

National Air Defense: Challenges, Solution Profiles, and Technology Needs

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ABSTRACT

Past and current air defence systems have performed well in conflict, but with less than the desired reliability in peacetime. Future systems will be challenged by a more stressing problem: defence vs. unconventional threats in “peacetime”. An air defence modernization strategy built to buy-down near-term risks and invest in technologies intended to permit cost-sensitive designs for next-generation systems are key to an economical approach to the challenge.

1.0 BACKGROUND

The air defence planning and design environment has become far more complex in the last decade. Nations previously designed their air defences for use against foreign conventional threats. These threats primarily consisted of attacks by multiple large, fast military aircraft, helicopters, and missiles. Past and most current air defence systems have been designed to efficiently engage threats after strategic warning, and especially after the onset of combat. Monitoring airspace in peacetime, identifying, and when necessary intercepting and destroying intruders has been a second primary objective. Even the best defences have occasionally failed to perform their peacetime mission adequately when not provided with strategic warning of attack. These failures have often playing a significant role in international affairs. Notable failures include:

- 1983: the former USSR mis-identifies and destroys Korean Airlines Flight 007
- 1987: the former USSR fails to detect a Cessna flying from West Germany to Moscow’s Red Square
- 1988: the U.S. mis-identifies and destroys Iranian Air Flight 655 in the Persian Gulf
- 1994: the U.S. mis-identifies and destroys two U.S. Blackhawk helicopters during peacekeeping operations over northern Iraq
- 2001: Al Qaida uses commercial airliners against targets in New York and Washington
- 2002: A suicidal 15 year old Al Qaida sympathizer uses a Cessna to buzz McDill Air Force Base and crash into a bank building in Tampa, Florida.

Whereas past and current systems have tended to perform well during conventional conflict and unreliably in peacetime, ***future systems must be built to operate in a more challenging environment: the unconventional***

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“peacetime” environment where air defences face non-traditional threats without the benefit of strategic warning and force generation.

2.0 THE CHALLENGE

The challenge faced by future air defence systems is in many ways the reverse of that which drove the design of legacy systems. Legacy systems were designed for defence against conventional attacks by nation-states. These attacks were expected to involve multiple, overt air vehicles, usually occurring after strategic warning, force generation, and dispersal of critical targets. We desire future capabilities to address individual or small numbers of clandestine and covert threats, launched primarily by non-state actors.¹ Most critically, future defences must operate **without** the advantage of strategic warning or force generation. Legacy systems could safely assume that threats would originate outside domestic airspace. Future systems must address threats originating in either domestic, foreign, or international airspace. The emergence of threats inside of domestic airspace collapses response times to as little as tens of seconds to minutes, and greatly increases coverage rates for threat detection relative to perimeter defence designs.

The challenges presented by civil and commercial aviation were exemplified in the 2002 crash of a Cessna 172 into the Bank of America building in Tampa, Florida. The threat emerged without strategic warning inside U.S. domestic airspace. Although the threat made no attempt to evade radar tracking and the Air Traffic Control (ATC) / air defence system received warning of a potential threat at the time of take-off, the time required to assess the situation, select a course of action, generate the defensive force, and intercept the threat was too great to prevent it from over-flying a major U.S. military base and ultimately crashing into a public building. Had the threat been armed with conventional explosives, the knowledge to pick a more sensitive or damaging target, and / or a Chemical, Biological, or Radiological (CBR) weapon, the damage would have been far worse (i.e., a “second 9/11” rather than a historical footnote).

Legacy systems were designed primarily to address large, fast vehicles penetrating an air defence boundary. UAV technologies have matured within the last five years to the point where relatively small (e.g., 3 meter wingspan) vehicles can deliver 2 – 20 kg payloads across regional and intercontinental ranges. Current examples of such systems include the Aerosonde and Scan Eagle UAV systems, shown in Figure 1. When equipped with altimeters and satellite navigation, systems like these are in principle capable of delivering small CBR payloads at long range and very low altitude. In addition to being inexpensive (i.e., a few 10,000s of euros), such systems require relatively simple ground support and launch infrastructure. There is every indication that such systems will continue to grow in capability and proliferate world-wide over the next decade.

¹ By definition, clandestine threats are detectable but difficult to discriminate as they appear to be ordinary civil aircraft. Covert or stealthy vehicles on the other hand are difficult to detect, track or intercept, but when found are sufficiently unique to discriminate as threats.





Threat	Operating Environment	Stressing Features
Civil Aviation (General and Commercial) 	<ul style="list-style-type: none"> • Peacetime (and war) • Domestic and foreign airspace 	<ul style="list-style-type: none"> • Clandestine threat in high-volume traffic • Extremely short response time
Endurance UAVs 	<ul style="list-style-type: none"> • Peacetime (and war) • Domestic and foreign airspace 	<ul style="list-style-type: none"> • Covert / stealthy vehicle • Low altitude / long-range • Minimal launch site • Low cost
Cruise Missiles 	<ul style="list-style-type: none"> • Peacetime and war • Foreign and international airspace 	<ul style="list-style-type: none"> • Covert / stealthy vehicle • Low altitude • Minimal launch site
Conventional Military 	<ul style="list-style-type: none"> • Crisis and war • Foreign and international airspace 	<ul style="list-style-type: none"> • Volume and speed of raid • Attacks on air defences • IFF / N

Figure 1: Overview of the Challenge.

Evolution and proliferation of conventional military air vehicle technologies will also continue, with systems akin to 1970s – 90s era NATO developments entering world-wide use. Cruise missile systems may become attractive delivery vehicles in unconventional conflict, most readily by modifying anti-ship cruise missile systems now in international inventories for land-attack. There are thousands of such systems in the inventory of many nations around the world. Proliferation, clandestine sale or theft of such weapons is quite possible. Such missiles may be launched from neighbouring countries or nearby commercial ships, would fly over land at 50 – 200m altitude to avoid detection, and the newest variants feature low-observable designs. Obviously, their payload is sufficient to severely damage nearly all civil targets, or to carry CBR and nuclear weapons.²

3.0 AIR AND ECONOMIC WARFARE

When judged **purely** in terms of technical feasibility, the NATO community is theoretically capable of building air defences to address all these threats. The difficulty comes in affordability: the intersection of air and economic warfare. In the 1970s, the U.S. conceived of deploying cruise missile and stealth technologies to lock the USSR into a financially ruinous spiral of air defence upgrades. Initial stealth and cruise missile systems were seen as a way of rendering the legacy Soviet air defence obsolete, and forcing a massive new round of defensive expenditures. Successive enhancements in cruise missile, stealth, electronic warfare, and hypersonic systems were then planned. These second and third-round enhancements were planned to render each anticipated generation of Soviet defensive upgrades obsolete, and continue the expenditure spiral. The purpose of this strategy was less to achieve offensive dominance, than to channel Soviet military expenditures

² Note however that their payload is substantially inferior to nearly all civil aircraft.

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into defensive rather than offensive capabilities and, coupled with competition in other areas, to disrupt the Soviet economy.

Certain features of today's challenge are similar to the U.S. strategy vs. the USSR of the 1970s – 1980s. Our legacy air defences are, in the absence of strategic warning, not capable of:

- **continuous** surveillance against low altitude, low-speed, low-Radar Cross Section (RCS) targets
- intercepting civil aviation, UAVs and cruise missiles over nation-sized areas
- discriminating between threatening and innocent general aviation aircraft, and negating these aircraft before they can strike their targets
- monitoring domestic airspace for low altitude, low-speed, low-RCS targets and negating these threats before they can strike their targets.

The core challenge faced by NATO is to conceive and execute a strategy which addresses the overall defensive problem at an acceptable economic impact – rather than applying legacy system concepts and technologies in brute force, rapid-deployment solutions to the challenge. In spite of the urgency felt as a reaction to the 9/11 attacks, such a strategy is unlikely to feature rapid leaps in capability across the full spectrum of threats. The U.S. experienced the economic and force operations tempo costs of attempting such a leap in the aftermath of 9/11. Thousands of hours of AWACS and fighter interceptor flight time were logged in an attempt to provide air defence capable of detecting and responding to unconventional threats without strategic warning. *Instead, an efficient approach will employ selected improvements to quickly “buy down” the most likely near-term risks and delay the onset of the most severe problems, mixed with research to lower the cost of solutions to the most challenging problems.* Various solution profiles (i.e., strategies to manage the air defence problem set over time) can be assembled, each with differing implications for risk, and expenditures on near-term capabilities and research.

4.0 SOLUTION PROFILES

A broad range of potential new capabilities are open to NATO in countering unconventional air attack. These include offensive options such as:

- Disrupting and destroying terrorist organizations and other non-state actors.
- Denying these groups access to Chemical, Biological, Radiological, and Nuclear (CBRN) weapons and components. This is especially critical as a means of slowing the emergence of Endurance UAVs as the premier air threat in the near and mid-term. With access to CBRN payloads, modest numbers Endurance UAVs could pose a severe threat to “peacetime” civil societies. Without access to CBRN payloads, Endurance UAVs are at most a nuisance threat.
- As in the past, adequate attack attribution and strategic retaliation capabilities will continue to be needed to deter unconventional air attack by state actors.

If successful, these options would substantially suppress unconventional air attacks, reducing and delaying the need for highly-capable new defensive capabilities in the near-term. This would “buy time” for research efforts to develop the critical enabling technologies for lower-cost air defence designs in the mid and far-term.

At present, there are few low-cost approaches to continuously monitoring, and rapidly identifying, formulating defensive responses, and intercepting civil aviation, endurance UAV, and cruise missile threats across nation-sized areas – **without** prior strategic warning. Defensive options include a number of measures

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already taken to secure civil aviation (i.e., securing airfields and aircraft, screening passengers, armed guards, cockpit intrusion protection and arming pilots, hijack alarms, and modest numbers of ground-alert fighters near likely target areas). The key residual issues for civil aviation are seizure of high-end general aviation aircraft, and limited response time available to respond to a successful commercial hijacking. Potential mid and **long-term** solution options might include:

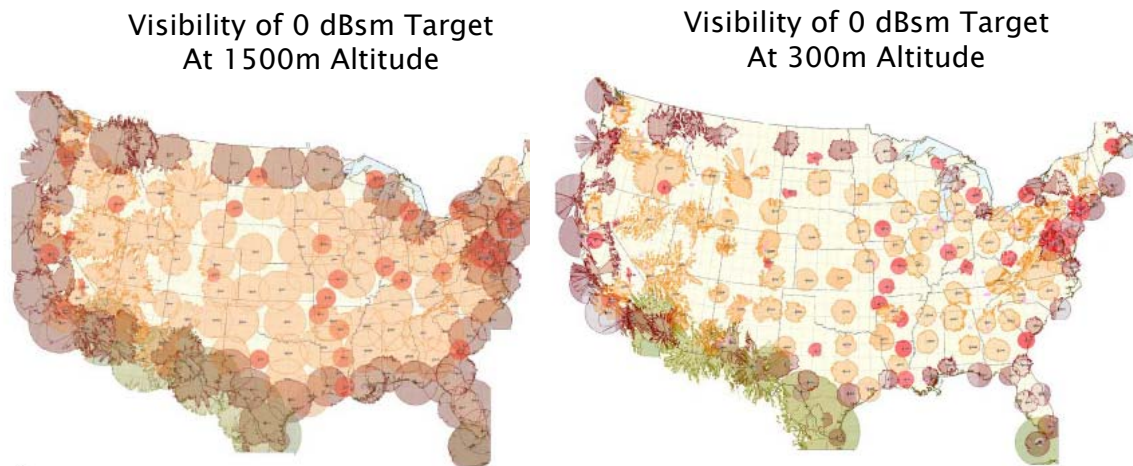
- 1) Designs for future high-end general aviation and commercial aircraft to require off-board radio signalling to permit engine start-up on the tarmac. This signal could be sent only after a valid identity code was sent to the tower by the pilot.
- 2) Ground processing systems to detect aircraft flight anomalies and alert air traffic controllers and fighters.
- 3) Hijack alarm + autopilot designs to put the aircraft into a safe loiter when activated. Future aircraft could be designed to react to the pilot triggering a hijack alarm by (1) engaging an autopilot programmed to move the aircraft to a safe altitude and loitering at that altitude, (2) broadcasting air Traffic Alert and Collision Avoidance System (TCAS) data to avert potential collisions with nearby traffic, (3) locking out the flight controls during the short, “loiter period” (e.g., ~15 minutes), and (4) returning control to the pilot at the conclusion of the loiter period. This loiter period would permit ground-alert fighters to launch and approach the hijacked aircraft.

While legacy and programmed air defence systems are designed to address conventional military aircraft and cruise missiles if given strategic warning, future systems must be capable of continuous nation-sized surveillance against small, slow targets at low altitude and rapid interception of cruise missiles in “peacetime”. Economical long-term options for such capabilities may include:

- 1) High-powered, aerostat-borne radars in the general area of high-value targets.
- 2) Satellite or ultra high altitude, long endurance UAV-borne receivers processing civil and military signals to detect adversary endurance UAVs (and possibly cruise missiles) over very large regions.
- 3) A suite of national air and missile defence interceptors capable of engaging ballistic missiles, aircraft and cruise missiles.

The first of these options is within the current state-of-the-art for small targets, but is not economical to proliferate on a nation-wide basis. Detecting small, slow targets with the second option is beyond today’s state-of-the-art. Needed coverage rates are somewhat moderated by the low speed of the endurance UAV threat. The attractiveness of such a permanent, wide-area, look-down detection capability is its ability to overcome terrain screening. (Figure 2 provides an example of the impact of terrain on ground based surveillance of even modestly low altitude threats.) Should NATO countries choose to deploy regional defences against ballistic missiles, the incremental cost of the third option (i.e., deploying long-range interceptor missiles capable of engaging aircraft and cruise missiles) might not be unduly high.

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Source: "Emerging Threats and Challenges For Homeland Air Security", RADM M. Mathis, JTAMDO, 2003, UNCLASSIFIED

Figure 2: Terrain Screening Impact on Surveillance of Moderate Altitude Threats.

As discussed in Section 3 above, a successful solution profile will delay evolution of the threat and selectively deploy defensive capabilities when and where needed, while accepting some level of risk in exchange for substantial cost-avoidance. Figure 3 presents one such profile. This strategy relies on deterrence vs. nation states and the ongoing offensive campaign against non-state actors to retard the threat, and on existing moderate-cost measures to secure civil aircraft. In the near-term, this program accepts the risk of attack by *conventionally* armed cruise missiles (whose damage is comparable to a car or truck bombing). The profile does not make large expenditures on endurance UAV or cruise missile defences in the near-term since (1) these only cause heavy damage if armed with CBRN payloads and (2) attempting to deploy such defences with legacy approaches would be exceptionally expensive.

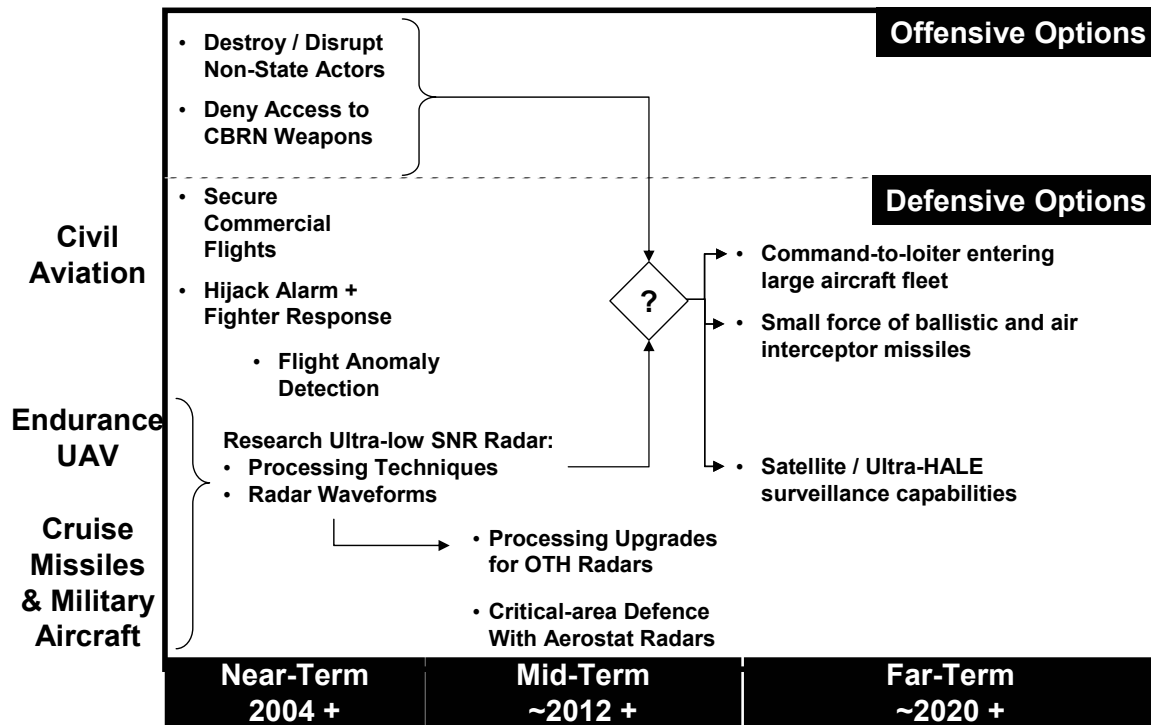


Figure 3: One Option for a Cost-Constrained Air Defence Modernization Strategy.

This profile relies on a rigorous radar research and development programme to enable options #4 and 5. It defers heavy investments in these options and in more aggressive measures to secure civil aircraft pending the outcome of the offensive campaign against non-state threats. For this strategy to be effective, NATO would invest relatively heavily in efforts to develop (non)cooperative bi-static radar waveforms and processing algorithms capable of detecting and tracking very small Radar Cross-Section (RCS) targets at relatively high area coverage rates. This implies ultra low Signal to Noise Ratio (SNR) detection algorithms and extraordinary noise-reduction algorithms. The first application of these techniques would desirably be implemented in Over-The-Horizon (OTH) and other legacy ATC and weather radars. This would allow relatively low-cost application in perimeter defences. Depending on the success of the offensive campaign vs. non-state actors, NATO might or might not need to actually deploy further nation-sized surveillance capabilities and expensive alterations to civil aircraft. This evolution profile is one of many possible examples, all with the same fundamental characteristics: buying down near-term risks and making technology investments to lower the eventual costs of advanced air defences vs. more stressing threats.

5.0 CONCLUSION

While NATO may face several stressing air defence challenges in the future, the alliance must balance the payoff vs. cost of major improvements. The key to addressing these challenges is to (1) make the key research investments necessary for low-cost mid and far-term system concepts, and (2) to phase the introduction of solutions consistent with life-cycle replacement of existing equipments. In the research area, the most badly needed investments are in look-down radar technology advances which permit us to design future systems on high-altitude, long endurance UAVs and satellites while avoiding large prime-power requirements. These advances may take the form of novel processing algorithms for ultra-low SNR detection or extraordinary



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noise reduction. Phased introduction of new capabilities to further secure civil aircraft (e.g., electronic locks, automatic loitering at the onset of a hijack attempt) are examples of long-term, phased introduction consistent with aircraft and ATC system evolution. The key to both approaches is a flexible decision strategy that avoids locking NATO into a spiral of overly expensive, premature upgrades.

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