Trends in Electro-Optical Electronic Warfare

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ABSTRACT

Protection of military aircraft from hostile threats is paramount to ensure the survivability of aircrews, platforms, and mission success. While the threat environment continues to become more complex, shrinking defense budgets places new challenges on the development of electronic warfare (EW) systems. This paper presents the trends in electro-optical EW system development including 1) features, 2) affordability, 3) open architecture, 4) multi-functionality, 5) integrated avionics survivability equipment, and 6) enabling technologies for sensors, and optical sources. While these system attributes are not new, they have grown in importance in the design of EW systems. And, if treated correctly can have a beneficial symbiotic relationship to each other and to the airframe they support.

1.0 Introduction

In the past, more specifically during the Cold War era, development programs were typically large and lengthy development efforts, including platforms like the B-1 (Figure 1), B-2 (Figure 2), missiles such as Minuteman, Pershing, and MX (Figure 3), atomic weaponry (Figure 4), very high energy directed energy (Figure 5), and other large complex and expensive endeavors. Many EW programs during this timeframe struggled to meet program budget and schedule. As an example, the B-1B EW system weighed ~3,000 lbs and cost as much as an F-16 of the day. While on this specific platform the airframe, engines, and multi-mode radar systems were all on budget and schedule, the early EW system development significantly overran the budget and unfavorably marked the entire B-1B program. EW systems of the Cold War era often had very lofty performance requirements as part of detailed technical specifications, rather than being performance based to support successful mission completion.

Figure 1. B-1 Bomber [1]

Figure 2. B-2 Bomber [2]

Technologies for Optical Countermeasures IX, edited by David H. Titterton, Mark A. Richardson,
Proc. of SPIE Vol. 8543, 854302 · © 2012 SPIE · CCC code: 0277-786/12/$18 · doi: 10.1117/12.978652

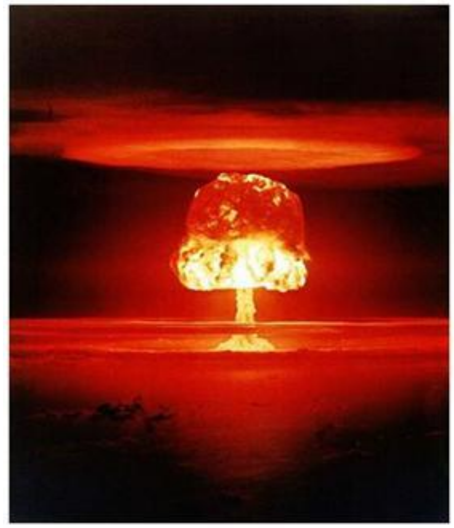

Figure 3. MX Missile [3]

Figure 4. Castle Romeo Atomic Weapon Test [4]

Figure 5. Airborne Laser (ABL) [5]

2.0 Change is Continuous

During the Cold War, EW equipment was known as "penetration aids. Their purpose was to get platforms and payloads through elaborate fixed enemy defenses. As time progressed, battlefield, tactics, the enemy, and equipment used in both offensive and defensive capability continually changed. This change, typically driven by technology or innovation, has resulted in what is known as "asymmetric warfare," where one side's arsenal and capability differs greatly from the other. Two interesting and historic examples are: 1) the Battle of Crecy in 1346 and 2) the Soviet invasion of Afghanistan during the 1980's. In the battle of Crecy, an army of English longbowmen defeated Genoese crossbowman through the longbow's superior range and greater rate of fire [6]. The second, and one of the best examples of asymmetric warfare of the century, was the Soviet invasion of Afghanistan where US provided Stinger missiles to the mujahedeen fighters changed the course of the war in favor of Afghanistan [7]. Without question, the Stinger had an immediate military impact. Although initial estimates may have been exaggerated with claims that the Stinger downed an aircraft per day during its first three months of deployment, the missile clearly represented an enormous qualitative improvement in air-defense capability. Previous mujahedeen anti-aircraft technology fielded paled in comparison. The Oerlikon required "twenty mules to transport making the weapon more a liability than an asset [8]." The Blowpipe which arrived in 1986, “was a disaster [9]”, during one engagement thirteen missiles were fired at exposed enemy aircraft without a single hit, “a duck shoot in which the ducks won [9].”

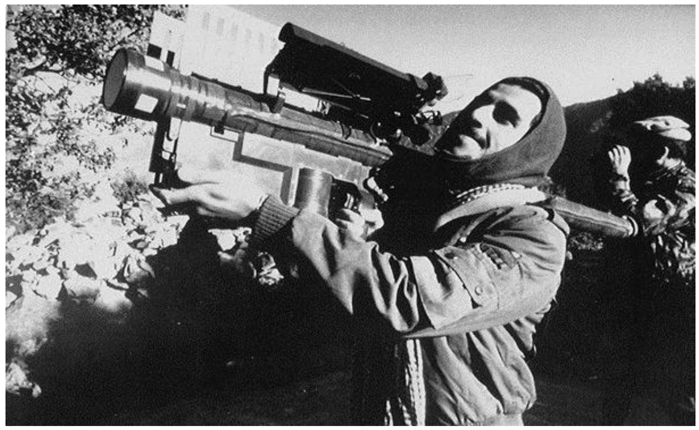

Figure 6. Mujahedeen gunner mounting a Stinger Missile [7]

The Stinger missile unquestionably shot down Soviet aircraft at an unprecedented rate in its first few months of use. The final outcome of the Afghan War was the emergence of man portable air defense systems (MANPADS) and their increasing use in the battlespace. MANPADS are low cost, plentiful, easy to use, and highly effective.

As technology advances, so does the capability of our adversary’s threat systems. Unlike the Cold War era, today technology advancements are most often driven by commercial and consumer product development applications versus military system development. The computer industry and personal electronic devices are two examples of significantly increased performance, radical size reduction, and multi-functionality, all at a reduced cost and with improved reliability. Implementation of emerging technologies for electro optical EW systems can provide significant capability expansion and performance improvement at a reduced cost. However, technology maturity and implementation risk must be well understood and mitigated by the system design team.

4.0 Emergence of the MANPADS Threat

MANPADS were originally developed to provide military ground forces protection from enemy aircraft. Notably, they have received a great deal of dubious attention as potential terrorist weapons that might be used against commercial airliners. These threats, affordable and widely available through a variety of sources, have been used successfully over the past three decades both in military conflicts as well as by terrorist organizations.

Twenty-five countries, including the United States, produce man-portable air defense systems. Possession, export, and trafficking in such weapons are, officially, tightly controlled due to the threat they pose to civil aviation, although such efforts have not always been successful. Figure 7 shows the evolution of MANPADS threats from the 1960’s towards the future.

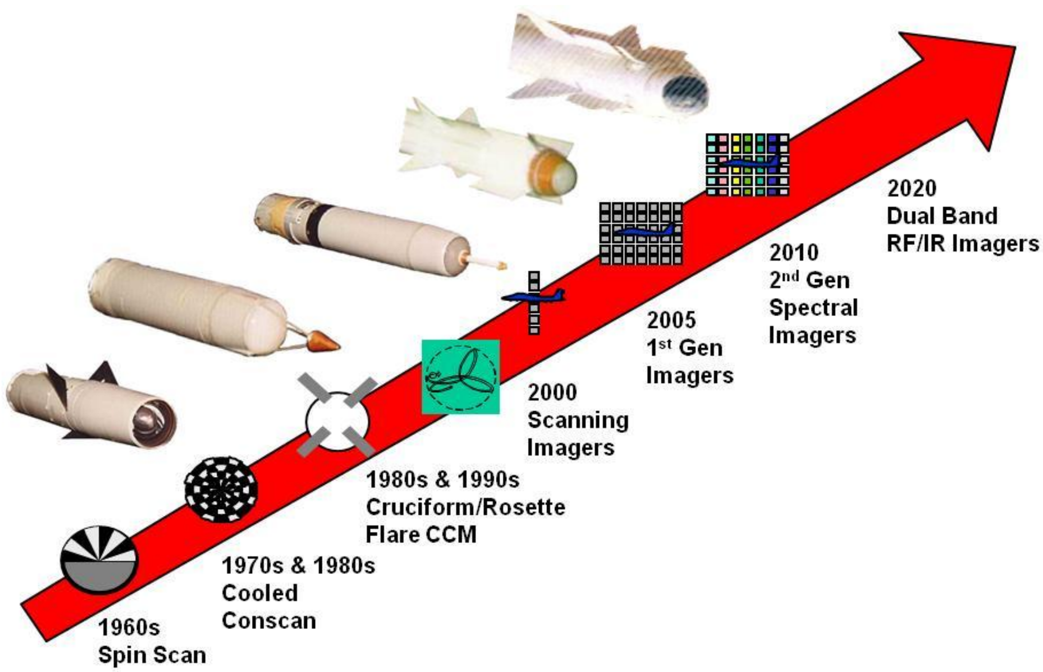

Figure 7. Evolution of MANPADS Threats [18]

Typically, the missiles are about 1.8 m (5 to 6 ft) in length and weigh about 18 kg (35 to 40 pounds) depending upon the model. Shoulder-fired surface to air missiles (SAMs) generally have a target detection range of about 10 km and an engagement range of about 6 km, so aircraft flying at 20,000 feet or higher are relatively safe.

4.1.1 First Generation Threats

First generation MANPADS are the U.S. Redeye, Figure 8, and early versions of the Soviet SA-7, Figure 9. All are considered "tail-chase weapons" as their seekers can only acquire and engage after an aircraft has passed the missile's firing position. Here, the aircraft's engines are fully exposed to the seeker and provide sufficient thermal signature for engagement. Also, these first generation missiles are highly susceptible to thermal background sources which many may make them somewhat unreliable.

Figure 8. U.S. Redeye SAM [19]

Figure 9. Soviet SA-7 SAM [20]

4.1.2 Second Generation Threats

Second generation MANPADS such as early versions of the Stinger, Soviet SA-14 [15], Figure 10, and Chinese FN-6 [16], Figure 11, use cooled seekers which enable IR background suppression as well as head-on and side-on engagement capability. These threats may also employ Counter-Countermeasures (CCM) to defeat decoy flares and may have backup target detection modes such as ultraviolet (UV); found on several missiles.

Figure 10. Soviet SA-14 SAM [21]

Figure 11. Chinese FN-6 SAM [22]

4.1.3 Third generation

Third generation shoulder-fired SAMs include the Russian SA-18 [17] and the U.S. Stinger B [18], shown in Figures 12 and 13 respectively, may utilize single or multiple detectors to produce a quasi-image of the target and also have flare recognition and rejection capability. While not true imagers they do rely upon the ability to distinguish an extended target from a point target.

Figure 12. Soviet SA-18 SAM [23]

Figure 13. Stinger B SAM [24]

4.1.4 Fourth generation

Fourth generation missiles include the Stinger Block 2, and several missiles believed to be under development in several countries that could incorporate 2D focal plane array guidance systems and other advanced sensor systems which will permit engagements at greater range. Conservative estimates place the number of MANPADS threats at over 1,000,000 worldwide [19], making MANPADS the preferred weapon of choice due to their operational simplicity, low cost, availability, and transportability. These threats can be found anywhere high value aircraft operate and truly represent a significant risk to all aircraft.

5.0 IRCM Technology and Growth

Infrared countermeasure (IRCM) systems can be grouped into two sub-categories, proactive and reactive and include flares, broadband jammers, and directed IRCM. As such, each has its own unique source requirements. Flares, or expendable countermeasures, which act as seduction decoys, are typically used with a missile approach warning sensor to declare the presence of a threat. Flares are then dispensed to decoy the approaching threat away from the target aircraft; Figures 14 and 15 show flares being dispensed from aircraft. Here, it is important to consider that flares, as an expendable countermeasure, have a limited capacity, and, once expended, so is the protection they provide.


Figure 14. Large platform expending flares [25]


Figure 15. Helicopter expending flares [26]

Early broadband jammers typically used resistive heater elements (hot bricks) or hyalide arc lamps to provide protection. In this case the source is modulated to deny the threat the ability to optically lock on to the intended target, thus, denying acquisition. Typically, hot brick sources are resistive heated elements which emit in the principal IRCM bands, typically un-modulated, and with the spin-by-carrier provided by a mechanical chopper assembly. These sources are typically employed in older pro-active architectures denying an adversary the ability to make lock on an intended target. Arc lamps are an extension of "hot brick" technology and bridge the operation between both pro-active and reactive architectures. Depending upon architecture, they may have capability to defeat threats pre and post target lock. Figures 16 and 17 depict some typical systems employing resistive heater and arc lamp technology.


Figure 16. AN/ALQ-144 IRCM System [27]


Figure 17. AN/ALQ-157 IRCM System [28]

Each system produces a pattern of pulses that is approximately synchronized with the rotation rate of these older seeker reticules. If sufficient energy is provided before the missile locks onto the target, it prevents the operator from firing the missile at the aircraft. If launch occurred, the directed energy steers the missile away from the aircraft and crew.
With continued advancement in missile warning sensor (MWS) capability and the ability to achieve high angle-of-accuracy handoff, new concepts in directed infrared countermeasures (DIRCM) became possible. A typical modern day DIRCM system consists of several MWS's to detect the threat launch; a turret containing a fine track sensor (FTS), and the IRCM source. In operation, the MWS on the platform detects the threat missile launch. Threat position is localized to within a few pixels on this MWS. This data is provided to the DIRCM processor for assessment and threat validation. Upon confirmation of threat, the system processor instructs the turret to slew to the threat position where a FTS contained within the turret acquires the threat and tracks the engagement. Finally, the IRCM source transmits jamming energy, disrupting the missile guidance, resulting in optical break lock and defeat of the incoming threat. Lasers serve as the source of transmitted energy for today's DIRCM systems.

Lasers represent probably the single greatest advancement in IRCM source technology and continue to evolve to meet ever more sophisticated threats. Lasers have been used with great effect in all modern IRCM systems and have evolved from frequency doubled CO2 lasers, to solid state lasers with optical parametric oscillators to generate the wavebands of interest, to semiconductor lasers including optically pumped semiconductor lasers and quantum cascade lasers (QCLs); these last devices represent the next breakthrough in IRCM source technology offering all-band coverage, architectural simplicity, significant reliability over conventional laser approaches and reduced cost. Lasers are typically used in reactive IRCM system where their small beam divergence ensures rapid and effective threat defeat at standoff ranges.

The advent of high quality non-linear optical materials enabled solid state lasers to operate in all wavebands of interest, hence, comprising the total IRCM spectrum. These devices signaled a paradigm shift in IRCM away from omni-directional to highly-directional. Figure 18 depicts Northrop Grumman's VIPER all-band IRCM laser and Figure 19 depicts Northrop Grumman's latest production DIRCM system showing several missile warning sensors, processor unit, control indicator unit, and mini-pointer tracker assembly with mounted Viper laser.

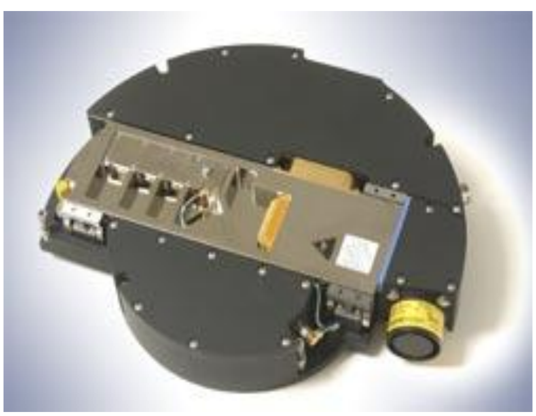

Figure 18. Northrop Grumman Viper Laser [29]

Figure 19. Northrop Grumman DIRCM [29]

5.0 Aircraft Survivability Equipment

EW is often referred to as “Aircraft Survivability Equipment (ASE),” and is no longer just an aid to weapons delivery. Radio frequency (RF) countermeasures and DIRCM are critical subsets of the platform ASE. The lethality of IR mobile and man /portable weapons systems has increased the need for DIRCM. Self protection in this spectrum is nearly mandatory for both non-strike aircraft and combat aircraft. While currently in use on transport aircraft (Figures 20 and 21), reconnaissance aircraft (Figures 22 and 23), and combat aircraft and helicopters (Figure 24 and 25), next generation ASE may find itself used on UAVs (Figure 26 and 27) due to their ever increasing cost and as a means to ensure mission success in areas of hostile fire.


Figure 20. Large Transport Aircraft [10]


Figure 21. Large Transport Helicopter [11]

Figure 22. AWACS [12]


Figure 23. Wedgetail [13]


Figure 24. AC-130 [14]


Figure 25. Blackhawk Helicopter [15]

Figure 26. Firescout UAV [16]

Figure 27. Globalhawk UAV [17]

5.1 Integrated Aircraft Survivability Equipment (IASE)

There is an evolving requirement to provide the war fighter with integrated solutions to improve battlespace situational awareness (SA), aircraft survivability, and mission effectiveness. Selectable and actionable data for the aircrew is essential to make critical decisions in theatre. Future IASE will be comprised of system solutions emphasizing modular open system architecture (MOSA), reduced size, weight, and power (SWaP), multi-functionality, and digitally interoperable approaches for data dissemination across the battlefield. System designers must explore solutions to short term requirements via rapid integrations such as enabling threat correlation or mission data recording. Customers and industry will need to work collaboratively to identify mission gaps and potential solutions through trade studies supported by digital modeling and simulation.

The ultimate goal is development of platform agnostic, fleet wide solutions whether one is a systems integrator or a sensor/system provider to develop affordable, rapidly deployable effective solutions. At the core of the platform agnostic approach is aircraft survivability. Pilots need to know their aircraft and crew are protected from any hostile threats ranging from SAMs guided by radar, MANPADS, laser guided threats such as beamriders, and hostile fire threats including rocket propelled grenades (RPGs), AK-47s, or anti-artillery aircraft (AAA). Pilots need to be able to plan a mission, fly into their intended objective area, perform their mission, and return to base safely with minimal interruption or risk to their flight due to threat of engagements by hostile forces.

Net centric operations and digital interoperability bring SA to the ultimate level. With several advanced systems being deployed, operators are in need of seeing the benefits of these systems across the battlespace. For example, if a terrorist shoots a MANPADS at a helicopter and the on-board system is able to geo-locate the threat, counter it, and act on it, the warfighter must have the option to return counter-fire immediately. Continued effort is required to network the battle space in order to provide the necessary information to the pilot, the troops in the back cabin of a helicopter, to a fixed wing jet flying a close air support mission, to the soldier on the ground, and ultimately to the commander in the Tactical Operations Center (TOC).

All of these key points roll into an integrated aircraft survivability suite that is able to ingest aircraft survivability data, correlate, fuse, and identify the threat. This is required to allow the system to optimize the countermeasure, and then push the information to the cockpit display or off-board the information to another platform, as shown in Figure 28.

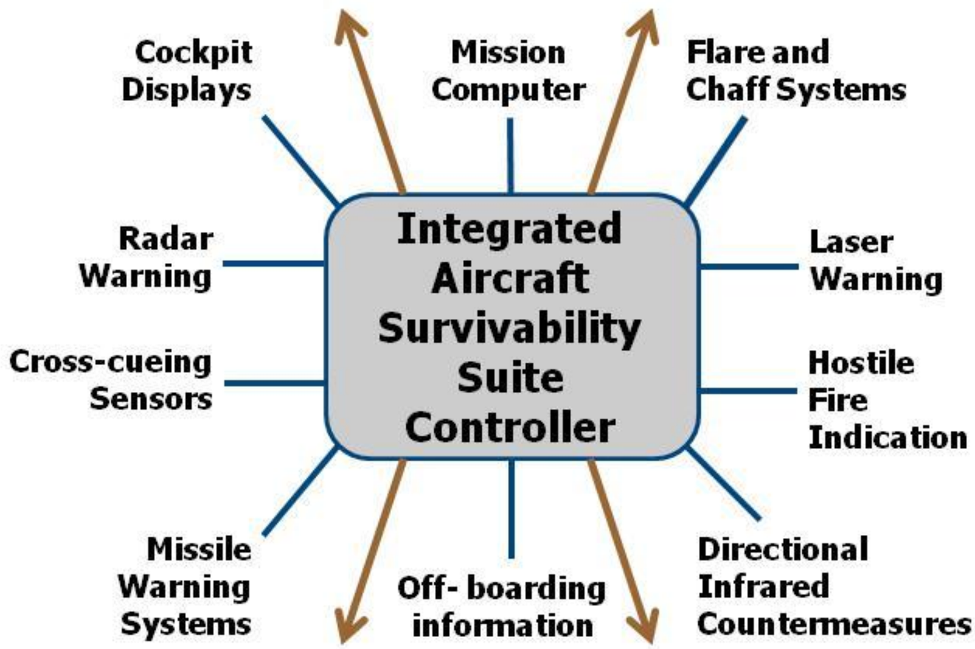

Figure 28. Integrated Aircraft Survivability Equipment Architecture

As defense budgets continue to shrink, there is a greater need to do more with existing systems. The challenge is to create exceptional new capabilities while doing so in an affordable manner. By using an integrated aircraft survivability architecture that relies on software to connect deployed systems and subsystems, designers are able to meet those needs. Additionally, since there are a declining number of large programs of records within the industry, system designers need to find innovative ways to showcase these capabilities. There have been several field exercises and demonstrations conducted across industry with industry partners and customers working collaboratively together to demonstrate what is possible with existing systems. Two such demonstrations and field exercises are shown in Figures 29 and Figure 30. As depicted, integrated aircraft survivability is possible today. By using the guiding principles of MOSA and interoperability, an integrated, affordable solution with improved SWaP is available to the Warfighter.

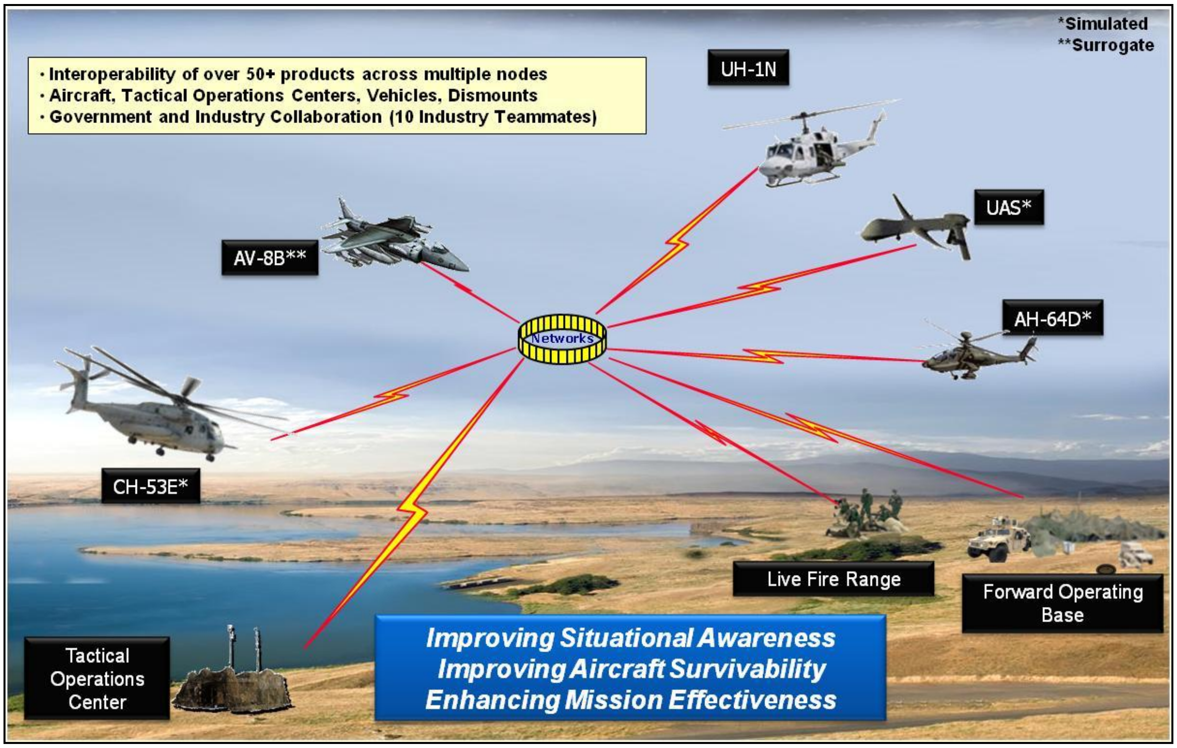

Figure 29: Digital Interoperable, Integrated Aircraft Survivability

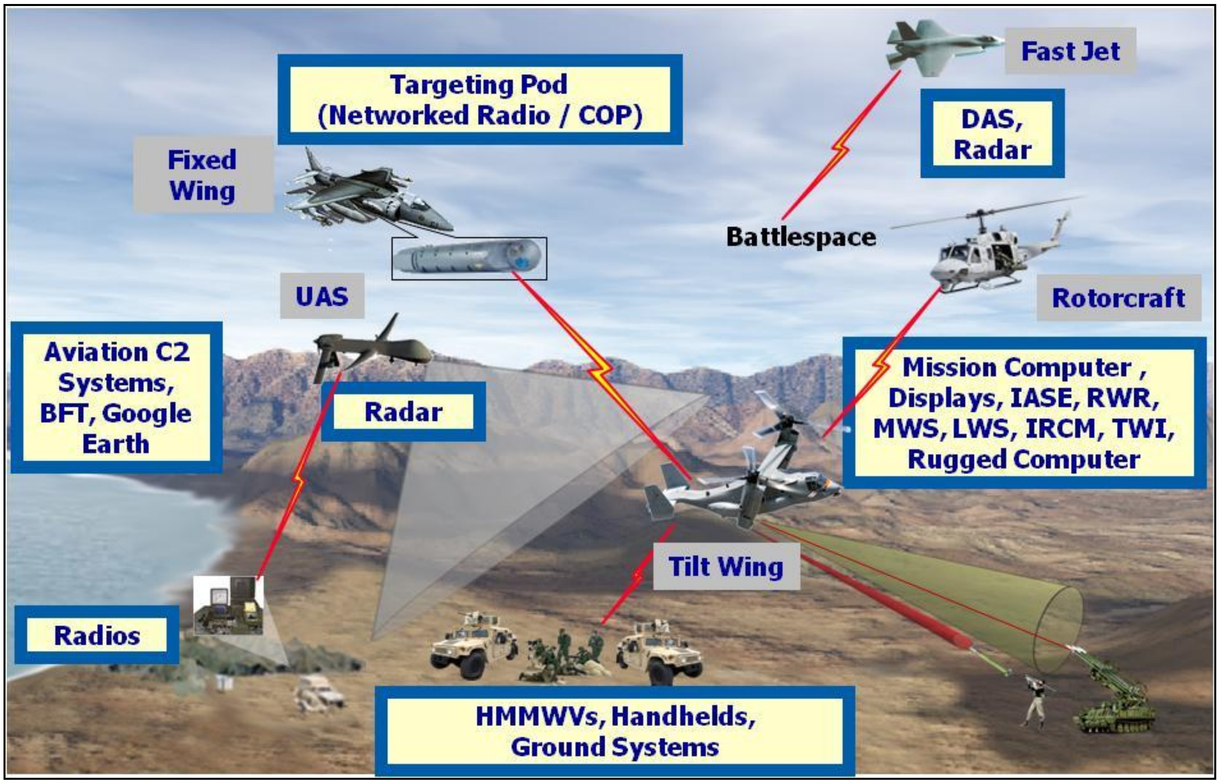

Figure 30: Advanced Integrated Aircraft Survivability Equipment

6.0 New Direction: Affordability & Multi-functionality

During the 1980's and 1990's, many countries and customers were willing to pay for world class performance supported by the latest technology. Over time, many cost saving measures were made by customers to reduce cost and cycle time (e.g. reduction of military specifications, utilization of commercial components and hardware.) Cost as an independent variable (CAIV) and design to cost (DTC) started to enter into the system designer's vocabulary, but never really held the same level of importance as performance. These changes, while significant at their point in time, do not meet the current need of our customers. The global economy has had a widespread impact, including the defense industry. Many countries have experienced, and are forecasting several additional years of economic hardship or challenge. The US Department of Defense has recently published documents requiring increased buying power, greater efficiency and productivity in defense spending. These latest initiatives in acquisition reform will impact everyone in the defense industry.

As a result, we are entering an era of "technically acceptable, lowest cost" for our EW system solutions. Many future programs will settle for the 80-90% solution to be affordable, meaning the customer will sacrifice some level of performance for significant cost reduction. Program risk (schedule, cost and technical performance achievement) is also a key factor. The customer community recognizes that high risk often results in program cost overruns and schedule extensions, both of which can result in program cancelation, especially in today's economic environment.

Future programs will benefit from a modular open system architecture, utilizing industry standard interfaces. MOSA supports system scalability and allows for spiral upgrades in system performance as new technology matures to an acceptable level for implementation and fielding. This helps protect the Customer's system investment over time so that necessary upgrades are possible to defeat emerging threat systems. Standard interfaces allow more members of industry to compete for the business, naturally driving prices of components, subassemblies and systems down. The inherent modularity in this approach allows for common building blocks. Common hardware supports volume discounts in pricing. The building blocks can be configured for specific platform needs, avoiding over designing/over performance for some applications while striving for economies of scale from commonality. MOSA also protects the system designer and Customer from diminishing material source (DMS) issues that naturally occur over the life of the system.

Multi-functionality is another way to reduce cost and SWaP, while improving reliability. An example of this is the multi-functionality available from infrared MWS's. While the primary role of the infrared MWS is missile warning, the sensor is available for situational awareness when not involved in a missile engagement, which is most of the time. Through technology infusion and innovation, the same sensor can be expanded to add laser warning and hostile fire indication (HFI) capability, therefore significantly reducing SWaP associated with other subsystems on the aircraft. The goal is to accomplish this task in the same footprint and interface requirements as the original sensor, avoiding very costly aircraft modifications. An example of this multi-functionality integrated into the volume of previously fielded MWS is the Advanced Threat Warner (ATW), shown in Figure 31. Innovation will often be the greatest asset of system designers working on the next generation EW systems.

Figure 31. Northrop Grumman Advanced Threat Warner (ATW)

Other concepts of future technology evolution, supporting affordability and multi-functionality include:

- Uncooled sensors for lower cost and improved reliability without significant sacrifice in performance
- Electro-optical steering with large field of regard and broad spectral coverage
- Multi-band lasers in an acceptable SWaP supporting DIRCM, laser communication, hostile fire countermeasures, range finding and targeting applications
- Turrets and pointer/trackers for targeting and DIRCM applications
- Infrared sensors for missile warning, diminished visual environment (DVE) and situational awareness

7.0 What's Next?

As threats evolve, DIRCM systems and their fundamental capability must also advance and be within affordability limits. Lasers and technologies enabling their development in the area of power and spectral coverage will be an essential part of this progression. Promising new source technologies include QCLs, Figure 32, and Femtosecond lasers, Figure 33. QCLs have recently gained tremendous interest in the DIRCM community given their simple architecture, robustness, direct electrical-to-optical output, and all-band operation. QCL's provide high efficiency, excellent beam quality, and a very compact size all at a very affordable price. Femtosecond lasers can provide tremendous peak power enabling new classes of

DIRCM, or high energy laser countermeasures (HELCM) to be explored [18, 19]. In this capacity these sources offer the potential for causing physical damage to the seeker or one of its elements, thus, defeating the threat. Recent advances in high energy fiber lasers, femto-second pulse lasers, spectral and spatial beam combining, and atmospheric aberration compensation can make this approach realizable in the next 5 to 10 years. One major advantage of this concept is the countermeasure technique is threat agnostic.

Distributed Aperture IRCM (DAIRCM) may replace centralized turrets with several apertures distributed about the platform. In this capacity, the pointer-tracker and laser aperture are coupled with the MWS thus eliminating the central turret. A centralized, high power laser with switch, provides power over fiber optic cable to the multiple sensor locations. Continued advancement in fiber optic cable power handing capability is expected, and required for this configuration.

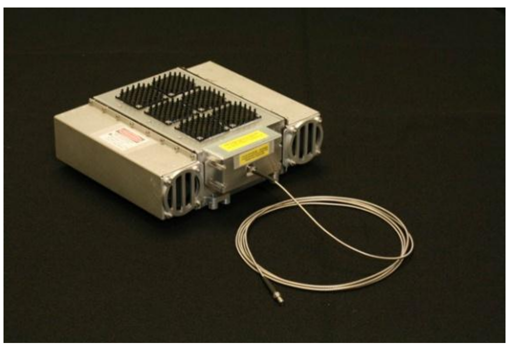

Figure 32. Daylight Solutions Aries High Power, Multi-Wavelength, QCL [31]

Figure 33. Raydiance Ultra-Short Pulse Laser [32]

Figure 34. High Energy Laser Countermeasure (HELCM) concept

Two additional concepts are 1.) pre-emptive IRCM and 2.) proactive IRCM. In the case of Pre-emptive IRCM, the threat is denied the ability to make lock with the target. Pre-emptive represents a true “non-kinetic” capability where the threat cannot obtain lock on the intended target, sometime referred to as hostile fire countermeasures (HFCM), or laser dazzling. In proactive IRCM, the threat is detected prior to launch and countermeasures against the threat are employed.

Figure 35: Pre-emptive countermeasure concept

8.0 Summary and Conclusions

During the relatively short time that IRCM has been in existence, the threat has continually evolved. Laser-based DIRCM represented the first real paradigm shift in IRCM capability from omni-directional to highly directional system solutions. A similar advancement in capability and performance is expected over the next decade to counter quasi- and full imaging weapon systems. EW systems must advance to give our war fighter the performance advantage in the battlespace. A clear understanding of the customer mission and requirements is essential to future success. Innovation supporting less complex solutions to reduce cost, risk and time to fielding will be critical. System designers must leverage mature and discriminating technologies whenever possible. Clearly, new and emerging technology will be a key part of future EW system designs. However, new technology should not be employed without thorough assessment of risk, and development of a mitigation plan, before implementation. Multi-functionality supported by technology will be one tool in meeting affordability and SWaP requirements. Understanding cost drivers at the onset of the design process to support effective trade studies will be required to meet affordability requirements. To be viable, system solutions must be open architecture to add additional features, scalable to support specific platform and mission needs, upgradable to defeat emerging threat systems and affordable to meet budget limitations.

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