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Vehicle DAS considerations for the Iron Gorget threats

Analysis, modelling and comments to operations researchers

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This study is in direct support of DAS for LAV as described in work unit 2fi16.

Abstract

Threats to Light Armoured Vehicles (LAVs) have been defined, modelled and analyzed. Procedures for analyzing the threats have been developed, compatible with DRDC measurement capabilities, and are described in detail in this study. The DAS is intended to be a modular, federated system, configurable for specific mission demands and developed based on field trials complemented by deterministic engineering models, scene generators and war-gaming simulators. Based on the analysis, a basic Defensive Aids Suite (DAS) for Light Armoured Vehicles (LAVs) has been proposed. To improve performance and reliability, the DAS is based on three complementary sensor technologies, including: acoustics, visible and infrared optics and radar. From these technologies, four DAS subsystems are defined:

1. Passive long range sensing with threat avoidance countermeasures,

2. Short range active sensing with interception of the threat,

3. Detection of active targeting systems, including HARLID$^{\text{TM}}$ based laser threat warning and radar warning receivers, and finally,

4. Acoustic threat detection based on extended sniper detection technology.

Specific issues were raised by operations researchers and are addressed in this study. The analytical procedures described in this study will be used to develop future DAS systems at reduced risk and defrayed cost through international collaboration.

Résumé

Des menaces contre les véhicules blindés légers (VBL) ont été définies, modélisées et analysées. Les procédures pour analyser les menaces ont été développées et rendues compatibles avec les capacités de mesure de RDDC qui sont décrites en détail. Dans cette étude, la suite d'aides à la défense (SAD) est prévue pour être un système modulaire, fédéré et configurable pour des missions précises dont le développement est basé sur des essais dans le champ et complété par des modèles de modélisation déterministes, des générateurs de scènes et des simulateurs de jeux de guerre. Basée sur l'analyse, une SAD de base pour les véhicules blindés légers (VBL) a été proposée. Pour améliorer la performance et la fiabilité, la SAD est basée sur trois technologies de capteurs complémentaires comprenant: l'acoustique, système optique visible et infrarouge et le radar. De ces technologies, quatre sous-systèmes de SAD sont définis:

1. détection passive à longue portée avec contre-mesures d'évitement de la menace,

2. détection active à courte portée avec interception de la menace,

3. détection des systèmes de ciblage actifs basés sur des récepteurs d'avertissement de menace au laser HARLID$^{\text{TM}}$ et des récepteurs d'avertissement radar, puis finalement,

4. détection acoustique de la menace basée sur la technologie adaptée de détection des tireurs embusqués.

Des questions précises ont été soulevées par des chercheurs en opérations, elles seront abordées dans cette étude. Les procédures analytiques décrites dans cette étude seront employées pour développer de futurs systèmes de SAD à risques réduits et dont le coût sera défrayé par la collaboration internationale.

Executive summary

Future Light Armoured Vehicles (LAVs) will operate in network environments relying on sensors to provide situational awareness for increased survivability and performance. A Defensive Aids Suite (DAS) has been proposed based on technology trends, expected CF requirements and anticipated future combat environments. The available sensor technologies include: acoustics, visible and infrared optics and radar. These are complementary technologies increasing the overall reliability by reducing the likelihood of catastrophic loss of the DAS. For example, a HEAT round can be detected by infrared sensors, radar and indirectly by acoustic sensors. This overlap in functionality can be used to mitigate the lack or unavoidable loss of sensors. These sensor technologies can be used to develop a DAS comprising four subsystems:

1. Passive long range sensing with threat avoidance countermeasures,

2. Short range active sensing with threat interception and destruction,

3. Detection of active targeting systems, including HARLID^{TM} based laser threat warning and radar warning receivers, and

4. Acoustic threat detection based on extended sniper detection technology.

The DAS is intended to be a modular, federated system, configurable for specific mission demands and developed based on field trials complemented by deterministic:

1. Engineering models, integrated

2. Scene generators and

3. War-gaming simulators.

The engineering models provide a detailed understanding of threat signatures, atmospheric transmission and background contrast. These models are too detailed and computationally intensive to provide useful dynamic information but can serve as the basis for a second level of modelling, the scene generators. Scene generators integrate simplified versions of detailed models sacrificing physical accuracy for real-time performance. Threat and countermeasure interaction can be analyzed based on few-on-few exchanges. The tactics and doctrine developed can be further examined and refined by brigade level war-gaming simulators. These three levels of modelling are essential to DAS research and development.

Specific issues, such as DAS response to certain threats, were raised by operations researchers and are addressed in this study. The analytical procedures developed and described in this study will be used to develop future DAS systems at reduced risk and defrayed cost through international collaboration.

Sommaire

Les futurs véhicules blindés légers (VBL) fonctionneront dans des environnements de réseaux s'appuyant sur des capteurs pour fournir une prise de conscience de la situation, et ce afin d'augmenter leur survie et leur performance. Une suite d'aides à la défense (SAD) a été proposée basé sur la base des tendances de la technologie, des demandes anticipées des FC et des exigences futures des environnements de combat. Les technologies de capteurs disponibles incluent : les capteurs acoustiques, optiques dans le visible et l'infrarouge ainsi que le radar. Ceux-ci sont des technologies complémentaires augmentant la fiabilité générale en réduisant la probabilité de perte catastrophique de la SAD. Par exemple, un tir HEAT pourrait être détecté par des capteurs infrarouges, le radar et indirectement par des capteurs acoustiques. Ce chevauchement dans la fonctionnalité peut être utilisé pour atténuer le manque ou l'inévitable perte des capteurs. Ces technologies de capteurs peuvent être utilisées pour développer une SAD comprenant quatre sous-systèmes:

1. détection passive à longue portée avec contre-mesures d'évitement de la menace,

2. détection active à courte portée avec interception et destruction de la menace,

3. détection des systèmes de ciblage actifs, incluant l'avertisseur de menace basé sur la détection laser par HARLID^{TM} et le récepteur d'avertissement radar et,

4. détection acoustique de la menace basée sur la technologie de détection des tireurs embusqués.

La SAD est prévue pour être un système modulaire, fédéré, configurable pour des missions précises et développé sur la base d'essais en situation réelle et appuyé par des outils déterministes tels que:

1. modèles d'ingénierie intégrés

2. générateurs de scènes et

3. simulateurs de jeux de guerre

Les modèles d'ingénierie permettent une compréhension détaillée des signatures de menaces, de la transmission atmosphérique du contraste de l'arrière-plan. Ces modèles sont trop détaillés et trop intenses au point de vue informatique pour fournir une information dynamique utilisable, mais peuvent servir de base à un second niveau de modélisation, les générateurs de scènes. Les générateurs de scènes intègrent des versions simplifiées de modèles détaillés en sacrifiant l'exactitude physique pour la performance en temps réel. L'interaction entre la menace et les contre-mesures peut être analysée sur la base de petits échanges à la fois. Les tactiques et la doctrine développées peuvent être examinées plus attentivement et raffinées par des simulateurs de jeux de guerre au niveau brigade. Ces trois niveaux de modélisation sont essentiels à la recherche et au développement de la SAD.

Des questions spécifiques, telles que la réponse de la SAD à certaines menaces ont été soulevées par les chercheurs en opérations et sont discutées dans cette étude. Les procédures analytiques développées et décrites dans cette étude seront utilisées pour développer les systèmes SAD futurs à risques réduits et des coûts répartis par la collaboration internationale.

J.L. Rapanotti, 2007, "Vehicle DAS considerations for the Iron Gorget threats: Analysis, modelling and comments to operations researchers," DRDC Valcartier TM 2004–356, Defence R&D Canada.

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Acknowledgements

1.   Introduction

The purpose of this study was to verify and validate the modelling and simulation approach used to develop DAS-based LAV survivability. In this study, threats of interest to the CF were defined, analyzed and modelled. A typical DAS, based on anticipated near-future 2010 sensor and countermeasure technology, has been proposed and the ability of the DAS to detect threats is determined in this study. The detection range and available response time for each threat were then used to determine an acceptable vehicle and crew reaction. The modelling of threats is resolved into a number of steps, compatible with the experimental capability at DRDC-V. This compatibility between modelling and experimental analysis will produce a valuable connection between DRDC experimental capabilities and military war-gaming needs.

The threat definition is presented in chapter 2 and includes Anti-Tank Guided Missiles (ATGMs), Rocket Propelled Grenades (RPGs), and various rounds for 30 mm and 125 mm caliber guns. The available sensor technologies include:

1. Active sensing, in the MMW regime and including various aspects of radar,

2. Passive sensing based on visible and infrared optics and

3. Acoustics to detect, recognize and classify threats.

These are complementary technologies intended to increase overall reliability by reducing the likelihood of catastrophic loss of the DAS. The sensor technologies can be used to develop a DAS comprising four subsystems:

1. Long range Passive sensing with threat avoidance countermeasures,

2. Short range active sensing with threat interception and destruction,

3. Detection of active targeting systems, including HARLID^{TM} based laser threat warning and radar warning receivers, and

4. Acoustic threat detection extending coverage down to smaller calibers based on extended sniper detection technology.

A more complete description of the DAS is presented in Annex A.

Virtually all threats rely on chemical energy for propulsion [1] either through short duration high energy release gun launches or longer duration energy release typical of rockets and missiles. Detection of these threats is most effective in the mid-infrared regime of 3 μm–5 μm. Based on information on motor design, nozzle orientation and nozzle dimensions, the missiles and rocket-propelled grenades are analyzed using the NATO IR Air Target Model (NIRATAM) [2]. The plume flowfields are determined using REP3D [3] and internal motor ballistics are calculated using NASA SP-273 [4]. The tank guns and All Burnt On Launch RPG-18 rocket motor are analyzed using NASA SP-273 and a numerical integration of the spectral radiance equation [5]. This analysis is described in chapter 3. In chapter 4, threat detectability and flight

profiles are used to estimate threat-avoidance capability. This DAS response is essential in simulations of LAV survivability and performance. Additional questions, raised by the operations researchers concerning expected DAS performance, are answered in chapter 4. The questions about modelling DAS performance are answered in chapter 5 including some of the more salient conclusions about DAS performance and and recommendations for future work. The DAS is intended to be a modular, federated system, configurable for specific mission demands and developed based on field trials complemented by detailed:

1. Engineering models of physics and chemistry, these models are then recast, to run in real time, and integrated into

2. Scene generators for sensor and countermeasure design. Tactics and doctrine can be developed and integrated into

3. War-gaming simulators for brigade-level simulations.

This approach to modelling and simulation is an effective means of transferring knowledge between the scientists, contractors and the military and is discussed in more detail in Annex B. More details can be found in some recent publications on the subject [6] – [11].

Until scene generators can be used to project radiometrically correct images, sensor and countermeasure development will require extensive field testing and evaluation. These evolving technologies, driven by new threat systems, will result in a penury that can be met by developing surrogate missiles. This approach is discussed in Annex C.

2.   Threat definition and susceptibility to detection

Weapons fire can be detected, except in the smallest calibers, by muzzle blast or rocket exhaust. Propellant combustion, needed to generate the necessary kinetic energy, produces high-temperature exhaust containing carbon dioxide, water and air detectable in the mid-IR region of 3-5 μm. A more direct assessment of the threat is possible with active sensors such as radar. The range, and in turn the response time, has to be limited to avoid being detected by another platform. Finally, acoustic threat detection can be used to overcome countermeasures such as flash suppression and silencers, especially in the smallest calibers. In some cases, the threat can be detected indirectly by detecting an active component of the targeting systems, for example lasers are used to determine ranges, designate targets and guide beam-rider missiles. In the following chapters, specific threats are analyzed and the susceptibility to detection is discussed.

2.1   Anti-tank missiles

Anti-tank missiles are shown in Figures 1 and 2. Common features include a boost motor exhausting through two nozzles on either side of the missile. This configuration avoids interference with the SACLOS guidance [1]. A clean-burning propellant is also essential in maintaining control of the missile. Detection of these missiles depends primarily on detection of the exhaust plumes at ranges up to 5500 m. Detection at closer ranges, and the boost motor is spent, is possible by infrared sensors and radar.

AT-5 Spandrel relies on wire guidance to correct the flight path relative to an infrared beacon at the back of the missile. A boost motor increases the velocity to about 208 m/s and a maximum range of 4000 m is achieved in about 19 s. The newer version, the AT-5B, allows the operator to switch to a manual mode if optical jamming is detected.

AT-11 Sniper is a laser-beam rider launched from the 125 mm tank gun. The maximum range is 5000 m.

AT-13 Metis-M is a wire-guided missile using a pyrotechnic flare as an infrared beacon. The boost velocity is 200 m/s and the maximum range is about 1500 m.

AT-14 Kornet relies on laser beam guidance to achieve a maximum range of 5500 m. The boost velocity is estimated to be 25025 m/s.

TOW 2A is shown for reference only.

2.2   Direct-fire weapons

Direct fire threats include 125 mm gun rounds shown in Figure 3 and 30 mm rounds shown in Figure 4.

2.2.1 Kinetic energy projectiles

The lethality of these threats can be mitigated by using appliqué armour.

125 mm APFSDS is actually a 30 mm diameter rod fitted to a 125 mm sabot. This threat is difficult to counter due to the high velocity over a relatively short range.

30 mm AP includes both a full-bore penetrator and a sub-bore, 14.5 mm, fitted to a sabot.

2.2.2 Shaped-charge warheads

Shaped-charge explosives can penetrate virtually any practical thickness of armour.

125 mm HEAT relies on a single shaped-charge warhead to defeat armour. Explosive reactive armour which normally can be used to defeat this type of threat cannot be used with LAVs because of the reduced structural integrity.

2.3   Anti-tank rockets

Both the RPG-16 and RPG-18 depend on rockets to deliver the explosive charge but the motor designs are very different as shown in Figure 5.

RPG-16 is described a being similar to the RPG-7 with a somewhat smaller warhead, at 58.3 mm caliber and a longer range, 800 m.

RPG-18 has a much shorter range, 200 m, and the propellant is all burnt on launch.

M-72 is shown for reference only.

2.4   Anti-personnel grenade

Explosive grenades can be fired from automatic grenade launchers with smaller calibers including 30 mm.

AGS-17 is shown in Figure 6. Although probably not a direct threat, vehicle sensors are relatively fragile and DAS performance can be degraded if enough sensors are lost.

2.5   Indirect fire weapons

Indirect fire weapons have a longer range but a lower muzzle velocity and therefore a high angle of attack.

M-712 Copperhead would be very difficult to detect except for the laser needed to designate the target. Being an active system, a jammer or a false target generator can be designed to defeat the missile. Otherwise the missile, shown in Figure 7 can be defeated by a hard-kill system.

An interesting example of an LSAH missile is the Israeli LAHAT designed by IAI subsidiary MBT. Unlike the Copperhead which is fired from artillery, the LAHAT can also be fired from existing 105 mm and 120 mm tank guns. The missile can be stored with other rounds in the vehicle.

Sensor-Fuzed Submunitions invariably use a shaped-charge warhead to defeat armour and can use multiple sensor to avoid countermeasures. These threats can be detected sufficiently early but the low velocity makes them difficult to interpret as a threat. Countermeasures to this type of threat include metal flake grenades with additional chaff launched at a relatively high angle. These countermeasure are described in more detail in Annex A on Soft-kill Strategies. Some examples of sensor-fuzed submunitions include:

– SADARM (Sense and Destroy Armor) which is a smart submunition for 155 mm artillery and MLRS. The SADARM uses a fusion of three sensors, active and passive MMW and imaging infrared, to detect and home in on targets.

– BAT (Brilliant Anti-Tank) is an acoustic and infrared guided submunition that searches, tracks and defeats mobile targets. The BAT is delivered to the target vicinity by MLRS and glides to the target.

– Swedish Bombkapsel m/90, BK90, Mjölner is delivered to the site by low-flying aircraft and releases a pattern of proximity-fuzed bomblets 250 m wide and as long as 400 m. There may be sufficient metal flake and chaff to trigger the proximity fuze but the real solution may be to fire on the aircraft.

– BLU-108/B submunition is dispensed by the SFW (NSN 1325-01-8801), which is a wide-area munition. The BLU-108/B in turn dispenses four submunitions using active laser and passive infrared to home in on the target.
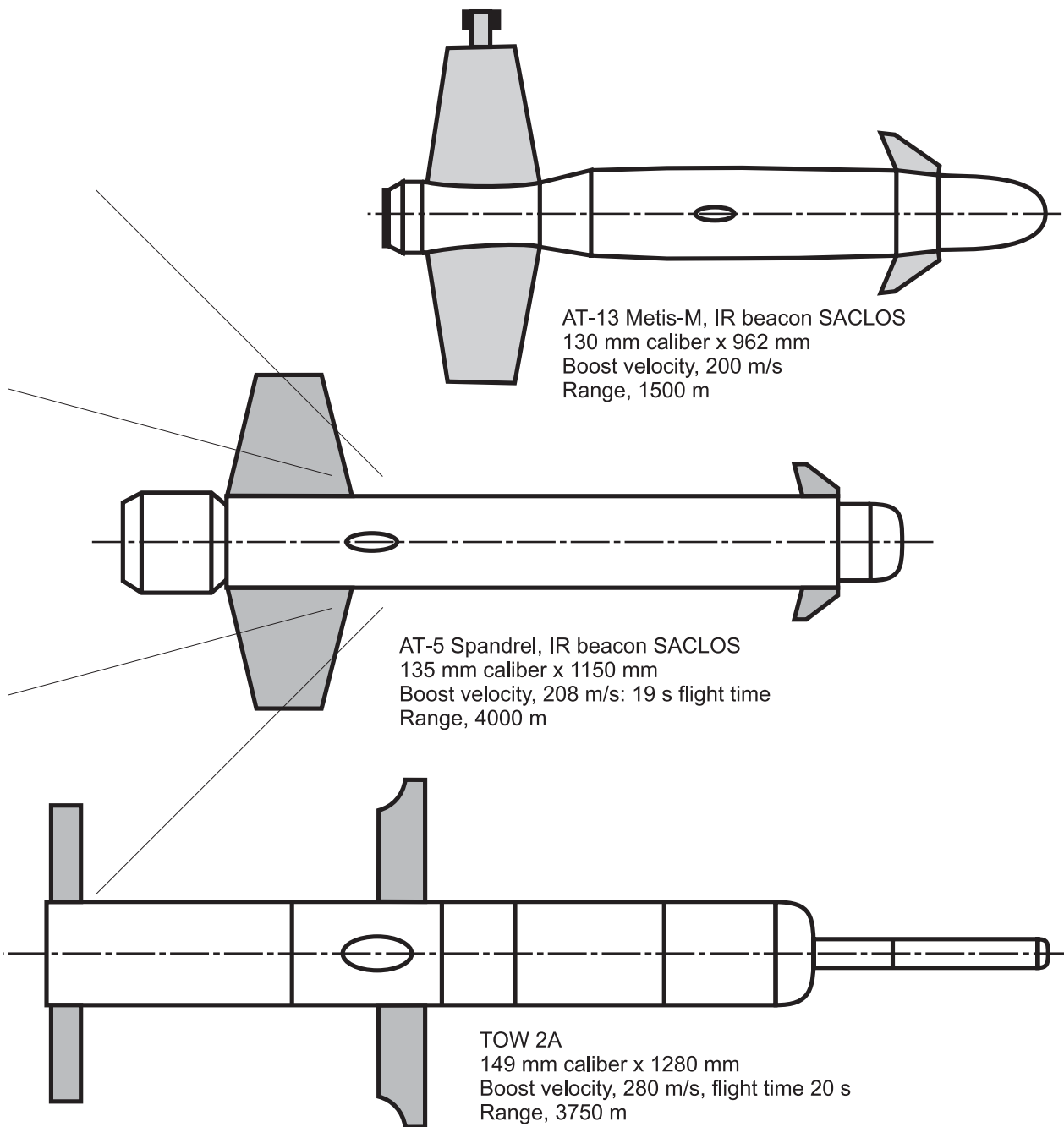
Figure 1. *The AT-13 Metis-M* (top) *and the AT-5 Spandrel* (middle) *both rely on IR beacons to guide the missile to the target. Both missiles are susceptible to jamming from false beacons and wide-area active smoke sources. The TOW 2A* (bottom) *is shown as a reference. The rocket nozzles are inclined 30° relative to the centerline. The exhaust plumes produced by the inclined nozzles are outlined for the AT-5. The fins and control surfaces are shaded.*

AT-11 Sniper, LBR SACLOS
125 mm caliber x 695 mm
Boost velocity,
Range, 5000 m

AT-14 Kornet, LBR SACLOS
152 mm caliber x 1210 mm
Boost velocity, 250 m/s
Range, 5500 m
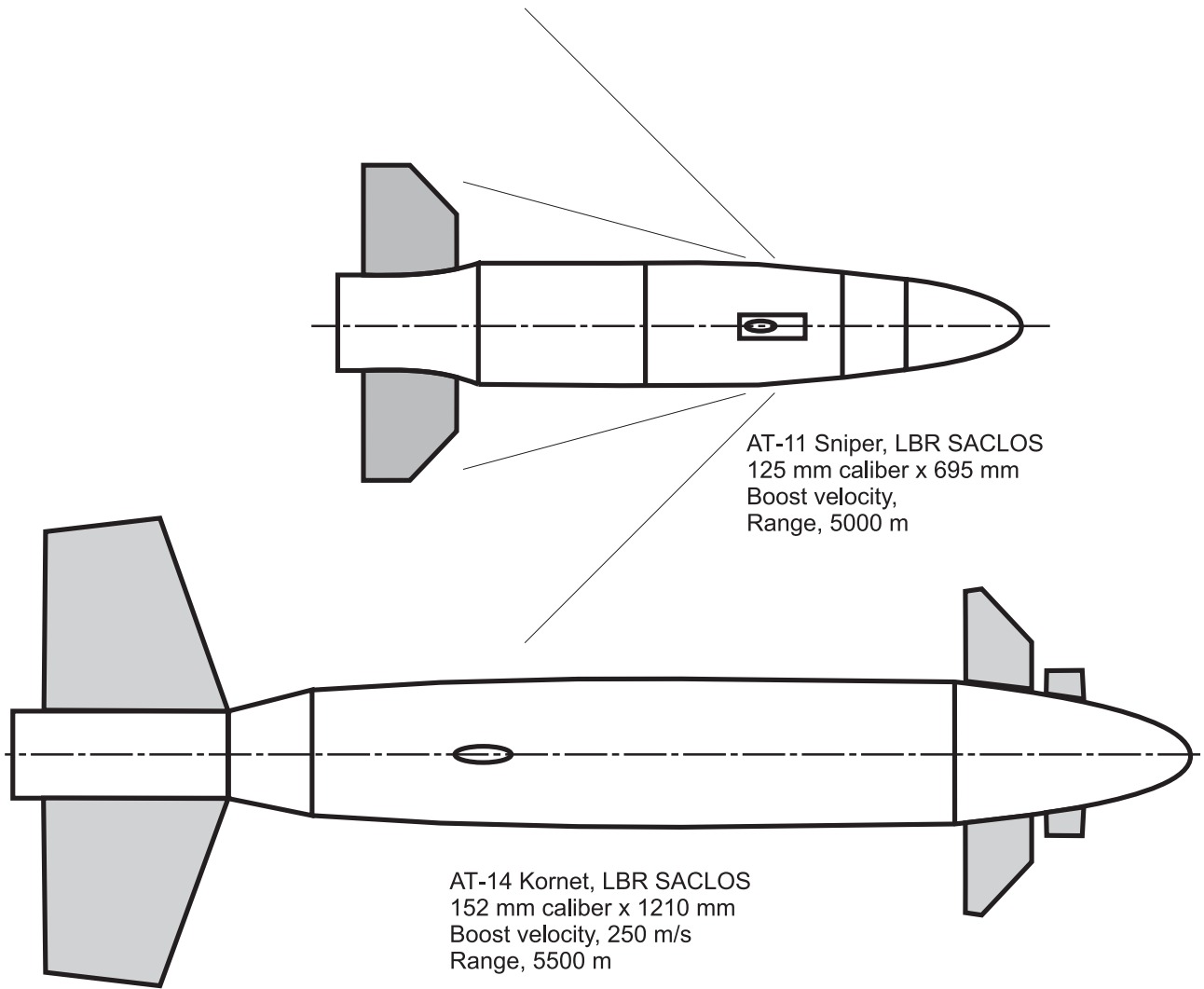
Figure 2. *Two beam riders, the AT-11 Sniper and the AT-14 Kornet, are depicted. The AT-11 is launched from the 125 mm gun.*

125 mm caliber, 30 mm APFSDS sub-bore
Muzzle velocity, 1700 m/s
Range, 2000 m

125 mm caliber, HEAT
Muzzle velocity, 915 m/s
Range, 4000 m
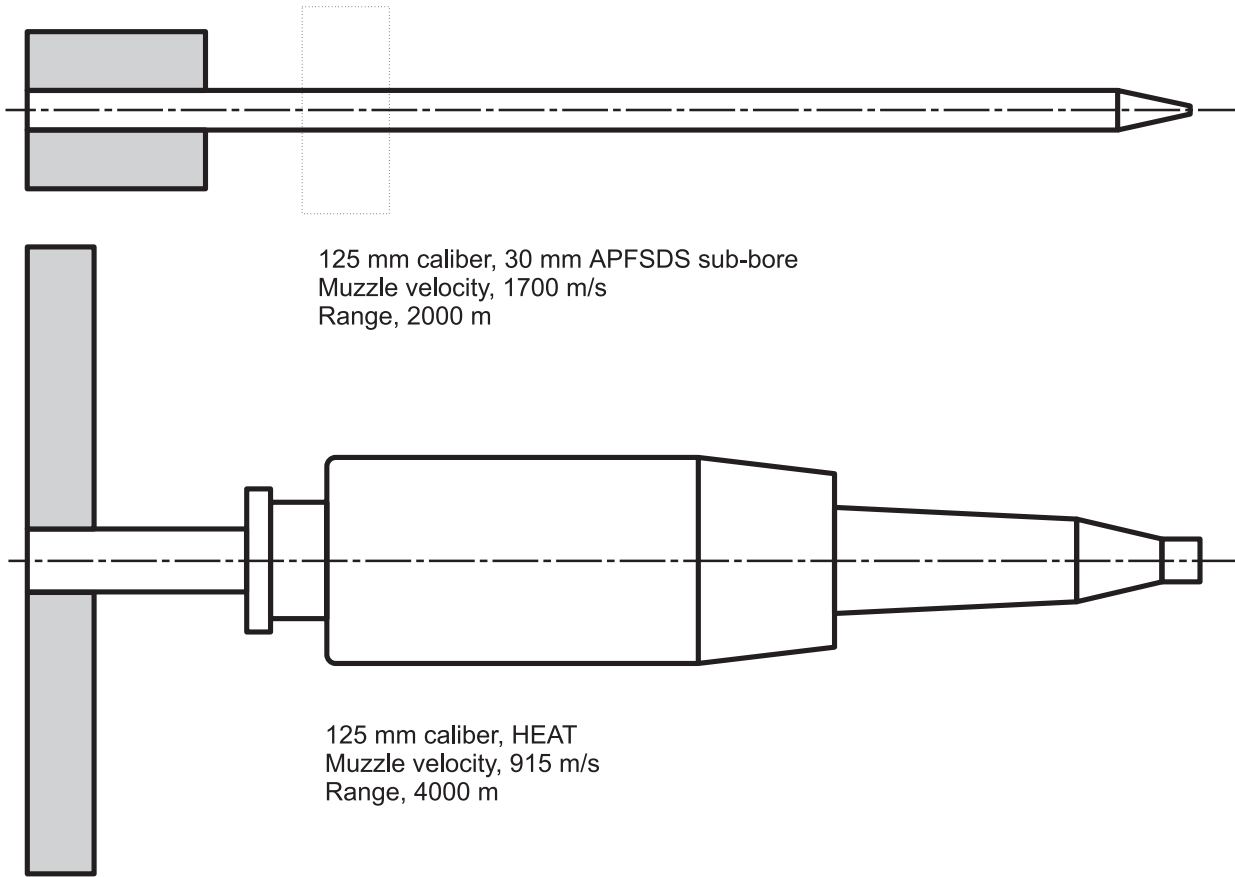
Figure 3. *Both rounds are fired from the 125 mm gun. The APFSDS rod* top *is a high density 30 mm rod fitted to a sabot. The 125 mm diameter is shown as broken lines for reference. The HEAT round* (bottom) *is a single shaped-charge explosive.*

30 mm caliber, AP
Muzzle velocity, 950 m/s
Range, 4000 m

30 mm caliber, APDS, 14.5 mm sub-bore
Muzzle velocity, 950 m/s
Range, 4000 m

Figure 4. *Automatic weapon 30 mm rounds are shown. Both are armour piercing projectiles. The full-bore projectile* (left) *is the same diameter as the APFSDS rod above. The hard-kill system has to distinguish by differences in velocity. The sub-bore projectile* (right) *is virtually as effective as the full-bore version but more difficult to detect.*

RPG-16
58.3 mm caliber x 1104 mm
Boost velocity, 350 m/s
Range, 800 m maximum

RPG-18, ABOL
64 mm caliber x 644 mm
Muzzle velocity, 115 m/s
Range, 200 m

RPG-7
80 mm caliber

M72
66 mm caliber
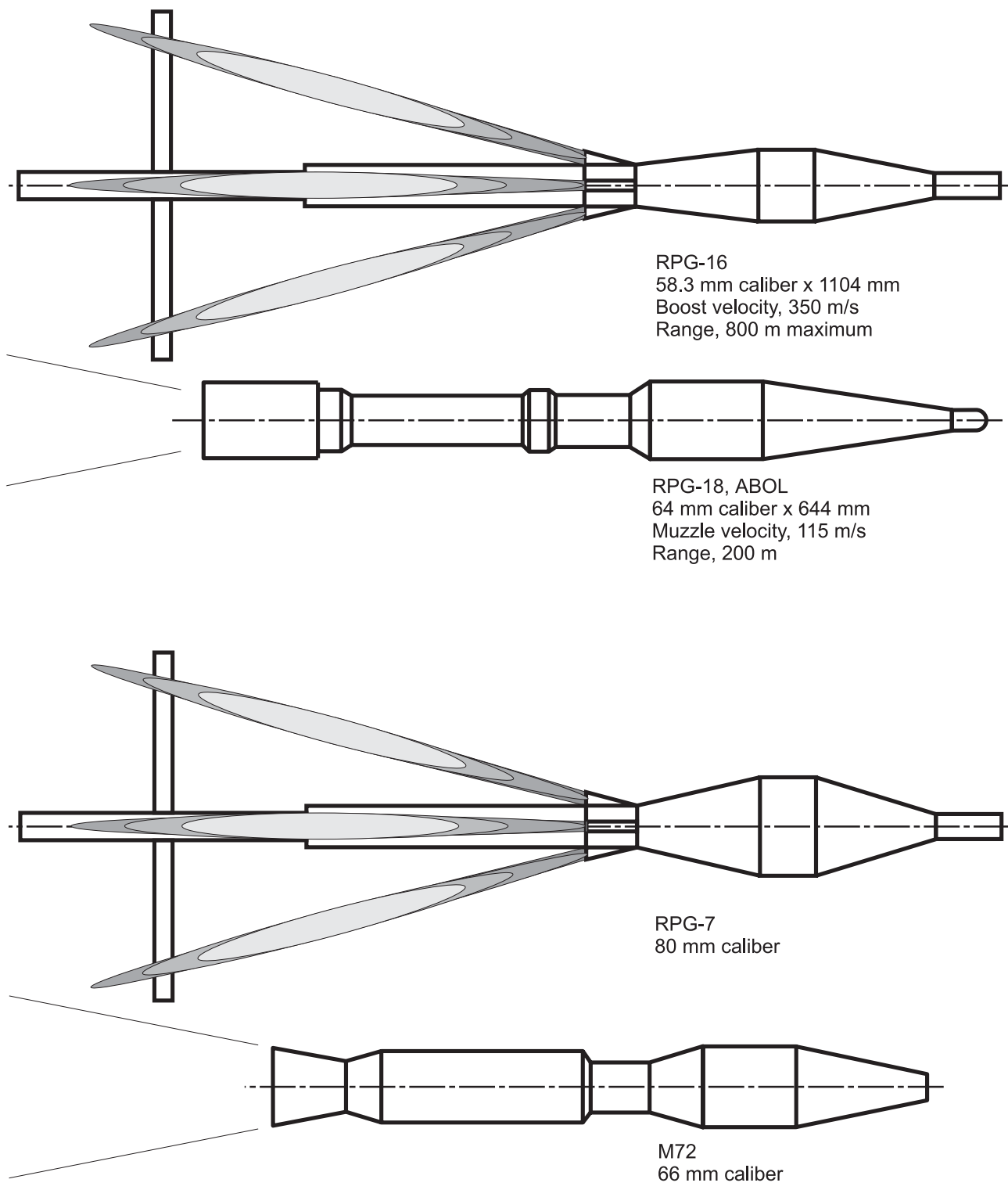
Figure 5. *Four rocket-propelled grenades are depicted. The RPG-16* (first) *is similar to the RPG-7* (third)*. The RPG-16 and RPG-7 designs have six exhaust nozzles inclined at 15°. The RPG-18* (second) *and the M-72* (fourth)*, shown for reference, have single rocket exhausts, shown in outline, and the propellant is all burnt on launch.*
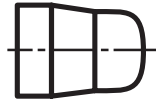
AGS-17, AGS-30, grenade
30 mm caliber x 40 mm
Muzzle velocity, 185 m/s
Range, 1700 m maximum

Figure 6. *The 30 mm grenade is an anti-personnel round, and as detectable as the 30 mm full-bore penetrator, but with a reduced muzzle flash.*
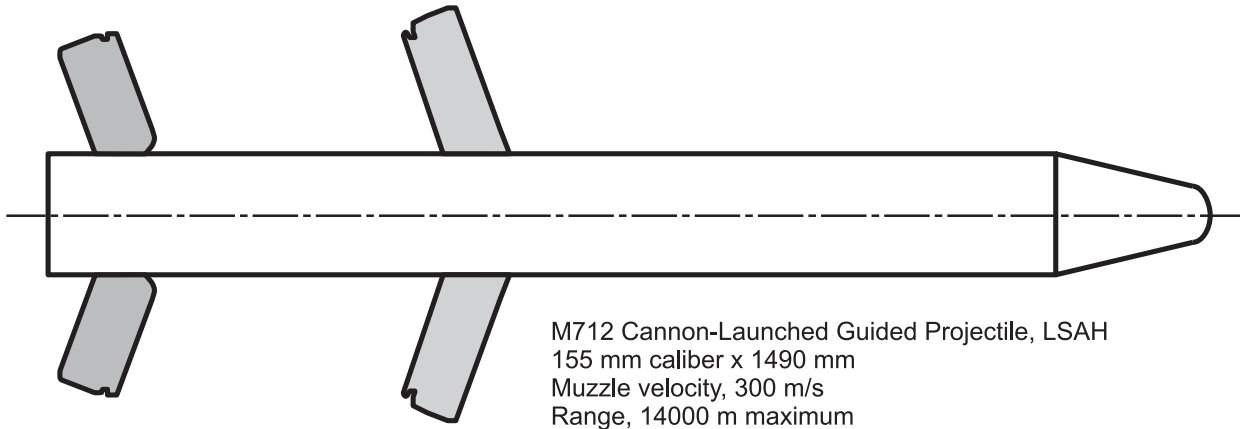
M712 Cannon-Launched Guided Projectile, LSAH
155 mm caliber x 1490 mm
Muzzle velocity, 300 m/s
Range, 14000 m maximum

Figure 7. *The M-712 missile is shown. The missile is difficult to detect due to the lack of a boost motor. The missile surface temperature is also relatively low due to the subsonic flight. Detection may be possible from the flash of the 155 mm artillery.*

Table 1. *Threat visibility and performance characteristics*

Anti-Armour Threats	Physical Variables		
Threat, caliber (mm)	Nose-on dimensions (m)	Combat range (m)	Average velocity (m/s)
M-712 Copperhead, 155	0.155 dia.	14000	255
AT-5 Spandrel, 135	1.83 × 0.33	4000	175
AT-11 Sniper, 125	0.63 × 0.13	5000	255 est.
AT-13 Metis-M, 130	1.34 × 0.23	1500	170
AT-14 Kornet, 152	1.22 × 0.16	5500	210
TOW 2A, 149	3.61 × 0.52	3750	235
RPG-7, 80	0.18 dia.	500	255
RPG-16, 58.3	0.18 dia.	800	300
RPG-18 rocket, 64	3.3 dia.	200	95
Tank gun round, 125, HEAT	6.6 dia.	4000	775
Tank gun round, 125, APFSDS	6.6 dia.	2000	1450
Tank AW round, 30	2.1 dia.	4000	815
Tank AW round, 30, APDS	2.1 dia.	4000	815

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3.   Estimated infrared radiation from threats

Threats are analyzed based on their detectability, which is either gun launch or rocket propulsion. Most threats to land vehicles are based on chemical propulsion and include guns with short duration, high intensity bursts of energy and rockets with low intensity, long burning propellant. In some missile systems, propellants burn cleanly to avoid interference with missile guidance but the products of combustion include significant amounts of hot water vapour, carbon dioxide and carbon monoxide radiating in precise rotational-vibrational bands. The more useful band centers include: 2.7 μm for water and carbon dioxide, 4.3 μm for carbon dioxide and 4.67 μm for carbon monoxide. Plume temperatures can exceed 2000 K, but with entrainment of surrounding air the products of combustion rarely exceed 1600 K. Based on these factors, the mid-infrared range of 3-5μm is chosen for detection of threats based on chemical propulsion.

3.1   Modelling of missiles and rockets

NIRATAM (NATO Infra-red Air Target Model), originally designed to predict IR signatures from free-flight aircraft, is used in this study to analyze the missiles. The various factors influencing missile detectability are considered and the signature, from 2μ to 14μ, is predicted. Detection is affected by adverse conditions including atmospheric attenuation over long distances, sun and sky background clutter and missile hardbody and plume geometries.

The missile surface is assumed to be at a uniform temperature of 307 K with surface properties including an emissivity of 0.55 and a specular reflectivity of 0.75. The plume signature is determined by first solving for the shape, structure and composition of the plume and then using the solution to determine the optical properties and concentration levels of the emitters. The spectral radiance from the plume is determined based on the temperature and composition along the non-homogeneous path.

The exhaust plume is a supersonic fuel-rich flow. Underexpansion of the flow can produce a series of oblique and normal shock waves which further heat the plume. As air is entrained through turbulent mixing, exothermic reactions raise the temperature even more and produce additional quantities of CO_2 and H_2O. The requirements for an optically clean guidance path and low mobility of the targets leads to exhaust gases directed away from the guidance path. Except for the rocket propelled grenades, each missile has two exhaust plumes angled at 30° relative to the centerline, shown in Figures 1 and 2. The rocket propelled grenades, such as the RPG-16, have 6 nozzles angled at 15°, shown in Figure 5.

REP3D (Rocket Exhaust Plume) was developed to model these complex flows. Boundaries for the plume flowfield include the nozzle exit plane and the ambient flow of air over the missile. The exit plane conditions are determined using NASA SP-273 assuming "frozen" flow through the nozzle. In this approach, thermochemical equilibrium is assumed in the motor chamber, and the relative concentrations of the product species remain constant up to the nozzle exit plane, in Table 2. NIRATAM is then used to determine the radiance images for the rockets and missiles in flight. The radiance images are shown in Figure 8 and Figure 9 and are used with the sensor suite described in Annex A to determine the detection ranges in Table 5.

Table 2. *Propellant composition and exit plane variables*

Double-based propellant, in mass fractions	
Nitrocellulose, $C_6H_{7.55}O_{9.9}N_{2.45}$ Nitroglycerine, $C_3H_5O_9N_3$ Combustion modifiers	0.510 0.386 0.10
Rocket exit plane	
Axial velocity, m/s Exit pressure, kPa Exit temperature, K Ambient velocity, m/s Ambient pressure, kPa Ambient temperature, K	2261 150 1129 100 101.3 290
Exhaust composition, mole fractions	
N_2 CO H_2O CO_2 H_2	1.174×10^{-1} 3.219×10^{-1} 1.474×10^{-1} 2.056×10^{-1} 2.076×10^{-1}

RPG-7
80 mm caliber
Intensity, 0.97 W/sr
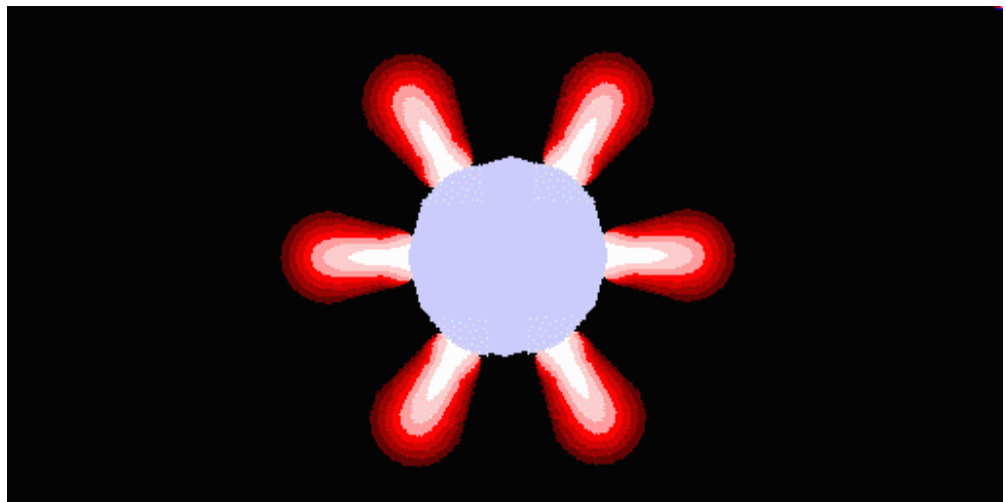
Figure 8. *A radiance image from the RPG-7, the image is 0.4 m wide and 0.2 m high.*

M712 Cannon-Launch
LSAH
155 mm caliber x 1490
Intensity, 0.92 W/sr
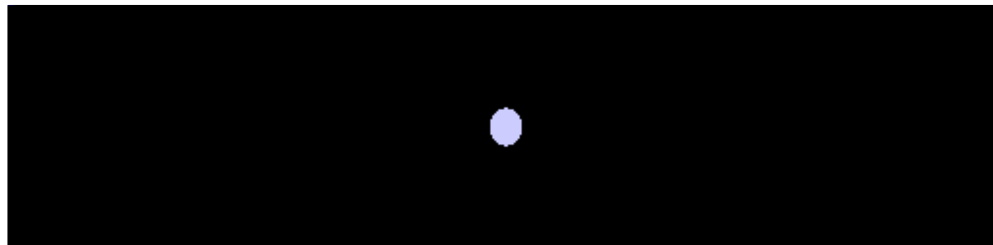
AT-11 Sniper,
LBR SACLOS
125 mm caliber x 695
Intensity, 4.29 W/sr
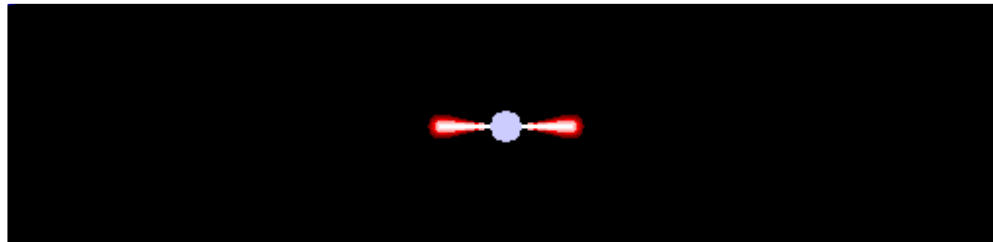
AT-14 Kornet,
LBR SACLOS
152 mm caliber x 1210
Intensity, 44.9 W/sr
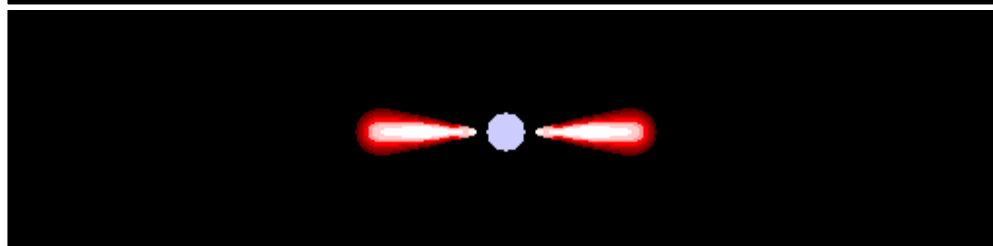
AT-13 Metis-M,
IR beacon SACLOS
130 mm caliber x 962
Intensity, 83.2 W/sr
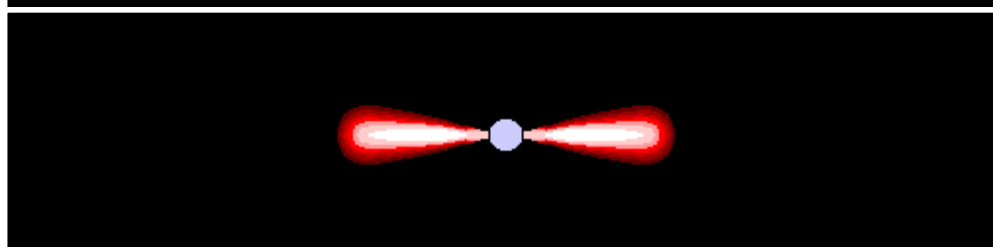
AT-5 Spandrel,
IR beacon SACLOS
135 mm caliber x 1150
Intensity, 203.3 W/sr
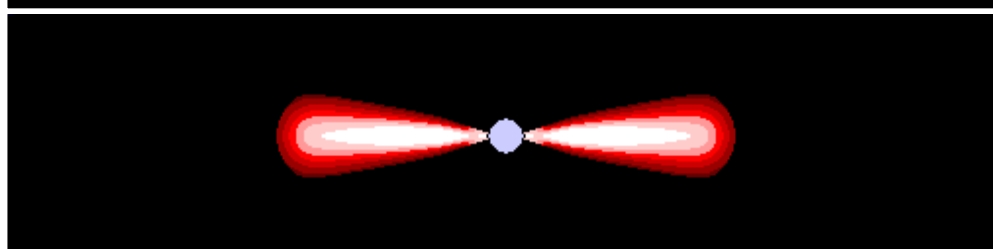
TOW 2A, IR SACLOS
149 mm caliber x 1280
Intensity, 1004.6 W/sr
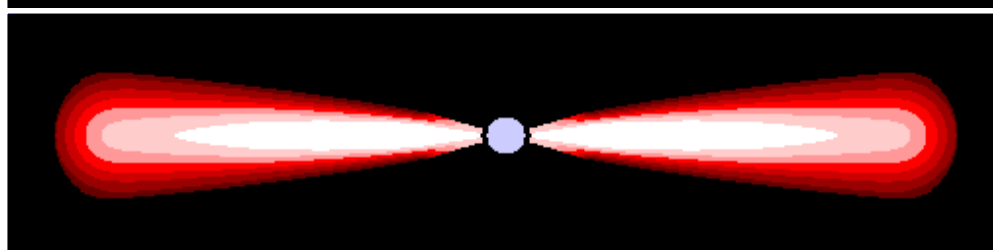
Figure 9. *Radiance images calculated for the various missiles. Each image is 4 m wide and 1 m high.*

3.2 Modelling of muzzle blast

Three projectiles including the 125 mm and 30 mm tank rounds and the RPG-18 are launched by an explosive charge. Radiation from the blast is calculated using the procedure described below. This procedure is based on data acquisition capabilities of ultra-spectral remote-sensing systems such as PIRATES [13]. PIRATES produce an image of the radiation source on a 8×8 pixel array. The spectral resolution is typically 4 cm^{-1} from which the composition and temperature can be determined. For a relatively fast event, such as an explosion lasting 50 ms, a number of explosions are essential to produce a statistically valid representation.

The composition of the blast is determined by assuming that the product gases are in chemical equilibrium. Combustion without energy loss results in an adiabatic flame temperature of 2836 K. An arbitrary quantity of air is then entrained lowering the flame temperature to 2395 K. Finally, energy conversion and transfer is assumed to lower the final temperature to 1500 K. These end states are calculated using models developed by NASA and published as NASA SP-273. Carbon, which along with other particulates can contribute significantly to the visible flash, does not occur in appreciable amount in equilibrium composition. A small amount of carbon is simply added to the final composition without affecting the mass balance. The composition of each state is presented in Table 3.

The local optical properties of combustion gases are determined from the temperature, pressure, and concentration of molecules: CO, CO_2 and H_2O and carbon particles. The molecular vibrational bands are made up of rotational lines represented by a narrow-band model with a spectral resolution of 5 cm^{-1}. The equation of the spectral radiance, N_ω, is stated as:

$$N_\omega \;=\; \int_1^{\tau_\omega} e_{b\omega} d\tau_\omega,$$

where $e_{b\omega}$ is the spectral emissive power and the spectral transmittance $\tau_\omega \;\equiv\; \exp[-X]$, is solved numerically along homogeneous optical paths, X using the narrow-band model. Solutions of this equation are presented in Table 4. The accuracy of this approach can be improved by further trials and improved interpretation of experimental results. In Table 4, the diameter of the blast from the 125 mm round is estimated to be 6.6 m. This estimated diameter can be compared with the dimension of the muzzle blast from the 120 mm gun on the Leclerc main battle tank shown in Figure 10. The dimensions of the muzzle blast are then used with the sensor suite, described in Annex A to determine the detection ranges listed in Table 5.

Table 3. *Blast composition*

Modelling Parameters	Chemistry and Energy Loss Effects			Radiant Mixtures	
Flame Characteristics	Adiabatic Flame	Air Entrainment	Energy Loss	Minimum Flash	Visible Flash
Reactants, mass fraction					
Nitrocellulose, $C_6H_{7.55}O_{9.9}N_{2.45}$ Nitroglycerine, $C_3H_5O_9N_3$ Air, O_2 $\quad N_2$	0.574 0.426	0.209 0.154 0.134 0.503	0.209 0.154 0.134 0.503	0.209 0.154 0.134 0.503	0.209 0.154 0.134 0.503
Product Mixtures					
Pressure, kPa Temperature, K Density, kg/m^3 Molecular weight, kg/kgmole	101.325 2836 1.149×10^{-1} 26.74	101.325 2395 1.519×10^{-1} 29.770	101.325 1500 2.444×10^{-1} 30.078	101.325 1500 2.444×10^{-1} 30.078	101.325 1500 2.444×10^{-1} 30.078
N_2, mole fraction CO_2 H_2O O_2 CO OH H_2 $C(s)$	1.442×10^{-1} 1.967×10^{-1} 2.659×10^{-1} 1.373×10^{-2} 2.918×10^{-1} 3.055×10^{-2} 5.687×10^{-2} $-$	5.926×10^{-1} 1.834×10^{-1} 1.305×10^{-1} 6.834×10^{-2} 1.427×10^{-2} 9.018×10^{-3} 1.742×10^{-3} $-$	5.987×10^{-1} 1.997×10^{-1} 1.381×10^{-1} 6.322×10^{-2} 3.839×10^{-6} 6.991×10^{-5} 1.031×10^{-6} $-$	5.987×10^{-1} 1.997×10^{-1} 1.381×10^{-1} 6.322×10^{-2} 3.839×10^{-6} 6.991×10^{-5} 1.031×10^{-6} $-$	5.987×10^{-1} 1.997×10^{-1} 1.381×10^{-1} 6.322×10^{-2} 3.839×10^{-6} 6.991×10^{-5} 1.031×10^{-6} 6.837×10^{-4}

Table 4. *Blast radiation*

Modelling Parameters			Minimum Flash		Visible Flash	
Threat	Propellant Weight, kg	Blast Diameter, m	Average Transmissity	Intensity kW/sr	Average Transmissity	Intensity kW/sr
Tank gun round, 125 mm	7.50	6.6	0.85	600	0.35	700
Tank AW round, 30 mm	0.25	2.1	0.85	10	0.45	12
RPG-18 rocket, 64 mm	0.96	3.3	0.85	70	0.45	95

Figure 10. *Typical muzzle blast produced by a 120 mm tank round fired by a Leclerc main battle tank. The vehicle hull is 6.88 m long and the height to the turret roof is 2.53 m.*

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4. Threat response of the proposed DAS

The proposed DAS, described in detail in Annex A, comprises four subsystems. Of these, the soft-kill system can respond to a threat by detecting and avoiding it while the hard-kill system is designed to intercept and destroy the threat. The hard-kill system will defeat every threat, described in this study, effectively except for the 125 mm APFSDS. The APFSDS can be intercepted but the blast interaction will produce sufficient debris to significantly damage the LAV. The response time of the hard-kill system can also be a factor. The AWiSS-K, for example, with a response time of 400 ms is too slow to intercept a APFSDS rod fired within 500 m. The sensors considered below will be the soft-kill system with additional information from the other DAS subsystems. Optimal DAS performance is achievable with early threat detection using the long-range passive sensors and with support from the:

> hard-kill system in **locating the launch platform** as outlined in Table A1 in Annex A and **cueing** from
>
> active targeting detection and
>
> acoustic threat detection to increase overall DAS performance and reliability.

The performance of the soft-kill sensors is shown in Table 5. Table 5 includes the detection ranges for both the WFOV and NFOV IR staring arrays and the ability of the LI/RG camera to detect the launch platform at the threat maximum range. Some of the more salient results are described below.

The **M-712 "Copperhead"** can be detected by both the WFOV and NFOV arrays and tracked by the LI/RG camera over the full range of 14 km. If the missile launch is not detected, the laser designator can be detected by the LWR. In a complete DAS, the hard-kill system provides a back-up if both subsystems fail or are not available.

The **AT-14 "Kornet"** relies on laser beam rider guidance to reach targets up to 5500 m away. Based on exhaust plume dimensions, the missile launch can be detected by the NFOV array in IRST mode. At close range the LWR should begin to detect the signal from the LBR guidance. At about 300 m, the WFOV should begin to detect the missile in post-burnout flight. Detection of the launch platform by the LI/RG camera is possible at the maximum range.

The **TOW 2A missile** is much easier to detect suggesting a fundamentally different philosophy in missile design.

The **Rocket-Propelled Grenades** are relatively easy to detect but very difficult to avoid because of the short distances involved.

The **guns and automatic weapons** are easy to detect with the WFOV arrays but unlike the rocket-based threats the flash duration is too short to detect effectively with an IRST.

Table 5. *Passive staring/scanning optics performance*

Anti-armour Threat	IR WFOV 90°× 90° 4096 × 4096	IR NFOV 2.5°× 2.5° 1024 × 1024	LI/RG Camera 0.5°× 0.5° 1024 × 1024		Threat Variables		
Type Caliber, mm	Distance, m	Distance, m	Threat,[A] pixels	Target[B] pixels	Dimensions, m	Range, m	Velocity,[C] m/s
M-712, LSAH, 155	400	3600	1.3	25 × 20	0.155 dia.	14000	255
AT-5, 135	4770 / 860 [D]	7740[E]	54 × 10	90 × 30	1.83 × 0.33	4000	175
AT-11, LBR, 125	1640 / 330	3050	15 × 3	70 × 23	0.63 × 0.13	5000	255
AT-13, 130	3500 / 600	5400	105 × 18	235 × 78	1.34 × 0.23	1500	170
AT-14, LBR, 152	3180 / 400	3750	26 × 4	64 × 21	1.22 × 0.16	5500	210
TOW 2A, 149	9410 / 1360	12200	113 × 16	94 × 31	3.61 × 0.52	3750	235
RPG-7, 80	470	4200	42 × 42	234 × 187	0.18 dia.	500	255
RPG-16, 58.3	470	4200	26 × 26	146 × 117	0.18 dia.	800	300
RPG-18, 64	8600[F]	1500[G]	37 × 37	586 × 469	3.3 dia.	200	95
Gun, HEAT, 125	17200	3050	16	90 × 30	6.6 dia.	4000	775
Gun, APFSDS, 125	17200	700	4	118 × 60	6.6 dia.	2000	1450
Gun, AP, 30	5480	700	4	118 × 60	2.1 dia.	2000 [H]	815
Gun, APDS, 30	5480	340	0.8	118 × 60	2.1 dia.	2000	815

[A] The dimensions of the threat,for example missile, in pixels at the maximum range on the right.

[B] The dimensions of the "RED" target, e.g. a vehicle firing a missile, at the maximum range.
For the M-712 threat, the target is a 3 m×2 m vehicle, for the missiles and gun rounds a 3 m×1 m turret, and an individual fighter, 1 m×0.8 m, for the rest.

[C] An average velocity estimated to be 85% of the boost or muzzle velocity.

[D] At 4770 m the image is one pixel wide, but not until 860 m is it one pixel high, or 6 ×1 total.
An efficient detection algorithm will detect the threat at about 4700 m, a less effective one at 900 m.

[E] Distance at which the image is one pixel high.

[F] Based on blast detection.

[G] Based on projectile detection.

[H] The next two ranges are reduced from 4000 m to a more useful 2000 m.

M-712 The copperhead is fired by artillery from as far away as 14 km. The blast should be seen and heard sufficiently well to slew the high-speed launcher and mini-turret towards the source. The copperhead has to be guided to a laser-designated target and, normally, the HARLID® would detect the signal. The missile can be detected by

IR NFOV optics at 3600 m, then classified and tracked by the **LI/RG camera** from about 14 s from the vehicle. The countermeasure response would be to:

– fire on the laser source, if possible

– launch a ground and mid-level screen and

– move the vehicle.

If the copperhead launch is not detected, the missile can still be detected by an IRST scan, as outlined in Annex A, Figure A2. Detection is also possible by

IR WFOV optics at 400 m, 1.5 s from the vehicle.

AT-5 The missile is normally an IR-beaconed SACLOS missile but can be guided manually if jamming is suspected. The missile can be detected by

IR NFOV optics at any practical range from the vehicle. The countermeasure response should be to:

– counterfire, if possible

– launch a ground screen and

– move the vehicle.

It can also be detected by:

IR WFOV optics by 900 m, which is 5 s from the vehicle, and the response should be to

– launch a ground screen, and, simultaneously

– change speed or move the vehicle.

AT-11 The missile is launched from the 125 mm gun and guided to the target by laser. Detected by the initial blast, the missile can be tracked by the

LI/RG camera over the full range. The missile can also be detected by

IR NFOV optics by 3050 m, which about 12 s from the vehicle. The response should be to:

– launch a ground screen, and, simultaneously

– change speed or move the vehicle.

It can also be detected by:

IR WFOV optics by 330 m, at only 1.3 s from the vehicle. Since the laser beam riders are guided by an active laser source, a more reliable procedure may to use the *Brilliant* system to detect the source and jam it.

AT-13 The missile is based on a SACLOS design with a pyrotechnic flare as a beacon. The missile is susceptible to countermeasures including false beacons and wide-area active smoke. It can be detected by

IR NFOV optics at any practical range from the vehicle. The countermeasure response should be to:

- counterfire, since the maximum range is 1500 m, and if not successful
- launch a ground screen and
- move the vehicle.

It can also be detected by:

IR WFOV optics by 600 m, which is 3.5 s from the vehicle, and the response should be to

- launch a ground screen, and, simultaneously
- change speed or move the vehicle or simply lock up the brakes automatically.

AT-14 The missile is LBR SACLOS design with a maximum range of 5500 m. Similar to the AT-11, *Brilliant* should be considered to detect and jam the missile. It can be detected by:

IR NFOV optics by 3750 m, 18 s from the vehicle. The response could be to:

- launch a smoke ground screen, and, simultaneously
- change speed or move the vehicle.

It can also be detected by the

IR WFOV optics by 400 m, only 1.9 s from the vehicle. The response could be to:

- change speed or move the vehicle or simply lock up the brakes automatically.

TOW 2A The missile is a SACLOS missile using a xenon beacon. The missile is therefore not susceptible to false beacons but can be susceptible to wide-area active smoke if the intensity is sufficiently high and noisy. The missile can be detected by

IR NFOV optics at any range from the vehicle. The countermeasure response should be to:

- launch a ground screen and
- move the vehicle.

It can also be detected by:

IR WFOV optics by 1360 m, which is 5.8 s from the vehicle while under boost, and the response should be to

- launch a ground screen, and, simultaneously
- change speed or move the vehicle.

In post-burnout the missile can be detected by:

IR WFOV optics by 400 m, which is 1.7 s from the vehicle, and the response should be to

- lock up the brakes automatically or move the vehicle, depending on threat location.

$\boxed{\textbf{RPG-7}}$ This is a generic RPG with a typically short range and high subsonic velocity sustained over the entire flight. It can be detected by the

IR NFOV optics at any range. Countermeasures would be to:

- change speed or move the vehicle or simply lock up the brakes automatically and, simultaneously,
- fire on the shooter.

It can also be detected by the

IR WFOV optics by 500 m, only 1.0 s from the vehicle.

Scanning the battlefield with the LI/RG camera on active will also detect the shooter through retroreflection. Dazzling while scanning can also disrupt any attempt to aim the weapon.

$\boxed{\textbf{RPG-16}}$ The grenade is similar to the RPG-7 but a smaller caliber. The range is also longer at 800 m. It can be detected by

IR NFOV optics at any range. The response would be to:

- change speed or move the vehicle or simply lock up the brakes automatically and, simultaneously
- fire on the shooter.

It can also be detected by the

IR WFOV optics by 500 m, only 1.0 s from the vehicle.

$\boxed{\textbf{RPG-18}}$ Unlike the two RPGs above the propellant in this grenade is all burnt on launch. The grenade is therefore relatively easy to detect by IR WFOV from the flash produced.

IR NFOV optics at the maximum range of 200 m. With an average velocity of 95 m/s, the flight time is 2.1 s. The response would be to:

- change speed or move the vehicle or simply lock up the brakes automatically and, simultaneously

– fire on the shooter. It can also be detected by

Gun: 125 mm HEAT The blast can be easily detected by the IR WFOV optics. The LI/RG camera can be used to track the projectile and at distances greater than 1500 m, 2.0 s from the vehicle, initial blast, the missile can be tracked by

LI/RG camera over the full range. The missile can also be detected by

IR NFOV optics by 3050 m, 12 s from the vehicle. The response could be to:

– launch a ground screen, and, simultaneously
– change speed or move the vehicle or simply lock up the brakes automatically.

Gun: 125 mm APFSDS The only reasonable response would be to hand off to the hard-kill system tracking radar. The IR NFOV optics and LI/RG camera can be used to provide more precise information for the hard-kill system.

Gun: 30 mm AP Detection of the blast by the IR WFOV can be used to slew the IR NFOV optics and the projectile is then tracked by the LI/RG camera. The first burst of 3-5 rounds is stopped by the appliqué armour, during this time the main turret is slewed to the threat and removed by counterfire.

Gun: 30 mm APDS Same process as above. The difference is that subbore projectiles are somewhat more difficult to detect.

Sensor-Fuzed Submunitions The submunitions are relatively easy to detect but difficult to classify as threats because of the low velocity. The IR WFOV would detect the submunition locked on the vehicle and the response would be to launch the top and mid-level obscuration and move the vehicle away from the threat. The hard-kill system would simply destroy the submunition with a fragmentation grenade.

5.   Discussion, conclusions and recommendations

The hard-kill system, based on search and track radar and intercepting grenades, will defeat most threats at close range. A vehicle equipped with a hard-kill system only will probably meet the desired level of survivability without additional technology. Acoustic threat detection, primarily needed for sniper detection, will increase the robustness of the DAS and extend the detection range to include small calibers. Detection of active targeting systems, based on laser and radar warning receivers, can be justified for Identification, Friend or Foe requirements. The remaining soft-kill subsystem includes long-range sensors used primarily for manoeuvring, targeting and surveillance with threat avoidance by countermanoeuvre, obscurants and counterfire. This study concentrated on the soft-kill subsystem performance which is the most variable and most difficult to analyze.

If some of the long-range sensors have been lost or are not available, the following threat avoidance procedures can be carried out.

IR WFOV only:, which is comparable in design to an Air Force IR MAWS. If the threat signal is

- inside 45° of fore or aft,

    - steer the vehicle away from the threat and simultaneously put out a
    - ground screen of three grenades plus one at mid-level.
    - counterfire when the vehicle clears the screen.
    - if counterfire is impossible, put out more smoke and remove the vehicle from the vicinity.

- outside the 45° arc,

    - launch a ground and mid-level screen,
    - lock-up the brakes to avoid running past the smoke screen, and after a few seconds,
    - counterfire when the vehicle clears the screen.

IR NFOV only:, which is comparable to a Navy IRST. The mini-turret optics can be set to scan automatically with a slew rate of $720°/s$.

- On level ground, the mini-turret can be used to scan for threats over a $135°$ arc in 1.9 s, which is long enough to detect any ATGM at 3 km. A $360°$ arc can be swept in 4.8 s during which the IR NFOV optics can detect missile launches, and subsequent post-burn out phase, closer than 1.5 km. On the mini-turret, dazzling, to inhibit aiming a weapon, and laser illumination, limited to $0.5° \times 0.5°$, to detect threat optics and hard surfaces is also available.

- On complex terrain, scanning is slower, and threats are closer to the vehicle. An arc $135° \times 30°$ would take 10.8 s to scan. Therefore, distant threats can be no closer than about 5 km from the vehicle for the IR NFOV optics to warn early enough.

The countermeasure response would be similar to the WFOV detection above. The following is a reply to issues raised by DGOR and DLR on the performance of a DAS equipped vehicle.

"...**possible scenarios for IRON GORGET have been discussed**" More details on the scenarios would be useful in fixing a reasonable DAS response.

"**danger area of any hard-kill DAS**" Deflecting a APFSDS rod has to occur by about 50m. A safe area would be 60m and if passive sensors are used then everyone, including vehicles, needs IFF.

"**DAS** ... **counter-fire** ... **pop smoke automatically**" The objective in developing the DAS is to fit as many countermeasures as possible in the timelines available. As the threat detection, classification and tracking algorithms mature and become more reliable, more countermeasures can be automated. Smoke, and dazzling when possible, should be used to remove RED targeting capability during which time the vehicle can be repositioned to counterfire or leave entirely. Automatic counterfire is set by the crew to respond to threats in an area where only RED forces are expected. If the crew needs to identify the threat, the LI/RG camera can be used to recognize and identify a 64×64 pixel 200mm image at 360m or a 2 m$\times$2 m object at 3.6 km

"**DAS against multiple shots** ... **overwhelm it with simultaneous shots**" Two scenarios are defined.

> **against an RPG firing line** The mini-turret was not scanning for this threat and it is being detected either by the hard-kill system, where the hand off to the soft-kill system is described in Annex A, Table A1, or by the IR WFOV optics. The response would be:
>
> – slew the high-speed launcher and mini-turret toward the threat,
> – destroy the first grenade, simultaneously dazzling and launching a 3-grenade smoke screen and slewing the main turret toward the threat, the elapsed time for this sequence is less than 0.24s. This is followed by
> – counterfire with the 7.62mm MG when the vehicle runs past the smoke screen.
>
> For the RPG line to function effectively, all RPGs have to fired within 0.24s of the first.
>
> **LAV enters a killing ground** RED weapons are being fired simultaneously, the DAS processors interpret this as an increase in the rate of threat detection. Above a certain threshold, two or more threats detected within 4s and widely dispersed, all forward smoke grenades are launched, the location of threats is recorded automatically, the vehicle is reversed away from the field and the hard-kill system defeats any threats approaching the vehicle. If the grenades include vis/IR/MMW screening, only the acoustics are working now.

A vehicle network [9] could respond to multiple threats more effectively but would probably not be sufficiently well developed by 2010.

"**multiple incoming rounds** ... **180 degrees of separation** ... **different for hard and soft-kill DAS**" Consensus is developing that peacekeeping vehicles can expect threats from

any direction. Both the hard-kill and soft-kill systems are based on that premise. The only way to remove the threats is by counterfire. Obscuration is used to offer some protection so that the LAV decides what the counterfire sequence should be and the hard-kill system protects against any rounds that get through.

"how many incoming rounds can it kill" Each high-speed launcher seems to hold 2 grenades. DRDC-Valcartier is developing expertise in these areas to work with suppliers in developing capabilities that meets CF requirements [12]. There should be an emphasis on understanding how these systems work. It is impossible to evaluate these systems without knowing what to test. For example the explosive grenade will deflect a 1700 m/s KE rod but not one at 2100m/s, such as CKEM and HEMi. This upper limit occurs because the blast wave from the explosion travels at about 2000m/s and the interaction time is too short.

"speed of the incoming round makes a difference ... **125 mm HEAT** ... **125 mm APFSDS"** KE rounds are difficult to destroy and will continue to be a problem. A deflected rod or debris from a broken or segmented rod is a less effective penetrator but the kinetic energy is still there. At the shorter timelines, errors in estimating position and velocity are greater and the demands on processing increase. All these factors increase the probability of making a mistake.

"whether an active DAS could deal with a steady stream of incoming medium calibre rounds" The damage by any weapon would include losing sensors. A soft-kill sequence ending with counterfire is shown in Annex A, Figure A6. A MEMS gyroscope, a gyroscope on a chip, can keep track of the target so the crew can fire through the smoke. Another possibility is to use visible screening only and use the IR optics for targeting.

"DAS counter artillery delivered TGMs (like SADARM)" Detected either by the blast or the released submunition by the IR WFOV or IRST. The latter is also detected and destroyed by the hard-kill system.

"laser designated PGMs (like Copperhead)" The laser source is detected by the LWR. The countermeasure response would be to counterfire and if necessary, launch smoke grenades at the designator and at mid-level. The blast is detected by the IR WFOV and the missile can be tracked by the LI/RG camera. At shorter ranges the missile is detectable by the IR WFOV optics at 400 m and possibly by the IRST by 3600 km. The hard-kill system will detect, classify and destroy it with a fragmentation grenade.

"what we will be able to model" These studies are needed to guide DAS development. Hardware performance is reasonably well understood but the algorithms and software needed to operate the hardware and integrate it on the vehicle have to be developed. These studies would be useful in determining the amount of hardware needed and the level of automation needed to fit the timelines.

"three or more levels of DAS performance" The DAS should be a modular, federated system capable of compensating for hardware and sensor failure [9] as discussed in Annex A. In fact the DAS at the beginning of the battle will probably look nothing like the DAS at the end. The DAS is not about a bolt-on black box but using all the technology on the vehicle to improve survivability. The hard-kill system is the only dedicated DAS subsystem. The other subsystems would be designed for a dual-purpose, for example for targeting or driving the vehicle.

In conclusion, current technology trends in sensors, computers and countermeasures can be exploited successfully to meet new vehicle requirements and anticipated future battlefield environments. The DAS used in this analysis was proposed before the list of IRON GORGET threats was made available, nonetheless, the DAS responds well and is inherently configurable to mission of battlefield requirements.

This emphasis on modelling and simulation as an R& D tool is a new procedure for developing and integrating DAS technology. Prototype development and field trials are legacy activities which can be combined with on-going modelling and simulation development. This new capability will provide a better estimate of vehicle performance on the battlefield and lower the cost of DAS development by complementing existing the Man-In-the-Loop facilities.

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List of
symbols/abbreviations/acronyms/initialisms

AOA – Angle-Of-Arrival

ABOL – All Burnt On Launch

AGS – Automatic Grenade System

AP – Armour Piercing

APC – Armoured Personnel Carrier

APDS – Armour Piercing Discarding Sabot

APFSDS – Armour Piercing Fin Stabilized Discarding Sabot

AT – Anit-Tank

ATGM – Anit-Tank Guided Missile

DAS – Defensive Aids Suite

DIRCM – Directional InfraRed CounterMeasure

FCS – Fire Control System, or Future Combat System

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

HEAT – High Energy Anti-Tank

IR – InfraRed

IRST – InfraRed Search and Track

KE – Kinetic Energy

LAV – Light Armoured Vehicle

LSAH – Laser Semi-Active Homimg

LWR – Laser Warning Receiver

LI/RG camera – Laser Illuminator/Range Gated camera

MAWS – Missile Approach Warning System

MBT – Main Battle Tank

MIL – Man In the Loop

MLRS – Multiple Launch Rocket System

MMI – Man-Machine Interface

MMW – MilliMetre Wave

NFOV – Narrow Field of View

OR – Operational Research

RWR – Radar Warning System

RPG – Rocket Propelled Grenade

sabot – contains the sub-bore projectile, separating from the projectile during flight

SACLOS – Semi-Automatic Command to Line of Sight

TOW missile – Tube launched Optically sighted Wire guided missile

VIRSS – Visible InfraRed Smoke Screen

WFOV – Wide Field of View

Annex A: DAS development based on technology trends

Light Armoured Vehicles meet the requirement for rapid deployment by replacing passive armour with sensors, computers and countermeasures to detect and avoid threats. The DAS is intended to be a modular, federated system, configurable for specific mission demands and developed based on field trials complemented by deterministic engineering models, scene generators and war-gaming simulators. Based on an analysis of threat profiles, a basic DAS for LAVs has been proposed. To improve performance and reliability, the DAS is based on three complementary sensor technologies including: acoustics, visible and infrared optics and radar. From these technologies, four DAS subsystems are defined:

1. Passive long range sensing with threat avoidance countermeasures,

2. Short range active sensing with interception of the threat,

3. Detection of active targeting systems including HARLID^{TM} based laser threat warning and radar warning receivers and finally,

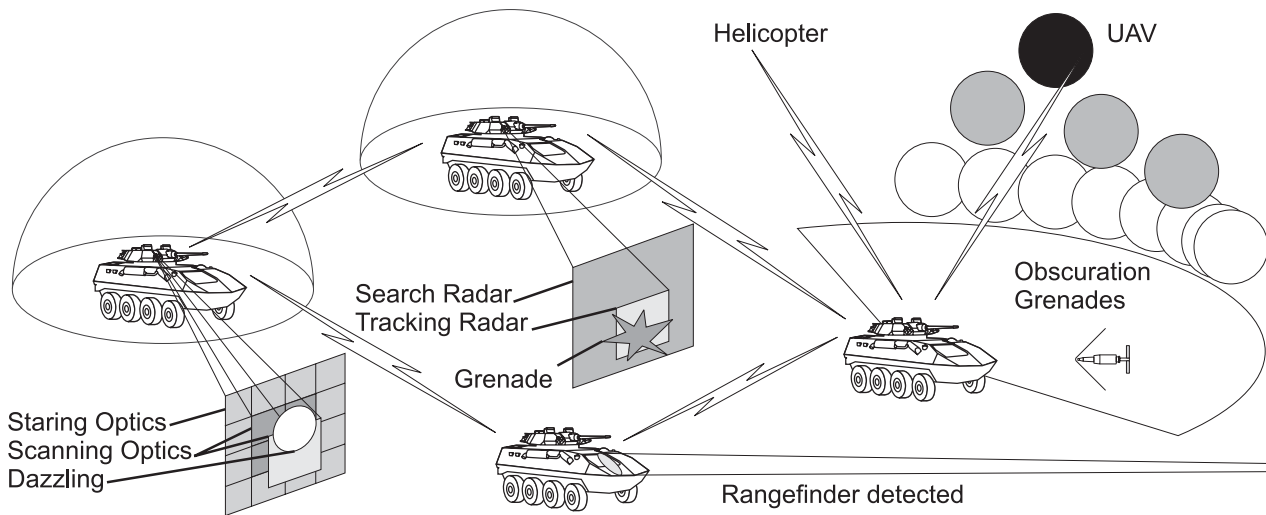4. Acoustic threat detection based on extended sniper detection technology.

Sensor cost is always an important factor and is kept as low as possible by basing the invention on dual-purpose sensors required primarily for manoeuvring the vehicle, targeting and surveillance. Sniper detection is extended to include all acoustic threats. Active targeting detection can be carried out by LWR and RWR needed primarily for IFF. The four-component DAS is shown in Figure A1.

Proposed 2010 DAS

The proposed DAS is based on technologies readily available by 2010. This approach provides sufficient time to develop vehicle requirements, tactics and doctrine to evaluate the design more completely. The DAS, relying on the federated, modular and mission configurable design, should 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. The DAS should be a general purpose solution providing acceptable performance for a wide range of requirements, robustness relying, for example, on data fusion from multiple sensors to avoid catastrophic failure of the DAS.

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 a high-speed grenade launchers.

SINGLE LAV	VEHICLE NETWORK
HARLID DETECTS RANGEFINDER AT 1.8 km	HARLID DETECTS RANGEFINDER AT 1.8 km
	UAV CORRECTS RANGE TO 1.853 km
COMMANDER CHOOSES FROM	COMMANDER CHOOSES FROM
APFSDS 150 ROUNDS	APFSDS *600* ROUNDS
HEI 60 ROUNDS	*ROCKETS 38*
	HEI *240* ROUNDS
APFSDS CHOSEN AND FIRED	APFSDS CHOSEN AND FIRED

Figure A1. *The four basic components of a DAS as shown including: hard-kill,* (top)*, and soft-kill systems, acoustic threat detection,* (supersonic round, far right)*, and detection of active targeting systems,* (rangefinder, bottom)*. Automated short-range communications will transform single LAVs in vehicle networks interacting with other available platforms. The soft-kill subsystem consists of the passive optics,* (far left)*, and smoke grenades,* (far right)*.*

2. Rocket-propelled grenades including

    (a) **blast grenades** to deflect kinetic energy projectiles at 50 m and

    (b) **fragmentation grenades** to destroy chemical energy threats at about 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 estimated that this system can be fielded by 2008. A typical hard-kill system can function as a stand-alone subsystem but there are advantages to integrating it with other DAS components. Information the hard-kill system can contribute is shown in Table A1.

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 being detected. Vehicles which can not be manoeuvred easily, such as long-range reconnaissance, must rely on jammers instead. Based on technology trends, a 2010 system based largely on off-the-shelf components could be designed as follows:

1. **Passive staring/scanning sensors**, the scanning optics are 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 $2.5^\circ \times 2.5^\circ$ 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 $0.5^\circ \times 0.5^\circ$ 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 robots and gyroscope to keep track of the threat.

The NFOV optics and LI/RG camera can be used to scan for threats as shown in Figure A2. 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

    – speed, how far to lead the grenade pattern

    – brakes

    – transmission, indicating forward or reverse gear

Table A1. *Hard-kill to soft-kill transition*

Hard-kill Sensor Information		Soft-kill Countermeasures
Angle of attack	Velocity range	Threat assumption and response
Greater than 30°	Greater than 700 m/s	**BLOS NLOS Helicopter-launched** – 2 s IRST for threat platform – mid-level obscuration and countermanoeuvres – counterfire on detection
	Less than 700 m/s	**Wide-Area-Munition, Sensor-Fuzed Submunition,** **Artillery launched Missile, Top-attack ATGM** – scan for threat – all-level obscuration and countermanoeuvres – counterfire on detection
Less than 30°	Greater than 700 m/s	**Direct Fire Weapon** – 2 s range-gated scan for threat platform – ground obscuration and countermanoeuvres – counterfire on detection
	Less than 700 m/s	**PGM or RPG** – scan for threat – counterfire on detection

  – wheel direction,

  – accelerator, if the brakes are on but his foot is on the accelerator the driver intends to move in that direction.

Based on the variables indicated and the threat detected the following variables can be selected:

Grenade variables

  – grenade selection

  – pattern selection

  – launch point of each pattern

OPTICAL CHARACTERISTICS		
SEARCH	TRACK	
IR WFOV 90° x 90° 4096 x 4096	IR NFOV 2.5^O x 2.5^O 1024 x 1024	LI/RG Camera 0.5^O x 0.5^O 1024 x 1024

IRST USING THE MINI-TURRET OPTICS

15° vertical displacement

135° horizontal scan, (2.5° x 54 frames)   aimed at 5 km

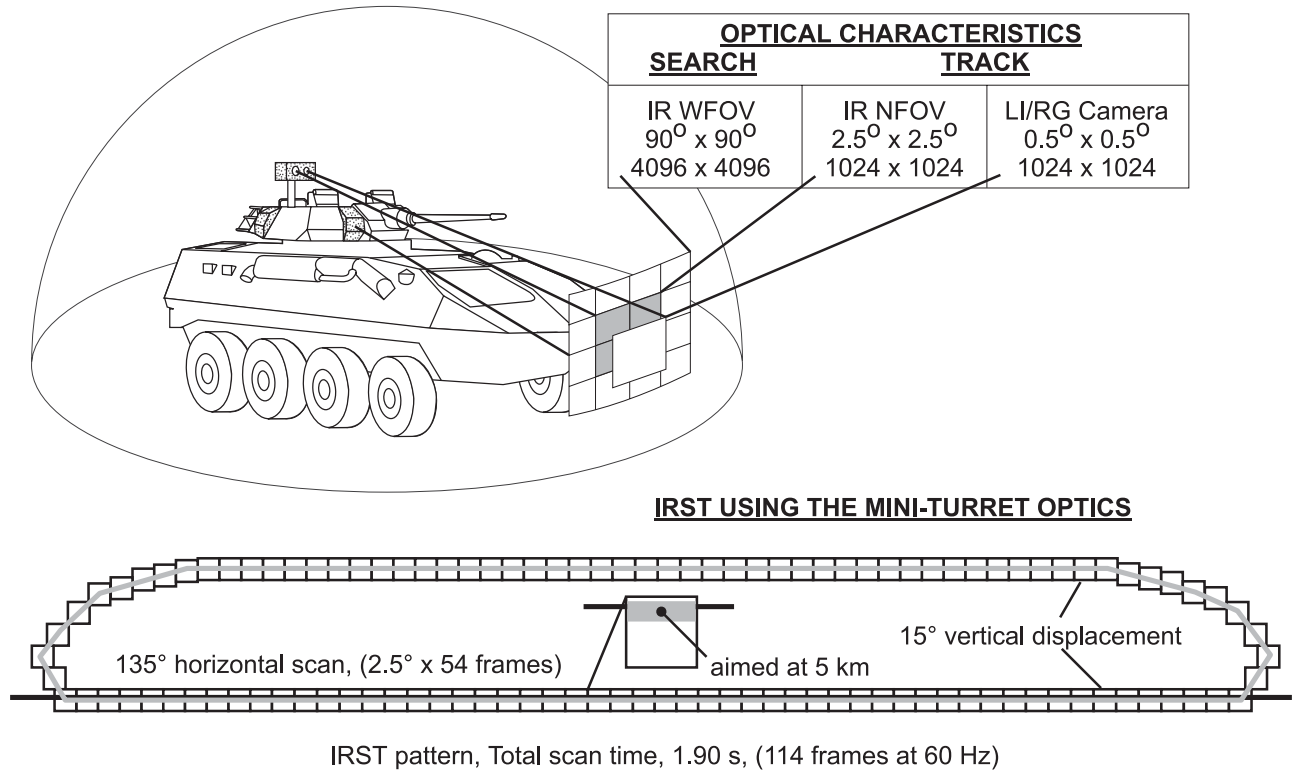IRST pattern, Total scan time, 1.90 s, (114 frames at 60 Hz)

Figure A2. The sensors for the soft-kill subsystem are shown including the staring arrays mounted on the main turret and the mini-turret optics, (top)*. Improved resolution, and detection, is possible by aiming or scanning with the mini-turret optics,* (bottom)*. The LI/RG camera is aimed at a virtual 5 km distance, to maximize threat detection of long-range weapons, during the ground scan.*

Acoustic Threat Detection, shown in Figure A3, 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 they will contribute to the robustness 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. Information from acoustic threat detection will also contribute to situational awareness, detecting and displaying weapons not detectable by other means.

Detection of Active Targeting relying on HARLLID-based laser warning receivers and radar warning receivers will detect the active sensors from more sophisticated weapon systems. Laser based threats include rangefinders, designators, and beam-rider guidance. Detection of radar systems would also include detection of MMW signals used by all-weather targeting systems. Both the LWR and RWR would be used primarily for IFF.
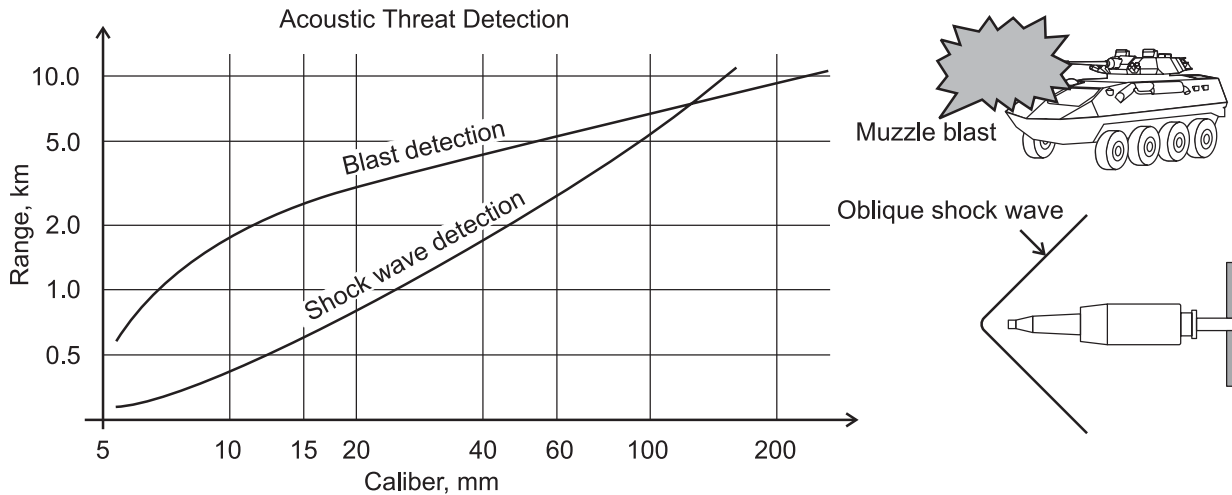
Figure A3. Typical performance of an acoustic system indicated by maximum threat detection ranges based on processing of blast and shock wave measurements.

DAS Vetronics environment

The 2010 DAS includes automatic, semi-automatic and manual response of counterfire, countermanoeuvres and obscurants. The optics used for detection and dazzling are depicted in Figure A2. Infrared Focal Plane Arrays provide a hemispheric coverage for increased situational awareness A system of organic UAVs is used to improve threat detection with a bird's eye view of the battlefield. Countermeasures are carried in sequence shown below, beginning with dazzling until full obscuration is achieved. Dazzling is intended to interfere with the operator by overloading his optical sight. Radar can be used with the infrared imaging system and smoke grenades to identify and defeat most threats.

High Availability (HA) principles are being used to develop reliable computer systems in critical applications and will probably influence the development of DAS. The high level of reliability and transparency to the user will make the DAS much easier to accept. High Availability technologies available through Jini[TM]include Alternate or Redundant Paths to Sensors, Dynamic Reconfiguration of the System comprising dynamic attachment and detachment and "hot pluggable" and "hot swappable" components include:

– Real Time Operating System (RTOS) with Java[TM]capability such as VxWorks[®]AE by Wind River Systems or LynxOS[®]by LynuxWorks[TM]

– Computer architecture based on, VMEBus or CompactPCI[TM]

The operating system is critical in the development of High Availability systems. Both VxWorks[®]AE, and LynxOS[®]have many of these features. VxWorks[®]AE is described as a RTOS with HA features including: Reliability, Availability, Serviceability, and Security (RASS).

Soft-kill strategies

Obscuration screens are a practical means of defeating many threats by direct interference of targeting and guidance systems. Some factors influencing the use of obscurants with LAVs are discussed below.

Increasing Sensor Accuracy and Precision New generations of sensors are being developed providing greater levels of situation awareness. These performance improvements are being accelerated by MEMS technology to produce even smaller, hybrid systems with new properties based on combined characteristics. An example of a new detector is the laser detecting HARLID$^{\rm TM}$. With an angular resolution of $\pm1°$, it is a significant improvement over existing systems. A current laser warning receiver with a typical resolution of $22.5°$, can detect a threat but not provide the position with sufficient accuracy. The only reasonable response from the crew is to launch smoke grenades and back the vehicle away from the threat. Based on the HARLID technology, a laser threat is detected in less than 1 ms, but with a resolution $\pm1°$ but is still not accurately enough to position the main gun. Combined with an IR staring array, the stream of pixels corresponding to the laser source can be analyzed to determine the nature of the threat and fix the position. The information is then sent to the Fire Control System and to other vehicles through a network. With a staring array operating at 60 Hz this process takes less than 20 ms, considerably less than the typical 1.5 s it takes to set up sufficient obscuration.

Obscurant Interference of Sensors Obscuration over a wide spectrum can be used to defeat various missile systems including optically sighted, Semi-Active Command to Line Of Sight, and laser or MMW semi-active homing missiles. SACLOS missiles use a beacon facing the launcher to correct any deviations between the missile and the launcher crosshairs. Earlier designs were easily defeated by placing false beacons on the vehicle. These false beacons were much more powerful than the missile beacon and were used by the launcher to provide false trajectory data to the missile. Improvements in missile design, by encoding the beacon signal, resulted in a missile that could not be easily jammed. Both designs are susceptible to smoke screens, as shown in Figure A4, and can still be defeated by obscuring the flight path to the vehicle. The launcher no longer sees the target vehicle and the beacon signal is scattered and absorbed by the obscurant. Obscuration will also stop designated missiles since the laser or MMW beam cannot penetrate the smoke screen. New missile designs based on hybrid seekers: laser semi-active homing and both imaging IR and MMW imagery are being developed which will require careful manoeuvring forcing the missile to reacquire the target and correct trajectory over the distance between the vehicle and smoke screen.

Obscurants designed to interfere with threat sensors will also interfere with vehicle sensors. A sufficient downrange distance is required to use active armour successfully. Careful selection and placement smoke screens is important in providing sufficient but not excessive downrange coverage. There is probably an optimum distance at which the smoke screen should be established, which can be determined through simulations with ModSAF.

Hemispherical Coverage from the Visible to MMW Range Light Armoured Vehicles will be deployed to peacekeeping environments where attacks can come from any direction. Sensors are being developed to provide the necessary hemispherical coverage but current grenade launchers, designed for Main Battle Tanks, need to be redesigned to provide a similar coverage. Improving sensor technology is also increasing the spectral range of weapons from visible and infrared to

millimetre wave operation.

Increased Operational Tempo Improved sensors and digital processing will automate many of the functions necessary in improving vehicle survivability. This automation with increased vehicle mobility and turret slew rate, will shorten response timelines and increase operational tempo. The grenade launch velocity can be increased and the time delay shortened accordingly but the interval between threat detection and full obscuration will still exceed 1s. During this interval, dazzling is considered to be a reasonable countermeasure since most anti-armour threats rely on an operator to aim or guide the weapon.

Automatic Configuration, Selection and Response Obscuration will be set up according to the nature and location of the threat detected. This could be carried out automatically by Defensive Aids Suite processors based on local sensors or information transmitted over a network. The grenade burst patterns would depend upon threat detection and vehicle operation, as described in detail below.

Additional Launcher Requirements The current MBT launcher has a $45°$ launch angle, which presents several problems. Any variation in the launch velocity, usually a function of the operating temperature, results in significant variations in the burst height. At very low temperatures, grenades often hit the ground before exploding. A second problem is the excessively long time delay, often in excess of 2.5 s, required by the longer flight path. These problems can be avoided by providing additional launch tubes at a shallower angle while retaining the $45°$ launch tubes for fragmentation grenades. Additionally, the shallower launch angle would be more appropriate for CS (2-chlorobenzalmalononitrile) grenades.

Launcher calculations

A simplified governing equation including a given launcher angle, initial velocity and required launcher height can be expressed as:

$$h = h_o + V_o \sin(\alpha + \theta)t - 1/2gt^2 + V_s \sin(\alpha)t - V_o \sin(\alpha)t \quad \text{where :}$$

h is the burst height of the grenade, 4.3 m at $20°$, 18.0 m at $45°$ and 26.7 m at $70°$,
h_o, is the height of the launcher, set to 2.5 m,
V_o, is the initial grenade velocity, 20 and 25 m/s,
α, is the vehicle incline angle,
θ, is the grenade launch angle (either $20°$, $45°$ or $70°$),
t is the time of flight, 1.5 s,
g, is acceleration due to gravity and
V_s, is the vehicle speed.

The burst pattern for the MBT can be improved by decreasing the grenade launch angle, increasing the launch velocity and shortening the time delay. Based on trials, the velocity is increased to 25 m/s and the time delay is fixed at 1.5 s. Solving for the burst height, for various launch angles and vehicle incline angles, results in a family of curves shown in Figure A4. For a wide range of vehicle inclines, the $20°$ angle gives the most acceptable distribution of burst heights. To maintain the requirement for fragmentation grenades, the $45°$ angle is retained for

mid-level coverage. Further protection against top-attack weapons is provided with a single grenade at 70°. A comparison between the MBT grenade system and the new LAV configuration is presented in Figure A4. The total number of grenades has increased from 8 to 48 seems excessive but from previous studies an automated system can be made more reliable if all the components are accessible by the computer. This implies installing all the grenades in the launcher instead of stored in the vehicle. The new burst pattern configuration for the LAV is shown in Figure A4.

Automated threat responses

Based on the grenade configuration shown in Figure A4, various scenarios can be developed for further analysis. The objective is to automate the threat response as much as possible and reduce the crew work load.

Slow-Moving or Stopped Vehicles In the first scenario, a threat is detected while the vehicle is stopped or moving too slowly to avoid the threat. The recommended burst pattern is shown in Figure A5. The ground screen is formed with four grenades biased toward the rear so the driver can backup under cover. All three mid-level grenades including the $70°$ grenade and two aft mid-level grenades are used to counter a possible top attack. This allows the vehicle to back up and countermanoeuvre for at least 30 s. In a reasonably quiescent atmosphere, the $45°$ and 70° grenades should provide coverage well beyond the 30 s required.

Moving Vehicle For a moving vehicle, which is less vulnerable to sensor-fuzed submunitions, the burst pattern in Figure A5 is suggested. Both ground and mid-level grenades are used to form a series of screens, biased in the direction of vehicle travel. This procedure can be automated by launching the next set of grenades when the angle between the vehicle and the last grenade in the series approaches the angle of the threat detected. While this ensures that the vehicle remains hidden, it may still be possible to locate the vehicle by extrapolating grenade trajectories back to the launcher. If the driver, intentionally slows down or stops the vehicle, the variation of the scenario described above would be used to provide protection while backing up.

Stochastic nature of the problem

The detection of threats by the staring array, the time to slew the scanning optics towards the threat and the time to slew the main threat are some of the stochastic variables that influence the usefulness of dazzling as a countermeasure. As suggested by Figure A2, if the time to slew the dazzling laser into place is excessive then the advantage over launching grenades may be negligible. Dazzling can be used pre-emptively with the scanning optics. Automatic processing can be used to quickly detect any anomalies against the background.
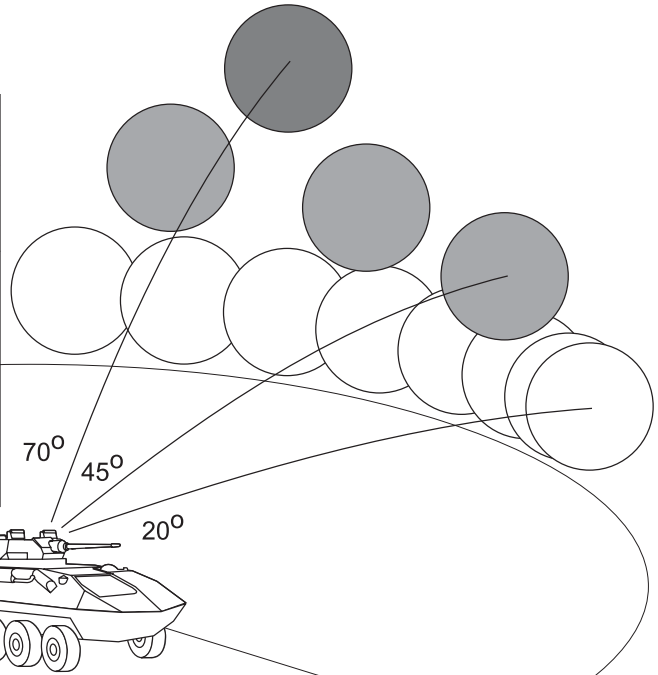
Missile countermeasures

Obscuration over a wide spectrum can be used to defeat various missile systems including optically sighted, Semi-Active Command to Line Of Sight, and laser or MMW semi-active homing missiles. SACLOS missiles use a beacon facing the launcher to correct any deviations
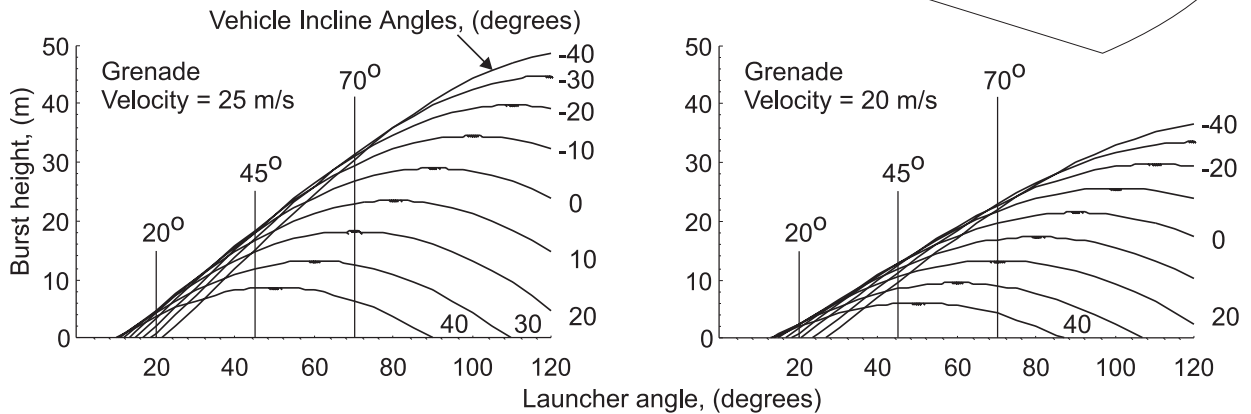
between the missile and the launcher crosshairs. Earlier designs were easily defeated by placing false beacons on the vehicle. These false beacons were much more powerful than the missile beacon and were used by the launcher to provide false trajectory data to the missile. Improvements in missile design, by encoding the beacon signal, resulted in a missile that could not be easily jammed. Both designs are susceptible to smoke screens, as shown in Figure A4, and can still be defeated by obscuring the flight path to the vehicle. The launcher no longer sees the target vehicle and the beacon signal is scattered and absorbed by the obscurant. Obscuration will also stop designated missiles since the laser or MMW beam cannot penetrate the smoke screen. New missile designs based on hybrid seekers: laser semi-active homing and both imaging IR and MMW imagery are being developed which will require careful manoeuvring forcing the missile to reacquire the target and correct trajectory over the distance between the vehicle and smoke screen.

GRENADE SYSTEM PARAMETERS

Composition	Metal flake/chaff
Spectral Coverage	Visible/IR/MMW
Time delay	1.5 s
Burst diameter	8 m
Ground screen radius	40 m
Total number of grenades	48
Ground level	32 launched at 20°
Mid level	12 at 45°
Top	4 at 70°

70° 45°

20°

GRENADE BURST HEIGHT CALCULATIONS

Vehicle Incline Angles, (degrees)

Grenade Velocity = 25 m/s

Burst height, (m)

70° 45° 20°

-40
-30
-20
-10
0
10
20

40 30

Grenade Velocity = 20 m/s

70° 45° 20°

-40
-20
0
20

40

Launcher angle, (degrees)

MISSILE GUIDANCE INTERFERENCE

SACLOS Missile Guidance Blocked

Laser Proximity Fuze Detonation
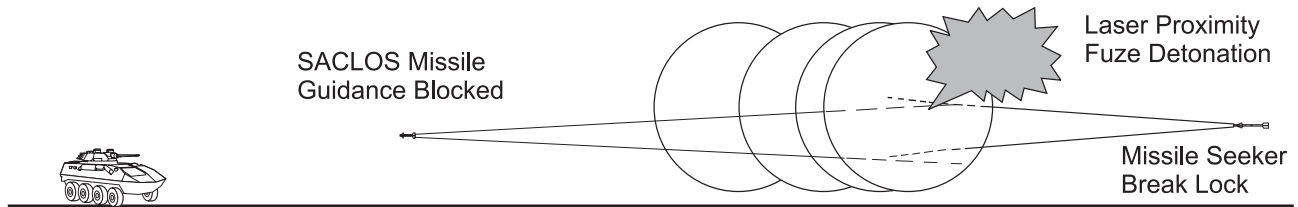
Missile Seeker Break Lock

Figure A4. *solution of the launcher equation for various launcher and vehicle angles are shown,* (top). *The effects of cold-environment operations are represented by launches at 20 m/s. For incline angles from -40° to 40° most grenades explode before hitting the ground. The grenade at 70° would rarely be needed unless optimum coverage is required for a stationary vehicle. Other parameters include a delay time of 1.5 s, a grenade initial velocity of 25 m/s, a vehicle forward speed of 4 m/s (14 .4 km/hr) and a launcher height of 2.5 m. The smoke screen can be used to block many missile guidance systems as shown,* (bottom).
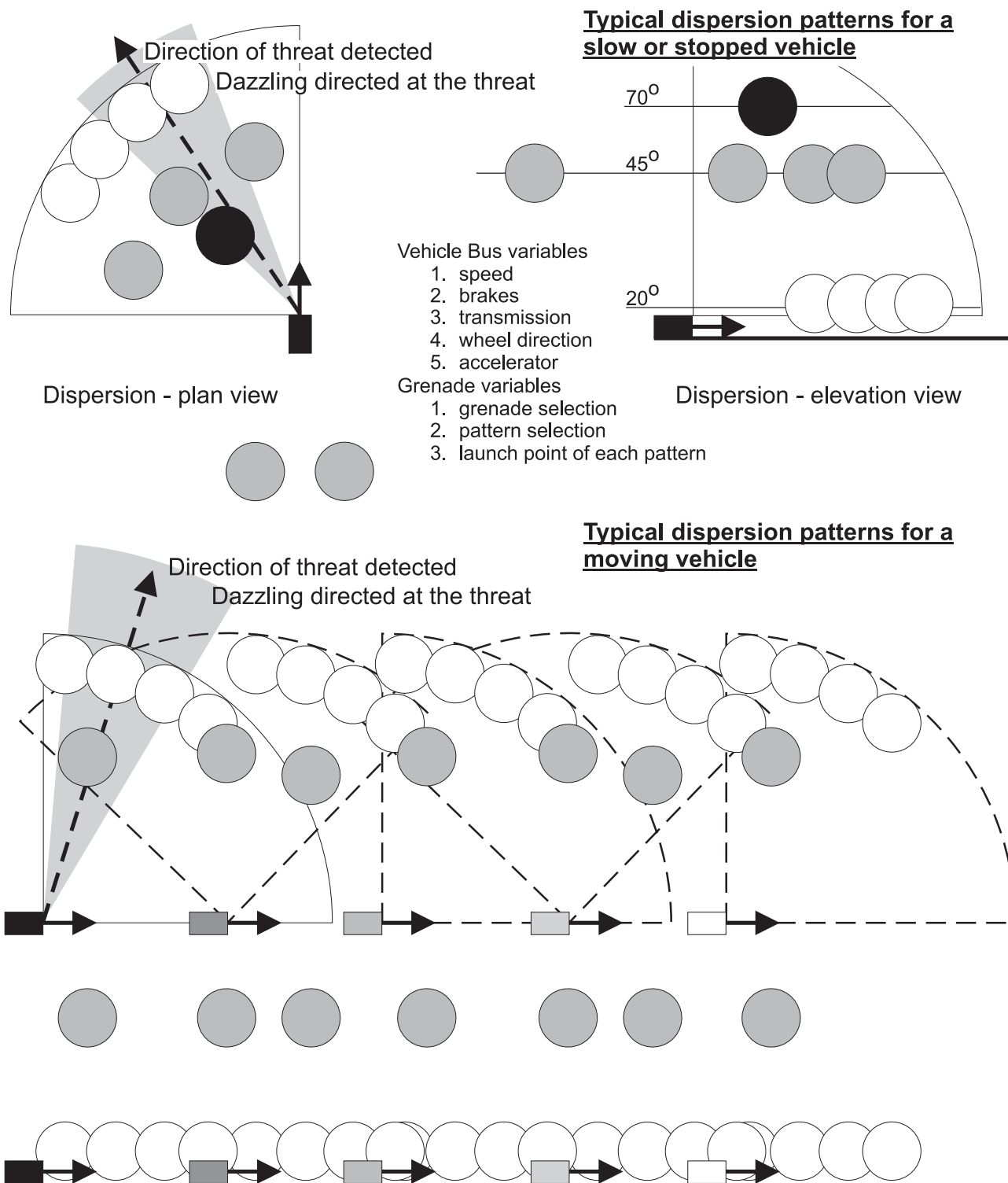
Figure A5. *Typical dazzling and grenade-burst patterns for slowing, stopping and backing-up manoeuvres are shown,* (top)*. Information from the vehicle bus is also important in selecting grenades, patterns and launch sequences. Typical patterns sequence are also shown for a moving vehicle,* (bottom)*.*
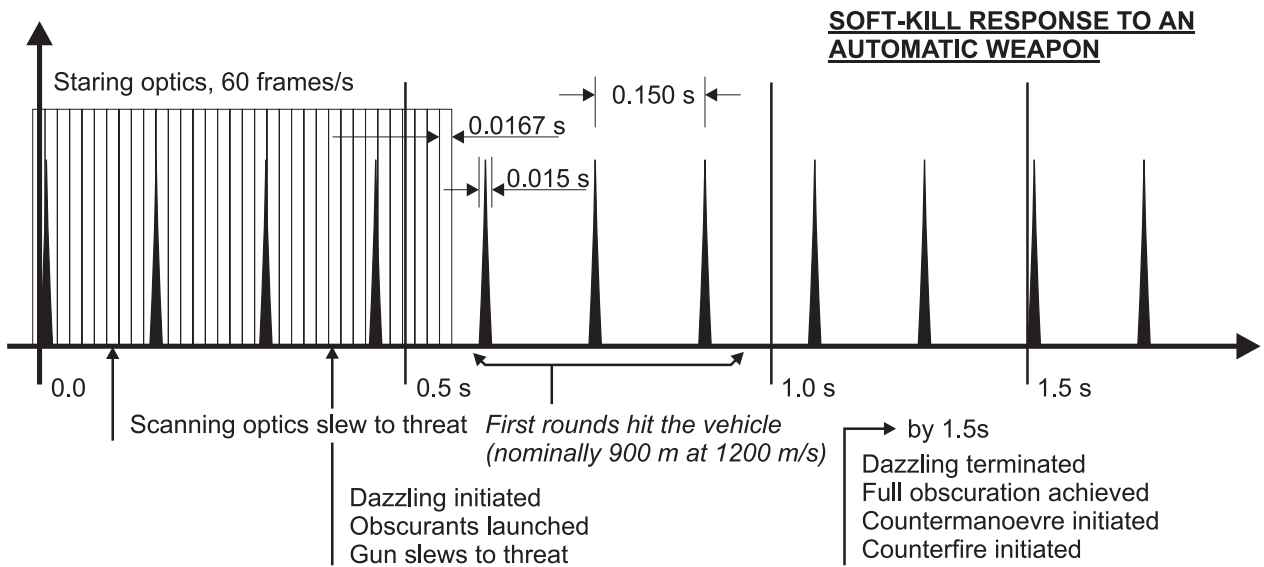
Figure A6. *An automatic weapon firing 400 rounds/min is detected by a staring array. A slewing optical system slews towards the threat and a dazzling laser is activated to disrupt the gunner. At the same time, smoke grenades are launched and the main turret slews towards the threat. By 1.5 s, full obscuration is in place and the main gun can be fired using data from the Fire Control System or a Vehicle Network.*

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Annex B: DAS development based on surrogate ATGM

Occasionally, the WFOV optics are able to detect a threat early enough to move the vehicle away from the threat. Prototype missiles based on Soviet propellant formulations should be built and tested to produce sensor data for algorithm development and development of sensor requirements.

The missile radiance images can be compared with actual measurements from tethered missiles fired at various ranges from the sensors as shown in Figure B1. The correct plume aerodynamics can be determined at the Open Jet Facility as shown in Figure B2. The data from these tests will be used to validate the models and evaluate fieldable optics and algorithms. Since only the rocket motor and exhaust nozzles are needed for this type of analysis, an existing rocket will be modified to the same configuration as the ATGM missiles and RPG rockets as shown in Figure B3.
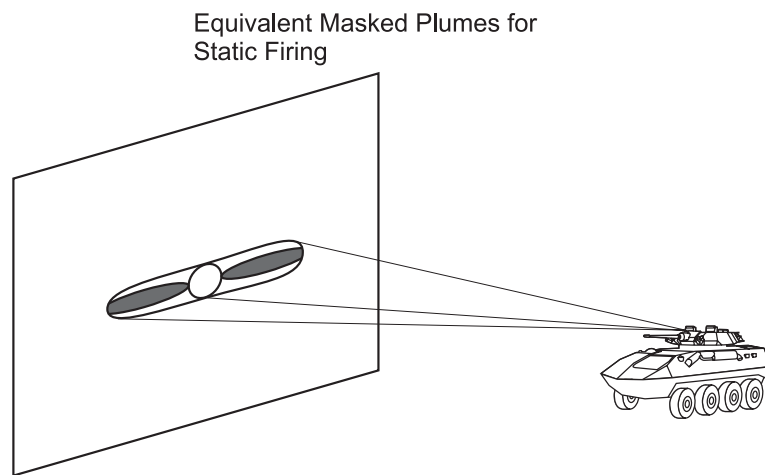

Equivalent Masked Plumes for Static Firing

Figure B1. *Static firing of the missiles produces plumes that are too long due to the absence of the airstream momentum. The correct image, determined at the OJF, is produced by masking out portions of the plumes.*
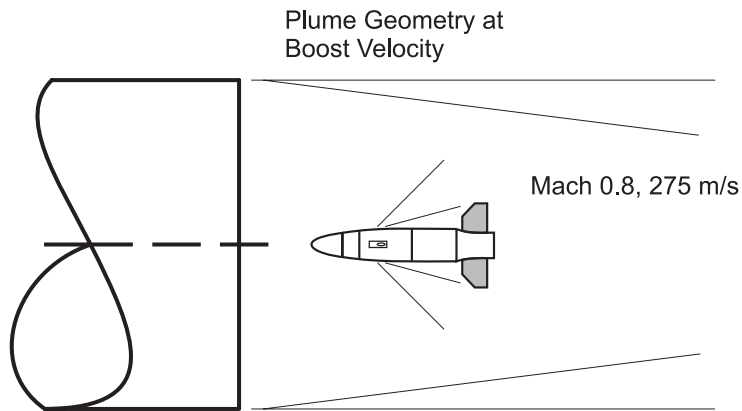
Plume Geometry at
Boost Velocity

Mach 0.8, 275 m/s

Figure B2. The Open Jet Facility produces an airstream of low turbulent intensity suitable for evaluating missile aerodynamics.

76 mm Navy Chaff Rocket

6 nozzles at 15°

2 nozzles at 30°
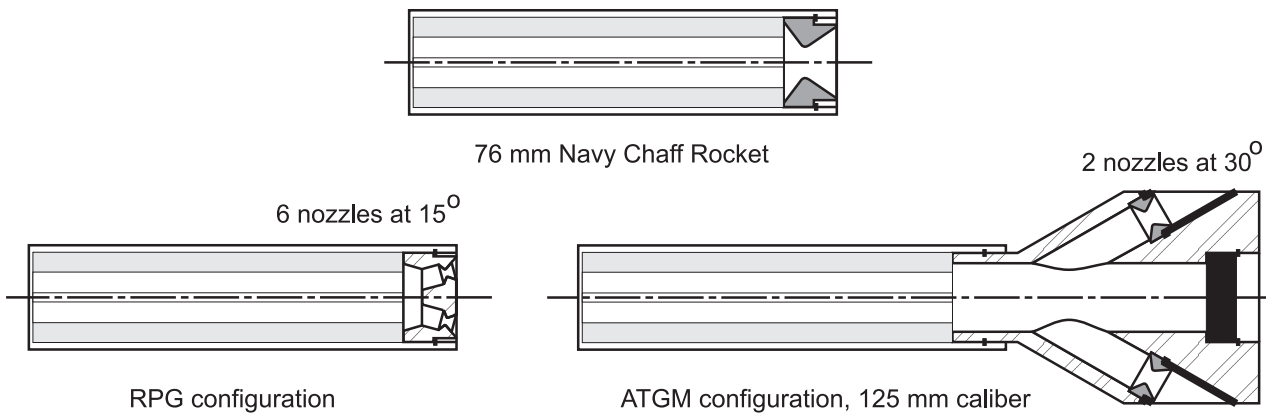
RPG configuration

ATGM configuration, 125 mm caliber

Figure B3. A gas generator based on an existing rocket is used to produce the correct plume structure and geometry for both the ATGM and RPG motors

Annex C: Modelling, scene generation and war-gaming for DAS development

Numerical analysis has always been limited by available computing resources. This leads to detailed analyses of a limited number of processes or many simplified processes such as simulation of the battlefield with many vehicles and threats. Three levels of modelling are described below ranging from deterministic models of missile signatures to highly stochastic modelling of the battlefield.

Detailed model development is based on physical principles and fundamental processes. Terrain features are represented in sufficient detail to study vehicle mobility, detection, defilade and other practical manoeuvres. Atmospheric phenomena are modelled to produce accurate effects of attenuation over distance, scattering by smoke and dust and insolation. Spectral effects in the atmosphere, such as propagation of artificial sources in the solar-blind ultraviolet regime, natural effects such as solar glint and complicated, variable missile signatures are also modelled. These models are deterministic in nature and have a proven validity over a wide range of application. The two stages of this development include the numerical solution of the mathematical formulation and validation through experiments. NIRATAM (NATO Infra-red Air Target Model) is used to analyze rockets and missiles. The radiance image for a typical RPG is shown in Figure 8. The ATGM radiance images are shown in Figure 9. These images can be compared with actual measurements from tethered missiles fired at various ranges as shown in Figure B2. The data from these tests will be used to validate the models and evaluate fieldable optics and algorithms. Since only the rocket motor and exhaust nozzles are needed for this type of analysis, an existing rocket will be modified to the same configuration as the ATGMs and RPGs as shown in Figure B3.

Scene generation is characterized by high-performance computations and real-time simulation to produce realistic few-on-few engagements. Threat, platform and countermeasure interactions are studied to develop hardware-in-the-loop simulations suitable for evaluation of field optics and algorithm performance. Figure C2 shows typical imagery produced by the scene generator.

Synthetic scene generation is not a new subject but recent advances in micro-mirrors, 3D modelling and ultra-spectral measurements can be brought together to evaluate and develop sensors, algorithms and countermeasures. In a typical battlefield scenario, an imaging infrared top-attack anti-tank missile will lock on to a vehicle to destroy it. A complete vehicle DAS will include long-range passive sensors which will detect the threat, recognize it as a missile, launch a specific grenade pattern to produce seeker break-lock and manoeuvre the vehicle away from the missile trajectory. If the missile clears the obscurant barrier and reacquires the vehicle, short-range active sensors will guide an intercepting device to destroy the missile. The synthetic scene generator will be used to study and assess the performance of the imaging seeker with targeting logic, the long-range sensors, obscuration and countermanoeuvres and the active armour subsystem. Computer-based scene generation will enable this type of evaluation to be achieved through various configurations, from fully manual to automatic response, in assessing candidate algorithms.

Scene generation will supplant field trials as the only means of analyzing and assessing

performance of a threat or weapon system. The scene generator will be used to analyze subsystem performance up the platoon level, which will become essential for command-centric vehicle networks. To generate the synthetic scene platform, models are needed for both the threats and targets consisting of textured wire-meshes with assigned temperature and radiative surface properties. Sensor models representing spatial and spectral resolution and sensor noise further degrade the image signal. The other scene generation models include ultra-spectral terrain measured directly by PIRATES, atmospheric transmission models based on MODTRAN, HITRAN and FASCODE to insert objects correctly at the required range, missile plume models based on SIRRM or NIRATAM and lastly battlefield smoke and obscuration based on COMBIC or SSPM.

War-gaming simulations of many-on-many engagements are used to study and assess technology on the battlefield including development of tactics and doctrine through operational analysis.

OneSAF is being developed to provide a common platform for DAS technology development. This approach has the advantage of representing technology in a context useful to the CF and sufficiently accurate to define vehicle and DAS requirements. As shown in Figure C1, there is a continuous cycle including planning field trials, evaluation of trial data and OneSAF development. In a separate cycle new development are transferred to LFDTS for brigade level and below simulations. In this context OneSAF is used to estimate the battlefield performance of new technologies. After a period of evaluation, tactics and doctrine can be developed for approved technologies. DGOR is also essential in evaluating the level of performance needed for a particular vehicle and determining what level of technology is needed to attain the required performance. Once, a vehicle is defined, the man-machine-interface is needed to integrate the technology on the vehicle. This activity should be carried out by the vehicle integrator. The prototype vehicle is then evaluated and OneSAF corrected accordingly. Since OneSAF is owned by the US Army and is therefore restricted, MATLAB modelling is important in communications with other contractors.
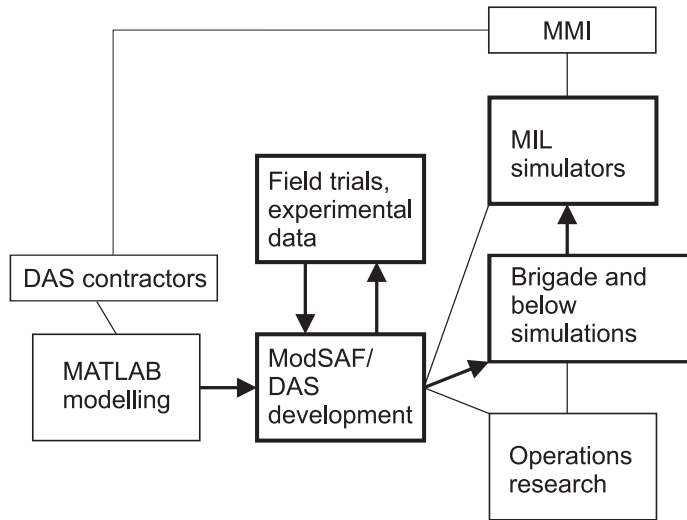
Figure C1. *The four aspects of OneSAF development are shown. MATLAB® is used as a quick-prototyping tool generating, transferable models and code usable by OneSAF. There a tight loop between field evaluations and OneSAF development used to design DAS prototypes and plan future trials. Larger battles are carried out in simulation labs where new tactics and doctrine are developed. OneSAF 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.*

Figure C2. *Static Scene: containing the 4 basic components: ultra-spectral terrain, vehicles corrected for range, battlefield obscuration and atmospheric transmission.*

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Threats to Light Armoured Vehicles (LAVs) have been defined, modelled and analyzed. Procedures for analyzing the threats have been developed, compatible with DRDC measurement capabilities, and are described in detail in this study. The DAS is intended to be a modular, federated system, configurable for specific mission demands and developed based on field trials complemented by deterministic engineering models, scene generators and war-gaming simulators. Based on the analysis, a basic Defensive Aids Suite (DAS) for Light Armoured Vehicles (LAVs) has been proposed. To improve performance and reliability, the DAS is based on three complementary sensor technologies including: acoustics, visible and infrared optics and radar. From these technologies, four DAS subsystems are defined:

1. Passive long range sensing with threat avoidance countermeasures,

2. Short range active sensing with interception of the threat,

3. Detection of active targeting systems including HARLIDTM based laser threat warning and radar warning receivers and finally,

4. Acoustic threat detection based on extended sniper detection technology.

Specific issues were raised by operations researchers and are addressed in this study. The analytical procedures described in this study will be used to develop future DAS systems at reduced risk and defrayed cost through international collaboration.

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