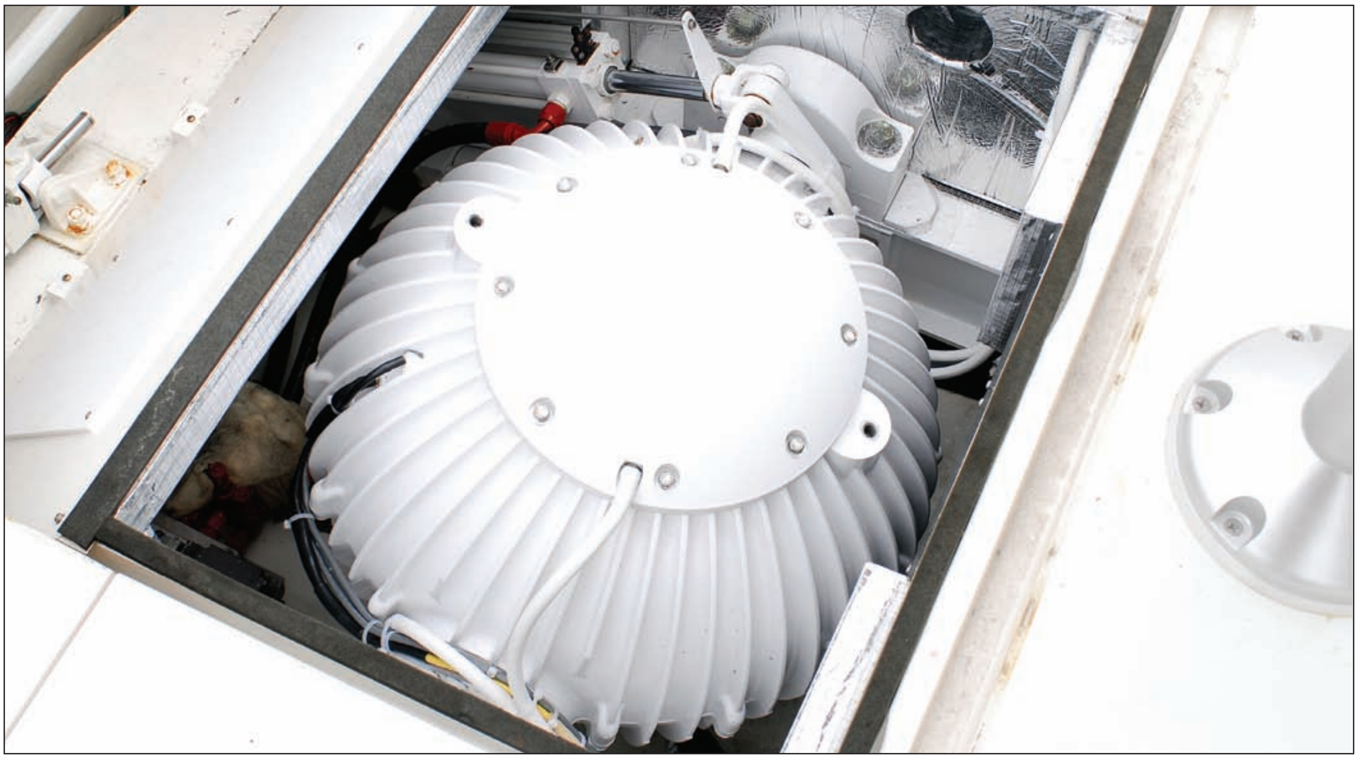


The Stability of Spin

Maryland-based Seakeeper has introduced the first in a series of gyroscopic stabilizers sized for smaller vessels.

by Steve D'Antonio

I'm one of the unfortunate subset of seafarers who suffer from seasickness. We accept as a necessary evil that no matter how many times we return to the sea, at some point the boat's motion will make us sick.

So the promise of a device that might minimize the roll of virtually any vessel, under way or at rest, got my attention. That's why last December, I found myself clutching the aluminum hardtop support on the flying bridge of a Viking 43 (13m) sportfisherman in confused seas off Virginia Beach's Lynnhaven Inlet, feeling queasier by the second, and clinging to the increasingly urgent hope that the boat's new Seakeeper gyroscopic stabilizer we were testing… would work.

Stabilization's History, in Brief

The balancing forces exerted by their sails and keels tend to make sailboats more stable than powerboats. So it wasn't until sail gave way to steam that there was a pressing need for a secondary means of damping a large vessel's unchecked rolling motion at sea.

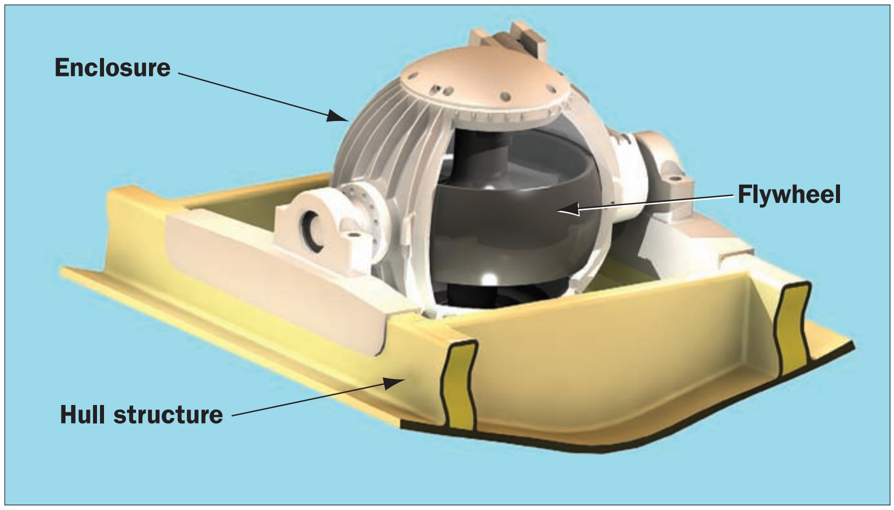
In the 1870s, *bilge keels* were added to the hulls of then relatively new steamships, to improve their stability. In the 1880s, *slosh tanks* came along; they rely on water moving through baffles in tanks to reduce a vessel's roll. In the 1920s, *active fin stabilizers* appeared; they protrude from the bilges and, to this day, are the most common stabilizers for everything from large ships to smaller yachts. While some active fin stabilizers can be applied at rest, most are designed to perform when a vessel is under way. A few vessels employ a variant of active fin stabilization, by independently and actively controlling the movements of twin rudders.

Then there are stabilizing *paravanes*, sometimes called flopper-stoppers, that are towed from outriggers on slow-moving trawlers. Paravanes, unlike most fin stabilizers, can, with some modification, be made effective while a vessel is at rest. On a passage from Chesapeake Bay to Bermuda a few years ago aboard a 30′ (9m) trawler yacht, I relied on the little vessel's flopper-stoppers to tame her lively motion, particularly in the lumpy Gulf Stream.

Let's back up for a moment to the early 1900s, when American inventor Elmer Sperry, founder of the Sperry Gyroscope Company, was experimenting with a *control moment gyroscope*, or CMG, a device first developed by Otto Schlicke in 1906. Sperry's gyrostabilizer was successfully tested in 1913 aboard the *USS Worden*, a 700-ton destroyer. Now, military vessels with narrow beams and tall superstructures are notorious for heavy rolling. The Sperry gyrostabilizer aboard the *Worden* weighed more than 5 tons, but it successfully reduced the ship's roll, making her gunnery more accurate in rough weather, and no doubt making the crew less queasy. Given this success, the Navy ordered a second Sperry gyrostabilizer that was installed aboard a submarine (presumably for use while it was surfaced).

The highlight of early ship gyrostabilization was likely the installation of a Sperry gyro aboard the Italian luxury cruise ship *Conto Di Savoia*, in 1932. Since this unit was large, heavy, and consumed considerable power, it was limited to ships with sufficient space and ample generating capacity. Consequently, by the mid-1900s active fins had become the dominant method of ship and small-vessel stabilization.

The gyroscopic vessel stabilizer didn't reappear as a serious option in the marine market until 2004, when Mitsubishi introduced its Anti-Roll Gyro, or ARG. Mitsubishi's system relies on a CMG similar to Sperry's early model, but is geared toward smaller vessels rather than cruise and war ships. To date, only a handful of Mitsubishi ARGs have been installed by United States builders (several at Bertram Yachts), and only about 100 have been installed in Japan. In Europe, distribution of the ARG is limited exclusively to the Ferretti Group; an ARG is standard equipment on several lines of Ferretti yachts.



Facing page—*Seakeeper's new gyroscopic stabilizer fits snugly under the cockpit sole of a Viking 43 (13m) sportfisherman. Vessel stability derives from a 400-lb (181-kg) flywheel spinning at 10,000 rpm inside a vacuum chamber.* ***Right—****Shepard McKenney, a principal investor in and developer of the Seakeeper gyro, discusses its technology in the company's research lab in Solomons, Maryland.*

Which brings us to where this article begins. The new Seakeeper unit we were testing off Virginia Beach is based on the same theory as the ARG or the Sperry, the difference being that the Seakeeper gyroscope spins faster and easier. That's an important distinction, because gyros for vessel stabilization function by spinning a heavy flywheel at high speeds, typically inside a protective container. The flywheel spins on a vertical axis like a giant toy top (see sidebar, page **xx**).

Since a gyroscope resists any change to its axis, it responds by exerting torque counter to a vessel's motion in the seas. The faster the gyro spins, the better able it is to resist the disruptive forces of the seas. Sperry's and later marine gyrostabilizers are passive rather than active. That is, they are optimized for only one sea condition, so that in smaller seas the system's maximum capacity cannot be applied, and in bigger seas it may be ineffective.

The Seakeeper's twofold advance over previous stabilizers is that (1) its flywheel spins in a vacuum where its weight remains the same, but air resistance is nearly eliminated; and (2) it automatically responds to *actively* counter a wide range of sea conditions.

Who's Behind the Gyro

Relatively few *Professional BoatBuilder* readers will recall the name Shepard McKenney, whereas many will have heard of the Hinckley Picnic Boat—McKenney's very successful (some would say industry-altering) creation. Despite a chorus of dissent regarding The Hinckley Company's claims to the proprietary nature of its Picnic Boat concept and design, these facts stand: McKenney commissioned a talented designer (Bruce King), built the prototype, and achieved enviable results with the finished product.

Even so, that successful introduction wasn't without its development challenges. For example, before the design could really take off, McKenney had to address one of the weaknesses of most jet-boat designs: maneuverability at low speed. In a technical troubleshooting program that can't help but have presaged the later Seakeeper stabilizer effort, McKenney brought together experts to help create the helm joystick, which electronically integrates the boat's jet and thruster in a single, deceptively simple control. It is now a standard feature of Hinckley powerboats and many other vessels as well.

McKenney was raised with plenty of opportunity for mechanical tinkering and innovation. His father operated a gas station in Great Bridge, Virginia, and worked as a mechanic for a nearby boatyard. The McKenney family boat was a Wheeler sedan cruiser Shep's father resurrected after a sinking. Young McKenney, who grew up on that Wheeler and around his father's shop, nurtured a love of things mechanical. However, after college he studied and practiced law for a decade, during which time he invested in the hotel business. He eventually turned that capital back to his passion for boats with an investment in The Hinckley Company, then family owned, and based where it originated, in Southwest Harbor, Maine. He became a friend and business partner of Bob Hinckley at a time when the company was struggling. McKenney went to the crew on the shop floor and made them a proposition, which included a 15% pay cut, while he and Bob agreed to take no pay for themselves until things turned around. The staff accepted, albeit reluctantly. As it happened, McKenney's intuition about the Picnic Boat proved to be correct, and things did turn around. McKenney repaid the 15%, with a bonus, and never looked back.

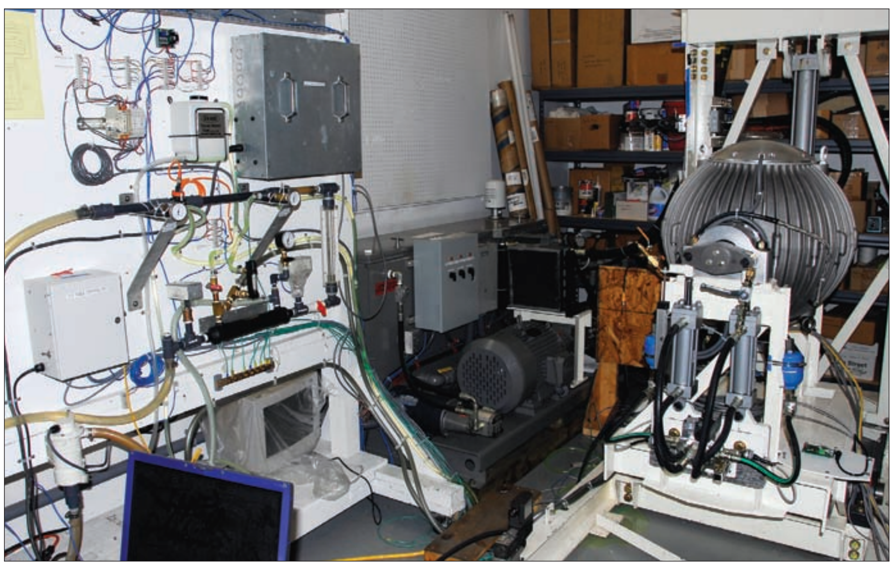
For McKenney, the development of the Picnic Boat *and* its joystick control—paired concepts—was, in his words, pivotal and life-defining. He said those ideas were successful because they had nothing to do with focus groups or with what potential customers *thought* they wanted. McKenney advocates "falling in love with an idea and then allowing things to fall into place to make it happen."

In 2003 John Adams, an engineer and naval architect whom McKenney had met while researching the joystick project, brought the Mitsubishi ARG to McKenney's attention. They discussed the gyro and what it could do for boating. Adams and McKenney believed they could improve on Sperry's and Mitsubishi's designs by making a single critical alteration: *spin the flywheel in a vacuum.*

One limiting requirement of a ship stabilization CMG is power, and lots of it. To turn the flywheel at several thousand rpm (the ARG turns at 4,000 rpm), the unit requires a powerful electric motor. In spacecraft, where CMGs have been successfully applied, the power needs are lower because there is no resistance from a surrounding atmosphere. McKenney and Adams planned to spin their Earth-bound CMG's flywheel in a near vacuum, substantially reducing the power demand and increasing effectiveness. Operating in a vacuum means the gyro's power requirement is a paltry 3 kW upon spooling up, and just 1.5 kW for steady operation. That's well within the capability of most existing small-vessel generators, and the lowest power consumption of any small-vessel gyro stabilization system.

The new gyro was another "fall in love, fall into place" idea—though McKenney admits now that neither he nor Adams anticipated just how difficult realizing that idea would be. With their own funds they rented space and built a lab where the experiments began, all on a shoestring budget. It took three-and-a-half years to produce a prototype.

While researching their new stabilizer, I visited the lab, set up in a waterfront building in Solomons, Maryland. It's impressively well equipped, but small. The brightly lit white-painted rooms are a sort of



Above—*Testing equipment crowds the lab where the myriad challenges of creating a small but sufficiently heavy gyroscope—and the vacuum to spin it in—were overcome.* ***Right***—*McKenney explains the hydraulic table that simulated wave motion during Seakeeper's technical development.*

Walls of the gyro's vacuum-chamber housing are reinforced cast aluminum, 1.25"-thick (32mm). The chamber allows the flywheel to spin freely, unimpeded by atmospheric resistance, and is strong enough to contain fragments of the flywheel should it disintegrate in motion.

gearhead nirvana, crammed full with (among other equipment) hydraulic rams, power packs, computers, and a large articulating table that simulates motion at sea. There were gyros and gyro parts everywhere. R&D was still very much in progress.

During development there were setbacks. No one had ever successfully operated a CMG in an artificial vacuum. The vacuum inside the Seakeeper chamber is 0.04″ (0.10cm) of mercury, compared to atmospheric pressure, which is approximately 30″ (76.2cm) of mercury at sea level. A reinforced aluminum pressure chamber had to be constructed that could hold a vacuum *and* the nearly 400-lb (181-kg) flywheel spinning at 10,000 rpm. In order to ensure its structural integrity at high rotational speeds, the flywheel is made of the same alloy as aircraft landing gear, but the chamber had to be strong enough to contain fragments of the flywheel should it fail.

Adams said the greatest technical challenge was developing bearings that could operate at 10,000 rpm while supporting the tremendous dynamic loads imparted by the flywheel. Whereas air is a liability when trying to power a high-speed flywheel, it's an asset to bearings and other components that generate heat during operation. Air helps cool the bearings in atmospheric gyros. But, since the Seakeeper gyro spins in a near-vacuum, a glycol liquid cooling loop had to be designed to remove heat from the Seakeeper's bearings.

Lubrication, too, was a problem to be solved. While ordinary grease may work fine for most similar bearing arrangements, it will boil or evaporate in the vacuum of a containment chamber. Spacecraft grease was the answer.

Besides operating at atmospheric pressure, all previous ship stabilization gyros were considered "passive"—meaning, they're geared to counter only a vessel's vulnerable natural roll period. As mentioned earlier, those stabilizers are permanently fixed to a vessel's hull, and are most effective at damping motion in the specific sea condition they were designed to target. If the given sea conditions are any different, such gyros are simply not as efficient.

McKenney and Adams overcame this limitation by making their gyro "active," or able to respond to differing sea conditions. The Seakeeper is mounted on twin gimbaled bearings. Dual hydraulic cylinders actively control the articulation of the vacuum chamber and the flywheel within, thereby regulating the direction of the force that the gyro imparts on the vessel.

During those December sea trials,

The Seakeeper actively responds to wave motion via control circuitry that carries electronic inputs from motion sensors to a pair of hydraulic rams. Those in turn articulate the stabilizer housing on its athwartship axis.

Gyro Basics

What do toy tops, bullets fired from rifled barrels, Frisbees, and the International Space Station have in common? All are affected or controlled in some way by gyroscopic principles, control moment gyros, or gyrocompasses.

A spinning top is perhaps the most prosaic example of a control moment gyroscope, or CMG. If you ever played with a top, you probably recall how it seemed to resist outside movement. That's because gyroscopes will always point to a fixed point in space, so long as they remain undisturbed.

If, however, a CMG is disturbed—that is, if you try to tilt a spinning gyro's axis—then the reaction will be at right angles to the direction of force applied. You can feel this effect clearly by holding the hub of a spinning bicycle wheel in your hands. When you try to turn the wheel, you'll feel the resistance of the gyroscope to your influence; stop the wheel, and you encounter no such resistance. This phenomenon of resistance to outside influence is known as *precession*. It's what makes gyroscopes useful as gyrocompasses, and for spacecraft and watercraft stabilization.

—Steve D'Antonio

The stabilizer can exert as much as two tons of vertical or horizontal torque. It mounts on bearings tied into the boat's main structural members—typically, the engine beds.

where I clung to the Viking as it rolled in a seaway, the Seakeeper's flywheel was rotating at 10,000 rpm, its hydraulic cylinders locked in the passive mode of other gyrostabilizers. Once the control circuitry was activated, though, I could see the vacuum chamber—driven by the automated hydraulics—begin to rock back and forth on the athwartships-axis gimbaled bearings. Motion sensors, and an automotive-style microcontroller, sense vessel roll and send signals to the two hydraulic cylinders, allowing the gyro's motion to be optimized for a variety of sea conditions.

Installation

Because the gyro is a torque device, in theory it can be installed anywhere aboard a vessel. But a limiting factor is the need for the surrounding structure to support the weight of the unit—just under 1,000 lbs (453.6 kg)—and the operating forces it exerts on a vessel. The vertical and horizontal torque applied to the hull can be roughly two tons in each direction. So, the gyro must be mounted to a structure—typically, hull stringers—substantial enough to absorb and distribute that load for thousands of cycles.

The gyro's own mounts are channel-shaped sections of aluminum designed to straddle a stringer. Proper

Left—*McKenney engages the stabilizer as the author pilots the test boat from the flybridge.* ***Right***—*Winds were brisk and seas choppy during the author's stabilizer test run off Virginia Beach's Lynnhaven Inlet last December.*

installation, and seeing to it that there is sufficient structural support, are up to the boat builder or yard installing the gyro as an aftermarket product. Seakeeper recommends that a naval architect be consulted for any installation. Although the unit's weight may be similar to that of an engine, the torque loads imparted by a gyro are unlike those of any other gear, making this virgin territory for most builders and installers.

Aboard the Viking, a well-built test vessel, no additional support was deemed necessary; the gyro was simply through-bolted and glued to the vessel's stringers below the cockpit.

Viewed through a glass port in the cockpit sole, the Seakeeper gyro tumbles and rotates automatically to best minimize the roll of the test boat.

McKenney described the Seakeeper project as the most exciting period of his professional career. The fact that the control moment gyro is an old idea that he's updating appeals to him.

Schlicke and Sperry were ahead of their time: the idea was viable, but the technology to actualize it had not been developed. That required the advent of DC brushless motors, literal "space-age" lubricants, high-tolerance machining, and an advanced motor before a practical gyrostabilizer for yachts and other small craft could be created.

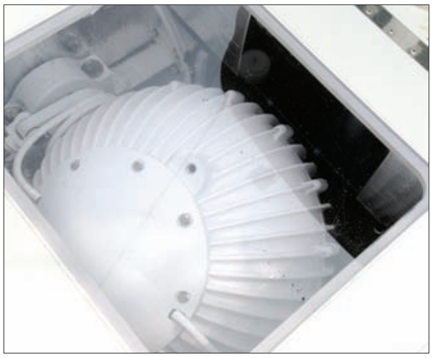
Sperry may have patented the concept of a gyro operating in a vacuum, but Seakeeper was the first to realize it. The company's recent patent covers McKenney's and Adams's practical implementation of Sperry's concept, along with the necessary proprietary control technology to make the jump from passive to active stabilization.

The existing Seakeeper model 7000, intended for boats in the 38′ to 55′ (11.5m to 16.7m) size range, retails for $55,000 before installation. Additional models—for larger and smaller vessels—are under development. Meanwhile, multiple units of the 7000 model can be installed in larger craft; for example, a 110′/33.5m yacht was being equipped with five 7000-series Seakeeper Gyros at the time of this writing.

The product is U.S. made; Seakeeper's "strategic manufacturing partner" is the JOMA Machine Co., located in Mohnton, Pennsylvania.

Sea Trial

As the test-bed Viking made its way through steep December seas off the Virginia coast, I watched the sine wave of the boat's motion on one of several computer monitors on the flybridge. The peaks grew as the



vessel rolled heavily. This visual representation amplified signals already traveling urgently between my brain and my stomach.

"OK. I'm really ready to see this thing work," I said, several times.

When the electronic command was sent to the controller to go active, I watched the gyro's finned aluminum housing (through an opening in the cockpit sole) begin to roll on its axis. Quickly the boat's roll subsided, although seas remained at 4′ to 5′ (1.2m to 1.5m), with spray breaking over the bow. On the computer monitor the sickening sine wave flattened. When we cycled the gyro's active control on and off several times to see how well it was working, I alternately relaxed and restored my death grip on the flybridge supports; regardless of whether the vessel was at rest or at cruising speed, the gyro reduced the boat's roll each time it was activated.

The technology proved its worth to me.

Now, if the unit can be manufactured more cost-effectively, and if proper technical direction for boatbuilders and aftermarket installers can be provided, and the system demonstrates that it can function reliably—then the Seakeeper Gyro will almost assuredly find an appreciative following among recreational boaters and marine professionals who, like me, suffer with every roll. PBB

About the Author: *A former full-service yard manager and longtime technical writer, the author now works with boat builders and owners, and others in the marine industry as "Steve D'Antonio Marine Consulting LLC." His book on marine systems will be published by McGraw-Hill/ International Marine this fall.*