INTERNATIONAL

Combat Arms

VOLUME 3, NUMBER 3 THE JOURNAL OF DEFENSE TECHNOLOGY MAY 1985

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FEATURES

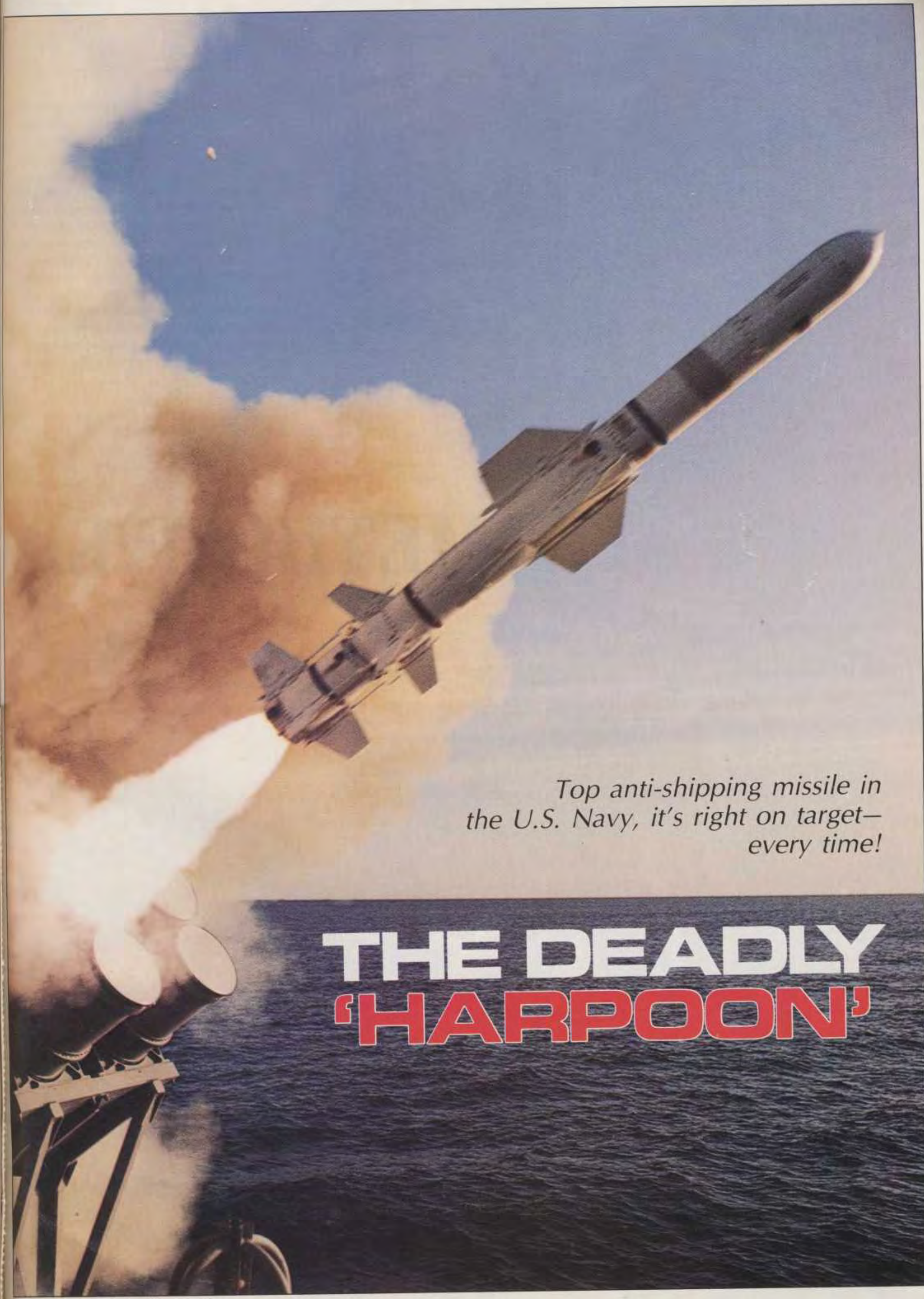
ICA TECHNICAL INTELLIGENCE

DEPARTMENTS

ON THE COVER

The largest ballistic submarine to join the fleet, General Dynamics' Trident class will greatly improve our nation's nuclear deterrent for many years to come. *ICA* wishes to thank the U.S. Navy for this dramatic cover photo of our "super underwater warriors."

INTERNATIONAL COMBAT ARMS MAY 1985 0-8227-2470-7 Volume 3, No. 3.



Top anti-shipping missile in the U.S. Navy, it's right on target— every time!

THE DEADLY 'HARPOON'

By Damian Housman

In the late 1960s, the U.S. Navy came to the conclusion that it would need more than the aircraft carrier to control the seas. Since World War II, our Navy had relied on carrier-borne aircraft to supply the anti-ship (ASUW) punch for the fleet, but it was no longer enough. Even before the sinking of the Israeli destroyer Eilat in the 1967 war by Soviet-built Styx missiles launched by Egyptian boats, the Navy was aware of the power and flexibility of this new generation of weapons. The Navy was also aware of a new threat to its carrier battle groups (CVBGs): the missile-armed submarine!

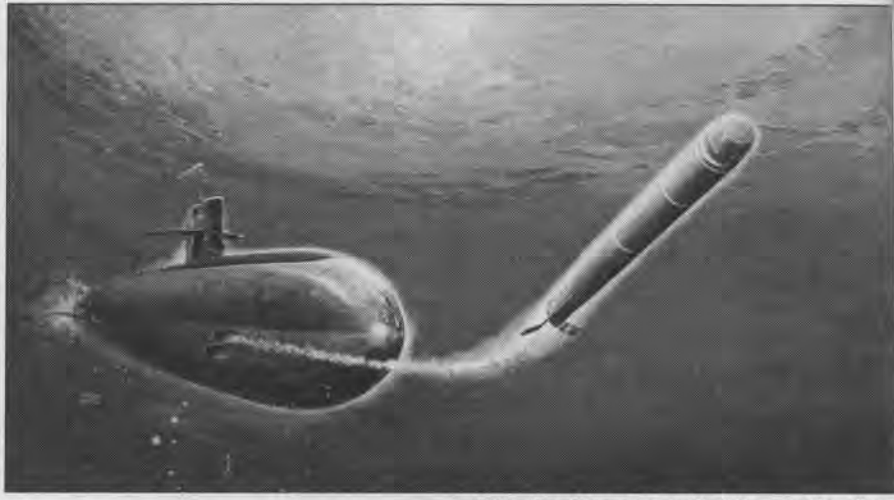
Those submarines, early Juliet and Echo II class, had to surface to fire their missiles. Today this sounds old fashioned, but there were, and are, advantages. When they surface, they are well above the minimum engagement depth of standard Mk 46 torpedoes. Also, their strong pressure hulls are proof against all but the largest warheads. A weapon which could get there fast and penetrate the hull of these subs was needed, and the result was Harpoon.

In the early stages of development it was decided that the original purpose of the missile, hitting surfaced subs, may not be the only useful thing it could do. There was a realization that we needed a standoff weapon to deal with the surface ships of the growing Soviet navy. Also, a variety of launch platforms were added to the original plan, which was to put them on land-based aircraft. Sea-based aircraft, surface ships and submarines were included in the plans. Of course, the latter meant that Harpoon would also have to fit in a torpedo tube for launch.

The McDonnell Douglas Corporation of St. Louis received its first Harpoon contracts in 1971, and the first ships were armed with the system in 1977. In May, 1984, the U.S. Navy took possession of its 3,000th Harpoon, so it is plain they did something right.

Today, more than 200 U.S. Navy surface ships carry Harpoon, in addition to all our attack submarines. The Navy plans to equip all P-3 Orions, A-6E Intruders, S-3 Vikings and F/A-18 Hornets to carry Harpoon, while the Air Force has modified some B-52s to carry it. Harpoon has proven so popular with our allies that they are equipping their ships, boats, subs and planes to carry it as well. The Australians carry it on their F-111C fighter bomber, and the Canadians have it for their CP-140 patrol plane. The British have even selected Harpoon over their *own* Sea Eagle for future surface ships, while they already have it on their submarines and Nimrod patrol planes. Some NATO allies have also modified their F-16s to carry it. Thus far, it is operated by the United States, Canada, the Netherlands, Denmark, the United Kingdom, Spain, West Germany, South Korea, Japan, Australia, Thailand, Pakistan, Saudi Arabia, Egypt, Turkey, Israel and Greece. Even Iran at one time had a small number when the Shah was still in power. They were the air-launched versions, and Iran has but a single aircraft capable of using it. More than 80 were on order, and these are now to be sold to the U.S. Air Force.

The reasons these countries have chosen Harpoon are many. They want a missile



With the Harpoon anti-ship missile, there is no need for the submarine to surface. Fired from the torpedo tube, the missile sheds its capsule and heads for its target!

HARPOON SPECIFICATIONS

Diameter:	13.5 inches.
Wing span:	36.0 inches.
Length (air launch):	151.5 inches.
(ship/sub launch):	182.5 inches.
Weight (air launch):	1,144.9 pounds.
(ship/sub launch):	1,503.3 pounds.
Fuel (JP-4):	100 pounds (JP-10 is heavier).
Engine:	Single spool turbojet.
Thrust:	600 pounds.
Booster:	Solid fuel composite, cast in case.
Thrust:	12,000 pounds for 2.9 seconds.
Range:	Approximately 60 miles with JP-4; approximately 70 miles with JP-10.
Speed:	Mach .85.
Warhead:	High explosive, blast, delayed detonation, 488.5 pounds.
Guidance:	Three-axis attitude reference assembly, digital computer, radar altimeter.
Seeker:	Solid state active radar, frequency agile, with selectable turn-on range and search pattern.
ECCM:	Home-on jam, moving target indicator, radar frequency agility, with others classified.

which is reliable, relatively easy to operate, requires little maintenance, doesn't cost an arm and a leg, is accurate, delivers a big punch, works well in an electronic warfare environment and is hard to shoot down.

The AGM-84A Harpoon is a cylindrical missile 151.5 inches long (182.5 inches with booster) and 13.5 inches in diameter, with folding wings which open to span 36.0 inches. The air-launched version weighs 1,144.9 pounds, while the ship and sub-launched version weighs 1,503.3 pounds. The warhead takes up a whopping 488.5 pounds of this weight and it can penetrate before detonating. Its high explosive, blast type effect has the power of a 2,000 to 3,000-pound bomb. One need only look at the results of the Falklands campaign, and compare it with the much smaller Exocet warheads and bombs, to see that this is a truly devastating weapon.

The engine is an air-breathing turbojet, weighing about 98 pounds, and puts out 600 pounds of thrust. It is a single spool engine with a combined axial/centrifugal compressor, and is made by both Teledyne CAE and Williams. One hundred pounds of JP-4 fuel carry the Harpoon about 60 miles at wavetop or on-the-deck level.

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'HARPOON'

Ship-sinking power many times over! Today, more than 200 U.S. Navy surface ships are carrying the Harpoon missile. It can be fired from a variety of different launchers including the MK 112 ASROC box, or canisters, and it has a range of over 50 miles.

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Shaft speed is 41,000 rpm, and it can go from zero to maximum thrust in seven seconds. When launched from ships and submarines a solid fuel booster is added to the rear of the missile. It produces 12,000 pounds of thrust for 2.9 seconds, and separates from the missile at 1,300 feet altitude. Then the turbojet takes over, and the cruising speed is "high subsonic," approximately Mach .85.

The control section mounts four aluminum, electromechanically driven control fins. Each fin, plus its actuating equipment, weighs eight pounds. They provide plus or minus 30 degrees of fin movement. As the missile leaves the launcher (or the buoyant capsule, in the case of the sub-launched version), the folded forward fins spring into position.

A variety of launchers have been used over the years. The first Harpoons were loaded in Mk 112 ASROC box launchers. Later, canister launchers were developed. A lightweight canister was fitted to patrol missile boats, while a shock resistant model was introduced for larger ships. Both have a cluster of four canisters on a supporting structure. Most ships have two clusters, holding eight missiles. Larger ships usually mount the launchers nearly amidships, though the new Ticonderoga class (CG-47) mounts them in a presumably more exposed position on the stern. However, given the fact that radar guided missiles generally head for the center of a target, it is possible that they are less, not more vulnerable to enemy missiles. Battleships USS New Jersey and USS Iowa have four quad canisters, with 16 missiles. Harpoon has also been fired from standard missile rail launchers, but the Navy does not like cutting into the magazine space used for surface-to-air missiles or ASW weapons.

The sub-launched Harpoon is exactly like the ship-launched version, except that it is installed in a buoyant capsule. The capsule is fired from the sub through the torpedo tubes, then rises to the surface. As the capsule comes to the surface, the solid fuel booster fires, the fins deploy and the missile flies along the same trajectory as the ship-launched version. A BQQ-5 long range sonar system and a Mk 117 fire control system are required for use of the missile. Most Los Angeles class submarines have these systems, though some older ones can fire the missile using the Mk 113 Mod 10 system.

Harpoon is radar guided in the final "attack" stage, the antenna being in the nose under a coated plastic radome. A three-axis, strap-down attitude reference assembly, a digital computer and a radar altimeter permit the missile to fly at "sea-skimming" height from the launch point to radar activation. There are several options for seeker search patterns, depending on how much information is available on the enemy ships. If precise information is known on their location, course and speed, a range and bearing launch (RBL) will be used. If only the direction of the enemy is known, a bearing only launch (BOL) will be used. With an RBL, the seeker will be turned on very close to the enemy, making detection of radar emissions extremely difficult. With a BOL, the seeker must be turned on much earlier. Precise search patterns are highly classified, but the seeker head is able to turn 45 degrees either side of boresight. This also allows the missile to make its terminal or final maneuver, where it pops up a short distance from the target and noses over so as to strike the target amidships on a sharply downward angle. Together with the delayed detonation of the warhead, Harpoon would, more than likely, do extensive damage to the very bowels of the ship. Tests consistently document a 90 percent probability of hit with Harpoon, with over 95 percent reliability of the missile.

In the past few years, gun defense systems have been introduced which are quite effective against anti-ship missiles. Our own Phalanx, which is radar directed and extremely fast reacting, is one of them. The Soviets have not been standing still either, and they have a 30 mm gun system which is thought to be quite good. The problem is that the terminal climb/dive maneuver allows more time for the gun to react, and also takes the missile higher, which is easier for the gun's radar to see. Later models of Harpoon permit selection of the terminal maneuver, or simply a sea-skimming attack without this maneuver. One tactical option may be to send a salvo of several missiles, some using the maneuver and others not. That should keep the target ship's air defenses busy, and ensure some devastating hits.

Once launched, it is not possible to change the course of Harpoon, give it additional instructions or receive information from it. It is a true "fire and forget" weapon. Information on target location must be programmed before its launch. This information comes from a variety of sources including radar, sonar, periscope, electronic surveillance or from a third party. Since Harpoon has an over-the-horizon range, third party data can be the most helpful. Firing at a target which you cannot see requires more data than one you can see, but there is also the advantage that the target cannot see you, and may not have a clue that the missile is on the way. The most common third parties are other planes and helicopters, as well as ships.

Once all data is available, it is plugged into the missile through the Harpoon Shiplaunch Command and Launch Control Set (HSCLCS). That is a "plug-in" fire control system which interfaces with standard U.S. Navy equipment. It is located in the Combat Information Center (CIC). Launch of the missiles is under the control of the CVBG Surface Warfare Commander (ASUWC). The ASUWC must analyze the tactical situation and determine the optimum method of employing Harpoon. Many factors affect his decisions, including the location of the enemy force, its size, its composition, whether or not the carrier battle group has been detected, and the present disposition of friendly forces.

The first U.S. Navy aircraft to use the RGM-84A air-launched Harpoon missile was the P-3C Orion. These long range patrol aircraft are often called "sub-chasers," but armed with a full complement of anti-ship missiles, they become a lot more potent!

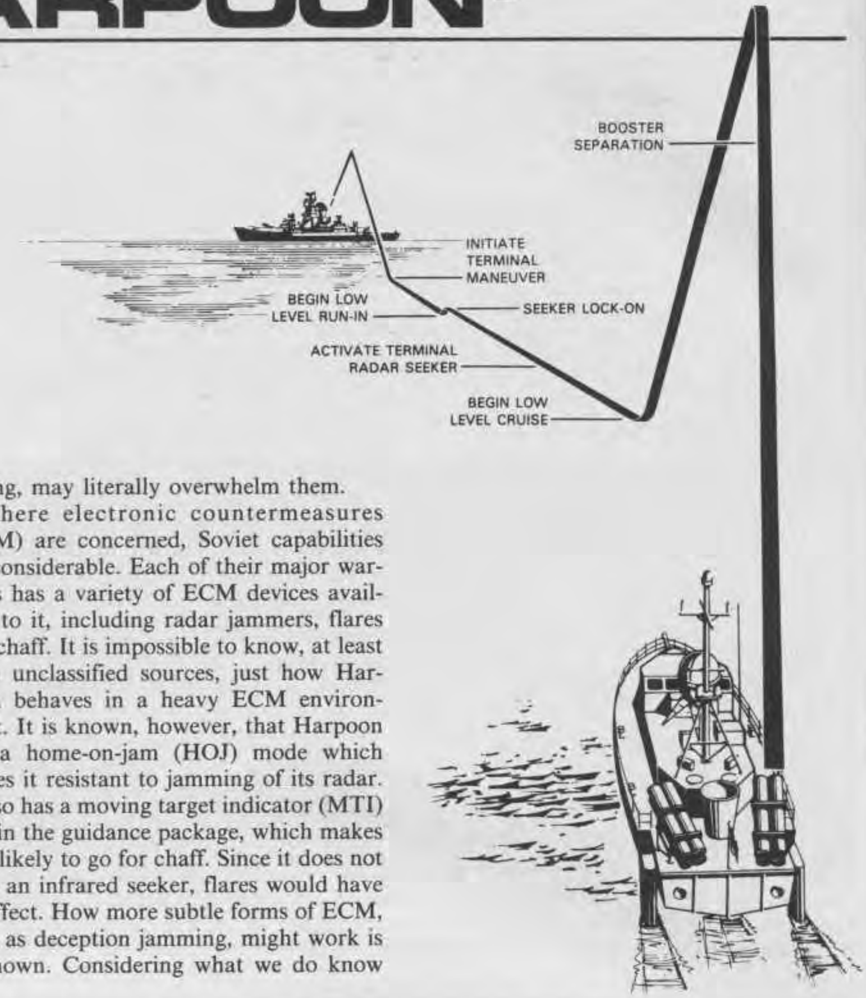
A variety of aircraft can carry the Harpoon, including the Navy's A-6E Intruder (left) and the Air Force's big B-52 bombers (below). Information on a target's location must be programmed into the missile before launch, for the Harpoon is a true "fire and forget" weapon.

If the carrier group has already been detected, then the commander will launch as soon as possible. He will also use whatever electronic countermeasure support is available to jam the enemy radars. Should the carrier group not be detected, he can use a variety of tactics suited to the missile. Long range S-3 Vikings may be sent from the carriers, as well as a strike package with A-6E and a A-7E attack planes. If the F/A-18 is available, it will go as well. The strike package will approach the enemy ships from a direction which does not betray the battle group's location. If possible, different approach routes will be used. This has two advantages. First, it makes it difficult for the enemy to hit all the missiles, meaning that some will get through no matter what. Second, when approaching from different directions, more than one or two ships in a formation will be hit. Harpoon will head for the first real target it sees, so if the same target is not to be hit over and over, different approach routes ensure that more than one ship is attacked. One tactic is to vary the time at which seekers are turned on, so that some ships may be bypassed to get to others. If the enemy is within range of our surface ships or subs, their Harpoons will be used as well, circumstances permitting. The commander usually attempts to have all the Harpoons arrive at the target at the same time, to tie up their defenses.

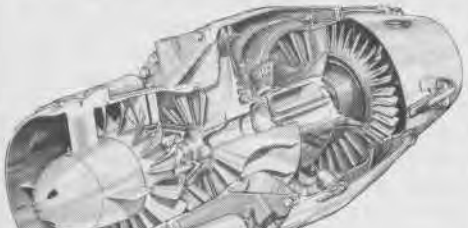
If the tactical situation allows, attacking aircraft and ships will launch anti-radiation missiles at the target ships. These can be HARM, Standard ARM or Shrike in the case of aircraft, and Standard ARM only in the case of ships. The ships, however, can only use these missiles at ranges under 20 miles. The reason for using these missiles, which home on radar, is that the enemy will likely need radar to detect and engage the Harpoons. That makes them good targets for the ARMs. Of course, if they shut off the radars to avoid the ARMs, the Harpoons all get through. Not a real pleasant choice! And all this time, U.S. ships and EA-6Bs are jamming their radars. If the enemy has located and attacked the carrier group first, the commander will order Harpoons to be fired in the direction from which the enemy missiles are coming. What makes this sensible is that the Harpoon outranges the Soviet SS-N-2 (all models), SS-N-7 and SS-N-9 anti-ship missiles, so if there is a ship launching one of these, Harpoon may get him. At the very least, it should cause the enemy ship to turn on his radar to locate and defeat the Harpoon thus allowing our passive systems to detect his radar. The Soviets have long range SS-N-3, SS-N-12 and SS-N-19 missiles which Harpoon does not outrange. They, however, require mid-course corrections from other ships or aircraft. In the vicinity of an American carrier group, that is a hazardous assignment.

This is not to say that the enemy has no chance to shoot down Harpoon missiles. He does, however difficult it may be. In addition to the close-in guns mentioned earlier, many Soviet ships are armed with the SA-N-4 surface-to-air missile. This small missile, similar to the land based SA-8, is excellent against fast, low altitude missiles and aircraft. The new SA-N-6, which is deployed in the new *Kirov* class cruisers, also appears to be a capable missile killer. The Soviets, however, do not have a single, integrated CIC in their ships as we do, and so a large salvo of Harpoons, with close timing, may literally overwhelm them.

Where electronic countermeasures (ECM) are concerned, Soviet capabilities are considerable. Each of their major warships has a variety of ECM devices available to it, including radar jammers, flares and chaff. It is impossible to know, at least from unclassified sources, just how Harpoon behaves in a heavy ECM environment. It is known, however, that Harpoon has a home-on-jam (HOJ) mode which makes it resistant to jamming of its radar. It also has a moving target indicator (MTI) within the guidance package, which makes it unlikely to go for chaff. Since it does not have an infrared seeker, flares would have no effect. How more subtle forms of ECM, such as deception jamming, might work is unknown. Considering what we do know



The missile's solid propellant booster launches the missile and accelerates it to cruise velocity. The turbojet engine then kicks in and the missile descends until pullout is commanded by radar altimeter. It then levels out at low cruise altitude.



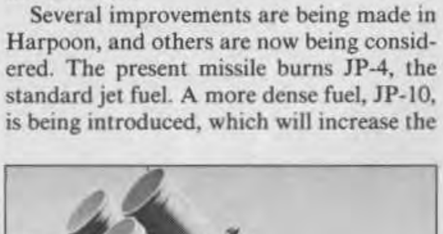
The turbojet powers the Harpoon after booster separation. Once the missile has closed to its preprogrammed distance from the target, the guidance system begins a terminal "pop-up" maneuver to counter an enemy's close-in defenses.

Soviet ships—also known as prime Harpoon targets! With the massive size of the Russian navy, there is no question that this top U.S. anti-shipping missile would be used in the event of conflict. Below, Harpoon is launched from Pegasus PHM 1.

The proof is in the warhead—and the effects to this target destroyer after it was hit by just a single Harpoon missile show just how well its warhead works.

about Harpoon, whatever its other ECM countering capabilities, they are probably as good as any anti-ship missile anywhere in the world.

Several improvements are being made in Harpoon, and others are now being considered. The present missile burns JP-4, the standard jet fuel. A more dense fuel, JP-10, is being introduced, which will increase the missile's range by about 15 percent. The Navy is considering going to a larger fuel tank, which would require lengthening the fuselage several inches. Together with the new fuel, the range could be double that of the original missile. The guidance is being improved to incorporate recent electronic counter-countermeasures (ECCM), thus improving its resistance to electronic warfare. Also, the Navy is considering a means of adding "waypoints" to the guidance system. This would permit the missile to fly to given points in space before turning toward the target. The advantage is that it would make it easier to attack different ships in a formation, since missiles can approach from several directions. Today, this function is handled by positioning the launching ship or plane. Waypoints would also take better advantage of the increased range, and make the location of the U.S. carrier forces harder to determine. Finally, a seeker improvement is being considered which can discriminate between targets. Today, Harpoon attacks the first target it sees. With the improved seeker, the commander can specify the largest target, first target, third target, etc. In addition, it may be a means of ensuring that friendly or nonbelligerent ships are not accidentally attacked.



The Harpoon canister launcher was developed so that the missile could be readily adapted to almost any surface launch application. The launch structure holds four canisters, and the missile's fins and wings are folded to fit inside them.

It has been only seven years since Harpoon was introduced to the fleet. It has already proven itself the most capable anti-ship missile in the world, and it refuses to allow itself to become obsolete. When combined with suitable launch platforms, sufficient numbers and tactical proficiency, Harpoon can rip an enemy surface action group apart in minutes. It appears that Harpoon will continue to serve with distinction in the navies of America and her allies for many years to come.

PUNCH-PACKING SEA SKIMMERS

Boeing's hydrofoils are some of the fastest water-fliers afloat today.

By John Christy

Admiral Elmo Zumwalt, Chief of Naval Operations from 1970 to 1974, has been credited—and occasionally reviled—for a number of changes that characterize today's U.S. Navy. Among these are the development of satellite-based communications and surveillance systems, the missile frigate (FFG), women in the Naval Academy and aboard ship, and, of lesser notoriety, the hydrofoil patrol combatant vessel.

The idea of the hydrofoil didn't orginate with the progressive admiral, but if it hadn't been included in his Operation 60, the hydrofoil would still be an experimental class of one or two. It possibly might even have been scrapped completely as far as the U.S. Navy, traditionally uninterested in small combat vessels, was concerned. Instead, thanks in part to Admiral Zumwalt's Operation 60, there exists an operational squadron of six Harpoon-carrying patrol hydrofoils (PHMs) known as PHM Squadron 2 (PHMRON 2) based in Key West, Florida. PHMRON 2 reached its full complement in 1983, but the story actually begins before World War II.

As early as 1921 an experimental ladder-type naval hydrofoil was tried, but it failed for a number of reasons. In 1936, the J. Samuel White naval shipbuilding firm crafted an 18-foot runabout on the design of a Royal navy commander. With a hullborne displacement of 1.34 tons, it could reach a speed of 33 knots foilborne with the hull clear of the water. By contrast, two hullborne boats, one with lighter displacement, could only reach 24 knots on roughly the same power. (*Ed. Note: Weight in reference to a boat or ship is that of water its hull displaces, not the actual weight of the vessel.*) The displacement of the foilborne boat was obviously far less than the hullborne displacement with consequently greatly reduced drag. A hydrofoil motor torpedo boat (MTB) was subsequently ordered by the Admiralty and ran sea-trials in 1940, but strut and foil technology was not sufficiently understood, and cavitation was so severe the MTB couldn't go any faster than the hullborne MTBs then in service. A later attempt in 1944 resulted in a speed near 46 knots, but there were two problems: it could not launch its own torpedoes and could not turn at high speed.

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SEA SKIMMERS

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The Germans, too, had been working on hydrofoils but apparently never reached the point of satisfactory naval application. The British went on to develop the hovercraft, or air-cushion concept, leaving the Russians to experiment and eventually evolve a commercial version, a number of which are in use as ferries and river passenger craft. In the early 1950s, a Soviet naval version called the PA-4 class appeared, rapidly followed by retrofitted P-6, P-8 and P-10 torpedo boats and the purpose-built Pchela class small patrol boat, 20 of which were built between 1964 and 1967. This experience led to the Turya class, a true strike craft that was first seen in 1973. Still in Soviet service, it is reliably estimated there are in excess of 120 of these 45-knot craft now in use. The latest, appearing in 1980, is the 42-knot Matka class, armed with two SS-N-2c Improved Styx missiles, a 76 mm gun and twin ADG 6-30 guns.

The actual beginning of the U.S. Navy's PHM came in 1970 with a NATO Naval Armament Group (NNAG) recommendation for development of a NATO-wide, commonly usable missile hydrofoil. Several different concepts were studied, with the choice being narrowed down to two: Grumman Aviation's Flagstaff (PGH 1) and Boeing Marine Division's Tucumcari (PGH 2). The two hydrofoils had begun earlier as experimental gunboats (hence the PGH designation), had served briefly in Vietnam and thus had considerable sea development time. They were dispatched on a tour of NATO nations in answer to NNAG recommendation, both making favorable impressions along the way. Grumman's PGH 1 was adopted by the Israelis and a number were ordered, but Boeing eventually got the NATO nod. Boeing's hydrofoil research dated back to 1958 which resulted first in a hydrodynamic test system (HTS), a hydroplane propulsion and dynamic test platform, and then in a series of true hydrofoils. The first of these,

PHM 1, foilborne, firing one its eight Harpoon missiles during early tests in evaluation period during which not only ship systems but tactics for the use of the punch-laden ships were worked out.

USS Pegasus (PHM 1), foilborne, top, hullborne and moored, below, was first of eventual six-ship squadron, now operational as PHMRON 2. Budget-caused delays of five years allowed time for construction improvement, and ensuing ships differ in detail. Compact CIC, bottom, controls Harpoon missiles, gun.

FRESH I was the experimental vessel built by Boeing to test foil types and configurations at high speeds. It still holds hydrofoil speed record of 84 knots.

PGH 1 in company with Coastal Patrol Interdiction Craft (CPIC), center, and Fast Patrol Craft (FPC). PGH 1, USS Flagstaff was built by Grumman in design competition with the Boeing-built PGH 2 for NATO consideration. It lost but was picked for the Israeli navy.

"Little Squirt," a purely company sponsored project, was a 20-foot runabout built to test and develop several systems used on most of Boeing's subsequent hydrofoils. Among these were the waterjet propulsion, automatic control system, acoustic altimeter and flap controls that govern ride height, pitch, roll and heave. Two U.S. Navy contracts followed which resulted in an ultra-high speed foil-test platform, a hydrofoil catamaran-type vessel powered by a single aircraft turbofan, and a Navy-designed 116-foot patrol craft prototype. The foil-test boat still holds the world's unofficial hydrofoil speed record of 84 knots (96.7 mph) set in 1963 on Puget Sound, but speed wasn't the primary object of the exercise. The craft, known as Fresh 1, was designed to test a number of foil configurations and locations, and to test its stability under extreme cavitation and speed conditions. From this came, among other things, the canard configuration of a single foil forward and a double foil aft.

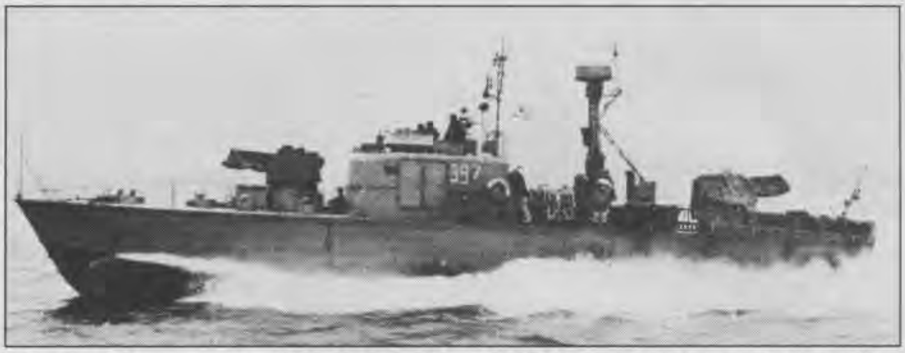
The other craft was a conventional planing displacement hull with fully submerged canard hydrofoils designed by the Navy's Bureau of Ships (BuShips). Christened U.S.S High Point (PCH 1), the patrol craft was delivered in 1963. It departed from Boeing and subsequent Navy practice in that it was powered by two Rolls-Royce Proteus turbine engines driving four propellers through gears and shafts in the two aft foil struts. PCH 1 became not only a test platform for the hydrofoil concept, but a test device for a number of other projects including the Harpoon anti-ship missile and its attendant fire control and launch methods. It was also used to test the feasibility of helicopter medivac at high surface speeds. From High Point came Tucumcari (PGH 2), a 74.6-foot gunboat with a hullborne displacement of 57.5 tons, delivered in 1967. There were a number of significant differences from the High Point aside from size. Propulsion was by waterjet, powered by a single Rolls-Royce Proteus turbine driving a two-impeller, double suction centrifugal pump that was to prove its reliability when it was checked five years later. It was in essentially as-installed condition, with no evidence of erosion, corrosion or cavitation damage. The foils, two aft on seperate struts and one forward, were fully retractable, allowing shallow-water operation in hullborne mode. The forward strut was steerable and an Automatic Control System (ACS) was incorporated, giving continous dynamic control of stability, hull altitude and ride quality, together with fully coordinated banked turning. The ACS operates through feedback control in which forces such as ship attitude, rates, acceleration and other vectors are sensed and compared by computer with desired values. The differences are then translated into commands and sent through servo systems to the foil control-surface linkages, causing the ship to respond in such a way as to minimize the differences.

Unfortunately for the concept, Robert Burns' comments concerning the best laid plans of mice and men eventually became applicable, going totally "agley" as far as NATO was concerned. By the time the NNAG studies, with input from as many as 11 navies, were completed and the three signatories to the "Memorandum of Understanding," the U.S., Italy and the Federal Republic of Germany, had completed the signing, the size of the projected vessel had *doubled*. With all the performance factors cranked into the equation, and all the machinery and weapons added, the 74-foot prototype design had grown to 130 feet with a hullborne tonnage of 224 tons (39.5

HMS Speedy was built for Royal Navy on Boeing's commercial Jetfoil hull and fitted to RN specs by Vosper Thorneycroft. It began North Sea patrol duty in 1980 for multi-role evaluation. Above: the Italian Sparviero class missile hydrofoils are license-built from Boeing PGH 2, USS Tucumcari design but carry Otomat I missiles and Oto Melara 76 mm auto cannon.

meters and 228 tonnes). Cost factors were commensurate with the increase in size, and by 1974, Italy and the FRG had opted out, leaving the U.S. and Boeing to go it alone. The Italians downscaled their requirements and made a license agreement with Boeing to use the original Tucumcari design, modified for missile use, and the Germans decided on the Lurssen S 143 hullborne FPB. The resulting Italian Sparviero became the working prototype of the six-boat Nibbio class PHMs built by Cantieri Navale Riuniti, which follow the PGH 2 design in almost complete detail except for the Italian-made equipment and heavier armament.

Boeing Marine Systems had been given the development and construction contract for the lead ship of what was then supposed to be the NATO Standard PHM. With this in mind, a number of factors had to be taken into account, the primary one being the use of metric measure and others being the inclusion of German and Italian equipment and specifications in such areas as weaponry and electronics. Since it was to be an all-new design, incorporating only the experience gained from earlier designs and, to a large extent, the control systems concepts, it was almost like starting from scratch. Normally, such a project can be estimated to take as much as seven years from design table to launch and completion, ready for sea trials. The first vessel, christened Pegasus (PHM 1) was launched in November, 1974, and made its first foilborne flight on February 25, 1975. (As might be expected, a certain amount of aviation jargon has come into use among hydrofoil people, including take-off, flight and landing.) Rigorous testing of components followed, both in the relatively smooth waters of Puget Sound and in the Pacific waters off Neah Bay where seas can reach sea state 5. In October, 1975, Pegasus set a record of 31 hours, 21 minutes time underway between Seattle and San Diego, an average rate of advance of 37 knots (42 mph). In May of 1976, Boeing was finally convinced that the PHM was ready for Navy Operational Evaluation, which was completed June 8th. The Navy did not, however, take delivery until the following year, finally commissioning Pegasus into the fleet on July 9, 1977. There were a number of reasons for the delay, none of them the fault of the ship. In the aftermath of the Vietnam "experience," Congress tended to blow around all points of the compass as far as defense expenditures were concerned, and there was a certain amount of turmoil in Navy priorities following the end of Zumwalt's term as CNO. The PHM program got caught in the backwash along with some other low-priority programs. The problem of Congress blowing hot and cold would crop up again, and although a contract was let in October, 1977 for the construction of another five PHMs, it would be nearly five years before the second and third PHMs were commissioned.



The Soviets were the first to put the hydrofoil concept into naval service, at first adapting fixed foils to FPBs such as Mo VI, above, and then purpose built fixed-foil craft like the Pchela class, seen cruising hullborne, below.

Boeing-built USS Tucumcari, PGH 2 was counterpart of Grumman PGH 1. It became the basis for the Italian CNR Sparviero.

The Pegasus class resembles the Tucumcari/Sparviero class in that both are missile hydrofoils, both use fully submerged hydrofoils in canard configuration, both use the Boeing-developed ACS and both are Boeing Marine Systems designs. There the comparison, except for similarities in armament, stops. The Pegasus class PHM is in all respects a considerably larger vessel with twice the length, four times the hullborne displacement and twice the foilborne range and endurance in terms of time. At 17,000 nominal shaft horsepower, the General Electric LM2500 turbine foilborne propulsor engine is more than three times as powerful as the Proteus turbine in the Tucumcari/Sparviero class, and there are two *Motoren und Turbinen-Union MB* 8V331TC81 diesel hullborne propulsor engines delivering five times the power of those in the Sparviero and Nibbios. Although the choice of the GE LM2500 engine represented increased machinery weight, larger machinery spaces and ducting, together with greater costs over the use of multiple LM500 or Proteus engines, the selection was made for good reason. The LM2500 engine is a second-generation plant with much lower fuel consumption, on the order of 20 percent, and a power increase potential of growth to 30,000 shp. In addition, it fitted in with the Navy's desire

THE HYDROFOIL DEFINED

The hydrofoil is, basically, a vessel that is capable of flying over water rather than cutting or proceeding in it. Like an aircraft, a hydrofoil uses lift devices similar in concept to the airfoil wings of an aircraft except that they use the lift buoyancy of water rather than that of air. Attached to the vessel's hull by means of strong struts, they lift the hull out of the water when the appropriate speed is reached, allowing the craft to zip along largely unaffected by the resistance of the water. The result is more speed, requiring less power to sustain it, along with a certain amount of immunity to wave motion. There are two types of hydrofoil craft. The most common form uses foils that are steeply slanted in an exaggerated form of a dihedral to pierce the surface of the water. These are laid out as in a conventional aircraft, with the largest foil forward and the smaller foil aft, and are usually nonretractable. In some cases only the large foil is used, usually just forward of the vessel's center of gravity.

The second type of foil runs totally submerged with only the struts piercing the surface. Being submerged, usually by six to eight feet, the foil itself is unaffected by wave motion and surface turbulence, affording a smooth ride even in fairly rough water and waves as high as 15 feet. This is the type, after much experimentation, that has found favor with U.S. builders, primarily its developer, Boeing Marine Systems, and the U.S. Navy.

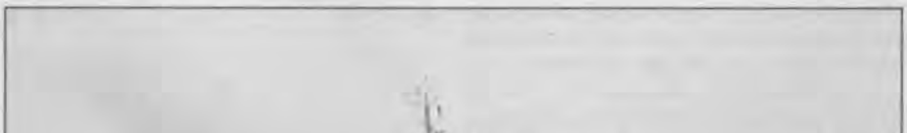
While the submerged foil as used by Boeing and the Navy tends to be more versatile and efficient, there is a trade-off. The surface-piercing foil is simpler and inherently stable, its pronounced dihedral causing the vessel to automatically bank against the force of water in turns without benefit of control surfaces. The submerged foil, usually laid out in canard form with the smaller foil forward and the larger aft, is inherently unstable in turns, especially in rough water. To gain the necessary stability, it requires the use of trailing-edge control surfaces similar to the ailerons on an aircraft wing or tail surface. To be truly efficient, these control surfaces must be operated by sensors responsive to incipient ship motion, and changes in course and height above the mean surface. The sensors transmit their data to the actual control systems, which must react instantly to the messages received and make the necessary corrections. In the Boeing Automatic Control System (ACS) it is done so efficiently that there is little or no perception of the correction process. The trade-off lies in the efficiency and controllability, as well as comfort and superior seakeeping, of the submerged foil system currently used.

The basic hydrofoil concept is anything but new, the original discovery of the effect being made in 1861 by an Englishman named Thomas Moy. In an attempt to study the aerodynamics of wings by observing their effect in water, he attached the wings under a boat and was thoroughly amazed when the boat rose perceptibly in the water. The first purposely crafted successful hydrofoil was designed by Enrico Forlanini, of Milan, Italy, whose craft, powered by aircraft-type propellers, hit a speed of 44 knots (50.6 mph) in 1898. Alexander Graham Bell also had something more to his credit than the invention of the telephone. He built one of the quickest hydrofoils of all time in 1918. Powered by two aircraft engines, his five-ton craft reached a top speed of 70.8 mph, a record not broken until Boeing's Fresh 1 cracked it with a speed of 96.7 mph (84 knots). *—J.C.*

Vertical view of USS Taurus, PHM 3, second ship in commission, clearly shows deck layout and forward foil deployed.

to standardize gas turbine engines to the LM2500s used in Spruance class destroyers (DDGs) and Oliver Hazard Perry class frigates (FFGs), which use four and two each, respectively. For these reasons, combined with the heavy combat punch, the size of the crew complement of four officers and 19 crewmen, and the fact that each example is a duly commissioned vessel, the PHM men are adamant that the PHM be called a *ship*. They'll accept the term "vessel" but balk at the word "craft," and use of the denigrating word "boat" will likely net any such user a violent reaction, figuratively or literally depending on their rank!

There are a number of other differences, other than size, power and armament, from earlier hydrofoils. The hull design, a simple hard-chine displacement bottom on the Tucumcari, was changed in accordance with considerations of weight, intact and damaged stability, two compartment flooding criteria, seakeeping, hullborne resistance, takeoff resistance and foilborne wave impact. There isn't much outward difference in appearance at first glance, but closer study shows detailed difference in chine angles, freeboard flare, propulsion outlets and especially provision for the foils. The foils themselves are radically different, both as a result of initial design and of the rigorous testing of the leadship before and after commissioning. The forward strut and foil are basically the same but considerably stronger with much-improved linkage and controls for the trailing edge control surfaces. The aft struts and foil system form a single unit with the foil being shaped in an inverted, wide "W" form, giving greater structural and hydrodynamic



PCH 1, High point, was the first military hydrofoil by Boeing to USN BuShips design. It was used for foil experiments and Harpoon missile developments.

efficiency than the two T-shaped foils in the Tucumcari. As a result, the aft foil system retracts rearward, rather than out and up, for shallow water hullborne operation. Distribution of foil area is, in the latest configuration, 31.8 percent forward and 68.2 percent aft, with the length of the struts calculated to allow foilborne operation in waves up to five meters (16 feet) depending on conditions of cresting and surface turbulence. The struts and foils are fabricated from 17-4PH martensitic, precipitation-hardening stainless steel, chosen for its corrosion fatigue properties over a more easily weld-repairable material for which these properties were unknown. During the extensive testing of PHM 1 and from operating experience with Boeing's commercial Jetfoil vessels, a great deal of previously unknown data on foil life and loads encountered in rough seas became available. This dictated a great change in design load criteria and a number of changes in the construction of the foils. The foils are now constructed from large, thick billets, computer-machined to form the lower surface, interior struts and leading and trailing edges in one piece. Only the upper surface is welded in contrast to the original PHM 1 foils which are fabricated top and bottom from 15 mm material. The lower surface is now 26.2 mm, the upper skin is 17.8 mm and the camber has been increased.

To even the not-so-casual observer, USS Pegasus PHM 1 appears to be identical to the other five follow-on ships. It is a reasonable assumption since the general layout and outward appearance are essentially the same, but there are some definite and significant differences that came from experience. There was a four-year gap between the keel-laying of PHM 1 and the final contract that funded the five others, known as the PHM 3 series. PHM 3? The hull that was to be the original PHM 2 was scrapped after a dovish and somewhat penurious post-Vietnam Congress curtailed funding in 1974. The plans, drawings and other paperwork for the original PHM 2 were the same as those for PHM 1, and a long development time had produced a new Produceability Study by the time October, 1977 rolled around. This study dictated a number of structural changes that would increase strength and materially reduce construction time. There were also some changes in layout below decks. The wardroom was eliminated and the head facilities were combined, allowing enlargement of the mess facility and the addition of a crew store room, which gave the crew enhanced live-aboard capability. The command and surveillance equipment and operator stations, originally set up to accommodate West German equipment compatibility, were rearranged to better suit U.S.

The USS Aquila, PHM 4, in Puget Sound tests with Boeing Jetfoil Bima Samudera I, built for the Indonesian navy. Performance is similar but purpose differs widely.

Combat Information Center (CIC) of PHM is compact but sophisticated, and capable of handling all combat mission data.

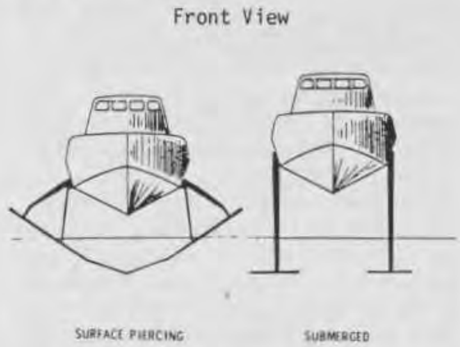
requirements and equipment. The structural changes are somewhat complicated to detail here, but they were primarily designed to eliminate weld-stress distortion and to enhance manufacturing through the use of aircraft experience and techniques. It obviously worked because, by the time the fifth ship was built, unit construction time was cut by more than half. A look at the times it took to build and commission the first three "production" PHMs and the time of the last two is instructive. Taurus (PHM 3), Aquila (PHM 4) and Aries (PHM 5) were laid down in late 1979 and early 1980 and all transited in the latter part of 1982 to Key West. Gemini (PHM 6) and Hercules (PHM 2) made the voyage three months after Aries, in February, 1983. The learning curve chart kept by Boeing indicates that PHM 2 was finished in a little over half the time it took to complete PHM 3.

The ships are 132.9 feet overall, with a maximum deck width of 28.2 feet and a hull displacement of 237.5 tons or 241.3 metric tons. The hullborne draft with foils retracted is 7.5 feet, and with foils down and locked it is 23.2 feet. The nominal draft when foilborne is 8.3 feet but can vary according to conditions of sea state and weather. The range in the hullborne mode is in excess of 1,200 nautical miles (NM) or 1,381 land miles. In foilborne mode the range is cut in about half with a quoted "in excess of 600 NM or about 681 land miles" (1,111.5 km), the difference being that those 600 NM can be traversed in 13 hours foilborne and 54 hours hullborne with considerably less comfort. The original ship's complement was four officers and 17 crewmen, but the latter figure has been raised to 19 since PHMRON 2 went into full operation. Provisions carried are for a nominal five days, but the ship can be replenished with both fuel and provisions at sea. This was tested and proven in 1978 when Pegasus made a speed run from Pearl Harbor at an average speed of advance of 16 knots, refueling in 20-foot seas. Fuel used by the PHM's engines is diesel or JP-5

Ships controls are more reminiscent of aircraft than traditional naval vessel. Foilborne ship actually acts like plane.

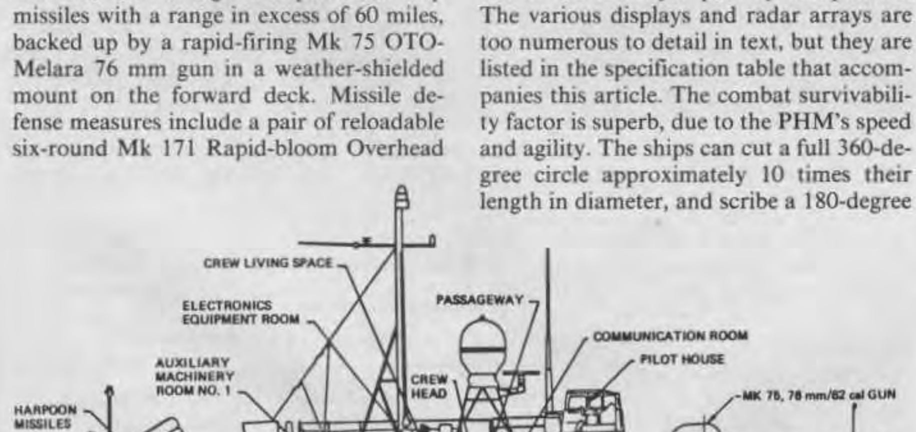
PHM's true turning radius is classified, but an idea of the agility can be gathered from this view of Pegasus cutting perfect figure eights at high speed during the early test period.

Artist's rendition of mobile PHM base which can be set up in marinas and fishing ports in almost any part of the world. Shops, offices, supplies and living quarters are all set up in modular trailer complex. Right: The difference between surface-piercing and retractable submerged foils. See sidebar.



jet fuel, giving it the capability of taking on fuel from any Navy ship carrying either type with the ability to rig a small fuel hose across.

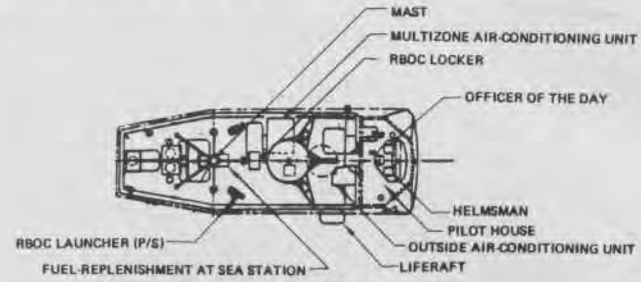
The PHM packs a heavy punch. Armament consists of eight Harpoon anti-ship missiles with a range in excess of 60 miles, backed up by a rapid-firing Mk 75 OTO-Melara 76 mm gun in a weather-shielded mount on the forward deck. Missile defense measures include a pair of reloadable six-round Mk 171 Rapid-bloom Overhead Chaff (RBOC) 4.4-inch launchers with infrared flare capability as well as chaff. Jamming and electronic decoying are provided by the ship's ESM system. The CIC suite carried by a PHM makes that of a WWII/Korea era destroyer pale by comparison. The various displays and radar arrays are too numerous to detail in text, but they are listed in the specification table that accompanies this article. The combat survivability factor is superb, due to the PHM's speed and agility. The ships can cut a full 360-degree circle approximately 10 times their length in diameter, and scribe a 180-degree turn with a radius of less than 700 feet in full flight. In terms of maneuver time, that could be translated to mean that a PHM can be a quarter of a mile to the right or left of its original position and going in the opposite direction in less than a minute. It would take an extremely agile anti-ship missile to score against such a rate of change of position and direction, even assuming the rate and turn were kept constant. Another manuever, not at present generally practiced due to the strain it can cause, is the emergency stop. By overriding the ACS, the ship can become hullborne, landing from full flight, and come to a full stop in *less than 500 feet*, another rate of change capable of throwing off hostile tracking for a significant moment. This agility, combined with high speed, hull and compartment integrity, redundancy of equipment and the multiplicity of defensive measures, makes a PHM a very difficult ship to kill, and a dangerous one with which to tangle. There is another theory, likely to remain a theory until proven or disproven in battle, that suggests the radar signature as seen from a waterjet hydrofoil's beam is deceptive. The cloud of spray left in the ship's wake increases the size of the signature and is said to displace the center of the picture aft and actually astern of the ship's hull. The big question is how much the distance of picture-center is displaced. A figure of less than about 100 feet wouldn't be significant, but anything above



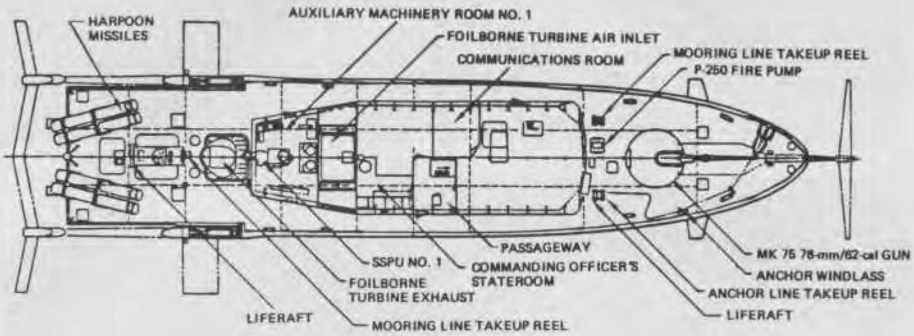
that could be. It's interesting as speculation, but the proven factors of the PHM's survivability are impressive enough to keep anyone from worrying about it.

While PHMs are specifically designed to operate within their radius of operation out of a base like any other small ship, there is a difference. The PHM Squadron was conceived from the beginning as a mobile force, not dependent on the permanent facilities of a major naval base. Although originally scheduled to be based around Norfolk-Little Creek, home of the Atlantic Amphibious force, it was decided to form PHMRON 2 on Key West at Trumbo Point, Florida, adjacent to the Naval Air Station. The decision to base the squadron out of the mainstream of the Atlantic Fleet Surface Forces was made to achieve the self-sufficiency and quick reaction deployment capability, for which the PHM concept was designed, as soon as possible. The Mobile Logistic Support Group is the basis of the concept, consisting, at full operational strength, of 73 mobile vans and a personnel complement of a nominal 130 officers and men. It currently has the capability of handling all the maintenance and support necessary to take care of the needs of the six ships except for a few heavy repairs requiring a major facility. The vans and their people can be moved by road to any port in the country capable of berthing the six ships, or sea-lifted by container ship to foreign ports and transported by road to their actual operating site. The ships themselves can proceed, in company with one or more replenishment vessels, to the deployed base or, if necessary, can even be sea-lifted or towed to a point where they can proceed on their own. At that point they become once more fully operational in the deployed mode.

At present, PHMRON 2 and its six ships are the extent of the Navy's PHM force, and no new construction is underway, the Navy having embarked on a wait-and-see development program as far as the PHM is concerned. However, those who have been directly or peripherally concerned with the PHM operations have expressed enthusiasm for the ships' known capabilities and their potential. Boeing hasn't dismantled their PHM construction facility, and officials there have indicated cautious optimism for future building programs. A six-ship naval force, packing a big-combatant ship punch with the ability to operate out of any large marina or fishing port in the world, has a lot in its favor, both from an economic and tactical point of view. Especially when a major potential enemy has in excess of 150 similar, if not as sophisticated, vessels in operation that they can turn over to any belligerent surrogate they wish—Cuba or Syria being interesting cases in point.



01 LEVEL



MAIN DECK

Construction of PHMs is actually a combination of aircraft and seacraft techniques. View of Boeing Marine plant shows both PHM and Jetfoil in the building stages.