SOUNDING OUT

Several operators of the NH90 NFH employ the aircraft in the ASW role. (Photo: Airbus Helicopters)

While other technologies are increasingly playing a part, dipping sonar remains at the heart of the contemporary ASW helicopter's detection capabilities.

By Peter Donaldson

Modern submarines are the most difficult threats against which naval forces must protect themselves, thanks to their stealth, constant evolution in quieting and the growing potency of their torpedoes and missiles.

The proliferation of submarines around the world is reviving an interest in ASW that subsided after the Cold War, with numerous nations – including Bangladesh, Canada, India, the Philippines, Poland, South Korea, the US and Vietnam – announcing new requirements, upgrades or significant milestones in ongoing ASW helicopter programmes.

While the sensor most closely associated with ASW helicopters is the dipping sonar, it is part of an integrated suite required for the prosecution of submarine targets, in which even radar plays a role. It can provide a short cut by detecting periscopes and other masts, all of which have low radar cross-sections.

The USN is in the process of upgrading its MH-60R fleet with up to 103 kits to provide the Telephonics AN/APS-153(V)1 radar with Automatic Radar Periscope Detection and Discrimination (ARPDD) capabilities, with fits to the Romeo fleet expected to be complete by September 2020, the US DoD announced last July. The ARPDD technology has been developed by Lockheed Martin Mission Systems and Training.

Waves in the waves

Sensors that exploit sound, however, still retain the top spot, and the complexity of the way sound waves move through water plays a crucial part in making submarines such challenging targets.

Sound travels roughly four times faster in water than in air, but its speed varies with water conditions and its path bends towards regions of lower sound speed.

Increases in depth and pressure cause sound to travel faster because the molecules are closer together and collide more often. Sound also travels faster in warmer water than in cold, because the molecules have more energy, which also increases the frequency with which they collide.

These effects mostly cancel out because deeper water is generally colder, but mixing by wind and waves produces a surface layer in which the pressure effect dominates.

Sound speed also increases with salinity, because dissolved salt makes water less compressible and better able to transmit energy. Salinity can be highly variable near the sea's surface and in shallow water near estuaries.

These interactions produce layers and channels that facilitate long detection ranges, but also create shadow zones into which little sound will penetrate and convergence zones where rays come together in annular regions of high intensity.

Convergence zones enable detection at long ranges, but in bands interspersed with others that hinder that detection. In shallow water, the seabed can reflect sound and enable 'bottom bounce' detections at long ranges or absorb sound and reduce range.

Going for a dip

While Russia and China make dipping sonar systems, little is known about them. Even NATO countries and others inclined to buy Western equipment can only effectively choose between two manufacturers, namely L3 Ocean Systems and Thales, whose products are divided into medium-frequency sonars that operate at around 10kHz and low-frequency systems working at 3-5kHz and below about 1.5kHz.

Sonars operating around 10kHz are called medium-frequency sets because that figure is in the middle of the human ear's frequency response, which extends approximately 10Hz to 20kHz.

All can operate as active sensors, transmitting pings and listening for echoes. Knowing when the ping was transmitted and multiplying the speed of sound by the time it takes for the echo to return and dividing by two reveals the range. Measuring changes in frequency between the transmitted pulse and its echo due the Doppler effect then reveals the target's speed.

US Navy technicians unload sonobuoys from an MH-60R Sea Hawk on the flight deck of the guided-missile destroyer, USS *Mason* (DDG 87). (Photo: US Navy)

Many sonars can transmit both continuous-wave (CW) and frequency-modulated (FM) pulses. CW pulses maintain frequency from the beginning to the end, while FM pulses change frequency as they proceed. FM signal processing provides significantly greater accuracy in range and range resolution.

Sonars can also act as passive sensors simply listening for the beat of propeller blades, flow noise, internal machinery frequencies or transients, such as cavitation or hull popping, that might reveal the presence of a submarine.

In this mode, they can determine range by triangulation, using successive target-bearing measurements, and measure speed by, for example, comparing the propeller beats with target databases.

Dipping sonars also carry instruments that measure water properties such as conductivity (which is affected by salinity), temperature and depth to update the sound speed profiles that are crucial to accurate performance prediction. Additionally, they can usually function as underwater telephones.

Advances in array design and signal processing enable modern systems to form multiple beams in azimuth and elevation, improving bearing accuracy, target discrimination and depth estimation.

Lower frequencies mean longer wavelengths, which are less susceptible to absorption losses and so offer longer detection ranges at the price of some range resolution – the ability to measure range precisely – while physics dictates that lower frequencies demand larger arrays.

Increasingly, dipping sonars are capable of multistatic operation in which one or more transmitters work with multiple receivers in different locations. Coordination over data link networks enable simultaneous triangulation on detected targets, making the submarine commander's life much more difficult.

AQS-13 and friends

The Western medium-frequency market is dominated by L3's AQS-13 and AQS-18 family. The AQS-13F built a reputation as the USN's primary 'inner zone' ASW sensor when deployed by Sikorsky SH-60F Seahawks from aircraft carriers.

It transmits on 9.23, 10 and 10.77kHz, because this allows filters tuned to these discrete frequencies to reject most sounds that are not echoes from the target.

All tactical sonars have to be loud, and L3 quotes a source level of 215dB measured at the standard distance of 1m from the AQS-13F's transducer. Such power is essential for long ranges in active mode, because spherical spreading losses reduce the power by 6dB for every doubling of the distance from the transducer.

The AQS-13F can transmit rectangular pulses lasting 3.5 or 35ms to aid Doppler moving target indication (MTI), or shaped pulses lasting 200 or 700ms to put large amounts of energy in the water to maximise the probability of detection.

In passive mode, it receives sound in channels with 500Hz bandwidth between 9 and 11kHz. ▶

The sonar data computer can run shallow-water algorithms for use in areas of high reverberation. Like all acoustic processors, it does not deal with sound directly but with digitised electrical signals, as the conversion between sound and electricity happens in the transducer. It can also control, process and display sonobuoys in a single integrated system.

Operators can select range scales with maxima of one, three, five, eight, 12 or 20 kiloyards – ie half a nautical mile to 10nm (900m-18.5km) plus numerical readouts of target range, rate of change of range, and target bearing.

Audio options include separate left and right headphone channels and automatic gain control, with a summed constant level as an alternative in which both the operator's ears get the same sound.

L3 quotes a nominal operating depth of 440m and says that the system's reeling machine can get the transducer there and back inside three and a half minutes.

The AQS-13F weighs 284kg and consists of a number of subsystems including the transducer, reeling machine, transducer control module, multiplexer, azimuth/range indicator, receiver and sonar data computer.

Upgrade options include new receiving, processing and display units that provide a claimed 14dB sensitivity improvement, better beam-forming, longer pulses and an FM mode. As a further option, L3 offers an upgrade to a low-frequency transducer to provide performance that the company says is comparable to that of a surface ship sonar.

Export variants

The AQS-18(V)-3 is the export version of the AQS-13F and uses an adaptable reeling machine compatible with a wider range of helicopters and a different acoustic processor, dubbed the Adaptive Processor Sonar (APS), which improves the system's ability to detect difficult targets in shallow water subject to severe reverberation, while minimising false alarms.

It uses fast Fourier transform techniques to provide narrowband analysis of the shaped CW pulse and to work better in non-reverberant conditions more typical of deep water.

An MH-60R Sea Hawk assigned to the Raptors of Helicopter Maritime Strike Squadron 71 lowers a dipping sonar into the water next to USS *John C. Stennis* (CVN 74) during an air power demonstration. (Photo: US Navy)

The AQS-18(V)-5 is similar to the (V)-3, sharing most of its performance parameters and the APS, but is lighter at 260kg thanks to a smaller reeling machine – the price paid for this is a lesser operating depth of 290m. Its electronics suite is divided into larger number of smaller modules, making it more adaptable to different cabin shapes and sizes.

The AQS-18A is L3's latest medium frequency dipping sonar system, offering both CW and FM transmissions.

L3 quotes CW frequencies of 9.23, 10.003 and 10.774kHz, plus FM frequencies of 9.485 and 10.520kHz. It is also significantly louder at 217dB to improve detection ranges.

Long pulses improve Doppler resolution in shallow water with high levels of reverberation, while its more refined FM processing enables detection of targets with low Doppler shifts and boosts range resolution. The display has a finer set of range scale divisions of 1, 1.5, 2.5, 5, 7.5, 10, 12.5, 15 and 20nm, suggesting better range discrimination out to the claimed 20nm (37km) maximum.

L3 emphasises that the system is compatible with 1553B databus architectures to ease integration.

Its 264kg weight is divided between the 88.9kg transducer assembly and the 122.7kg dome control, reeling machine and cable assembly, with the remaining 51.8kg accounted for by the sonar interface unit, cable interface power supply and sonar control unit. It has the same operating depth capabilities as the AQS-18F and (V)-3 variants.

Signal processing takes place in the sonar interface unit, which runs algorithms specifically designed for increased pulse lengths and has spare processing capacity for additional features such as computer-aided detection and classification, multi-sensor target fusion, embedded training or performance prediction, with the latter based on environmental data.

L3 says that the AQS-18A has 80% commonality with the Helicopter Long Range Active Sonar (HELRAS) DS-100, the main difference lying in the 'wet end' transducer systems. This commonality, says the company, enables navies with both large and small helicopters to combine the two sonar types in bistatic or multistatic operations.

Low frequency HELRAS

L3 claims that the HELRAS DS-100 is the highest performing helicopter dipping sonar in the world, with its long-range detection and wide-area search prowess demonstrated in deep and shallow water.

A high source level of 218dB and narrow vertical transmitted beams extending from -15 to +15°, along with high array gain provide a high figure of merit, says the company. For reception, it forms 32 half-beams and 16 full beams.

The system is claimed to be able to track ten targets simultaneously, while the display offers selectable range scales of 1, 1.5, 2.5, 4, 6, 10, 16, 25, 40 and 60nm.

Active operation is based on transmissions centred on three frequencies, namely 1.311, 1.38 and 1.449kHz. HELRAS can transmit CW pulses with widths from 0.039 to 10s. FM modes include linear period pulses with widths from 0.156 to 5s, plus FM triplets with pulse widths from 0.625 to 1.25s. The latter include 50 or 100Hz downsweeps at three centre frequencies and a 300Hz down-sweep at a single centre frequency of 1.380kHz.

This last active centre frequency, combined with proprietary transducer and beamforming technologies, allows multiple boundary interactions, says the company, meaning that it can take account of reflections from the surface, the seabed and even temperature changes that define layers in the water, while reducing the effect of reverberation caused by reflections from suspended particles in the water and even fish. It also enables interoperability with shipboard sonars and sonobuoys in bistatic or multistatic operations.

High-resolution Doppler processing and long, shaped pulses aid detection of faint, slow-moving targets, says L3, adding that broadband FM pulses up to 5s long can be used to detect near-zero Doppler targets. The company claims a maximum operating depth of 500m and a figure of merit high enough to achieve second convergence zone detections in deep water.

HELRAS's folding array allows it to fit a large aperture essential for low-frequency operation into spaces aboard helicopters that previously only had to accommodate relatively small medium-frequency transducers.

The projector comprises eight elements (seven sonar and one underwater telephone) in an array 5.2m from top to bottom when fully extended, below a 1.2m tall receive array, whose arms fold out under hydraulic pressure to a diameter of 2.6m.

As a standalone system, HELRAS weighs 341.3kg, but by sharing display resources with other sensors and avionics in an integrated suite, it weighs in a little lighter at 326kg.

FLASH rival

HELRAS's principal rival is Thales' Folding Light Acoustic System for Helicopters (FLASH), which has a slightly smaller wet end with a receive array that folds out to deploy above the transmitter.

Thales' heritage in lightweight dipping sonars came from predecessor company Thomson Sintra Activités Sous Marines, which developed the DUAV-4 plus the HS12 and HS312 models.

Operating at higher frequencies between 3 and 5kHz, FLASH uses wideband transmitter rings, allowing full-power pings even in shallow water, where many sonars are limited by cavitation – the formation and collapse of water vapour bubbles on the surface of the emitter caused by large, rapid pressure changes.

Thales emphasises that FLASH's low frequency and large bandwidth enable it to match its detection range to the reach of modern lightweight torpedoes, such as the Raytheon Mk 54 and the Eurotorp MU90. The large bandwidth in particular helps minimise the difficulties caused by reverberation, particularly in shallow water. In active mode, it transmits on three frequencies within its range of 3-5kHz, emitting FM, CW and combined FM/CW pulses.

FLASH can operate at depths of between 15 and 750m, the long cable allowing the transducer to put sound into the whole water column, penetrating layers to maximise probability of detection, although the lightweight Compact FLASH variant has a shorter cable, limiting it to a maximum of 300m. Furthermore, the short dip cycle enabled by the fast reeling machine maximises the area coverage rate.

It can operate as a standalone system or be integrated with the company's SONICS sonobuoy processing suite, which includes a COTS acoustic processor and a digital wideband VHF receiver. SONICS provides up to 32 channels and can process all NATO standard buoys.

The system is capable of processing data from sonobuoys, and the dipping sonar can at the same time participate in multistatic operations with sonobuoy fields laid by the helicopter or by other aircraft, and with Thales shipboard variable-depth and hull-mounted sonars.

FLASH operator aids include displays of raw returns in passive and active modes, a panoramic display to improve situation awareness, the ability to track multiple targets simultaneously, performance predictions calculated using regularly updated sound speed profiles, and tools to help find the optimum depth for the transducer.

SONICS provides a similar range of operator aids, including a tool to optimise the placement of buoys.

Multistatic complexity

Evidence of the sheer complexity of modern multistatic ASW emerged last May when the USN announced its search for innovative solutions that would enable an operator to detect and discriminate targets efficiently in an airborne ASW mission.

> ***"It is no longer practical for a sonar operator to sift through detections one by one to find the target."***

The service said that the growing number of sources and receivers and the resulting higher transmission rates are creating a dramatic increase in the number of contact reports generated automatically from the signal processing, declaring that it is no longer practical for a sonar operator to sift through detections one by one to find the target.

The USN wants techniques and tools that consolidate information from the contact reports to enable the operator to find and focus on target detections rapidly. Active contact reports typically provide time difference of arrival, bearing, signal-to-noise ratio and Doppler information, along with geographical areas in which the target is probably located, while the USN is interested in display innovations to reduce operator workload by ranking detections and automatically suppressing clutter.

Areas of particular focus include information superiority through data fusion, continual monitoring of changes in the situation to assess potential impacts on and limitations of the mission plan, modifications to the plan to maximise the probability of detection and, finally, tactical decision aids.

As long as submarines remain a threat, helicopters are likely to be pitted against them, and low-frequency sensors, ever smarter algorithms and the promise of maturing multistatic capabilities look set to remain at the heart of their ability to do so effectively. ■