Defeating Cruise Missiles

by Dr Carlo Kopp

When Fieseler's engineers perfected the V-1 'doodlebug' in 1944, little could they have imagined the long term impact of their creativity.

The V-1 became the forerunner of a family of weapons which has decisively influenced many aspects of modern air warfare since then, and will continue to do so for the foreseeable future.

The media definition of a cruise missile is any weapon similar to the US Navy Tomahawk or US Air Force AGM-86 ALCM/CALCM, but the technical definition is any weapon which automatically flies an essentially horizontal cruise flight profile for most of the duration of its flight between launch and its terminal trajectory to impact. They can be further divided into 'tactical'/'sub-strategic'/'theatre' and 'strategic' categories, and then divided by warhead into 'nuclear' and 'conventional'. A further division, somewhat arbitrary with the arrival of the SLAM/Block II Harpoon and Russian equivalents, is the split between 'Anti-Ship Cruise Missiles' (ASCMs) and 'Land Attack Cruise Missiles' (LACMs).

The most widely deployed are ASCMs, which typically start with ranges of tens of nautical miles, with warhead sizes around 100kg, and subsonic cruise profiles. The Exocet, Harpoon, Kh-35U and YJ-8 families are the most widely used examples. At the opposite end of this spectrum are the awesome Russian heavyweights, like the rocket propelled subsonic 2.5 tonne class Styx family (Chinese C-601/611 Kraken), the Mach 3+ six tonne class Kh-22M Burya (AS-4), the ramjet Mach 2+ 4.5 tonne class Kh-41 Sunburn, and three tonne class Kh-61 Yakhont/Brahmos.

Less widely deployed but increasingly available are land attack cruise missiles in various forms, including derivatives of anti-ship cruise missiles. To date the most widely used weapons in this class are the UGM/RGM-109 TLAM (Tomahawk Land Attack Missile) family and AGM-86C CALCM, with the Apache/Storm Shadow, KEPD-350, AGM-158 JASSM, Kh-55/65 (AS-15), 3M-54/3M-14 (SS-N-27) and Chinese clones now entering service.

From a technology perspective, the 'commodification' of GPS, Ring Laser Gyro, third generation microprocessor and Monolithic Microwave IC technologies will have a major long term impact, reducing guidance package costs, but also breaking down the historical technology barriers which limited large scale inventories to the US and USSR. Modern guidance technology has already seen the absorption and reuse of Cold War era cruise missile warstocks, with the remanufacture of US Navy UGM/RGM-109 Tomahawk Anti-Ship Missile (TASM) and US Air Force AGM-86B (nuclear ALCM) airframes into conventional LACMs. The large remaining warstock of Russian weapons may also see reuse, the recent guidance upgrade package for the Kh-22M being a good example, as well as the ever evolving Chinese C-601/611.

Strategically, precision guided cruise missiles can have significant military effect, but even inaccurate guidance permits their use as terror weapons against civilians, as the Scud has been used.

Historically, the main attraction in cruise missiles has always been in the often very significant stand-off range provided, keeping the delivery platform out of the reach of most if not all air defence weapons. An equal attraction has been the difficulty in detecting, tracking and killing a small and often very low flying cruise missile.

The drawback in all cruise missiles has always been economic – the warhead weight was typically less than 50%, while the cost of these weapons has been of the order of 50 times or greater than guided bombs. Complex guidance and propulsion systems have been the main cost drivers. While the US have repeatedly performed large scale bombardments using up to several hundred weapons per bombing campaign, the cost proved unsustainable even for the US budget. The current effort to field the 'low cost' $US500,000 class JASSM and 'Tactical Tomahawk' weapons reflects this reality – even at half of the cost of older cruise missiles. Primarily these weapons will be used to kill heavily defended high value targets.

For the ADF, cruise missiles will likely become the principal missile defence and air defence issue in coming decades, reflecting not only the wide proliferation of shorter ranging ASCMs and land attack missile derivatives, but also the strategic im-

Title photo – The Backfire will become the most capable cruise missile delivery platform in the region, combining 2500nm (4630km) class combat radius with excellent supersonic dash capability to evade interception. (RuMoD) pact of China's introduction of TLAM/CALCM class weapons as these mature, and Badger and Backfire bomber delivery platforms.

Delivery Techniques for Cruise Missiles

Since the 1940s cruise missiles have been launched by aircraft and surface launchers, the latter at first fixed and mobile ground launchers, and by the 1950s ships and surfaced submarines. The Tomahawk extended the latter domain to include submerged submarines. Today, a cruise missile could be fired by a large aircraft, a fighter, a surface ship, a submerged submarine and a ground based Transporter Erector Launcher (TEL). An alternative repeatedly discussed in recent US debate has been the converted maritime tramp freighter, or its aviation equivalent, the pretend charter air transport – the latter reflecting US and UK proposals for 747 and A340 ALCM carriers respectively.

Each of these delivery techniques presents its own unique challenges to a defender, and none can be ignored when planning a cruise missile defence strategy.

Large aircraft such as strategic and theatre bombers and modified transports present the capability to move a respectable number of cruise missiles over regional or global distances in hours or tens of hours, at cruise speeds of the order of 450kt (835km/h). Range and speed afford flexibility in timing attacks, and in choosing launch points to best disadvantage the defender. On a typical profile the aircraft would fly to a preplanned launch point and spend several minutes releasing the weapons, before departing for base. Support jamming to confuse defences is an option. This is the concept pioneered by the B-52/ALCM system, and since adopted by the Russians with the Bear/Blackjack/Kh-55/55M/555 system. It is expected to be used by China's PLA-AF once its H-6H/ALCM system and Backfire mature.

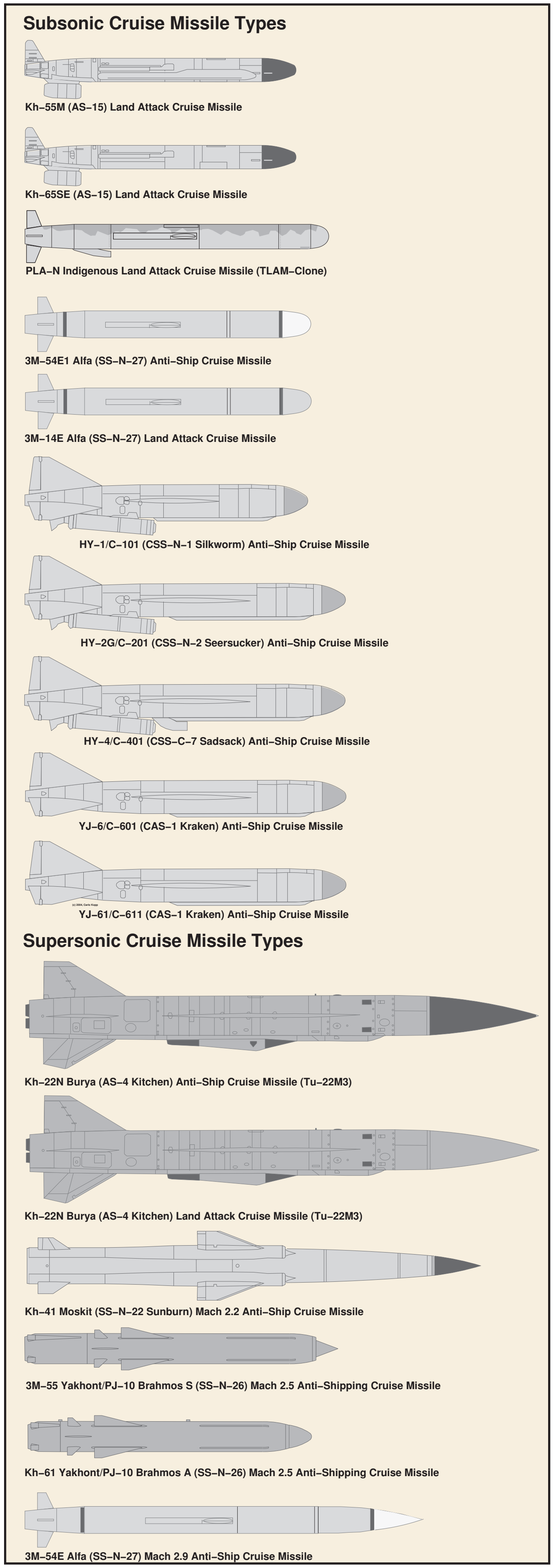
The performance of the delivering aircraft and weapon mean there are many variations on this theme. The Kh-22M armed Backfire penetrating to the launch point supersonic and high is one extremity, whereas the B-52 going in low and armed with AGM-86Cs is the other. The nearer the bomber can get to an opponent's defensive perimeter, the deeper the weapons can penetrate and the more flexibility the weapon has in routing its flightpath around known defences.

The use of tanker supported fighters presents another variation on the same theme. While fighters are inherently more survivable than lumbering heavy bombers, their supporting tankers are not and present similar opportunities to a defender. The operational economics of this game continue to favour heavy bombers.

Surface warships have been used extensively by the US Navy to deliver TLAMs, and regional weapons like the 3M-54/14 series will eventually become a feature of regional surface warship inventories. The key issue for the attacker is the range of the weapon, as the warship must remain outside opposing defences.

Submarines are the most viable naval delivery system as they permit surprise not available to a surface warship. This was central to Soviet AV-MF sea control operations, with weapons suitable for submerged launches developed. Depth and subsurface topology permitting, a submarine can get quite close to an opponent's coastline before launch, thus reducing warning time and presenting only low signature cruise missiles in flight to opposing air defences.

However this tactical advantage comes at the price of the high acoustic signature of multiple launches. This is easy to detect and the missiles in flight also betray the area in which the submarine is operating. While weapons like the TLAM and 3M-54/14 are compatible with attack submarine torpedo tubes, this style of launch is at the expense of torpedo payloads. The favoured approach are vertical or slant launch



The only two fighters ever specifically built for cruise missile/bomber defence were the Russian MiG-31P Foxhound (above) and US Navy F-111B (below). The MiG-31P was built to kill B-52s and B-1s, and the F-111B the Backfire. These airframes are nearly identical in cardinal weight/size parameters, built to carry large look-down/shoot-down radars, IRST systems and similar R-33/AA-9 and AIM-54 missiles. (US DoD)

tubes. Last December the US Navy contracted to have the Ohio class SSBNs USS *Ohio*, *Michigan* and *Georgia* converted into SSGN 726, 727 and 729 respectively, each armed with 154 TLAMs in vertical tube packs, replacing the ballistic missile launch tubes.

The third technique for launching cruise missiles is the mobile ground based TEL, typically using a large all wheel drive truck or semi-trailer. This is yet another a variation of the theme of Wernher von Braun's truck mobile A-4/V-2 launchers used in 1944. The most widely deployed modern ground based cruise missile system was the BGM-109G Gryphon four round TEL deployed in 1983 to counter Soviet SS-20 IRBMs. The Intermediate Range Nuclear Forces (INF) Treaty saw the 500 or so BGM-109Ls scrapped by 1991. India's BrahMos TELs, China's Seersucker TELs and the plethora of coastal defence missile TELs present other examples.

Ground mobile TELs present the same advantages and disadvantages as ballistic missile TELs. If dispersed and well camouflaged before the onset of hostilities, they provide surprise as SLCMs do, but also expose their TELs in a similar fashion. Their slow transit speeds present similar problems to submarines and warships in sustaining a high rate of fire, and in successfully egressing launch areas after firing.

There is a clear split in capabilities between air launched and surface/subsurface launched weapons. While the latter offer surprise, they lack the mobility and transit speeds for rapid escape and to sustain a high rate of fire. Air launched weapons offer less surprise, but easily offset this limitation by the tenfold or greater speeds of the launch aircraft and the distances over which the weapons can be quickly delivered, and repeat strikes launched.

In the Australian/regional context air and submarine launched delivery matter most, as these permit strikes across the sea-air gap. Surface warship and ground launched cruise missiles are of less concern, although the latter are an issue for RAN surface fleet operations and especially amphibious operations in the region.

Cruise Missile Defence Strategies

Since 1944 cruise missile defence has remained a persistent headache. As defensive systems have evolved, so has the cruise missile threat. Stealth techniques have complicated the issue, with the cancelled 1990s US AGM-137 TSSAM and its replacement, the current AGM-158 JASSM, designed from the outset for true very low observable performance. As cruise missiles are easier to design for low radar signature than a full sized aircraft is, it is inevitable now that second generation European, Russian and indigenous regional weapons will follow the US lead.

A key contributor to Soviet bankruptcy was the deployment of the AGM-86B on the B-52 and its contemporary, the BGM-109L GLCM. The Soviet response was to field large numbers of expensive MiG-31P Foxhounds, Su-27 Flankers, S-300P semi-mobile SAM batteries, S-300V mobile SAM batteries, and supporting assets. With hundreds of each of these systems deployed to counter a modest inventory of US cruise missiles, Soviet PVOS and V-PVO budgets bloated out of control during the 1980s. This remains the classical case study of the asymmetric use of technology to effect massive strategic damage on an opposing economy.

With regional ALCM/SLCM proliferation, including weapons with hundreds of nautical miles of range, Australia is presented with similar geo-strategic and technological problems to those faced by the Soviets two decades ago, albeit not on that scale. Siberia and Australia's deep north share the common topographical problem of widely separated population centres, military bases and industrial facilities, and the dilemma of an enormous coastline to cover with a finite pool of assets. They also share the advantages of a sea-air gap to the north.

While Australia does not face the threat of nuclear armed cruise missiles, the damage effect produced by even conventional cruise missiles against the gas/oil infrastructure would be similar in effect due to the combustible nature of the targets involved. With the Burrup Peninsula and Gorgon/Barrow liquid natural gas tank farms each storing, when full, energy equivalent to a one megatonne TNT class weapon, the warhead issue is truly moot for these economic targets.

Defensive strategies for dealing with cruise missile threats fall broadly into two categories, the first being the denial or deterrence of launch and `counterforce' strategies, the second being the interception of launched weapons.

Deterrence strategies amount to threatening credible retaliation, regardless of weapons used. But Australia's current force structure plans make this hard, given the limitations of the JSF supported by a small number of tankers.

Counterforce strategies amount to pre-emptive destruction of the opponent's cruise missile capability before it can be deployed or launched. This approach requires similar capabilities to deterrence, but involves much more specific targeting.

Denial of launch strategies amount to 'shooting the archer, not the arrow', paraphrasing the 1980s US maritime strategy. This involves killing cruise missile carrying aircraft, sinking cruise missile armed ships/subs, or destroying ground mobile TELs before they have the opportunity to fire. This approach also requires a robust force structure, including good maritime and land strike capabilities, good air defence capabilities, and good ASW capabilities.

Interception of launched cruise missiles presents its own challenges, especially in terms of fighter persistence, speed, missile payload, radar performance, tanker and AEW&C numbers. However, in strategic terms it is often the only option left, especially during the period preceding an outbreak of full scale hostilities. As cruise missiles present an attractive first strike weapon to disrupt air defence infrastructure, their use is most likely in the opening round of a conflict.

Implementing Cruise Missile Defence

To implement either deterrent or direct counterforce strategies to defeat an opposing cruise missile force requires significant targeting and strike capability. This strategy requires that an opposing force armed with cruise missiles be attacked and destroyed in situ, for instance by demolishing airfields, launch aircraft and missile stocks on the ground, or similarly by strikes against naval bases hosting cruise missile armed warships or submarines.

Targeting, with the exception of ground mobile TELs, is less challenging as airfields and naval bases are large fixed infrastructures which can be effectively surveilled using satellites or human intelligence assets, although timeliness can be an issue if signs of strike preparation are the trigger for a pre-emptive attack. Cruise missile warfare, like ballistic missile warfare, to a large extent obeys the 'use them or lose them' rule, and there are strong incentives to fire off as much of the warstock as early as possible in a campaign.

Interdicting cruise missile armed submarines, or intercepting cruise missile carrying aircraft, also present interesting challenges. However, while a riskier strategy than counterforce strikes in situ, interdiction/interception achieves a similar effect by inflicting cumulative attrition on the opponent's delivery force. Rather than destroying the force in a small number of concurrent or closely timed strikes, the attrition occurs overs days or weeks as the opponent's assets

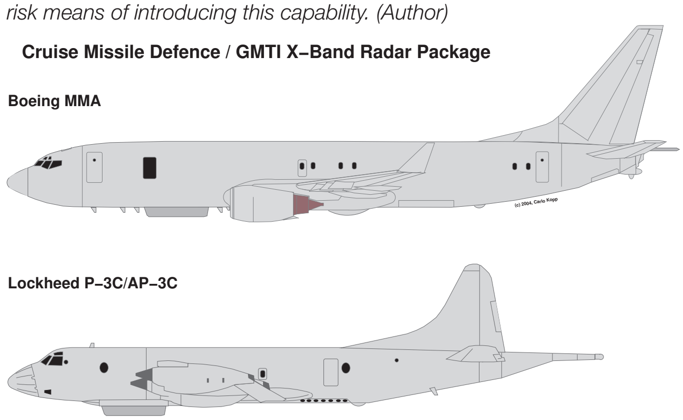
The two most important regional strategic developments over the last two years have been the PLA-AF's June 2004 disclosure of its intent to purchase Tu-22M-3 Backfires, and the 2002 development of the cruise missile carrier H-6H Badger derivative. US sources claim at least 25 H-6Hs are planned. At this stage it is not known whether the nine tonne bomb bay fuel tank used with the H-6U tanker has been incorporated, or whether a refuelling probe will be fitted. The photograph is part of the Zhuhai 2002 AVIC I promotional video, depicting the prototype on takeoff, carrying four Kh-55/65 class missile bodies. (AVIC/Author)

are ground down to impotence. In political terms counterforce strikes, especially if pre-emptive, are problematic, but interdiction/interception of delivery platforms presents a clear cut case of defensive action with clear hostile intent by an opponent. The risk is that not every opposing platform is stopped before it launches, and that many will escape to attack yet again.

When interdiction of a submarine or interception of a strike aircraft fails, and cruise missiles are launched, the challenge becomes to engage and destroy these before they reach their targets.

In practice any model for defeating a cruise missile armed opponent must be multi-layered, even if the counterforce strike option is not implementable due to inadequate strike capabilities. Launch platforms must be detected, tracked and

The gap in RAAF inner zone cruise missile defence surveillance capabilities could be plugged by fitting an X-band AESA – such as the MP-RTIP – to a maritime patrol aircraft. This would provide a dual role cruise missile defence and littoral/battlefield GMTI capability. The AFTS/RLM Multi Mission Sensor System (MMSS) proposal for a palletised bomb bay system for mounting various ISR sensors in the AP-3C would provide a low cost/risk means of introducing this capability. (Author)



The US Air Force solution for outer zone cruise missile defence is the F/A-22, which will exploit its supersonic persistence and large APG-77 radar to kill cruise missiles and delivery aircraft. (Lockheed Martin)

engaged, and if this fails, the cruise missiles must be detected, tracked and engaged. The sea-air gap is valuable in this respect, as it provides a defacto free-fire zone for fighters tasked with cruise missile intercepts, and the distances involved provide for repeat engagement opportunities, fighter fuel and weapon payloads permitting.

Reliance on land based SAM systems for terminal defence of target areas is a popular but relatively ineffective strategy, as high performance SAMs with expensive high power-aperture radars are required, and even with mast mounted antennas to improve coverage the footprint is bounded by ranges of miles to at most tens of miles. Placing SAM batteries on warships increases this expense for some gain in mobility.

Defeating Sub Launched Cruise Missiles

Submarine launched cruise missile defence is inherently dual pronged, and involves using long range maritime patrol aircraft, warships and submarines to engage the launch platform, and AEW&C, tankers and fighters to destroy any missiles which are launched.

The range of the opposing SLCM type will critically determine the effectiveness of either prong in this model. A shorter ranging 160nm (295km) missile like the regional 3M-54/14 series forces the submarine into a relatively small zone surrounding the target, increasing opportunities for anti submarine warfare forces to find and kill it, especially once it has fired its missiles off. Conversely, with a 450kt (835km/h) sub launched cruise missile cruise speed, aerial interception opportunities are compressed into a 20 minute time window, making the odds of successful missile strikes greater.

A 400 to 650nm (740-1205km) range class sub launched cruise missile frustrates ASW operations as the footprint to be patrolled increases with the square of missile range, but it also much increases opportunities for aerial interception by tripling if not quadrupling missile flight duration over water.

The conventional force structure model used for defeating submarine launched cruise missiles is inherently expensive – continuous ASW patrols using aircraft and naval assets must be combined with 24/7 AEW&C, tanker and fighter patrols. While ground alert interceptors are an option, the ten minutes required to get them airborne on station reduces available time to effect engagements against the inbound SLCMs. Supersonic climb-out and sustained dash would minimise the time to station, but this is not an option for the F/A-18 and JSF.

The biggest cost burden in defending against sub launched cruise missiles lies in the need for concurrent airborne patrols using maritime patrol and AEW&C aircraft, effectively doubling up on the required airborne ISR component of the defending force. This is a byproduct of the role specialisation of these platforms.

Maritime patrol aircraft on station searching for submarines being positioned for launches present an opportunity to free up AEW&C aircraft for other tasks – if the patrol aircraft is equipped with radar/datalink capability to cue interceptors to cruise missiles in flight. Existing search radars on maritime patrol aircraft have neither the power-aperture performance nor azimuthal coverage to be useful in this role.

A viable radar is an X-band active phased array in the class of the MT-RTIP family of radars planned for the E-8 JSTARS upgrade, the E-10 MC2A and Global Hawk variants. These radars will be used by the US Air Force for cruise missile defence, mobile ground target tracking, and likely by the US Navy for the BAMS maritime search role on UAVs – the Global Hawk being a leading candidate.

A maritime patrol aircraft equipped with such a radar acquires an inherent capability to detect and track SLCMs, in addition to gaining improved ASW and ASuW surface search capabilities, and JSTARS-like littoral GMTI search capabilities. This is an important synergy in functions which should not be ignored. Supplementary AEW&C capability for naval surface action groups, and over the horizon midcourse guidance and illumination for shipboard SAMs are also feasible.

While submarine launched cruise missiles lack the sustainable rate of fire, and achievable weight of fire of air launched cruise missiles, they do present a complex equation for a defender.

Defeating Air Launched Cruise Missiles

The force structure demands required to defeat cruise missile armed aircraft, and cruise missiles once launched are similar, but the latter presents greater demands both in fighter missile payloads and air intercept radar performance. Supersonic cruise missiles impose further demands on fighter dash speed and supersonic persistence. The conceptual model for cruise missile defence is the combined use of AEW&C, fighters, tankers and in many instances, airborne X-band surveillance radars to detect, track and engage both launch aircraft and cruise missiles.

A key issue in killing launch aircraft is the range of the cruise missile being carried. A weapon which has 160nm (295km) of range offers good opportunities for the defender, especially if the AEW&C aircraft and combat air patrols can be positioned between the intended targets and known threat axis from which the opponent appears. Australia's JORN and the geography of the sea-air gap are especially useful, providing the opponent does not exploit JORN blind periods to get a head start before detection.

These advantages decline with increasing ALCM range. A weapon in the 400 to 650nm (740-1200km) range class presents opportunities to launch against a coastal target even if the AEW&C/combat air patrol packages are orbiting well over the sea air gap. The upside for the defender is that a 60 to 90 minute ALCM flight duration presents excellent detection and repeat engagement opportunities.

Historically only two fighters were custom designed for cruise missile/bomber defence. The first was the US Navy F-111B, the second the MiG-31P Foxhound. It is no accident that both designs have similar empty weight, internal fuel load, high supersonic performance, huge radar bays, and carried similar payloads of similar sized AIM-54 Phoenix and R-33/AA-9 Amos missiles.

Current US Air Force thinking on cruise missile defence envisages a two zone scheme. The outer zone comprises the E-3 AWACS, E-8 JSTARS/E-10 MC2A and the F/A-22, and is intended to detect, track and kill launch aircraft and cruise missiles which might be launched. This outer zone is supplemented by an inner zone, comprising E-8 JSTARS/E-10 MC2A equipped with MP-RTIP X-band radars to track cruise missiles, and a mix of F/A-22, F-35 JSF and AESA equipped F-15C/APG-63(V)2 or F/A-18E/F fighters to destroy 'leakers' which might penetrate the outer zone of F/A-22 defence. The US is currently introducing fusing changes to the AIM-120C-6 AMRAAM to improve its ability to kill cruise missiles.

The limited look-down performance of the E-3 radar forces the use of the E-8 JSTARS as a gap-filler. The more capable E-10 MC2A will later absorb most of this role. The heavy reliance on the F/A-22 in the US model is a direct consequence of the F/A-22's exceptional X-band radar performance and supersonic persistence, which allows it to patrol a much larger footprint than a conventional fighter does, and its ability to operate in contested airspace. The performance of the APG-77 permits head on engagements, and after passing the targets the F/A-22 would reverse heading for a repeat pass against any surviving cruise missiles.

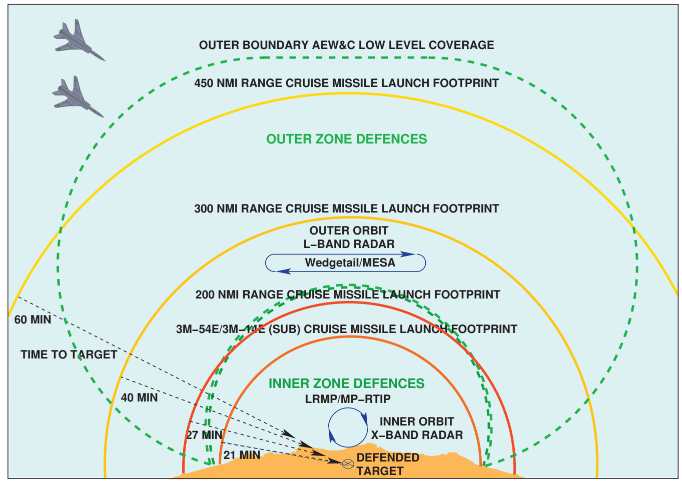
The US Air Force envisage attackers launching waves of cruise missiles, the aim being to deplete fighter missile payloads and fuel, to create openings for a following wave of cruise missiles. The two zone model provides a mechanism to stop a second wave while outer zone interceptors are replenished.

For Australia, JORN and Wedgetail provide excellent outer zone defensive capabilities, but JORN blind periods and Wedgetail numbers will remain as real problems. And the absence of a JSTARS-like capability seriously limits inner zone surveillance and tracking capabilities, especially against SLCM threats, constraining locations of Wedgetail orbits to cover both outer and inner zone areas.

The bigger hole in RAAF capability however lies in the plan for the fighter fleet, centred on F/A-18 and later F-35, with modest tanker support. The F/A-18 and F-35 are not F/A-22s in radar capability, missile/fuel payload or supersonic persistence.

In fact the plan to retire the F-111 deprives the RAAF of a very economic inner zone cruise missile defence interceptor

EXAMPLE CRUISE MISSILE DEFENCE CONOPS



The US Air Force model for cruise missile defence envisages inner and outer zones, patrolled by E-3 AWACS and E-8 JSTARS respectively, with F/A-22A providing outer zone intercepts, and AESA equipped legacy fighters inner zone intercepts. Current RAAF planning leaves gaps in inner zone X-band surveillance capability, and totally inadequate fighter capability in terms of radar performance, supersonic persistence and missile payloads. This chart depicts an alternative model for the RAAF. (Author)

airframe. The combination of persistence and supersonic dash performance, and large payload, provides the F-111 with the ability to cover inner zone patrol areas without tanker support, in an environment where its lack of close-in air combat agility is irrelevant.

An F-111 can orbit on station 200nm (370km) from a runway for about four hours without refuelling. Retrofitting a suitable radar like an APG-79, APG-80 or APG-81, a JTIDS terminal and clearing the AMRAAM would be a cost effective investment, given the reduced tanker demand and supersonic intercept capability against the Backfire – not to mention the resulting gains in F-111 strike capability.

Growth in regional cruise missile and long range bomber capabilities is now an inevitability. ✈

The arrival of cruise missiles in the region presents genuine long term issues for Australia's air defences. The north hosts a large oil/gas industry, and key runways for air defence. Both are high value strategic targets, be it in economic terms or in stripping away air defence capability across the north. This map compares launch footprints for cruise missile of various ranges against fighter intercept radii. (Author)

NORTH WEST SHELF AND TIMOR SEA AIR DEFENCE ENVIRONMENT