal watercraft: High-speed fun, high-speed defects

A mechanical engineer explains why these can be the most dangerous vessels afloat

By Craig Good

In the 1990s, the popularity of personal watercraft (PWC) exploded in North America. Personal watercraft are vessels less than 13 feet long that use a water jet as the primary source of propulsion. The jet exits the rear of the craft from a steerable nozzle. Generally, a PWC is designed to be operated by a person positioned on, rather than within, the confines of a standard hull. A typical personal watercraft seen on North American waterways is shown in Figure 1. People have been drawn to these craft due to their high speeds, their nimbleness and maneuverability when under power, and their portability and beachability. A high power-to-weight ratio provides operators with a thrilling ride. The National Marine Manufacturers Association (NMMA) estimated that in 2009 there were 1.29 million PWCs on the waterways in the United States.

Attempts at regulation

Personal-watercraft use is not without controversy and debate. PWC owners and operators love the thrills and enjoyment they get from their jet-powered craft, yet many waterway users are frustrated with the noise and safety concerns. Tempers often flare when waterway users discuss PWCs and regulation of their use has been highly controversial. Federal and local governments have considered and enacted PWC bans on certain waterways. Most states have restrictions on an operator's age, and many now require mandatory boating-safety education for PWC operators.

Regulation varies greatly across the country. Hawaii and Pennsylvania, for example, require that all PWC operators complete a boating-safety course. Other regions mandate boating education only for certain age groups, and many extend the requirement to other motorized

vessels as well as PWCs. In Canada, proof of competency has been required by all PWC operators countrywide since 2002, and all recreational power vessel operators since 2009. Information on PWC bans and boater education and age requirements can be accessed from the Reference Guide to State Boating Laws on The National Association of State Boating Law Administrators (NASBLA) Web site at www.nasbla.net; and on the Personal Watercraft Industry Association (PWIA) Web site at www.pwia.org.

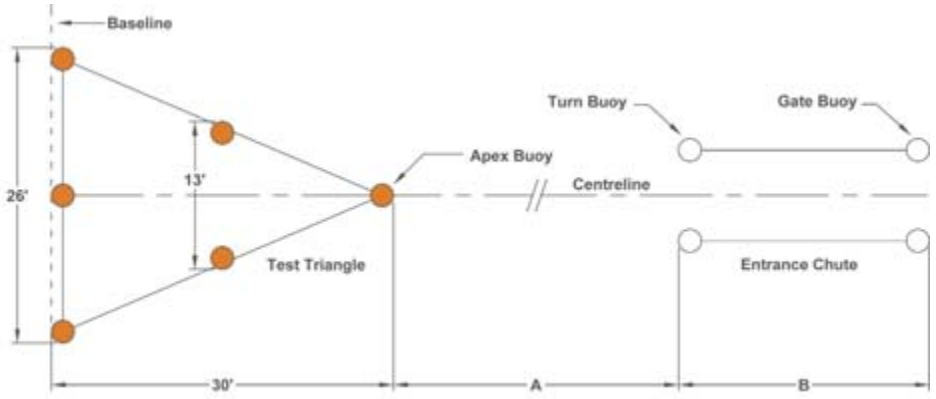
Disproportionate accident rate draws attention

In 1998, the National Transportation Safety Board (NTSB) released a much anticipated report titled Safety Study: Personal Watercraft Safety, NTSB/SS-98/01, PB98-917002. This study found that, while PWCs comprised only seven percent of all registered recreational boats; 36 percent of all reported boating accidents and 41 percent of all boating injuries involved PWCs. Personal watercraft appeared to be overrepresented in the accident statistics for recreational vessels. Even after recent advances in PWC safety technology, 2008 U.S. Coast Guard data (see Recreational Boating Statistics 2008, COMDTPUB P16754.21, U.S. Dept. of Homeland Security, U.S. Coast Guard, Office of Auxiliary and Boating Safety) shows that 23 percent of vessels involved in recreational boating accidents were PWCs and 28 percent of boating injuries involved PWCs although, according to the NMMA, they still only accounted for eight percent of recreational watercraft in use.

The NTSB and U.S. Coast Guard data show that the major cause of accidents involving PWCs is collision. Some portion of the collisions and injuries may be attributed to the operating design of personal watercraft. It has been suggested that the high accident and collision rate is related to lack of operator control during off-throttle steering situations.

Under normal *powered* operation, a PWC is highly maneuverable. Turning the handlebars steers the water jet at the stern to give *very responsive* control. However, consider an emergency situation where a PWC operator realizes a collision with another object is imminent. Many operators instinctively release the throttle and attempt to steer around the impending collision. This is a logical reaction; people are conditioned from an early age to respond in this way, whether it be while riding a bicycle or driving a car. Once the throttle on a PWC has been released, however, the water-jet is essentially shut off. Since the water-jet steers the vessel, all steering control is lost. Little evasive action can be taken to avoid the collision; the PWC continues to travel along its original path.

PWCs also require long distances to stop. A typical stopping distance for a



Test Speed	A	B	Test Speed	A	B
30 mph	58'	22' 0"	45 mph	103'	33' 0"
35 mph	73'	25' 8"	50 mph	117'	36' 8"
40 mph	88'	29' 4"			

Figure 2: PWC Testing Course

Figure 4: Collision Analysis Rudder System

PWC traveling at 30 mph is 150 feet, and 220 feet at 40 mph. Many PWCs have top speeds over 60 mph. The lack of steerability in an off-throttle situation, coupled with long stopping distances, can understandably be a contributing factor in high collision and injury rates.

These operating characteristics have been disastrous for novice operators. Many beginners aren't even aware that steering control is lost once the throttle is released. According to the 1998 NTSB study, *supra*, nearly one-third of PWC operators involved in accidents reported that they had operated a PWC fewer than 10 times, and 84 percent of operators had no PWC training prior to the accident. Personal watercraft owners often loan their craft to inexperienced family and friends with minimal instruction or supervision. The July 2007 issue of Seaworthy, published by BoatU.S. Marine Insurance, Alexandria, VA, reports that claims show PWC owners were involved in only 18 percent of accidents, while their siblings accounted for 29 percent and their friends 53 percent of accidents.

Rental operators often provide PWCs at summer waterways to the inexperienced public with inadequate instruction on the vessel's inherently dangerous control problems. A 1996 Canadian Coast Guard paper, *Assessment of Concerns Associated with Personal Watercraft* (Consulting and Audit Canada, Canadian Coast Guard, Office of Boating Safety) reports, "The industry representatives interviewed stated that rental machines have been responsible for most if not all of the fatal accidents in Canada." The 1998 NTSB study reported that rental PWCs were involved in 24 percent of all PWC accidents in the U.S., and recent U.S. Coast Guard data shows that number is virtually unchanged (23 percent for 2008). The Florida Fish and Wildlife Conservation Commission reported that in 2009, only two percent of all registered personal watercraft in that state were rentals, but they accounted for 37 percent of all personal watercraft accidents. While some states now mandate that PWC rental operators provide some sort of instruction or ask for proof of competency from potential renters, many have no such requirements according to NASBLA's *Reference Guide to State Boating Laws* (www.nasbla.net).

Figure 3: Off-Throttle Maneuverability Test

Personal watercraft litigation

The operating characteristics of personal watercraft, particularly the lack of off-throttle steering, have resulted in litigation against the PWC manufacturers. The first plaintiff's verdict against a personal watercraft manufacturer involved the case of *David Cuenllas vs. Yamaha Motor Corporation, U.S.A., et al.* (2000), Los Angeles County Superior Court, BC 196681. In August 1997, two California friends, on a working holiday in the Bahamas, rented personal watercraft for an hour of thrills. On returning to shore, David Cuenllas, operating the lead unit, cut his throttle and coasted to a stop near shore. Burt Diaz, operating the PWC following Cuenllas, also cut his throttle. When he realized he would not stop in time, he attempted to steer and avoid a collision with his friend. The steering effort had absolutely no effect and the Yamaha WaveRunner III overrode the Cuenllas unit, striking Cuenllas directly in the back, rendering him a paraplegic.

Key issues of the case were (a) whether or not a defect existed; (b) identifying the defect, if any; and (c) determining the feasibility of an alternative design. Test results of two identical Yamaha WaveRunner IIIs showed that the craft could not avoid striking a 48-inch wide target (approximate width of a Yamaha WaveRunner III) from distances

of 100 ft and 50 ft at 30 mph with the throttle released. Numerous types of aftermarket, add-on rudders were installed and tested. It was found that with the addition of a small rudder attached to the jet nozzle of the watercraft, it could easily avoid the target in an off-throttle situation.

These results were documented, videotaped and produced at a subsequent trial in Los Angeles. In February 2000, a jury returned a verdict of $8.36 million against Yamaha on the basis that it failed to install a rudder. Since the Cuenllas case, PWC test protocol and equipment have become much more sophisticated and accurate, as described in the following sections.

Personal watercraft testing

Of the recommendations resulting from the 1998 NTSB personal watercraft safety study, manufacturers, the Personal Watercraft Industry Association, and the U.S. Coast Guard were asked to work together in evaluating PWC design, and research ways in which to provide PWC operators "more control in an off-throttle steering situation."

Ultimately, they were to develop standards specific to steering. Based on this recommendation, The Society of Automotive Engineers (SAE) formed the Personal Watercraft Subcommittee consisting of manufacturers and North American safety experts. SAE Recommended Practice J2608, *Off Throttle Steering Capabilities of Personal Watercraft,* was issued in September 2003 and was to apply to model year 2006 and newer personal watercraft (excluding stand-up models).

SAE J2608 has also become the basis for personal watercraft testing in litigation.

In addition to off-throttle maneuverability testing based on SAE J2608, testing protocols have been developed to determine stopping distance and acceleration performance. The following section highlights some specific tests.

• Off-throttle steering capability

The premise of SAE J2608 is to evaluate a PWC's off-throttle turning capabilities. This is accomplished by measuring the craft's advance (longitudinal) and transfer (perpendicular) travel distances after the operator has released the throttle and turned the handlebars. An entrance chute is set up consisting of gate and turn marker buoys. The PWC operator approaches the entrance chute at a specified speed, releases the throttle at the gate marker buoys and turns the handle bars at the turn marker buoys. Minimum transfer distances must be met depending on the speed at which the test is run. A triangular layout of six target buoys may also be used in testing. The target buoys are set at specific distances from the entrance chute depending on the test speed (see Figure 2 on previous page) for a schematic of the J2608 test course). In essence, if the PWC avoids entering the region defined by the target buoys, the PWC passes the maneuverability test.

Figure 5: Bombardier Off-Throttle Control Flaps

Figure 3 (on previous page) shows a sequence of a PWC retrofitted with a prototype off-throttle steering device designed and manufactured by Collision Analysis passing an off-throttle maneuverability test. One can observe the operator releasing the throttle, lifting his throttle hand in the air to show the throttle is not applied and steering hard to the left. In this case, the PWC successfully navigates the course without encroaching on the triangular area defined by the target buoys (buoys in foreground). Most production personal watercraft made prior to the early 2000s cannot meet the recommended practice. When a PWC fails the test, the results are often dramatic as the PWC strikes down the target buoys at high speed. Figure 4 (on page 2) shows one example of a prototype off-throttle steering system.

Advanced technologies are used to perform off-throttle maneuverability testing. A digital data acquisition system including a differential global positioning system and an electronic gyro-compass provide means with which to track the path of the vessel as it travels through the test course. This provides much more information than a simple pass/fail verdict obtained by observing a PWC navigate the course during the test.

Since the early 2000s, PWC manufacturers have recognized the market demand for off-throttle steering systems and have added this system to many PWCs in their lineup. Before this time, manufacturers were reluctant to add these devices. As shown in Figure 5, one option is to use simple add-on rudders or flaps to improve the off-throttle steerability of their

personal watercraft. Bombardier uses this concept in its O.P.A.S. (Off-Power Assisted Steering) system.

Other manufacturers have added throttle reapplication systems, which are engine control devices that automatically increase the throttle to provide maneuverability and control should sudden throttle release and steering input be applied. Yamaha's Y.E.M.S. (Yamaha Engine Management System), Kawasaki's KSS (Kawasaki Smart Steering) and Honda all use a form of throttle reapplication. Bombardier also uses a throttle reapplication system on some of its models, dubbing it O.T.A.S. (Off-Throttle Assisted Steering).

As of 2006, all sit-down personal watercraft on the market have some device intended to improve off-throttle steering performance.

• ***Stopping distance and acceleration performance***

Deceleration or stopping distance (to idle speed, usually around 2 to 3 mph) and acceleration performance of a personal watercraft can be determined with relatively little test setup. To determine stopping distance, the PWC operator releases the throttle from a specified speed, and the PWC coasts to idle speed. Speed measurements taken at 30 times per second using radar and a digital data acquisition system enable precise calculations of the stopping distance. Acceleration performance tests can also be performed using the radar data acquisition system.

For model year 2009, Bombardier introduced the first personal watercraft braking system as part of its *iControl* (Intelligent Control) system. The brake is actuated with a lever mounted on the left handlebar, much like on a bicycle. Bombardier claims PWCs equipped with this system will stop in one-half to one-third the distance of a standard model. Initially, two Bombardier Sea-Doo models were available with this braking system. For model year 2010, seven of their 12 models are brake equipped.

Research papers

Methodology and results from a group of personal watercraft tests can be viewed in two SAE technical papers by Collision Analysis: Good, et al., *Stopping Distance and Acceleration Performance of Personal Watercraft*, SAE 2005-01-1176, Society of Automotive Engineers, Warrendale, PA (2005); and Good, et al., *Off-Throttle Turning Performance of Personal Watercraft for Accident Reconstruction*, SAE 2005-01-1198, Society of Automotive Engineers, Warrendale, PA (2005).

Conclusion

Personal watercraft have become common on North America's waterways and it is expected that they will remain there for many years to come. Although all current machines (except stand-up models) come equipped with some form of off-throttle steering capability, there are still many hazardous older models in use. Bombardier is currently the only manufacturer to produce machines with braking capabilities and this capability is only available on select Sea-Doo watercraft.

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