Weekend Life on the Water—Evolution of the Runabout

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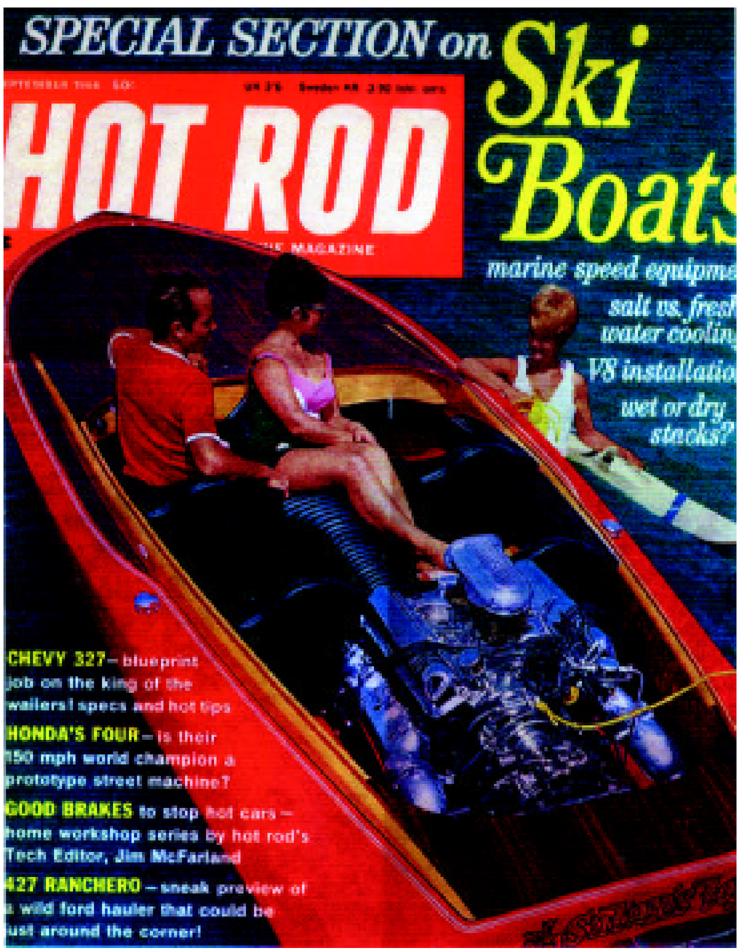
Previous articles (THE BENT, Spring 2000, Spring 2001, Fall 1999) presented the evolution of three competing modes of travel: the railroad, the automobile, and the boat (for the latter, only one specific type, the canal boat, now extinct in America). The reasons for the eventual domination of the auto over the railroad, at least for moving people, are complex; but certainly one of the major ones is that the car served not only for business, but for pleasure. The same car that took Father to work and Mother to the grocery store also took the kids to the park or the whole family on vacation. True, there were excursions on the railroads, but these were limited and became fewer and fewer until now the regular railroads run strictly business trains.



Boats went the other way. Surely the vast majority of small boats (roughly 15-35 ft.) are pleasure boats (12 million in the country). (I realize some sport fishermen actually eat the fish they catch, but it is a lot cheaper to go to the grocery store than pay $20,000 for a boat and fishing tackle.) A few years back, when the family was a standardized unit, one out of eight families owned a boat. My guess is that half of them never touched the water in a given year, but that defies engineering analysis.

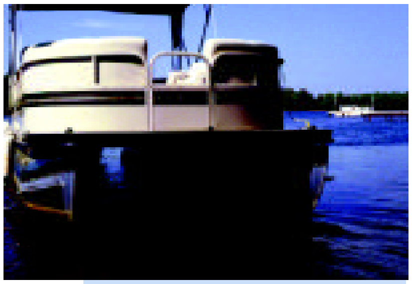
I have chosen the term *runabout,* which has historical precedent. These boats are also referred to as *speedboats,* but that term includes racers, a distinctly different genre. *Powerboat* is also used, but this term includes much bigger boats and indeed is usually slanted that way.

ORIGINS

Let's start at the beginning. Water travel is pre-historic; likewise, it is impossible to determine whether it originated for business or pleasure. Water must have been attractive for the former, being basically level, and logs floating downstream or with the tide must have fascinated primitive man.

The first craft were not boats but rafts. A raft is an object or assemblage of objects having density less than that of water, so it floats. It is of limited use, being at the mercy of currents and tides, and having limited carrying capacity. (The charming drawings of Tom Sawyer and Huck Finn floating down the river on a log raft with most of each log exposed is not scientifically accurate, unless they used balsa wood.)

A boat is an object or assemblage of objects normally of density higher than that of water (for exceptions, see sidebar on page 16) which floats by keeping the water out of a substantial space; i.e., it is mostly air so the average is less dense. We presumably owe our pastime to that unknown semi-noble ancestor who tired of getting his feet wet straddling a log, hollowed out part of the inside with crude tools or fire, stepped inside, and undoubtedly capsized. After



Pontoon boat—two aluminum tubes, a platform, seats, and an outboard motor. What could be simpler?

learning empirically to keep the center of gravity below the center of buoyancy, he succeeded, the envy of his neighbors on the block. Hollowing out more of the log to carry goods or friends, he serendipitously invoked Archimedes' principle, not formulated until Archimedes got a bathtub in the third century B.C., that a boat will sink until the weight of the volume of water displaced is equal to the gross weight of the boat.

The next major advance was when tools and methods became sophisticated enough to assemble a boat from parts, e.g., the legendary birch-bark canoe of the American Indian. A boat-builder named Noah is reported to have built a rather large boat using a type of wood that swells when wet, so leaks tended to be self-sealing.

SAILING

Next we must pay tribute to sailboats, although their relation with powerboats is akin to that of cats and dogs—they *can* coexist, theoretically. Sail was the first non-human mechanical propulsion and was highly refined in the many centuries that passed before motors were invented. Had it not been for sail, the New World might not have been discovered, the Earth not circumnavigated, and we would have flat globes.

Landlubbers (a nautical corruption of land-lovers) and even most powerboaters have a poor appreciation of sailing. Sailing is an exercise in geometry, or frustration depending on one's attitude. At first thought, maximum speed would be with the wind, and hence limited by wind speed. A study of the diagram on the right shows that the optimal wind direction is from the side and that the speed theoretically becomes infinite as the sail is drawn closer and closer to the axis of the boat. Trying to achieve this is fraught with realities, and optimal sailing is a fine art.

The diagram on the right (top view) is deceptively simple. What it does not show is that the wind would rather just blow the boat sideways with the sail drawn close. To counteract this, the boat has a plane surface below the hull to allow the boat to move forward but not sideways. This is called a keel or, if it can be drawn up, a centerboard. This adds drag, and, because it must be rigid, it cannot be infinitely thin. So, performance is a compromise. Now the boat won't go sideways, but the wind tries to blow it over, *spilling* the wind out of the sail, or worse. Sometimes the bottom of the keel is weighted, but then the boat sits lower in the water, and drag increases. Designing sailboats in the past was likewise a fine art; modern computers are easing the job.

CATAMARANS AND TRI-HULLS

A catamaran is a twin-hulled boat. It is particularly suitable for sailboats. Rather than having to design a single hull to resist tipping from the side force on the sail, an entire hull (nearly half the weight of the boat) is available at the end of a significant lever arm (half the width of the boat) to resist, and the boat sails nearly flat. The downside is that once the hull clears the water, there is no more restoring force available, and the only factor resisting tipover is spillage of wind from the sail as it moves toward horizontal. This is often not enough, and my *cat* came with provision for re-righting. For large boats requiring a cabin, a center hull is added, called a trimaran.

This is not to be confused with a tri-hull. With the advent of fiberglass boats, a variation was tried adding secondary hulls on either side of the main hull. This added space, capacity, and stability. But the boats pounded badly in rough water, and in the extreme there was a disastrous consequence; as motor sizes and speeds increased, they could *launch* off a wave or wake and catch enough air to flip backwards. The design was abandoned, but has recently reappeared as a fiberglass version of a pontoon boat (see above). The new ones are much larger, and the problem has not reappeared—yet.

The tri-hull is not to be confused with the hydroplane design, basically catamaran in front and single hull in the rear. Some modern small boats with huge engines at full speed ride with the hull almost entirely out of water, supported partially on an air cushion trapped underneath. They must be stable not only hydrodynamically but aerodynamically!

THE RAFT THAT DIDN'T FLOAT

Some youths at our lake decided to build a raft. Because the material was to be purloined, they wanted only the best; a raft of pressure-treated wood should last for a long time. What they didn't know was that freshly treated wood can be heavier than water. The raft was found very close to shore.

UNSINKABLE BOATS

Most early boats up to the second half of the twentieth century were made of wood. Most wood floats marginally, so in the case of *sinking* boats, they often actually remained on the surface. Hence the admonition— "Stay with the boat!" This also applies to the modern runabouts that have flotation foam added. A construction that is inherently "unsinkable" is used in the *Boston Whaler*. Its hull is a sandwich of closed-cell foam sheathed in fiberglass. The company boasts a famous photograph of one of its boats cut into three sections, all floating, with a man in each!

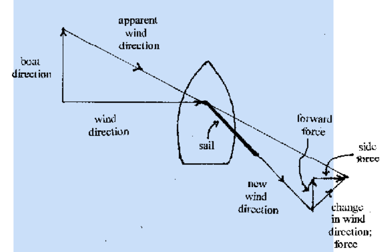


FIG. 1 SAILBOAT GEOMETRY

THE FIRST POWER BOATS

Steam engines, being large and heavy, were successful in trains, large boats, and, to a limited extent, in large carriages. But the personal boat, like the automobile and the airplane, had to await the invention of the gasoline internal combustion (IC) engine. Daimler, generally credited with being the second person to build a true automobile (after Benz) and a leading proponent of the IC engine, started selling boats with IC engines in 1887. (The idea had been first tried in 1870.) Of course, a sailing hull was initially used, not proving entirely satisfactory. Others followed, and workable powerboats were demonstrated.

RACING

Today's runabouts came as a result of racing. As soon as several makers arrived on the scene, there were contests to see whose boat was *best* (read: fastest). To go faster and faster, boats were made longer and longer (but no wider) to accommodate larger engines, or simply more of them. These longer and larger-engined boats were themselves surpassed by smaller boats with less horsepower; they skimmed along the top of the water rather than knifing through it (see sidebar). This shouldn't have surprised anyone who had ever skipped a rock across a pond.

These boats were termed *hydro-planes*, literally *water-plane* as opposed to air-plane, the idea first proposed in 1872. (Today *hydroplane* refers to a specific design of twin outboard *catamaran* hulls at the front and a single central hull at the rear, used chiefly for racing. Oddly enough, a sketch from the turn of the century is very similar, and Apel built a three-point design in 1914.) Like aircraft, these had to await refinement of the gas engine and took place in the same time frame, first being tried in 1900.

Hulls retained the vertical pointed bow in front to cut through waves and wakes, widening to a flat bottom at the rear which skimmed across the water at high speed, lifting the bow above flat water. Fauber pushed the idea; his design broke the 60 mph barrier in 1915. Wood was the only material available, and the hulls were either heavy or fragile. More speed was achieved by adapting aircraft engines, which had huge displacement and high power at relatively low weight and rotational speed (rpm). Up to four engines were used, totaling thousands of horsepower. These craft were evil-handling to the point of being dangerous, even in calm water. Nevertheless, daredevils competed both head-to-head on closed courses and for absolute straight-line top speed. Some of the records were certified posthumously.

The sanctioning authorities, increasingly appalled, defined classes with much smaller engines (although *unlimited* racing continued independently). This led to the use of automobile engines rather than aircraft

DISPLACEMENT VS. PLANING

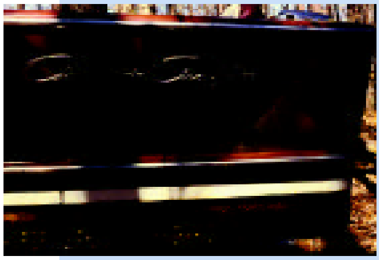
At slow speed a boat *displaces* the water sideways from its bow, which later closes in behind. In absence of opposing current or wind this is a very efficient form of movement; I have watched two men move a 100-ton boat by hand; in an emergency one boat can easily tow another, even a much larger one. For this mode, the narrower the boat, the better. At high speed a flat-bottomed boat can *plane*. The water cannot move sideways in time and is accelerated downward, the resulting force lifting the boat. Most runabouts leave less wake the faster they go, indicating less energy used per mile. (This may not be the best miles-per-gallon because several other losses increase: water friction, spray, internal engine friction.)

The region between these modes (roughly 5-15 mph for the boats considered here) is an undesirable situation, not unlike an airplane going through the sound barrier. The water is pushed ahead of the boat in a hump, which the boat has to climb, raising the bow and aggravating the situation further. This creates a huge wake and is seriously inefficient. Inexplicably, it is a favorite operating mode of the weekenders. Recently, one boat ran over another; the operator had the bow so high that it blocked his view of the other boat!

MARINIZING

An automobile engine can be adapted to a boat with few changes in some applications, although in others there are many—mostly external. The biggest change is the cooling system: A *water-cooled* auto engine really isn't; air through the radiator does the job. A boat sits in a virtually infinite source of cool water, which may be used directly. Although, sometimes an intercooler is used, and the engine contains the usual anti-freeze mixture. Usually an auxiliary pump lifts water to the normal recirculating water pump and thermostat. For an enclosed engine, or exhaust exiting through the hull, the hot water from the engine goes through the exhaust headers and is then dumped into the exhaust pipe. Thus, the exhaust cannot be above boiling; rubber hoses can be used for pipes and mufflers made of fiberglass! A variation is to run the water through the headers first to preheat it, then through the engine with no thermostat, then into the headers. Performance boats with open engines and *dry-stack* headers out the top do not need cooled exhaust.

A special alternator may be used for greater output at idle, as boats typically spend much time idling and travel relatively short distances between start/stops. For salt-water operation special valve springs are required, as standard ones fail prematurely from stress corrosion. Steel casting plugs are replaced with brass. Oil coolers are more common, as there is no appreciable airflow over the oil pan. A water separator is often added to the fuel line, because the best assumption is that water is going to get into everything.



Chris Craft emblem—Christopher Columbus Smith brought boating to the masses, the name of his firm becoming almost synonymous with powerboat.

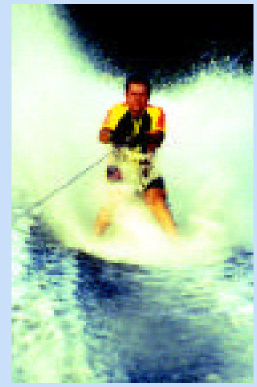
(see sidebar). They also instituted rules requiring the boats to be more practical, such as covering the engines, previously exposed, inches away from the driver. In fact, they defined a class called *runabouts* which were *not* allowed to be raced. These were the forerunners of today's family boats. Pictures of boats and persons learning to waterski in 1930 and in 1990 are remarkably similar. A few major changes and a lot of minor ones have taken place. The rudder has been moved from the front to the stern (rear). The driver now sits in front of the engine. The bottom of the hull is now continuous from front to back rather than a series of steps. The top of the bow has been flared outward to direct the spray away from the boat and passengers, allowing the cockpit to become completely open. The hull at the rear has reverted from completely flat to a shallow vee or *stepped* (half-and-half) design—and my ski boat has not a single piece of wood inside.

CHRIS CRAFT

Several men pioneered the development of speedboats, constantly competing with each other both in racing and in sales, but one name stands out as bringing boating to the masses, becoming almost generic. Christopher Columbus Smith was good in all aspects. He opened a company in 1910 to mass-produce runabouts for ordinary people. He was engaged in racing, winning in 1914 and then consistently for years. He was the first person to go a mile in less than a minute. (The earlier record was over a shorter distance.) He instituted mass-production techniques while maintaining quality and beauty. He sold boats of widely differing sizes and purposes. He involved his whole family, and they marketed their products with great enthusiasm. The Chris Craft marquee endures today, but the company has passed through several hands and bankruptcies and is now owned by the British investment firm Stellican.

FIBERGLASS CONSTRUCTION

The next major change came in 1946 with the sale of the first fiberglass boat. There is widespread misunderstanding about fiberglass. The technical terminology is (fiber)glass-reinforced-plastic (FRP or GRP). Bulk glass is strong but brittle, subject to fracturing or even shattering. But when drawn into thin strands it is quite flexible while retaining great tensional strength with relatively little stretch. These strands can be woven into cloth or *mat*. When impregnated with plastic (or, better yet, epoxy), a strong solid but flexible sheet results. It can be made into virtually any shape, can have the color built in, and can be easily repaired. It is still labor-intensive, but far more practical than wood. Major structural



THE HUMAN BODY AS WATERCRAFT

The human body was obviously not designed for water. In displacement mode it barely floats, and then only with sufficient air in the lungs. The standard appendages are woefully inadequate and are always augmented by rubber fins by commercial swimmers (e.g., Navy Seals). For planing mode, the horsepower-to-weight ratio is hopeless. It is only recently that a human-powered planing vehicle has been successful, and that, like human-powered aircraft, required an Olympic-quality cyclist.

When pleasure boats became able to plane with power left over, *sleds* were towed for people to ride on.

True water-skiing began in 1922, when Ralph Samuelson took the rope in his hands to pull himself across the surface on skis.

The ultimate was achieved in 1947 when A.G.Hancock stepped off the skis entirely and planed on the soles of his feet. Again, these work much better on land; about 40 mph is required on water. My ski boat gets 2.0 mpg (note decimal) pulling me barefoot (above).

NON-VISIBLE HAZARDS

The winter day was cold, but quite livable since there was no wind at all. Four fishermen set out on the Chesapeake Bay, noting that the water was glassy smooth, unusual for the Bay. It was, in fact, too smooth; it was covered with a thin layer of ice. The first indication the men had was seeing the boat rapidly filling with water. It had been cut nearly in two, so badly that they couldn't make it to shore. It would be humorous except for the ending—two stayed with the boat and were rescued; two swam for shore, but only one made it.

The biggest cause of a small boat sinking is simply being launched with the drain plug still out. What to do when you look around and the water is advancing up the floor? I know, from experience. Hit full speed forward. If you can achieve even a partial plane the back of the boat will be above the surface, and the water will run out. You then have a choice of jumping in and quickly inserting the plug or racing by the dock and shouting for someone to put the trailer back in the water.

THE 20' BY 8' BOAT

At one time Coast Guard regulations required boats less than 20' to contain enough flotation foam to be unsinkable, a nuisance. Conversely, some insurance companies considered anything larger than 20' to be a *yacht,* requiring a special policy. Anything wider than 8' requires a special highway permit in some states and hence is not considered *trailerable*. Not surprisingly, many boats were exactly 20' by 8'. Both of my honest-to-goodness powerboats are.

members (transom, floor, stringers, dashboard, braces) until recently were still wood or marine plywood, sheathed in fiberglass. Marine plywood is also misunderstood. The glue will withstand water, but the wood will still rot. Many a boat owner has been shocked to find a beloved boat that still looks good is rotten inside.

PRE-REVOLUTIONARY TIMES

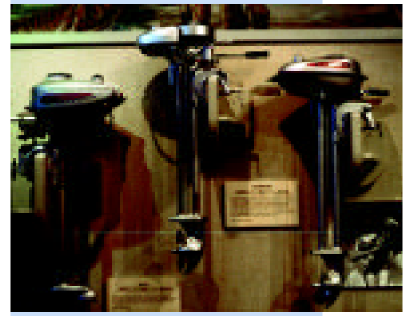
As of a decade ago, small pleasure boats had become standardized to a large degree, with a few exceptions (see sidebars) and a few options (see following sections). At least 15 brands of ski boats were indistinguishable to the untrained eye. I asked my dealer, "Why so many?" He replied: "Because you can start a boat business in your garage!" The hulls were pretty similar; you could use a competitor's as a basic mold, make your own modifications and "lay up" the fiberglass. You adapted it to an engine/drivetrain combination ready-to-go from one of several manufacturers. Get the flashiest upholstery and trim you can imagine from competent suppliers, meet a few Coast Guard regulations, and you are ready to advertise and sell to a customer that probably has more excitement than sense (speaking from experience). The lifespan of a typical boat company is not very long. The main options are engine and drivetrain, and these are related.

OUTBOARD MOTORS

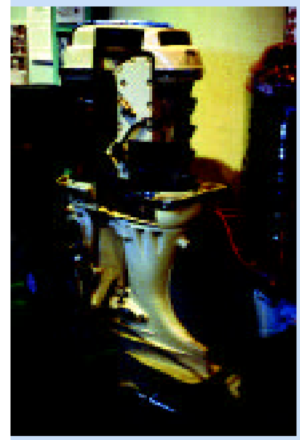
The primary choice was whether the motor was inboard or outboard; this also defined the engine type. The theory behind an outboard motor was originally quite simple. It was a small but complete unit: motor, transmission, propeller, fuel tank. You took it out of the trunk of your car and thumbscrewed it to the transom of a waiting boat. It wasn't much faster than rowing, but a lot easier, although sometimes rowing seemed easier than pulling the starter cord until the engine finally fired.

To steer, you turned the entire assembly on a pivot by means of a handle. For reverse, you turned it around 180 degrees. If it struck bottom, it flipped up on another pivot and out of harm's way. A damaged propeller could be replaced on the spot, but otherwise it either worked or it didn't. If it caught fire, with a little luck you could get it loose and submerge the whole mess.

To achieve a better power-to-weight ratio, the manufacturers turned to an idea that had been abandoned after the success of the Otto (four-cycle) engine. The only stroke (cycle) that is absolutely necessary is the power stroke. If every downstroke could be a power stroke, the engine would (theoretically) have twice the power. The piston must return to the top, so either an exhaust or a compression stroke is



Early outboard motors—note picture of model easily holding one; not so today.



Outboard motor—cutaway view (Calvert Marine Museum).

ALUMINUM BOATS

Aluminum was tried as a construction material long before fiberglass, borrowing on aircraft technology. Although the lightest rigid construction available, it remains used only for small fishing boats. This aluminum is hard to join and seal (and repair), and relatively vulnerable to debris. It is much better suited to aircraft, where the medium is around a thousand times less dense.

PONTOON BOATS

Take two large tubes (pontoons), add a flat deck across the top, put an outboard motor on the rear, and you have a powered barge. Add streamlining and spray deflection to the front of the pontoons, a rail with seats around the edge, a control console somewhere near the center, a canvas convertible top, and you have a pontoon boat. With enough power it will plane after a fashion. It handles like a floating living room, but when you turn a 100 hp motor sideways, anything will turn. Basically a catamaran design, it is quite stable in rough water. That is, until the waves or wakes exceed the deck height, at which point it becomes quite messy but not dangerous. What about a hole in the bottom of a pontoon? It might not sink! Some water will enter until the pressure equalizes enough to keep it out. The catch is that if the water collects where the hole is, the deeper it sinks, the more the pressure increases, etc. The lesson is: If one corner of the boat seems low, and everybody runs over there to see why, you will find out the hard way! Pontoons have become quite popular (and large, fancy, and powerful); some approach the mile-a-minute mark!

available for free. Without compression only about a tenth as much air-fuel mixture is available, so it is a practical necessity. If slots are cut near the bottom of the cylinder, most of the exhaust gas will escape as each is uncovered. Likewise, fresh mixture can be introduced into the cylinder via slots if it is under pressure. This can readily be done by passing it through the crankcase, which has just been pressurized by the piston coming down. A one-way valve, usually a simple reed valve, admits mixture to the crankcase without allowing it to back up.

There are some serious problems. The intake and exhaust slots are open at the same time, so the top of the piston must be carefully shaped to encourage the spent gases to leave the cylinder and the fresh gases to stay. The fuel and lubricating fluid are one and the same. Gasoline is actually a very light oil, but not quite good enough, even with roller bearings. Some oil must be mixed in, which tends to foul the spark plug and cause smoke in the exhaust. Early motors ran as little as a 10:1 gas/oil ratio and left a trail of smoke.

Modern multi-cylinder engines have overcome the difficulties surprisingly well, although you can no longer pick them up without a crane. At one time most of the small boats on the river used outboards. The new ones, up to 250 hp, have such additions as generator, battery, starter, reversing transmissions, power tilt, and power steering. Exhaust is normally exited underwater, but they are still noisy. Oil is in a separate tank and is injected automatically, as little as 100:1 under favorable conditions. But outboards cannot match the efficiency of a four-stroke, and it is doubtful whether they will be able to meet the 2006 emissions requirements.

INBOARDS

Inboard boat engines are modified versions of automobile engines. The choice here is the drive system. The oldest, still used in most ski boats, is for the engine to drive a propeller directly (actually through a transmission, but this is usually 1:1 in forward). The engine sits in the center of the boat, good for balance and low moment of inertia, but somewhat of a nuisance. Also, it must sit at a considerable slant so the drive shaft goes down through the hull; older engines sometimes had a wedge under the carburetor to level it. The prop thrust is thus angled downward, but this does not seem to matter much. The transmission has only one forward speed, plus neutral and reverse. Modern ones are built using automatic-transmission technology, with the propeller itself acting as the fluid coupling. Steering is effected by a rudder placed directly behind the prop, so water flow from it helps steer the boat at low speed. Steering in reverse ranges from poor to nonexistent. Because the prop cannot be lifted, a ski boat cannot be beached unless the shore is both soft and steep.

PROPELLERS AND CAVITATION

An ideal propeller screws a helical path through the water, disturbing it as little as possible. Indeed, propellers on large ships are called *screws*. If the prop is overpowered or poorly shaped (including being damaged or entangled with debris), a vacuum gap can form on the back of the prop. This is aggravated by dissolved air being sucked out of the water into bubbles. The next blade hits the bubbles or they collapse on the back of the prop. It effectively loses traction, and an irregular vibration (shuddering) ensues. If allowed to continue, cavitation can damage, or even destroy, a metal prop!

A racing variation, called the super-cavitating prop, uses the opposite philosophy: Only the bottom part of the prop is in the water, and slings it so hard there is not time for the bubble to collapse. Not surprisingly, these tend to *sing* loudly.

The *propeller* inside a jet drive looks quite different. It is actually a simple single-stage turbine. It can be *shrouded* (encircled), and the water flow is precisely routed, so it is less sensitive to cavitation.

Ski boat—note the engine cover in the center of the boat.

Outdrive—similar to the bottom half of an outboard motor, but the engine is inboard.

Jet drive—no propeller, just a stream of water blasted out the back

WHY A MILE-A-MINUTE IS FASTER AT SEA

A mile to most of us is 5,280 ft.; this is termed a *land mile* or *statute mile*. Thus 60 mph is 88 ft./sec. This is carried over to runabouts because *landlubbers* are used to it. But large ships use the *nautical mile* of about 6,000 ft., so a mile a minute is 100 ft./sec., or about 12% faster. A nautical mph is called a *knot*, as originally a ship's speed was determined by laying a rope in the water with knots at calibrated intervals and counting the number of knots that passed in a specified time.

A variation is the vee-drive. The engine faces backward and sits at the rear. The transmission gears reverse rotational direction and lower the drive line so that the shaft goes back underneath the engine. It may also change the angle so the engine may sit level.

The inboard-outboard is just that—a compromise. Also called stern-drive, the engine is inboard, but the drive is equivalent to the lower part of an outboard. The drive coupling between the two must vary through a range of angles in both the steering plane and the lift of the "outdrive." This system combines the advantages of both inboard and outboard, but also the disadvantages. However, these have become more popular than straight inboards, partly because the engine is placed at the rear, out of the way.

Jet-drive boats are usually referred to simply as *jets*, causing considerable confusion. The engine is purely conventional, but the drive is a big pump forcing a stream of water out the back. It is sometimes referred to as "having the prop inside the boat," but this is oversimplification to the point of error. It works by the holy grail of the engineer, Newton's law: $f = ma$. Accelerating water out the back creates a force that drives the boat forward. Or, in terms of action-reaction, the water accelerates rearward, and the boat accelerates forward. Steering is effected by a swivel nozzle aiming the water jet left or right, and hence is proportional to engine speed or lack thereof. No transmission is needed. Reverse is accomplished by moving a clamshell over the jet to redirect the thrust, like the thrust reversers on a jetliner. Indeed, this process can be used as a brake, not normally available on a boat short of throwing out the anchor. Neutral is simply half forward and half reverse.

There are other advantages. Propellers must be below the hull so the thrust lifts the front end, already a problem. The thrust of the jet is higher, near the center of gravity. Jets are less prone to cavitation (see sidebar, page 20)—that is, unless debris is sucked into the intake. There is nothing below the hull to snag rocks or lines. Jet drives can handle prodigious amounts of power (mine was rated to 1,000 hp) and are popular in high-performance boats. It cannot be changed like a prop, but, on the other hand, it performs well over a wide range of conditions because it is simply a thruster. It is less efficient than a prop, but rivals an outboard at mid-range. The engine is mounted level, near the rear. A jet's behavior is less like a car than a prop boat and is hence harder to master, but in the hands of an expert it handles magnificently.

BOATS THAT DON'T NEED WATER

There are two basic types of *air boats*. *Air cushion* vehicles have a fan (air propeller) that blows a cushion of air under the vehicle to lift it slightly off the surface. The perimeter is usually an inflated rubber tube to absorb surface irregularities. Such a craft obviously doesn't care whether it is over water or flat land, although water is more likely to be flat and less likely to damage the rubber. To propel the boat, some of the fan blast is diverted to horizontal. Little is required, as the craft is basically frictionless.

Swamp boats are wide, flat-bottomed barge-like boats powered by aircraft engines and propellers. Steering is by a huge rudder in the air blast. Thus there is nothing required below the hull; it is basically a zero-draft boat. It will go through shallow water choked with reeds or even across level ground covered with wet grass.

Either type will go into the shallowest reaches of the wetlands, where they are typically banned. Being extremely noisy doesn't help.

Personal watercraft—marina? No, just a family outing on Lake Anna, VA. Note the smaller size of the stand-up model.

THE REVOLUTION

In the 1990s pleasure boating changed radically. It all started some time earlier with the frustration of waterskiers sitting on the shore with no boat and/or driver available. Kawasaki marketed the *Jet Ski*, a tiny self-powered craft that you could stand upon after it was planing. At 300 lbs., it was not something you carried to the water and strapped to your feet, but it did require some balance and skill, particularly in *getting up*. It would fit in the back of a standard pickup, tailgate up. Although it has become a generic term, it was not popular until it evolved into a significantly different craft. It was lengthened somewhat, widened considerably, and a straddle seat added. One could climb aboard at the dock without getting wet and operate at any speed without falling off. It required virtually no skill, negating the sport involved in the original and appealing to a much broader segment of the public. It was called a *Wave Runner*, which has become generic, but *Jet Ski* is now used for both types.

Several manufacturers followed suit, but Bombardier, inventor of the *Ski-Doo* for snow, virtually seized the market with its Sea-Doo in an unbelievable variety of models. Although technically known as "personal watercraft" (PWC), *Sea-Doo* has also become generic. The original Jet Ski was a marvel of simplicity, the controls being steering, throttle, and start/stop. There was no *kill* lanyard; if you fell off, it circled back to you at idle. Instrumentation consisted of a *tell-tale* water spout that indicated cooling water was flowing. The engine was a two-stroke derived from motorcycle technology. Cooling water was taken from the jet-drive pump. The bilge pump was a simple venturi tube in the jet stream. It was small enough that a bilge fan was not required. For some unfathomable reason, provision was made for a fire extinguisher; I for one am not going to swim back to a burning Jet Ski. Cost of a PWC is roughly half that of a boat. They are virtually all jet-drive because falling off is part of the fun, but not if there is a propeller turning like a meat slicer.

In the *Great American Tradition*, PWCs soon got bigger and fancier. Today many have full instrumentation and reversing and are big and powerful enough to seat four, tow a waterskier, or exceed the magic 60 mph mark. (Trust me, you do not want to fall off at that speed.) They are often purchased in *his & hers* pairs, the total cost being equal to that of a boat and the resulting trailer being just as wide. Worse yet, these are usually operated dangerously close together with the drivers shouting at each other as they attempt to communicate. Recently, a husband and wife in such a situation collided; one was killed. The accident rate for PWCs is much higher than for boats.

TWIN-ENGINED BOATS

The ideal powerboat has not only two engines, but two complete drivetrains, steering, charging/starting systems, etc. The first reason is simple: redundancy. Among boats, cars, and planes, boats are the least reliable. In most respects they operate in the roughest environment. Thus, when one system fails (most commonly, an engine fails to restart), you limp home on the other.

Secondly, single-engined boats have good steerage only at speed, a problem with docking. A twin-engined boat can make a tight turn at low speed, or even turn in place by running one engine in forward and the other in reverse.

The last reason is not obvious—the rotating mass of the engine creates an undesirable gyroscopic effect. An intended turning force creates an unintended force at right angles. My jet boats turned right much better than left. A propeller is far from symmetrical; the top is much closer to the surface or hull than the bottom. The wake is noticeably asymmetrical! With counter-rotating engines and props, all rotational moments cancel, and handling is truly neutral.

WHY IS THE STEERING WHEEL ON THE RIGHT (WRONG) SIDE?

One of the great mysteries of life—although there have been a number of explanations advanced, none is satisfactory. So the driver can grab the dock? What if you come in from the other direction or on the other side of the dock? Because the control is usually *single-handle*, controlling both direction and speed, and mounts nicely on the side for the right hand? Then the left hand has to steer, equally critical. Note that performance boats that use a foot throttle have to have the steering wheel on the port (left) side. I have recently noted a few new boats also with the wheel on the port side. Confusing? I had a pair of jets, one each way.
The mind adapts.

Twin jet drives—a popular new style of boat: twin two-stroke inboard engines, twin jet drives.

RULES OF THE ROAD
There are, naturally, rules of right-of-way. On a typical small-boat outing these are totally ignored. (Exceptions are two instinctively carried over from the highway: when in doubt, keep to the right; and, when in serious doubt, stop.) This sounds like mayhem, but it is relatively safe, thanks simply to geometry.

A crowded highway is a one-dimensional problem; you cannot go faster than the vehicle in front of you or slower than the vehicle behind you without eventually colliding. Water is a two-dimensional surface. If two boats drive aimlessly in a fog, they probably will not collide, because the likelihood of two bodies occupying the same longitude and the same latitude at the same time is slight. Indeed, collisions are so infrequent that they are usually reported in the news. (Not so with cars!)

As an aside, airplanes have three-dimensional freedom. With no air control at all (other than around airports where planes are directed into the same channel) there would still be few collisions! What, then, is the problem? Plane crashes usually produce a large number of fatalities and make great TV footage. The drive to the airport is much more dangerous than flying, but the money will go to air safety.

PWCs often outnumber boats at many lakes. They have been banned at restricted times or altogether at numerous locations. Their popularity cannot be explained in rational terms; maybe it heralds a return of American individuality.

As so often happens, the inevitable occurred. The technology was adapted to full-fledged boats, small at first, but getting bigger and bigger. Not enough power? No problem. Complete twin-engine/drive assemblies are used, not a novelty in the nautical world (see sidebar), but the end may be in sight.

THE FUTURE

Another radical change is on the horizon. It is generally agreed that two-stroke engines will not be able to meet the proposed 2006 environmental standards. What will happen? Probably a temporary loss in performance, and hence popularity, as happened when auto-emission standards were imposed around 1970. There are plenty of four-stroke motorcycle engines which could be adapted to PWCs, at least the sit-down versions. Electronics has become cheaper to the point where almost anything can have a computer-controlled EFI (electronic fuel injection). The programming costs far more than the computer. (Note: since this article was penned, Bombardier has announced a four-stroke Sea-Doo.)

Outboard engines have gotten bigger and car engines smaller until the twain have nearly met. If small-car engines cannot be adapted directly (with aluminum blocks, overhead cams, and turbochargers, power-to-weight can rival two-strokes)—certainly the technology can.

The models of car engines used in most existing inboards have been mostly discontinued. However, all parts, including blocks, are available from independent suppliers, and the new replacement engines will surely be adapted. Barring an outright ban on older equipment (not likely), there should be no problem boating on the water.

NOTES
The material in this article was drawn from various sources, mostly the author's experience and memory of anecdotes from reasonably reliable sources. It was checked, corrected, and augmented from the references listed below.

REFERENCES:
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