Defence Research and Development Canada Recherche et développement pour la défense Canada

DEFENCE DÉFENSE

Preliminary study of defensive aids suite technology for the armour combat vehicle programme

J.L.Rapanotti
A.Cantin
R.G.Dickinson
DRDCValcartier

Defence R&D Canada – Valcartier
Technical Memorandum
DRDC Valcartier TM 2003-274
February 2007

Canada

Preliminary study of defensive aids suite technology for the armour combat vehicle programme

J.L. Rapanotti
A. Cantin
R. G. Dickinson
DRDC Valcartier

Defence R & D – Valcartier

Technical Memorandum

DRDC Valcartier TM 2003–274

February 2007

Author

J.L. Rapanotti

Approved by

Philip Twardawa

Head, Electro-Optical Warfare

Approved for release by

Gilles Bérubé

Chief Scientist

This study is in direct support of the major project FAVS-TD (Future Amoured Vehicle Systems - Technology Demonstrator) and minor project DAS for LAV as described in work unit 2fi16.

Abstract

On future missions, the Leopard 1 Main Battle Tank (MBT) and Cougar tank trainer will be replaced by an Armoured Combat Vehicle (ACV) providing direct fire support for Light Armoured Vehicles (LAVs). These new ACVs will be significantly better than the Cougar but will lack the survivability of the MBT. To overcome this deficiency, a suite of sensors and countermeasures will be proposed. This Defensive Aids Suite (DAS) will include sensor data processing to provide prioritized solutions to threats while interfacing with other vehicle resources through a data bus. The initial DAS design will detect virtually all laser-based threats and counter with obscurants, evasive manoeuvres and direct fire. A modular, federated approach to the design of the DAS, will facilitate upgrades and mission configurability. Future upgrades recommended are missile launch detection and tracking, directed infrared jamming and laser dazzling and a hard-kill system based on radar. Related areas of investigation have been identified including camouflage and signature management to improve vehicle stealth. Additional areas of development include modelling and simulation to determine the benefit of new technologies, sensor, countermeasure and algorithm development, scene generation for the DAS processor and crew training. This will be a preliminary study and will serve as a reference for future study in this area.

Résumé

Au cours des missions futures, les chars d’assaut (CCP) Léopard 1 et le véhicule “Cougar”, seront remplacés par un véhicule blindé de combat (VBC) fournissant l’appui-feu direct pour les véhicules blindés légers (VBL). Ces nouveaux VBC seront nettement meilleurs que le “Cougar” mais leur surviabilité n’égalera pas celle du CCP. Afin de pallier ce défaut, une suite de capteurs et de contre-mesures sera développée. Cette suite d’aides à la défense (SAD) inclura le traitement de données de capteurs pour fournir des solutions prioritaires aux menaces tout en se connectant par interface à d’autres ressources du véhicule par un bus de données. La conception initiale de la SAD détectera pratiquement toutes les menaces laser et y réagire à l'aide d'obscurcissants, de manoeuvres évasives et du tir direct. Une approche modulaire et fédérée à la conception de la SAD facilitera la mise à niveau et la configuration de missions. Les futures mises à niveau recommandées sont la détection de lancement de missiles et le brouillage infrarouge dirigé et éblouissant par laser et un système de destruction de la menace basée sur la détection par radar. Des domaines de recherche connexes comprenant le camouflage et la gestion de la signature pour améliorer le furtivité du véhicule ont été identifiés . Les domaines additionnels du développement incluent la modélisation et la simulation afin de déterminer l’avantage des nouvelles technologies, des capteurs, des contre-mesures et le développement d’algorithmes, des modèles de champs de bataille pour l’ordinateur de la SAD et la formation d’équipages. Ce sera une étude préliminaire qui servira de référence dans ce domaine.

Executive summary

The Leopard 1 Main Battle Tank (MBT) and Cougar tank trainer will be replaced by an Armoured Combat Vehicle (ACV) providing direct fire support for Light Armoured Vehicles (LAVs). Preliminary war-gaming studies have shown that the new vehicle will successfully replace the Cougar but will have a low survivability from the reduction in passive armour. Explosive reactive armour is a possible option but it is limited by new missile designs based on multiple shape-charge warheads. LAV survivability can be improved through:

Detection Avoidance based on advanced camouflage techniques and signature management, and

Threat Avoidance to compensate for the reduction in passive armour through DAS technology to defeat or avoid threats.

The Defensive Aids Suite (DAS) will include sensor data processing to provide prioritized solutions to threats while interfacing with other vehicle resources through a data bus. The initial DAS design will detect virtually all laser-based threats and counter with obscurants, evasive manoeuvres and direct fire. A modular, federated DAS design, will facilitate upgrades and mission configurability. Future upgrades recommended are missile launch detection and tracking and a radar-based hard-kill system.

A vehicle with suitable camouflage and signature management can engage targets at long range without being detected and use the DAS to defeat short range threats. Signature management requires a coordinated approach to reduce to background levels: the vehicle radar cross-section and signatures in the following regimes: visible, infrared, electronic, acoustic, seismic and magnetic. Based on more mature technology first, the initial DAS system should counter laser-based threats with hemispheric coverage and $\pm 1^\circ$ resolution. Presently, the more important threats to the vehicle use lasers for guidance, ranging or target designating. The countermeasures would include obscurants, manoeuvres and direct fire. At fixed intervals, typically five years, the state of sensor and countermeasure technology should be reviewed and assessed for improvements. At year 5 (2010), missile launch detection and tracking should be available using infrared staring arrays to provide the same hemispheric coverage and levels of accuracy. With reliable missile detection available, directional infrared countermeasures can be installed to counter missiles relying on infrared guidance beacons. The directional platform can also include dazzling since an operator is generally in the loop and therefore offers a capability to handle multiple threats. At year 10 (2015), active armour, including radar for accurate targeting information should be available to counter virtually all projectiles. Additional areas of development which will be pursued in the future include modelling and simulation to determine the benefit of new sensors, countermeasures and algorithms.

J.L. Rapanotti, A. Cantin and R.G. Dickinson, 2007 “Preliminary study of defensive aids suite technology for the armour combat vehicle programme,” DRDC Valcartier TM 2003–274, Defence R& D Canada.

Sommaire

Le char d’assaut principal Léopard 1 (CCP) et le “Cougar” seront remplacés par un véhicule blindé de combat (VBC) pouvant fournir un appui-feu direct pour les véhicules blindés légers (VBL). Des études préliminaires de simulations de guerre ont démontré que le nouveau véhicule remplacera avec succès le “Cougar”, mais sa surviabilité sera réduite à cause de la réduction du blindage passif. Le blindage réactif est une option possible, mais celle-ci sera limitée par de nouvelles conceptions de missiles basés sur des ogives à charges-creuse multiples. La surviabilité d’un VBL peut être améliorée par :

L’évitement de la détection basé sur le camouflage et la gestion de la signature et

L’évitement de la menace pour compenser la réduction du blindage passif par la technologie SAD afin de défaire ou éviter des menaces.

La suite d’aides à la défense (SAD) inclura la gestion de données du capteur afin de fournir des solutions prioritaires aux menaces pendant l’interaction avec les ressources des autres véhicules par l’intermédiaire d’un bus de données. La conception initiale SAD détectera virtuellement toutes les menaces basées sur les lasers qui seront contrées avec des obscurcissants, des manoeuvres évasives et l’attaque directe. Une conception modulaire et fédérée de la SAD facilitera la mise à niveau et la configurabilité des missions. Les mises à niveau futures recommandées sont la détection de lancement de missiles ainsi que leur pistage et un système de destruction basé sur le radar.

Un véhicule avec du camouflage et une gestion de la signature peut affronter des cibles à une grande distance sans être détecté et utiliser la SAD pour vaincre les menaces à faible distance. La gestion de la signature exige une approche coordonnée afin de la réduire à des niveaux d’arrière-plan : la section transversale du radar du véhicule et les signatures dans les régimes suivants : visible, infrarouge, électronique, acoustique, sismique et magnétique. D’abord, basée sur des technologies plus matures, la SAD initiale devrait contrer les menaces laser avec couverture hémisphérique avec ±1° de résolution. Présentement, les menaces les plus importantes utilisent le laser pour le guidage, l’estimation de la distance au ciblage. Les contre-mesures pourraient inclure des obscurcissants, des manoeuvres et l’attaque directe.À intervalles fixes de cinq ans, l’état de la technologie des capteurs et des contre-mesures pourrait être révisé et évalué pour amélioration. À la cinquième année (2010), la détection de lancement de missiles et le pistage devrait être disponible en utilisant des dispositifs infrarouges pour fournir la même couverture hémisphérique et les mêmes niveaux de précision. Avec un système de détection de missiles, les contre-mesures directionnelles infrarouges pourront être installées afin de contrer les missiles basés sur des balises de guidage infrarouge. La plate-forme directionnelle pourra aussi inclure l’éblouissement, puisqu’un opérateur est généralement dans la boucle, et de ce fait offrir la capacité de prendre en charge plusieurs menaces.

À la dixième année (2015), le blindage actif incluant le radar pour un pistage précis devrait être disponible pour contrer virtuellement tous les projectiles. Des domaines additionnels de développement qui seront entrepris dans le futur incluront la modélisation et la simulation pour déterminer les bienfaits des nouveaux capteurs, contre-mesures et algorithmes.

J.L. Rapanotti, A. Cantin and R.G. Dickinson, 2007 “Preliminary study of defensive aids suite technology for the armour combat vehicle programme,” DRDC Valcartier TM 2003–274, Defence R& D Canada.

Table of contents

Abstract i

Résumé i

Executive summary ii

Sommaire iii

Table of contents v

List of figures vii

List of tables viii

Acknowledgements ix

1. Introduction 1

2. Threats of operational significance 4
    2.1 Threat classification 5
        2.1.1 Threat countermeasures 5

3. Current and near-future DAS technologies 7
    3.1 DAS Systems for laser-based threats 9
    3.2 DAS systems for SACLOS missile threats 10
    3.3 Obscurants and launcher systems 10
    3.4 DAS Processors 11

4. Relative maturity of DAS technology 12
    4.1 In-production equipment 12
    4.2 Working prototypes 12
    4.3 Engineering/advanced development model 12

5. Cost-benefit and sensitivity considerations 15
    5.1 Indicative costs 17
    5.2 DAS effectiveness toward ACV survivability 17

5.3 Cost versus technical risk 18

6. DAS development based on operations research 19

6.1 General approach to studying DAS effectiveness 20

6.2 DAS system effectiveness study 21

6.2.1 Inputs for system effectiveness study 22

6.2.2 Availability of data from trials such as Pronghorn 23

6.2.3 Man machine interface 23

6.2.4 Man-in-the loop, hardware-in-the-loop simulation 23

6.2.5 Countermeasure tactics 23

6.2.6 Questions for system effectiveness study 24

6.3 DAS battlefield effectiveness study 24

6.3.1 Inputs for war-gaming 24

6.3.2 Questions for battlefield effectiveness study 26

7. ACV definition and implementation 27

7.1 Modular DAS development project 27

7.2 DAS Development through modelling and simulation 27

7.3 Missile Launch detection and tracking (MLDT) 27

7.4 MLDT Development with third parties 28

7.5 Platform signature management 28

7.6 Threat Missile signature trials 28

7.7 Soft-kill and hard-kill systems 28

7.8 General purpose DAS for LAV variants 29

8. Concluding remarks 32

9. References 33

List of symbols/abbreviations/acronyms/initialisms 35

Annex A: Detection and tracking avoidance through signature management 37

Distribution list 39

List of figures

Figure 1. Layers of survivability. 3

Figure 2. Incremental evolution of DAS technology. 7

Figure 3. The DAS prototype developed for use at the pronghorn trials 13

Figure 4. ModSAF development. 21

Figure 5. A notional event timeline for defence against missile attack. 22

Figure 6. A notional defensive probability curve for use in high-level war-gaming 25

List of tables

Table 1. threat missiles classified by guidance or communications system 4

Table 2. Lockheed Martin MCD SACLOS effectiveness 14

Acknowledgements

The authors would like to thank Messrs. Christian Carrier and David Saint for suggesting this work. The support provided by Majors Mark Espenant, Robert Bouchard and James Atkins is greatly appreciated.

This page intentionally left blank

1. Introduction

An operational requirement has been identified to acquire an Armoured Combat Vehicle. The ACV will improve the direct fire support capability arising from the expanding role of the LAVs. Under current doctrine, Canadian troops must be protected in Armoured Personnel Carriers (APC). The direct fire support will suppress hostile direct fire including threats from Main Battle Tanks (MBTs), Infantry Fighting Vehicles (IFVs) and strong points. The ACV project, (Ref. [1]), can be conducted in two phases:

1. Phase One will replace 195 of the Cougar tank trainers. Operationally, the ACV will provide direct fire in support of some combat operations and in Operations Other Than War (OOTW);
2. Phase Two will replace the Leopard 1 MBT with a light vehicle similar to the ACV in phase one but capable of undertaking the most demanding combat operations.

According to the project definition, (Ref. [1]), the phase I ACV will not be able to replace the MBT in all roles but must be capable of firing kinetic energy rounds, chemical energy rounds and anti-tank guided missiles. The vehicle will be a LAV and use signature management, a Defensive Aids Suite (DAS) and local hardening, (Ref. [2]), to maximize crew survivability through detection and hit avoidance and reduced armour penetration. The various aspects of vehicle defence are often depicted as layers as shown in Figure 1. Advanced sensor systems and communications will provide the crew with a high degree of situational awareness and integration. The unpredictable operational environment, planned longevity of the platform and rapid advances in technology, will require an ACV with a high degree of growth potential through modularity and mission configurability.

A war-gaming study, (Ref. [3]), was undertaken to determine the effectiveness of a conceptual ACV using a 105 mm gun. It was shown that the ACV was likely to suffer half the casualties and kill twice the number of enemy compared to a Cougar force. The conclusion is that the basic ACV would be a successful replacement for the Cougar.

In a comparison of the Abrams M1A2 MBT with a T-80, the M1A2 defence is twice as effective as that of the ACV and the attack is three times more effective. In considering the lethality of the basic ACV, the ACV can only defeat the T-80 head-on when the MBT is exposed and at close range. War-gaming results also show that the ACV is very vulnerable when exposed. Equipping the ACV with a through-the-barrel missile resulted in an increased long-range capability, a fourfold improvement in the number of head-on engagements and a corresponding increase in the loss exchange ratio. An up-armoured ACV with 400 mm of additional frontal armour was not significantly better. In assessing the vulnerability to indirect fire the ACV was shown to suffer three times the losses of the M1A2.

Vehicle survivability can be represented usefully by a series of layers, as shown in Figure 1. New vehicles designs emphasize the first two layers, detection and hit avoidance, to survive an attack. In the first layer, survivability can be improved by reducing the size and silhouette of the vehicle and through signature management, which is the reduction to background levels of the radar cross-section and signature in the visible, infrared, electronic, acoustic, seismic and magnetic domains.

The next layer, the DAS layer, relies on a system of sensors to collect data, which is then processed to determine the presence of any threats. This system is interfaced to countermeasures through processors, which will determine a prioritized list of responses. As the challenges of hit avoidance, including short timelines and numerous threats, are addressed, the solutions will lead to weapons of greater precision and increased tempo on the battlefield through automation.

In the war-gaming study, (Ref. [3]), a DAS would have decreased vehicle vulnerability and therefore significantly improved the performance of the basic ACV. However, the ACV was still highly vulnerable. The high performance of the M1A2, as suggested by the study, justifies the reluctance demonstrated by the US Army in improving that platform and instead channeling more resources in developing the Future Combat System (FCS). In general, a MBT will survive small calibre rounds and debris from indirect fire better than the DAS-equipped LAV. The LAV however will be better suited to handle single anti-tank threats. These differences will help define roles for both vehicles in the future armies.

The principal objective of this study is to identify, prioritize and recommend options for the ACV DAS. The threats to the ACV of operational significance are defined. The following chapters are included in the report. Chapter 2.0 describes two techniques to reduce threats to the ACV. These include signature management and DAS technology. Chapter 3.0 explains in more detail current and near term DAS technologies. Chapter 4.0 ranks the DAS in terms of readiness for use in the field. In Chapter 5.0 the more promising systems are analyzed for cost versus benefit. The various aspects of operations research in developing the DAS are outlined in Chapter 6.0. In Chapter 7.0 the DAS and DAS-related activities, recommended for the ACV definition study are discussed. Conclusion and concluding remarks are outlined in Chapter 8.0. The reference materials used in the report are listed in Chapter 9.0. A list of acronyms is also included at the end of the memorandum.

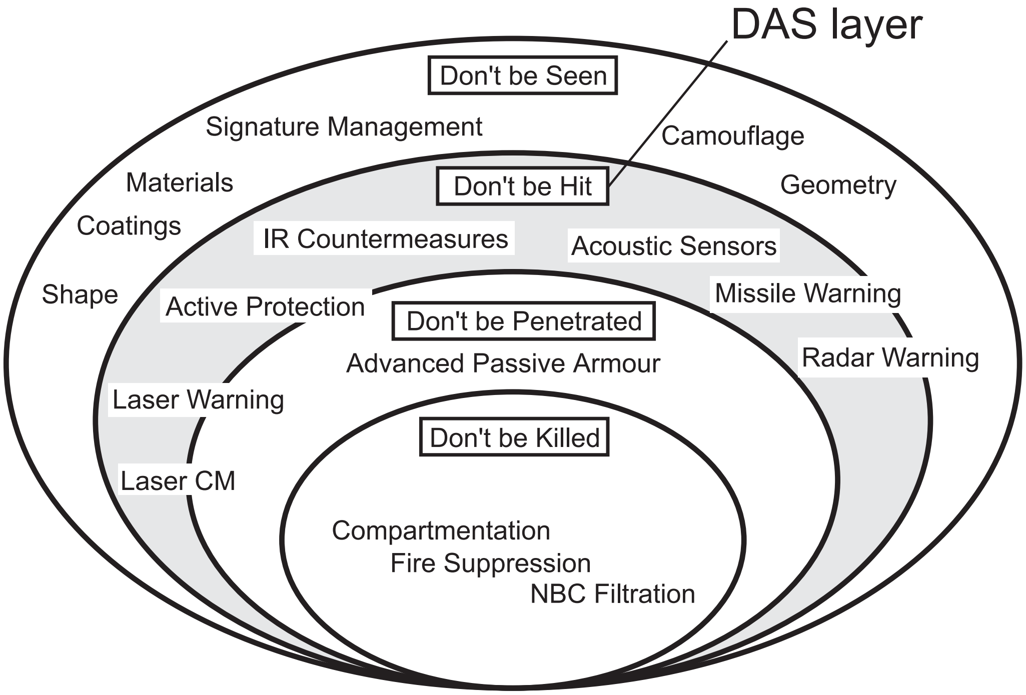

Figure 1. *Layers of survivability. With the reduction of passive armour, greater emphasis is placed on detection avoidance and on hit avoidance, the DAS layer.*

2. Threats of operational significance

The ACV must be suited to a wide range of the operations from peacekeeping and OOTW to high intensity conflicts. The ACV must provide the necessary firepower, survivability, mobility and reliability to enable the crew to fight, survive and conduct operations independently, as a troop, or as part of a combined arms team. The ACV will require protection against attack by medium cannon, artillery fragments, mines, shaped charge attacks, missiles, lasers, and dismounted personnel. Of special concern is the protection against tank or ACV guns, vehicle and air-launched guided missiles, guided and unguided anti-tank weapons, plus conventional and smart artillery-delivered munitions and submunitions. The latest generation of anti-tank missiles, and in particular top-attack weapons, offer sufficient lethality to render passive or reactive armour solutions too heavy.

The light armoured ACV will encounter numerous threats, (Ref. [2]), which must be addressed through improved technology to avoid detection and tracking and avoid being hit if detected. Detection and tracking avoidance or stealth can be achieved through signature management (described in more detail in Annex A). Signature management has to be a coordinated effort to achieve a balanced result to avoid canceling previous solutions. Stealth and the vehicle DAS are complementary and must be considered together. Signature measurements are fundamental in identifying the basic DAS requirements and in eliminating any flaws from the vehicle design or the design of the upgrade kits.

Among the many threats to land vehicles, a list of 89 missiles was compiled by guidance and communication links used, (Ref. [4]) and presented in Table 1. Based on the total number of missile configurations, 26% (25 missiles) can be detected and as laser-based threats. Of these threats, six rely on laser designators, sixteen of the missiles are beam riders and another three use either a laser based guidance or communications link. A total of 41 (43% of the missiles) are a SACLOS design and could be defeated by jamming the signal from the IR beacon used to correct

Table 1. *threat missiles classified by guidance or communications system*

Number	Missile Type, (Ref. [4])
41	Semi-Automatic Command to Line of Sight (SACLOS)
16	Laser Beam Rider (LBR)
11	Manual Command to Line of Sight (MCLOS)
8	Fibre-optic guided missiles (FOGM)
7	Imaging Infrared
6	Laser and millimetric wave designation, including Semi-Active Homing
3	Laser based guidance or communications link
2	Automatic Command to Line of Sight (ACLOS)
1	Radio Frequency Homing
89/95	Total missiles/Total configurations

the missile trajectory. Therefore, a countermeasure, such as smoke, designed to counter laser-based threats and SACLOS missiles can defeat a total of 66 missiles or 69% . Another eleven are of MCLOS design, the two ACLOS missiles are fired without operator intervention, eight rely on a fibre-optic link for guidance, and seven are based on imaging infrared seekers. The last missile in the list relies on RF illumination of the target.

In this list, missiles that rely on lasers are numerically less significant but are the more serious threats to the vehicle. Virtually all of these missiles have an operator in the loop which can be defeated by using a combination of dazzling and obscuration to disrupt aiming. An effective basic DAS could be based on laser threat detection, missile detection and tracking sensors and countermeasures including: dazzling , obscurants, evasive manoeuvres and counterfire. This soft-kill solution is independent of any specific missile design. The alternative to this soft-kill approach is the hard-kill solution where the missile is physically destroyed. A combination of soft-kill and hard-kill designs will probably provide an optimum performance.

2.1 Threat classification

There is a requirement for a comprehensive, integrated DAS to provide threat warning and threat assessment systems which are linked to all vehicle countermeasures and other vehicle systems, so that response can be taken with little or no action by the vehicle crew. Command and control for the ACV commander is made increasingly difficult by such factors as enlarged areas of responsibility, expanding amounts of intelligence, greater range, lethality, accuracy and speed of engagement of weapon systems, and the growing capability to conduct day and night, all weather operations. The DAS coverage should be hemispheric and sufficiently precise and accurate to relay adequate information to the vehicle Fire Control System (FCS) and other countermeasures. In the infrared regime, staring focal plane arrays can be used to detect and track other vehicles, missiles and submunitions through a contrast with the background clutter. Radar would also provide useful information about these threats including more precise position, speed and aid in threat identification. Acoustic sensor systems can also be useful in determining sniper positions. Combat identification would provide a necessary means of avoiding direct fire from friendly forces.

2.1.1 Threat countermeasures

Once a threat is detected and identified, countermeasures are required to either avoid or neutralize it. The possibility of multiple threats must also be considered. System redundancy can counter multiple threats and provide an alternative when expendables are depleted.

There is a requirement for a local, rapid obscuration system with good spatial coverage that produces visible and IR screens. Coverage must obscure the vehicle from the threat position within 2 s of activation and last for at least 30 s. This coverage requirement should be extended to include selective hemispheric coverage, without blocking driver vision, and include MMW screening.

There are also advantages to developing a hard-kill system capable of destroying the threat a safe distance from the vehicle. A hard-kill system will require the additional information possible with radar that must be balanced by the need to maintain stealth. The advantage would include an ability to stop supersonic Kinetic Energy (KE) rounds.

3. Current and near-future DAS technologies

The long service life of the vehicle, uncertainty about the types of missions to be encountered and rapidly evolving sensor technology are a strong influence on DAS technology. The DAS should be a federated, modular and mission configurable system, interfaced to the vehicle bus for access to other systems such as the Fire Control System. To keep the cost as low as possible the DAS based on more mature technology first and because of the rapidly evolving nature of technology modified through 5-year upgrades. DAS evolution, represented in Figure 2, could be carried out as described in the chapters below. The 2010 and 2015 vehicles would be designed to operate in a network.

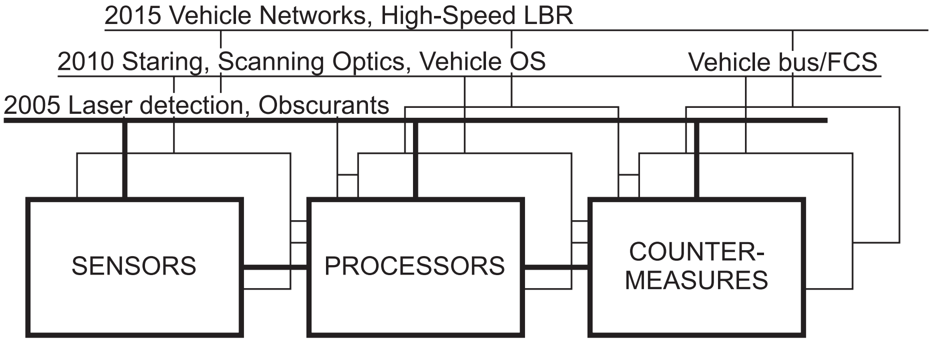

Figure 2. *The rate at which computer and sensor technologies are developed justifies 5 year upgrade increments. The more mature technology is implemented beginning with laser-aided threat detection and visible/IR/MMW obscurants. Improved situational awareness, detection and identification is possible with staring and scanning optics. An operating system is needed to interface the vehicle bus and fire control system with the DAS for efficient use of LAV resources. By 2015, improved survivability can be achieved through vehicle networks and increased operational tempo and firepower with high-speed missiles. The 2010 and 2015 vehicles would be designed to operate in a network.*

Some desirable DAS features include, modularity, mission configurability and eventually a ‘plug and play’ capability. Integrated components and sensor fusion may have better performance but are less desirable than modular, federated systems that are easier and less costly to upgrade and optimize. With a modular approach, the DAS can be upgraded incrementally as the technology and funding becomes available. A federated system can rely on the vehicle bus architecture and computers to connect the components or subsystems together to form a complete system. The Galix system described above is an example of a system that can be used to configure and optimize the vehicle for a wide range of missions.

1. Fitted for, but not fitted with, approach providing a quick response at low cost implies designing the vehicles for equipment upgrades according to the mission requirements without needing to purchase for the entire fleet,

2. Modularity including minimizing the interference among subsystems, which can complicate an upgrade and incremental upgrades of best of breed technology of a federation of modules instead of an integration of fused sensors,

3. Mission configurability relying, for example, on the Galix grenade system that offers a wide range of capability from CS gas and stun grenades for peacekeeping to obscurants and fragmentation grenades for higher intensity warfare and a

4. Plug and play capability facilitating fast upgrading and replacement, and

5. General purpose solutions providing acceptable performance for a wide range of requirements,

6. Robustness avoiding catastrophic failure of the DAS with sensors based on complementary technologies and data fusion to improve performance and to replace lost sensors.

This level of readiness also facilitates rapid acquisition of up-to-date technology and further facilitates rapid deployment.

Based on discussions with UK and US researchers and contractors an optimal solution for a DAS on the ACV should begin with an implementation of the more mature technology first. The vehicle should be designed and fitted to receive the newer technology, as it becomes available. Software should be upgraded at regular intervals to implement new equipment on short notice. Following this approach, the DAS would be initially designed to counter laser based threats followed by missile approach warning and radar detection. Countermeasures would begin with obscurants, counterfire and manoeuvres followed by IR jammers and active protection. Combat identification is also necessary both in protecting the vehicle against friendly fire and in choosing an appropriate response to a threat. This modular approach is preferable when rapidly evolving technology has to be adapted to a vehicle with an expected useful life exceeding 25 years.

In this preliminary study, the availability, maturity and ultimately the affordability of technology will drive the selection of countermeasures to these threats. Based on these criteria, the basic DAS should consist of laser threat detection with obscurants, evasive manoeuvres and direct fire as countermeasures. Sensors and algorithms must be developed to reliably detect missiles, rockets and other threats directed at the vehicle. With reliable missile detection, the first upgrade can include installation of a DIRCM to jam certain missiles. The directional platform can also include a laser dazzling for detection and defeating targeting systems. A second upgrade is envisioned to include radar, providing accurate targeting information, interfaced to a hard-kill system.

Two active major trends in DAS technologies include detection of laser-based threats and IR jamming to defeat SACLOS (Semi-Automatic Command to Line of Sight) missiles. Presently the detection of laser threat detection is limited to visible and near infrared (0.4-1.7 μm) and includes detection of designators, range finders and beam-riding missiles. This range excludes lasers operating at 10.6 μm. Beam-rider detection generally occurs in a characteristic narrow range of 0.85-0.95 μm. SACLOS missiles rely on an infrared beacon located on the rear of the missile. The beacon signal is received at the launcher and compared with the position of the crosshair on the target. Based on this comparison, the guidance system corrects the flight path. Jamming occurs when the IR signal generated at the vehicle is significantly more powerful than the signal produced by the infrared beacon. The launcher interprets an incorrect missile position and the flight path information returned to the missile causes the missile to veer off course. Xenon lamps, lasers or even pyrotechnic flares can be used to produce the jamming signal.

The challenge in defeating the SACLOS missile, as it is for any surface-to-surface missile, is in detecting and identifying the missile. The missiles use a gas generator to pitch the missile out a safe distance before the boost motor ignites. After a relatively short boost phase, to increase the velocity up from about 75 to 300 m/s, a sustain or coast phase is used to maintain missile velocity. With current UV Missile Approach Warning System (MAWS) technology, missile detection has to occur during the ignition or boost phase when there is sufficient heat produced and the temperatures are high enough to result in significant emission in the IR or even UV regimes. High temperatures, however, are not essential in subsonic missiles aimed at slow moving targets. Low performance, but clean burning, double-base propellants can be used instead of metallic composite propellants to generate the necessary thrust and also avoid obscuring the guidance system. The problem of detection can be further exacerbated by suppressed plume afterburning to impede the mid-IR radiators and flash-suppressed igniters to avoid any UV emission. Missile detection and tracking, if presently adequate, will eventually have to rely active sensors such as radar.

3.1 DAS Systems for laser-based threats

Raytheon Danbury Optical Systems has developed the AN/VVR-1 Laser Warning Receiver (LWR) based on the AN/AVR-2A(V), (Ref. [5]). The LWR operating from 0.5-1.6 μm is a staring system and provides angle-of-arrival (AOA) information based on detection of range finders, designators and beam-riders using four sensors to provide a coverage of 360° in azimuth and ±55° in elevation. According to Communications Electronics Command (CECOM) at Fort Monmouth, laser warning is the most mature of the sensor technologies. The AN/VVR-1 was scheduled for use with the M2A3 Bradley Fighting Vehicle (BFV) but has not gone into production. The 218S LWR is based on the AN/AVR-2A(V) and is installed on Canadian LAVs. The 218S is a staring system with a total coverage of 360° in azimuth and 110° elevation using five detector assemblies. With sensor FOV overlap the 218S can provide 22.5° AOA accuracy. The AOA has been improved to ±1° for a newer version, the VVR-1 described above, for all laser threats but the beam-riders. Future development of LWR technology will focus on detection of longer wavelengths and threat identification. Threat identification will rely on real-time parameters such as characteristic modulation, wavelength and pulse rate. A successful countermeasure used against laser designator systems has been the laser decoy. Laser decoying occurs when illuminating a spot on the ground generates a second homing signal.

A prototype DAS based on a 2-band HARLID^{TM}(High Angular Resolution Laser Irradiation Detector), (Ref. [6]), and the DRDC-Valcartier beam-rider detector (WARNLOC) is being developed to detect and locate laser-based threats. The spatial coverage will be better than that of the AN/VVR-1 extending to hemispheric coverage and detecting laser sources with a typical accuracy of ±1°. Similar to the AN/VVR1 the prototype DAS uses staring technology to detect rapid events. Future improvement should include integrating the HARLID and WARNLOC in a single module. Four modules will be distributed about the turret for additional reliability. The contract to build this prototype was awarded to Litton Systems Canada and is therefore tentatively called the Litton DAS. The ability to rapidly detect all significant laser-based threats with pinpoint accuracy over a hemisphere is a significant advantage over similar systems.

3.2 DAS systems for SACLOS missile threats

The DAS systems being developed to defeat SACLOS missiles are described in more detail in Section 4.4 on concept or technology demonstrators.

3.3 Obscurants and launcher systems

The grenade launcher can be used with a wide range of grenade types depending on the threat encountered. Smoke, CS gas or fragmentation grenades can be chosen.

The Visible IR Smoke Screen (VIRSS) grenade is a Canadian technology, (Ref. [7]), and can be adapted to the specific requirements of the ACV, (Ref. [8]). The original requirements were for a grenade capable of providing spectral coverage from 0.3 to 14 μm in less than 3.5 s and lasting at least 20 s. The requirement is attained by eight grenades launched at 45° to provide a coverage of 110° in azimuth, 7 m high 30 m from the vehicle. Presently, the grenade is a 76 mm canister used with Wegmann launchers. The Light Armoured Vehicle (LAV) Coyote uses two sets of launchers without overlap to provide 220° coverage.

Lacroix Defense and Giat Industries have developed an interesting system, the Galix, (Ref. [9]). For a vehicle intended for OOTW, the launchers have the advantage of being mission configurable and modular. The system is based on 80 mm diameter canisters that can carry a greater volume but are incompatible with existing 76 mm systems. The following list describes the various expendables developed for the Galix system:

Galix-4 consists of two spherical fragmenting grenades covering a region from 5 to 60 m from the vehicle.

Galix-6 is an IR-decoy flare for second generation SACLOS missiles and consists of an IR pyrotechnic source fixed over the vehicle. The tethered flare provides omnidirectional coverage and does not need to be pointed like a DIRCM system. When jamming of the SACLOS missile occurs, the elevated position of the flare will drive the missile into the ground. This would also be a useful countermeasure against IR seeking missiles that would be drawn to the much hotter flare.

Galix-7 is a rocket deployed parachute flare to provide night fire support. The flare generates a minimum of 5 lux in a 300 m diameter, 1000 m from the vehicle for 30 s.

Galix-13 is a multi-band smoke with visible and IR coverage and an effective screening in less than 2 s and a persistence greater than 30 s at 20 m from the vehicle. It is a two part system producing ground coverage as well as an air burst. Coverage extending to the MMW regime is being planned. This would be a significant improvement and the possibility of exporting this technology to Canada is being investigated.

Galix-15 is a canister system containing seven CS gas loads, for crowd control and dispersal, launched 200 m ahead of the vehicle.

Galix-19 is a stun grenade system that can be activated in less than 2 s.

Galix also provides various training rounds for ecological and operator safety.

3.4 DAS Processors

A computer system is required to access and coordinate vehicle resources. A DAS processor has been developed by the US Army TACOM TARDEC through Lockheed Martin (Sanders) called Commander's Decision Aid (CDA). The CDA is independent from the Suite of Survivability Enhancement Systems (SSES) being developed by the Program Manager for Ground System Integration (PM-GSI) for use on the Abrams MBT and the BFV. Since there is no funding for the SSES, it would appear that the limited resources are not being use to upgrade the existing vehicles but are instead directed at the new FCS. The CDA, which was originally developed for the Crusader vehicle, has been offered to Canada and is therefore of interest. The CDA receives information from a suite of sensors, processes the information with additional information about available countermeasures and generates a list of prioritized responses. The CDA then communicates with the countermeasures and the Vehicle Interface System (VIS). Therefore, the DAS, or the Integrated Defense System (IDS) as commonly referenced by the US Army, interfaces with the VIS. An automated response system is the only effective way of reacting to short timeline events. Crews are often hesitant to rely completely on an automatic system, but as the crew gains experience and confidence in the system performance using such simulators they will learn when to rely on semi-automatic and automatic mode. Both the US and UK researchers feel that crews will only feel comfortable with an automatic mode once they have had a chance to familiarize themselves with the DAS and DAS controller software.

4. Relative maturity of DAS technology

The amount of effort required to modify and improve current technology presents a certain technological risk in obtaining the required level of performance. The following chapters describe the available technology ranked according to levels of product development.

4.1 In-production equipment

There are no DAS systems currently in production, but relevant technology exists in the form of LWRs, discussed above, acquisition and surveillance.

DRS Technologies has acquired Raytheon Ground Electro-Optical Systems, developers of the Long-Range Advanced Scout Surveillance System (LRAS3), and the Improved Bradley Acquisition System (IBAS). IBAS is an upgrade for the Bradley vehicle, increasing target acquisition performance. IBAS allows the gunner to detect, identify and engage targets at longer ranges for increased self-survivability and lethality. System improvements also provide enhanced shoot-on-the-move capability for the Bradley 25 mm gun. IBAS incorporates the Horizontal Technology Insertion (HTI) Second Generation B-Kit Forward Looking Infrared (FLIR) Thermal Imaging System, also produced by DRS, direct view optics, dual automatic target tracking capability, eye safe laser range finder capability, a daylight television, and a two-axis, stabilized pointing head mirror assembly. The IBAS is a scanning system and therefore lacks the ability to detect rapid events available with staring optics.

4.2 Working prototypes

The Litton DAS will be a prototype designed and built to exploit 2-band HARLIDs and scheduled for demonstration on LAVs during trial PRONGHORN in October 1999 at CFB Gagetown. This multi-national trial, comprising the US, UK and Canada, will demonstrate the effectiveness of a DAS system protecting a LAV Coyote against laser range finders, laser weapons and laser-aided weapons. The prototype will include a laser warning receiver, a DAS demonstration processor and a DAS display unit. The prototype block diagram is depicted in Figure 3. The DAS processor will control the deployment of smoke grenades and will provide the crew with targeting information to align the turret gun on the laser threat for counterfire. DELCO GM will be responsible for integrating the prototype on the LAV turret. Based on results of laboratory and field evaluations, a LWR demonstrator based on HARLIDs was capable of detecting and locating a 1.064 μm laser source to within $\pm 1^\circ$ up to a distance of 3 km and directed as much as 7 m off-axis from the vehicle. This performance was obtained during the multinational trial SPRINGBOK held at CFB Gagetown on October 1995.

4.3 Engineering/advanced development model

The Israel Military Industries have developed the Pedestal-Operated Multi-Ammunition Launching System (POMALS). The POMALS, (Ref. [10]), uses the Amcoram LWS-2 laser warning system to initiate the firing of smoke, flares or decoys from one or more traversing multiple-tube launchers. Each launcher contains 16 tubes. The ability of this system to move the launcher independently of the turret can be an advantage for the ACV.

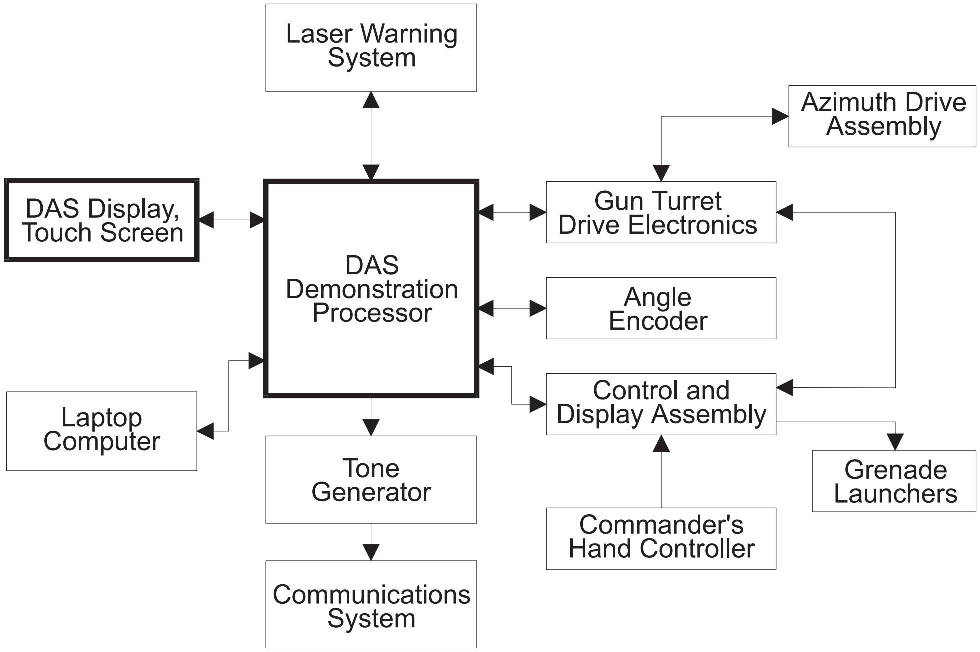

Figure 3. *The DAS prototype developed for use at the pronghorn trials*

Lockheed Martin (Sanders) and Northrop Grumman have developed similar systems to counter SACLOS missiles. During demonstrations at Socorro, NM, (Ref. [11]), the US Army and Lockheed Martin (Sanders) mounted five missile-warning sensors on a vehicle. The sensors, four UV and one IR, are based on the UV staring arrays of the AAR-57 and the Sanders ALQ-212 Advanced Threat IR Countermeasures System (ATIRCM) system. Of the five missiles that engaged the vehicle, all were defeated when the ATIRCM jammed the guidance system.

Lockheed Martin, (Ref. [12]), is developing the AN/VLQ-6 Missile Countermeasure Device (MCD). The MCD has a beacon mounted at the top and to the left of the turret. When the missile is detected, the turret is pointed at the threat and a beam 40° in azimuth and 12° in elevation is emitted. As the missile reaches 50% distance to target, the MCD signal becomes stronger than the missile beacon signal received at launcher and the guidance system is captured. The missile course is corrected based on the beacon that is above and to the right of the crosshair. The correction causes the missile to fly down and to the left eventually hitting the ground. Table 2 illustrates typical MCD performance.

Northrop Grumman Electronics and Systems Sector at Rolling Meadows collaborated with CECOM to develop a DIRCM, (Ref. [11]), for ground vehicles based on the AAQ-24(V) Nemesis DIRCM. Low-power diode lasers to generate the false beacon replaced the Xenon lamp source from the Nemesis. A Northrop Grumman AAR-54 passive missile warning system detected missile launches. The AAR-54, originally designed for aircraft, uses six staring UV

Table 2. *Lockheed Martin MCD SACLOS effectiveness*

Missile launched at	Missile capture occurs at	Missile grounds at
1000 m (from vehicle)	500 m	250 m
2000 m	1000 m	500 m
3000 m	1500 m	750 m
4000 m	2000 m	1000 m

arrays to provide a near-complete spherical coverage. The jammer was successful in live-fire demonstrations conducted during March 1996 at the Yuma Proving Grounds. Following the tests, Northrop has refined the system, now known as the Directed Missile Countermeasures Device (DMCD), with its own funding. Due to the reluctance of the US Army to install expensive systems to defend a relatively low cost platform, cost been a major consideration in the design. The price of the DMCD is about 250K US.

5. Cost-benefit and sensitivity considerations

The term “cost-benefit analysis” can be ambiguous. When examining system options for the vehicle numerous criteria must be satisfied. Effectiveness is important, but it may not be the only or even necessarily the most important criteria. A multiple criteria, evaluation, as done by GD Canada, (Ref. [13]), for concepts, is necessary for specific system options. Their study makes two observations that are of special note. First, they observe that “many concepts designed to detect and defeat the specific threat within a scenario failed to score well against the[ir] evaluation criteria”. Second, they observe that in the final analysis “many of the concepts were either too expensive, immature or very complex.”

Evaluation of specific DAS system options should begin with a multiple criteria evaluation. There are different models that could be used for bringing out the risks and benefits. First, however, the evaluation criteria would have to be agreed. This could include a range wide range of criteria including the following:

Weight
Size
Cost
Reliability
Adaptability
External mounting

Response times
Integration issues
Detection ranges
Technology complexity
Mission-configurable
Power consumption

Vulnerability
Government R& D
Industry R& D
Environmental Requirements
. . .
. . .

The selected criteria could also include specific aspects of these broader criteria. It would be necessary to prioritize each criterion. For each criterion an assessment scale would be established. This could take a variety of forms such as high, medium, low; a scale of 1 to 10; or statements of conditions to satisfy higher or lower assessment. The assessment may be defined qualitatively or quantitatively. Each system would then be assessed according to each criterion by the assessment scale for that criterion. Risks, benefits and uncertainties would be assessed for each criterion. Processing of these assessments could vary according to the criteria and assessment scales. The final result would be an identification of the highest risk and benefit factors for each option and some ranking of the options.

As one of the criteria, effectiveness could be given more attention. and examined at different levels. Initially it could be determined whether the basic stated requirements can be met effectively. This requires looking at timelines to ensure threats can be detected in time with high probability and appropriate actions or decisions can be made in time. This is based on technical performance probabilities defined as given a threat is in range what is the probability the system will detect it.

The probabilities in an event tree can be compared to costs to develop a sense of cost effectiveness trade-off. Thus a system with very expensive active armour which adds a small overall increase to probability of successful defence would have a high cost to effectiveness ratio. Another system with inexpensive obscurants that effectively contribute to vehicle defence would have a lower and more desirable cost to effectiveness ratio. Some sensitivity analysis could be applied on these systems. The probability estimates (ranges of values would be best) would have to be supplied by technical experts.

For a DAS system composed of a set of components where the effects are probabilistically independent, the overall effectiveness is at least as great as for its most effective component. Thus, for example, if a very close-in defence system was highly effective against all threats, then it could form a strong basis for any DAS. For the MBT, the armour provided this effective basis of defence; for the ACV a system like Smart Armour PROtection System (SAProS) could be an effective basis. If any particular component is to be the solid basis around which a system is built, then its performance must be well understood and its performance assessment well founded.

In fact, the components for a DAS will probably not have independent effect and indeed a component like the laser warning receiver will be an important cueing system for all other sensors and countermeasures. In this case, a particular component can have a much greater influence over the overall effectiveness of the DAS.

The active armour system, SAProS, could be the most effective contributor that can be used to illustrate the complexity of the issues in evaluating and selecting components for a DAS. A close-in defence system, which was highly reliable in defeating any threat in the terminal stages of attack could provide a good basic survivability. The prominence of SAProS was primarily because of their assessment of the importance of the very short range RPG threat; no other system could react quickly enough for a weapon fired at less than 500 m. The weighting given to the RPG threat should be tempered by the likelihood that it would be employed in any scenario of interest and by the likelihood that there would be opportunities for engagement with it. There are many other factors to consider, as well. The foremost factor to consider in recommending a plan for DAS development, is that SAProS is a developing technology which is not mature enough to be implemented within the next ten years. This also means that the effectiveness of such a system is largely conjectural and so the results of the analysis may not be valid. Furthermore, there are important operational and reliability questions about such a close-in system. SAProS is an active system and thus must be on, or at a high state of readiness, all the time to be effective. Does this compromise the operations of the vehicle? Availability and reliability are the keys to making the system effective, but are not always easy to achieve in military systems. For example, the naval Close-In Weapon System (CIWS), a weapon of last resort for defence against anti-ship missiles, has had continual problems achieving and maintaining a high availability. In short, there are clearly many issues, which must be considered and balanced as specific DAS system proposals are developed.

A more important level of effectiveness is that in a scenario or battlefield context. If the DAS concepts, basic timelines and technologies are very similar it is unlikely that there would be any significant difference of effectiveness on the battlefield. This type of study can require a great deal of effort to set up and execute properly, often involving seemingly irrelevant factors. CASTFOREM could be a useful tool for battlefield impact analysis, and US Army TRAC may be in a position to do something, since they already have the basic models. However, even then, there would be a good deal of preparation of systems data required. Certainly for us to do it ourselves on CASTFOREM, the effort required to build databases, to learn the system, to develop scripts and be comfortable with the results from the data available would demand at least half a year of effort and probably much more.

Those most prepared to do effectiveness analysis are probably those who would be proposing systems for consideration. For example, a company like GD Canada would probably be in a position to quickly run some effectiveness assessments at different levels.

As a first approximation, an effectiveness study would need

- timings and the distribution of timings for all engagement events
- time for processing
- time to pass data
- time for decision making
- time to effect action
- probabilities of engagement events
- probability of sensor detection In various scenarios, environments, threats
- probability of successful obscuration
- probability technology will do what it is supposed to do in given conditions

Another approach to effectiveness that has not been explored is to ask, what are things that would make a system proposal ineffective? Given the tight time constraints for the study, perhaps it can only be expected to narrow the field to two or three for closer evaluation.

5.1 Indicative costs

Costs have to be estimated based on contractor suggestion and past experience with similar systems. The Litton DAS with hemispherical coverage and pinpoint accuracy of virtually all laser threats, is estimated to cost less than 200K US per vehicle. The US countermeasures to SACLOS missiles will cost about 250K US as complete turnkey systems. Combining the two systems will cost less than the total due to the modular design and sharing of components such as the DAS controller, software and data bus.

The Litton DAS will focus uniquely on laser-based threats, while the two US systems are virtually equivalent in countering only SACLOS missiles. Competition among the US contractors will ensure that neither will have a significant advantage over the other. The cost of either US system is expected to be 250K US.

5.2 DAS effectiveness toward ACV survivability

Obscurants, counter-manoeuvres, counter-fire, dazzling and jamming can be used to defeat most threats with acceptable levels of success. The most significant challenge, however, is to detect the missile, rocket or projectile directed at the vehicle. Even with a staring system, detection of the missile launch and flight requires substantial thermal radiation. It is relatively easy to suppress radiation and reduce it to insignificant levels. Eventually, the hard-body itself has to be detected and tracked before the assessment of a threat can be made.

5.3 Cost versus technical risk

In general, the technical risk is low since the systems are based on well-understood technology. The most cost-effective DAS solution will be the Litton DAS with obscurants from a flexible system like the Galix. Additional coverage extending to the SACLOS missiles is possible with the US systems. Presently, only SACLOS missiles that can be readily detected can be effectively countered. The exact number of missiles that can be detected has not be determined but the MAWS used in the trials described above were designed to detect the significantly more powerful motors needed by supersonic anti-aircraft missiles. Future surface-to-surface missiles will be virtually invisible.

6. DAS development based on operations research

Various DAS system concepts were examined in a comprehensive U.S. study called Guardian, (Ref. [13]). The study concluded that:

Laser Warning Receiver (LWR) were the most effective against long range ATGM,

Missile Approach Warning System (MAWS) was the most effective in performance but higher in cost,

Radar Warning Receiver (RWR) were the most effective against radar seeking projectiles,

LWR was the most effective at the lowest cost, and.

LWR and MAWS, combined were the most effective overall.

To cover all the possible missile threats a DAS system should have a LWR, a MAWS and a RWR, but cost and development status would suggest this is a long term goal. A follow-on study to Guardian, referred to as IPS, is being undertaken by Aberdeen Proving Grounds, which might indicate some of the basic assumptions have changed or the results were not fully accepted. In general, the evidence gathered in preparation of this study supported these results.

The GD Canada DAS Definition Study, (Ref. [13]), which examined system concepts, concluded that a baseline for a robust modular DAS systems that can be upgraded and expanded as required comprises:

- infrared (IR) missile approach warning system (MAWS),
- high accuracy laser warning receiver (LWR),
- multi-spectral smoke,
- counter-fire, and
- evasive manoeuvres.

They further stated that technologies which were not mature enough but which should be considered as additional components for a future DAS system are:

- imaging systems,
- MMW radar receivers,
- active armour, and
- dazzlers and jammers.

The conclusions stated in both the GD Canada report and Project Guardian are useful and similar to the current beliefs of US, UK and Canadian researchers in this area, except for one important difference. According to the US Army TACOM TARDEC, an assumption in the Project Guardian study was that MAWS would be effective against threat missiles. This may be true when a current technology MAWS is used, as designed, to defend airborne platforms against high speed missiles. Anti-tank missiles, due to differences in motor design, are much more difficult to detect and track and determining the missile time of arrival is virtually impossible. Also, an IR MAWS for land vehicles, as suggested by GD Canada, is not yet practical. The actual trend is to incorporate the MAWS algorithms with a general purpose thermal sight as stated elsewhere in this report. From these two studies, it is clear that a combination of a variety of components is necessary to defeat the range of threats which might be encountered in warfighting scenarios. It is also clear that the approach for development described in this study, based largely on technological maturity, is in good agreement with these studies. The overall effectiveness of DAS system options with specific proposed sets of components will have to be determined as, and when, reliable information and performance data are available.

6.1 General approach to studying DAS effectiveness

There are two main ways of thinking about DAS system effectiveness: its effectiveness as a system in defeating threats; and its effectiveness in making a difference on the battlefield. The approaches required to examine each of these are different and one can learn different things from each. There is also interaction between these two approaches.

Some simple modelling of effectiveness of DAS systems in defeating threats should be done first, and should help in understanding the key processes or weakest links in the process. This should also provide initial performance estimates that could be used in war-gaming. System effectiveness can be explored more fully with increasing attention to detail using modelling of components and a man-in-the-loop, hardware-in-the-loop simulator to determine what developments would be useful to the ACV crew. These simulations are extremely important when a human is directly involved and they can also be used to refine the tactics of response, given that a missile has been fired. Once a potential DAS solution is established, war-gaming using models such as Janus can then be used to develop tactics for employment on the battlefield. Results from this stage may also indicate vulnerabilities or weaknesses that suggest changes must be made to the DAS system. More extensive statistics can be generated using scripted models such as CASTFOREM. The modelling and experimental analysis loop can then be closed by trials to validate the DAS solution.

As shown in Figure 4, a continuous cycle of model-test-model can be established using field trials and experimental data to develop models and simulations. Ideally, models should be based on physical principles but when this is impractical, systems can still be analyzed phenomenologically. Both approaches can be implemented in ModSAF. ModSAF (Modular Semi-Automated Forces) was developed for training and doctrine development and provides a capability to define and control entities, on a simulated battlefield. It is a model of the dynamic behaviour of simulated units, their component vehicles and weapons systems with sufficient realism for training and combat development. ModSAF simulates an extensive list of entities including fixed and rotary wing aircraft, ground vehicles, dismounted infantry, and additional special models such as howitzers, mortars, minefields, and environmental effects. The behaviour of the simulated entities can be scripted, so they can move, fire, sense, communicate and react without operator intervention. The entities can interact with each other as well as manned simulators over a network supported by Distributed Interactive Simulation. Operating over a network is also useful in maintaining a necessary level of security.

These basic features in ModSAF are sufficient to define the participation of three group of workers and implement their requirements free from mutual interference. To gain general acceptance, ModSAF development must meet the requirements of the scientists and engineers who develop the technology, the operations research community and the military developing tactics and doctrine. MATLAB®, which is designed for quick-prototyping and code generation, can be used for ModSAF development. MATLAB®modelling can also be used to share information with contractors and other researchers As shown in Figure 4, an important application of ModSAF is the generation of a battlefield environment for the man-in-the-loop simulators at GD Canada. The MIL simulators are critical in the development of a suitable man-machine-interface for the DAS.

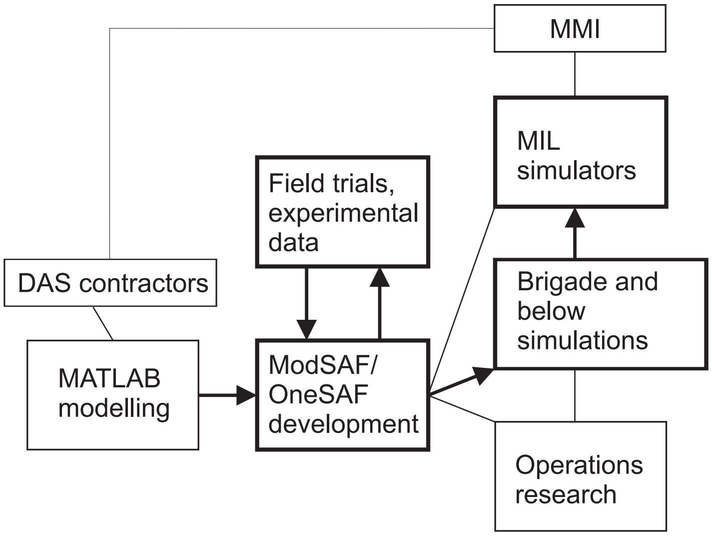

Figure 4. *The four aspects of ModSAF development are shown. MATLAB®is used as a quick-prototyping tool generating, transferable models and code usable by ModSAF. There a tight loop between field evaluations and ModSAF development used to design DAS prototypes and plan future trials. Larger battles are carried out in simulation labs where new tactics and doctrine are developed. ModSAF is also used to provide the battlefield around man-in-the-loop simulators. From the simulators, the man-machine interface and vehicle operating systems are developed.*

6.2 DAS system effectiveness study

To study the DAS as a system to defeat threats it is necessary to examine the possible components, the expected performance characteristics and the relationship between these components. These can be studied using increasingly detailed techniques.

It is important for this part to understand how threat missiles can be detected and tracked. Extensive analysis exists for surface-to-air missiles, but there is virtually nothing for surface-to-surface threats.

A simple event tree and/or timeline using estimated timings and performance can be used for a first order and sensitivity analysis of the DAS as a system to defeat threats. Some DAS components, such as the HARLID-based LWR, already exist and performance is well understood. For other components, such as the MAWS, it would be necessary to make reasonable estimates from similar systems or physical characteristics. The probabilities of successful employment of each component against specific threats are then combined according to the designs of the DAS systems. For example, a simple DAS with a series of events that must happen sequentially will have a probability of success equal to the product of the probability of success of each step in the sequence. The sensitivity of success to various components can be determined firstly, by the marginal improvements overall for small changes in the success of the component and, secondly, by the magnitude of improvement possible with technological advances.

6.2.1 Inputs for system effectiveness study

Figure 5 shows what a timeline might look like and some of the key events. The order of some events may change and some events may not occur or may not be strictly necessary, such as tracking or analyzing the threat situation, or even identification. There also may be several possible events of each type from different systems, in parallel. The events in italics are those in which a human might play a role. With each event there is some probability of success which may be estimated against a given threat in a given environment. The timings are very important to determining whether a successful defence is even possible, while the component performance estimates will determine the extent to which the defence might be successful.

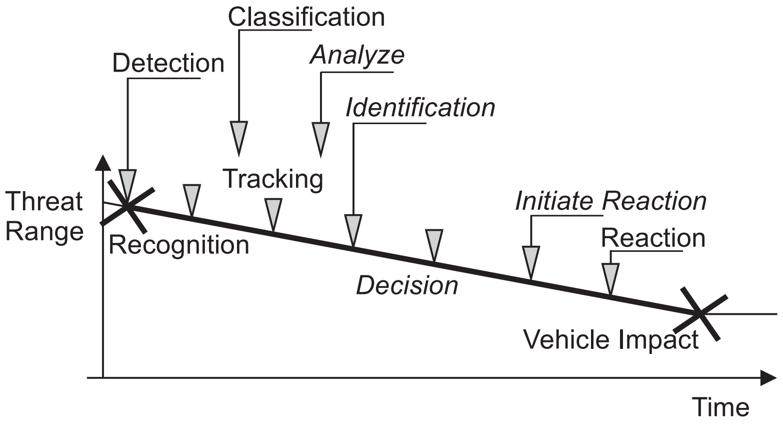

Figure 5. *A notional event timeline for defence against missile attack.*

6.2.2 Availability of data from trials such as Pronghorn

Some of these data will have to come from, or be validated by, trials like SPRINGBOK, (Ref. [14]), and PRONGHORN. Without these performance benchmarks for DAS components, which are under consideration, the effectiveness analysis is somewhat conjectural. It is extremely important in these trials to accurately record the timings and carefully describe situations where difficulties were encountered.

6.2.3 Man machine interface

Human factors can influence the effectiveness of the system and needs to be closely evaluated. The effectiveness in “alerted” and “unalerted” response should be examined. Trials like the Pronghorn trials can provide valuable data. The AVTB would be an excellent way to examine the responsiveness with a man-in-the loop and to explore crew-DAS interaction and interfaces.

6.2.4 Man-in-the loop, hardware-in-the-loop simulation

The more detailed modelling of components and the use of man-in-the-loop or hardware-in-the-loop simulation will lead to more confidence that the relationships between components are well understood. They can be used as engineering tools to examine reliability and process decisions.

Modelling increases in importance, as platforms become more sophisticated and capabilities increase in complexity. Based on developing trends, an effective approach would include an initial investigation of technology using a man-in-the-loop, hardware-in-the-loop simulator to determine what developments would be useful to the ACV crew.

Simulators are also important in developing crew teamwork, in developing and maintaining acceptable levels of skill, and in using the vehicle proficiently. This should also include crews that spend long periods of time in the field. DAS systems would likely be designed with semi-automatic and automatic modes.

6.2.5 Countermeasure tactics

Once the timings and performance can be predicted, tactics for the employment of countermeasures can be developed. These tactics will depend on the threat, the geometry and the environmental conditions. Tactics have been well developed for anti-ship missile defence and the way in which these tactics were developed and the issues raised there are informative. The defence against missiles in the land battle is quite different from anti-ship missile defence, however a few points can be noted. The diversity of anti-ship missile threats means that it was difficult to find robust tactics that would work well for all threats. Thus, classification was very important to having improved effectiveness. Furthermore, for some missiles the best defence options can be quite narrow, so that small changes in the situation could mean large differences in countermeasure effectiveness.

6.2.6 Questions for system effectiveness study

For the kind of studies of the DAS as a system to defeat missile threats, then, one can expect to answer the following kinds of questions:

1. The ability to counter specific threats under different conditions,
2. The best selection of components,
3. The reliability and redundancy required,
4. Automatic versus semi-automatic,
5. The order of decisions, e.g. classify before deployment of countermeasures, and
6. The tactics of response, i.e. best geometry, countermeasure deployment.

6.3 DAS battlefield effectiveness study

This defeat of the threat missile, of course, occurs within a broader context that is just as important. Clues, which alert the crew to possible imminent attack, are extremely important. These may come through situation awareness, detection of enemy communications and various other indications and warnings. Detection of a threat platform and its activity provide the opportunity to avoid detection or place you in a safer position. Signature reduction is also a valuable contribution to DAS effectiveness because it provides for

1. Greater effectiveness of countermeasures,
2. Greater difficulty for the enemy to classify and/or identify your vehicle, and
3. Smaller range of initial detection.

It is equally important to understand the relationship between the use of tactics and the DAS functioning. For example terrain can be used to advantage, but may lead to initial detection and engagement ranges within the minimum range of the DAS. This kind of concern can be addressed in this next stage where battlefield effectiveness is examined.

6.3.1 Inputs for war-gaming

The results of an evaluation of the systems concepts, which explores the likely range of performance of the system and its components, could be something like a set of curves of the probability of successful defence against threat firing range shown in Figure 6. These curves would depend on the type of threat and the situation or environment in which it was encountered.

There would be a minimum range because it takes at least some time to recognize and respond to a threat, and even a missile could travel a significant distance in even a few seconds. If there is a counter for the threat, then there could be some reasonable level of success. There would probably be a fairly steep increase in probability just beyond the minimum range and then a sustained likelihood of success for ranges out until the limitations of sensors to provide warning or detection begin to have an effect.

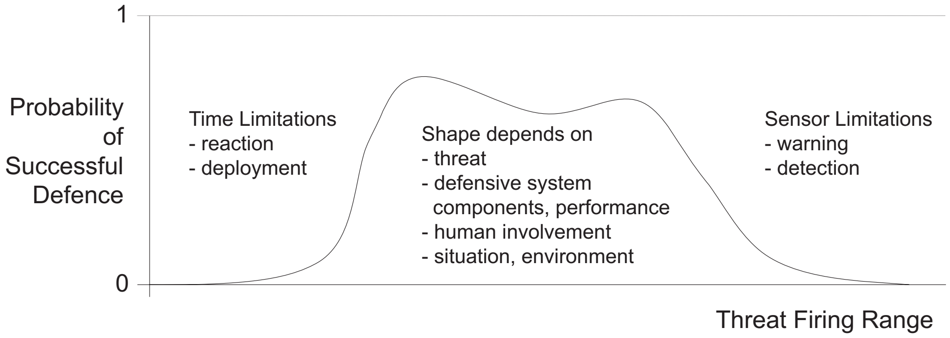

Figure 6. *A notional defensive probability curve for use in high-level war-gaming*

The flight time for a high-subsonic missile travelling 1000m is about 4 seconds. This may be a tactically significant distance. Probably very little can be done to improve geometry. Smoke may be deployed quickly, but will it be full enough, fast enough. The minimum range can be very important in considering the tactics of vehicles on the battlefield.

It is the gross features of such curves: a minimum range, the general shape and height of the curve and a maximum effective range that are important for determining battlefield effectiveness and examining vehicle tactics.

The approaches used to study the DAS as a factor on the battlefield are usually higher level modelling and simulation or war-gaming. The war-game context gives the likelihood that the mission and tactics will produce opportunities for attack.

Different combat models or war-games have different data requirements. CASTFOREM has environmental models and does calculations for smoke effectiveness within the program. Janus, on the other hand does not have such calculations within the program, and this would be assumed in the performance data provided for the DAS. The kind of curve displayed in Figure 6, for different threats, conditions and response tactics is the kind of input which would be useful for Janus.

Canada uses a pre-processor for Janus, (Ref. [15]), which calculates the two probability factors, which together give probability of kill or incapacitation for use in the war-game:

1. Probability of hit as a function of weapon firing range for a given weapon against a given target; and

2. Probability of target kill (or incapacitation) given a weapon hit.

The pre-processor does not include any defensive counter in its calculations. The second part essentially calculates the ability of armour to prevent damage. This part could be adapted to incorporate reactive armour or any other very close in defensive factor that might come into play given that the weapon will hit the target. The first part, however, could not easily be adapted since it is viewed from the weapon perspective and not the defensive perspective. The above curves for successful defence, determined by means other than this pre-processor, would give the probability that the weapon will not hit the target, and so they would be one minus the probability of a hit at range of firing. All the other DAS factors, the alert, the timing, the countermeasure, the manoeuvre, all contribute to providing this probability of hit.

6.3.2 Questions for battlefield effectiveness study

The kinds of questions that can be addressed through these higher level models are:

1. Relationship between tactics, countermeasure deployment and overall system effectiveness,
2. Value of the DAS enabling continuation of a mission,
3. Type and number of countermeasures for mission load-out,
4. Impact on group effectiveness,
5. Trade-off between tactics and time to respond (enemy coming within response range), and
6. Battlefield approach in an environment with difficult threats for any DAS.

7. ACV definition and implementation

The recommended activities to define, develop and implement an ACV DAS are discussed below

7.1 Modular DAS development project

The advantage of a modular, federated system is exploitation of mission configurability and lower upgrade cost. At fixed intervals, typically five years, the state of sensor and countermeasure technology should be reviewed and assessed for improvement. Based on the current state of technology, technology driving factors and vehicle survivability requirements, the following DAS development project is reasonable. The initial DAS system should consist of the Litton DAS for hemispheric coverage and pinpoint accuracy in locating laser-based threats. The countermeasures should include obscurants, counterfire and counter-manoeuvre. At year 5 (2010), missile launch detection and tracking should be available using IR staring arrays to provide the same hemispheric coverage and levels of accuracy. With reliable missile detection available a DRICM can be installed to counter SACLOS missiles. The directional platform can also include a dazzler since an operator is generally in the loop and therefore offer a capability to handle multiple threats. At year 10 (2015), active armour, including radar for accurate targeting information should be available.

7.2 DAS Development through modelling and simulation

Once a potential DAS solution is established through the simulator, as described above, war-gaming using models such as Janus can then be used to develop an optimum set of tactics. More extensive statistics can then be generated using scripted models such as CASTFOREM. The modelling and experimental analysis loop can then be closed by trials to validate the DAS solution.

A second aspect to modelling is the need to gain an understanding of how threat missiles can be detected and tracked. Extensive analysis exists for surface-to-air missiles, but there is virtually nothing for surface-to-surface threats. More analysis is needed to develop MAWS for ground systems. The difference between threats and generally greater cost precludes the use of MAWS developed for airborne platforms in ground systems.

Physical models are needed to represent a realistic battlefield environment to the DAS controller. Once implemented warning of atmospheric or background conditions favouring high signature contrast and estimates of threat missile detection ranges are possible.

7.3 Missile Launch detection and tracking (MLDT)

There is a significant disagreement between contractors, selling MLDT equipment,and researchers who know that missile detection is very difficult if not impossible with the sensors used. Modelling or a detailed analysis of the problem can be used to determine the requirements for MLDT and estimate when the technology will be in place to consider implementation on a vehicle. Meanwhile the necessary algorithms can be developed for detection and tracking. Eventually vignettes or image sequences can be developed and used as benchmarks to test the capabilities of contractor prototypes to detect and track various missiles and under variable conditions.

7.4 MLDT Development with third parties

The consensus is that a basic DAS should consist of laser threat detection and obscurants with counter-manoeuvre as a countermeasure. The next step in technology is the development of sensors and algorithms to detect missiles, rocket and projectiles directed towards the vehicle. Since this is a major undertaking the technical risk can be reduced to acceptable levels by collaboration with allies and contractors in developing a common system. Participating in this endeavour will also give us an opportunity to understand how (and how well) the system works and how to use it effectively.

7.5 Platform signature management

Vehicle signature management provides the necessary stealth and complements the DAS in providing a total vehicle protection. The US Army TACOM TARDEC has offered to provide maps or profiles of the radar, visible, infrared and acoustic signatures. These measurements would be very useful in identifying and eliminating any flaws during the design phase of the programme.

7.6 Threat Missile signature trials

Although the SACLOS missile countermeasures perform well during tests, trials carried out by the US Army and Germany indicate that missile launch detection and tracking cannot be done reliably. As implied above initial flash of the launch motors and igniter can be suppressed and rocket propellant designed for low emission. Therefore current UV MAWS technology is inadequate. The detection and tracking of missiles requires more research including spectral imaging and modelling to further sensor development. Both the US Army and Georgia Tech are interested in collaborating in this area. Researchers at Fort Monmouth are interested in developing a signature database for surface-to-surface missiles.

7.7 Soft-kill and hard-kill systems

The need for active armour arose when the MBT became too heavy for additional passive armour and explosive reactive armour could no longer stop modern weapons, (Ref. [12]). The objective of active armour is to destroy the projectile when being hit is inevitable. It is therefore the last step in protection offered by the DAS. Many countries, including Canada, are developing active armour or hard-kill systems but only the Russians have succeeded in developing systems for production. Russian active armour and countermeasure systems include: Drozd, Shtora-1, and

Arena.

Drozd uses MMW radar sensors on each side of the turret to detect incoming projectiles. Filters are used to ensure that the system responds only to targets flying at typical ATGM speeds. Once engaged, one or two small rockets with fragmentation warheads are fired at the target. Poor elevation resolution and a high probability of collateral damage limit Drozd capability. The system has a cost of 30K US and is reported to be about 80% successful against rocket propelled grenades.

Shtora-1 is actually a soft-kill system using an electro-optical jammer to defeat IR seeking missiles, SACLOS missiles, laser rangefinders and laser designators. The system comprises four components:

a laser warning receiver with a 360° azimuth and -5 to +25° elevation field; and

a bank of forward-firing aerosol-screen grenade launchers mounted on either side of the turret;

the electro-optical interface unit including the jammer, modulator, and control panel;

a control system including the microprocessor.

The screening aerosol can be deployed in less than 3 s at a range of 50-70 m and persists for about 20 s. In a typical scenario the LWR detects the threat, the turret is oriented in the direction of the threat and the grenades are launched. The screen is a hot smoke covering the spectral region from 0.4 to 14.0 μm. The heat generated is sufficient to decoy an IR seeking missile. The jammers emit over the region 0.7 to 2.5 μm injecting a coded pulsed IR signal into the SACLOS guidance system. The jammers provide an effective coverage of $\pm 20^\circ$ in azimuth and 4° in elevation within 2 s of target identification.

Arena is the latest and most advanced of the Russian systems and is based on a multidirectional radar fixed to the turret to detect a potential threat within 50 m of the tank. At a distance between 7.8 to 10.06 m from the vehicle, a tethered explosive device, similar to a Claymore mine, is launched and detonated 1.3 to 3.9 m from the threat. The directed charge of particles destroys the missile. The Arena is an expensive system costing about 300K US.

The Canadian system SAProS, (Ref. [16, 17]) relies on electro-optical sensors to provide an early warning. When the projectile is detected the threat is handed over to a radar system for more precise target location and timing information. At a suitable distance from the vehicle, a shaped charge explosive is selected and detonated. The rod of liquid metal, typically travelling at Mach 35, has sufficient time to destroy the projectile.

7.8 General purpose DAS for LAV variants

Based on analysis of the ACV threat environment and typical compatibility requirements for the CF and ABCA allies, the following general purpose DAS is proposed as a initial step to the iterative process of configuring an optimum DAS, (Ref. [18]). The general DAS comprises four subsystems:

Hard-kill systems are designed to either destroy or deflect the threat away from the vehicle. Active sensors are required to classify the threat and provide ranging data. A system of this type includes the AWiSS-K, designed by DIEHL Munitionssysteme with:

1. Active staring/scanning sensors
    (a) Ka-band search radar providing hemispheric coverage out to 800 m and
    (b) Ka-band tracking radar mounted on high-speed grenade launchers.
2. grenades including
    (a) blast grenades to deflect kinetic energy projectiles at 50 m and
    (b) fragmentation grenades to destroy chemical energy threats 15 m from the vehicle.

The search radars are based on radar elements fixed to each corner of the turret. The normal configuration consists of two high-speed launchers mounted at the rear of the turret. Each turret contains 2 grenades and a tracking radar. The launcher slew rate is 90° over 120 ms. The total system response time is 400 ms. DIEHL Munitionssysteme estimates that this system can be fielded by 2008.

Soft-kill systems rely on obscurants and countermanoeuvres to avoid threats. Sensors for these systems detect threats at much longer ranges and are passive to avoid detection. Vehicles which can not be manoeuvred easily, such as long-range reconnaissance, must rely on jammers instead. Based technology trends, a 2010 system based largely on off-the-shelf components could be designed as follows:

1. Passive staring/scanning sensors, include scanning optics assumed to be mounted in a mini-turret similar to the high-speed launcher above.
    (a) mid-infrared staring arrays providing hemispherical coverage, 4096 × 4096 pixels per corner operating at 60 Hz
    (b) mid-IR scanning array, 1024×1024 pixels with a field of view of 2.5° × 2.5° at 60 Hz
    (c) a laser illuminator and range-gated camera based on a near-IR scanning array, 1024 × 1024 pixels with a field of view of 0.5° × 0.5° at 60 Hz
2. Obscuration and countermanoeuvres consisting of:
    (a) passive smoke grenades based on metal-flake and chaff providing hemispherical coverage, laser dazzling can also be used safely against personnel to fill in the 1.5 s gap until full obscuration is achieved,
    (b) manoeuvring the vehicle will benefit from various technologies, including robotics and MEMS gyroscopes to keep track of the threat.

Information on the vehicle status and driver intent is useful in selecting and automatically maintaining an optimum level of obscuration. The following information can be read from the vehicle bus:

Vehicle bus variables including vehicle speed to lead the grenade pattern, braking, transmission forward or reverse position, wheel direction, and accelerator position.

Based on these variables and the threat detected, the following

Grenade variables can be selected including grenade type, the appropriate pattern and the launch point of each pattern.

Acoustic threat detection will detect muzzle blast and sound waves from a wide range of projectiles, and contribute to the performance of the vehicle. Only rarely will the acoustic microphones outperform the hard-kill and soft-kill sensors but the sensors will contribute to the overall robustness of the DAS by avoiding catastrophic failure from loss of the more fragile sensors. Acoustic threat detection is useful in detecting small arms fire where flash and blast has been suppressed and under battlefield conditions where smoke and dust interfere with other sensors.

Detection of active targeting systems consisting of both LWR and RWR are required for both DAS and IFF functions. The HARLID-based LWR, with the improved ±1° resolution, will reduce the burden required to detect the platform over the current 22.5° resolution. The LWR capability should be extended to include detection of beam-rider missile lasers using, for example, WARNLOC. The RWR will detect the more advanced MMW targeting systems that are now replacing laser-based targeting.

8. Concluding remarks

The ACV will successfully replace the Cougar tank trainer but will have a low survivability typical of a LAV. Survivability can be increased by:

1. Reducing detection and tracking through signature management and
2. Reducing hit probability with a DAS to detect and counter threats.

Signature management requires a coordinated approach to reduce to background levels: the vehicle radar cross-section and signatures in the following regimes: visible, infrared, electronic, acoustic and magnetic. Expertise in all these areas would require considerable time and resources to develop but the US Army TACOM TARDEC is willing to collaborate with us on this mutual problem.

The DAS should be a federated, modular, mission-configurable system based on more mature technology first. The initial DAS with 5-year upgrades would evolve as follows:

1. Initial DAS including HARLID and WARNLOC technology with hemispheric coverage and a typical accuracy of $\pm 1^\circ$. Countermeasures would include obscurants, countermanoeuvres and direct fire.
2. Year 5 (2010), reliable missile launch detection and tracking should be available using infrared staring arrays to provide the same hemispheric coverage and levels of accuracy. A directional platform can also include a dazzler since an operator is generally in the loop and therefore offer a capability to handle multiple threats.
3. Year 10 (2015), active armour, based on radar for accurate targeting information to counter virtually all projectile threats and networking to use available resources more effectively.

Based on analysis of the ACV threat environment and typical compatibility requirements for the CF and ABCA allies, the following general purpose DAS is proposed as a initial step to the iterative process of configuring an optimum DAS, (Ref. [18]). The general DAS comprises four subsystems:

1. Hard-kill systems based on radar as active sensors to classifiy and range the threat,
2. Soft-kill systems on the long-range passive infrared sensors available on the vehicle for manoeuvring and targeting,
3. Acoustic threat detection, complementing the radar and infrared sensors to detect small arms fire and provide a degree of system reliability
4. Detection of active targeting systems based on LWR and RWR to provide both DAS and IFF capability.

9. References

1. “The Future Army: Armoured Combat Vehicle Concept Paper,” Fort Frontenac, Kingston, 19 May 1998.
2. “Project L2636 Armour Combat Vehicle Statement of Operational Requirement,” Draft no. 3, July 1997.
3. M. Ormrod, P. Bender, and Maj. N. de Tilly, “Quarré de Fer: Analysis of the ACV in War-Fighting Tasks” ORD PR9817, DOR(J& L) , December 1998.
4. R.G. Lee, T.K. Garland-Collins, D.E. Johnson, E. Archer, C. Sparkes, G.M. Moss and A.W. Mowat, “Guided Weapons,” Bassey’s (UK) Ltd., Third Edition 1998.
5. J. Knowles, “Covering the Spectrum the Army’s EW Triad,” Journal of Electronic Defense October 98, pp 51-81.
6. A. Cantin et al, “Miniaturized Digital High Angular Resolution Laser Irradiation Detector (HARLID$^{\mathrm{TM}}$) Technology and its Performance as Integrated in a Laser Warning Receiver (LWR) Demonstrator (U),” October 1998, DREV.
7. G. Roy, P. Brière, D. Sanschagrin and G. Couture, “Development of a 76-mm Visual and lR Smoke Screening (VIRSS) Grenade for the Wegmann Launcher,” DREV TR-9605, December 1996, UNCLASSIFIED.
8. J.L. Rapanotti and M. Palmarini, “Dazzle and obscuration strategies for light armoured vehicles”, Ground Target Modeling & Validation Thirteenth Annual Conference, August 2002.
9. Personal communication with Maurice A. Clermark, Clermark Inc.
10. D. Richardson, “Steel Alone is no Longer Enough on Tanks,” Armada International 3, 1998 pp 34-46.
11. B. Sweetman, “A New Approach to Missile Warning,” Journal of Electronic Defense October, pp 41-78.
12. Capt. T. J. Meyer, “Active Protective Systems: Impregnable Armor or Simply Enhanced Survivability? ,” Armor, May-June 1998, pp 7-11.
13. “Defensive Aids Suite - Definition Study (DAS-DS), DAS Final Report,” 971483 CDRL:005, Computing Devices Canada Ltd., July 1998.
14. B. Manatt, A. Cantin, C. Brown and K. Burrett, “Final Report for the Electro-Optical Performance and Countermeasure Trials of SPRINGBOK (U),” TTCP Subgroup Q, QAG-16 report OTD-TR-8-95, 21 April 1997, SECRET (Releasable to UK/ CAN/ AUS/ NEWZEA).
15. Maj. L. Mader, and P.S. Ladouceur, “Current Modelling - Weapons and Targets Used by DOR(J& L) Ph/Pk Pre-processor,” DOR(J& L) Research Note RN 9806, March 1998.

16. “Active Armour Concept Demonstration Program,” Bendix Avelex Inc., May 1990, (Confidential), Volumes 1 and 2 and 4 dated May 1990, Volume 3 dated February 1990

17. “Enhanced Armour Protection System, Phase 2,” Final Report No. AETR 46824, Allied-Signal Aerospace Canada Inc., August 1992, 3 volumes (Confidential).

18. J.L. Rapanotti and M. Palmarini, “Common DAS development for LAV variants,” 14th Annual Ground Target Modeling and Validation Conference, August 2003.

List of symbols/abbreviations/acronyms/initialisms

ACV – Armoured Combat Vehicle

AOA – Angle-Of-Arrival

APC – Armoured Personnel Carrier

ATIRCM – Advanced Threat InfraRed Countermeasures System

BFV – Bradley Fighting Vehicle

CDA – Commander’s Decision Aid

CECOM – Communications Electronics COMmand

CITV – Commander’s Independent Thermal Viewer

DAS – Defensive Aids Suite

DIRCM – Directional InfraRed CounterMeasure

DLR – Director of Land Requirements

DMCD – Directed Missile Countermeasures Device

FCS – Fire Control System, or Future Combat System

FLIR – Forward Looking InfraRed

HARLID^{TM} – High Angular Resolution Laser Irradiation Detector

HTI – Horizontal Technology Insertion

IBAS – Improved Bradley Acquisition System

IDS – Integrated Defense System

IFF – Identfication, Friend or Foe

IFV – Infantry Fighting Vehicle

IR – InfraRed

KE – Kinetic Energy

LAV – Light Armoured Vehicle

LRAS3 – Long Range Advanced Scout Surveillance System

LWR – Laser Warning Receiver

MAWS – Missile Approach Warning System

MBT – Main Battle Tank

MCD – Missile Countermeasure Device

MLDT – Missile Launch Detection and Tracking

MMI – Man-Machine Interface

MMW – MilliMetre Wave

OOTW – Operations Other Than War

OR – Operational Research

SAProS – Smart Armour PROtection System

PM-GSI – Program Manager for Ground System Integration

POMALS – Pedestal Operated Multi-Ammunition Launching System

RWR – Radar Warning System

SACLOS – Semi-Automatic Command to Line of Sight

SSES – Suite of Survivability Enhancement System

VIRSS – Visible InfraRed Smoke Screen

VIS – Vehicle Interface System

WARNLOC – DRDC-V beam-rider detector

Annex A: Detection and tracking avoidance through signature management

Survivability of a light armoured vehicle can be improved by reducing any contrast between the vehicle and the sensor background. The signature or cross-section regimes to be considered are visible, thermal, electronic, acoustic, radar, magnetic and seismic. Unique signatures that improve detection, recognition and identification of the vehicle have to be avoided. An important signature reduction technique is to keep the overall size and profile of the ACV as low as possible. The reduction in size is also important in transportability of the ACV by air.

Visible and infrared signature

The visible regime is one of the more important and can be controlled through traditional camouflage, paint and coatings or more advanced active camouflage where the infrared contrast is kept low by cooling or heating surface plates. These phenomena are well understood and can be analyzed through modelling with the more expensive field trials restricted to validation.

Radar cross-section

The radar cross-section cannot be eliminated but it can be reduced to the background levels. Similar to IR analysis, radar cross-sections can be determined analytically. Surface properties are usually not important but certain geometric features such as large flat surfaces and acute-angle surfaces that can act as corner reflectors can greatly increase radar returns. Reduction of the radar cross-section is becoming more important. Terminally guided submunitions that normally use IR contrast to detect the target can be designed to use MMW radar to detect moving targets. Variations of missiles such as Hellfire, which use laser designation, are being adapted to use mmW designators.

Electronic signature

All electro-magnetic emission from the ACV should be suppressed to avoid the possibility of intercept and detection by enemy electronic support measures. The availability of optical fibre for data transfer is becoming more important as a means of reducing electronic noise.

Acoustic signature

The acoustic frequencies for the ACV range from 50 Hz-20 kHz. Noise reduction techniques vary from using quieter components to judicious operation of the vehicle. Surface maps of vehicle vibration can be used to identify and eliminate constructive wave phases leading to excessive noise.

Magnetic signature

Reduction of magnetic signature is possible through increased use of non-ferrous materials and will reduce the susceptibility of the ACV to magnetic fuses and sensors typically found in land mines.

Seismic signature

Future sensor networks are being developed to distinguish between track and wheel-based vehicles. Wheeled-based LAVs generate the least amount of vibration.

Distribution list

Internal

1 – Director General
1 – Head Electro-Optical Warfare
1 – Head Precision Weapons
1 – Head Energetic Materials
3 – Document Library
1 – Dr. J.L. Rapanotti (author)
1 – Mr. G. Pelletier
1 – Mr. E. Thibeault
1 – Dr. J. Fortin

External

1 – DRDKIM (pdf copy)

1 – Mr. Davis Saint
DSTL 5
National Defence Headquarters, 12 NT
101 Colonel By Drive
Ottawa, ON, K1A 0K2

1 – Head FFSE
DRDC Ottawa
3701 Carling Avenue
Ottawa ON, K1A 0Z4

1 – DLR 2-5
National Defence Headquarters, 12 NT
101 Colonel By Drive
Ottawa, ON, K1A 0K2

1 – LCol Luc Petit
DLR 3
LSTL 1st Floor SE 02
555 blvd de la Carrière
Gatineau QC, K1A 0K2

1 – Capt. Mark McNeil
DLR 3-3 LSTL

1st Floor SE 02
555 blvd de la Carrière
Gatineau QC, K1A 0K2

1 – Director DLSC
Fort Frontenac
PO Box 17000, Stn Forces
Kingston, ON, K7B 7B4

1 – Dr. Paul A. Roman
Army Synthetic Environment Coordination Office
Army Simulation Centre
PO Box 17000, Stn Forces
Kingston, ON, K7B 7B4

1 – J2 DSI 7-3
National Defence Headquarters
101 Colonel By Drive
Ottawa, ON, K1A 0K2

1 – J2 DSI 7-3-2 ATGM
National Defence Headquarters
101 Colonel By Drive
Ottawa, ON, K1A 0K2

1 – Maj. Gordon Fisher
J2 DSI 7-4
National Defence Headquarters
101 Colonel By Drive
Ottawa, ON, K1A 0K2

1 – Maj. Luc Nadon
J2 DSI 7-4-4
National Defence Headquarters
101 Colonel By Drive
Ottawa, ON, K1A 0K2

1 – Maj. Michel Lavallé
RWGT
National Defence Headquarters, 6 CBS
101 Colonel By Drive
Ottawa, ON, K1A 0K2

1 – Maj. Les Mader
Land Staff Secretariat
Decision Support Cell
National Defence Headquarters, 12 NT
101 Colonel By Drive
Ottawa, ON, K1A 0K2

This page intentionally left blank

DOCUMENT CONTROL DATA

1. ORIGINATOR (name and address)
J.L. Rapanotti, DRDC Valcartier

2. SECURITY CLASSIFICATION
(Including special warning terms if applicable)
Unclassified

3. TITLE (Its classification should be indicated by the appropriate abbreviation (S, C, R or U)
Preliminary study of defensive aids suite technology for the armour combat vehicle programme (U)

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)
Rapanotti John L., Cantin André and Dickinson Robert G.

5. DATE OF PUBLICATION (month and year)
February 2007

6a. NO. OF PAGES
55

6b .NO. OF REFERENCES
18

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. Give the inclusive dates when a specific reporting period is covered.)
Technical Memorandum

8. SPONSORING ACTIVITY (name and address)
DRDC Valcartier

9a. PROJECT OR GRANT NO. (Please specify whether project or grant)
2fi

9b. CONTRACT NO.

10a. ORIGINATOR'S DOCUMENT NUMBER
TM 2003-274

10b. OTHER DOCUMENT NOS
N/A

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

☒ Unlimited distribution
☐ Restricted to contractors in approved countries (specify)
☐ Restricted to Canadian contractors (with need-to-know)
☐ Restricted to Government (with need-to-know)
☐ Restricted to Defense departments
☐ Others

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

On future missions, the Leopard I Main Battle Tank (MBT) and Cougar tank trainer will be replaced by an Armoured Combat Vehicle (ACV) providing direct fire support for Light Armoured Vehicles (LAVs). These new ACVs will be significantly better than the Cougar but lack the survivability of the MBT. To overcome this deficiency a suite of sensors and countermeasures will be proposed. This Defensive Aids Suite (DAS) will include sensor data processing to provide prioritized solutions to threats while interfacing with other vehicle resources through a data bus. The initial DAS design will detect virtually all laser-based threats and counter with obscurants, evasive manoeuvres and direct fire. A modular, federated approach to the design of the DAS, will facilitate upgrades and mission configurability. Future upgrades recommended are missile launch detection and tracking, directed infrared jamming and laser dazzling and a hard-kill system based on radar. Related areas of investigation have been identified including camouflage and signature management to improve vehicle stealth. Additional areas of development include modelling and simulation to determine the benefit of new technologies, sensor, countermeasure and algorithm development, reality models for the DAS processor and crew training. This will be a preliminary study and will serve as a reference for future study in this area.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

DAS
LAV
ACV
land vehicle
survivability
LWR
RWR

Defence R&D Canada

Canada's Leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE DÉFENSE

WWW.drdc-rddc.gc.ca