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# AIRBORNE STEALTH IN A NUTSHELL – PART II

## Countering Stealth – Technologies & Tactics

By Dimitris V. Dranidis

In Part I of this article, we saw how stealth technology and its principles work when applied to aerial warfare, and how they can be used effectively in operations to confer a decisive advantage. It is now time to examine the opposite side of the coin, the defender's dilemma against this form of combat. Like all military technologies & principles, stealth has certain drawbacks and limitations, which, if properly exploited, can allow successful countermeasures to be undertaken against it, and either neutralize it altogether or reduce its actual effects.

As already seen, Stealth is not merely a technology. Rather, it is a paradigm of fighting, a concept of how to do the job. In fact, it is not nearly as new as some think – submarines have been using stealth since their inception to maximize their effectiveness and improve their survivability, and soldiers have long adopted camouflage to get that extra edge in concealment – and hopefully surprise. Like all principles of warfare, stealth is an integration of technology and tactics. Thus, counters to it have to include both technological means and also the suitable strategy & methods to maximize their effect.

### Technologies

#### Low-frequency (long wavelength) radars

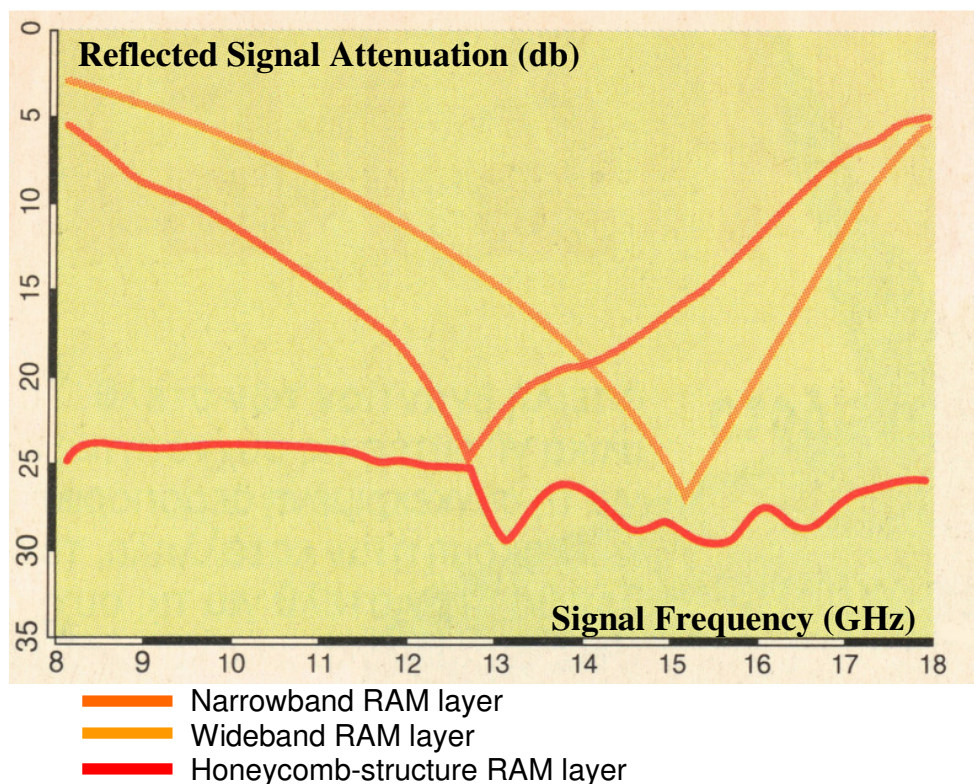
Radar-absorbent materials and structures (RAM and RAS) are physically limited in their ability to absorb incoming electromagnetic energy. This is because, as seen in Part I, their actual physical depth has to be driven by the wavelength of the incoming signal. For a high-frequency signal (as is the case with the majority of tracking/fire-control radars in service today, generally in the 5-200GHz range) this is not a problem, since the wavelength may be a few millimeters or even fractions of a millimeter, and thus RAM can be applied in a thin-skin or paint form. What happens, however, when the signal frequency is much lower? In this case the absorber material has to be so deep that practical problems begin to arise with regards to its applicability to the aircraft. While you can build a house with 3m-deep walls, doing the same to an airplane produces a very inefficient design; weight and volume restrictions will virtually prohibit the carriage of any significant payload over meaningful ranges. Great skin depth also tends to severely limit maintainability (imagine a repair crew digging its way through the skin in order to remove an avionics box or an engine part), which in turn hurts the practical sortie rate.

The effectiveness of long wavelengths against low-RCS targets rests on resonance effects between the direct reflection from the target, and scattered waves which "creep" around it. Resonance may occur on individual components as well as on the entire aircraft body. A gun muzzle may be resonant even when illuminated by an X-band fighter radar with a 3-cm wavelength. The E-2 Hawkeye, with a radar typically operating at 400 MHz in the UHF band, puts out a 75cm wave, so that quite large components (fin or wingtips, or the cross section of a missile body) may fall within the resonance region.

Low-frequency sets are among the earliest forms of radar systems. They were quick to be adopted by early users as their low frequency made their signal less susceptible to atmospheric interference & absorption, an important factor back when signal processing was extremely limited (or non-existent) and every single dB made a world of difference in detection range. Such systems became widely used in the strategic early-warning radar fences of the superpowers



during the Cold War's bomber race, and offsprings of their development continued to dominate the EW/GCI scene well into the 70s. Henceforth, advances in signal processing and increased computing power allowed their gradual replacement by medium-frequency systems which offer better detection resolution, reduced clutter interference and reduced vulnerability to jamming without a significant reduction in absolute detection range.



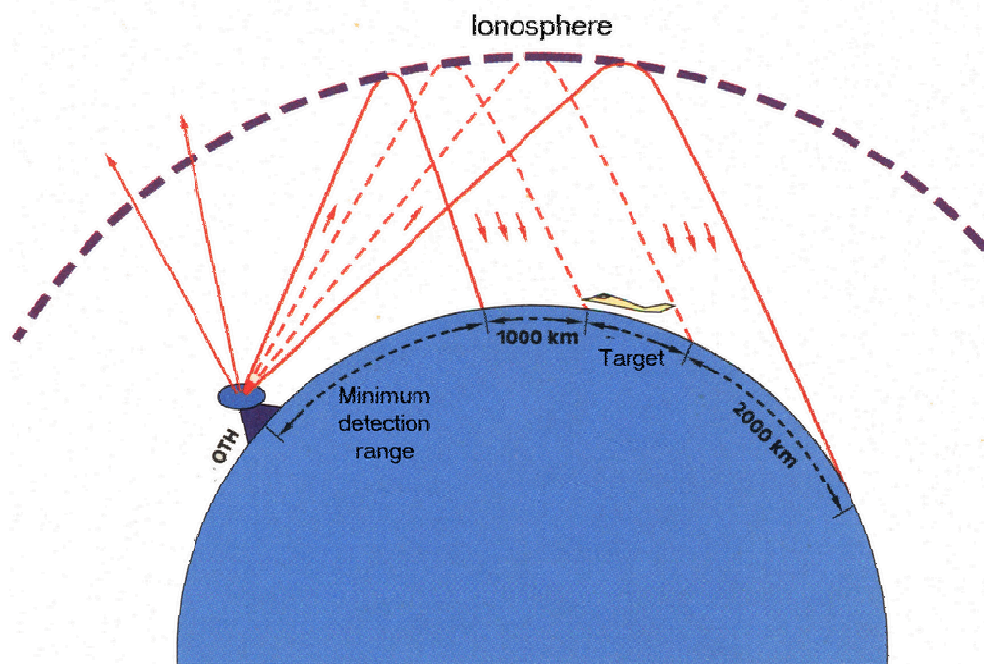
They can still be found in service however, particularly in former Eastern block and third-world countries where fiscal restrictions have forced their operators to maintain them in operational status (often in an updated form or another).

As an example, many of Russia's older early-warning radars typically operate in the VHF band. Some of these are mobile, such as the Spoon Rest associated with the SA-2, SA-4 and SA-6 systems. Others, like the very large (and surprisingly still widely used) Tall King, are fixed and are used for strategic air and missile defence. Precise frequencies vary, but

Tall King is fairly typical at 160 to 180 MHz, with wavelengths of 165 to 190 cm. At this point, the major structural components of an aircraft, such as its wings and fins, may resonate.

Over-the-horizon (OTH) radars like the Australian Jindalee invariably operate in the HF band with frequencies around 10 MHz and wavelengths of 30m, because their operating frequency is confined to the band in which atmospheric reflection is effective. At that point, any target will generate some kind of resonance and shaping will be largely irrelevant to the size of the target's RCS.

However, lowering the frequency (i.e. increasing the radar wavelength) is hardly a trivial matter. The size of the



Operating scheme of OTH radar systems

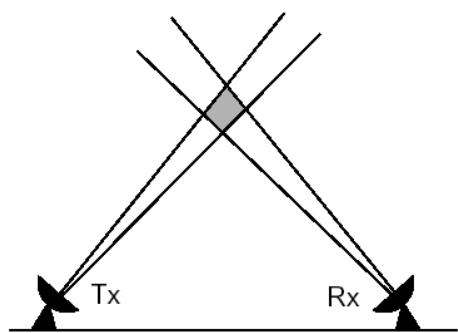
antenna aperture has to grow in proportion to the wavelength in order to maintain a narrow beam and adequate resolution. So-called "mobile" VHF radars are still a pain to assemble and strike down, and strategic early-warning radars such as Tall King are large fixed structures and typically provide coverage of only one sector. OTH radars are larger still, their receivers often occupying vast empty land areas.

Another problem with VHF and, to some extent, UHF radars is that those wavebands are already stuffed with communications traffic. In the tactical environment, this generates so much noise that the ability of such radars to detect anything, let alone a stealth aircraft, is reduced. This is why most such radars are found in the early-warning role, staring mostly over empty territory (or the sea), rather than in tactical overland applications.

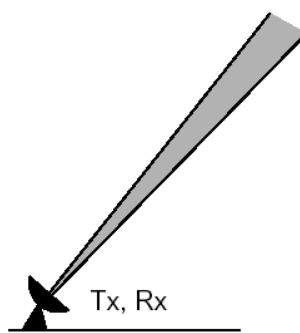
## Bistatic/Multistatic radars

It has already been shown how faceting, the dispersion of radar reflections away from the conventional transmitter/receiver unit, can help drastically reduce an air asset's RCS. What needs to be emphasized is that the electromagnetic energy is still there; it is simply redirected to directions other than the radar unit and thus considered useless for conventional systems.

Now, what if that scattered energy is picked up by receiver units in various other directions? Provided that the



Multistatic

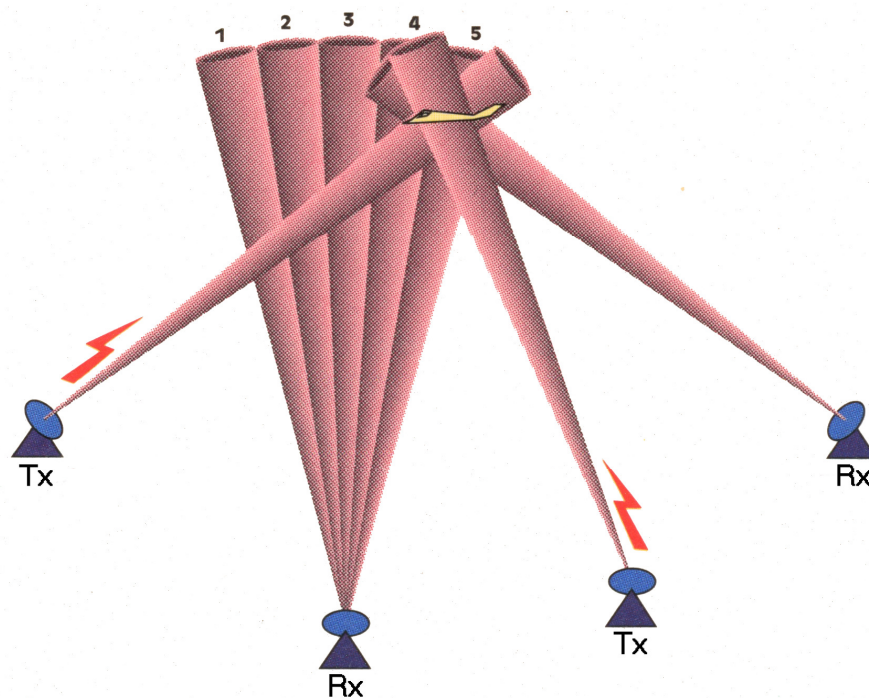


Monostatic

received signal is accurately correlated with the original emission from the radar transmitter, the successive bearings from which it is received can be compared, and a pretty accurate estimate of the reflection point can be deduced. Aircraft that make heavy use of faceting, such as the SR-71 or the F-117 can thus be detected with a fair probability of success. Such radar systems are called bistatic (in the case of a single transmitter and a single receiver), or multistatic if the number of Tx or Rx units is greater – typically one transmitter coupled to multiple receiver

sets.

Putting this theory into practice requires several steps. To begin with, each successive radar pulse must be uniquely identifiable in order to correctly perform the spatial correlation between the outbound signal and the inbound returns. This is an already existing practice in modern pulse-Doppler radar systems and is thus a modest technical challenge. More difficult is the combination of all the signal correlations into a meaningful positional estimate. A radar return may arrive at the transmitter from a variety of directions other than the "true" reflection, both as a result of multipath or



Operating principle of multistatic radar systems

mirror effects and other factors such as anomalous atmospheric propagation, signal distortion due to interference etc. Sorting out the true-bearing returns from the fakes is a difficult task even for straightforward conventional radar sets, and it becomes even more complex in the case of multistatic receivers. A simple tracking algorithm may try to follow the consistent returns and wash-out spikes that seem inconsistent with the target's expected motion; this is the simplest of examples, and the software associated with such functions can be expected to be mind-numbingly complex.

As conventional monostatic radars divide their area of air surveillance into segments successively scanned by their main beam (lobe), so do multistatic systems. The difference here is that the intersections of the segments can intersect between nodes of the system, thus forming surveillance "cells". These cells are then monitored in rapid succession for any reflection of a signal consistent with the one originally emitted by the Tx element of the system.

An early example of this type is the French RIAS experimental radar, set up since the mid-70s in the French island of Levant, to explore to potential benefits of the principle. This uses a single transmitter element in the metric band with a number of receivers (a series of dipoles spaced 15m apart and forming 2 co-axial rings, the outside ring being 400m in diameter) to provide 3-dimensional target data. At least 3 receivers are needed to provide a 2D fix, and another one for a height estimate. The main problem at the time of the system's inception was the limited computing power then available. In the early tests, with an IBM Cyber-360 mainframe handling the monitoring of the multiple cells, it took nearly a week to fully process the input of just two minutes of surveillance. From the mid-80s, however, the replacement of this system with a Cray-II supercomputer enabled the signal processing to be performed in near real-time. With computing power being so abundant and cheap nowadays, this restriction can be assumed not to present an issue anymore.

## Passive & covert radar systems

The availability of massive computing power in the late years has also enabled the realization of another radical concept – using the radio-electronic background noise itself as the means of detection. As already mentioned, certain bands of the EM spectrum are regularly used by civilian radio & electronic devices (anything from radio/TV station transmitters to mobile phones to wireless PCs etc. etc.) and such bands are literally stuffed with electronic traffic. Ordinarily, radar designers tend to shy away from using these frequencies, as this would guarantee a very high background noise level in the operation of their system – and the higher the interference, the worse the degradation of its performance.

The thickness of EM noise in these bands, however, presents a significant characteristic: like a body of liquid, anything that disrupts its normal state by passing through it leaves a noticeable trace - even momentarily. Space observers have long been tracking black holes by looking in the galaxy for places where background light should be there, but isn't. Tracking an airborne target covertly follows a similar logic: look for spots in the sky where there is an abnormal absence of EM noise, an "EM black hole". Another variation of this principle is to track a target by looking at the changes in the EM noise patterns in a specific area. By monitoring these patterns in an area over a period of time, a fairly consistent EM noise "map" can be created. Now, whenever a sufficiently large air target passes through this area, it will unavoidably disturb the normal EM flow, alter the random scattering of regular EM emissions etc. This abrupt disruption in the local EM "status quo" creates spikes in the stored pattern, and thus can be tracked.<sup>1</sup>

As usual, implementing the theory is a bit trickier than simply stating it. To begin with, enormous processing power is required to analyze the EM traffic patterns over a given area – and the bigger the area, the more acute the problem. Then there is the challenge of storing the absolutely massive data for later comparison – and being able to retrieve it instantly when needed. Some degree of redundancy is also desirable: a spike on a single receiver is just that, a spike. The same blip appearing on several adjoining receiver stations is a more solid indication of "something" being in the air. Furthermore, because the EM pattern can shift as a result of a host of reasons other than the presence of an air target (something as simple as a passer-by with a strong-signal cell phone), any heads-up will have a varying degree of reliability – lots of false alarms are an inherent headache in the design. Such a system is also likely to be relatively short-ranged: as distances increase, the perceptible pattern disruptions in local EM fields are going to be harder to pick up.

The effectiveness of a passive radar system is going to be higher in urban areas where the EM field pattern is thicker – however, this is also the place in which random non-target spikes are most likely to occur. A more effective solution may be to deploy multiple low-cost, low-power active transmitters over large uninhabited or rural areas, to create an

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<sup>1</sup> In his novel "The Sum of All Fears", T.Clancy theorises that the Russians might begin searching for US Ohio-class SSBNs by using the "black hole" principle, looking for the absence of background noise in the sea room that these ultra-quiet subs occupy. It is unknown if the Russian subs are indeed using this technique in their sonar systems. They have, however, been using non-acoustic environmental sensors since at least the late-70s/early-80s to detect enemy subs by tracking the water disturbance created by their wakes. These sensors are reportedly unreliable and short-ranged (though whether this is an inherent design weakness or a result of poor-quality implementation from the Russians' part is unclear).



equivalent field. The receivers would then be randomly placed among the transmitters or in pre-surveyed optimal positions. Such an arrangement (which closely resembles a multi-static radar system) has the advantage of presenting enemy SEAD planners with a large number of emitters which will take a huge effort to neutralize – and which can be replaced easily with a minimal cost. Of course, the greater the number of elements in the system, the more complex the C4I infrastructure supporting it will have to be in order to really exploit its potential. The real-time dissemination of processed data to relevant consumers (anyone from theatre-wide air commanders to the pilot in the cockpit) is a demanding task in itself, and the imprecise nature of this system is likely to call for other assets (such as IR sensors) to pinpoint the target after the initial localization.

Practical & technical considerations notwithstanding, the appeal of passively tracking a stealthy air target (or any other target for that matter) is too strong to ignore, and numerous military branches are starting to take an intense interest in practically fielding such systems. China has long been rumored to be developing a system based on these principles, called PCLS (Passive Coherent Location System); its operational status is unclear at the moment. Western militaries and defence contractors are also exploring similar concepts (such as Lockheed's "Silent Sentry" system), partially as a response to the increased market presence of LO aircraft and weapons and the possibility of them being used extensively by third world armed forces.

## Advanced ESM/SIGINT systems

In the last few years, it has become commonplace for "shocking" reports to crop-up in western media about some new "anti-stealth radar" being sold to a number of third world countries like Iraq, Syria or North Korea. These ambiguous reports usually refer to the sale (or sale negotiations) of advanced ESM/SIGINT systems like Tamara or Kolchuga.

The use of advanced SIGINT systems in tactical & theater anti-air operations (rather than in war-warning & strategic



Deployment of a Tamara unit

reconnaissance duties as is common with NATO & western branches) was a principle long sought by the Warsaw Pact since around the mid/late-60s, after the doctrinal shift of both European alliances re-emphasized conventional counter-air means & tactics instead of nuclear strikes. For the WP this meant a re-emergence of the problem of NATO's vast superiority in tac-air capabilities and a number of methods to deal with it were considered. The experience of the Middle East conflicts as well as the US SEAD campaign in Vietnam convinced the WP that active air defences alone were insufficient to deal with NATO's air onslaught. Therefore, they would have to be reinforced with more covert means of airspace surveillance and control.

The increasing reliance of aircraft on radar for the purposes of navigation, low-level penetration and target acquisition & engagement provided an Achilles' heel that could be exploited. If the sensor and communication emissions of NATO's aircraft could be collected, correlated and analyzed fast enough, their location could then be triangulated and estimated accurately enough to provide an initial cue for other ground-based sensors or for friendly "silent" aircraft. Interestingly, the main development effort for such systems seems to have been undertaken in Czechoslovakia and Ukraine rather than Russia.

The first practical products of this development endeavor were the Czech "Kopac" and "Ramona" systems, for which little hard information is available. Their service introduction timeframe must have been around the mid-to-late 1970s. The first fully operational system was the Czech "Tamara", a more capable and comprehensive system introduced in the early 1980s. It is produced by the Tesla corporation and has gathered considerable press attention in the late years. This is a fully mobile system capable of recording and analyzing all emissions from emitting aircraft such as attack & navigation radars, communication radios, terrain-following radars etc. In order to achieve sufficiently good coverage against low-flying intruders (one of the classic headaches of the WP air defences) the system uses a cylindrical drum receiver mounted on an extensible tube-pike, which is unfolded by a cross-country truck when striking-down for deployment. The system may operate autonomously or, as is usually the case, be integrated to a larger C4I network and contribute its information to the overall air picture. According to Maj. Gen. Oldrizhikh Barak, president of Tesla, Tamara uses a so-called "chronometric hyperbolic principle" that with three units spaced "several miles apart" can track aircraft from distances of "about 12 miles". Also JDW credits the system as being able to track 72 targets concurrently.



**Kolchuga**

Similar to the Tamara but apparently more capable is the Ukrainian "Kolchuga". This system was designed and produced by Topaz (Donetsk). The company has its own design and research facilities and production facilities left over from the former Soviet state-owned defence industry. The Kolchuga is essentially a high-precision, passive, signals-intelligence (SIGINT) system, consisting of four elements: three detection and tracking stations and a command-and-control (C2) element with powerful analysis capabilities. Normally, when the system is deployed in the

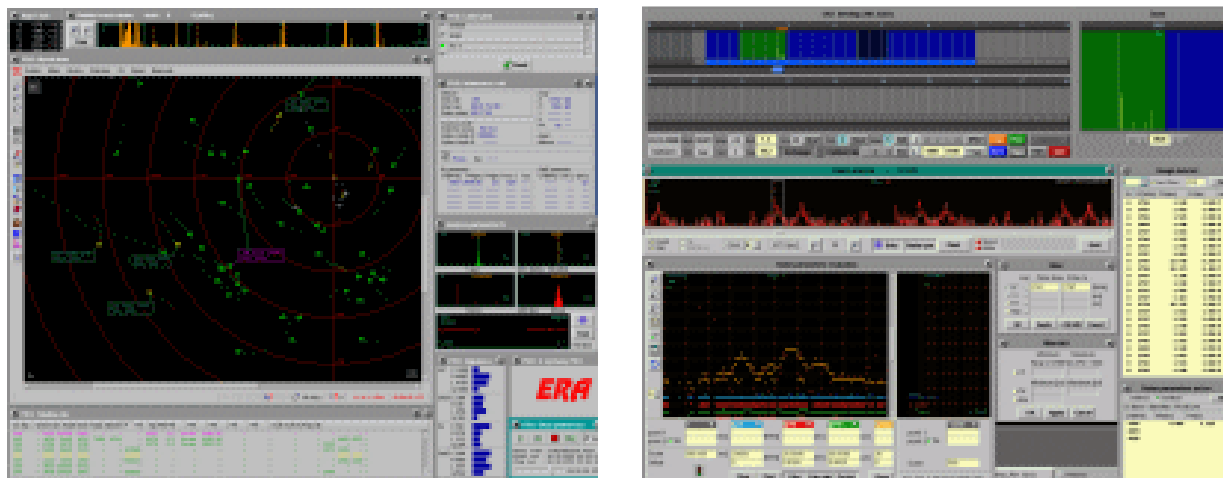


field, the detection elements are separated by about 60 km from each other, which enables precision location of an air target by tracking it with two or three stations simultaneously. Each station is equipped with a set of rotating antennas, covering the 0.1- to 18-GHz frequency band. The antennas and receivers are able to detect, track, and output data for further analysis. All aircraft emissions - such as non-autonomous navigation aids (e.g., TACAN), radar altimeters and Doppler radars, communications, fire-control radars, and IFF signals - can be intercepted and analyzed. About 40 elements of signal characteristics are analyzed, which ensures (according to the producer) a 90% probability of target identification and recognition (as a particular type of aircraft or helicopter). The system has two basic modes with two different ranges - one up to 600 km and another up to 200 km - but under ideal circumstances, it can track targets up to 1,000 km away. The system's intercept probability and ability to track multiple targets, however, is much better when operating at shorter ranges.

The system software on the C2 vehicle allows a basic assessment of the air situation, provides target prioritization, and determines the target's trajectories and modes of operation based on the target's radar mode - i.e., navigation, ground attack, air-target track etc.). The whole system is mounted on heavy cross-country tracks and is, thus, highly mobile. Each mobile element possesses its own means of autonomous secure communications for real-time data transmission and synchronization of operations with the other stations, as directed by the C2 element. The deployment and redeployment time is short, which enables the system to change positions rapidly, thereby increasing its combat survivability.

Though probably not designed specifically with VLO targets in mind, such systems can probably contribute significantly to an air-defence system's ability to cope with targets that are more likely to register on passive rather than active sensors. Hard as they are to detect on radar, VLO aircraft still have to use radar for navigation & target acquisition purposes (particularly when hunting mobile targets such as Scud launchers or mobile SAMs), in addition to regularly communicating with other assets to facilitate a flexible C4I and battle management system. For non-stealthy aircraft that are already tracked by radar, the giveaway of these emissions is not a great deal in the tactical confines (subsequent enemy analysis and eventual decoding of the emissions is a longer-term worry), but for stealthy assets the loss of the surprise factor can mean the difference between accomplishing their mission and having to abort as a result of enemy defences being pre-alerted and too dangerous to challenge (or worse, trying and dying).

Far from simply providing the friendly integrated air-defence system (IADS) an ambiguous heads-up or the general location of possible targets, modern systems can actually perform a substantial part of the detect-classify-track-



**Typical workstation consoles for the VERA-E system**

engage loop in complete electronic silence. This was amply demonstrated during the state acceptance trials of the advanced S-400 SAM system on the Kapustin Yar test range on September 2003. One of the test-firings involved using the S-400's ability for "late lock", the Russian equivalent term for lock-on-after-launch capability. A Kolchuga system fed the S-400 initial targeting information and the missile launch was performed in total EMCON. When the missile reached the target area, the radar was switched from stand-by to normal operating mode, and the engagement was successfully completed<sup>2</sup>.

<sup>2</sup> It is reasonable to assume that, against a maneuvering target, the S-400 battery would have to partially break EMCON in order to uplink course corrections and target updates to the missile(s). However, these emissions would probably be significantly harder to sniff than the very strong signal of the main phased array radar. Furthermore, the uplink signal, while a strong indication that missiles are in the air, does not provide a clear clue (to enemy RWR or ELINT systems) of just **who** is being targeted and should take defensive action. Therefore, a significant degree of tactical surprise is still maintained even in this case.



The series production of the Kolchuga system started in 1987, and since that time, system manufacturer Donetsk has produced 76 systems. Through January 1, 1992, under a Soviet order, 46 systems had been produced and introduced into Soviet service. Of these, 14 were deployed in Ukraine and were subsequently taken over by the Ukrainian armed forces, when the former Soviet republic became an independent state. After the collapse of the Soviet Union, Ukraine produced 30 more systems (both the Kolchuga and the improved Kolchuga-M), of which 18 were delivered to Russia, eight to Ukraine, and four to China. The systems in Ukrainian service have been replaced by newly produced Kolchuga-M.

Aside from these, an unspecified number of the systems produced under the aforementioned Soviet order were left in Ukraine after the collapse of the USSR, modernized, and sold to Ethiopia. An idea as to the number of the systems exported to Ethiopia can be deduced from the Ukrainian government's statement that the country currently has 19 Kolchuga sets, which might suggest that three were exported. (It is often misinterpreted that a "set" means a single Kolchuga station, but a set, or system, actually consists of four such stations – 3 snoopers and a central C2 node). Delivery of these systems to a country in the developing world, such as Ethiopia, makes it unlikely that their further fate can be traced with any great certainty, and it is technically possible that some of them could have been re-acquired by other interested customers.

The Ramona and later the Tamara systems were common in Warsaw Pact dedicated air-defence SIGINT regiments (usually one per country, except for the Soviet Union, which had numerous sets, both Czechoslovakian and domestically produced). Presently, Russia operates large numbers of Kolchugas (not to be confused with the more modern Kolchuga-M, presently offered by Ukraine). Another system, VERA-E is produced by ERA (a kind of "daughter company" of Tesla) and is being negotiated for sale to China, and the BORAP system is manufactured by Tesla itself. India is interested in purchasing BORAP systems, and talks are underway.

Ukraine was recently accused by US authorities to have sold four Kolchuga-M systems to Iraq through Jordan just prior to PGW-III, but since a single Kolchuga system consists of four elements, this could be a misunderstanding. It is not known whether the sale was of four full systems or four elements of a single system. However, the value of the transaction - \$100 million - indicates the latter. According to some reports, the system might have helped Saddam Hussein evade the "decapitation strike" from a US Air Force F-117A early in the air operation. Reportedly, the system was capable of detecting an approaching F-117A some five to seven minutes before the aircraft reached its target, enabling Hussein to evacuate the target zone just in time, before the attack was executed. This is technically possible and explains some early "misses," but the story is not fully confirmed.

If Iraq had indeed purchased a passive detection system like the Kolchuga, it need not have come from Ukraine. Many countries have worked extensively on such systems - four Eastern European countries among them. The Czech Republic, with its long-established experience (e.g., its Kopac, Ramona, and Tamara systems) currently offers no less than three: SDD, VERA-E, and BORAP. Poland has just developed and fielded on a limited scale its MUR-20 system, and Ukraine and Russia have their own such systems: Kolchuga and VEGA, respectively. All these systems are production rather than prototype hardware, and all have been fielded.

Interest in such systems has recently increased, as a result of their effectiveness in the management of air-defence systems in a heavy jamming (i.e. radar-eroding) environment. It has been reported (without any solid confirmation) that the use of such passive detection systems helped Serbian forces in shooting down a USAF F-117A over Yugoslavia in 1999, as well as badly shooting-up another one. Until recently, western tactical-level SIGINT systems (including the abortive and highly sophisticated PLSS) focused more on tracking ground forces (particularly HQ units and mobile SAM elements) than directly contributing to the immediate air picture. However, as part of the renowned interest in non-emitting airspace control techniques, western interest in this technological sector is likely to increase in the near future.

### **Advanced IR & EO sensors**

The concept of using infrared and electro-optical sensors to supplement radar is hardly new. Both superpowers had extensive practice with in the last 3 decades of the Cold War, albeit with different priorities. Such systems appear to be making a comeback in the race against VLO technology.

As explained in Part I, airborne stealth as a principle is by and large a radar-based arena, simply because radar has dominated the air-detection game for a good six decades now. While such aspects as IR, acoustic and smoke signature suppression are certainly being taken in consideration, RCS reduction is where the big bucks are spent. This in turn means that there are promising dividends to be delivered to anyone smart enough to hedge his bets and invest in detection methods that rely on other means.

The USAF deployed IR sensors on its F-106 interceptor aircraft and briefly the US Navy flirted with IR systems in the early F-4 versions, but these were dropped as the results were deemed insufficient to justify the expense. More successful were EO systems like the TISEO, mounted on numerous F-4E airframes, or the TCS which was a standard fit on most F-14B/Ds. US systems in general were not designed with VLO targets in mind; they were rather

oriented towards taking over in the case of radar malfunction/failure (not an unusual case in the 1950s/60s), and in the case of EO systems providing the very important positive ID at ranges practical for BVR engagements. The TISEO also offered increased magnification levels for Maverick missiles and other early EO-guided ground attack weapons. In the 1970s and 80s both the USAF and USN fielded a successful series of FLIR systems optimized for the recognition, tracking and (with an aligned laser designator) marking of ground targets; some of these demonstrated a secondary limited air-to-air capability.

The Soviets were early to adoptIRSTs specifically to counter US & NATO electronic warfare successes on the radar spectrum. Their PVO interceptors were fitted with primitive systems already from the mid-60s, and the remarkable MiG-25 paved the way for “silent” BVR engagements with the IR version of its monster R-40/AA-6 missile (of course, detecting and acquiring the weapon target in the first place was a different matter altogether). Far more capable systems were fielded in the late-70s and 80s on the new generation of fighters and interceptors the entering service. Systems such as the OLS-27 or OLS-M reportedly are able to track airborne targets reliably out to 30-50km depending on aspect and throttle settings.

IR and EO systems have also been deployed for some time on ground and shipboard elements. As with most electronics-based systems, it is generally easier to package such sensors in non-airborne sets as the weight, volume, power and cooling limitations are usually less strict. Again, the Soviets were quick to supplement their radar-guided SAM systems with back-up optical devices as the effectiveness of US SEAD systems and tactics became evident. While not sufficient to allow a fully silent engagement cycle<sup>3</sup>, they do offer the significant advantage of reduced duration of active emissions and thus (particularly when combined with good mobility) reduced vulnerability to enemy EW assets. The probability of a successful engagement is also increased as the target has a significantly reduced reaction time available. Modern systems such as the French Crotale NG or the Russian SA-15 or Panzir-S1 employ such sensors not as back-ups but rather as active consorts to their primary radar sensors. The Crotale NG goes even further, monitoring all three of its primary sensors (the Gerfaut radar, an EO/LLTV camera and an IIR array) concurrently and selecting in real-time the data deemed most reliable.

Until recently, most systems employing such sensors usually did so for reasons other than countering VLO targets. In the non-stealth context, an IR or EO sensor is useful where heavy ground/surface clutter is present (e.g. short-range SAMs with a requirement for engaging very low-flying targets), where the enemy is particularly effective in his EW & SEAD efforts, or in cases where a radar set of given volume, weight, complexity or cost parameters simply fails to meet performance specs. More recently, with the recognition of stealth aircraft as the new threat benchmark to beat, these passive sensors are regaining increased attention. This is augmented by significant improvements in existing tried-and-tested technologies, as well as new innovations.

On the infrared spectrum, for example, simpler spot-style IR seekers are well on their way of being superseded by imaging infrared (IIR) systems. Whereas a spot seeker will sense targets as blips of infrared energy (said blips being anything from valid targets to countermeasure flares to simply sunlight glinting off flat surfaces on the ground), an IIR seeker provides a TV-like image of the area being scanned. Naturally, this translates to an inherent ability to reject most false targets. Most recent IIR designs are also dispensing with mechanically moving, pointed sensor heads and instead adopting fixed-in-place staring arrays with very large fields of view<sup>4</sup>. Apart from the obvious benefits in mechanical simplicity and reliability, this enables them to track a specific target instantaneously and also track a large number of targets concurrently.

Neither is seeker technology the only sector of improvement. With older spot seekers “seeing” only blips of IR emissions, simple algorithms for tracking these spots were sufficient. With IIR seekers reaching maturity, however, acquiring and tracking targets is a more sophisticated process: how do you pick out an airplane out of a TV-like image? Humans can do it easily, but then again the human brain is still largely an unexplored miracle. Thankfully, the technology for image-based recognition existed already, from the neighboring EO sector: Early EO-guided bombs and anti-surface missiles like the Maverick were programmed to lock-on to high-contrast blobs on the screen, typically tanks or buildings. This basic technique was subsequently enhanced to take such parameters as background elements and the target’s apparent “shape” into effect<sup>5</sup>, and compare them with digital pre-stored data. We have now reached a point where EO/IIR seekers fitted on high-precision attack weapons like the SLAM-ER missile can fully autonomously detect targets, confirm them as “the” target and guide to attack. Anti-air seekers are similarly benefiting from this level of sophistication: A video clip of live-fire AIM-9X tests released by Raytheon about a year ago clearly shows the missile acquiring a QF-4B target drone and homing straight and true to the center of its fuselage (fitting seeker and computer electronics into the body of a Sidewinder-class weapon is in itself an engineering feat).

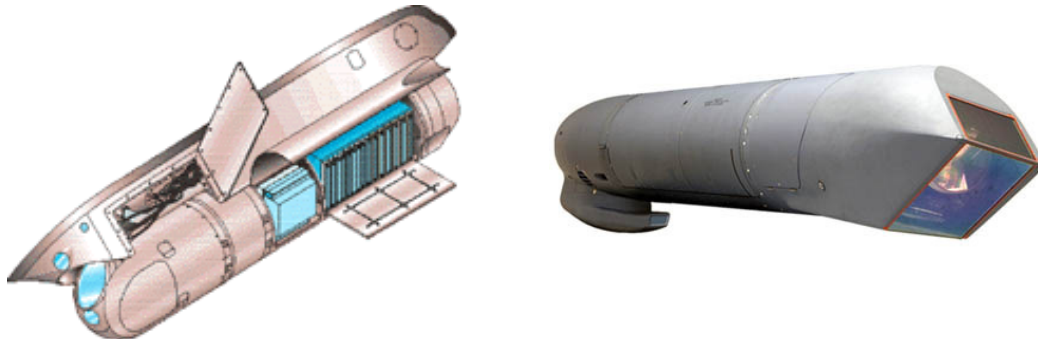
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<sup>3</sup> Unless the missile is fitted with a passive seeker for the end-game phase, as Iraq has recently done by fitting R-73/AA-11 seekers to SA-6 missiles.

<sup>4</sup> Narrow fields of view used to be a necessary evil in older IR seekers in order to avoid most random (or deliberate) interference outside the immediate area of the target being acquired. With IIR seekers being supported by intelligent image processing to clear-out invalid cues this is no longer a problem.

<sup>5</sup> Incidentally, much of the funding for automatic target recognition originated from the desire to automatically engage fleeting high-value targets like mobile Scud launchers, another mindset legacy of the 1991 Gulf War.

These technological advances allow IR/EO sensors to take over a much broader responsibility in the detect-track-engage cycle than before. While past systems had demonstrated a good capability to track airborne targets, they typically did so only after being cued to a relatively narrow piece of the sky from the radar, which almost always made the initial detection<sup>6</sup>. This reliance on radar is naturally a no-no when discussing usability against stealthy targets. Modern sets however, with increased FOV, range and IRCCM capability are able to handle the initial search & detection themselves, and at significantly greater ranges. This capability not only enables the application of a much more restricted EMCON state while searching for targets (e.g. normal-mode IR scan with only periodic, randomly-varied radar sweeps as a back-up), with apparent benefits in own-forces' EM discretion, but is also of particular importance when stealth-hunting.



**Advanced IR/EO systems like the ATFLIR (left) or the Sniper-XR (right) can significantly enhance the defender's ability to silently detect and track VLO targets at useful ranges**

Why is that? A common evasion tactic of VLO aircraft, for example, is to remain at strict EMCON themselves, track hostile emitters in dangerous proximity and then steer clear of them. But if the stealth-hunter can reliably search at meaningful ranges (i.e. more than a few km) without emitting, then the rules of the game change considerably. The VLO pilot can no longer be confident that his RWR shows him the whole picture; evading fighter patrols or nasty pop-up SAM threats becomes more a game of chance (of not stumbling upon them) rather than a logical exercise in detecting them at a nice, safe range and maneuvering around them. And the more silent hunters there are, the less the degree of confidence in success of penetration. Even if the stealth driver can get a better SA through external data-feed (e.g. a link from a friendly AWACS/JSTARS) to improve his chances, he will still be uncertain as to who, if any, has actually picked him up. A stream of fighters converging on his position is certainly a good indication – but what if his pursuer is smarter than that? What if the VLO aircraft is being silently monitored and deliberately left alone until it reaches a trap position? Again, more uncertainties. The more uncertain the VLO-employer's mission plan becomes as the result of such factors, the less likely he is to commit his (typically few, precious and hardly replaceable – not to mention their political price tag) silver-bullet assets to an operation. Thus the defender “wins” simply by presenting the possibility of being “out there”, watching silently – and this is arguably the greatest contribution of IR & EO systems in the counter-stealth arena.

## Tactics & Strategy

### Deny basing

Stealthy air assets, like any other aircraft, need a base or carrier from which to operate<sup>7</sup>. That home base itself is vulnerable to a preemptive attack. Be it by aircraft carrying airbase-denial mines, or by ballistic missiles spreading thousands of bomblets, or by cruise missiles impacting right at the doors of hardened shelters, the principle is the same and the benefits obvious. An airbase or carrier represents an unusually high concentration of targets, ripe for attack by a variety of weapons. While individual HAS-plinking, as in Desert Storm in 1991, may not be feasible without already-established air supremacy (unlikely when challenging an adversary with such advanced assets), there is still plenty of opportunity for attack.

A typical strike plan may involve tossing a few stand-off weapon dispensers on the runways to prevent alert fighters from scrambling, while concurrently showering the base's terminal defences and any perimeter SAMs with anti-radiation weapons or cruise missiles. Scenarios also exist where the arrival of manned assets follows a massive initial barrage of accurate ballistic missiles tipped with cluster and penetrator munitions. Subsequently, the main attack force can close on the base complex and target individual installations such as shelters, revetments, control towers and related facilities, fuel and munition dumps, personnel buildings and miscellaneous heavy machinery equipment.

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<sup>6</sup> This was true even for impressive FLIR systems like the LANTIRN or the AAS-38 Nite Hawk.

<sup>7</sup> Even the STOVL version of the JSF will not be able to operate for long from “parking lots” and other such oft-quoted sites without a major logistical train to support it.



While it can be expected that most or all stealthy aircraft will be protected by the hardest available shelters which will be very difficult to destroy in large numbers, most other facilities and equipment are significantly more vulnerable. Any aircraft's availability and sortie rate will suffer as a result of damage or destruction of a base's facilities. An aircraft that survived the strike but cannot be refueled, cannot be maintained, cannot be re-armed, cannot take off (if the runway is damaged) or has no pilot left alive to fly it, is almost as useful as one that has been destroyed on the ground. This will be even more so true for stealth assets, whose very sophisticated and expensive special maintenance, coating and calibration equipment is unlikely to be stored in anything more durable than a standard repair hangar or, at best, a spare shelter.

At the very least, inflicting significant damage on forward operating bases forces the stealth-using adversary to fall back on bases in further distances and substantially complicates his planning of air operations. Major mid-air refuelling assets have to be committed to allow the continuation of effective operations (and additional escorts allocated to their protection), sortie schedules have to be scaled-down to compensate for the longer ranges, airborne C4ISR units have to trade-off between proximity to the battle area and own security etc. All these factors are critical to the effectiveness of stealthy assets, and all are negatively affected. Thus, keeping the adversary at just a bit longer arm's length is a useful dividend of this method.

This wartime concept of basing denial has a peacetime or in-crisis equivalent. In the last decade, stealth assets have been used mostly from allied foreign bases in expeditionary mode, rather than their normal peacetime locations. If sufficient pressure is applied towards the host of such bases, both on the political and also on the military level (through overt and covert threats, "accidental" leakages of contingency plans for massive strikes against these bases with "every means necessary" etc. etc.), then it is quite possible that the base host may deny the use of the local facilities to the expeditionary force. An example of this method is China's frequent diplomatic pressure towards Japan regarding the use of Japanese bases by US forces. Another example might be the recent US-Turkish disagreement over the availability of Turkish bases to act as a springboard for a second US front in the Third Gulf War. Much like the wartime fallback to rearward bases, the peacetime uncertainty of availability of friendly bases forces radical changes in force structure and contingency operational planning.

To counter such problems, the USAF has proposed the so-called "Global Strike Task Force" scheme, under which a special expeditionary wing composed almost entirely of stealthy assets (F-117, B-2 and in the near future F-22 and JSF) and husbanded with miscellaneous C4ISR and support assets, will operate directly from the continental US and execute offensive operations (or, in the view of unofficial quotes, "kick down the door") anywhere in the globe within short notice. While the concept is theoretically possible, and its appeal to an air force becoming increasingly worried about the vulnerability & availability of its overseas bases is certainly understandable, there are still quite a few practical considerations into actually making it work. Trans-oceanic distances make timely target intelligence a problem, even with an abundance of reconnaissance assets. Aerial refuelling must be very carefully choreographed, particularly for the shorter-legged aircraft, and significant redundancies allowed (as was the case in such past examples of long-range strike ops as "Black Buck" or "El Dorado Canyon"), which again reduces the effective force size available. One of the biggest hurdles would probably be the crew endurance for the tactical aircraft – how combat effective is a single pilot going to be after an 8-14hr cruise to the target area? These and other concerns have to be addressed before the GSTF proves a definite response to the basing problem. In the meantime, basing denial in both war and peace remains an effective counter-stealth approach.

## Target non-stealthy combat & support assets

Despite the technological leaps of the last two decades, stealth technologies remain an expensive and complicated affair. This limits their applicability<sup>8</sup>. Stealthy assets are still the "silver bullet" force of a selected few airframes who undertake the toughest assignments. Stealth aircraft however do not operate in a vacuum; critical to their operational effectiveness is an entire mix of support assets such as C4ISR aircraft (AWACS, JSTARS, Rivet Joint, ABCC etc.), force-multiplier support aircraft such as tankers, specialized offensive assets such as SEAD escorts, as well as an entire series of older combat aircraft who



**An F-22 being refueled by a KC-135 tanker. AAR assets are few, precious and thus highly valuable assets to protect – and destroy. Stealthy assets owe much of their operational freedom to the airborne gas stations.**

<sup>8</sup> This is going to gradually change in the near-future with the introduction of mass produced aircraft that incorporate stealth technology (F-22, Eurofighter, Rafale, F/A-18E/F, JSF etc.). Notice however that all of these airframes are front-line fighters, not support assets.

flesh out the force. All these assets are non-stealthy and are likely to remain so in the near and medium term. They are thus far more vulnerable to attack.

To fully comprehend the importance of these units in the success of stealthy forces, one may simply ask: what happens if they are unavailable?

**C4ISR:** The loss of even a single AWACS or JSTARS or SIGINT platform over the battlefield immediately creates a gap in sensor coverage, particularly if the patrol sector is not covered by any other asset. This means tactical units have to step-in and temporarily take over the duty until another asset can be brought forth. Stealthy aircraft usually exploit their VLO property to roam about the battlefield in near-complete EMCON like silent predators, being fed data by external C4ISR platforms. Sticking to a tight patrol pattern and (by necessity) often emitting actively, even with LPI sensors, is definitely not their style of fighting and robs them of much of their operational freedom.



**Stealthy fighters may get the glory these days, but the workhorses who get most of the job done are still conventional fighters like this F-16C. Without them, VLO assets have to stretch themselves thin – possibly too thin.**

without at least a pair of EA-6Bs on a tethered leash. Air defences are naturally one of the prime enemies of stealthy aircraft (and any other aircraft for that matter). There are certain defensive networks so thick that even stealthy assets have a hard time slipping through; a SEAD escort can provide that extra edge that is needed to get the job done. If that help is not around, other ways need to be found – an extra problem for the VLO employer.

**Conventional non-VLO aircraft:** These are the “regular troops” that make the bulk of any air force. The need for them is evident when one considers the range of tasks that the AF has to perform at any given point: Anything from air patrols to aggressive offensive counter-air to interdiction to close air-support to reconnaissance etc. Until stealth technology becomes more affordable, the majority of the operations fulfilling these tasks will need to be undertaken by non-VLO assets. Not having these aircraft available means that the precious few stealthy assets have to “do everything”, in a sense. This not only significantly stretches their tasking schedules and adds to their maintenance requirements (with apparent results in their overall operational readiness), but also places them in predicaments and situations for which they are ill-suited and can lead to increased vulnerability: Imagine, for example, a squadron of F-35 JSFs having to do round-the-clock low-alt CAS with rockets and cannon strafe-passes (how many 23/30mm rounds to bring them down?) because there are no A-10s or helicopters in the theater. Or F-117s being forced to loiter above a highway, hunting elusive mobile targets, instead of doing what they do best: get in, strike and get out.

**Tankers:** Not being able to refuel in the air means having to return to the base as soon as bingo fuel level is reached (a significant amount if the base is distant). Again, this denies stealthy assets much of their freedom to move around the battlefield and reduces their edge. Stealth tactics often rely on weaving complex multi-waypoint routes around dangerous air-defence facilities to minimize the chances of detection; not having the gas to do that is a most undesirable situation.

**SEAD assets:** Many will probably recall that even the mighty B-2 did not operate over Kosovo



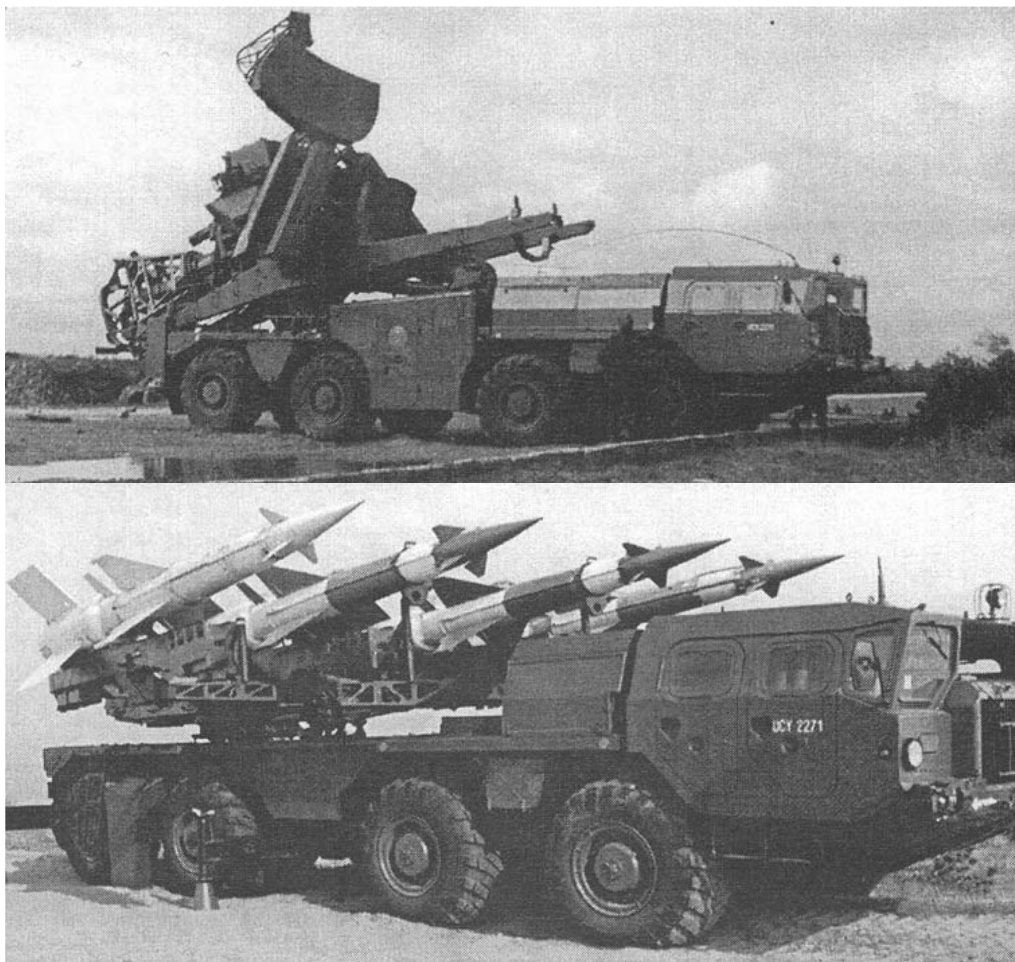
**The loss of specialised C4ISR platforms like the E-8 JSTARS can seriously hamper the operations of stealthy assets**

The exact method of targeting all these supportive assets can vary. They can be neutralized on the ground as part of a pre-emptive OCA operation or, alternatively, engaged in the air. While they can certainly be defended in the air (and may well be used as ambush baits), simply the existence of credible threat to them means that extra fighters need to be allocated to the task – aircraft that would otherwise be doing something else more productive.

## Restructure the air-defence network

The experience of the air campaigns of WW2 and their decisive effects shaped the structure of air-defence networks for the entire post-war period up to our days. Despite the great technological advances in the last 6 decades, the hierarchical, pyramid-style layout of a typical IADS has remained pretty much unchanged. There is usually a single national-level command center, which controls several regional centers, which in turn control many more sector-level centers, which ultimately then control the EW/GCI sensors and SAM/AAA stations, as well as fighters.

This layout has remained unchanged over the years for a number of reasons, system inertia and the expense of major restructuring being chief amongst them, but primarily because up to now it really did work. Any aircraft that attempts to



**Smart move: A complete SA-3 complex mounted on mobile trucks**

challenge the IADS is typically detected and engaged by the outer layer first. Survivors of the first layer who proceed deeper are then engaged by additional defences etc. It is very difficult to significantly penetrate the system without repeated clashes with the enemy defences – clashes in which the home team usually has the upper hand<sup>9</sup>.

The big shift in this picture came with the advent of VLO platforms and long-range, very accurate conventional cruise missiles. It was now possible to attack even the top nodes of the system without risk of attrition to the defensive layers. Alternatively, these “silver bullet” systems may selectively destroy certain parts of the IADS (or pull it apart

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<sup>9</sup> There were always certain exceptions to this. Accurate, long-range nuclear-tipped ballistic missiles (and conventional cluster-munition weapons in the 80s, at least against lightly armored targets) could destroy any node in the hierarchy without being subjected to defensive fire. This however was a doomsday scenario and thus not applicable to conventional air ops. Also, skillful low-level flight can allow a significant penetration without detection and engagement. However, this severely restricts the range of the aircraft and thus limits its attack options.



completely, if the resources are sufficient) in order to allow the rest of the air war complex to perform its tasks unhindered.

There are two prime reasons that these attacks on the IADS can be so spectacularly effective. One is the strict hierarchical structure of the system – a natural continuation of the traditional business layout, which is optimized for the quick and efficient flow of information, compartmentalization and adherence to a clear-cut chain of command. The second reason is that a modern IADS is typically composed of a very limited number of nodes, a consequence of the escalating costs of operating them. This means that every single node is much more capable than in the past (e.g. modern EW/GCI radars can effectively cover millions of square miles of airspace), but also far more irreplaceable. Though a certain degree of redundancy is not uncommon, it is far from enough to ensure the system's ability to absorb numerous losses and continue to function. As a result, quite often the selective destruction of even just one or two nodes can neutralize a significant portion of the system and make it far more vulnerable to follow-up attacks.

A textbook example of this approach was the Coalition air campaign against Iraq in 1991. The Iraqi KARI air defence system, although designed primarily with an east-west orientation (to face threats from Israel and Iran) was still a worrisome factor in the plans of the Allied air campaign. Its neutralization was thus given top priority, and it was accomplished within a very small amount of time. Following the destruction of a few key nodes of the system by cruise missiles, F-117 attack aircraft, SEAD aircraft and other less conventional means (such as AH-64 helicopters) the rest of the system saw its effectiveness plummet and was methodically exterminated as the remaining system elements were picked-off piecemeal.

Addressing these inherent vulnerabilities calls for a multi-pronged approach.

One method is to increase the mobility of the system nodes. A big part of SEAD operations is planning based on the available electronic order of battle (EOOB), i.e. the known locations and types of the active emitters comprising the IADS. If the nodes are fixed in place, they only need to be mapped once (a procedure much easier to perform against a fixed emitter). Afterwards, they're simply targets waiting to be attacked – again, a task much easier against fixed assets. Providing the system elements with increased mobility goes a long way in increasing their survivability as well as their operational effectiveness. For one, they're not sitting ducks anymore – striking a fixed installation is a lot easier than to hunt an equivalent target down the road. Just ask the frustrated F-15E aircrews that participated in the Scud-hunting operations in the Gulf, or the F-16CG pilots chasing around SA-6 batteries all over the rugged Serbian terrain. Moreover, being in unexpected places offers opportunities for surprise shots against overhead aircraft. Neither are the weapon elements the sole beneficiaries of movement; operation centers and command nodes of the system also benefit from the increased survivability of "living on the road", much as it reduces their communication options. It is hardly a coincidence that almost all air-defence systems under development or in production incorporate a high degree of mobility as a primary design spec. Older systems such as the SA-2/3 are also being substantially upgraded, simply by replacing the older electronics and mounting the launcher assemblies on top of various vehicle options instead of fixed sites.

Then there is the subject of the few, vulnerable, terribly expensive and near-irreplaceable system nodes, and of their restrictive hierarchy. Ideally, one might be able to replace them with a much denser network of nodes, each of them less capable (radars with smaller range, radio transmitters with reduced range, coverage and capabilities etc.) but much more affordable. The benefits of such a structure are that the elimination of any given node does not severely affect the system, thus providing far greater redundancy. Constructing such a dense network might seem prohibitively costly, but in reality the economies of scale are in the defender's favor, and the lower technological level required for each single element means that they can be mass-produced at total prices far lower than that of equivalent-coverage premium-tech systems.

Think of a 1000-km front being covered by just three big sophisticated radars evenly spaced apart (not an uncommon situation for many AD networks today). Taking out one of the radars leaves a 300-km wide penetration corridor, with no clear indication of where exactly in that space the enemy is going to attempt penetration. Now consider the same front covered by 50 rudimentary radars at 20km intervals. If one of them is taken out, there is immediately a good indication of where the attacker wants to push – and the loss of coverage is comparatively negligible. If nothing else, the attacker now has to strike at a much larger number of system nodes in order to create a sufficient breach to exploit – and each destroyed node acts as an "alarm bell" trip-wire that can cue the defender's mobile assets (such as fighters and AEW aircraft) to the likely positions of the intruders with a good probability of interception.

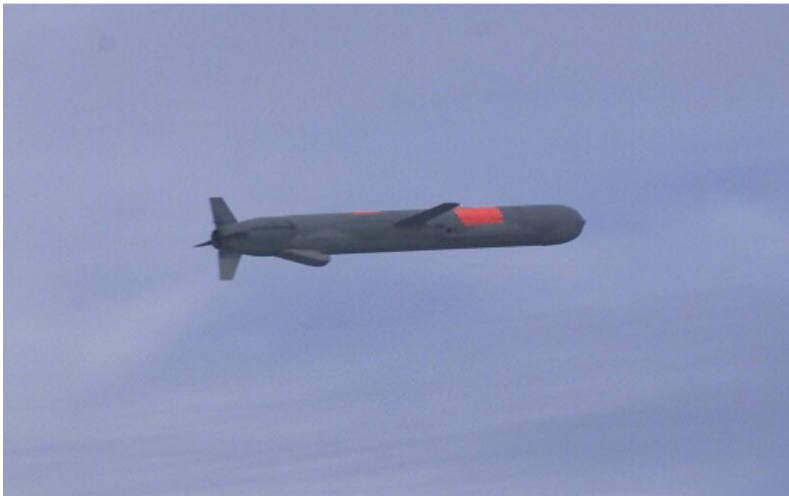
Breaking free of the restrictive hierarchical structure and the flow of information through specific comms channels is also a big factor in decreasing the vulnerability of the IADS to the selective neutralization of its critical elements. "Network-centric warfare", a concept of warfighting that covers every branch of the armed forces and emphasizes an Internet-style multi-routing data flow, is seen as a key direction towards this goal<sup>10</sup>. As a Lockheed Martin executive comments:

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<sup>10</sup> An extensive presentation of the application of network-centric techniques on air-defence networks can be found on JED's May 2001 article "Good Move" [www.jedonline.com](http://www.jedonline.com)

*"The wave of the future as we see it what we're calling 'sensor-centric networking' or 'network-centric warfare'. If you are networking sensors, you are giving them - almost by definition - built-in survivability, because you don't have any one critical node that can be knocked out [that will bring down the system]. You have sort of a broadcast of all sensor information and the appropriate headquarters of the appropriate agencies that are going to take action in an air-defence role are getting that information through various [redundant] channels."*

More intelligent emission control (EMCON) is also key to increasing the system's effectiveness. In the 1991 air campaign, Iraqi SAM crews tended to continuously emit their systems, thus advertising their presence and location – until destroyed by Allied SEAD efforts or forced to shut-down under the overwhelming threat of overhead HARM-shooters. Fast forward to 1999, and the Serbian army's air defences gave Allied air forces a much harder time not by better hardware but simply by much more sophisticated tactics. Mobility was a key factor – indeed, the vast majority of legacy fixed sites in the Serbian inventory (mainly fixed SA-2 & SA-3 batteries) were quickly eliminated, while their mobile counterparts survived the air campaign in significant numbers. Another factor was the careful coordination of emissions between different sensors so as to minimize each individual unit's transmission time while at the same time providing the maximum coverage possible. One mobile radar would transmit for a while, and then it would shut down, pack up and leave in a hurry, the coverage responsibility of its sector being taken up by someone else. This presented NATO EW operators with a constantly changing EOOB which was much more difficult to keep updated than in Iraq.



**Accurate conventional cruise missiles like the US Tomahawk, in consort with stealthy strike assets, marked the beginning of the end for traditional-structured AD networks**

In fact, the operating methods and performance of the Serbian IADS during operation "Allied Force" provided a strong model for future IAD networks that have to deal with advanced adversaries, including stealthy assets. Coupled with Serbia's rugged mountainous terrain (contrasted to the flat desert plains of the Middle East) which made active tracking of the mobile ground units a tough assignment, the task of eliminating the Serbian IADS was never fulfilled in a manner similar to the Desert Storm triumph. Indeed, the continuing active presence of the IADS and the threat it represented forced significant shifts in the air operations; for example, allied aircraft rarely operated under 20000ft, the limit of the coverage envelope of the majority of the Serb mobile SAM systems. Stealthy assets suffered from this as well.

The case of the F-117 shoot-down is well-known; the Serbs combined the increased mobility of their assets (probably SA-3 conversions plus mobile AAA), careful EMCON, sound tactical thinking and a good deal of luck to bring down an aircraft which, by common sense, should be untouchable to their AD resources. Another F-117 was badly shot-up and had to abort its mission. B-2 bombers, commonly advertised as being able to operate completely autonomous (with no EW/SEAD support and no fighter escort), actually always flew escorted by both heavy SEAD assets (EA-6Bs husbanded from the USN) plus fighter protection just in case. Overall, NATO pilots were never "Iraq-confident", and frequently had to operate in altitudes that hindered their effectiveness at locating and engaging targets<sup>11</sup>. The results of the air campaign (limited damage to Serbian ground forces, lots of decoys hit instead of real targets, many misses etc.) reflected this.

## Exploit windows in the availability of VLO forces

Current operational stealth aircraft still represent the first few generations of VLO technology. As already emphasized, they are still too expensive, and too maintenance-intensive. This limits their sortie rate, leaving significant availability gaps in their task scheduling unless a huge number of them is present in-theater (again an unlikely case). A clever adversary will likely attempt to fully exploit these opportunities when not many (or even better not any) of those precious assets are in the air. Ideally, information on the operational status of these birds will originate from real-time intelligence sources such as pre-inserted special-forces teams, high-resolution reconnaissance satellites or tactical signal-intelligence units. This can allow for sufficient time to quickly coordinate actions of opportunity by employing own assets deliberately set aside on moments-notice readiness, e.g. strike aircraft already in the air or missile platforms in launch positions. It is up to the air-ops commander to decide exactly how the window of opportunity is to

<sup>11</sup> This was particularly true in the case of mobile targets such as tanks, trucks, mobile SAM elements etc., because no weapon similar to the JDAM GPS-guided bomb that could engage them, and high-altitude LGB attacks were troublesome as a result of targeting pod limitations and frequent heavy cloud cover. One can only hypothesize about what could happen if this air operation had to be performed a few years earlier (with no all-weather PGM capability available to NATO at all, except for cruise missiles).

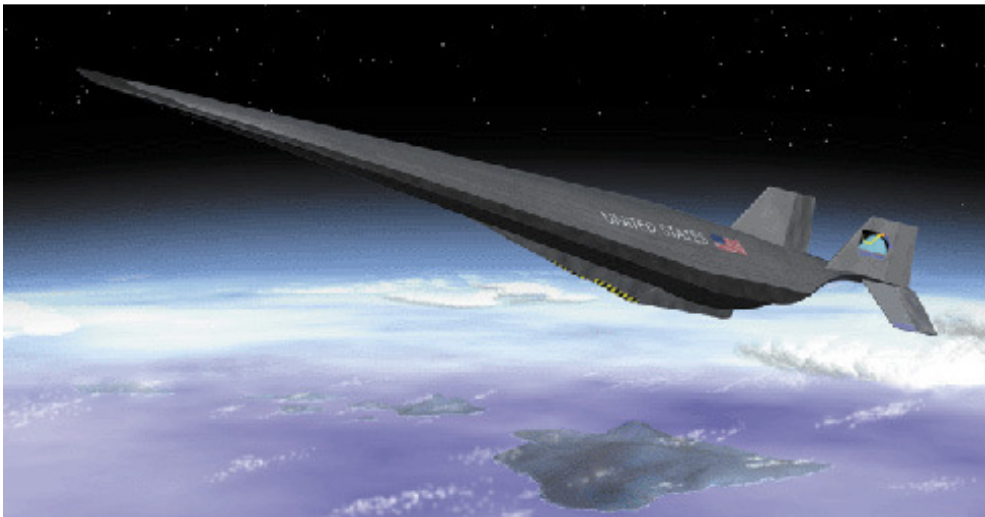
be exploited: Will friendly forces be used to their full effect against pre-planned targets without fear of being massacred by invisible interceptors? Will the enemy's non-VLO air assets be given high priority, in order to reduce the support environment that his stealthy aircraft normally enjoy? Or will the grounded silver-bullets themselves be targeted? The answer obviously hinges on the dispositions, status and sensor coverage of friendly and enemy forces, and the opportunities that these create. An E-3C patrol guarded by F-15Cs instead of the usual F-22 escort, for example, presents an interesting target – still a tough nut by any standards, but less of a suicide mission than before.

Of course, the accuracy of the provided intelligence is of critical importance for such a technique to work. An artful employer of VLO assets may well go the extra mile of deliberately providing false cues as to the status and whereabouts of his forces, and then spring a number of traps by luring his adversary into “target of opportunity” areas that in reality are pre-selected kill-sacks. To follow the previous example, placing a pair of F-22s offset well back from the E-3 & F-15 group can form such a trap quickly. A group of fighters detecting only the AEW bird and the non-VLO escorts is likely to be tempted to come-in blazing for a quick AWACS-kill; only to find themselves trapped-in and outmatched as the E-3 pulls back and the Raptors and Eagles dash forward. Like many aspects of warfare, this is a chess match of moves, countermoves and their endless variations.

## The Future

As we saw, stealth appears set to gradually follow the timeless pattern of novel war principles, a cycle that has been repeated in the past with concepts such as the airplane, the armored warship, the tank, the submarine, the nuclear weapon etc: Initially the “new way” is met with resounding success, as there is virtually no counter for it in place, and is frequently hailed as the precursor of a revolution in military affairs (said revolution sometimes indeed happening, and sometimes not). Subsequently, as the lessons of its initial uses sink in, solutions to dealing with it are explored and at the same time its operational use is refined. Eventually, the new principle finds its true niche within the art of war

and becomes one more arrow in a full quiver, rather than the silver-bullet as originally envisioned.



**A possible view of the future: the HyperSoar bomber**

An interesting shift in counter-stealth research in the last few years is the visibly increased western attention in the field. This is hardly a surprise when one considers that, until quite recently, the west held a decisive advantage in SEAD, VLO and cruise missile technologies, all resulting from its superiority in electronics

and miniaturization. As this gap however tends to shrink, western military branches increasingly find themselves faced with potential threats that may employ such technologies against them. Little wonder, then, that technologies such as passive/covert radar systems or advanced long-range IR sensors are being generously funded. Hard details on VLO programs in the east are usually hard to come by, but what is known is enough to cause interest – and in some cases unrest. Technologies such as plasma-stealth and active cancellation, prototypes with a clear LO inclination such as the S-37, MiG-1.42 and even the still-shady J-10 and high-precision strike systems like the latest generation of Russian, Chinese and Indian missiles are a clear indication of things to come.

At the same time, technologies previously reserved for high-value or silver-bullet forces (primarily due to cost and complexity) are gradually trickling down to even-wider portions of the air forces. Fitting phased-array radars to light combat aircraft or advanced trainers was an absurd idea a decade ago for example, yet it is actively considered nowadays. Similarly, stealth will likely find its way into such aircraft classes as multi-mission and C4ISR platforms, transports, utility craft and maybe even trainers. At this point, no doubt having lost much of its still-present glamour, it will have to compete with other principles that may yet be beyond our grasp. Interestingly, the next “darling” principle may not have to be something completely new, but rather a novel way of re-visiting already established priorities. For example, the USAF is currently exploring the options for a future endo/exoatmospheric hypersonic bomber, perhaps an indirect admission that stealth alone will not cut it in the future. Going retro with the B-70/F-108 idea? Time will tell.

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