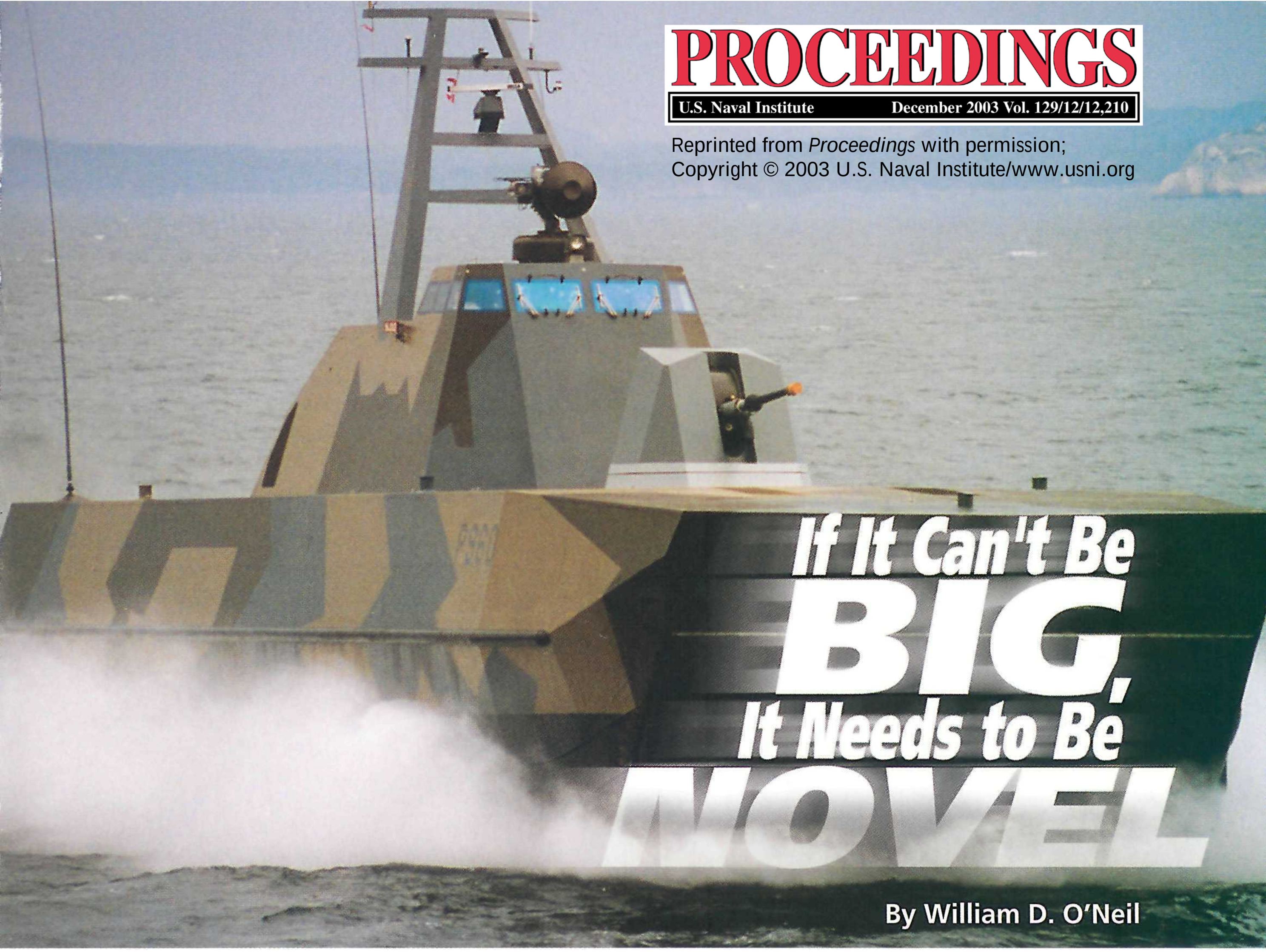
PROCEEDINGS
U.S. Naval Institute December 2003 Vol. 129/12/12,210



If It Can't Be BIG, It Needs to Be NOVEL

By William D. O'Neil

ROYAL NORWEGIAN NAVY

For the first time in years, U.S. naval engineers are being pressed to build smaller, faster, and deadlier ships that can fight and survive in the littorals. Radical new design concepts, such as the Norwegian surface effect ship *Skjold,* are giving builders more options for hull designs than ever before.

Nature unfairly favors large ships. An aircraft carrier ten times the displacement of a destroyer needs only about three times the power for equal speed, carries more than ten times the war load, and has far better sea keeping and survivability—all at about five times the cost. A destroyer enjoys similar advantages over a ship one-tenth her own size.

Some needs, however, cannot be filled by a few big ships. The challenge is to develop small ships offering good capabilities affordably. Three decades ago, a surge of interest in novel hull forms for small ships resulted in the construction of six *Pegasus* (PHM-1)-class 235-ton hydrofoil missile craft and an unsuccessful project to develop a large surface effect ship. New ship requirements and new designs have come along since then:

† *Fast Ferries and Catamarans.* More cars and trucks in Europe and Asia in the 1980s brought demands for car and passenger ferries offering economy, speed, and regular operation. Firms in Norway and Australia settled on twin-hulled craft—catamarans—as their answer.

Catamarans combine simplicity with reduced wave-making drag. Pressure varies along a hull as it moves—rising at the bows, falling amidships, rising again aft—producing waves whose wave energy acts as a drag force that peaks when the hull's speed (in knots) reaches about 1.7 times the square root of its waterline length (in feet), when it may be three times as great as water friction. A ship 1,024 feet on waterline steaming at 32 knots is operating at $1.0\sqrt{\text{length}}$ with relatively moderate wave-making drag. But for a 256-foot ship, 32 knots is 2.0

$\sqrt{\text{length}}$, bringing high wavemaking drag. A catamaran's two hulls each can be narrower than is possible for a monohull, where stability limits slimness. Very slender hulls still make waves, but pressure does not build up as much, so their waves are smaller and absorb less power.

More than 100 large catamaran ferries were built in the 1990s, with the Australian firm Incat leading the way. Fast catamarans up to 4,000 tons displacement now are in service. Some make up to 60 knots in sheltered waters, but cats on sea routes usually are designed to cruise between 30 and 40 knots. Their broad flat decks are especially attractive for ferries. With two hulls and a cross deck, catamarans have a lot of structure for their size. To increase payload weight, they are built in aluminum. Most are powered by diesels to cut fuel consumption, although the lighter weight and easier maintenance of gas turbines attracts some operators.

† *SWATHs and Wave Piercers.* One way to counter ship motions in a seaway is a small waterplane area—a hull very narrow at the waterline so that buoyancy does not change so sharply in waves. Also, a submerged hull makes smaller waves and responds less to sea motion than a hull of similar volume at the surface. Joining these ideas, designers came up with the SWATH (small waterplane area, twin hull)—two submerged submarine-like hulls, connected by narrow vertical struts to a raised cross deck.

The bow waves of the two hulls are smaller but interact, canceling at some speeds but reinforcing at others. Reinforcements bring peaks in drag, limiting the speed of bulky-hulled SWATHs.

Even so, the SWATH's reduced motions fill a need for fast ferries, whose passengers complained about shaip catamaran motions. One answer was a semi-SWATH form, with submerged hulls and narrow struts forward that merge into broader, wall-sided hull forms aft. mitigating pitch motions while leaving room for propulsion machinery and avoiding too much change in draft with load changes.

Others, notably Incat, adopted "wave-piercing bows"—hulls that are very narrow forward and project well ahead of the main body at the waterline. sweeping back into the struts. Again, these broaden out aft. Wave piercers dig into waves and pitch less. A vestigial center hull on Incat designs cushions the impact of waves that reach the cross deck, at the cost of some added drag and longitudinal accelerations when waves meet it. Others approach the problem of cross-deck slamming by raising the structure, which costs weight.

Catamarans can be uncomfortable in beam seas. Roll angles are generally small, but they have a quick, stiff roll that many find upsetting. And motions at low speeds can be very troublesome, with a "corkscrew" effect. Catamarans also have greater drag at low speeds than a similarly sized monohull because of the added friction of twin hulls. Slow speeds, however, are of little importance to ferries, which normally run near their maximum continuous speeds.

In 2001, the U.S. Department of Defense leased two Australian-built fast cats. The *WestPac Express,* a semi-SWATH built by Austal Ships, transports Marines quickly and economically between their Okinawa base and training areas around the Western Pacific. Incat's *Joint Venture* (HSV-X1) is leased for joint tests involving a variety of missions. While both encountered some problems associated with adapting civilian ferries to very different military missions, the overall experience with these ships has been quite positive.

In 2003. two more catamaran ferries were leased—both from Incat and both newer and slightly larger than the *Joint Venture*. The Navy got the *Swift* (HSV-2) as an interim

U.S. NAVY

Among the more practical of the new designs for small ships is the double-hulled catamaran. The Australian-built *Joint Venture* (left) and *Spearhead* (right) currently are leased by the U.S. Navy and Army, respectively, for use in testing employment of high-speed transports in a variety of missions. The overall experience with these ships has been positive.

Figure 1: Representative Small Ships

Name	USS *Hercules* (PHM-2)	*WestPac Express*	*Joint Venture* (HSV-X1)	*Swift* (HSV-2)	Aries MDV 3000	R/V *Triton*
Hull form	Submerged canard foils supporting deep-vee monohull	Catamaran with semi-SWATH hulls	Catamaran with semiplaning wave-piercing hulls	Catamaran with semiplaning wave-piercing hulls	Hard chine/deep-vee monohull	Trimaran outrigger
Mission	Missile patrol craft	Theater sealift	Theater sealift	MCM support/ sealift	Vehicle and + passenger ferry	Test ship for trimaran concept
Builder/designer	Boeing	Austal Ships	Incat Australia	Incat Australia	Fincantieri	U. Coll. London and QinetiQ
Length overall (ft)	133	331	313	319	476	318
Waterline length (ft)	116	283	282	302	422	295
Beam overall (ft)	28.2	86.9	87.3	87.3	72.2	73.8
Beam of single hull (ft)	28.2		14.7	14.7	72.2	19.7 center; 3.3 outrigger
Light displacement (long ton)	169	1,300	971	1,131	2,000	1,100
Loaded displacement (long ton)	238	2,050	1,700	1,800	3,200	
Propulsion system	1 Gas turbine, 1 waterjet	4 Diesel-geared, 4 waterjets	4 Diesel-geared, 4 waterjets	4 Diesel-geared, 4 waterjets	2 Diesel + 2 gas turbine, 4 waterjets	Diesel-electric, 1 prop
Max power (SHP)	17,000	38,600	38,600	38,600	95,000	4,700
Max speed (kt)	51	42	45	42	44	20
Speed/$\sqrt{\text{length}}$	(Not applicable)	2.5	2.7	2.4	2.1	1.2
Operational speed (kt)	45	35	35	35	40	20
Fuel + payload (long ton)	750 nmi @ 45 kt	1,500 nmi @ 35 kt	3,000 nmi @ 35 kt	1,400 nmi @ 35 kt	400 nmi @ 40 kt	3,000 nmi @ 12 kt
Principal hull materials	Aluminum (steel foils)	Aluminum	Aluminum	Aluminum	Steel (aluminum superstructure)	Steel
1st of class in service	1977	2001 for U.S.	1998 (ferry svc.)	2003 for U.S.	1998	2000 for U.K.

mine-countermeasures support ship to participate in a variety of tests and gain further experience with high-speed ships. Sister ship *Spearhead* (TSV-1X) serves the Army as an operational prototype of a planned class of fast intratheater transports.

† *Planing and Deep-vees.* As speeds increase, conventional displacement-hull wave patterns tend increasingly to suck the stern down, further increasing drag and reducing stability. Designers of early fast ships incorporated a flat run with low-vee angle (deadrise) aft. Water flowing swiftly past this provided dynamic lift, keeping the stern from sinking too far. Semiplaning forms such as this are universal in high-speed (high relative to square root of length) displacement ships such as destroyers, and are common in catamarans.

Venturesome racers in the early 1900s developed the fully planing boat. With gasoline engines, they skimmed across the surface at more than 50 knots (at least in calm waters), supporting almost all of their weight with the dynamic lift of the hull’s planing surface rather than by displacing water. In succeeding decades, more practical and seaworthy planing forms became dominant for high-speed boats and small ships.

Like any craft moving on or near the surface, planing vessels make waves. They minimize friction, however, and are able to reach speeds more than 3.0 $\sqrt{\text{length}}$, where they begin to outrun their waves and drag. Of course, friction continues to rise as speed increases, but passing the "hump" of high wavemaking opens the way to higher speeds.

Modern seagoing planing hulls generally have deep-vee-type forms forward to minimize high-speed pounding, with moderate deadrise aft. Deep-vees now are used widely for light warships up to several hundred tons in displacement. Looking for economical alternatives for high-speed ferries, some shipbuilders began producing larger deep-vee monohulls in the 1990s, up to several thousand tons. Although too large to support much of their weight with planing lift at 40-knot speeds, refined deep-vee hull forms give them superior sea keeping. Monohulls roll through larger angles than catamarans, but their softer roll motions are more tolerable.

† *Multihulls and Other Concepts.* Recently, the ancient outrigger has been revived in the form of trimarans and pentamarans. A trimaran's slender central hull provides virtually all its buoyancy, but small outrigger hulls, normally just slightly immersed, dig in to provide stabilizing buoyancy in waves. A pentamaran has two sets of outriggers, the after set immersing first.

These multihull structures are more compact and less highly stressed than catamarans, and provide an extremely long and narrow hull for low wavemaking, plus a cross structure for broad decks. The United Kingdom has built a 1,300-ton ship to test the trimaran concept, the R/V *Triton*, reportedly with encouraging results. Multihull ferries have been built, and Austal Ships recently has contracted to deliver a large trimaran, 415 feet long with an overall beam of 98 feet, to provide 40-knot ferry service in the Canary Islands.

While monohulls, twin-hulls, and multihulls have been making the waves in the fast ferry market, other concepts have been pursued elsewhere. A Lockheed Martin variation on the SWATH called Slice has four submerged hulls and supporting struts instead of two, set at the corners. Because hulls and struts are short they reach high levels of wavemaking at low speeds. But once past that hump, wavemaking drag falls off, so Slice has low wave drag at high speeds, with added lift and control fins projecting from the pods.

Other concepts combine the idea of submerged bodies with the dynamic lift of hydrofoils in different ways. Navatek Ltd. in Hawaii has converted a 340-ton Navy test vessel to demonstrate one concept. Navatek also is completing a 100-foot hybrid deep-vee demonstrator with submerged lift bodies.

Surface effect ships, riding on a fan-fed cushion of air trapped between narrow side hulls and contained by skirts or flexible seals fore and aft, remain attractive at very high speeds. Norway recently built a 260-ton, 55-knot missile-armed surface effect ship, the *Skjold.*

Finally, a variant on topside form deserves mention: the "wavepiercing" tumblehome ship. Its inward-sloping sides and back-raked bows were common on warships a century and more ago, but fell out of favor as experience and improved methods of analysis showed their tendency to capsize or plunge quickly when heavily damaged. Interest recently has been revived for radar stealth. It is possible to build safe ships with tumblehome and wavepiercing bows, although it requires increases in size over a more conventional form as well as some operational restrictions.

New Materials

Steel has dominated shipbuilding for 120 years. Nothing matches its combination of high tensile strength, low cost, and easy fabrication. For small ships, however, steel has drawbacks. Steel's density—7.8 times that of water—means that hull plates with enough tensile strength to handle the stresses of a small ship will be only millimeters thick. Steel so thin cannot resist impact and buckling loads without heavy reinforcement.

Consequently, small ships often are built of aluminum. Its tensile strength is less than steel's, but its lower density—about 35% of steel's—allows thicker and stiffer plates for less weight. With flat or singly curved sections, shipbuilders employ extruded plates with integral stiffening ribs, considerably reducing welding. But aluminum is more expensive than steel and more difficult and costly to weld. Aluminum ships can have trouble with cracking and corrosion at welds.

Long used in boat building, glass-reinforced plastics are too flexible for larger craft. Carbon-reinforced plastic composites have been

U.S. MARINE CORPS

The WestPac Express, a semi-SWATH built by Austal Ships, transports U.S. Marines quickly and economically between their Okinawa base and Western Pacific training areas.

used increasingly where high strength and more stiffness than fiberglass is required. A notable "plastic ship" is Sweden's new 650-ton corvette, the *Visby*. Her hull is formed from a strong but light "sandwich" with a core of low-density plastic bonded to facing sheets of high-strength carbon-reinforced composites. The ship builder, Kockums AB, developed the new material and claims overall weight savings of about one-third in a typical small ship compared to one built of steel. Cost has slowed use of carbon-reinforced plastics, but prices are declining as volumes grow. Although widely used in aircraft, there is little experience with them yet in ships, and many questions remain to be answered. Nevertheless, they show exciting promise for small warships.

LOCKHEED MARTIN

The innovative Sea Slice uses a semi-SWATH design with four underwater hulls that produce low-wave drag at high speeds. In tests, she has achieved speeds up to 30 knots in 12-foot seas, with minimal wavemaking.

Warships Are Different

U.S. Navy warships must deploy halfway around the globe, transit and operate with fast strike groups without replenishing too frequently, keep the sea for weeks or even months, operate effectively in high seas, weather great storms, and get their voyage repairs accomplished in local commercial shipyards. Their war loads must be adequate for high-threat areas and allow them to operate independently. Within the limits of size they must be able to take hits and survive.

A conventional destroyer-like steel ship able to meet these needs could not be much smaller than 3,000 tons at full load. New hull forms and materials offer hope for size reduction, but there are limiting factors, including weight and volume of war load, fuel for normal operations, and weight of ship's structure. There does not appear to be any particular reason why the choice of hull form would have a great effect by itself on war-load requirements. Of course, a truly stealthy ship will need less defense. Stealth has its own price, however, and it does not seem likely that it will be a ship-shrinker overall.

If it is not to require fueling more often than every third day, a ship must steam mostly at lower speeds. None of the advanced hullforms is likely to be as efficient below 20 knots as a destroyer-like monohull; some are distinctly less efficient, meaning they will burn fuel faster than a conventional ship at the same speed, and thus have to carry more or make up the difference in other ways.

Regardless of whether they offer much size reduction, new hull forms may bring important advantages in other ways:

† *Speed.* While destroyer-type hull forms in the 2,000-3,000-ton range have reached top speeds up to 45 knots in low sea states, higher seas are another matter. Each hull form responds differently to the details of sea spectrum and direction, but several can hold their speeds better in rougher seas and with lower fuel consumption.

† *Bulky loads and topweight.* The large deck spaces of catamarans and multihulls accommodate bulky war loads that do not fit comfortably in small conventional ships.

† *Aviation capabilities.* With broad decks and small roll angles, catamarans and multihulls should suit helicopters and unmanned aerial vehicles especially well.

† *Unmanned underwater and surface vehicles.* Multihull and twin-hull ships can deploy heavy objects into the water and recover them more easily and safely in a seaway than conventional monohulls.

All this assumes a need for self-sufficient, deployable, survivable ships able to operate with reasonable flexibility near potentially hostile shores. It is possible the Navy will conclude it can sacrifice some independence and capability to cut the size of its small ships, employing different operational concepts. This could open the door to other hull-form options. Hydrofoils, such as the PHMs, offer 45-knot speeds and good sea keeping at speed. Surface effect ships, such as the *Skjold*, can reach higher speeds with reasonably good sea keeping. Other forms could be near-term possibilities in small sizes.

Warships below about 2,500 tons displacement, however, generally have not lasted more than 15 years in Navy service since World War II. They were too limited in capabilities to have broad utility, and their modest direct costs of operation were offset by dependence on external support. On the other hand, the prospect of short lives for such small ships, together with lower costs, might encourage experimentation with new materials and other risky innovations.

The naval services and the Army are pursuing several advanced ship initiatives, including the littoral combat ship, littoral support craft, and theater support vessel, as well as several purely experimental efforts. They are aided a great deal by the technology and experience of the fast ferry industry and the foreign development of small coastal warships. With imaginative and focused effort to further extend the technology base, the services can look forward to a new generation of smaller ships to meet vital needs.

Mr. O'Neil is the chief scientist and vice president of CNA Corporation. A retired Naval Reserve surface warfare officer, he has served in a variety of technical and management posts in government and the marine and aerospace industries. Many of his articles have appeared in *Proceedings* over the past 30 years.