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WARP D
UNDER

Traveling inside drag-cutting bubbles,

RIVE
WATER

BY STEVEN ASHLEY

secret torpedoes and other subsea naval systems can move hundreds of miles per hour

When the Russian submarine K-141 Kursk *sank last August, rumors rapidly arose that the mysterious blasts that sent the big boat to the bottom of the Barents Sea were connected to the testing of an ultrahigh-speed torpedo. Several months earlier, when American businessman* Edmond Pope was arrested in Moscow on charges of espionage, it was said that he had been trying to buy the plans for an ultrahigh-speed torpedo. Although the details surrounding both the tragic naval accident and the celebrated spy case remain unsettled, evidence does suggest that both incidents revolved around an amazing and little-reported technology that allows naval weapons and vessels to travel submerged at hundreds of miles per hour—in some cases, faster than the speed of sound in water. The swiftest traditional undersea technologies, in contrast, are limited to a maximum of about 80 mph.

Of late, it has become increasingly apparent that the world's major naval powers are developing the means to build entire arsenals of innovative underwater weapons and armadas of undersea watercraft able to operate at unprecedented speeds. This high-velocity capability—a kind of "warp drive" for water—is based on the physical phenomenon of supercavitation. This fluid-mechanical effect occurs when bubbles of water vapor form in the lee of bodies submerged in fast-moving water flows. The trick is to surround an object or vessel with a renewable envelope of gas so that the liquid wets very little of the body's surface, thereby drastically reducing the viscous drag. Supercavitating systems could mean a quantum leap in naval warfare that is analogous in some ways to the move from prop planes to jets or even to rockets and missiles.

Although current funding levels for supercavitation research are said to be modest (around $50 million in the U.S., for example), the list of potential supercavitating weapons and naval vessels is extensive and altogether startling. It includes high-speed underwater bullets aimed at mines, homing torpedoes, boats—even low-flying aircraft and helicopters—from submerged gun-pods that look like the turrets on World War II–era aerial bombers. Other possibilities include high-velocity antiship and antitorpedo torpedoes and "midrange unguided engagement breakers," which are larger weapons intended to force an end to a conflict between two submarines. Also envisioned are small, superfast surface craft as well as nuclear-capable subsea missiles designed to neutralize entire aircraft-carrier battle groups.

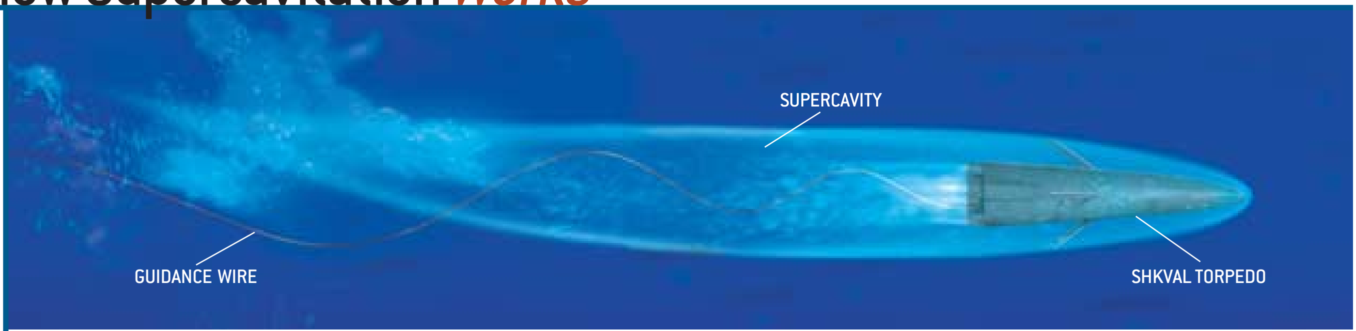
Some naval experts believe that supercavitating systems could alter the nature of undersea warfare, changing stealthy cat-and-mouse stalking contests between large submarines into something resembling aerial combat, featuring noisy high-speed dogfights among small, short-range "subfighters" shooting underwater bullets at one another after having been launched from giant "subcarriers."

Overview/*Swift Subsea Weapons*

- The world's major navies are developing arsenals of innovative high-speed undersea weapons and vessels based on the phenomenon of supercavitation, which allows them to reduce hydrodynamic drag by traveling inside self-generated bubbles of water vapor and gas.
- The Russian navy has already deployed a rocket-powered supercavitating torpedo—the Shkval (Squall)—that is said to go 230 miles per hour. Cash-strapped Russia is looking to sell an improved version of the weapon to other countries. The Shkval has already turned up in France, China and Iran.
- The extensive list of potential supercavitating naval weapons includes short-range underwater projectiles to destroy mines and incoming torpedoes, high-velocity torpedoes, large subsea missiles for destroying entire battle groups, small ultrahigh-speed surface ships, and perhaps even supercavitating submarines. A long-range, multistage strategic torpedo/missile tipped with nuclear warheads that could possibly defeat "Star Wars" defenses has also been envisioned.

PHILIP HOWE (*preceding page*)

How Supercavitation *Works*



WATER FLOWING RAPIDLY around an object causes the fluid pressure to fall. At speeds beyond about 50 meters per second, the pressure drops sufficiently to allow the water to dissociate into water vapor, forming a gas bubble behind the object (cavitation). When the gas bubble fully encloses the object, it is called supercavitation. Slender axisymmetric bodies, such as the high-speed Russian Shkval torpedo (above) create long ellipsoidal supercavities. High-velocity fluid flow (from the right) produces supercavitation above the top surface.

Other experts point to the possibility of fielding long-distance, multistage supercavitating torpedoes/ missiles fitted with nuclear warheads ("long-range guided preemptive weapons") that could prove to be a relatively cheap and effective counter to future "Star Wars" missile defense systems. These devices could dash in from many miles out at sea entirely underwater, pop out of coastal waters close to their targets, and drop their lethal payloads before any aerial or space-based defenses could react.

Surprisingly, we now know of at least one supercavitating weapon that has existed for many years. In 1977, after more than a decade of research and development, the Soviet navy secretly introduced a rocket-powered torpedo called the Shkval (Squall) that can "fly" through water at 100 meters per second (about 230 miles per hour) or more inside a self-generated gas cavity. Although this nuclear-tipped underwater missile is in some ways a bit crude and less than entirely effective, news of it in the early 1990s forced the Western military powers to take notice of supercavitating technology.

There's no doubt that many significant challenges beyond the merely technical would have to be addressed before any of these next-generation technologies achieves reality. Environmental concerns as well as navigation issues would have to be considered, for instance. Probably the biggest barrier to advancement would be finding sufficient capital to develop and build supercavitating marine systems. Nevertheless, history shows that military technology often finds financial support when money for other purposes is scarce.

"Since very few of these things have been built so far, in many ways we're at a stage similar to that of the airplane right after the Wright brothers first flew," says Robert Kuklinski, an engineer and hydrodynamics research scientist at the Naval Undersea Warfare Center (NUWC) Division Newport in Rhode Island, the lead U.S. Navy laboratory investigating supercavitating systems. "But unlike then, we know a lot more about the underlying physics and technology than those early aerial pioneers did."

Propelling a body through water takes considerable effort, as every swimmer knows. Speeding up the pace makes the task even harder because skin friction rises with increased velocity. Swimming laps entirely underwater is even more difficult, as water produces 1,000 times more drag resistance than air does.

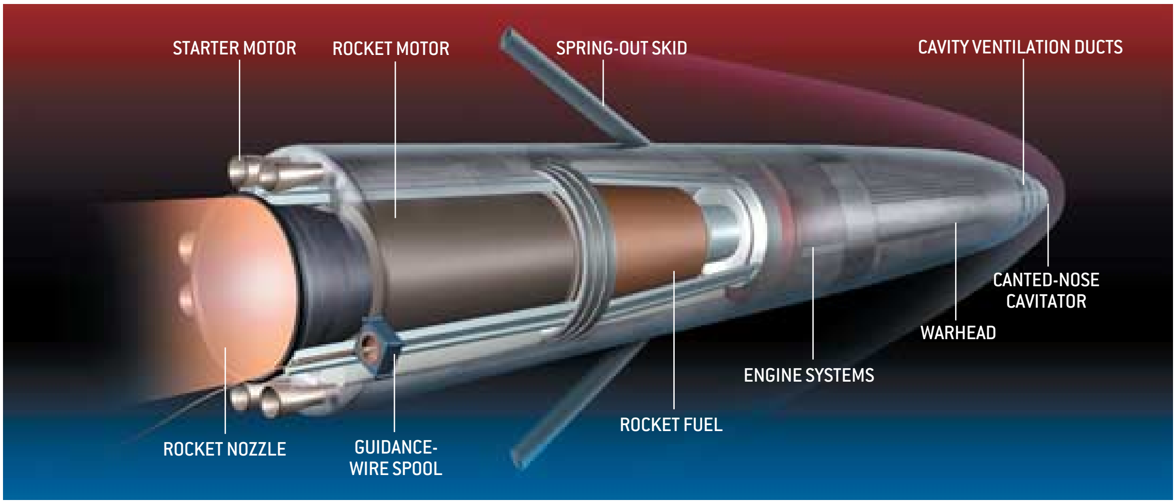
Supercavitation Fundamentals

NAVAL ARCHITECTS AND marine engineers vie constantly with these age-old problems when they streamline the shapes of their hull designs to minimize the frictional drag of water and fit their ships with powerful engines to drive them through the waves. It can come as a shock, therefore, to find out that scientists and engineers have come up with a new way to overcome viscous drag resistance and to move through water at high velocities. In general, the idea is to minimize the amount of wetted surface on the body by enclosing it in a low-density gas bubble.

"When a fluid moves rapidly around a body, the pressure in the flow drops, particularly at trailing edges of the body," explains Marshall P. Tulin, director of the Ocean Engineering Laboratory at the University of California at Santa Barbara and a pioneer in the theory of supercavitating flows. "As velocity increases, a point is reached at which the pressure in the flow equals the vapor pressure of water, whereupon the fluid undergoes a phase change and becomes a gas: water vapor." In other words, with insufficient pressure to hold them together, the liquid water molecules dissociate into a gas.

"Under certain circumstances, especially at sharp edges, the flow can include attached cavities of approximately constant pressure filled with water vapor and air trailing behind. This is what we call natural cavitation," Tulin says. "The cavity takes on the shape necessary to conserve the constant pressure condition on its boundary and is determined by the body creating it, the cavity pressure and the force of gravity," he explains. Naval architects and marine engineers typically try to avoid cavitation because it can distort water flow to rob pumps, turbines, hydrofoils and propellers of operational effi-

RUSSIAN SQUALL
The Russian Shkval torpedo (*in cutaway*) is thought to feature a flat disk cavitator at the nose to create a partial cavity that is expanded into a supercavity by gases injected from forward-mounted vents. Small starter rockets get the weapon moving until a cavity is formed, whereupon the large central rocket kicks in.



ciency. It can also lead to violent shock waves (from rapid bubble collapse), which cause pitting and erosion of metal surfaces.

Supercavitation is an extreme version of cavitation in which a single bubble is formed that envelops the moving object almost completely. At velocities over about 50 meters per second, (typically) blunt-nosed cavitators and prow-mounted gas-injection systems produce these low-density gas pockets (what specialists call supercavities). With slender, axisymmetric bodies, supercavities take the shape of elongated ellipsoids beginning at the forebody and trailing behind, with the length dependent on the speed of the body.

The resulting elliptically shaped cavities soon close up under the pressure of the surrounding water, an area characterized by complex, unsteady flows. Most of the difficulties in mathematically modeling supercavitating flows arise when considering what Tulin calls "the mess at the rear" of cavities, known as the collapse or closure region. In reality, the pressures inside gas cavities are not constant, which leads to many of the analysis problems, he says.

However they're modeled, as long as the water touches only the cavitator, supercavitating devices can scoot along the interiors of the lengthy gas bubbles with minimal drag.

CAVITATORS
Different nose geometries can be used to create supercavities—flat disks, cones, "gear-shaped" plates and cones (*top* and *middle*), faceted concavities and cavitators with inscribed cones that move in and out like the tips of ballpoint pens (*bottom*).

PHILIP HOWE

U.S. Supercavitation Efforts

ALTHOUGH SUPERCAVITATION research in this country focused on high-speed propeller and hydrofoil development in the 1950s, the U.S. Navy subsequently opted to pursue other underwater technologies, particularly those related to stealth operations, rather than high-velocity capabilities. As a result, experts say, the U.S. Navy currently has no supercavitating weapons and is now trying to catch up with the Russian navy.

Supercavitating weapons work in the U.S. is being directed by the Office of Naval Research (ONR) in Arlington, Va. In general, the ONR's efforts are aimed at developing two classes of supercavitating technologies: projectiles and torpedoes.

The first class of weapons is represented by RAMICS (for Rapid Airborne Mine Clearance System), a soon-to-be-requisitioned helicopter-borne weapon that destroys surface and near-surface marine mines by firing supercavitating rounds at them. The 20-millimeter flat-nosed projectiles, which are designed to travel stably through both air and water, are shot from a modified rapid-fire gun with advanced targeting assistance. (The fielded RAMICS projectiles are expected to be enlarged to 30-millimeter caliber.) Raytheon Naval & Maritime Integrated Systems in Portsmouth, R.I., is the chief contractor for RAMICS, and engineers at C Tech Defense Corporation in Port Angeles, Wash., developed the projectiles [*see box on page 35*]. The U.S. Navy is also considering deploying a surface ship–borne, deck-mounted RAMICS-type close-in weapons system that could destroy deadly wake-following torpedoes.

The next step in supercavitating projectile technology will be an entirely subsurface gun system using Adaptable High-Speed Undersea Munitions (AHSUM). These would take the form of supercavitating "kinetic-kill" bullets that are fired from guns in streamlined turrets fitted to the submerged hulls of submarines, surface ships or towed mine-countermeasure sleds. The sonar-directed AHSUM system is hoped to be the underwater equivalent of the U.S. Navy's Phalanx weapons system, a radar-controlled rapid-fire gun that protects surface vessels from incoming cruise missiles.

The other supercavitating technology of interest to the ONR is a torpedo with a maximum velocity of about 200 knots. Substantial technical and system challenges stand in the way of the desired torpedo in the areas of launching, hydrodynamics, acoustics, guidance and control, and propulsion, to name a few, according to ONR program manager Kam Ng. NUWC

The U.S. Navy opted to pursue stealth rather than HIGH VELOCITY. With no supercavitating weapons, the U.S. Navy is now trying to CATCH UP with the Russian navy.

Newport is doing the applied research and some of the basic research work as well. The effort is supported by the Applied Research Laboratory at Pennsylvania State University (ARL/Penn State), the University of Florida, Anteon Corporation and Lockheed Martin.

With regard to the computational fluid dynamics (CFD) work on the torpedo being done at ARL/Penn State, "we're trying to simulate the conditions in which the torpedo would operate, which is the so-called two-phase flow regime where there's both water and gas," Ng says. "We want to know what the water is doing, what the gas cavity is like, and how we make sure the gas cavity encloses the body at all times. Remember, once the cavity is disrupted, the wetted surface increases and the speed is going to drop off very quickly.

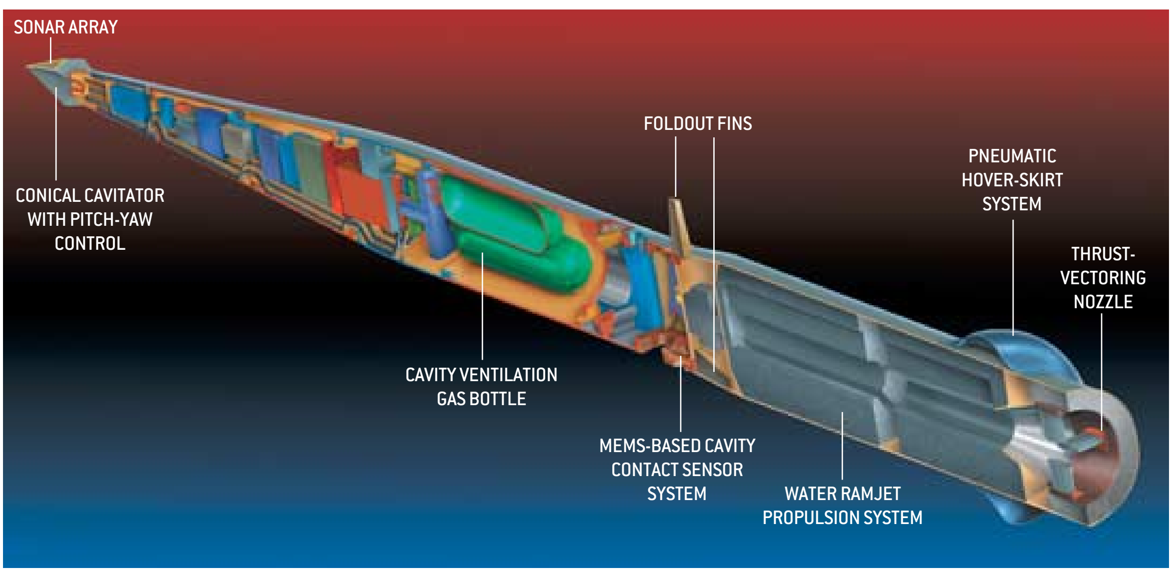
"So far the CFD is doing a fairly good job, but it's not yet to the point that we're happy with it," he continues. "It's both a matter of computational issues and our fundamental understanding of the physics. This is not a Newtonian fluid we're working with here; it's much more complex than a single-phase flow."

Profile of a Supercavitating Torpedo

AS THE FOREMOST existing example of a supercavitating device, the Russian Shkval underwater missile is ideal for the purpose of illuminating the basic parts of a first-generation design. The torpedo, which is reportedly 27 feet long and weighs 5,940 pounds, is "really a big projectile with a rocket on the end," jokes Yuriy N. Savchenko, who directs the research group at the Ukrainian Institute of Hydromechanics in Kiev, where most of the fundamentals of supercavitating weapons technology were first developed.

In general, the weapon consists of a large cylindrical hull containing a solid-rocket motor that tapers to a cone enclosing the warhead. The wide aperture of a rocket nozzle protrudes from the center of the aft end encircled by eight small cylinders, which are said to be small starter rockets. These get the Shkval moving up to supercavitation speed, whereupon the main engine cuts in. Nestled between two of the starter motor nozzles is thought to be a spool of guidance wire that unravels as the torpedo makes its way through the water. The wire would allow submarine personnel to control the weapon's operation and warhead detonation.

Up front, things get a bit more speculative. Experts believe that the nose of the torpedo features what is likely to be a flat disk with a circular or perhaps elliptical shape. This is the all-important cavitator, which creates the gas cavity in which the craft moves. The cavitator disk will be tilted forward at the top, providing an "angle of attack" to generate the lift needed to support the forebody of the device. The cavitator's edge is apt to be sharp, which hydrodynamicists say creates the cleanest or least turbulent gas/water boundary, what they call a "glassy" cavity. Just aft of the cavitator sit several rings of ventilation ducts that inject rocket exhaust and steam into the cavitation bubble to enlarge it. About two thirds of the way back from the nose are four spring-out cylinders angled toward the stern. Although they loosely resemble fins, these spring-tensioned skids actually support the aft end of the torpedo by allowing it to bounce off the inner cavity surface. Western experts believe that the Shkval actually "pre-



PHILIP HOWE

PROTOTYPE WEAPON A future supercavitating torpedo based on U.S. Navy design concepts could feature a range of innovative cavitator, sensing, control and propulsion technologies.

cesses" slowly around the cavity's circumference, repeatedly ricocheting off the walls as it makes its way through the water.

The Shkval is considered to be somewhat unrefined because it can travel only along a straight trajectory, but future supercavitating vehicles are being designed to maneuver through the water. Steering is possible through the use of cavity-piercing control surfaces such as fins, and thrust-vectoring systems, which are directional nozzles for jet exhaust. Extreme care must be taken to keep the body inside the cavity during turns, however, because should it stray from the cavity, the force of slamming into the surrounding wall of water would abruptly turn it into "a crushed Coke can," according to Ivan Kirschner, an engineer at Anteon's Engineering Technology Center in Mystic, Conn.

"Three-dimensional pitch and yaw maneuvers could also be accomplished by moving or rotating the nose cavitator in two planes simultaneously," Kirschner continues, "although such devices would be more complicated." Researchers have also considered using forward-actuated canards.

Supercavitating vehicles could be highly agile if the control surfaces were coordinated correctly, says NUWC's Kuklinsky. The idea is to skew the cavity to one side to create the desired side forces with an articulated nose cavitator or with control surfaces and then track the vehicle in it. If the fore and aft control systems operate in phase so that the "back end keeps up with what the front is doing, very fast turns can be accomplished," he notes.

Part of the solution to the control problem is to install a reliable, real-time feedback control loop that can keep abreast of cavity conditions in the rear of the craft and make the appropriate response to measured changes. As supercavitating systems travel unsupported inside low-density gas bubbles, their afterbodies often bang off the inside wall of cavities. Specialists call this the "tail-slap" phenomenon, which is regularly observed in high-speed test photography of supercavitating devices. The ONR has sponsored the development of a "tail-slap" sensor—a monitoring system based on microelectromechanical components that will track intermittent afterbody contact with the cavity.

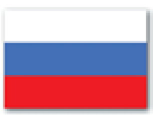
SUBSEA GUNS The U.S. Navy is developing underwater launchers for rotating gun turrets that would be fitted below the waterline to fire "kinetic-kill" projectiles at mines, obstacles, surface craft, homing torpedoes—even low-flying airplanes and helicopters.

PHILIP HOWE

Advanced Propulsion Systems

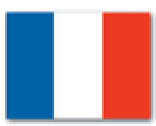
AN IMPORTANT POINT regarding future supercavitating vehicles is the fact that transitions from normal underwater travel into the supercavitating regime and back out again can be accomplished by artificially ventilating a partial cavity to maintain and expand it through the velocity transitions. Thus, a small natural cavity formed at the nose (at lower speeds) can be "blown up" into a large one that fully encloses the entire body. Conversely, braking maneuvers can be eased by augmenting the bubble with injection gases to maintain and then slowly reduce its size so as to gradually scrub speed.

International *Supercavitation Research*



RUSSIA: Although Russia leads the world in supercavitating weapons technology based on its early and extensive work in the field, it is unclear exactly how much progress that country has made in recent years. A significant classified program on supercavitating weapons is reportedly ongoing at TsAGI, the renowned Central Aerohydrodynamic Institute in Zhukovsky, which is thought to have done much of the engineering work on the Shkval underwater missile. Western experts believe that Russian researchers were the first to attain fully submerged supersonic speeds through water. Some say that TsAGI engineers are investigating the possibility of developing supercavitating submarines as well.

UKRAINE: Much of the fundamental technology that underlies the Russian Shkval torpedo came out of the Ukrainian Institute of Hydromechanics in Kiev, which in Soviet times was directed by academician Georgy Logvinovich, one of the pioneers of supercavitation theory. That facility contains a sophisticated water-tank testing system in which wire-riding models are catapulted or jet-propelled through water while under close observation. Researchers at the Institute of Hydromechanics, who are known for their successful semianalytic mathematical approach and extensive testing work, have been trading information about supercavitating technology with their American counterparts since the fall of the Soviet Union.



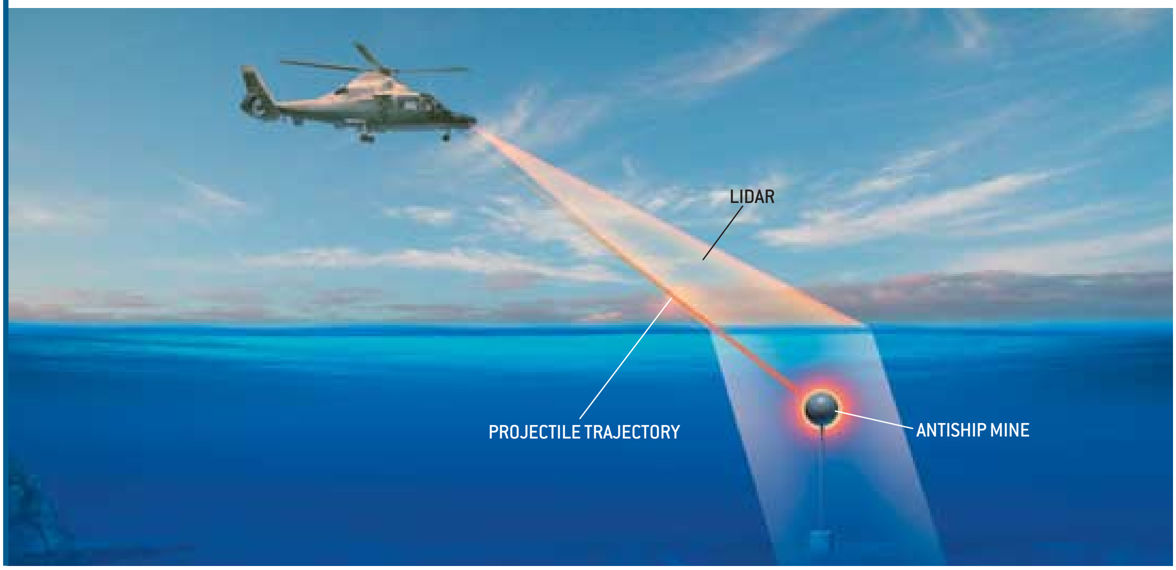
FRANCE: In the past decade, under the supervision of the Directorate of Research, Studies and Techniques (DRET), France has supported a program called Action Concertée Cavitation. Reliable sources report that the government is strongly, if covertly, pursuing supercavitating weaponry. For example, France has reportedly purchased several Shkvals from the Russians for evaluation. Tests of prototype air-launched antimine supercavitating projectiles are being performed at the French-German Research Institute of Saint-Louis.

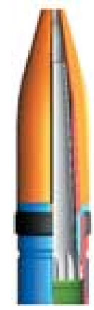
GERMANY: The German Federal Office for Defense Technology and Procurement in Koblenz is cooperating with U.S. Navy researchers in a joint development program on new cavitator designs and the modeling of homing systems for torpedoes. Engineers have also completed initial development of a supercavitating torpedo prototype that is expected to begin trials soon in the U.S.

Neutralizing *Mines*

EVERYONE HAS SEEN action-movie heroes avoid fusillades of bullets by diving several feet underwater. The bullets ricochet away or expend their energy surprisingly rapidly as a result of drag and lateral hydrodynamic forces.

When the Office of Naval Research was asked to find a cost-effective way to stop thousand-dollar surface mines from damaging or destroying multimillion-dollar ships, they turned to supercavitating projectiles. The result was RAMICS—the Rapid Airborne Mine Clearance System, which is being developed for the U.S. Navy by a team led by Raytheon Naval & Maritime Integrated Systems in Portsmouth, R.I. Operating from helicopters, RAMICS will locate subsurface sea mines with an imaging blue-green lidar (light detection and ranging) system, calculate their exact position despite the bending of light by water refraction, and then shoot them with supercavitating rounds that travel stably in both air and water. The special projectiles contain charges that cause the deflagration, or moderated burning, of the mine's explosives.





ANTIMINE PROJECTILE
Supercavitating projectiles shot from above the ocean surface must fly stably in both air and water—a difficult engineering task. The RAMICS round (*partially visible*) was developed by C Tech Defense Corporation.

PHILIP HOWE

Most existing and anticipated autonomous supercavitating vehicles rely on rocket-type motors to generate the required thrust. But conventional rockets entail some serious drawbacks—limited range and declining thrust performance with the rise of pressure as depth increases. The first of these problems is being addressed with a new kind of high-energy-density power-plant technology; the second problem may be circumvented by using a special kind of supercavitating propeller screw technology.

"Getting up to supercavitation speeds requires a lot of power," says researcher Savchenko. "For maximum range with rockets, you need to burn high-energy-density fuels that provide the maximum specific impulse." He estimates that a typical solid-rocket motor can achieve a maximum range of several tens of kilometers and a top speed of perhaps 200 meters per second. After considering propulsion systems based on diesel engines, electric motors, atomic power plants, high-speed diesels, and gas turbines, Savchenko concluded that "only high-efficiency gas turbines and jet propulsion systems burning metal fuels (aluminum, magnesium or lithium) and using outboard water as both the fuel oxidizer and coolant of the combustion products have real potential for propelling supercavitating vehicles to high velocities."

Aluminum, which is relatively cheap, is the most energetic of these metal fuels, producing a reaction temperature of up to 10,600 degrees Celsius. "One can accelerate the reaction by fluidizing [melting] the metal and using water vapor," Savchenko explains. In one candidate power-plant design, the heat from the combustion chamber would be used to melt stored aluminum sheets at about 675 degrees C and to vaporize seawater as well. The resulting combustion products turn turbine-driven propeller screws.

This type of system has already been developed in Russia, according to media reports there. The U.S. also has experience with these kinds of systems. Researchers at Penn State's Applied Research Laboratory are operating an aluminum-burning "water ramjet" system, which was developed as an auxiliary power source for a naval surface ship.

In the novel American design, powdered aluminum feeds into a whirlpool of seawater occurring in what is called a vortex combustor. The rapid rotation scrapes the particles together, grinding off the inert aluminum oxide film that covers them, which initiates an intense

As there are NO KNOWN COUNTERMEASURES, to such a weapon, its deployment could have a significant effect on future maritime operations.

exothermic reaction as the aluminum oxidizes. High-pressure steam from this combustion process expands out a rocket nozzle or drives a turbine that turns a propeller screw.

Tests have shown that prop screws offer the potential to boost thrust by 20 percent compared with that of rockets, although in theory it may be possible for screws to double available thrust, Savchenko says. Designs for a turbo-rotor propeller system with a single supercavitating "hull propeller," or a pair of counterrotating hull props that encircle the outer surface of the craft so they can reach the gas/water boundary, have been tested. He emphasizes, however, that "considerable work remains to be done on how the propeller and cavity must interact" before real progress can be made.

Fears for the Future

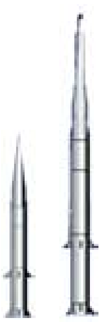
WHATEVER THE YEARS AHEAD may hold for supercavitating weapons, they have already exerted a strong influence on military and intelligence communities around the world. Indeed, they seem to have spurred some reevaluation of naval strategy.

For example, when news of the Shkval's existence emerged, a debate soon ensued regarding its purpose. Some Western intelligence sources say that the Shkval had been developed to allow the noisy, low-tech diesel subs of the then Soviet Union to respond if suddenly fired on by ultraquiet American submarines lurking nearby. On hearing the screws of the incoming conventional torpedo, the Shkval would be launched to force an attacker to evade and thereby perhaps to cut the incoming torpedo's guidance wire. In effect, they say, the Shkval is a sub killer, particularly if it is fitted with a tactical nuclear warhead.

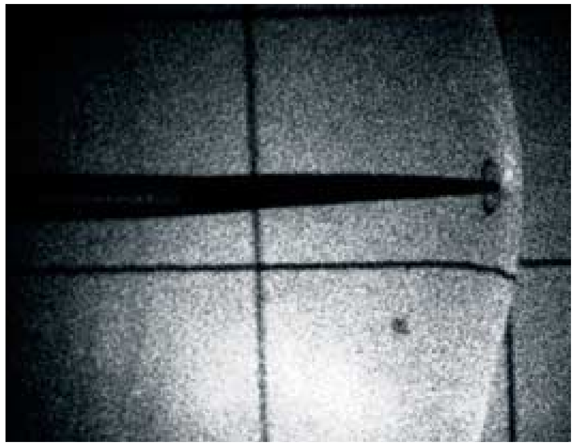
Other informed sources claim that the missile is in fact an offensive weapon designed to explode a higher-yield nuclear charge amid a carrier battle group, thereby taking out the entire armada. During a nuclear war, it could even be directed at a port or coastal land target.

"As there are no known countermeasures to such a weapon," states David Miller's April 1995 article "Supercavitation: Going to War in a Bubble," in *Jane's Intelligence Review,* "its deployment could have a significant effect on future maritime operations, both surface and subsurface, and could put Western naval forces at a considerable disadvantage."

In recent years, cash-strapped Russia has openly offered the Shkval for sale at international arms shows in Abu Dhabi and Athens, a development that causes grave concern in the Pentagon. Well-placed sources say that several Shkvals have been sold to Iran, for example.



UNDERSEA MISSILES The U.S. Navy is considering design concepts for large, extended-range supercavitating weapons. On the left is a "midrange unguided engagement breaker"; on the right is a "long-range guided preemptive weapon."



SUPERSONIC BULLET In 1997 a research team at the Naval Undersea Warfare Center Division Newport in Rhode Island demonstrated the fully submerged launch of a supercavitating projectile with a muzzle velocity of 1,549 meters per second, which exceeds the speed of sound in water.

U.S. NAVY/NUWC

Of equal worry is an August 1998 report that China purchased around 40 Shkval torpedoes from Kazakhstan, raising the possibility that Beijing could threaten American naval forces in a future confrontation in the Taiwan Strait. News from China (reportedly confirmed by U.S. Navy sources) that a Chinese submarine officer was on board the sunken *Kursk* has also raised alarms. He was there, they say, to observe the test of a new version of the Shkval.

U.S. intelligence has received several indications that the Russians were working on an advanced, much longer-range Shkval. For example, Russia's Itar-Tass news agency reported in February 1998 that tests of a "modernized" Shkval were scheduled by Russia's Pacific Fleet for that spring.

The *Kursk* incident, the Pope trial and the ambiguity surrounding both reinforce the fact that the end of the cold war has in no way halted the clandestine arms competition to secure an edge in any future conflict. Clearly, the secret storm over the Shkval rages on. SA

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