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ABSTRACT

In the near future, strategic and other critical assets will be subject to attack from a new range of air threats, including highly accurate aircraft-launched weapons that offer long stand-off ranges and which are capable of travelling at high speed as well as manoeuvring at high *g* rates. This study uses simple probability theory to determine the relative utility of current generation air-defence guns against this type of highly manoeuvrable weapon. The rationale for this study is that whilst guns may have the advantages of offering a low cost-per-shot and reasonable magazine capacities, they are also severely limited in their abilities as they are only designed to fire at a predicted intercept point in space. As a result, should the target alter its direction during an engagement, the target will no longer pass through the projectile's flight path.

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Limitations of Guns as a Defence against Manoeuvring Air Weapons

Executive Summary

In the near future strategic and other critical assets will be subject to attack from a new range of air threats including highly accurate aircraft-launched weapons that offer long stand-off ranges, and are capable of travelling at high speed and manoeuvring at high g rates.

This paper examines the value of current generation air-defence guns against this type of highly manoeuvrable stand-off weapon (SOW). The rationale for this study is that whilst guns may have the advantages of offering a low cost-per-shot and reasonable magazine capacities, they are also severely limited in their abilities as they are only designed to fire at a predicted intercept point in space. As a result, should the target alter its direction during an engagement, the target will no longer pass through the projectile's flight path.

This study uses simple probability theory to determine the number of gun munitions that would be required for a 50% chance of hitting a generic SOW capable of conducting manoeuvres in any direction at the precise moment an air defence gun would have begun to open fire.

Based on this approach, it has been determined that even under ideal conditions, the best current generation air defence guns, which either employ air bursting munitions with their greater area of influence, or low drag munitions fired from guns with extremely fast cyclic rates, would have little likelihood of success against a stand-off weapon capable of manoeuvring at high g rates, at engagement ranges greater than 500 m. Even then, due consideration would have to be given to any practical limitations and logistics associated with the number of guns that could be deployed on the battlefield and on the mobility of any such arrangements.

It must be pointed out that had the additional effects of high SOW transit speeds (i.e. mach 5+), gun and computational error budgets as well as target terminal effectiveness been taken into account, there would be little doubt that none of the current generation air defence gun systems would have had any chance of success at preventing fast and manoeuvrable SOWs from reaching their intended target.

Authors

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Christian Wachsberger graduated from the South Australian Institute of Technology (now the University of South Australia) in 1981 with a degree in Applied Science majoring in Applied Physics. He worked for two and a half years as a Research Assistant conducting research for the Photocopying Industry. Thereafter he joined Defence Science Technology Organisation as a Professional Officer where he gained considerable training and expertise in gun systems with particular emphasis on research involving small arms ammunition and weapons. In June 1998 he was appointed as the Explosives Safety Officer for Weapons Systems Division to maintain, improve and enforce safety standards associated with all explosives operations undertaken at DSTO, eventually returning to perform R&D activities in advanced weapons concepts in 2003.

Michael A. Lucas
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Dr Lucas was born and raised in the Gippsland region of Victoria. Dr Lucas obtained his B.Sc.(Hons) and Ph.D. from the University of Melbourne majoring in Physics and is a Fellow of the Institute of Physics in London. For five years from 1983 Dr Lucas was the principal research scientist for Chamber Ridge Pty. Ltd. developing material analytical equipment based on plasma optical analysis. For two years from 1988 Dr Lucas lead a development team working on biomedical sensors at the University of Tasmania. From 1990 to 2000 Dr Lucas has been a Senior Research Scientist with DSTO working in the areas of Guided weapon systems analysis and directed energy weapons. Major Areas of responsibility during this period included support to the AIM 7 Sparrow weapon system, running Australia's Ground Based Air Defence studies and support and investigations of the use of High Energy Lasers as part of weapon systems. Dr Lucas from 2000 on has been a Principal Research Scientist within the Weapons Systems Division and is Head of the Advanced Concepts Group as well as at present the STCC for FRAC L10.

Alexander R. Krstic
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Having obtained his B.A., B.Sc., and First Class Honours degrees from the Flinders University of South Australia, Alexander Krstic was then awarded a Defence Postgraduate Research Fellowship by the DSTO to undertake full-time Doctoral studies in the area of Novel High Energy-Density Propellants. Having completed his Doctorate in 1994, he returned to Explosive Ordnance Division's Weapons Technology Group, working in the area of Small Arms weaponry and Human Vulnerability. After a lengthy period in the Terminal Effects Group, where he authored several international Patents covering the Weapons Systems Division's Human Surrogate Technologies, *he moved to his current position as a Senior Research Scientist in the Advanced Concepts Group. Dr Krstic's current research activities now focus around Ground Based Air Defence and the potential contribution that High Energy Lasers might bring to the cause.*

Contents

1. Introduction

During World War II manually aimed, rapid-fire guns provided an effective defence against the relatively large, slow and cumbersome bomber aircraft of the time. Bomb delivery proved to be particularly inaccurate owing to the unguided nature of the iron bombs that were carried and their dependence on aircraft release conditions (i.e. airspeed and altitude) and prevailing wind conditions. As a result aircraft needed to travel in groups and drop large quantities of bombs just to deliver a modest tactical result. Furthermore, bomber aircraft were extremely vulnerable to damage by attack from flak guns (guns that fired high-explosives-filled shells that were fitted with time adjustable fuzes so that they would burst at predetermined altitudes). The resulting attrition in combination with the psychological trauma aircrews faced when being subjected to a hail of gunfire and fragments, had reduced the effectiveness of the bombing campaigns to the extent that damage to their adversaries' industrial and military capabilities proved minimal.

Thirty years later different technologies were needed to mount credible air defences against the jet bomber aircraft of the day. These aircraft could travel at stratospheric altitudes (e.g. B52 Stratofortress) or fly close to the ground using terrain following radar to guide them (e.g. F111 strike aircraft) and could deliver ordnance onto selective ground targets with significantly greater levels of precision. High-speed, strike aircraft would only be exposed to any line-of-sight ground-based weapon systems for short periods of time, however, improved tracking and engagement radars together with optical sighting systems enabled remotely controlled guns to remain effective.

Yet another thirty years have passed and the technology that was designed for warfare in the seventies no longer remains suited to dealing with modern and emerging air weapon systems. Strategic and other critical assets will be subject to attack from a new range of air threats and these include:

- stealth aircraft,
- armed helicopters,
- highly accurate aircraft-launched weapons that emit low RF and IR signatures, offer long stand-off ranges (beyond 150 km), are capable of travelling at high speed (mach 5+) and can manoeuvre at high *g* forces,
- high-speed, long-range cruise missiles,
- armed unmanned aerial vehicles (UAVs),
- surface-launched missiles,
- ballistic artillery missiles,
- precision-guided, long-range artillery shells,
- large numbers of low cost sub-munitions, and
- highly coordinated attacks involving combinations of the aforementioned weapon systems.

The future air threat will therefore be hard to see, present in high densities, intelligent, accurate and highly lethal.

This paper will examine the value of current generation air-defence guns against a nominal future air threat - the long-range and highly manoeuvrable stand-off weapon (SOW). The rationale for this study being that while guns have the advantages of offering a low cost per shot and reasonable magazine capacities they are also severely limited in their abilities as they are only designed to fire at a predicted intercept point in space. As a result, should the target alter its direction during an engagement, the target is no longer likely to pass directly through the projectile's flight path.

2. Approach

2.1 Ground Based Air Defence Gun Systems

A literature review of current ground-based air defence (GBAD) guns used by NATO countries and their allies has revealed the existence of gun systems with calibres ranging from 12.7 mm through to 76 mm. A list of GBAD guns together with a summary of some of their ammunition details and important characteristics are shown in Table 1.

Guns with calibres less than 30 mm tend to use ammunition designs that require them to make direct contact with a target in order to inflict damage. These include non explosive varieties i.e. ball, armour piercing (AP), sabotted light armour piercing (SLAP), armour piercing discarding sabot (APDS) and fin-stabilised armour piercing discarding sabot (FAPDS) as well as their tracered variants. High order and low order explosive filled rounds include armour piercing incendiaries (API), multi-purpose (MP), high explosive incendiary (HEI) and semi-armour piercing high explosive incendiary (SAPHEI) ammunition and their tracered variants. These explosively based ammunition families use either a mechanically or a pyrotechnically initiated fuze that functions upon contact with a hard surface. Some of these rounds also include a self-destruct mechanism, which initiates their HE content after a specified time. This is an in-built safety feature designed to prevent the dispersal of unexploded ordnance onto the ground should it fail to successfully engage its target. A range of new munitions have also appeared on the market that incorporate aerodynamic improvements (i.e. low drag) thereby reducing time-of-flight (ToF) characteristics and increasing their residual kinetic energy c.f. traditional designs.

Guns with calibres greater than 30 mm tend to be equipped with air bursting munitions (ABM). These are the direct descendants of the flak guns seen during WWII. When compared to their WWII ancestors there have been notable improvements in ammunition design in terms of their propulsive elements (exhibiting both increased and more consistent projectile muzzle velocities), projectile aerodynamic efficiency (i.e. reduced drag), HE filling (featuring reduced sensitivity and increased blast effectiveness), and projectile construction to yield optimum fragmentation size and distribution. There have also been significant improvements in fuze design. Simple ABMs use variable time-set fuzes that must be manually adjusted prior to launch. Other types of ABMs incorporate infra-red fuzes, which are designed to initiate when a shell comes within sensing range of a hot source, such as a jet engine.

A most recent design is the advanced hit efficiency and dispersion (AHEAD) ammunition, which incorporates an electronically timed fuzing system that programs itself automatically during a firing. The fuze programming is directly linked to the gun's fire control and target acquisition systems that determines the likely range of the target and compares this with the time-of-flight characteristics of the round being fired, automatically compensating the fuze time function for any variations to each round's actual muzzle velocity.

Table 1. Characteristics of GBAD guns and their ammunition.

	Gun System							
	12.7 x 99 mm Browning Heavy Machine Gun (M2HB)	20 x 103 mm Vulcan Air Defence System (VADS)	25 x 137 mm KBA cannon (Includes Bushmaster Chain Gun)	25 x 184 mm KBB Oerlikon Breda Gatling Gun	30 x 173 mm Oerlikon Contraves ABM Gun	35 x 228 mm KD (Gepard)	40/70 mm L70 (Bofors cannon)	76/62 mm Oto Melara (OTOMATIC)
Rate of fire (shots per minute)	450 -550	3000	600	5000 x 2	Unknown	550 x 2	240 - 300	120
Quoted Dispersion	300 mm @ 550 m (F1 Ball)	12.7 mm @ 200 m (Mean Radius)	0.43 mils @ 2000 m(PGU-32/U SAPHEIT) 0.75 mils @ 2000 m(M792/ PGU-22 HEIT)	Unknown	Unknown	Unknown	Unknown	Unknown
Muzzle velocity (m/s)	870 (F1/M33 Ball) 900 (NM140 MP)	1030 (M56A3 HEIT)	1100 (SAPHEIT) 1100 (HEIT) 1345 (M791 APDS-T)	1285 (APDS-T) 1270 (AMDS) 1160 (HEI)	1080 (ABM)	1050 (AHEAD) 1175 (HEI) 1400 (FAPDS)	1025 (PFHE Mk2)	1053 (HISP-PFF)
Calculated time-of-flight (s) ax^2+bx+c where x = range	MP $a=7x10^{-7}$ $b=7x10^{-4}$ $c=4.6x10^{-2}$	HEIT $a=9x10^{-7}$ $b=5x10^{-4}$ $c=4.5x10^{-2}$ MPLD $a=6x10^{-7}$ $b=5x10^{-4}$ $c=5.2 x10^{-2}$	HEIT $a=6x10^{-7}$ $b=5x10^{-4}$ $c=8x10^{-2}$ APDS-T $a=1x10^{-7}$ $b=7x10^{-4}$ $c=2.3 x10^{-2}$	Unknown	ABM $a=3x10^{-7}$ $b=8x10^{-4}$ $c=6 x10^{-15}$	HEI $a=2x10^{-7}$ $b=6x10^{-4}$ $c=3.7x10^{-2}$ FAPDS $a=5x10^{-8}$ $b=7x10^{-4}$ $c=2.9 x10^{-3}$ AHEAD $a=1x10^{-7}$ $b=9x10^{-4}$ $c=5.5 x10^{-3}$	PFHE Mk2 $a=2x10^{-7}$ $b=8x10^{-4}$ $c=2.1x10^{-2}$	HISP-PFF $a=7x10^{-8}$ $b=9x10^{-4}$ $c=2.6x10^{-2}$
Mass of projectile (g)	42.9	94	185 (HEIT) 135 (APDS-T)	230	362	750 (AHEAD) 550 (HEI) 396 (FAPDS)	880	5250
Number of rounds in burst	Up to 100	10, 30, 60, 100	Unknown	Unknown	Unknown	20 to 40	Up to 26	Up to 26

2.2 Representative Air Targets

Four currently available SOW (albeit non-manoeuvring) are:

- AGM-65 'Maverick' (length 2490 mm, diameter 305 mm),
- AS-12 'Kegler' (length 4190 mm, diameter 275 mm),
- AS-13 'Kingbolt' (length 5100 mm, diameter 380 mm), and
- AS-18 'Kazoo' (length 5690 mm, diameter 380 mm).

To keep the hit probability calculations simple, a generic SOW target with dimensions of length 2500 mm and diameter 300 mm was selected as this is close to the minimum dimensions for all of the SOW under consideration. No allowances have been made for the wing area or control surfaces (noting for example that the AGM-65 has a wing area as large as 7200 mm^2), as these would have further complicated the calculations.

For the purpose of this exercise the generic SOW is capable of conducting manoeuvres up to a maximum of 10 *g*. It would also be possible for the SOW to change direction at any stage during its flight, which would include making a manoeuvre at the precise moment an air defence gun would begin to open fire.

2.3 Hit Probability for stationary targets

The hit probability of non-bursting projectiles against a stationary target can easily be calculated depending on the size and shape of the target, the number of rounds fired, the dispersion angle characteristics of the gun and the range to the target. This probability is provided that the target is located centrally within a circular symmetrical engagement zone and that normal Gaussian distribution rules apply. No allowances have been made for the ellipsoid distribution pattern generally seen with guns.

The equations used in this study are:

Probability of a single hit, against a circular target (frontal aspect),

$$P_{hit(s)} = 1 - e^{-r^2/2\sigma^2} \qquad (1)$$

Where r is the radius of the target in metres, which in this case is represented by the frontal aspect of the target having a radius of 0.15 m, and σ is the standard deviation (in metres) calculated for the gun at any given engagement range.

As the distribution is identical for multiple shots and a time delay is not considered between shots the hit probability for a burst against a circular target is simply denoted by:

$$P_N = 1 - (1 - P_{hit(s)})^N \qquad (2)$$

Where N equals the number of rounds in a burst.

For this study calculations are made of the number of rounds required to obtain $P_N = 0.5$ or 50%, the definition of Circular Error Probable (CEP), at various ranges up to a maximum of 3000 m.

Substituting $P_{hit(s)}$ with equation (1) and rearranging equation (2) for $P_N = 0.5$ gives:

$$1-(0.5)^{1/N} = 1-e^{-r^2/2\sigma^2}$$

hence

$$e^{-Nr^2/2\sigma^2} = 0.5$$

and therefore

$$N = -2\sigma^2/r^2 \ln 0.5 \qquad (3)$$

In the case where the target is being engaged side-on the hit probabilities of both the horizontal and vertical aspects must be calculated separately and then the product determined.

Hit probabilities of $P_{hit(s)}$ are either determined using tables for cumulative normal distribution using the integral:

$$P_{hit(s)} = 1/\sqrt{2\pi} \int_{-\infty}^{x} e^{-\sigma^2/2} d\sigma$$

Or they can be approximated using the following equation:

$$P_{hit(s-approx.)} = 1/2 + 1/2(1-e^{-2\sigma^2/\pi})^{1/2} \qquad (4)$$

which has a maximum error of 0.4% for values of σ between 0.4 and 3.2.

As equation (4) is simple to use in numerical calculations it has been used during this analysis.

Therefore substituting equation (4) into (2) gives:

$$1-(0.5)^{1/N} = 1/2(1-e^{-2/\pi x^2})^{1/2}.1/2(1-e^{-2/\pi y^2})^{1/2}$$

where x represents the target length (horizontal aspect) in metres and y represents the diameter (vertical aspect) in metres.

Simplifying the expression so that

$$1-(0.5)^{1/N} = A.B$$

then $(1-A.B)^N = 0.5$

$$1-A.B = (0.5)^{1/N}$$

and $\ln(1-A.B) = 1/N \ln(0.5)$

therefore

$$N = \ln(0.5)/\ln(1-A.B) \qquad (5)$$

In all of these cases, calculations have been made for guns having single standard deviation dispersion angles of 0.5, 1.0, and 1.5 milli-radians (mrad). These have been determined to cover a broad range of gun types and conditions including exceptionally accurate guns, which exhibit minimal barrel whip and impart negligible cant angles to the projectiles during launch (0.5 mrad), guns with commonplace accuracy (1.0 mrad) and noticeably worn guns (1.5 mrad). Other gun-related errors such as gun jump, muzzle velocity variations, gun training and stabilization variations as well as barrel alignment errors have not been considered. Similarly, computational errors that include target acquisition, tracking prediction algorithm errors and meteorological variations have not been taken into account. Combining these gun-related and computational errors would undoubtedly increase the spread on the target. As the determination of each of these errors is strictly scenario dependent no effort has been made here to accommodate for them, so it can be accepted that the results provided herein would only be representative of the very best possible outcome.

Air-bursting munitions, however, need to be considered differently in order to represent the likely effect of a burst on the target. Rather than complicate the calculations for hit probability (which assumes that the attacking projectiles are dimensionless) one option is to increase the representative dimensions of the target in proportion to the maximum airburst diameter. For example, 40 mm L70 pre-fragmented high explosive (PFHE) ammunition is quoted to have an effective airburst radius of 4.5 m. This would infer that a 40 mm PFHE round would be capable of influencing the target if it passed anywhere within 4.5 m of the target's exterior surface. In the case of a frontal attack on the generic SOW, the new representative target would therefore possess the equivalent dimensions of a circle having a diameter of 18.3 m, which is twice the diameter of the effective airburst plus the diameter of the original target. Similarly, a side-on attack would yield new target dimensions of 20.5 m (length) x 18.3 m (height). Figures 1 and 2 illustrate this effect.

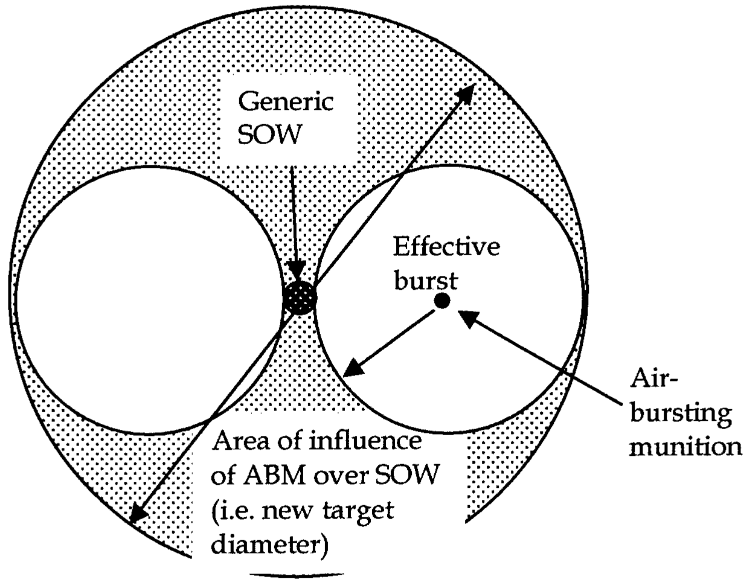

Figure 1. Illustration of the area of influence an air-bursting munition would have on a SOW (frontal aspect) illustrating the new representative target dimensions

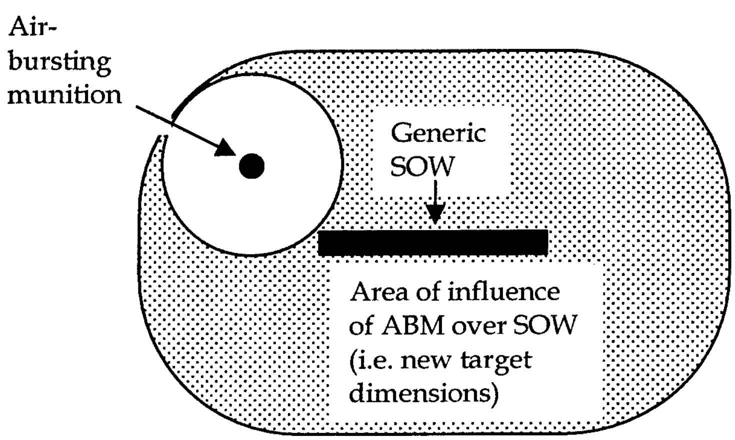

Figure 2. Illustration of the area of influence an air-bursting munition would have on a SOW (side-on aspect) illustrating the new representative target dimensions

This option, however, seems to provide an unrealistic representation as it assumes that the timing of the airburst is at its maximum effective radius at the very moment it intercepts the target. Such precision, despite advances in modern fuzing and detection systems, is highly unlikely.

Another alternative is to accept that the hit probability calculations would remain similar for ABMs as for non-bursting varieties because the fragmentation pattern, visualized as an expanding cylinder (or ring if viewed end-on), would still only have a point influence on the target, but having a larger area of influence. Calculations are therefore made relative to the size of the gun's dispersion. As, for practical purposes, virtually all rounds fall on a given plane within a circular area having a diameter corresponding to $\pm 3\sigma$ (standard deviations) and because an ABM could fall anywhere within the extreme circular boundary of this dispersion, a burst of ABMs could cover a circular area whose diameter measures $6\sigma + 2r_{ABM}$, where r_{ABM} is the effective airburst radius for the ABM in question. The 40 mm PFHE round, for example, would fall within a circular dispersion area with a diameter that is 9 m larger than the normal calculated dispersion of the gun, irrespective of range.

2.4 Hit Probability vs Kill Probability

The estimation of kill probability is a far more complex process than a determination of hit probability, as it is reliant on several additional factors. With hit probability, success is simply measured on the likelihood of scoring a singular hit on the target. A kill is entirely scenario dependent and would require detailed knowledge of the position of a given impact on the target together with details of the size, mass and impact velocity of the projectile or fragment striking it as well as an understanding of the vulnerability characteristics of the various elements of the target itself before a determination of likely damage to the target's integrity can be calculated. Given its complexity no attempt will be made to determine kill probability during this assessment.

2.5 Dealing with maneuvering targets

A SOW that manoeuvres at the precise moment a gun has achieved lock and has begun to fire presents additional difficulties. To keep the analysis straightforward two different approaches are used here. Firstly, and in both cases, a dispersion cone must be calculated for each gun having circular distribution with a diameter corresponding to $\pm 3\sigma$ (standard deviations), which for practical purposes represents 97% (virtually 100%) of all rounds fired. In the case of a gun firing against the front surface of a manoeuvring SOW, the target could be anywhere within a circular area having a radius related to the square of the attacking round's time-of-flight and the target's acceleration away from the original line of flight, i.e. $r = 1/2\, gt^2$.

A single gun, aimed at a predicted point in space, will only be able to have an influence on the target provided that the target remains somewhere within its dispersion cone. Figure 3 illustrates the point at which a manoeuvring SOW (with 1, 5 and 10 *g* escape conditions) remains within dispersion cones for a 12.7 mm weapon firing MP ammunition having standard deviation gun dispersion angles of 0.5, 1 and 1.5 mrad. As can be clearly seen a gun having a 1.5 mrad dispersion angle would only be able to engage the front surface of a 300 mm diameter SOW manoeuvring at 1 *g* at ranges less than 600 m. For the case where the SOW manoeuvres at 5 g the possible engagement range would drop below 100 m and even less than this for an SOW manoeuvring at 10 g. As this constitutes virtual point blank range it can be seen that a standard gun firing non-ABM rounds would be ineffective against highly manoeuvrable SOW.

If it were possible to provide the gun with a variable and wide reaching dispersion capability so that it could engage a manoeuvring target at any given range, the number of rounds required to achieve a 50% hit probability, should the target fall within the centre of that dispersion, could be determined. This can be considered a shotgun approach. Using this particular method, the hit probability would drop markedly as the target approached the outer limits of the dispersion cone, which is the most likely region that a manoeuvring SOW would be located. Conversely, it also follows that the likelihood of a hit in the outer regions of the dispersion cone would also be 50%, so the argument remains valid.

The other, and possibly more suitable, approach is to consider a case involving a number of guns, each having fixed dispersion limits, and arranged in such a manner so as to have overlapping fields of fire. As each dispersion cone has a base radius of 3σ, intersecting the adjacent dispersion cone at a distance of $0.707 \times 3\sigma$ from their centres would result in perfectly square overlaps. For a given range the number of guns required can be determined and the number of rounds that would be required to achieve a 50% hit had the target fallen within the centre of each gun's dispersion cone can thus be calculated. The product would reveal the total number of rounds required. By way of illustration figure 4 shows Gaussian distribution bell curves for sixteen guns, with overlapping fields of fire in a 4 x 4 matrix.

Multiplying the number of guns required for a square matrix by $\pi/4$ gives an approximation to the number of guns that would be needed to occupy a circular area (as would be the case during a frontal assault) that would be needed to contain a manoeuvring SOW.

The number of guns required for a side-on shot would be quite different, however, as a manoeuvring target would only appear to alter its vertical position when viewed from the gunner's line-of-sight. This is because any change in sideways motion (i.e. back and forth) cannot be visualised from the gunner's perspective. The number of guns that would be required would have to cover an area approximately the shape of a vertical column having a length that corresponds to the target's maximum distance travelled for a given intercept time (i.e. the time-of-flight of the attacking shell) and a width equal to a singular gun's area of influence (i.e. its dispersion diameter).

Allowing for overlapping fields of fire and the number of rounds required to obtain a 50% hit probability within each gun's area of influence, a calculation of the total number of rounds required to defeat the target at any given range can thus be made.

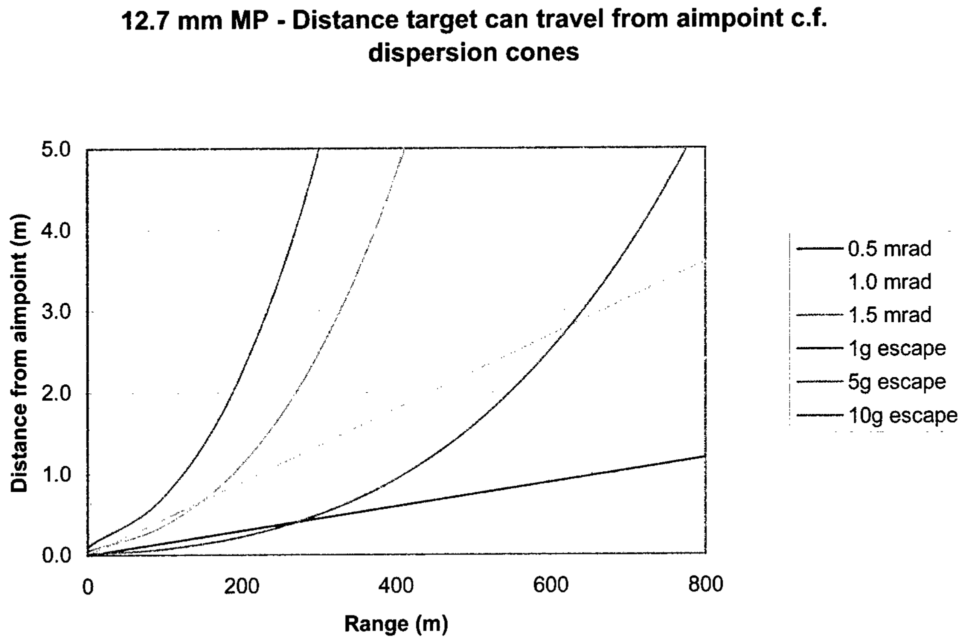

Figure 3. Representation of the positions a manoeuvring SOW can have in relation to the dispersion cones of a 12.7 mm gun firing MP ammunition

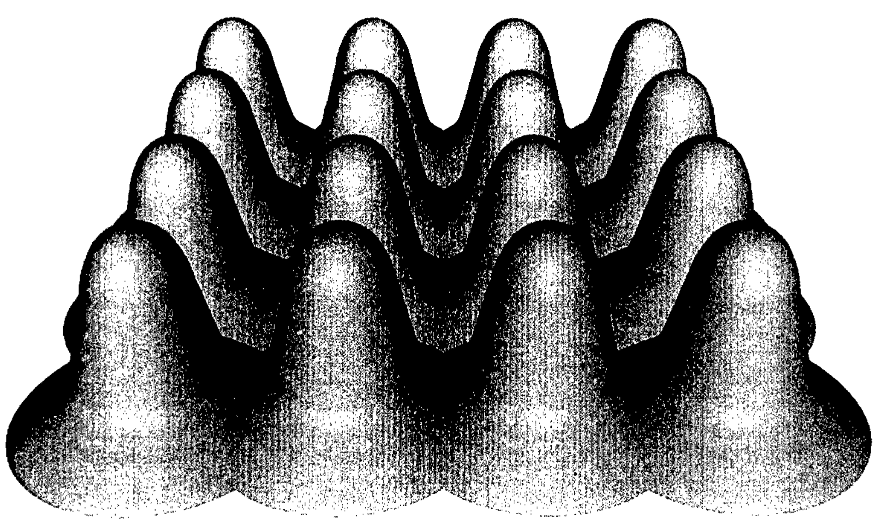

Figure 4. 3D graphical Gaussian representation of gun dispersion at a given plane for a matrix of 4 x 4 guns having overlapping fields of fire

3. Results

3.1 Non-manoeuvring SOW

3.1.1 Firing non-air bursting ammunition at the front face of the target

Table 2 summarises the number of rounds required to achieve a hit probability of 50% on the front face of a 300 mm diameter stationary target over various ranges up to 3000 m, for guns with single standard deviation dispersion angles corresponding to 0.5, 1.0 and 1.5 mrad.

Table 2. Number of rounds required to achieve a 50% hit probability on the front face of a stationary SOW of diameter 300 mm with guns exhibiting σ dispersion angles of 0.5, 1.0 and 1.5 mrad at ranges up to 3000 m

Range (m)	Number of rounds required for $P_N = 0.5$		
	$\sigma = 0.5$ mrad	$\sigma = 1.0$ mrad	$\sigma = 1.5$ mrad
100	1	1	2
200	1	3	6
300	2	6	13
400	3	10	23
500	4	16	35
600	6	23	50
700	8	31	68
800	10	40	89
900	13	50	113
1000	16	62	139
1100	19	75	168
1200	23	89	200
1300	26	105	235
1400	31	121	272
1500	35	139	312
1600	40	158	355
1700	45	178	401
1800	50	200	450
1900	56	223	501
2000	62	247	555
2100	68	272	612
2200	75	299	671
2300	82	326	734
2400	89	355	799
2500	97	385	867
2600	105	417	938
2700	113	450	1011
2800	121	483	1087
2900	130	519	1166
3000	139	555	1248

3.1.2 Firing non-air bursting ammunition at the side of the target

Table 3 summarises the number of rounds required to achieve a hit probability of 50% onto the side of a stationary SOW measuring 2500 mm in length x 300 mm in diameter over various ranges up to 3000 m, for guns with single standard deviation dispersion angles corresponding to 0.5, 1.0 and 1.5 mrad.

Table 3. Number of rounds required to achieve a 50% hit probability on the side of a stationary SOW of diameter 300 mm and length 2500 mm with guns exhibiting σ dispersion angles of 0.5, 1.0 and 1.5 mrad at ranges up to 3000 m

Range (m)	Number of rounds required for $P_N = 0.5$		
	$\sigma = 0.5$ mrad	$\sigma = 1.0$ mrad	$\sigma = 1.5$ mrad
100	1	1	1
200	1	1	1
300	1	1	2
400	1	2	3
500	1	3	4
600	1	3	6
700	2	4	8
800	2	5	10
900	2	6	12
1000	3	7	14
1100	3	8	17
1200	3	10	20
1300	4	11	23
1400	4	13	27
1500	4	14	31
1600	5	16	35
1700	5	18	39
1800	6	20	43
1900	6	22	48
2000	7	24	53
2100	8	27	59
2200	8	29	64
2300	9	32	70
2400	10	35	76
2500	10	37	83
2600	11	40	89
2700	12	43	96
2800	13	47	104
2900	13	50	111
3000	14	53	119

3.1.3 Air bursting ammunition

Using the method whereby the size of the target is proportionately increased to reflect the possible interaction area with an ABM it has been determined that no more than one ABM round would be required to achieve a 50% hit probability on the front face of a 300 mm diameter stationary target, for guns with single standard deviation dispersion angles corresponding to 0.5, 1.0 and 1.5 mrad, irrespective of the range (up to 3000 m) or calibre of the round. As this is clearly misleading, and highly unrepresentative of reality, this method of calculation will no longer be considered for the assessment of ABM hit probabilities.

3.2 Manoeuvring SOW

3.2.1 A single gun firing non-air bursting ammunition at the front face of a manoeuvring target

Table 4 summarises the number of rounds required to achieve a hit probability of 50% on the front face of a manoeuvring 300mm diameter target over a selection of ranges up to 3000 m, for a single gun with variable dispersion capabilities.

Table 4. Number of rounds required to achieve a 50% hit probability on a manoeuvring SOW of diameter 300 mm for a gun exhibiting variable dispersion angles at ranges up to 3000 m

Ammo type	Range (m)	No. of rds. at 1 *g* manoeuvre	No. of rds. at 5 *g* manoeuvre	No. of rds. at 10 *g* manoeuvre
12.7 mm MP	200	1	11	38
	500	21	455	1786
	1000	733	18051	71995
	1500	8458	209536	837425
	2000	53558	1336534	5344323
	2500	238755	5961195	23838393
	3000	836946	20914079	83644351
20 mm MPLD	200	1	2	6
	500	6	112	433
	1000	251	6059	24195
	1500	3239	80073	320142
	2000	22048	549638	2197389
	2500	102983	2569540	10275642
	3000	373094	9316164	37263061

20 mm HEIT	200	1	6	21
	500	14	312	1238
	1000	733	18051	71855
	1500	10493	260449	1040460
	2000	76703	1914677	7655087
	2500	377582	9426698	37701973
	3000	1423197	35567428	142266592
25 mm APDS-T	200	1	5	16
	500	6	112	433
	1000	81	1921	7614
	1500	489	11762	46878
	2000	1853	45528	182000
	2500	5502	136200	544220
	3000	13832	343653	1373692
25 mm HEIT	200	1	9	32
	500	11	226	898
	1000	331	8031	31982
	1500	3765	92994	371497
	2000	24195	602854	2410196
	2500	109636	2736580	10945453
	3000	390554	9754038	39011248
35 mm HEI	200	1	5	14
	500	5	101	380
	1000	86	2181	8125
	1500	624	15284	60942
	2000	2863	70876	283086
	2500	9964	248048	991932
	3000	28879	719321	2875951
35 mm FAPDS	200	1	3	9
	500	5	81	303
	1000	60	1351	5348
	1500	321	7660	30411
	2000	1113	27215	108772
	2500	3033	74974	299465
	3000	7032	174927	698612

3.2.2 A single gun firing non-air bursting ammunition at the side of the manoeuvring target

Table 5 summarises the number of rounds required to achieve a 50% hit probability aimed at the side of a manoeuvring SOW measuring 2500 mm in length x 300 mm in diameter over various ranges up to 3000 m, for a gun with variable dispersion angles.

Table 5. Number of rounds required to achieve a 50% hit probability on a manoeuvring SOW of diameter 300 mm and length 2500 mm for a gun exhibiting variable dispersion angles at ranges up to 3000 m

Ammo type	Range (m)	No. of rds. at 1 *g* manoeuvre	No. of rds. at 5 *g* manoeuvre	No. of rds. at 10 *g* manoeuvre
12.7 mm MP	200	1	1	1
	500	1	12	43
	1000	70	1703	6792
	1500	1795	44536	179205
	2000	20204	511240	2137268
	2500	141003	3751003	18655694
	3000	716403	22690551	283355317
20 mm MPLD	200	1	1	1
	500	1	4	11
	1000	25	572	2282
	1500	688	16996	68125
	2000	8315	208448	848499
	2500	60731	1556684	6795462
	3000	317753	8772884	50673865
20 mm HEIT	200	1	1	1
	500	1	9	30
	1000	70	1703	6779
	1500	2226	55387	223146
	2000	28941	737039	3142929
	2500	223327	6172501	35838939
	3000	1226035	47170403	19865643264
25 mm APDS-T	200	1	1	1
	500	1	4	11
	1000	9	182	719
	1500	105	2496	9947
	2000	700	17173	68749
	2500	3242	80348	322470
	3000	11736	292585	1182749

25 mm HEIT	200	1	1	1
	500	1	6	22
	1000	32	758	3016
	1500	799	19741	79098
	2000	9125	228762	932856
	2500	64659	1660941	7295651
	3000	332686	9232223	54464427
35 mm HEI	200	1	1	1
	500	1	4	10
	1000	9	207	767
	1500	134	3243	12933
	2000	1080	26741	107050
	2500	5871	146507	590626
	3000	24505	614931	2517439
35 mm FAPDS	200	1	1	1
	500	1	3	8
	1000	7	128	505
	1500	69	1626	6452
	2000	421	10264	41055
	2500	1788	44200	176974
	3000	5966	148660	597093

3.2.3 Multiple guns engaging the front face of a manoeuvring target with non-air bursting ammunition

Table 6 shows the estimated number of guns and rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) on the front face of a 300 mm diameter target manoeuvring at 1 g over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 6. Number of guns and rounds required to achieve a 50% hit probability on an SOW of diameter 300 mm manoeuvring at 1g at ranges up to 3000 m

Ammo type	Range (m)	No of guns in circle 0.5/1 g	Total no of rds in circle 0.5/1 g	No. of guns in circle 1.0/1 g	Total no of rds in circle 1.0/1 g	No. of guns in circle 1.5/1 g	Total no of rds in circle 1.5/1 g
12.7 mm MP	200	2	2	1	2	1	1
	500	9	34	2	34	1	33
	1000	75	1197	19	1160	8	1155
	1500	383	13422	96	13326	43	13294
	2000	1366	84683	341	84341	152	84228
	2500	3897	377991	974	375068	433	375393
	3000	9486	1318584	2372	1316212	1054	1315420
20 mm MPLD	200	1	1	1	1	1	1
	500	3	10	1	10	1	10
	1000	26	409	6	396	3	395
	1500	147	5139	37	5102	16	5090
	2000	562	34860	141	34720	62	34673
	2500	1681	163040	420	161780	187	161920
	3000	4229	587799	1057	586741	470	586388
20 mm HEIT	200	2	2	1	2	1	1
	500	6	23	1	23	1	23
	1000	75	1197	19	1160	8	1155
	1500	476	16650	119	16531	53	16492
	2000	1956	121278	489	120789	217	120626
	2500	6163	597780	1541	593158	685	593671
	3000	16131	2242204	4033	2238171	1792	2236824
25 mm APDS-T	200	1	1	1	1	1	1
	500	3	10	1	10	1	10
	1000	8	133	2	129	1	128
	1500	22	776	6	770	2	768
	2000	47	2929	12	2917	5	2913
	2500	90	8711	22	8644	10	8651
	3000	157	21792	39	21753	17	21740

25 mm HEIT	200	2	2	1	2	1	1
	500	4	17	1	17	1	17
	1000	34	540	8	523	4	521
	1500	171	5974	43	5931	19	5917
	2000	617	38256	154	38102	69	38051
	2500	1789	173574	447	172232	199	172381
	3000	4427	615306	1107	614199	492	613830
35 mm HEI	200	1	1	1	1	1	1
	500	2	8	1	8	1	8
	1000	9	141	2	136	1	136
	1500	28	991	7	984	3	981
	2000	73	4527	18	4508	8	4502
	2500	163	15774	41	15652	18	15666
	3000	327	45499	82	45417	36	45390
35 mm FAPDS	200	1	1	1	1	1	1
	500	2	8	1	8	1	8
	1000	6	97	2	94	1	94
	1500	15	510	4	506	2	505
	2000	28	1760	7	1753	3	1750
	2500	50	4802	12	4765	6	4769
	3000	80	11079	20	11059	9	11052

Table 7 shows the estimated number of guns and rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) on the front face of a 300 mm diameter target manoeuvring at 5 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 7. Number of guns and rounds required to achieve a 50% hit probability on an SOW of diameter 300 mm manoeuvring at 5 g at ranges up to 3000 m.

Ammo type	Range (m)	No of guns in circle 0.5/5 *g*	Total no of rds in circle 0.5/5 *g*	No. of guns in circle 1.0/5 *g*	Total no of rds in circle 1.0/5 *g*	No. of guns in circle 1.5/5 *g*	Total no of rds in circle 1.5/5 *g*
12.7 mm MP	200	27	27	7	20	3	18
	500	186	742	46	742	21	722
	1000	1841	29462	460	28542	205	28439
	1500	9500	332493	2375	330117	1056	329325
	2000	34085	2113245	8521	2104723	3787	2101881
	2500	97295	9437633	24324	9364657	10811	9372757
	3000	237047	32949518	59262	32890240	26339	32870459
20 mm MPLD	200	5	5	1	4	1	4
	500	46	183	11	183	5	178
	1000	618	9889	155	9580	69	9546
	1500	3630	127059	908	126152	403	125849
	2000	14017	869054	3504	865549	1557	864380
	2500	41939	4068039	10485	4036583	4660	4040074
	3000	105592	14677344	26398	14650938	11732	14642127
20 mm HEIT	200	16	16	4	12	2	11
	500	127	509	32	509	14	495
	1000	1841	29462	460	28542	205	28439
	1500	11808	413281	2952	410329	1312	409345
	2000	48829	3027368	12207	3015159	5425	3011088
	2500	153857	14924142	38464	14808741	17095	14821550
	3000	403133	56035440	100783	55934629	44792	55900988
25 mm APDS-T	200	13	13	3	9	1	8
	500	46	183	11	183	5	178
	1000	196	3135	49	3037	22	3026
	1500	533	18664	133	18531	59	18486
	2000	1161	71986	290	71696	129	71599
	2500	2223	215629	556	213961	247	214146
	3000	3895	541415	974	540441	433	540116

25 mm HEIT	200	23	23	6	17	3	15
	500	92	369	23	369	10	359
	1000	819	13107	205	12698	91	12652
	1500	4216	147563	1054	146509	468	146158
	2000	15374	953195	3844	949351	1708	948069
	2500	44665	4332493	11166	4298992	4963	4302711
	3000	110555	15367201	27639	15339554	12284	15330328
35 mm HEI	200	13	13	3	9	1	8
	500	41	166	10	166	5	161
	1000	223	3560	56	3449	25	3437
	1500	693	24253	173	24079	77	24022
	2000	1807	112065	452	111613	201	111462
	2500	4049	392705	1012	389668	450	390005
	3000	8153	1133268	2038	1131230	906	1130549
35 mm FAPDS	200	7	7	2	6	1	5
	500	33	133	8	133	4	129
	1000	138	2206	34	2137	15	2129
	1500	347	12155	87	12068	39	12039
	2000	694	43030	174	42856	77	42799
	2500	1224	118697	306	117779	136	117881
	3000	1983	275592	496	275096	220	274930

Table 8 shows the estimated number of guns and rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) on the front face of a 300 mm diameter target manoeuvring at 10 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 8. *Number of guns and rounds required to achieve a 50% hit probability on an SOW of diameter 300 mm manoeuvring at 10 g at ranges up to 3000 m*

Ammo type	Range (m)	No of guns in circle 0.5/10 *g*	Total no of rds in circle 0.5/10 *g*	No. of guns in circle 1.0/10 *g*	Total no of rds in circle 1.0/10 *g*	No. of guns in circle 1.5/10 *g*	Total no of rds in circle 1.5/10 *g*
12.7 mm MP	200	96	96	24	72	11	64
	500	729	2914	182	2914	81	2833
	1000	7344	117506	1836	113834	816	113426
	1500	37967	1328830	9492	1319338	4219	1316173
	2000	136292	8450111	34073	8416034	15144	8404669
	2500	389076	37740420	97269	37448594	43231	37480986
	3000	948052	131779223	237013	131542144	105339	131463030
20 mm MPLD	200	16	16	4	12	2	11
	500	177	706	44	706	20	687
	1000	2468	39490	617	38256	274	38119
	1500	14514	508003	3629	504374	1613	503164
	2000	56038	3474375	14010	3460363	6226	3455691
	2500	167713	16268170	41928	16142377	18635	16156340
	3000	422352	58706859	105588	58601242	46928	58565997
20 mm HEIT	200	53	53	13	40	6	36
	500	505	2021	126	2021	56	1965
	1000	7330	117277	1832	113612	814	113205
	1500	47172	1651008	11793	1639214	5241	1635282
	2000	195222	12103747	48805	12054936	21691	12038657
	2500	615350	59688935	153837	59227393	68372	59278623
	3000	1612495	224136844	403124	223733609	179166	223599048
25 mm APDS-T	200	42	42	10	31	5	28
	500	177	706	44	706	20	687
	1000	777	12427	194	12039	86	11996
	1500	2125	74386	531	73854	236	73677
	2000	4641	287768	1160	286607	516	286220
	2500	8882	861597	2221	854935	987	855675
	3000	15570	2164212	3892	2160319	1730	2159019

25 mm HEIT	200	81	81	20	61	9	54
	500	366	1465	92	1465	41	1424
	1000	3262	52199	816	50568	362	50387
	1500	16843	589494	4211	585283	1871	583879
	2000	61465	3810852	15366	3795484	6829	3790358
	2500	178645	17328601	44661	17194608	19849	17209481
	3000	442166	61461078	110541	61350506	49129	61313608
35 mm HEI	200	37	37	9	28	4	24
	500	155	620	39	620	17	603
	1000	829	13261	207	12846	92	12800
	1500	2763	96703	691	96012	307	95781
	2000	7219	447598	1805	445793	802	445191
	2500	16190	1570406	4047	1558263	1799	1559610
	3000	32597	4530976	8149	4522825	3622	4520105
35 mm FAPDS	200	23	23	6	17	3	15
	500	124	494	31	494	14	480
	1000	546	8729	136	8456	61	8426
	1500	1379	48256	345	47912	153	47797
	2000	2774	171983	693	171290	308	171058
	2500	4888	474107	1222	470441	543	470847
	3000	7918	1100643	1980	1098663	880	1098002

3.2.4 Multiple guns engaging the side of a manoeuvring target with non-air bursting ammunition

Table 9 shows the estimated number of guns and rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) onto the side of a SOW, measuring 2500 mm in length x 300 mm in diameter, manoeuvring at 1 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 9. Number of guns and rounds required to achieve a 50% hit probability on the side of a SOW of diameter 300 mm and length 2500 mm manoeuvring at 1 g at ranges up to 3000 m

Ammo type	Range (m)	No of guns in column 0.5/1 *g*	Total no of rds in column 0.5/1 *g*	No. of guns in column 1.0/1 *g*	Total no of rds in column 1.0/1 *g*	No. of guns in column 1.5/1 *g*	Total no of rds in column 1.5/1 *g*
12.7 mm MP	200	2	2	1	1	1	1
	500	3	3	2	5	1	4
	1000	10	29	5	34	3	46
	1500	22	88	11	155	7	228
	2000	42	292	21	500	14	737
	2500	70	704	35	1303	23	1949
	3000	110	1539	55	2912	37	4359
20 mm MPLD	200	1	1	1	1	1	1
	500	2	2	1	3	1	2
	1000	6	17	3	20	2	27
	1500	14	55	7	96	5	141
	2000	27	187	13	321	9	473
	2500	46	463	23	856	15	1280
	3000	73	1027	37	1944	24	2911
20 mm HEIT	200	2	2	1	1	1	1
	500	3	3	1	4	1	4
	1000	10	29	5	34	3	46
	1500	25	98	12	172	8	254
	2000	50	349	25	599	17	882
	2500	89	886	44	1639	30	2451
	3000	143	2006	72	3798	48	5685
25 mm APDS-T	200	1	1	1	1	1	1
	500	2	2	1	3	1	2
	1000	3	10	2	11	1	15
	1500	5	21	3	37	2	55
	2000	8	54	4	93	3	137
	2500	11	107	5	198	4	296
	3000	14	198	7	374	5	560

25 mm HEIT	200	2	2	1	1	1	1
	500	2	2	1	4	1	3
	1000	7	20	3	23	2	31
	1500	15	59	7	103	5	152
	2000	28	196	14	336	9	495
	2500	48	477	24	883	16	1321
	3000	75	1051	38	1989	25	2978
35 mm HEI	200	1	1	1	1	1	1
	500	2	2	1	2	1	2
	1000	3	10	2	12	1	16
	1500	6	24	3	42	2	62
	2000	10	67	5	116	3	170
	2500	14	144	7	266	5	398
	3000	20	286	10	541	7	810
35 mm FAPDS	200	1	1	1	1	1	1
	500	2	2	1	2	1	2
	1000	3	8	1	10	1	13
	1500	4	17	2	30	1	44
	2000	6	42	3	72	2	106
	2500	8	79	4	147	3	220
	3000	10	141	5	267	3	400

Table 10 shows the estimated number of guns and rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) onto the side of a SOW, measuring 2500 mm in length x 300mm in diameter, manoeuvring at 5 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 10. Number of guns and rounds required to achieve a 50% hit probability on the side of a SOW of diameter 300 mm and length 2500 mm manoeuvring at 5 g at ranges up to 3000 m

Ammo type	Range (m)	No of guns in column 0.5/5 *g*	Total no of rds in column 0.5/5 *g*	No. of guns in column 1.0/5 *g*	Total no of rds in column 1.0/5 *g*	No. of guns in column 1.5/5 *g*	Total no of rds in column 1.5/5 *g*
12.7 mm MP	200	6	6	3	3	2	2
	500	15	15	8	23	5	20
	1000	48	145	24	169	16	226
	1500	110	440	55	770	37	1136
	2000	208	1458	104	2500	69	3680
	2500	352	3520	176	6511	117	9738
	3000	549	7691	275	14559	183	21792
20 mm MPLD	200	3	3	1	1	1	1
	500	8	8	4	11	3	10
	1000	28	84	14	98	9	131
	1500	68	272	34	476	23	703
	2000	134	935	67	1603	45	2360
	2500	231	2311	116	4275	77	6393
	3000	367	5133	183	9717	122	14544
20 mm HEIT	200	4	4	2	2	1	1
	500	13	13	6	19	4	17
	1000	48	145	24	169	16	226
	1500	123	490	61	858	41	1267
	2000	249	1745	125	2992	83	4405
	2500	443	4426	221	8188	148	12245
	3000	716	10030	358	18986	239	28419
25 mm APDS-T	200	4	4	2	2	1	1
	500	8	8	4	11	3	10
	1000	16	47	8	55	5	74
	1500	26	104	13	182	9	269
	2000	38	269	19	461	13	679
	2500	53	532	27	984	18	1472
	3000	70	986	35	1866	23	2793

25 mm HEIT	200	5	5	3	3	2	2
	500	11	11	5	16	4	14
	1000	32	97	16	113	11	151
	1500	73	293	37	513	24	757
	2000	140	979	70	1679	47	2472
	2500	238	2385	119	4412	79	6598
	3000	375	5253	188	9942	125	14882
35 mm HEI	200	4	4	2	2	1	1
	500	7	7	4	11	2	10
	1000	17	50	8	59	6	79
	1500	30	119	15	208	10	307
	2000	48	336	24	576	16	848
	2500	72	718	36	1328	24	1986
	3000	102	1426	51	2700	34	4041
35 mm FAPDS	200	3	3	2	2	1	1
	500	7	7	3	10	2	9
	1000	13	40	7	46	4	62
	1500	21	84	11	147	7	217
	2000	30	208	15	357	10	525
	2500	39	395	20	730	13	1092
	3000	50	703	25	1331	17	1993

Table 11 shows the estimated number of guns and rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) onto the side of a SOW, measuring 2500 mm in length x 300 mm in diameter, manoeuvring at 10 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 11. Number of guns and rounds required to achieve a 50% hit probability on the side of a SOW of diameter 300 mm and length 2500 mm manoeuvring at 10 g *at ranges up to 3000 m*

Ammo type	Range (m)	No of guns in column 0.5/10 *g*	Total no of rds in column 0.5/10 *g*	No. of guns in column 1.0/10 *g*	Total no of rds in column 1.0/10 *g*	No. of guns in column 1.5/10 *g*	Total no of rds in column 1.5/10 *g*
12.7 mm MP	200	11	11	6	6	4	4
	500	30	30	15	46	10	41
	1000	97	290	48	338	32	451
	1500	220	879	110	1539	73	2272
	2000	417	2916	208	4999	139	7359
	2500	704	7038	352	13021	235	19473
	3000	1099	15382	549	29115	366	43581
20 mm MPLD	200	4	4	2	2	1	1
	500	15	15	7	22	5	20
	1000	56	168	28	196	19	262
	1500	136	544	68	952	45	1405
	2000	267	1870	134	3205	89	4719
	2500	462	4621	231	8549	154	12785
	3000	733	10266	367	19433	244	29088
20 mm HEIT	200	8	8	4	4	3	3
	500	25	25	13	38	8	34
	1000	97	290	48	338	32	451
	1500	245	980	123	1716	82	2532
	2000	499	3490	249	5983	166	8808
	2500	885	8851	443	16375	295	24489
	3000	1433	20060	716	37971	478	56837
25 mm APDS-T	200	7	7	4	4	2	2
	500	15	15	7	22	5	20
	1000	31	94	16	110	10	147
	1500	52	208	26	364	17	538
	2000	77	538	38	922	26	1358
	2500	106	1063	53	1967	35	2942
	3000	141	1971	70	3731	47	5585

25 mm HEIT	200	10	10	5	5	3	3
	500	22	22	11	32	7	29
	1000	64	193	32	226	21	301
	1500	146	586	73	1025	49	1513
	2000	280	1958	140	3357	93	4942
	2500	477	4769	238	8823	159	13195
	3000	750	10505	375	19884	250	29763
35 mm HEI	200	7	7	3	3	2	2
	500	14	14	7	21	5	19
	1000	32	97	16	114	11	152
	1500	59	237	30	415	20	613
	2000	96	671	48	1150	32	1694
	2500	144	1436	72	2656	48	3972
	3000	204	2852	102	5399	68	8081
35 mm FAPDS	200	5	5	3	3	2	2
	500	13	13	6	19	4	17
	1000	26	79	13	92	9	123
	1500	42	168	21	293	14	433
	2000	59	416	30	713	20	1050
	2500	79	789	39	1459	26	2183
	3000	100	1406	50	2661	33	3983

3.2.5 Multiple guns engaging the front face of a manoeuvring target with air bursting ammunition

Table 12 shows the estimated number of guns and ABM rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) on the front face of a 300 mm diameter target manoeuvring at 1 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 12. *Number of guns and ABM rounds required to achieve a 50% hit probability on an SOW of diameter 300 mm manoeuvring at 1g at ranges up to 3000 m*

Ammo type	Range (m)	No of guns in circle 0.5/1 *g*	Total no of rds in circle 0.5/1 *g*	No. of guns in circle 1.0/1 *g*	Total no of rds in circle 1.0/1 *g*	No. of guns in circle 1.5/1 *g*	Total no of rds in circle 1.5/1 *g*
30 mm ABM + 3 m	200	1	1	1	1	1	1
	500	1	1	1	2	1	3
	1000	3	45	2	99	1	142
	1500	17	601	8	1169	5	1552
	2000	65	4022	29	7121	16	9000
	2500	188	18194	78	29844	42	36489
	3000	454	63169	178	98524	94	117181
35 mm AHEAD + 3.5 m	200	1	1	1	1	1	1
	500	1	1	1	2	1	3
	1000	2	27	1	61	1	91
	1500	7	254	4	520	2	712
	2000	21	1323	10	2467	6	3201
	2500	50	4839	22	8343	12	10449
	3000	100	13913	41	22753	22	27662
40 mm L70 + 4.5 m	200	1	1	1	1	1	1
	500	1	1	1	1	1	2
	1000	1	19	1	48	1	74
	1500	7	232	4	517	2	743
	2000	23	1441	12	2930	7	3983
	2500	64	6184	30	11601	17	15165
	3000	148	20621	66	36593	37	46285
76 mm HISP-PFF + 10 m	200	1	1	1	1	1	1
	500	1	1	1	1	1	1
	1000	1	5	1	15	1	26
	1500	1	50	1	141	1	237
	2000	4	275	3	724	2	1153
	2500	11	1059	7	2596	5	3964
	3000	23	3182	13	7401	9	10878

Table 13 shows the estimated number of guns and ABM rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) on the front face of a 300 mm diameter target manoeuvring at 5 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 13. Number of guns and ABM rounds required to achieve a 50% hit probability on an SOW of diameter 300 mm manoeuvring at 5 g at ranges up to 3000 m

Ammo type	Range (m)	No of guns in circle 0.5/5 *g*	Total no of rds in circle 0.5/5 *g*	No. of guns in circle 1.0/5 *g*	Total no of rds in circle 1.0/5 *g*	No. of guns in circle 1.5/5 *g*	Total no of rds in circle 1.5/5 *g*
30 mm ABM + 3 m	200	1	1	1	1	1	1
	500	4	14	2	40	2	64
	1000	69	1099	39	2395	25	3437
	1500	424	14843	208	28884	123	38363
	2000	1613	100017	717	177091	403	223828
	2500	4672	453136	1931	743270	1048	908769
	3000	11347	1577245	4432	2460012	2344	2925858
35 mm AHEAD + 3.5 m	200	1	1	1	1	1	1
	500	3	12	2	34	2	57
	1000	39	626	23	1435	15	2124
	1500	179	6261	92	12844	56	17563
	2000	530	32844	248	61256	143	79500
	2500	1237	120022	538	206939	299	259180
	3000	2493	346508	1021	566698	552	688962
40 mm L70 + 4.5 m	200	1	1	1	1	1	1
	500	2	7	1	22	1	37
	1000	29	459	18	1139	13	1774
	1500	162	5672	91	12671	58	18202
	2000	577	35788	295	72742	178	98876
	2500	1588	154009	750	288922	436	377694
	3000	3699	514100	1644	912312	925	1153950
76 mm HISP-PFF + 10 m	200	1	1	1	1	1	1
	500	1	2	1	7	1	14
	1000	7	114	6	345	4	621
	1500	35	1222	25	3464	19	5827
	2000	110	6830	73	17962	52	28622
	2500	271	26279	167	64392	113	98344
	3000	570	79217	332	184216	217	270782

Table 14 shows the estimated number of guns and ABM rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) on the front face of a 300 mm diameter target manoeuvring at 10 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 14. Number of guns & ABM rounds required to achieve a 50% hit probability on an SOW of diameter 300 mm manoeuvring at 10 g at ranges up to 3000 m

Ammo type	Range (m)	No of guns in circle 0.5/10 *g*	Total no of rds in circle 0.5/10 *g*	No. of guns in circle 1.0/10 *g*	Total no of rds in circle 1.0/10 *g*	No. of guns in circle 1.5/10 *g*	Total no of rds in circle 1.5/10 *g*
30 mm ABM + 3 m	200	1	1	1	1	1	1
	500	14	57	10	157	7	253
	1000	274	4388	154	9564	99	13723
	1500	1695	59337	831	115470	492	153364
	2000	6448	399755	2866	707810	1612	894612
	2500	18678	1811807	7719	2971869	4191	3633595
	3000	45385	6308487	17728	9839278	9377	11702513
35 mm AHEAD + 3.5 m	200	1	1	1	1	1	2
	500	11	46	8	132	6	218
	1000	155	2479	92	5684	61	8412
	1500	714	24981	369	51252	225	70078
	2000	2115	131102	990	244509	572	317335
	2500	4946	479736	2148	827144	1195	1035955
	3000	9967	1385381	4082	2265725	2207	2754550
40 mm L70 + 4.5 m	200	1	1	0	1	1	1
	500	7	28	5	85	4	147
	1000	115	1834	73	4549	51	7082
	1500	647	22638	364	50571	233	72648
	2000	2306	143002	1177	290664	712	395092
	2500	6350	615918	3001	1155466	1742	1510486
	3000	14789	2055694	6573	3647993	3697	4614215
76 mm HISP-PFF + 10 m	200	1	1	1	1	1	1
	500	2	8	2	28	2	54
	1000	28	452	22	1370	18	2469
	1500	140	4885	100	13846	75	23290
	2000	440	27282	290	71751	206	114329
	2500	1083	105088	669	257496	454	393266
	3000	2278	316697	1327	736463	867	1082539

3.2.6 Multiple guns engaging the side of a manoeuvring target with air bursting ammunition

Table 15 shows the estimated number of guns and ABM rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) onto the side of a SOW, measuring 2500 mm in length x 300 mm in diameter, manoeuvring at 1 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 15. Number of guns & ABM rounds required to achieve a 50% hit probability on the side of an SOW of diameter 300 mm and length 2500 mm manoeuvring at 1 g at ranges up to 3000 m

Ammo type	Range (m)	No of guns in column 0.5/1 *g*	Total no of rds in column 0.5/1 *g*	No. of guns in column 1.0/1 *g*	Total no of rds in column 1.0/1 *g*	No. of guns in column 1.5/1 *g*	Total no of rds in column 1.5/1 *g*
30 mm ABM +3 m	200	1	1	1	1	1	1
	500	1	1	1	1	1	1
	1000	2	6	1	10	1	16
	1500	5	19	3	46	3	78
	2000	9	64	6	145	5	241
	2500	15	155	10	368	7	608
	3000	24	337	15	797	11	1301
35 mm AHEAD + 3.5 m	200	1	1	1	1	1	1
	500	1	1	1	1	1	1
	1000	1	4	1	8	1	13
	1500	3	12	2	31	2	53
	2000	5	36	4	86	3	144
	2500	8	80	5	194	4	325
	3000	11	158	7	383	5	632
40 mm L70 + 4.5 m	200	1	1	1	1	1	1
	500	1	1	1	1	1	1
	1000	1	4	1	7	1	12
	1500	3	12	2	30	2	54
	2000	5	38	4	93	3	160
	2500	9	90	6	229	5	392
	3000	14	192	9	486	7	818
76 mm HISP-PFF + 10 m	200	1	1	1	1	1	1
	500	1	1	1	1	1	1
	1000	1	2	1	4	1	7
	1500	1	5	1	16	1	30
	2000	2	17	2	46	2	86
	2500	4	37	3	108	2	200
	3000	5	76	4	218	3	396

Table 16 shows the estimated number of guns and ABM rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) onto the side of a SOW, measuring 2500 mm in length x 300 mm in diameter, manoeuvring at 5 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 16. Number of guns and ABM rounds required to achieve a 50% hit probability on the side of an SOW of diameter 300 mm and length 2500 mm manoeuvring at 5 g *at ranges up to 3000 m*

Ammo type	Range (m)	No of guns in column 0.5/5 *g*	Total no of rds in column 0.5/5 *g*	No. of guns in column 1.0/5 *g*	Total no of rds in column 1.0/5 *g*	No. of guns in column 1.5/5 *g*	Total no of rds in column 1.5/5 *g*
30 mm ABM +3 m	200	1	1	1	1	1	1
	500	2	2	2	5	2	6
	1000	9	28	7	49	6	79
	1500	23	93	16	228	13	388
	2000	45	317	30	725	23	1201
	2500	77	771	50	1834	37	3032
	3000	120	1683	75	3982	55	6502
35 mm AHEAD + 3.5 m	200	1	1	1	1	1	1
	500	2	2	2	5	1	6
	1000	7	21	5	38	4	62
	1500	15	60	11	152	8	262
	2000	26	182	18	426	14	716
	2500	40	397	26	968	20	1619
	3000	56	789	36	1911	27	3155
40 mm L70 + 4.5 m	200	1	1	1	1	1	1
	500	1	1	1	4	1	5
	1000	6	18	5	34	4	56
	1500	14	57	11	151	9	267
	2000	27	190	19	465	15	798
	2500	45	450	31	1144	24	1955
	3000	69	961	46	2425	34	4083
76 mm HISP-PFF + 10 m	200	1	1	1	1	1	1
	500	1	1	1	2	1	3
	1000	3	9	3	19	2	33
	1500	7	27	6	79	5	151
	2000	12	83	10	231	8	429
	2500	19	186	15	540	12	997
	3000	27	377	21	1090	17	1978

Table 17 shows the estimated number of guns and ABM rounds required in total to achieve a 50% hit probability (calculated as though the target were to lay within the centre of each gun's area of influence) onto the side of a SOW, measuring 2500 mm in length x 300 mm in diameter, manoeuvring at 10 *g* over various ranges up to 3000 m, for guns with σ dispersion angles of 0.5, 1.0 and 1.5 mrad.

Table 17. Number of guns and ABM rounds required to achieve a 50% hit probability on the side of an SOW of diameter 300 mm and length 2500 mm manoeuvring at 10 g at ranges up to 3000 m

Ammo type	Range (m)	No of guns in column 0.5/10 *g*	Total no of rds in column 0.5/10 *g*	No. of guns in column 1.0/10 *g*	Total no of rds in column 1.0/10 *g*	No. of guns in column 1.5/10 *g*	Total no of rds in column 1.5/10 *g*
30 mm ABM + 3 m	200	1	1	1	1	1	1
	500	4	4	4	11	3	12
	1000	19	56	14	98	11	157
	1500	46	186	33	455	25	776
	2000	91	634	60	1450	45	2401
	2500	154	1542	99	3668	73	6063
	3000	240	3365	150	7963	109	13003
35 mm AHEAD + 3.5 m	200	1	1	1	1	1	1
	500	4	4	3	10	3	11
	1000	14	42	11	76	9	123
	1500	30	121	22	303	17	524
	2000	52	363	36	852	27	1430
	2500	79	794	52	1935	39	3237
	3000	113	1577	72	3821	53	6308
40 mm L70 + 4.5 m	200	1	1	1	1	1	1
	500	3	3	3	8	2	9
	1000	12	36	10	68	8	113
	1500	29	115	22	301	17	534
	2000	54	379	39	929	30	1596
	2500	90	899	62	2287	47	3909
	3000	137	1921	91	4849	69	8165
76 mm HISP-PFF + 10 m	200	1	1	1	1	1	1
	500	2	2	1	4	1	6
	1000	6	18	5	37	5	67
	1500	13	53	11	158	10	302
	2000	24	166	19	462	16	858
	2500	37	371	29	1080	24	1995
	3000	54	754	41	2179	33	3955

4. Discussion

4.1 Non-manoeuvring SOW

These results suggest that guns would be quite capable of dealing with non-manoeuvring targets of the dimensions chosen for the generic SOW, provided that all of the error budgets are constrained within the dispersion angles considered. It would be more likely, even if the target were to fly directly to the predicted intercept point (i.e. no computational errors), that typical gun errors alone would further reduce the target strike rate, possibly by as much as 70%.

4.2 Manoeuvring SOW

4.2.1 A single gun firing non-air bursting ammunition at a manoeuvring target

These results demonstrate that the chance of a successful engagement by non-air bursting ammunition against a swiftly manoeuvring SOW would be extremely low, irrespective of the gun or munition type, for ranges greater than 500 m. The use of low drag munitions (including MPLD, APDS-T and FAPDS rounds) would mean slightly less rounds would be needed to achieve success because of their reduced times-of-flight, however, any increase in effective range would be minimal.

4.2.2 Multiple guns engaging a manoeuvring target with non-air bursting ammunition

In order to gauge the quality of the results obtained using the probability method, straightforward calculations were performed to determine the number of attacking rounds that would be required if it were possible for those rounds to be dispersed, at equally spaced intervals, across a two-dimensional square array covering the area of uncertainty for a manoeuvring SOW. The maximum spacing between adjacent rounds that would ensure that at least one round would make contact with the front circular face of a manoeuvring SOW equates to the length of the sides of a square that just fits within the confines of the circular target. As the generic SOW has a diameter of 300 mm the interspatial distance measures approximately 212 mm (i.e. $\frac{1}{\sqrt{2}}$ x 300 mm).

Therefore doubling the interspatial distance between rounds (i.e. 424 mm) should halve the chance of making contact with the manoeuvring SOW. The total number of rounds within the entire array should thus approximate a hit probability of 50%. Using the time-of-flight details for any given round the number of rounds at each selected range can be calculated using the equation:

$N = \pi (0.5gt^2)^2 d^{-2}$ where d is the interspatial distance between adjacent rounds in metres, t is the time-of-flight for a given range in seconds and g is the acceleration of the target from its original flight line in m/s^2.

The results below represent the number of 12.7 mm NM140MP rounds that would be needed, using the aforementioned approach, to evenly occupy, at 424 mm intervals, a square area of uncertainty for a generic SOW manoeuvring at 1 *g*, 5 *g* and 10 *g* at selected ranges of engagement.

Table 18. Number of evenly distributed 12.7 mm NM140 MP rounds needed to occupy a square area of uncertainty to give a 50% chance of hitting an SOW of diameter 300 mm manoeuvring at 1 g, 5 g and 10 g at ranges up to 3000 m

Range (m)	Calculated time-of-flight (s)	Number of 12.7 mm MP rounds		
		1 *g* escape	5 *g* escape	10 *g* escape
200	0.214	1	22	88
500	0.571	45	1115	4460
1000	1.446	1834	45859	183436
1500	2.671	21355	533883	2135531
2000	4.246	136374	3409340	13637359
2500	6.171	608461	15211517	60846066
3000	8.446	2135082	53377058	213508234

These results suggest that the calculations for 50% hit probabilities with either single or multiple guns tend to be conservative, but reasonable. It remains clear that even at ranges as close as 200 m, guns firing non-air bursting ammunition would have little chance of hitting the front of an SOW manoeuvring at 10 *g*.

The situation improves somewhat when engaging the SOW from the side. The larger area presented by the target coupled with the reduced size of the area of uncertainty that can be occupied by a manoeuvring SOW gives guns a fighting chance. Ranges greater than 500 m seem possible, particularly so for guns that fire rounds with reduced time-of-flight. Nonetheless, it would still take an array of between 3 to 6 guns firing 3 to 4 low drag munitions each to give a 50% chance of a hit at 500 m.

4.2.3 Multiple guns engaging a manoeuvring target with air bursting ammunition

The methodology used in this report to determine the effectiveness of guns against manoeuvring air targets clearly favours the use of air bursting munitions. This is particularly evident at moderately close ranges. The extended area of influence afforded by ABM makes frontal assaults on fast manoeuvring SOW possible at ranges between 200 and 500 m with the best results, not surprisingly, obtained when using large calibre 76 mm HISP-PFF munition with its effective burst radius of 10 m. The results show, however, that even at 500 m at least two 76 mm guns would have to be deployed firing between 4 and

13 rounds each to give a 50% chance of a hit. A single gun with a relatively worn barrel would require 48 rounds to do the same job and, as the maximum magazine capacity for this type of gun system is 26 rounds, this would not be possible.

As before, the situation for a side-on attack improves the case for guns, particularly when firing ABM. As few as four to five 76 mm HISP-PFF rounds would be needed out of a single gun to achieve a hit rate of 50% at 500 m. The results suggest that even the 30 mm ABM, with its lower 3 m effective burst radius, could have some hope of engaging a fast manoeuvring SOW at this range.

It is, however, important to bear in mind that rate of fire as well as quantity of fire is critical at these short ranges. In the case where a manoeuvring SOW travels at just below supersonic speeds, i.e. 300 m/s, then a 76 mm Oto Melara gun firing at 120 rds/min at an engagement range of 500 m would only be able to expend two to three rounds before the SOW has closed in on its intended target. Under the same attacking conditions the 35 mm Gepard would be able to fire up to 14 rounds from each of its two guns (quite plausible for side-on shots), and the 40 mm L70 Bofors cannon could fire 6 rounds.

Comparing this with the most capable gun that fires non-ABM rounds, the 25 mm KBB Oerlikon Breda Gatling Gun, and assuming similar ballistics to the APDS-T KBA round, this gun would be able to fire 133 rounds from each of its two guns in the time that a SOW would strike its intended target from a distance of 500 m. The study reveals that a frontal assault of a generic SOW would still require more rounds to offer sufficient probability of a hit, however, a side-on attack does appear quite feasible.

If the attacking SOW were capable of mach 5 speeds, i.e. 1,655 m/s, then the 76 mm would only have enough time for a single shot engagement of the SOW at the predicted intercept point 500 m away, while the 35 mm Gepard could fire up to three rounds from each of its two guns and the 40 mm Bofors could fire only one round in the time it would take the SOW to strike its intended target. Even the extremely rapid 25 mm KBB gun would only be able to fire 25 rounds from each of its two guns during the SOW's brief transit time. Thus it appears that if a SOW was capable of high g manoeuvrability and could travel at speeds in the region of mach 5 it would be virtually impossible for any gun system to successfully engage it.

5. Conclusions

Based on the methodology used in this report to determine the hit probabilities of current generation air-defence guns against a stand-off weapon capable of manoeuvring at high g rates it appears unlikely that any of these systems, even under ideal conditions, would be capable of providing an effective air defence at engagement ranges greater than 500 m.

Of these guns, the most effective systems seem to be those deploying air bursting munitions, with their greater area of engagement, and low drag munitions that can be fired from guns with extremely fast cyclic rates. Having made this statement, it must be realised that due consideration should be given to the practical limitations and logistics associated with the number of guns that could be deployed on the battlefield and on the mobility of any such arrangements.

Finally, if the additional effects of high SOW transit speeds (mach 5+), gun and computational error budgets and target terminal effectiveness had been taken into account, there is little doubt that none of the current generation air-defence gun systems would have any chance of success.

6. References

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Appendix A: Time of Flight Data

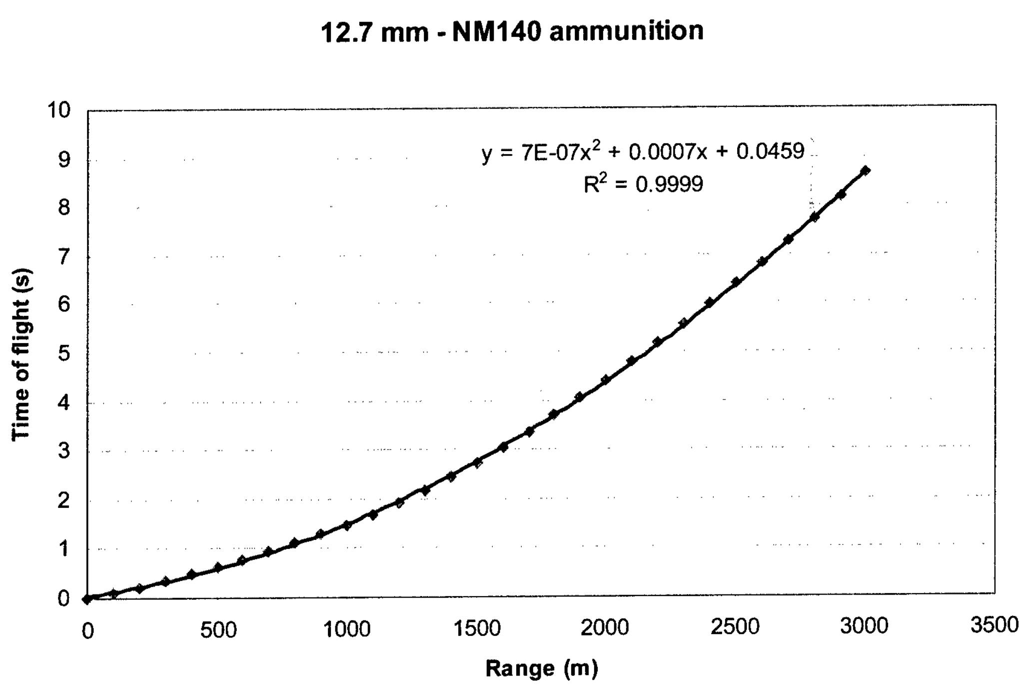
A.1. Time of flight (ToF) data for 12.7 mm, 20 mm, 25 mm and 30 mm ammunition (acquired from technical reports)

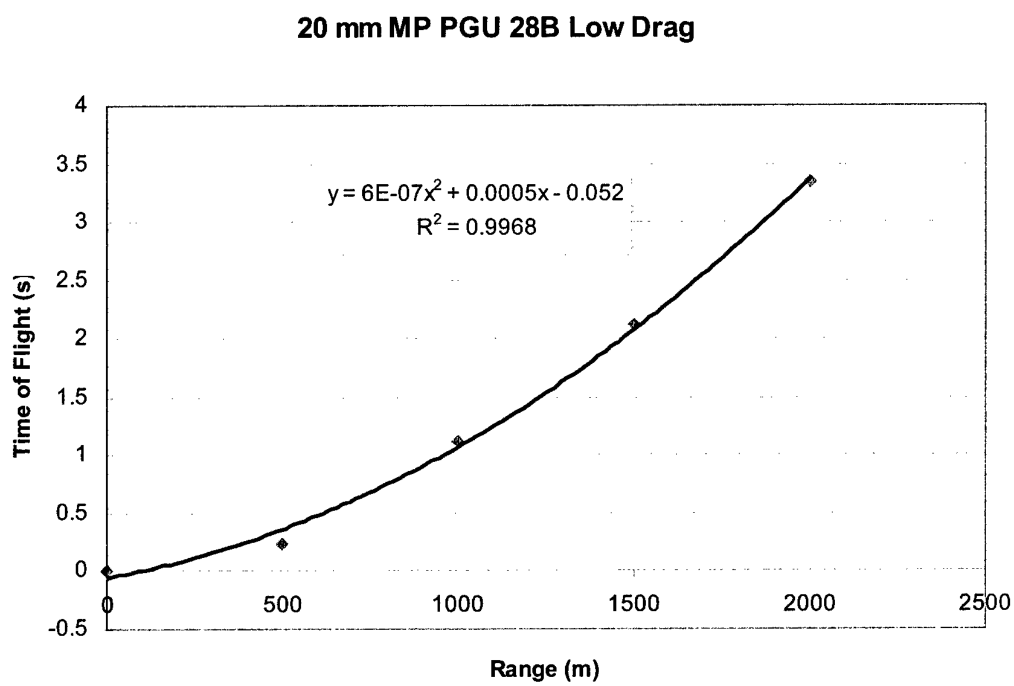
Range (m)	ToF – 12.7 mm MP (s)	ToF – 20 mm MPLD (s)	ToF – 20 mm HEIT (s)	ToF – 25 mm HEIT (s)	ToF – 25 mm APDS-T (s)	ToF – 30 mm ABM (s)
0	0			0	0	0
100	0.114				0.074	
200	0.223			0.191	0.149	
300	0.359				0.226	
400	0.492			0.404	0.304	
500	0.633	0.24	0.563		0.383	
600	0.781			0.641	0.463	
700	0.94				0.545	
800	1.109			0.908	0.628	
900	1.29				0.712	
1000	1.484	1.125	1.413	1.209	0.798	1.1
1100	1.694				0.886	
1200	1.922			1.553	0.975	
1300	2.171				1.065	
1400	2.442			1.947	1.157	
1500	2.734	2.125	2.771		1.25	
1600	3.042			2.403	1.346	
1700	3.364				1.442	
1800	3.699			2.928	1.541	
1900	4.047				1.641	
2000	4.408	3.34	4.551	3.522	1.744	2.71
2100	4.78				1.848	
2200	5.164			4.174	1.954	
2300	5.56				2.062	
2400	5.968			4.872	2.171	
2500	6.387		6.732		2.283	
2600	6.819			5.612	2.396	
2700	7.262				2.514	
2800	7.718			6.393	2.632	
2900	8.186				2.753	
3000	8.667		9.411	7.217	2.876	

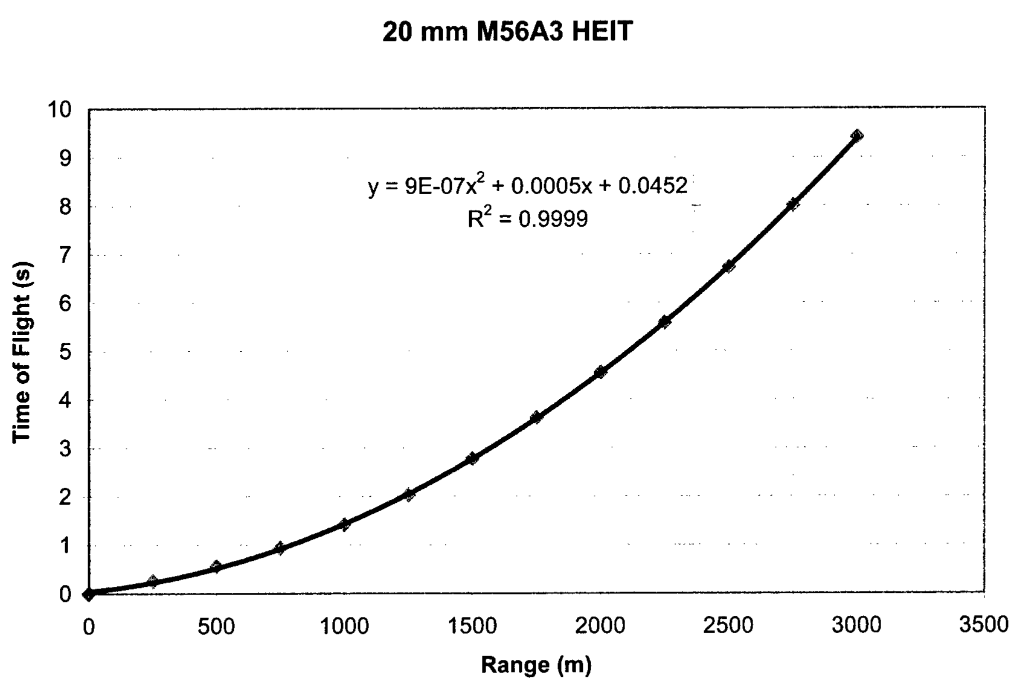
A.2. Time of flight (ToF) data for 35 mm, 40 mm and 76 mm ammunition (acquired from technical reports)

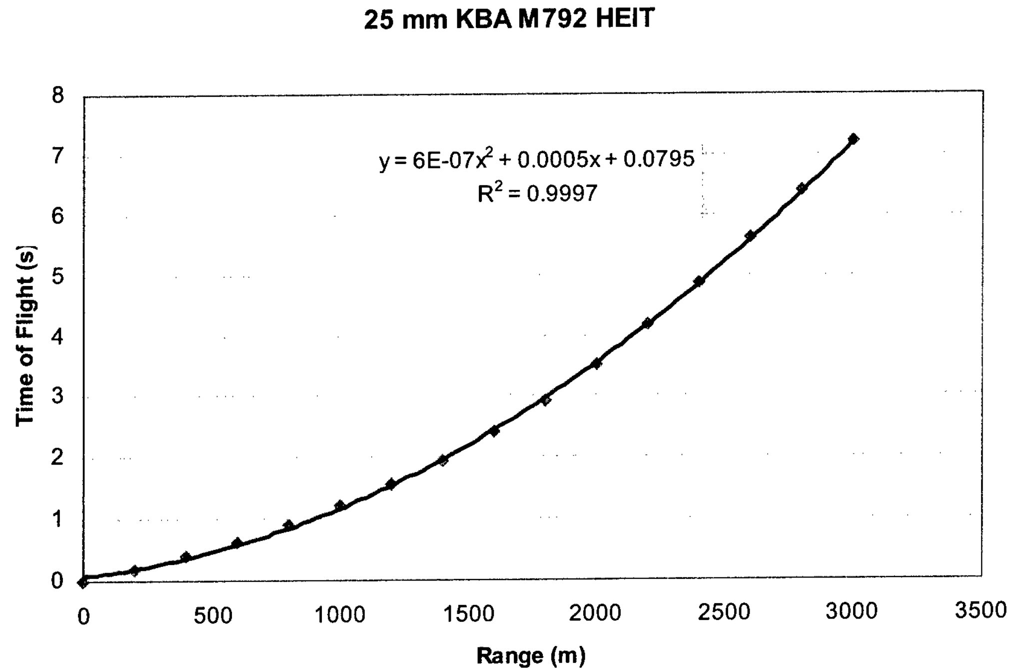
Range (m)	ToF – 35 mm HEI (s)	ToF – 35 mm APDS (s)	ToF – 35 mm AHEAD (s)	ToF – 40 mm PFHE (s)	ToF – 76 mm HISP-PFF (s)
0	0	0	0	0	0
1000	0.96	0.73	1.05	1.1	1
2000	2.18	1.54	2.34	2.44	2.09
3000	3.8	2.44	3.98	4.44	3.3
4000					4.64
5000					6.14
6000					7.86

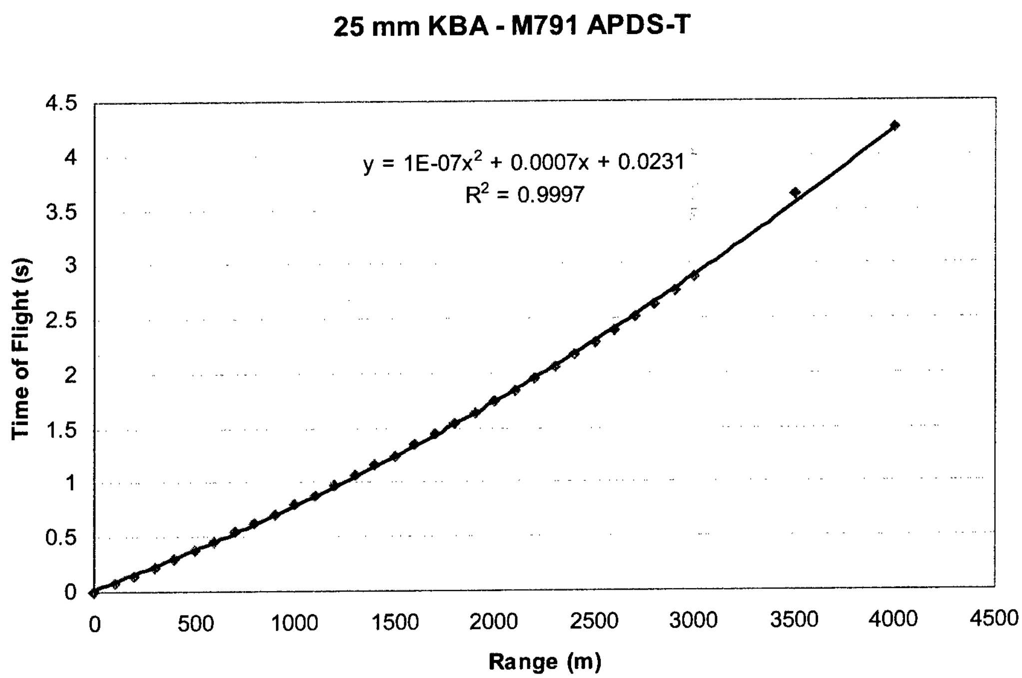
A.3. Time of flight graphs for 12.7 mm through to 76 mm ammunition

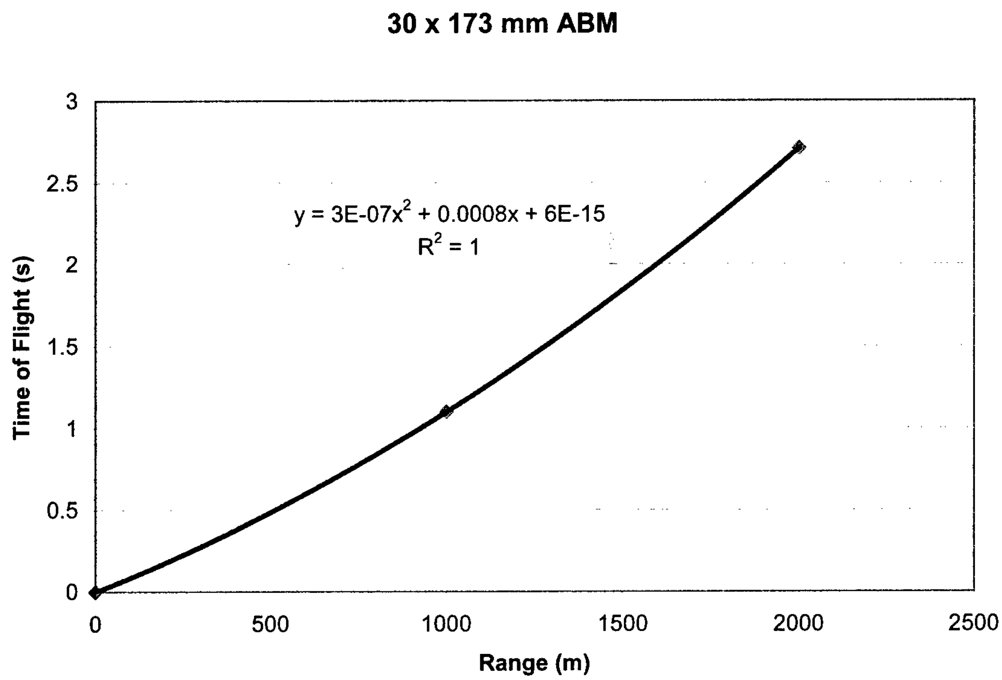


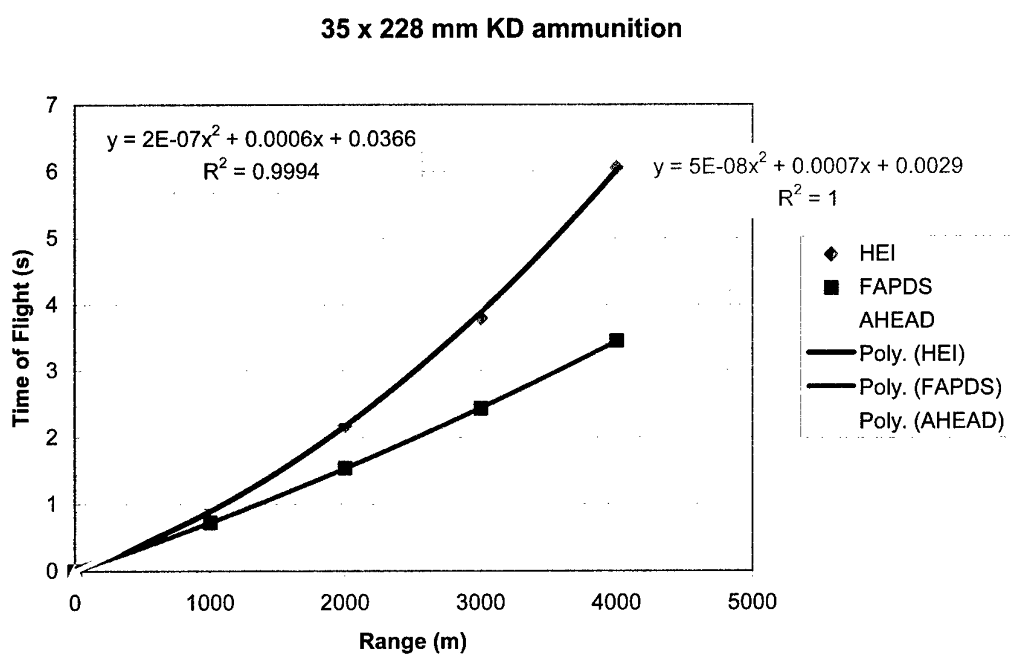

20 mm MP PGU 28B Low Drag
y = 6E-07x2 + 0.0005x - 0.052
R2 = 0.9968
Time of Flight (s)
Range (m)
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
500
1000
1500
2000
2500

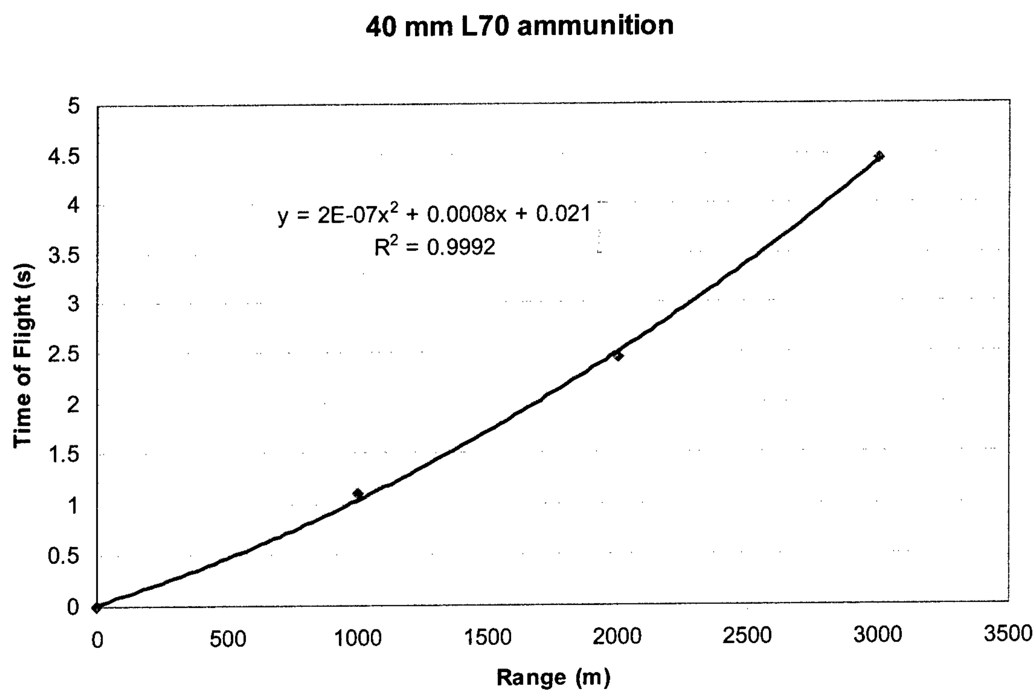

20 mm M56A3 HEIT
y = 9E-07x2 + 0.0005x + 0.0452
R2 = 0.9999
Time of Flight (s)
Range (m)
10
9
8
7
6
5
4
3
2
1
0
0
500
1000
1500
2000
2500
3000
3500

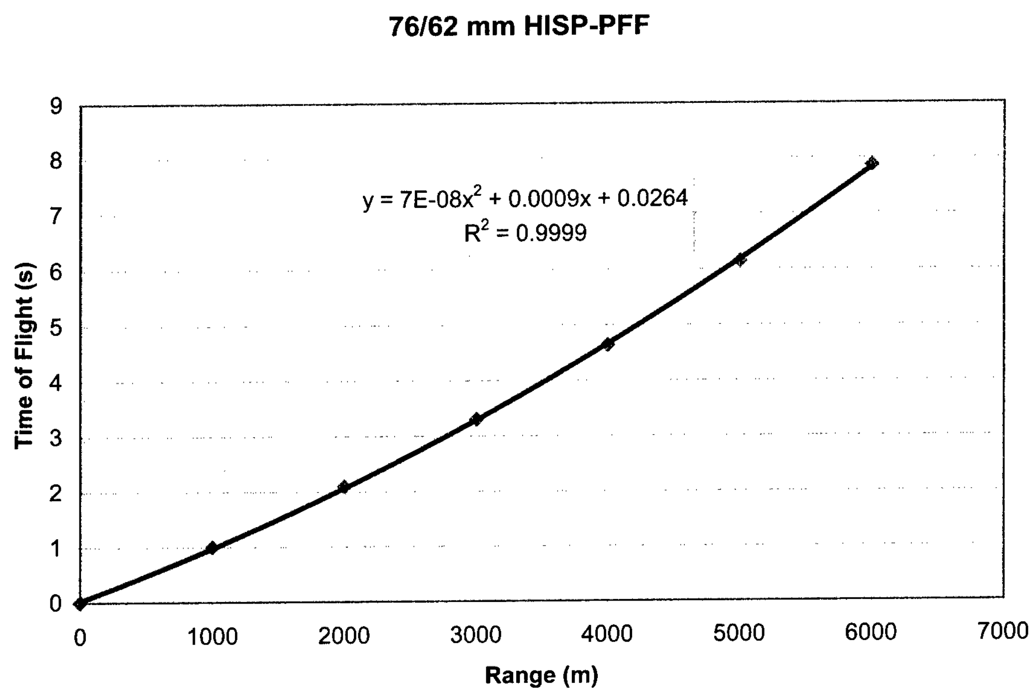

25 mm KBA M792 HEIT
y = 6E-07x2 + 0.0005x + 0.0795
R2 = 0.9997
Time of Flight (s)
Range (m)
0
1
2
3
4
5
6
7
8
500
1000
1500
2000
2500
3000
3500


25 mm KBA - M791 APDS-T
y = 1E-07x2 + 0.0007x + 0.0231
R2 = 0.9997
Time of Flight (s)
Range (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
500
1000
1500
2000
2500
3000
3500
4000
4500


30 x 173 mm ABM
y = 3E-07x^2 + 0.0008x + 6E-15
R^2 = 1
Time of Flight (s)
3
2.5
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
Range (m)


35 x 228 mm KD ammunition
y = 2E-07x^2 + 0.0006x + 0.0366
R^2 = 0.9994
y = 5E-08x^2 + 0.0007x + 0.0029
R^2 = 1
HEI
FAPDS
AHEAD
Poly. (HEI)
Poly. (FAPDS)
Poly. (AHEAD)
Time of Flight (s)
7
6
5
4
3
2
1
0
0
1000
2000
3000
4000
5000
Range (m)


40 mm L70 ammunition
y = 2E-07x2 + 0.0008x + 0.021
R2 = 0.9992
Time of Flight (s)
Range (m)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
500
1000
1500
2000
2500
3000
3500


76/62 mm HISP-PFF
y = 7E-08x2 + 0.0009x + 0.0264
R2 = 0.9999
Time of Flight (s)
Range (m)
0
1
2
3
4
5
6
7
8
9
0
1000
2000
3000
4000
5000
6000
7000

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Christian Wachsberger, Michael Lucas and Alexander Krstic

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Air defense; Guns (ordnance); Air launched standoff weapons; Probability theory

19. ABSTRACT

In the near future, strategic and other critical assets will be subject to attack from a new range of air threats, including highly accurate aircraft-launched weapons that offer long stand-off ranges and which are capable of travelling at high speed as well as manoeuvring at high *g* rates. This study uses simple probability theory to determine the relative utility of current generation air-defence guns against this type of highly manoeuvrable weapon. The rationale for this study is that whilst guns may have the advantages of offering a low cost-per-shot and reasonable magazine capacities, they are also severely limited in their abilities as they are only designed to fire at a predicted intercept point in space. As a result, should the target alter its direction during an engagement, the target will no longer pass in front of the projectile's flight path.

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