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Evolving shipboard air and missile defence systems

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The history of naval air defence, encompassing shipboard defences against Anti Ship Cruise Missiles, is colourful and convoluted, as technologies were developed to overcome the ever-increasing capabilities of threat systems. At present, the advantage falls to the attacker, as anti-shipping weapons have evolved faster over the last decade than have defensive systems.

Prior to the 1940s the principal play between offence and defence was in the development of armour piercing large calibre gun rounds and torpedoes, and the development of armour plating to defeat the former. This led to the development of armoured behemoths as the primary surface combatants in most fleets.

This model collapsed during the 1940s, as air power played an increasing role in naval warfare. Saturation air attacks by dive bombers and torpedo bombers proved too much even for well armoured battleships and battle cruisers. In 1943 the Luftwaffe introduced radio link guided glide bombs which significantly increased the lethality of air attacks. The Japanese improvised this capability with suicide bombing attacks, eventually developing the Yokosuka MXY-7 Ohka, essentially a rocket propelled air launched Anti Ship Cruise Missile (ASCM) with a human guidance system.

In the 1950s and 1960s there was explosive growth in ASCM technology, many of these designs remaining in use or even production at this time. A surface combatant in a contemporary conflict may encounter attacks by subsonic and supersonic ASCMs with turbojet, turbofan, ramjet, solid rocket or liquid rocket propulsion. The ASCMs were equipped with active radar, passive anti-radiation, imaging or scanning infrared or multimode guidance. These missiles could be launched by opposing surface combatants, submarines, shipboard helicopters, fixed or mobile coastal batteries, plus land based or shipboard tactical or long range maritime patrol and strike aircraft, or any combination of these launch systems. Moreover, evolving smart bomb technology made direct attacks by land based or shipboard air power a distinct prospect, as the 1982 Falklands campaign demonstrated, even ‘dumb’ bombs are very effective at puncturing hulls and sinking warships.

The latest addition to inventories of anti-shipping weapons are terminally guided Anti Ship Ballistic Missiles (ASBM) such as the new Chinese DF-21 variant. ASBMs may be launched from mobile coastal batteries, submarines or surface combatants.

Evolved Sea Sparrow Missile launch.

Shipboard defences have evolved in response to evolving threats. During the 1930s and 1940s defences comprised batteries of Anti Aircraft Artillery pieces, usually covering a range of calibres and rates of fire. A major innovation during the late 1940s were proximity fused rounds.

The advent of ASCMs resulted in the deployment of naval Surface to Air Missile (SAM) systems, primarily using semi-active radar homing or command link guidance and radar. These quickly stratified into medium / long range systems, usually carried by cruisers, destroyers and some frigates along with short range terminal defence systems carried by most combatants, including capital ships.

The arrival of sea skimming ASCMs during the late 1960s resulted in another cycle of defensive systems development, with highly automated terminal defences based on closed loop tracking guns and automatic command to line of sight, semi-active radar homing and infrared homing SAMs.

The evolution of lethal defences was paralleled by the evolution of various countermeasures, initially smoke generators, then chaff firing mortars, and eventually well developed suites of active radar jammers, either shipboard or offboard. ASCM designers countered by improving radar and infrared seeker countermeasures resistance, introducing passive anti-radiation homing and home-on-jam seekers, and in larger Soviet missiles, equipping the ASCM with its own jammers to confuse the radars on the victim warship.

Tactics in air and missile attacks have always, in practice, favoured saturation attacks intended to overwhelm shipboard defences. Serious operators of specialized anti-shipping capabilities have always planned, trained and equipped around launching saturation attacks. The exceptions to this reality have tended to be novices in maritime strike warfare, such as the Argentinians in 1982 who were still able to inflict almost decisive damage on the British fleet despite poor tactics and planning, and having only a small inventory of Exocet ASCMs and compatible jets.

Strategies for defending warships have varied. The most effective have been 'pre-emptive' or 'outer air battle' approaches where the launch platforms for ASCMs have been destroyed before they can reach a viable launch range. The US Navy termed this approach during the Cold War as "killing the archer rather than the arrow". The model envisages using long range high performance fighters to kill opposing airborne and surface based ASCM launch platforms as early as possible in the engagement, with submarines deterred or killed by ASW aircraft such as the S-3 series.

The model remains popular with the Russians and Chinese, the former operating the Su-27K/Su-33 Flanker D and the latter seeking to procure it. The model has been abandoned in the West with the premature retirement, without replacement, of the Grumman F-14 Tomcat, and the Lockheed S-3 Viking. Current US Navy air wing planning is centred on the F/A-18 family of aircraft, which lack the range and performance for this role, and the F-35C CV JSF, which is a specialised bomber.

The West has wholly abandoned the 'outer air battle' approach to surface fleet air defence – and claims that the low performance aircraft planned for carrier air wings can perform this role fall short since none can perform the 'deck launched interceptor' or 'outer air battle' supersonic dash profiles in any credible fashion due to their basic design. Therefore, Western surface fleets will be in coming decades wholly committed to fighting the last ditch 'inner air battle', which amounts to shooting down incoming ASCMs and now also ASBMs within the last 10 to 50 nautical miles.

From a technological strategy perspective the contemporary Western approach is thus centred in the idea that a fleet can shoot down opposing ASCMs and ASBMs at a rate faster than that at which an opponent can shoot them. The model also assumes that the single shot kill probability of defending weapons is extremely high, and that magazines are not emptied at any point during an engagement. As noted earlier, these are assumptions that have not held in any known recent conflicts.

To put this in context, the kill probability of the AIM-120 AMRAAM series of beyond-visual-range air-to-air missiles, against non-manoeuvring and non jamming, effectively 'docile' targets in real combat has been less than 50 per cent per shot. The MIM-104 Patriot PAC-1 SAM when employed as an ABM in 1992 achieved a marginal success rate, with many rounds fired per typical Scud TBM kill. The belief that current naval SAMs such as the RIM-66/67/156/161 Standard series and RIM-162 ESSM series SAMs can achieve single shot kill probabilities of the order of 90 per cent or better against modern manoeuvring targets supported by jamming and other countermeasures is difficult to fathom.

Even assuming that these SAMs have a 90 per cent kill probability per shot, the high damage potential per ASCM or ASBM round dictates at least two SAM shots per inbound target to get a total kill probability of ~99 per cent.

This inevitably leads analysts to the 'magazine depth problem', which put simply is how long can a warship keep firing SAMs before its magazines are exhausted, assuming a cooperative attacker does not opt for a saturation missile attack?

A number of technologies have been proposed to deal with the challenges faced by contemporary and future surface fleets.

Robert Work and Thomas Ehrhard then of the Washington based CSBA think tank, now both in senior Pentagon posts, proposed the use of 1,500 nautical mile range stealthy transonic UCAVs as the primary air wing component of a carrier force. The exceptional range of these unmanned aircraft would allow a surface fleet to engage and attack from outside the range of most 'anti-access' weapons, such as an ASCM firing fighter aircraft, coastal batteries and surface combatants, as well as most ASBMs. This model has the advantage of forcing an opponent into the use of long range ASCM carrying aircraft and aerial refueling of fighters, which in turn reduces the size of the attacking force and drives up the cost per attack. The downside of this model is that it still leaves opportunities for some saturation ASCM attacks, and the 1,500 nautical mile striking radius severely impairs the achievable optempo of the subsonic cruising UCAV force.

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Saturation problems with warship fire control radars and processing subsystems can be alleviated – but not eliminated – by employing SAM designs with active homing radar or imaging infrared seekers rather than semi-active homing radar seekers. This simple but costly design change permits a much higher number of concurrent SAM engagements, as the fire control systems are no longer squeezed into the performance bottleneck of timesharing radar antenna time for terminal illumination of targets for each and every SAM seeker.

This approach has considerable merit but is not and never will be a panacea solution as Digital RF Memory (DRFM) based jammer technology has proliferated globally, and even sophisticated SAM seekers and radars are challenged by such. Stealth technology applied to ASCMs presents similar issues, reducing the range at which radars can effectively track inbound ASCMs and ranges at which SAM seekers can autonomously track such targets.

The RIM-174A SM-6 ERAM (Extended Range Active Missile), a fusion of the RIM-156 SM-2ER Block IV airframe and AIM-120C AMRAAM active radar seeker is the best known example of this design approach. The intent of this design is to provide a missile which can be fired at remote targets, even if they are not being tracked by the launching warship's radar – a radio uplink to the missile permits it to fly out to the target until it is close enough to acquire the target autonomously with its active seeker. Tracking data would be provided by the CEC (Cooperative Engagement Capability) data fusion system.

The SM-6 ERAM will overcome to some extent the limitations of existing medium/long range semi-active homing SAMs but will be an expensive missile due to its greater complexity compared to earlier semi-active homing SAMs. It will be supplemented in the ABM role by the RIM-161 SM-3 which is a three stage weapon, equipped with a thermal imaging terminal seeker and solid propellant gas thruster Divert and Attitude Control System for exo-atmospheric control of the kill stage.

Considerable research and development investment is now being made in High Energy Laser directed energy weapons (HEL / DEW) for shipboard terminal defence applications. The very successful US Army THEL trials some years ago demonstrated that near infrared lasers with hundreds of kilowatts of continuous wave power were capable of very effectively killing katyusha rockets, mortar rounds and 155 mm artillery shells in flight. Lasers based on chemical gasdynamic technology, laser diode pumped solid state technology and doped optical fibre technology are in development and test at this time. The latter two categories are especially attractive as they are electrically powered, so as long as fuel is available to power electrical generators, the lasers can continue to fire. In this respect laser weapons have 'very deep magazines'.

High power lasers are not a panacea for terminal shipboard defences. They are unable to penetrate fog or low cloud effectively, and perform best under clear sky / clear air conditions. The issue of protecting the optical apertures on the beam directors used for such weapons against salt laden sea spray is an issue in its own right. Finally most current solid state lasers in development for such applications have major heat dissipation problems, limiting the sustained firing rate of such weapons.

These limitations aside, all laser weapons have an inherent tradeoff between transmitted power, range to the target, and "dwell time" on target, which is the number of seconds the laser 'spot' must be kept on a specific part of the target to effect burn-through of the target skin and lethal damage effect. If the target is hardened against laser weapons by the use of ablative or reflective coatings, the dwell time can be significantly extended before lethal effect is produced. Saturation of laser defences by multiple inbound targets is a real prospect.

A 500 kiloWatt laser weapon has considerable potential in the shipboard defence role, once the technology matures, with the caveat that this technology is inherently weather limited.

There are two other technologies with good potential in the ASCM defence role, but both are very immature. High Power Microwave (HPM) beam weapons have potential to burn out internal avionics in missiles, but present 'self kill' risks due to sidelobe emissions, and kill effects can be unpredictable given intended or unintended variations in target microwave hardness.

Electromagnetically driven railguns firing hypersonic projectiles with MegaJoules of kinetic energy have considerable potential, and numerous successful experiments have been performed by the US Navy in recent times. Unlimited by weather and highly lethal, railguns may be the eventual replacement for most close in terminal defence weapons. However, the technology is at least a decade away from operational deployment, with major durability problems the main obstacle.

The latter technologies will be the subject of future analysis.