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WEAPON DANGER AREAS / ZONES FOR UNGUIDED WEAPONS

DETERMINISTIC – METHODOLOGY – APPLICATIONS

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NATO LETTER OF PROMULGATION

1 July 2015

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CHAPTER	RECORD OF RESERVATION BY NATIONS
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RECORD OF SPECIFIC RESERVATIONS

[nation]	[detail of reservation]
POL	1. Poland reserves the right to conduct research allowing a particular weapon system (with ammunition), not included in range certificated, for firing as part of reconnaissance for the training of allied troops. The purpose of this research is to develop documentation allowing the use of particular weapon system and munition on the range. 2. The postponing results from Poland's declared position on the referenced STANAG's (in ARSP-1 EDB): 2921, 2402, 3606 ED6.
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CHAPTER 1

Introduction

0101 The WDA/Z And Associated Hazards

1. A Weapon Danger Area/Zone (WDA/Z) is a defined two- or three dimensional space (area or zone), which contains hazards of different levels of severity, caused by firing specific weapons into it. A low probability hazard remains outside the WDA/Z. As a consequence, a WDA/Z does not give the total risk area. Protective measures for personnel or material required to be inside the WDA will not be covered in this document. The hazards, which may occur, are identified and assessed in ARSP-1 Volume **I**, Chapter 2.

0102 The Shape Of A WDA

1. It is common to produce outlines in range and deflection for Weapon Danger **Areas** (WD**As**). The shape (or outline) and its contained area will be called the template (plain figure) of a WDA. Separately, constant heights will be added to the template to cater for aircraft safety (WD**Z**). Thus, most parts of this document will be restricted to WD**A** without loss of generality.

2. The real shape of a WDA/Z is not explicitly shown. A fitting shape (outer limit of a WDA as a technical drawing (with technical information)) is needed to transform the WDA onto a map.

3. For WDA based on deterministic methodologies (common approach) their shape may be created by using simple geometric figures, which consist of a continuous array of straight lines and arcs, for easy drawing. This will result in an outline, which becomes the outer shape of the WDA. Depending on the composition it may turn out that some areas inside this outline are overestimated, which is done for simplification reasons.

4. Altogether, the depicted WDA outline is a **minimal requirement** in relation to the accepted risk outside the WDA. Range Safety Organisations have to apply the WDA outline and resulting safety conditions onto the range (ARSP-1 Volume **I**, Annex A).

0103 Requirements For A WDA Outline

1. A WDA outline will be produced for a single weapon system and a single target (point target). This outline may not be to scale but it will give all the information (including data tables) to produce an appropriate WDA template to a given scale and produced for convenient application to a range map.

2. In the case of more than one weapon (location) and/or more than one target (location) the corresponding WDA can be found by overlaying the (different) separate outlines.

0104 The Scope

1. The producing and publishing of WDA outlines (templates) are achieved by:

   a. Using the same factors and processes (as described in ARSP-1 Volume I).
   b. Developing WDA outlines in the way described in this document.
   c. Specifying all assumptions for producing the outline and its range of validity (as type of weapon, implemented met conditions and range height (e.g. sea level), elevation range, use of maximum range or applying the Maximum Ricochet Range (MRR) - see ARSP-1 Volume I, Chapters 3 and 4).

2. Nation specific outlines (or templates), which fit the rules described in this document, may have dimensions varying from nation to nation for the same weapon and munitions.

3. The development of WDA outlines will apply to weapons and munitions covered in ARSP-1 Volume I.

4. Specific basic WDA outlines will be developed in steps, which, if composed in the right order, will result in the WDA outline (the so called generic WDA outline).

0105 The Content

1. An overview of the content of this publication is shown by two figures on the next two pages. Chapters 3 - 6 will follow ARSP-1 Volume I. In Chapters 7 and 8 generic WDA outlines for single targets will be developed. Specific outlines for different kinds of weapons are collected and comprehensively described in the Annexes. Beyond that, the areas of probable errors and hit probabilities of rectangles and ellipses outline downrange closures and drift correction are considered, and a lexicon with a list of abbreviations is given.

2. Annexes C, D, and E are divided into different Appendices, each of which refers to a particular item. Example: Appendix C3 refers to the third Appendix of Annex C.

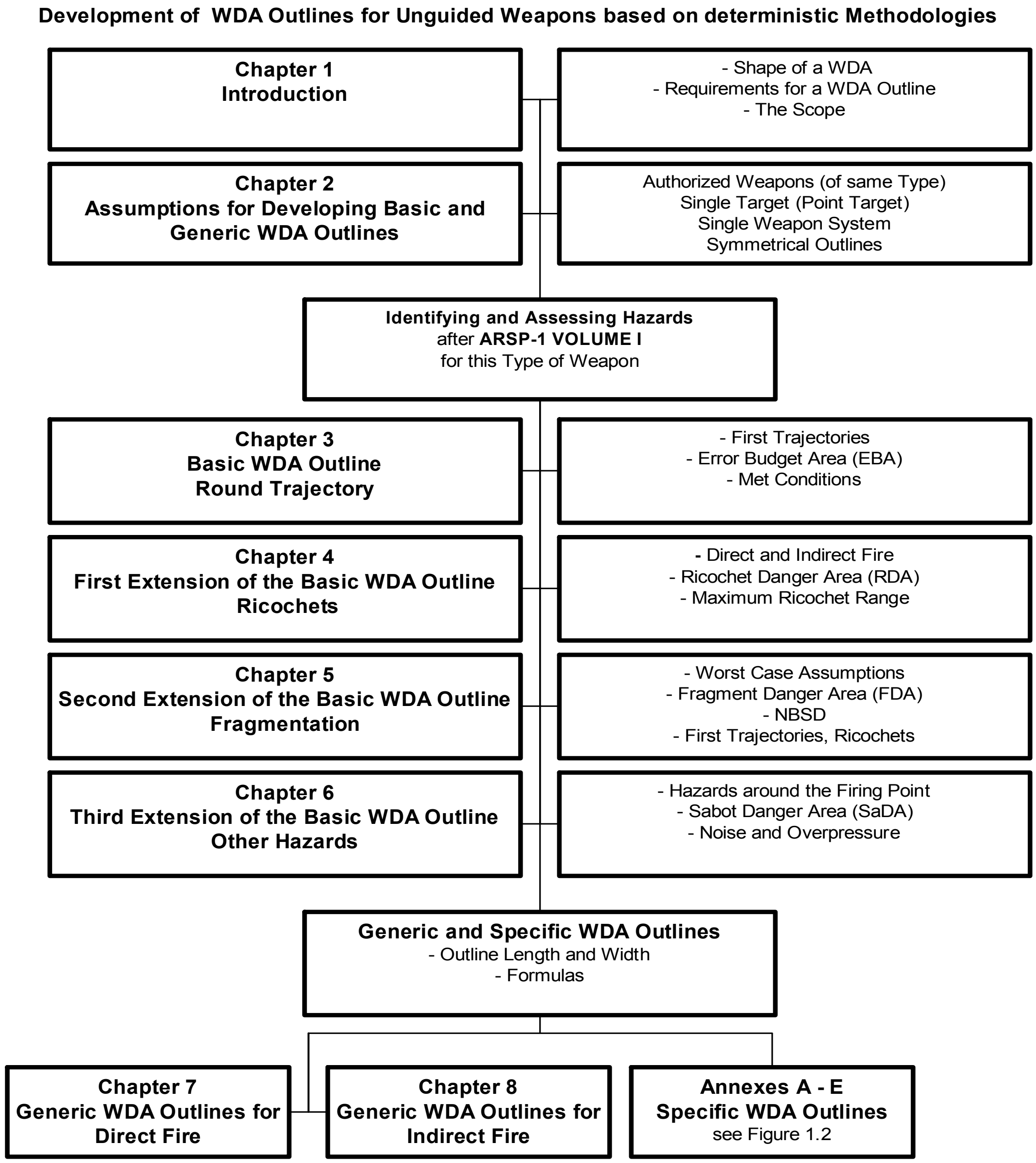

Figure 1.1: Chapters 1 - 8

Development of WDA Outlines for unguided Weapons based on deterministic Methodologies

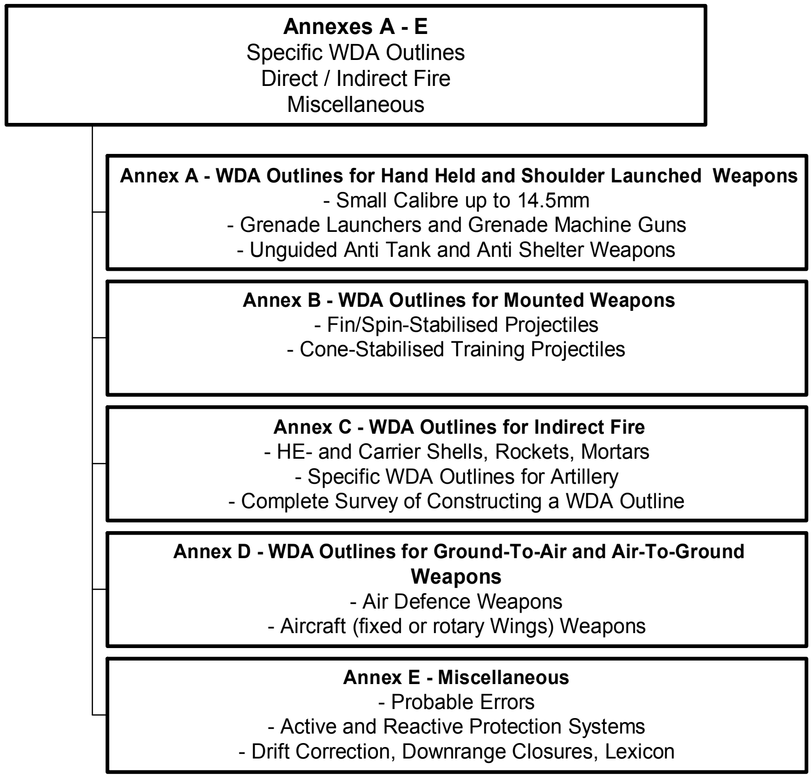

Figure 1.2: Annexes A - E

CHAPTER 2

Assumptions For Developing Basic And Generic WDA Outlines

0201 Introduction

1. By assessing the first trajectories with specific probabilities, using deterministic methods (such as worst case assumptions) for ricochets, fragments and other hazards, WDA outlines will be developed under the following assumptions.

0202 Assumptions

1. Assumptions for basic and generic WDA outlines and WDZ outlines with heights are given by the following catalogue:

a. The coordinate system is a Cartesian x-y-z-system, where the horizontal range to the target is on the x-axis (line of fire), the lateral distance (deflection, cross range) is on the z-axis and the height above range (relative height) is on the y-axis. The system is originated in the firing point FP (muzzle of the barrel or trunnion).

b. The WDA outlines will be derived for a flat range surface only (that is in the x-z plane) as 2-dimensional figures. A constant air danger height on the template will be added separately (a WDZ parameter).

c. The WDA outlines should be applicable to all military ranges. In case of range specific topography and environment (e.g. range is significantly steep or has some big slopes in it or beyond or it is located in a hilly area) a modified WDA outline may be required (see Appendix D2 (D205)).

d. The WDA/Z outlines produced in this document are time independent.

e. One single (authorised) weapon system with one specific kind of projectile will engage single targets. The centre of a single target is called a Point Target (**PT**), which is located on the line-of-fire axis at an arbitrary or at a fixed position. The distance (range) from FP to a PT is marked by $\mathbf{d_t}$.

f. If not otherwise noted the firing position FP and target PT are located on the same ground level.

g. The distance to a *first* impact is called $\mathbf{d_i}$ that is normally related to the *smallest* occurring d_t. The minimum target distance (depending on engagement rules or on fragmentation (see Chapter 5)) is called $\mathbf{d_m}$. It is assumed that impacts may occur in front of the target, in which case $d_i < d_m$.

h. If not explicitly shown all targets are surface based. It is to distinguish between soft targets and hard targets (for definition see lexicon in Appendix E5).
The range surface itself may be of soft or hard material and is treated like a soft or a hard target.

i. WDA outlines shown in safety manuals are often not to scale; their proportions may be distorted in order to make the drawings clear and understandable.

When applied to a map the derived template from the outline has to match the scale of the map and the preconditions of the outline.

j. Polar diagram like figures with additional simple geometric forms will be used to produce the basic and generic WDA outlines. Options for different down range closures of outlines will be given (Appendix E3).

k. The step-by-step development will lead to generic WDA outlines for direct and indirect fire. Those WDA outlines are orientated to the firing position. They may also be centred in the target location itself (mostly for indirect fire).

l. The spin deviation and the correction angle to bearing (drift correction) will not be addressed when developing the WDA outlines (an exception is made in Appendix D1 (D102, 1a) when considering spin deviation for engaging aerial targets). It is assumed that the target will be engaged with adequate fire control inputs (for details see Appendix E2). Normally, each <u>WDA outline is made symmetrical to the line of fire</u>.

CHAPTER 3

Basic WDA Outline: Projectile Trajectory

0301 Introduction

1. If projectiles of the same kind are fired towards the same aiming point from a fixed firing position they will hit an area around this point due to random and systematic errors.

2. To this portion other areas will be added, which contain hazards coming from ricochets and fragmentation. For these hazards error budgets will not be considered in the common approach. The size of these additional areas is determined by purely deterministic methods as shown in Chapters 4 - 6.

0302 The Applied Error Budget

1. Let PT be the centre of a fixed single target with distance d_t to FP. When projectiles are fired towards the aiming point PT they will disperse around a Mean Point of Impact (MPI). Generally, this point is different from PT (ARSP-1 Volume I, Figure 3.2). The slant distance is the bias. By applying the Error Budget (EB) as shown in ARSP-1 Volume I (0305) to these projectiles, a specific Error Budget Area (EBA) will be created, which contains all expected impacts of the first trajectories up to a given (nationally approved) factor of the total error (ARSP-1 Volume I, Chapter 3, Figure 3.2) in range and deflection.

2. The size of the EBA strictly depends on the choice of the EB parameters (various Mean Point of Impact (MPI) and Round-to-Round (RTR) errors (see for details ARSP-1 Volume I, Chapter 3 (0306) and (0307))) and on their standard deviations (shown later).

Assuming uncorrelated normal distributions for these errors they are characterised in practice by mean values and standard deviations (sd) coming from samples. By applying standard formulas (see examples in Appendix C1) resulting (joined or combined) sd for the RTR and MPI errors can be calculated. These two final data sets are given in range and deflection depending on the distance $\mathbf{d_t}$.

3. Let these two pairs be $(sd_{x,RTR}(d_t), sd_{z,RTR}(d_t))$ and $(sd_{x,MPI}(d_t), sd_{z,MPI}(d_t))$.

   a. Using the standard formula for joint sd, total errors (given as variances) in x and z direction (ARSP-1 Volume I, Figure 3.2) are

      (1) $\mathbf{sd^2_{x,EB}(d_t) = sd^2_{x,RTR}(d_t) + sd^2_{x,MPI}(d_t)}$

      (2) $\mathbf{sd^2_{z,EB}(d_t) = sd^2_{z,RTR}(d_t) + sd^2_{z,MPI}(d_t)}$.

      In case of direct fire vertical screen data $(sd_{y,RTR}(d_t), sd_{z,RTR}(d_t))$ and $(sd_{y,MPI}(d_t), sd_{z,MPI}(d_t))$ can be transformed into equivalent data on the horizontal x-z surface.

   b. The total errors are used to produce an adequate EBA around PT. Usually, the $\mathbf{sd_{x,EB}}$ and $\mathbf{sd_{z,EB}}$ data will define a **dispersion ellipse** around PT.

However, this ellipse may be replaced by a rectangle for easier drawings. This **rectangle** (polar rectangle in a polar diagram) is the smallest one containing the ellipse. The polar rectangle is shown in Figure 3.1 (half sided figure with corners A B C D; symmetry assumed).

c. Normally, only RTR-errors contribute to the EB because the MPI error is often not known or reduced to zero (see ARSP-1 Volume I, Chapter 3, 0307). Thus, for $sd^2_{x,EB}$ and $sd^2_{y,EB}$ the MPI-part is set zero.

4. Specific factors m (a national choice) for $sd_{x,EB}(d_t)$ and $sd_{z,EB}(d_t)$ will be used to create an EBA for first trajectories. The dimensions of the EBA are chosen in a way that the residual risk for the generic WDA outline (with ricochets and fragmentation) is minimised (ARSP-1 Volume I, Chapter 1 (0101) and Chapter 7 (0703)). Examples are shown in the Annexes. A standard number for m is 5.4 (see Chapters 7, 8 and Appendix E1, where specific choices of m are listed in connection with probabilities).

5. For the following let $m_x(d_t) = m\ sd_{x,EB}(d_t)$ and $m_z(d_t) = m\ sd_{z,EB}(d_t)$. In Figure 3.1 the value $m_z(d_t)$ is chosen much bigger than $m_x(d_t)$ for better visibility. Usually, $m_z(d_t)$ is much smaller than $m_x(d_t)$). For d_i it is $d_i = d_t - m\ sd_{x,EB}(d_t) = d_t - m_x(d_t)$.

6. By using the values $m_x(d_t)$ and half opening angle $\alpha_t = \alpha(d_t) = \arctan (m_z(d_t) / d_t)$ the half polar rectangle ABCD as half the EBA is defined. The angle α_t varies with the target distance d_t. Taking as half opening angle α the maximum $\alpha(d_t)$ over all target engagement distances the size of the EBA with this α is valid for all distances d_t. A fitting standard rectangle is also shown in Figure 3.1. The angle α in addition defines a cone of fire originated at FP, which is addressed in Chapter 7.

7. Neglecting curvature of the trajectories which originate at FP, the sector with opening angle 2α is called EB fan (or safety fan; see Figure 3.1) and contains the area under first trajectories. The sub-sector between FP and EBA is called intermediate area (IMA). The IMA belongs to the WDA outline. It is an area under the trajectories as a basic area for the WDZ. For indirect fire the IMA can be excluded from the WDA.

8. Especially for direct fire it may be convenient to have the polar rectangle unsymmetrical in range with different factors m. That means in Figure 3.1 the distances A to PT and PT to D are different: dist(A,PT) = $m_1\ sd_{x,EB}(d_t)$ and dist(PT,D) = $m_2\ sd_{x,EB}(d_t)$ with $m_1 < m_2$ as a rule. However, without any restrictions it is set $m_1 = m_2 = m$ for simplicity in all following Chapters and Annexes.

0303 Projectile Trajectory - Met Influence

1. Implementing meteorological (met) data for common WDA is related to first trajectories only. In case met data (wind, atmospheric pressure, temperature and density) may, or can not be considered when firing it is recommended to implement met data into the calculations of first trajectories, which is necessary to determine the WDA outline (see calculating the trajectories for the Maximum Ricochet Range (MRR)). For example, engaging aerial targets with hand held or mounted weapons strong lateral or head wind will have a significant contribution to the size of the WDA. To apply met data generally to these calculations is mostly connected with direct fire weapons (indirect fire weapons (artillery or some mortar systems) are equipped with devices to implement and apply real-time met data).

2. Wind has a significant contribution to the dimensions of the WDA in comparison to the WDA based on standard atmosphere. Wind components can be implemented into the calculations (other met data in a similar way, see Chapter 7 (0705)) by using:

a. A ballistic wind (e.g. 15m/s; head, tail and cross wind) in all layers, independent of the trajectory height,

b. Layer dependent climatic average data of a longer period,

c. Current wind data.

Random and systematic met measurement errors are issues of the Error Budget (see 0302 and ARSP-1 Volume I, Chapter 3 (0311.4d)). Advises for values of met data are given in Chapters 7 and 8.

3. Range height above mean sea level (MSL) will have an effect on maximum range (MR) as well as on MRR.

0304 EBA For Carriers

1. This issue is mainly for indirect fire. From the point of ejection of the payload, the dispersion of the sub-munitions, the impact point of the empty carrier or the malfunctioned projectile have different error budget areas (of various sizes). These EBA are developed in Appendices C2 and C3.

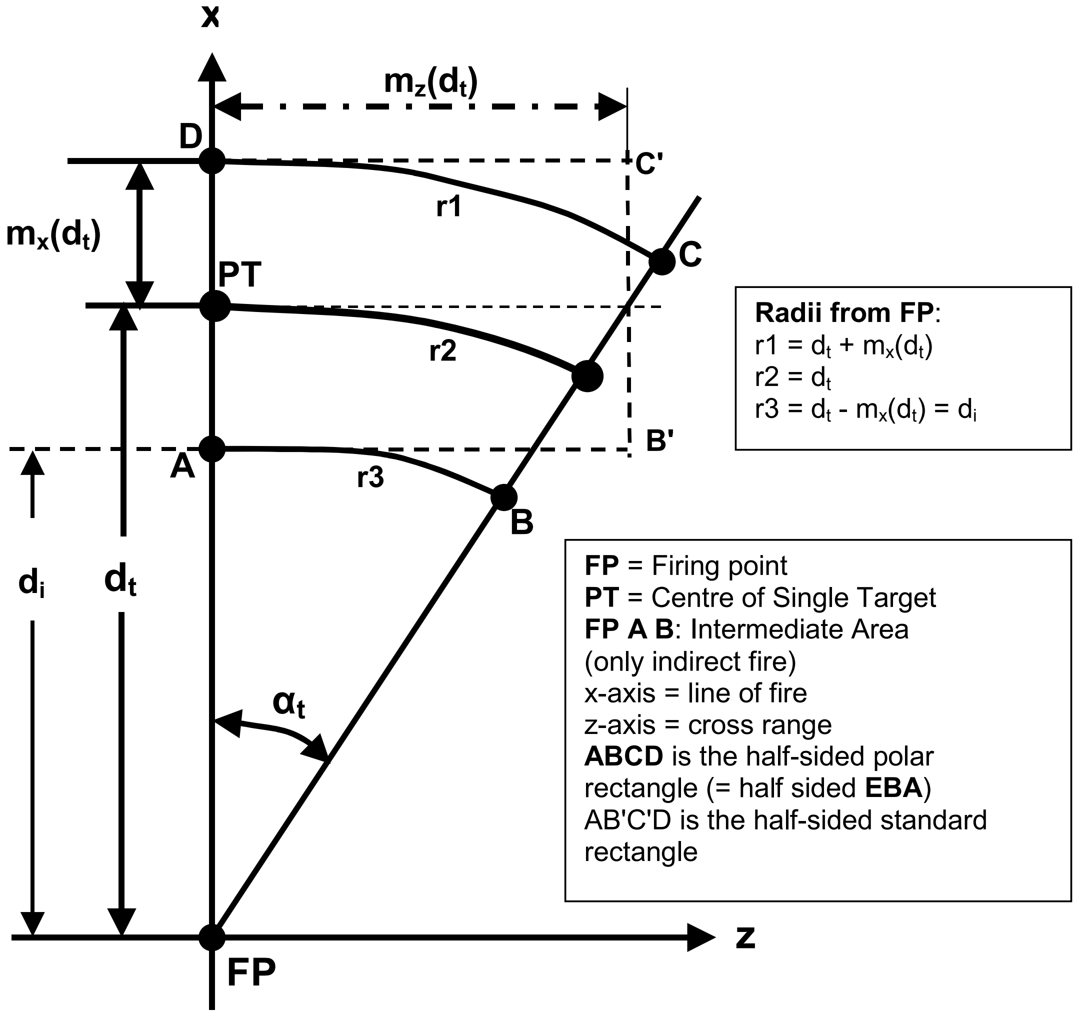

Figure 3.1: Basic WDA Outline
Half sided Error Budget Fan for first Trajectories

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CHAPTER 4

First Extension Of The Basic WDA Outline: Ricochets

0401 Introduction

1. Following the previous Chapter and Chapter 4 of ARSP-1 Volume I ricochets may originate in any point of the EBA. The Ricochet Danger Area (RDA) will start at the lower end of the EBA with a specific opening angle. The size of the RDA is based on the value of the MRR belonging to the type of projectile fired. In the following the RDA will be created for direct and indirect fire. A specific EB for ricochets is not considered.

0402 The Maximum Ricochet Range (MRR)

1. The MRR (ARSP-1 Volume I, Chapter 4 (0402)) is a definite distance in x-direction beginning at FP. It corresponds with the EBA and RDA as shown in Figure 4.1. Note the following characteristics of MRR:

   a. For direct fire in almost all cases the distances to first impacts are less than MRR.

   b. For indirect fire this is not the case. If $QE > QE_{crit}$ (ARSP-1 Volume I, Chapter 4 (0402.3)) no ricochets are expected (although impact distances less than MRR may be possible, e.g. firing artillery projectiles in a high register role).

   c. The use of MRR indicates that RDA is determined deterministically.

   d. If <u>all</u> distances to first impacts are greater than MRR a RDA is not required.

2. The MRR for a given angle IA_{crit} of fall (ARSP-1 Volume I, Chapter 4 (0402.3)) contributes to the total length and width of the WDA outline (choices of IA_{crit} are given in Chapters 7 and 8). When firing air-to-ground (from rotating/fixed wing platforms) the critical impact angle may not be unique. Thus, the presented formulas may not be applicable (for more details see Annex D2).

3. <u>Remark</u>. Instead of using an impact angle (IA_{crit}) a fixed parameter QE_{crit} may be used for assessing ricochet occurrence for developing the RDA.

0403 The RDA Length And Width

1. The length of the RDA is the difference **MRR - d_i**. For the RDA width (w_R, see Figure 4.1) a **fraction** of the difference **MRR - d_i** is recommended. The data d_i varies with the distance of the impact area to FP as shown:

   a. For direct fire it is set $d_i = d_t - m_x(d_t)$ (because of typically low angle fire and short target ranges). The data d_i is then a fixed value for a specific munition and target type. For the sake of simplification it is also convenient to set $d_i = 0$.

b. For indirect fire d_i is related to the nearest target (PT) of the designated impact area.

c. The following table gives recommendations for the RDA width. The recommended width is a worst case assumption depending on the type of target.

Type of Target	RDA Width
Soft target	w_R = (MRR - d_i) / 8
Hard target	w_R = (MRR - d_i) / 4
Conservative choice	w_R = (MRR - d_i) / 2

Table 4.1: Recommendations for the RDA Width

0404 The RDA Outline For Direct/Indirect Fire

1. Figure 4.1 will be the basis for the generic WDA outline for direct/indirect fire. The size of the flanking-area-angle β will depend on the lateral deviation of the ricochets and on the fact that a projectile having a strong lateral deviation at impact will have no significant lateral ricochet range. Suggestions for the angle β and the width w_R are given in Chapters 7 and 8 and in the Annexes. For different downrange closures for RDA see Figure 4.1 and Appendix E3.

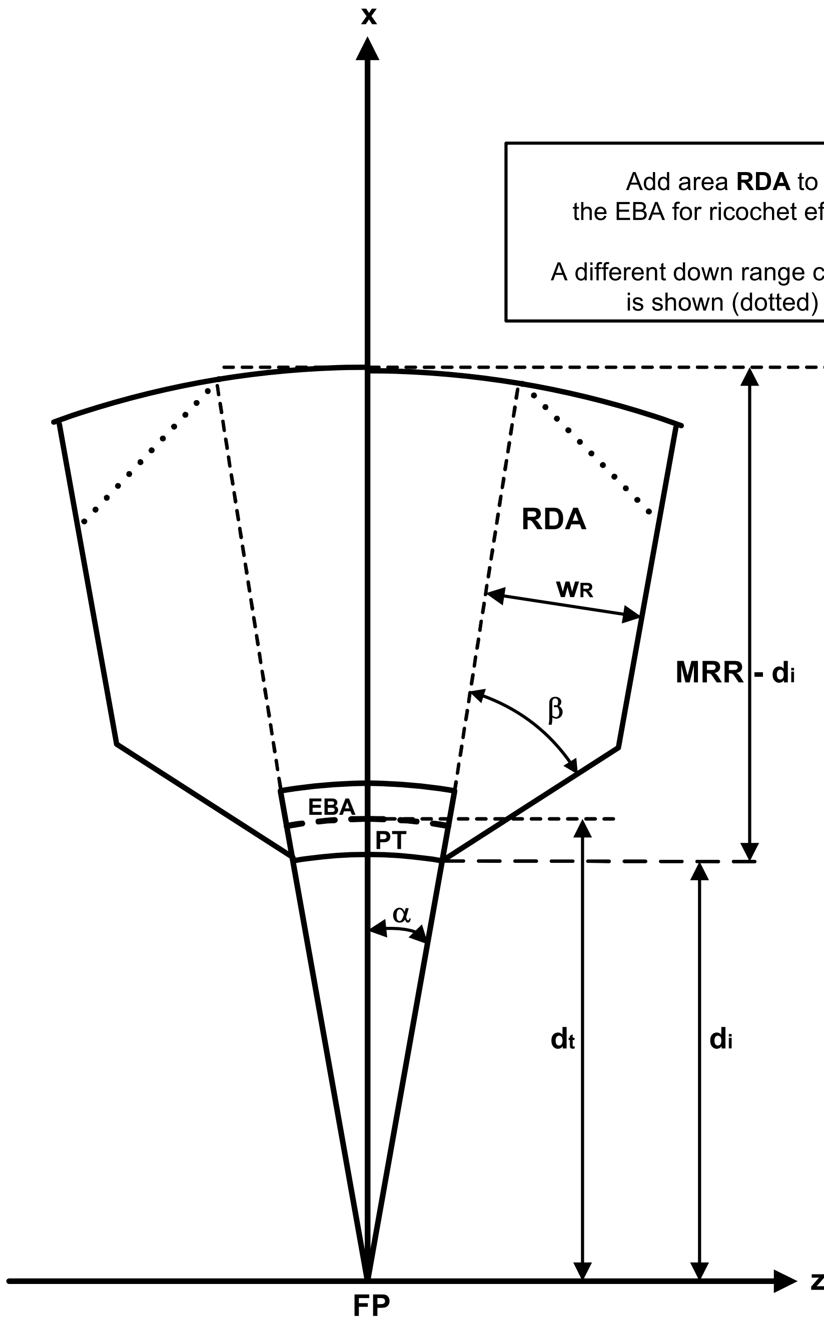

Figure 4.1: First Extension of the Basic Outline Ricochet Danger Area for MRR > d_i

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CHAPTER 5

Second Extension Of The Basic WDA Outline: Fragmentation

0501 Introduction

1. When firing HE, HEAT, PELE, FAPDS or KETF projectiles fragmentation may occur at any point inside/above (due to intended ground, air burst or target impact) the EBA or inside/above the RDA. A ricocheted projectile may detonate at second impact when failed at first impact. The Fragment Danger Area (FDA) surrounds the RDA and the lower part of EBA. Carriers with fragmenting sub-munitions are addressed in Appendix C3 (C306j). There is no EBA for fragmentation, the size of the FDA is determined by the constant value Normal Burst Safety Distance (NBSD, see ARSP-1 Volume I, Chapter 5).

2. For the following let s be the fragment distance NBSD. In case of direct fire it is assumed that the travelling distance of back splashing fragments (rearward hazards, ARSP-1 Volume I, Chapter 5 (0505)) off the target and backward travelling fragments of the projectile impacting at close targets are normally less than s because of the high speed of the projectile. If early functioning at the first trajectory has to be considered it is to be noted that the fragment distance will be increased when bursting occurs at significant height (the enlarged NBSD is called $\mathbf{s_p}$), which appears mostly in case of indirect fire.

0502 The FDA For Direct/Indirect Fire And Ricochets

1. For fragmentation effects the extended WDA outline is given with Figure 5.1, which is based on Figure 4.1. The lower part of the FDA is related to the distance d_i that means to the lower end of the EBA (the back splashing distance is related to the target). For direct fire (including direct fire artillery) the FDA may start at the firing position itself, which is shown in Figure 7.1.

2. Some recoilless weapons and rockets cause rearward debris at the firing position, for this effect a Rearward Danger Area (RWDA; see Annex A (A004.5)) at FP is added (as sketched in Figure 5.1).

3. If early functioning of the fuze is a possibility a separate fragment danger area should be added to the IMA (0302.7). This extended outline starts with distance **s** to the upper end of the EBA and extents to the lateral distance s_p (> s). The distance s_p is the trajectory height dependent NSBD (see ARSP-1 Volume I, 0504.1). The angle φ is taken at both ends of the additional area. For the nearest possible functioning (mostly regarding electronic fuzes) also a circle with appropriate radius belongs to the WDA (see Figure 5.1).

4. For <u>indirect fire</u> with HE projectiles, under the assumption of no fuze function at second impact it is possible to arrange the FDA around the EBA only. This is illustrated in 0503 and Figure 5.3 (shown for no ricochet effect) and in Appendix C3 (C305 j-m, Figures C3.8 - C3.10).

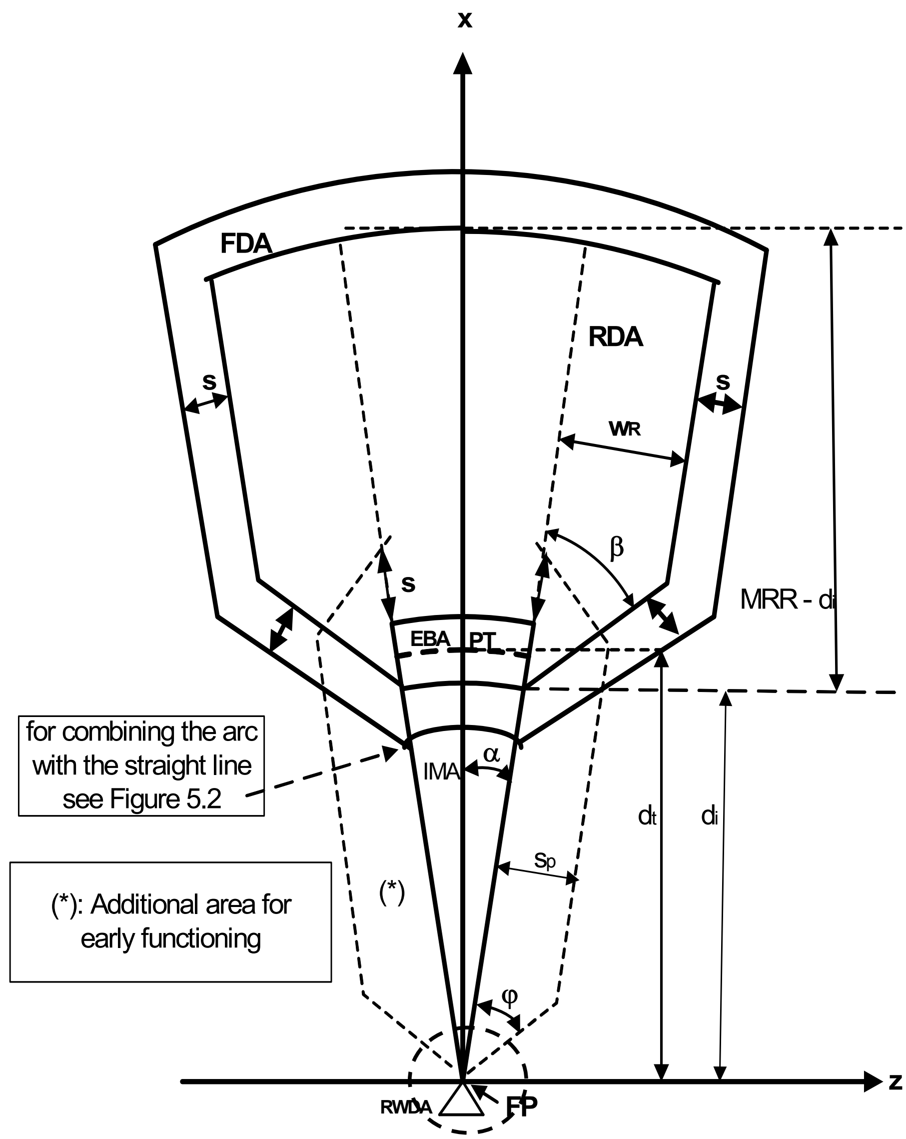

Figure 5.1: Second Extension of the Basic Outline Fragment Danger Area

5. The FDA at the two lower edges of EBA has to be shown in an enhanced view (Figure 5.2) to indicate in which way the geometric figures are matched together.

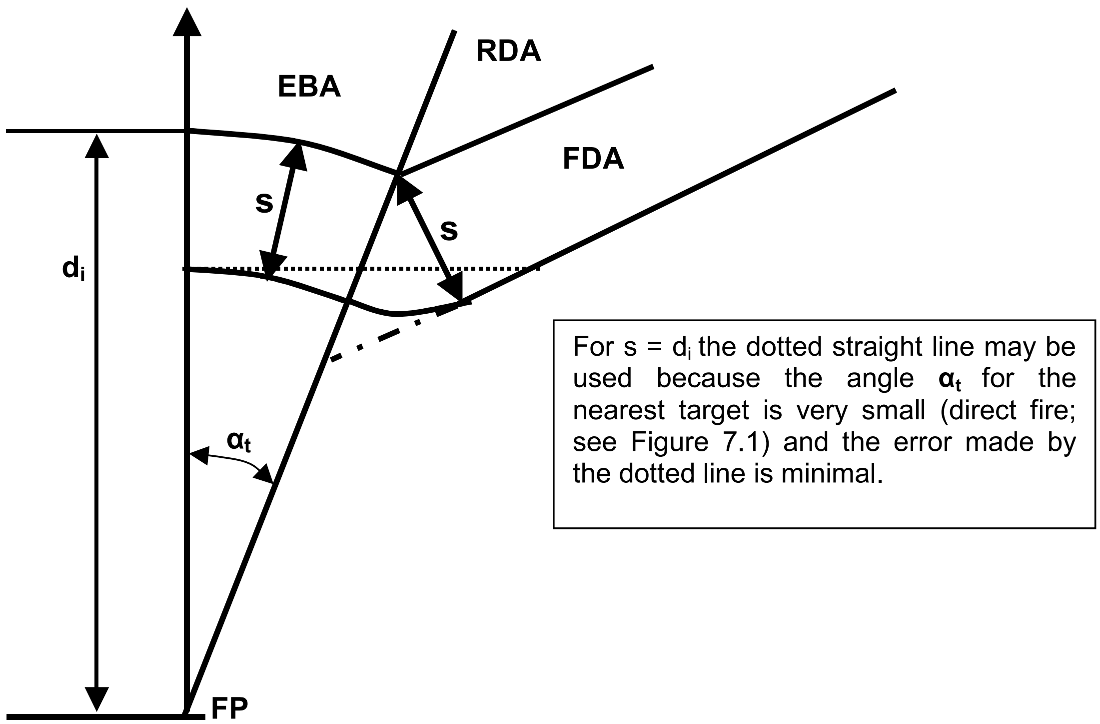

Figure 5.2: Combining the Arc of the EBA with the straight Line of Distance s to FDA

0503 The FDA For Indirect Fire And No Ricochets

1. When firing artillery at high elevations (greater than QE_{crit}) or when firing mortars (in the high register role) the MRR will not be applied. The resulting WDA outline (Figure 5.3) only depends on the distance d_t and the resulting EBA. The FDA surrounds the EBA. The intermediate area has the same meaning as before.

2. For some mortar weapon systems an enlarged EBA (= EBA_{enl}) as indicated in Figure 5.3 is needed in case no met corrections (especially wind of all directions) are possible (see also Chapter 3 (0303)). The mortar projectile may detonate inside the area EBA_{enl}, thus the fragment danger area surrounds EBA_{enl}.

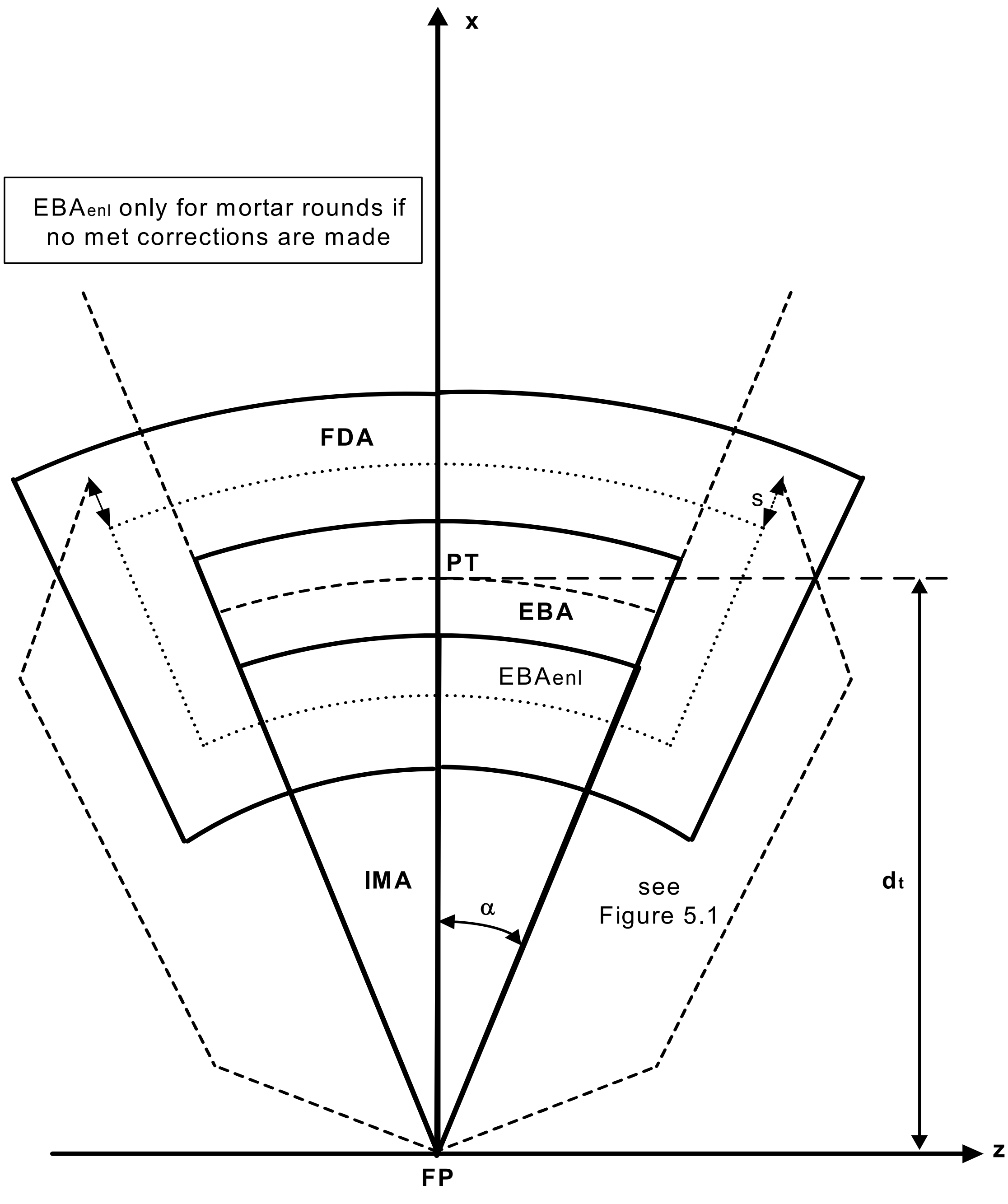

Figure 5.3: Second Extension of the Basic Outline Fragment Danger Area Indirect Fire, no Ricochets

CHAPTER 6

Third Extension Of The Basic WDA Outline: Other Hazards

0601 INTRODUCTION AND OUTLINE

1. For debris of firing specific WDA around their point of origin are needed. In detail:

a. WDA for sabots (Sabot Danger Area (SaDA)) shown as an example below): This SaDA starts at the firing position and extends to the maximum range l_{sa} and width w_{sa} of the released parts in front of the weapon system. Depending on the quadrant elevation and head wind sabot parts may hit an area behind the firing position. The ranges of sabot parts are small in comparison to the range of the projectile fired with, but the lateral spread may be larger than the EB fan. The width of SDA can be found by experiment. The opening angle β_{sa} may go beyond the z-axis in case of high angle fire (caused by headwind).

b. WDA for pusher plates: A WDA similar to SaDA works for pusher plates and their sabot-like elements.

c. WDA for recoilless weapons: See Annex A.

d. WDA for released cartridges:
(1) Ground based weapons: A cone covering the maximum flight (in length and width) of the empty cartridge starting at the point of release.
(2) Arial platform: A circle on the surface centred underneath the weapon.

e. WDA for charge debris: Similar to d(1).

2. Noise and overpressure hazards caused by a weapon system may be covered by a circle of radius r_{no}. Its value is given by national standards. As an option two different circles are possible.

3. In Figure 6.1 only the right half of the outline is shown; the outline is symmetrical to the x-axis.

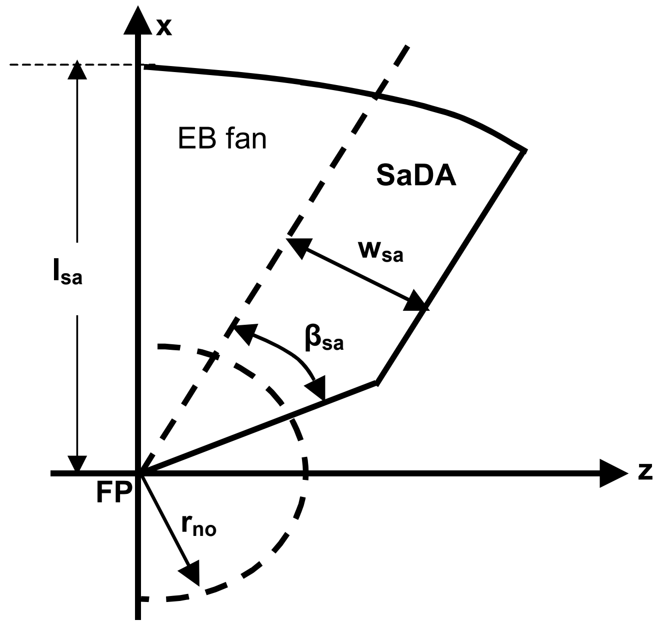

Figure 6.1: Third Extension of the Basic Outline Sabots (as example), Noise and Overpressure

CHAPTER 7

Generic WDA Outlines For Direct Fire Weapons

0701 Introduction

1. Using the basic and extended outlines of the previous chapters a generic WDA outline will be developed for direct fire weapons (including direct fire artillery). This outline is applicable for single ground based weapons and ground targets (for aerial targets see Annex D). The size of the EBA for generic WDA outlines will be chosen to be valid up to the maximum engagement range. The WDA outline length is based on the MRR or the maximum range of the projectile.

0702 The EBA

1. In case of direct fire the standard deviation data in range and deflection are often derived from recorded impacts on vertical witness screens in individual engagement distances. The standard deviation sd_y is related to the deviation in the (given) fixed elevation, the standard deviation sd_z to the lateral deviation, which indicates the azimuth of the trajectory (in relation to the line of fire). The standard deviation sd_y is negligible in case of applying the maximum range; in other cases the variation in elevation will be covered by applying the cone of fire (see below No. 2). The sd data in deflection are taken to define the half opening angle α for the EB Fan (see Chapter 3 (0302.6)) to represent the factor $m_z(d_t)$ by taking for sd_z the maximum data over all target distances d_t. It is recommended to take the factor **m** = **5.4** to calculate $\alpha = \max(\alpha(d_t)) = \max(\arctan(m_z(d_t)/d_t))$ over all distances d_t (see Chapter 3 and Appendix E1). If data for the opening angle α are not available examples given in the Annexes may be used.

2. The angle α may represent random *and* systematic errors. In addition α also defines a cone of fire with origin at FP. When calculating the WDA length this angle may also represent random variations in elevation (see sub-paragraph 0706.1) by taking sd_z for sd_y.

0703 The MRR And The WDA Outline Length

1. When firing ground-to-ground in the direct mode typically low QE will be used. In case a line of sight may have a steep grade (e.g. firing ground-to-air), the QE can be large. The variable QE is besides the MRR a parameter to determine the WDA outline length shown by the following.

2. If the projectile misses or penetrates the target it may ricochet in front of, beyond or beside the target. Also it may ricochet from hard targets. All possible ricochets for any target distance, which does not exceed MRR, are included in the MRR. Thus the WDA outline length should not be less than the MRR. For a given weapon and munition the specific value of MRR depends on the choice of the critical angle of impact (IA_{crit}) and the additional weather conditions (see Chapter 3 (0303)) under which the trajectory for MRR is calculated.

0704 Choices Of The Angle IA_{crit} For The MRR

1. The following critical angles of impact are recommended if valid data are not available:

a. Spin stabilised projectiles

(1) Small calibre projectiles with high tendency of being damaged on impact — IA_{crit} = 25°

(2) Any other projectiles — IA_{crit} = 30°
(for artillery projectiles see Chapter 8 (0803.2))

b. Fin stabilised projectiles
The choice of **IA_{crit}** is generally less than for spin stabilised munitions. The IA_{crit} may be up to 10° for full calibre munitions. For discarding sabot (long rod) munition the IA_{crit} may be less then 3° (mostly those projectiles tend to break apart on impact).

0705 Special Met Conditions (SMC)

1. Special met conditions are used instead of standard prescriptions by ICAO to make the dimensions of a WDA principally independent of wind speed, air pressure and temperature (see Chapter 3 (0303)). When calculating a first trajectory (e.g. maximum range or the MRR) the following met conditions for the entire trajectory may be (at least) implemented (extreme weather conditions will be excluded):

a. Constant head or tail or cross (ballistic) wind up to 15 m/s.

b. Reduced atmospheric pressure by 100 hPa in relation to ICAO standards.

c. Using the real surface height above sea level if the range level is at significant altitude, which is normally about 800 m and higher.

0706 Two Formulas For The Generic WDA Outline Length

1. For determining the WDA length l for direct fire two alternatives (formulas) are presented:

a. **Alternative 1.** Without QE limitation, the WDA length is the maximum range of the projectile. It is not practical to apply this alternative to long rod-tank ammunition (except special practice rounds (TPCSDS) with reduced range).

b. **Alternative 2.** Using a limited QE (called **QE_l**) a reduced WDA outline length between MRR and maximum range results. The maximum QE applied to the weapon is QE_l-α and hence QE_l must be greater than α. A standard recommendation for QE_l is 10° for spin stabilised projectiles and up to 5° for fin stabilised projectiles.

2. For **alternative 1** the formula is given by

$l = l_m$ = maximum range (calculated by applying SMC) + s, where **s** is the NBSD (related to one of a HE, HEAT, PELE, FAPDS or KETF projectile). Pieces of long rods may travel further than the NBSD in the direction of line of fire.

3. For **alternative 2** the WDA outline length is the value of **MRR** or the **range to the given QE_l**, whichever is greater. In addition the application of SMC is advised as shown below. The corresponding formula is

$\mathbf{l = l_r = max\ \{MRR(IA_{crit},\ SMC)\ ,\ x(QE_l,\ SMC)\} + s}$, where s is as under paragraph 2 and

$MRR(IA_{crit},...)$	: to calculate MRR for the critical angle of impact
MRR(...,SMC)	: to calculate MRR by applying SMC
$x(QE_l$, SMC)	: to calculate the range x for QE_l with SMC

4. It is MRR ≤ l_m and therefore $l_r < l_m$. In many cases the second alternative is sufficient and results in a smaller WDA outline length. Taking the maximum range of the projectile is a conservative choice for the WDA outline length that may be overestimated.

0707 Estimates Of The Generic WDA Outline Width

1. The WDA width added to the EB fan is a composition of the lateral ricochet deviation w_R (for RDA, see Chapter 4) and or of the NBSD (for FDA, see Chapter 5). The share for the opening angle β regarding RDA resp. FDA depends on the lateral spread of the ricochets resp. fragments.

2. Data for the ricochet width $\mathbf{w_R}$ can be found by tests. If no data is available a fraction of **MRR - $\mathbf{d_i}$** may be taken for w_R (see Table 4.1 in Chapter 4 (0403.1c)).

3. The NBSD - determined in accordance with ARSP-1 Volume I (Chapter 5 (0503)) - is also a measure for the lateral fragment spread for HE projectiles. For fragments of FAPDS, KETF or PELE projectiles, canister munition and flechettes there is a smaller lateral spread, but longer fragment distances in range have to be considered. Thus the NBSD is overrated in width and therefore real calculations are necessary.

4. In case no data for the angle β is available, a value of 30° is advised.

0708 Minimum Target Distance

1. A minimum target distance d_m is normally established to protect the gunner against rearward travelling fragments and debris (back splash effects) off the target. Values for d_m are listed in *national* safety manuals. The spread of fragments affects the size of the FDA in the neighbourhood of the EB Fan (see Figures 5.2 and 7.1).

2. It was seen by comprehensive experiments that hard core ammunition fired at hard targets may produce significant backward ricochets of hard cores which in addition may be lethal to the personnel standing nearby. This fact concerns mostly a variety of ammunition up to 12.7mm (see also ARSP-1 Vol. I paragraphs 0402.6, 0402.11 and A002.7 in this volume).

0709 A Generic Outline For Direct Fire

1. The generic outline in Figure 7.1 is based on the outline given with Figure 5.1. The EBA is the EB Fan with length l_r. The range to target distance d_t is now arbitrary. Because of very small sd_x for close targets it is common to set $m_x(d_m) = 0$ and therefore $d_i = d_m$.

2. For inert projectiles it is s = 0. The area FDA is not necessary. However, when engaging nearest targets with inert projectiles, back-splashing effects may occur. An appropriate half circle centred at the target is then taken instead of FDA. The distance d_m is the radius of that circle.

3. The outline represents the WDA length calculated after alternative 2 (0706.3). The residual length l_r - MRR indicates that the range x(QE_l, SMC) for the prescribed QE_l exceeds the difference MRR after the formula for l_r in paragraph 0706.

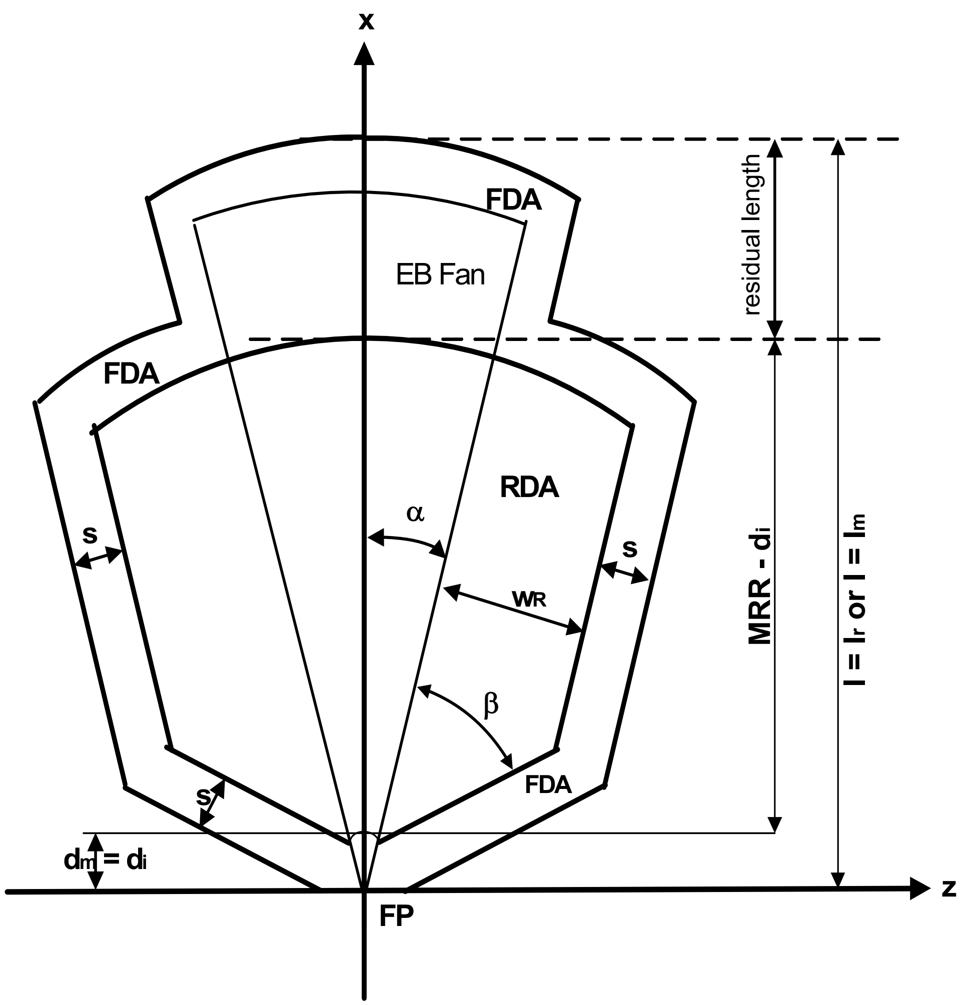

Figure 7.1: Generic WDA Outline for Direct Fire with Formula l_r or l_m

CHAPTER 8

Generic WDA Outlines For Indirect Fire Weapons

0801 Introduction

1. The WDA outline for indirect fire weapons is based on the principles shown in Chapter 4. In contrast to direct fire the target range may go beyond the MRR up to the maximum range of the projectile.

0802 The EBA

1. Opposed to the direct fire WDA outlines of Chapter 7, the total error in range will be considered when calculating the WDA length. For generating the EBA the factor m = 5.4 for the total errors ($sd_{x,EB}$(d), $sd_{z,EB}$(d)) in range and deflection (see Chapter 3 (0302.3a-c/4)) is a common choice. Because of their major significance and availability often only RTR data from firing tables (e.g. PE data of Table G for artillery) may be taken for calculating the EBA (for PE data the analogous factor is m = 8 (8 PE = 5.4 sd); see also ARSP-1 Volume I, Chapter 3 (0311), Appendices C1 and E1 of this volume). In Appendix C1 a way of deriving hit probabilities is shown when using RTR errors with the factor m.

0803 The Length Of The Generic WDA Outline

1. The MRR is a set of data for the kind of projectile to be fired and it is a function of IA_{crit} (the approved critical angle of impact), SMC (as described in Chapter 7), charge number and charge system.

2. Variety of **IA_{crit}**. For (spin-stabilized) artillery munitions, the critical angle of impact is usually taken between 178 mils (10°) (ricochet off water) and 722 mils (40°), whereas 533 mils (30°) is often used for standard conditions. An IA_{crit} greater than 533 mils may be used for artillery projectiles which do not break apart when impacting but ricochet whenever possible (e.g. malfunctioned carriers). If actual data for IA_{crit} are available (e.g. data from tests), they should be used to calculate the appropriate MRR and its correspondent critical elevation QE_{crit}.

3. The WDA outline for a fixed (but arbitrary) single target PT (distance d_t from FP) starts at the EBA of PT. This approach supports target distant depending total errors, and the formulas are related to a single target ($d_i = d_t - m\ sd_{x,EB}(d_t)$). Then:

a. The formula for the WDA length l for d_i < MRR and $d_i \geq$ MRR is

$l = \max\{MRR, d_t + m\ sdx,EB\ (d_t)\} + s$

b. The length of the RDA is MRR - d_i (see Figure 8.1).

0804 Estimates Of The Generic WDA Outline Width

1. The WDA outline width $\mathbf{w_R}$ is a composition of the lateral size of the EB fan, the ricochet deviation w_R (for RDA) and of the NBSD (for FDA). A conservative choice for the opening angle is β = 800 mils (45°).

2. The width $\mathbf{w_R}$ is a function of **MRR - $\mathbf{d_i}$**, which implies that the RDA approaches zero when d_i approaches the MRR. It may be taken as a fraction of MRR - d_i (d_i is a variable for indirect fire) if no real data are available; the fraction number is related to the surface and type of target (see Chapter 4, Table 4.1).

3. The NBSD may be calculated in accordance with ARSP-1 Volume I (Chapter 5 (0503)). The WDA outline width perpendicular to the EB Fan is $w_R + s$.

0805 A Generic Outline For Indirect Fire

1. For artillery firing it is common to place the WDA outline around the single target PT. Note: The outline is orientated to the firing position on principal. For early functioning see Chapter 5 (0502.3). The Generic WDA outline is given with Figure 8.1, which is based on Figure 5.1. The indicated point target PT is arbitrary and its distance from the firing position may go beyond MRR.

2. For mortars, fired in the high register role, the outline given with Figure 5.3 may be used (it is standard to have the IMA as a danger area).

3. Rocket artillery may need an additional area for stabilization failure at the firing position (for more details see Appendix C3 (C306.2c)).

4. When using electronic fuzes there is a possibility of an early functioning (therefore the circle of radius s_p around FP for covering fragmentation belongs to the WDA). For the distance s_p see the paragraph 0502.3; the value of s_p varies with the height of the trajectory.

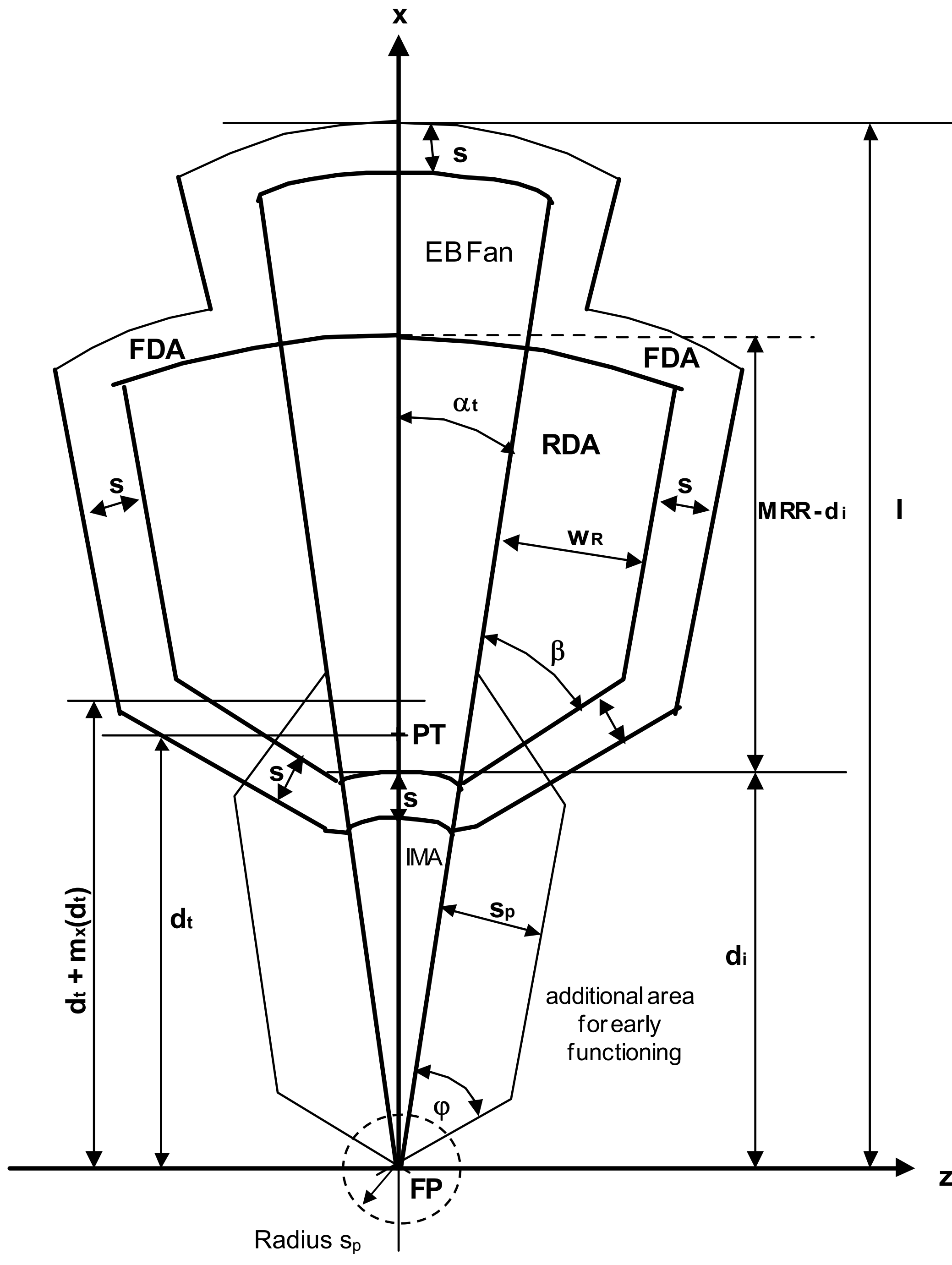

Figure 8.1: Generic WDA Outline for Indirect Fire

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ANNEX A

WDA Outlines For Hand Held And Shoulder Launched Weapons

A001 Introduction

1. This Annex illustrates in more detail, as generally demonstrated in the main part, how to establish WDA outlines for small calibre hand held weapons in section A002, for grenade launchers/grenade machine guns in section A003 and for shoulder launched weapons (unguided rockets) in section A004. The method is based on Chapter 7, supported by some examples. It is intended to present some most used, common approaches or options for developing WDA related to those weapons. The user may decide which is the best possible solution for him based on given own requirements and assessments. The WDA outlines in this Annex are for direct fire weapons in a ground-to-ground role.

2. A selection of weapons addressed in this Annex is:

   c. Personal Defence Weapons (revolvers, pistols and sub machine guns).

   d. Individual Combat Weapons (rifles, shotguns and light machine guns).

   e. Crew Served Weapons (medium and heavy machine guns).

   f. Grenade Launchers (hand held grenade launchers and grenade machine guns on a mount).

   g. Shoulder launched unguided Rockets (anti-tank/anti-shelter weapons).

3. Generally, small calibre weapons use spins stabilised munitions, which have no explosive fillings or incendiary charge (apart from API, APEI or MP rounds for example) and have no fuzes. Munitions for grenade launchers have explosive or pyrotechnic fillings, illumination or smoke devises and fuzes. Shoulder launched rockets are fin stabilised and launched from a tube.

A002 Constructing WDA Outlines For Small Calibre Hand Held Weapons

1. In this paragraph the step-by-step development of a WDA outline is shown for small calibre weapons. Because of the frequent possibility to fire at very close targets without loss of generality the distance d_i is set zero (see paragraphs 6 and 7).

2. Error budget and half opening angle **α** of the EB fan. Apart from the accuracy and consistency of the weapon itself (see Chapter 7 (0702.1)), human errors make a major contribution to system errors when exercising with small calibre hand held weapons, which influences the size of **α**. The choice of **α** is a national decision and values up to 6° are used. These values are a product of various factors such as random or system errors, training level, infrastructure and range control measures. Table A.2 at the end of this Annex shows some examples of national accepted data.

3. Remark. For qualified firers (for example snipers) using special equipment (e.g. high accurate munitions with low RTR errors by design) aimer errors will be considerably smaller than for standard small calibre weapons. The WDA may end at a stop butt, if all shots are captured by its structure, and it has been designed, constructed and maintained to contain the complete projectile upon impact. An example is given in Appendix E1 (E104.2b(3)).

4. The WDA length. As described in Chapter 7 (0706), the two different ways to determine the length of a WDA outline are the methods using Maximum Range (l_m) under SMC or using the Maximum Ricochet Range under SMC (for applying SMC see Chapter 7 (0705)):

h. Recommendations for SMC:
   (1) Wind (head, tail and cross): 12 m/s -15 m/s,
   (2) Reduced atmospheric pressure of 100 hPa in relation to ICAO,
   (3) Taking the real height (above sea level) if the firing position is higher than 800 m altitude.

i. For small calibre weapons the parameters l_m and l_r can be determined by free flight trajectory calculations with Point Mass Models (ARSP-1 Volume I, Chapter 3 (0303)). If no other information is available, firing tables from the supplier may be applied. In such cases an extra margin of safety (e.g. for SMC) may be added to the chosen WDA length (for example to add +10% of the length).

j. l_m is the maximum range under weather conditions and may be found by iteration. The reduced range is given by l_r = max {MRR(IA_{crit}, SMC), x-range(QE_l, SMC)} (see Chapter 7 (0706), with QE_l considered to be equal **10° - α** (common value)) and IA_{crit} considered to be equal **30°** (or 25° for projectiles with high tendency of being damaged on impact) for spin stabilised projectiles as example.

5. The Danger area width and RDA. The opening angle β (see Chapter 7, Figure 7.1 and Figure A.1) depends on the lateral spread of the ricochets and defines together with MRR the ricochet danger area.

k. Since data on ricochet behaviour are rare and difficult to generalise in a simple manner, an estimation for the width as shown in Table 4.1 of Chapter 4 is added lateral to the error budget fan (commonly used data).

l. Remark. Ricochet-behaviour will also depend on the geometrical form of the target itself, especially when armoured vehicles, geometrically designed to offer low attack angles, are employed. For spherical surfaces or in wooded areas the calculated width (for hard targets) may be doubled.

6. Fragment danger area (FDA). For small calibre AP, API, APEI or MP rounds generally no FDA is added to the RDA because of their small lateral spread. Consequently, the RDA may originate at FP for simplicity. Also it is an older practice to start the angle β at the line of fire (this angle is called β’ and includes the opening angle α) – see Figure A.1. This can be done without any restrictions.

7. Minimum target distance (d_m). For small calibre weapons a rearward danger zone is needed because of possible back-splashing effects from targets and stop butts. The risk being injured by ammunition or by parts of target material coming back to the firer/to the gun may be minimised by imposing an appropriate minimum target distance. Generally the risk of an injury is high when engaging hard targets. For example back splashing hard cores from cal. 12.7mm can be lethal at 200m backwards and even more if the target was not penetrated.

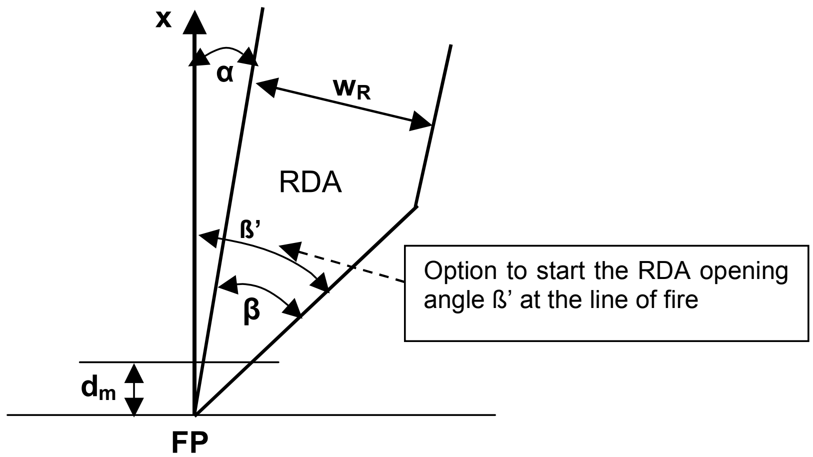


Figure A.1: Essential Parts of a small Calibre WDA Outline (half-sided)

8. Example for a WDA outline for small calibres. A WDA outline for 7.62 mm x 51 Ball and Tracer munition engaging ground soft targets (skilled firer and opening angle α = 2° and β = 30°) is given in Figure A.2. For the specific downrange closure see Appendix E3.

9. General advises for developing WDA outlines for any kind of small calibre weapons are illustrated in Table A.1 (including sketches of outlines in Figure A.3). This is a nation specific scheme, so some symbols and notations are different from those used in this document.

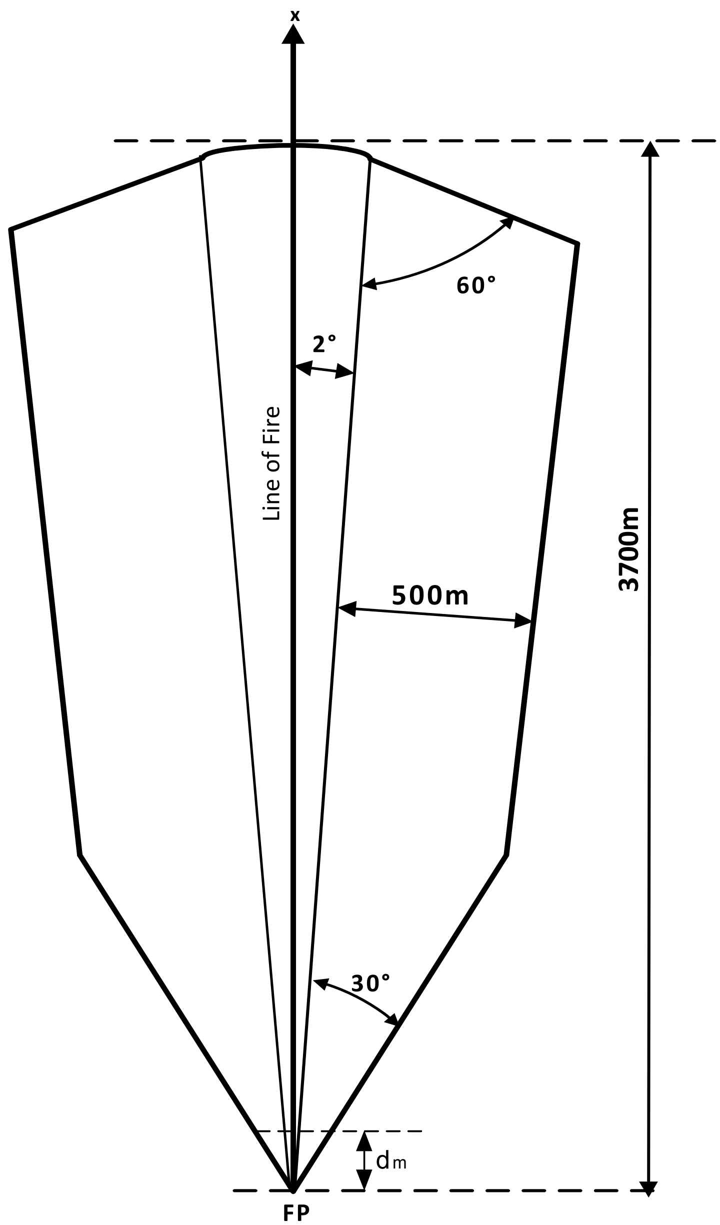


Figure A.2
WDA Outline for 7.62mm x 51 Ball for Firing on Ground soft Targets

Collect the following values: • Maximum range : **d_{max}** ________meter • Maximum Ricochet Range : **d_{533}** ________meter • Critical elevation : **QE_{533}** __**NA**__ mils • Width WDA (ricochet) : **b** ________meter **Hard b_{rh}** : **d_{533}** / **4** (or soft target **b_{rz}** : **d_{533}** / 8) • Burst Safety Distance : **c** ________meter • Opening angle : α_{hand} ____**6**__° • Lateral ricochet angle : β ___**30**__°	• Construct a line from the weapon in the **firing direction**. • Mark the maximum range **d_{max}** and the maximum ricochet range **d_{533}** on this line. • Construct two lines at angle β to the line. • Construct two lines on both sides of the firing direction from the weapon at angle α. • The lines at angle α have the length **d_{max}** so an arc through **d_{max}** with as centre point the weapon can connect them. • Parallels to these lines (at angle α) are now constructed at distance **b**. • At the weapon side these lines are connected to the lines at angle β and at the top by an arc through **d_{533}**. • If applicable a burst safety distance **c** must be constructed around the just constructed impact area.

Table A.1
WDA for Direct Fire small Calibre Hand Held Weapons *(in use by NLD Army)*

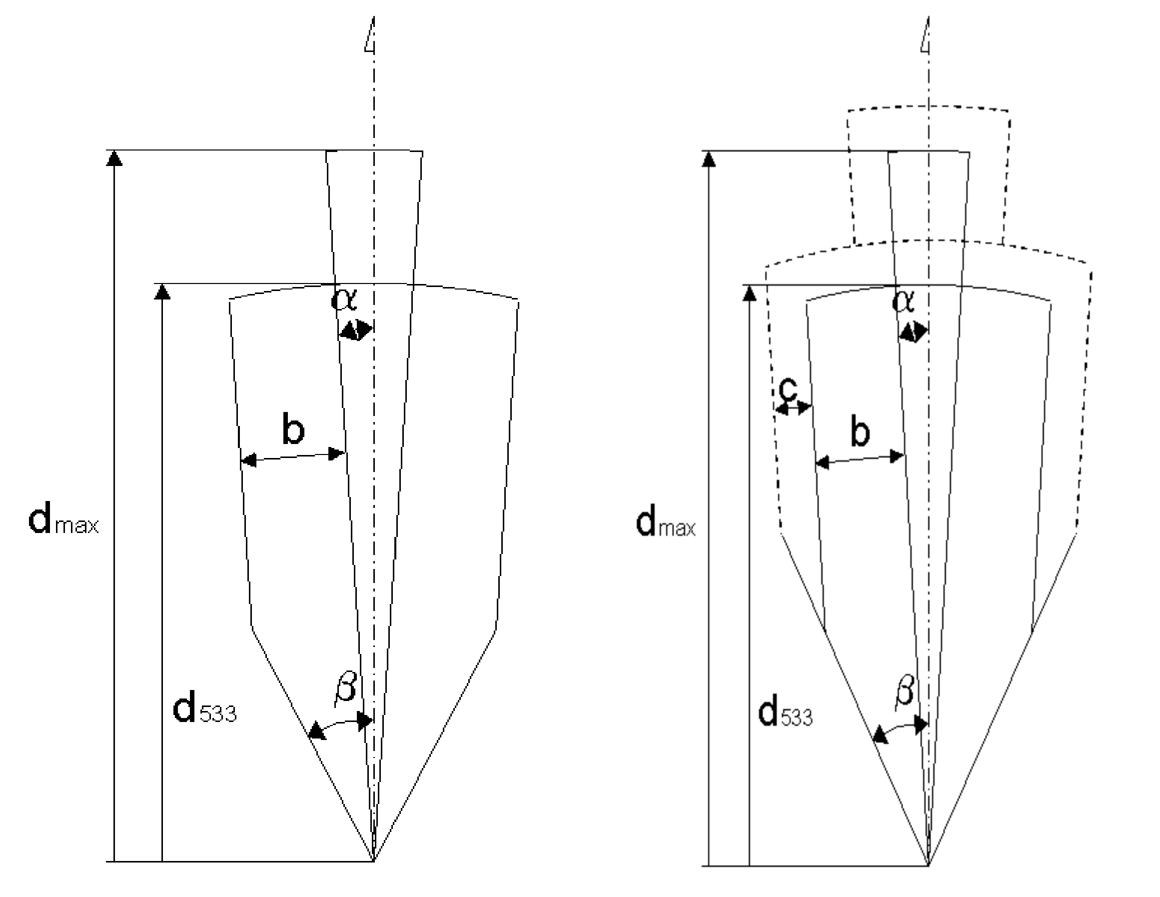


Figure A.3. Examples of WDA Outlines corresponding to Table A.1
(in use by NLD Army)

A003 Example: WDA Outlines For Grenade Launchers/Grenade Machine Guns

1. Increased firepower can be given to the individual soldier by equipping him with grenade launchers or Grenade Machine Guns (GMG). For future individual combat weapons grenade launchers/GMG will be an integrated part of the system. Different types of grenades (spin stabilised munition) exist (e.g. HE, signal, illumination, smoke, tear-gas (riot control version)). Focus of this part of the Annex will be the HE version with suitable numbers for the WDA outline.

2. Hand held grenade launchers (calibre 40 mm, low velocity). The munition is used for engaging soft and medium targets. The principles applied for creating outlines for these systems are comparable to those listed above. The following elements have to be taken into account. For the WDA outline the Figure 7.1 is taken with outline length $\mathbf{l = l_m}$ in the shape of Figure A.4 (which the following data refer to):

a. The aimer deviation is normally higher than for standard small calibre firings because of its functioning in connection with inadequate aiming possibilities. A half opening angle **α** of **10°** for the EB fan is advised.
b. The maximum range is small (l = 500 m) because of low v_0 of the projectiles.
c. Ricochet behaviour (minor effects because munition is of low spin and of low velocity): a MRR is not necessary (for Figure A.4 let MRR = l). It is advised: β = 30° and w_R = 150 m.
d. Fragmentation (major effects) is covered with s = NBSD = 165 m.
e. Minimum firing distance (in relation to NBSD) is d_m = 165 m.

3. (Mounted) Grenade machine guns (GMG, calibre 40 mm, High Velocity (HV); HE, HEDP, TP, illumination). The munition is used for firing at soft and hard targets. The outline for a GMG is also given with Figure A.4 (the following data are based on **USA HE** and **HEDP** munition):

a. The half opening angle **α** is **10°** (because of weapon mounting).
b. A minimum target distance $\mathbf{d_m}$ is advised (fragmentation rounds; failure modes; d_m = 430 m).
c. The WDA outline length l is the maximum range (2600 m) of the HV round plus NBSD.
d. The MRR for the HV projectiles is 1250 m.
e. The angle β of the RDA permits to reduce the ricochet area with the nature of the target. It is β = 60° for hard targets and 30° for soft (earth) targets. The maximum width of the ricochet area is given with w_R = 470 m (hard) and w_R = 170 m (soft) (rounded up experienced data).
f. The NBSD (s) is 310 m for HE and HEDP.

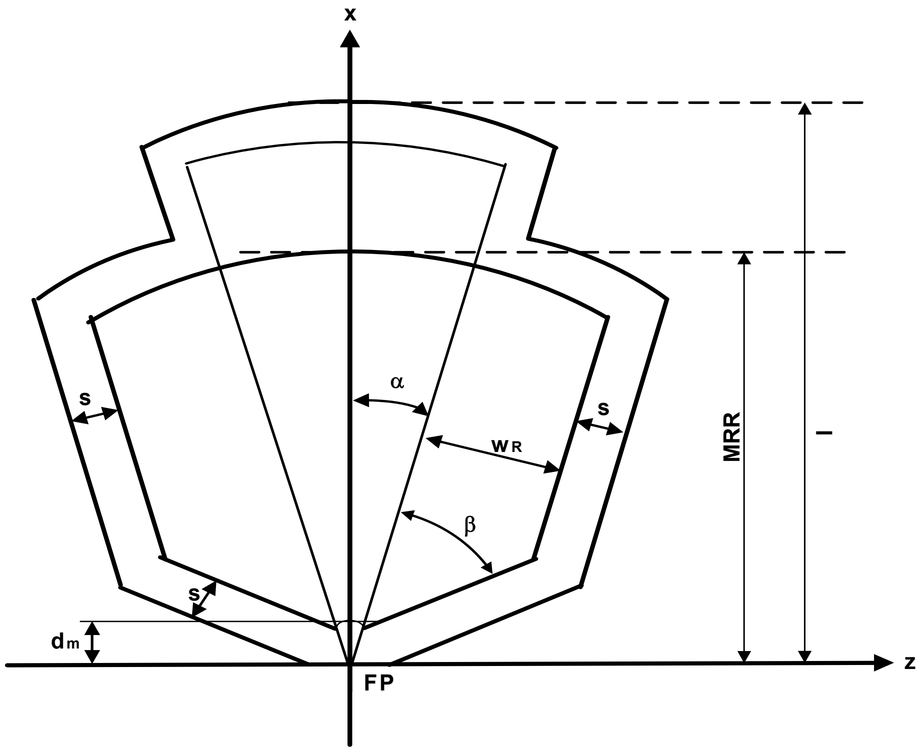


Figure A.4: WDA Outline for Grenade Launchers / GMG Calibre 40 mm, low and high Velocity

A004 WDA Outlines For Shoulder Launched Anti Tank and Anti Shelter Weapons

1. Shoulder launched Anti Tank weapons produce their effect by shaped charged projectiles (jets) and fragmentation of the warhead case. Shoulder launched Anti Shelter weapons may employ prefabricated fragments (cubes, balls) and fragments from the case of a secondary charge for anti personal engagements after penetrating walls. The development of WDA outlines follows the previous sections. The WDA outline is equivalent to Figure A.4 with an added rearward WDA at the firing position for released debris from the back of the launcher (recoilless weapon). The area behind the launcher has to be cleared of personnel and obstacles.

2. Shoulder launched weapons of paragraph 1 are established with adequate aiming devices, so that depending on the munition, the error budget angle α is smaller than for grenade launchers but comparable to small calibre hand held weapons, see Table A.2 for examples. The maximum range of shoulder-launched rockets is relatively small because of the short burning time of the rocket motor.

Consequently, the WDA length may be taken as the maximum range of the weapon under normal weather conditions.

3. The ricochet behaviour has minor effects because the rocket is fin stabilised and of low impact velocity. A small ricochet area is the result. An opening angle β = 30° for RDA is advised.

4. Fragmentation has to be considered for the FDA around EBA and RDA. The detonation of the rocket warhead produces fragments:

a. Origin from the shaped charge (jet particles, slug), which will be released mainly in the direction of the projectiles trajectory;

b. Coming from the case or secondary charge (possibly prefabricated fragments), which are expected to travel in any direction;

c. Coming from the motor device, which produces rearward travelling debris.

A FDA width parameter s is added as shown in Figure A.4. It is expected that fragments will range less than 300m, therefore a value for s of 300m is appropriate except the slug (one single fragment) that needs special treatment related to the FDA. For training projectiles the area FDA is not necessary.

5. The rearward danger area of the launcher is for parts of the counter-mass and blast wave. It is an isosceles triangle with apex at the breech. The triangle contains an inside sector of a circle for the backward blast – this sector must be kept free of obstacles in addition. The triangle (sector) is symmetrically to the rearward extension of the line of fire. The depth of the sector is smaller than the side of the isosceles triangle. The size of the triangle (base and depth) may be found by experiment. Usually the opening angle at the Breach Point (BrP) is 90° (2 x 45°).

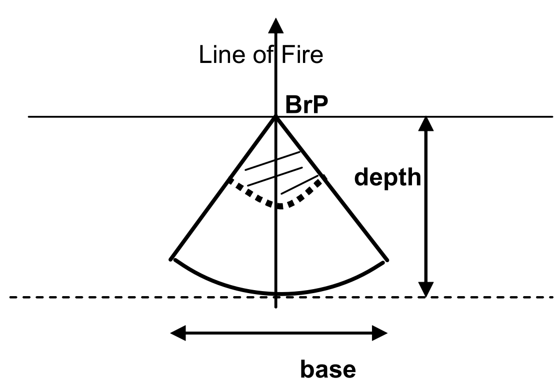


Figure A.5: Rearward Danger Area

6. A minimum target distance is advised. The distance depends on the type of munitions used and varies up to NBSD. For some munitions (especially those with prefabricated fragments) eye protections are recommended when engaging nearest targets.

A005 Examples Of National Choices For The EBA Angle α

1. A table with national accepted data for the half opening angle α is shown below.

Total Error for Direct Fire WDA Outlines for Hand Held/ Shoulder launched Weapons 0305 EBA Angle α					
	0306 Hand Held Weapons			Shoulder launched unguided Weapons (Rockets)	
Nation	basic firing	combat exercises	sniper	stationary targets	moving targets
BEL	6°	6°	2° (2)	10°	10°
CAN	-	-	-	-	-
DEU	6°	6°	1° (2)	6°	6°
DNK	6°	6°	2°	10°	10°
GBR	2.25°	3.38°/ 5.06°	0.30°	10°	10°
NLD	6°	6°	1° (2)	6°	6°
NOR (1)	6°	6°	6°	5°	10°
USA (3)	5°	5°	1°	5°	5°
SWE	3°	5.7°	1° (2)	-	-

(1) If range is less than 200 m: 9° for all weapons

(2) For specially qualified snipers

(3) 5° may be reduced by unit commander to 2°

Table A.2: Values of the Angle α used by some NATO/PFP Nations for different Types of Firing with NATO/PFP Munitions and Hand Held/Shoulder launched Weapons

ANNEX B

WDA Outlines For Direct Fire Mounted Weapons

B001 Introduction

1. This Annex shows similar to Annex A the essential issues for determining WDA outlines for mounted weapons of medium and large calibre in the direct fire mode for soft or hard targets in a ground-to-ground role. They are illustrated by some examples. It is intended to present common approaches or options for the user who decides which is his optimal solution related to his own requirements and assessment. Note: WDA outlines for helicopter mounted unguided weapons are addressed in Appendix D2. For simplicity reasons mounted grenade machine guns are treated in Annex A in combination with grenade launchers.

2. Mounted weapons (mainly) address infantry fighting vehicles, tanks and air defence weapons in a ground role. Different types of medium and large calibre munitions are employed. A selection is given below (for abbreviations see Appendix E502):

a. Spin stabilised KETF, HE, HEAT, PELE, AP, API and practice projectiles.
b. Fin/Cone stabilised HE, HEAT, HEAT-MP, PELE, KE (APFSDS/TPCSDS) projectiles including practice / training projectiles.
c. Spin stabilised AP and FAP discarding sabot munitions (APDS/FAPDS).
d. Sub-calibre (in bore) training devices.

B002 Constructing WDA Outlines For Mounted Weapons

1. The step-by-step development of WDA outlines is taken from Annex A. Only major differences (as longer ranges, fragmentation, mode of stabilisation) are considered below.

2. Error budget and half opening angle α of the EB fan. Apart from the accuracy and consistency of the projectile/weapon system itself human errors may be excluded from calculations because the task of aligning sight of the target is largely mechanized and fire control systems are used. These control systems may also cater for local meteorological effects. Recommendations for the angle α (Chapter 7, 0702) are given (see also the table in paragraph B003) as follows:

a. Firing from a fixed stationary position the aimer error will be small. Based on results from firings at screens positioned at standard target distances the choice **α = 2°** is assumed to be conservative.
b. APFSDS/TPCSDS projectiles have a high muzzle velocity (e.g. 1600 m/s) and high precision the angle α may be reduced (e.g. α = 1°) for those projectiles.
c. For moving targets and/or moving firing platforms the angle α may be increased up to 5° in case of non-stabilised weapon systems.

3. The WDA outline length. The two common ways to determine that length and recommendations for SMC (Chapter 7, 0705) are taken as in Annex A shown (large calibre tank munition data are based on different ICAO basic data). Special issues are:

d. Maximum range $\mathbf{l_m}$ (Chapter 7 (0706.3)) for the outline length. The maximum range may not be practicable for artillery in the direct fire mode and large calibre APFSDS projectiles because of their extreme range (except reduced range TPCSDS rounds). Instead of l_m the length l_r (see below) should be used.

e. $\mathbf{l_r}$ (Chapter 7 (0706.2)) for the reduced outline length. The formula is given with l_r = max {MRR(IA_{crit}, SMC), x-range(QE_l, SMC)}. Recommended (experienced) data for QE_l for different types of projectiles are as following (Chapter 7 (0702.1) and (0706.1) for the meaning of QE_l).

(1) Medium calibre spin stabilised projectiles: QE_l = 15° (the MRR of those projectiles are reached at a QE between about 8° and 15°). IA_{crit} is considered to be equal **30°**, which is also valid for spin stabilised APDS and FAPDS projectiles.

(2) Fin/Cone stabilised projectiles: The QE_l depends on the shape of the projectile's nose and lower IA_{crit} for those rounds. QE_l varies between 3° and 10°.

(3) For artillery projectiles in the direct fire mode the length l_r may depend on MRR only (e.g. IA_{crit} = 30°).

c. Remark. Long rod KE projectiles are of high accuracy at ranges up to 4000 m. High precision (low total error) may be an option for a specific choice of a reduced WDA outline length by means of a stop butt (Appendix E1 (E104, 2b(3))).

d. For **APFSDS** munitions an extra margin of safety for the WDA length is recommended (e.g. 10% of the calculated length), because the trajectory data of those long-range projectiles may not be available up to their termination points. For **TPCSDS** (reduced range) and **HEAT** projectiles that extra margin of safety is not necessary.

4. The WDA outline width. The opening angle β (see Chapter 7, Figure 7.1) may be different for spin or fin stabilised projectiles; but common practice is to make no difference. The angle β = 30° is a conservative selection. For simplicity the angle β may start at the line of fire (see Annex A (A002.6)).

5. Fragmentation. Besides HE/HEAT projectiles, APFSDS (and FAPDS), KETF or PELE projectiles cause hazardous fragments through the effect of impacting especially at hard (armoured) targets or they break upon impact (see ARSP-1 Volume I, Chapter 5 (0504) and Chapter 7 (0707.3)). The WDA outline for mounted weapons is completed by a surrounding fragment danger area (FDA) as shown in Figure B.1. When firing inert practice projectiles (except frangible rounds) at soft impact media the FDA may be eliminated.

6. Sabots/pusher plates. In front of the firing position a WDA outline for sabot/pusher plate parts may be applied (see Chapter 6). Their outlines may be contained in the generic outline for the WDA of the projectile themselves.

B003. Examples Of National Choices For EBA Angle α

1. A table with national accepted data for the half opening angle α is shown below.

Total Error for Direct Fire WDA Outlines for mounted Weapons EBA Angle α						
	Small Calibre up to 14.5 mm		Medium Calibre		Large Calibre	
Nation	stationary targets	moving targets	stationary targets	moving targets	stationary targets	moving targets
BEL	2° (12.7 mm) 6° (others)	2° (12.7 mm) 6° (others)	2°	2°	2°	2°
CAN	-	-	-	-	-	-
DEU	2°	2°	2°	2°	2° (3)	2°
DNK	2° (12.7mm) 6° (others)	2° (12.7mm) 6° (others)	2°	2°	2°	2°
GBR	3.38°	5.06°				
NLD	6° (4)	6°(4)	6° (4)	6° (4)	2°	2°
NOR (1)	3°	6°				
USA (5)	5°	5°	2°	2°	2°	2°
SWE	6° (2)	12° (2)				

(1) If range is less than 200 m: 9° for all weapons
(2) For side blocked weapons
(3) For direct fire artillery the half opening angle α is contained in the angle β (60°)
(4) 2° for mechanical aimed/controlled weapon systems
(5) 5° may be reduced by unit commander to 2°.

Table B.1: Values of the Angle α used by some NATO/PFP Nations for different Types of Firing with NATO/PFP Munitions and Mounted Weapons

B004. An Example for a WDA Outline for Mounted Weapons (Direct Fire)

1. The outline given with Figure B.1 is valid for all direct fire mounted weapons, including HE projectiles. It shows a minimum target distance d_m that must be applied. The FDA starts at the lower part of the RDA because fragments are expected to be generated not before the distance d_m. Also, because of high velocity of the bursting projectile at lower target distances the lateral spread of fragments is small. In case the distance d_m is small, for fragments occurring at nearest targets, a circle of radius s around the target or impact area is advised as part of the WDA outline.

2. The outline length may be calculated by MRR (length l_r) or by maximum range (length l_m) - see paragraph B002.3. For simplicity the RDA starts at the gun position. However, it may be moved to the target if there are no intermediate crests or obstacles that could create an early ricochet.

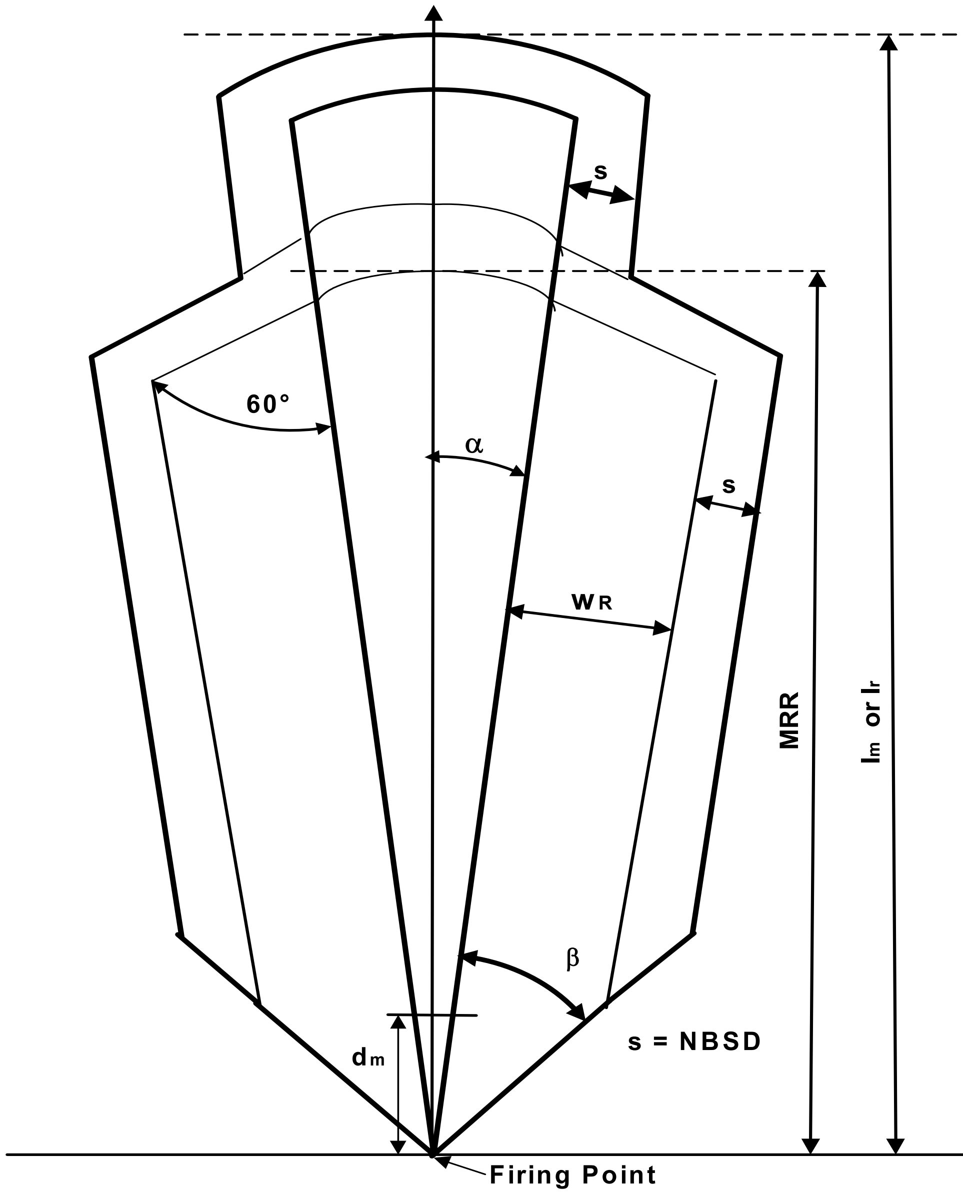


Figure B.1: WDA Outline for Mounted Weapons and Direct Fire

ANNEX C

WDA Outlines For Indirect Fire

C001 Introduction

1. The main aspect of Appendix C1 is a specific error budget for indirect fire and the resulting WDA outline for first trajectories including fragmentation at impact. The set of parameters for calculating the error budget is explicitly developed addressing different round-to-round and mean-point-of-impact errors in addition with their joint probabilities (using PE data only from firing tables is also considered). With those errors hit probabilities may be calculated as shown.

2. Because of the time dependent series of events carriers show a variety of error budgets, which is shown in Appendix C2 with the example of an ICM projectile. This is seen in connection with Appendix C3. However, the resulting WDA is not time dependent.

3. In Appendix C3 a comprehensive survey is given of all components and data necessary to develop WDA outlines for any kind of mortar and artillery munitions (including unguided rockets) for indirect fire. In more aspects as in Chapters 3 - 8 considered it is demonstrated in which way individual outlines may be generated and composed step-by-step. For each of those outlines proposals for dimensions (using PE data) are given. Referring to Chapter 5, there is an option left for a specific WDA outline for artillery HE projectiles and indirect fire. It is assumed that a ricocheted HE round will not detonate at a second impact (fuze failure at first impact with ricochets). This item is also addressed in this Appendix. A worked example (ICM projectile) completes this Annex.

APPENDIX C1

Specific Error Budgets And A WDA Outline For Indirect Fire

C101 Introduction

1. Two different approaches for the error budget are considered. A corresponding WDA outline with fragmentation at impact is shown. An example for a hit probability of the EBA completes this Appendix.

C102 Parameters For The EBA (Ellipse Or Rectangle)

1. Let the total errors $sd_{x,EB}$ in range and $sd_{z,EB}$ in deflection be defined as in Chapter 3. Basic models use PE data (a composition of specific RTR errors) only as major factors for the total error. The more comprehensive feature is the assumption that various, statistically independent RTR and MPI errors (see ARSP-1 Volume I, Chapter 3) can be treated to a first approximation for the total error.

a. The Error Budget with PE data. PE data from artillery or mortar firing tables may be called PE_x in range and PE_z in deflection. The resulting sd data are indexed by **FT** instead of **EB**. The values $sd_{x,FT}$ and $sd_{z,FT}$ can be determined as a function of the distance d_t between FP and PT from the values in firing tables (STANAG 4119) by using following formulas

(1) $sd_{x,FT}(d_t) = PE_x(d_t)/0.6745$ and $sd_{z,FT}(d_t) = PE_z(d_t)/0.6745$

or by using for each charge the max PE value in range and deflection, taken over all d_t (which are then distance independent values):

(2) $sd_{z,FT} = \max PE_x(d_t)/0.6745$ and $sd_{z,FT} = \max PE_z(d_t)/0.6745$

b. The Error Budget with statistically independent MPI and RTR (sub-paragraph 2a) or only RTR (sub-paragraph 2b) errors. The equations defining $sd_{x,EB}(d_t)$ and $sd_{z,EB}(d_t)$ for a given single target PT depend on different input parameters and they are given by

(1) $sd_{x,EB}(d_t) = \sqrt{sd_{x,MV}^2 + sd_{x,MET}^2 + sd_{x,WL}^2 + sd_{x,AM}^2 + sd_{x,PR}^2}$

(2) $sd_{z,EB}(d_t) = \sqrt{sd_{z,MET}^2 + sd_{z,WL}^2 + sd_{z,AM}^2}$

with the parameters:

(3) dependent on d_t by transforming into metres (see sub-paragraph 2c)

MV = Muzzle Velocity and propulsion assistance
MET = Meteorology
AM = Aiming
PR = Projectile weight

(4) independent of d_t

WL = Weapon Location

Each sd under the square root can be a composition of corresponding RTR and MPI errors (see ARSP-1 Volume I, Chapter 3 (0311.4)).

2. The estimates of the various sd in formulas 1b(1) and 1b(2) are created with the knowledge (quality) of the input parameters (the gun, the topographical basis, the equipment used to determine the gun position, the firing direction, the muzzle velocity, met data etc.). The composition of $sd_{x,EB}(d_t)$ and $sd_{z,EB}(d_t)$ can be based on two different assumptions:

f. Using MPI and RTR errors, which has to be done in the beginning of a live firing period when the knowledge of system errors are limited (e.g. the first rounds), see following sub-paragraph (1).

g. Using only RTR errors, which can be done in order to reduce $sd_{x,EB}(d_t)$ and $sd_{z,EB}(d_t)$. Before using that method the knowledge of MPI errors must be so good that the influence on $sd_{x,EB}(d_t)$ and $sd_{z,EB}(d_t)$ is negligible, see following sub-paragraph (2).

(1) **MPI** and **RTR Errors.** An example of the different input parameters is shown in the Table C1.1 below. The values show the accuracy in which the different input parameters can be determined by using different equipment or methods.

Range	**Statistic Value (sd Data)**
Weapon location (WL)	25 m
Aiming (AM)	0.5 mils
Muzzle velocity (total) (MV): - Barrel wear (MV_1) - Charge (MV_2) - Lot (MV_3)	11 m/s
MET ballistic density (MET_1)	50 g/m^3
MET ballistic temperature (MET_2)	12º C
MET ballistic wind (MET_3)	18.0 kts
Weight of the Projectile (PR)	½ Squares
Deflection	
Weapon Location (WL)	25 m
Aiming (AM)	0.5 mils
MET ballistic wind (MET)	18.0 kts

Table C1.1: RTR and MPI Errors vs Accuracy of Input Parameters

(2) **RTR Errors**. An example of the different input parameters is shown in Table C1.2. The values show the accuracy in which the different input parameters can be determined by using different equipment or methods.

Range	Statistic Value (sd data)
Aiming (AM)	0.5 mils
Muzzle velocity (MV)	6.0 m/s
MET ballistic density (MET_1)	10 g/m^3
MET ballistic temperature (MET_2)	3º C
MET ballistic wind (MET_3)	6 kts
Weight of the Projectile (PR)	½ Squares
Deflection	
Aiming (AM)	0.5 mils
MET ballistic wind (MET)	6 kts

Table C1.2: RTR Errors vs Accuracy of Input Parameters

(3) All the errors based on different equipment or methods mentioned above have to be changed into metres by using "azimuth and range correction" in firing tables (normally shown in Table F).

Example: $sd_{x,MV}$ = 6 m/s
From firing table results:

Range [m]	Range correction [m] for a change of ± 1 m/s in MV	$sd_{x,MV}(d_t)$ [m] for a change of 6 m/s in MV
5000	12.4	6 x 12.4 = 74.4
9000	19.2	6 x 19.2 = 115.2
12000	22.8	6 x 22.8 = 136.8

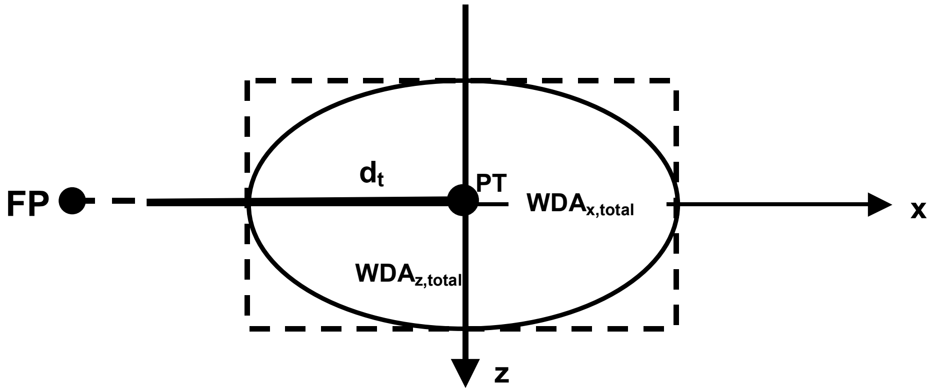
Table C1.3: Numbers for the Example

(4) Using methods either from paragraph 1, a or b, the total error in range is given with formula (1) and $sd_{x,MET} = \sqrt{sd_{x,MET1}^2 + sd_{x,MET2}^2 + sd_{x,MET3}^2}$ and for deflection with formula (2).

C103 An Example For A WDA Outline For A Single Target Without Ricochets

1. After having determined/calculated $sd_{x,FT}(d_t)$ and $sd_{z,FT}(d_t)$ or $sd_{x,EB}(d_t)$ and $sd_{z,EB}(d_t)$ for a single target PT – called $\mathbf{sd_x}$ and $\mathbf{sd_z}$ for simplicity – an EBA will be established by using an ellipse (or a rectangle) with axes due to the multiples of sd_x and sd_z. For implementing the NBSD, the HE round specific value has to be added as shown below. This step results in an enlarged error budget ellipse (or rectangle) with half-axes $WDA_{x,total}$ in length and $WDA_{z,total}$ in deflection.

Neglecting ricochets this becomes the WDA outline for that given single PT (see Figure C1.1; the intermediate area is not shown).



with $\mathbf{WDA_{x,total} = m\ sd_x + NBSD}$ and $\mathbf{WDA_{z,total} = m\ sd_z + NBSD}$

Figure C1.1: The WDA Outline (Ellipse or Rectangle) around PT (no Ricochets)

C104 An Example For A Hit Probability For An EBA (Rectangle)

1. A projectile fired towards the aiming point PT will hit *the rectangle* (the EBA with centre PT) with half axes $5.4*sd_{x,FT}$ and $5.4*sd_{z,FT}$ (by neglecting the bias) with the probability P = 0.99999986 when taking m = 5.4 as conservative choice.

2. The complementary probability Q of a projectile impacting outside that specific rectangle is given by Q = 1 - P = 1 - 0.99999986 = $\mathbf{0.137\ 10^{-6}}$ (two dimensional probable errors; see Appendix E1 and Table E1.1).

APPENDIX 2

Error Budget Areas For Carriers

C201 Introduction

1. This Appendix illustrates the different error budget areas for carriers. It may be seen as an introduction for the next Appendix, which covers this subject highly detailed.

2. Carriers for illumination, smoke, bomblet (ICM)) or sensor fuzed munitions require specific additional EBA, RDA and FDA to cover areas under and around the ejection point, around the pattern of the sub-munitions, the WDA for the projectile with no fuze function and the empty carrier including their ricochets. Additional RDA and FDA are treated in Appendix C3.

C202 An Example For An EBA For 155mm ICM Projectiles

1. Let d_t be the distance to the planned impact point for the central sub-munitions. The EBA on the surface for the ejection point (related to d_t) with distance $d_{ej} < d_t$ is the area EBA_{ej} in Figure C2.1 with opening angle α_{ej}.

2. The area AFDA (shown in Figure C2.1) with the adjacent angle η covers the debris that is generated by the carrier during and after ejection of its payload (ARSP-1 Volume I, Chapter 5 (0502e)). The width W_D depends on the lateral spread of the debris (under met conditions) of the spinning and descending round.

3. The areas EBA_B, SMP (sub-munition pattern) and FDA_{sm} indicate the sub-munition pattern. The area EBA_B is the EBA for the central grenade with the total error $m_x(d_t)$ and half opening angle α_t. The surrounding area SMP is the total sub-munitions pattern around the central sub-munitions. FDA_{sm} stands for the fragment hazards of all sub-munitions (with NBSD = s_m). Note: For sensor-fuzed sub-munition this part of the WDA may be very complex.

4. The projectile with non-fuze function or the empty carrier have different EBA (EBA_r [with angle α_r] or EBA_{eh} [with opening angle α_{eh}]) because of different ballistic properties (in Figure C2.1 without restriction it is set $\alpha_r = \alpha_{eh}$). The RDA is added for ricochets of the empty carrier or the round with non-fuze function.

5. The following figure is drawn in its right half side because of simplicity. It is symmetrical to the line of fire (x-axes).

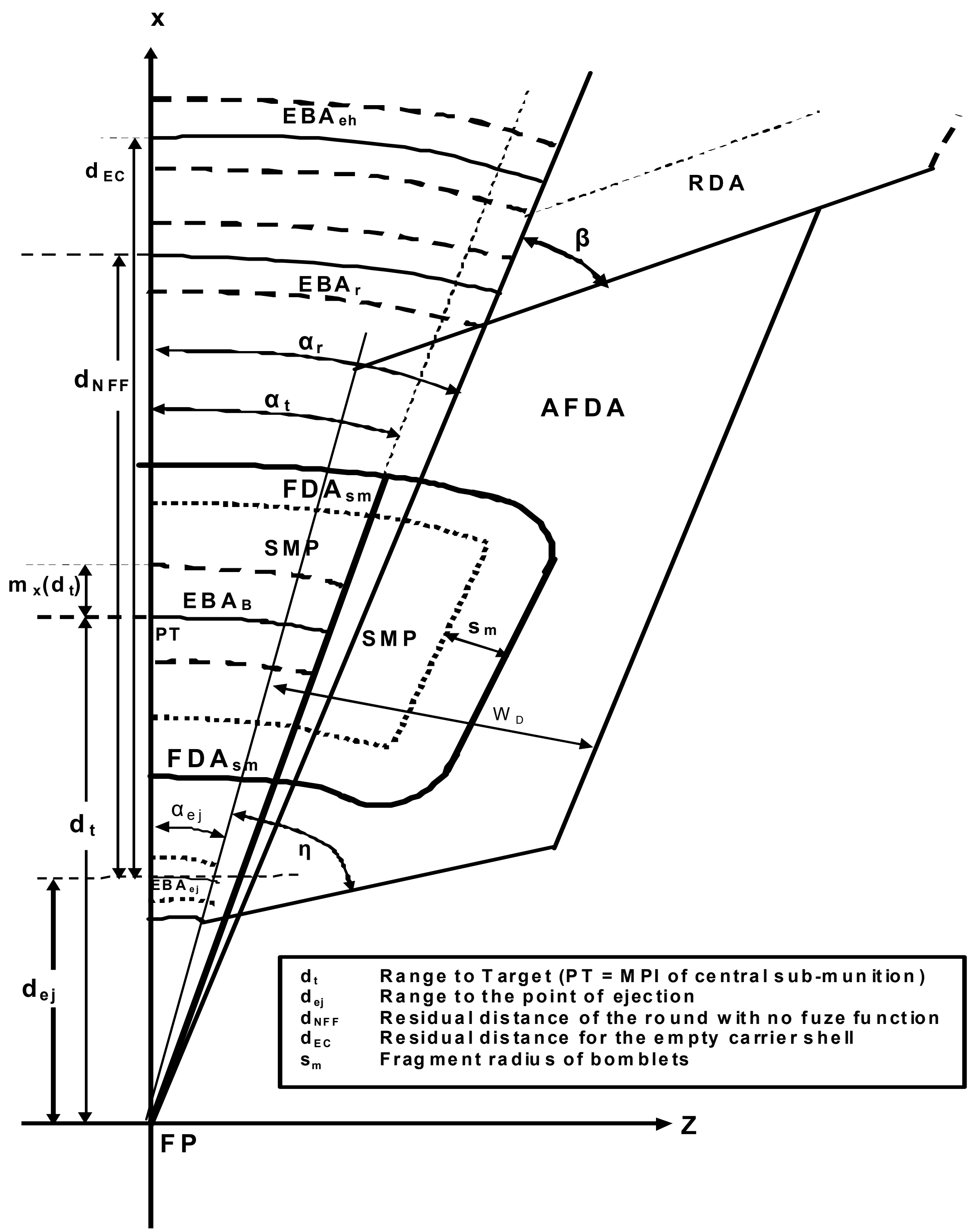


Figure C2.1: Error Budget Areas for Carriers (ICM)

APPENDIX 3

Basic WDA Outlines For Indirect Fire: A Complete Survey

C301 Introduction

1. This survey describes the components to be considered when constructing WDA for indirect surface-to-surface artillery including mortars and rocket artillery. All types of projectiles for these weapons are covered, including training projectiles, but excluding those ones with active in-flight guidance. This survey does not cover the use of any of these weapons in a direct firing mode.

2. It is the intention of this Appendix to summarise all needed factors and principles ("The Components") of Chapters 3 and 4 of ARSP-1 Volume I to have them explained in more detail. The last paragraph contains a worked example.

C302 The Components

1. The different components to be considered when building a WDA outline are listed below according to the time of event.

a. **Shot noise.** The noise created by the launching of the projectile or by the combustion of the rocket booster.

b. **Launch debris.** Some systems, notably rocket artillery, may eject tube covers, fin release devices and sabots used for fitting the projectile into the launcher tube. These will usually be released when passing the launcher/cannon muzzle and will have an unstable and unpredictable flight path. For rocket artillery a significant amount of debris will also be ejected rearwards.

c. **Stabilisation failure.** Some projectiles, notably rockets, will activate their stabilisation devices after launch. If these features fail or are damaged, the projectile may continue along an erratic trajectory. Examples: the MLRS rocket may fail to unfold its fins, or a fin-stabilised bomb - mortar delivered - may loose its tail.

d. **Round-to-round deviation (RTR error).** This deviation that has components both in elevation and azimuth (range and deflection), is composed by the following most relevant components:

(1) aiming inaccuracy
(2) muzzle velocity deviation
(3) tip-off (rockets only)
(4) variations in projectile mass
(5) variations in projectile drag
(6) meteorological variations
(7) fuze inaccuracy
(8) terminal phase deviation

These components are added to get a variance in azimuth (deflection) and a variance in elevation (range).

e. **Mean Point of Impact Deviation (MPI Errors).** These are systematic error components that do not change from round to round within a salvo. The result is a deviation of the mean point of impact from the aiming point. There are several components of which the most important are:

(1) changes in the meteorological conditions

(2) boost phase deviation (rockets)

(3) positional errors

(4) gun wear

(5) propellant temperature deviation

(6) terminal phase deviation

(7) lot-to-lot variations

The different coefficients are added to get a total variance in azimuth (deflection) and a total variance in elevation (range).

f. **Propulsion failure.** For projectiles with auxiliary propulsion the propulsion unit may fail to ignite resulting in a short impact. This applies only to rounds with base burn (base bleed) elements and rocket assisted projectiles (RAP).

g. **Early fuze function.** Due to malfunctioning or by entering an area with heavy precipitation, the fuze system may operate prematurely.

h. **Cargo (payload) dispersion.** The cargo may be ejected from the carrier in different ways, forward, rearward or lateral. This process may also be spread out in time.

i. **Cargo debris.** The ejection of the cargo will also release large pieces of material with an unstable flight path. These may be pieces of the fuze, pieces of the outer warhead shell, the pusher plate, the carrier bottom plate, and support material for the payload.

j. **Fragments (NBSD).** All projectiles containing high explosives will create high-velocity fragments upon detonation. Depending on the shape of the warhead, a few fragments may be heavy and may have an extreme range.

k. **Projectile ricochets.** When the impact angle is shallow and the fuze fails to function, a ricochet may occur. The state of the ground will influence the nature of the ricochet.

l. **Empty carrier impact.** After the release of the cargo, the remaining carrier may continue in a more or less stable flight and impact far beyond the cargo impact area. Empty rocket motor bodies may also show this kind of behaviour.

m. **Empty carrier ricochet.** An empty carrier may by shallow impact with the ground result in a ricochet. The ricochet behaviour may be different from that one belonging to the complete (no-fuze-function) carrier.

n. **Impact at no-fuze-function.** If a time fuze fails to function the impact may take place far beyond the intended target. The impact area of the complete no-fuze-function (malfunctioned) carrier may be different from the impact area of the empty carrier. A NBSD may need to be considered.

C303 Components Versus Payload

1. Table C3.1 on the next page shows which components should be present when constructing a WDA outline depending on what kind of munitions is used.

Components	M & TA HE	M & TA Smoke	M & TA ILL	M & TA Cargo	TA mines	TA SFM	M & TA Inert	TA Inert Cargo	RA Cargo	RA Inert Cargo	RA Mines
Shot noise and sonic boom	X	X	X	X	X	X	X	X	X	X	X
Aiming deviation	X	X	X	X	X	X	X	X	X	X	X
Launch debris									X	X	X
Stabilisation failure	x [1]	x [1]	x [1]	x [1]			x [1]		X	X	X
Impact RTR error	X	X	X	X	X	X	X	X	X	X	X
MPI deviation	X	X	X	X	X	X	X	X	X	X	X
Propulsion failure	X	X	X	X	X	X	X	X			
Early fuze function	X	X	X	X	X	X		X	X	X	X
Cargo dispersion		X	X	X	X	X		X	X	X	X
Premature cargo detonation				X		X			X		X
Fragments	X			X		X			X		
Ricochet	X	X	X	X	X	X	X	X	X	X	X
Empty carrier impact		X	X	X	X	X		X	X	X	X
Empty carrier ricochet		X	X	X	X	X		X	X	X	X
NFF impact		X	X	X	X	X		X	X	X	X
NFF fragments				X		X			X		

Abbreviations

M & TA	Mortar and Tube Artillery	NFF	No-Fuze-Function
TA	Tube Artillery	RTR	Round-to-Round
ILL	Illumination	MPI	Mean Point of Impact
SFM	Sensor Fuzed Munition	RA	Rocket Artillery

1) Mortars only

Table C3.1: Components versus Payload

C304 Data Requirement

1. In order to determine the size and shape of the WDA outline for a particular firing, the following parameters have to be found:

(a)	d (= d_t)	Range to aiming point (FP - PT distance)
(b)	d_{max}	Maximum range possible for this round/charge combination
(c) and	$PE_{x,RTR}$	Probable error (alternatively standard deviations $sd_{x,RTR}$
(d)	$PE_{z,RTR}$	$sd_{z,RTR}$) for round-to-round error in range and deflection
(e) and	$PE_{x,MPI}$	Probable error (alternatively standard deviations $sd_{x,MPI}$
(f)	$PE_{z,MPI}$	$sd_{z,MPI}$) for the mean point of impact in range and deflection
(g)	sb_x	Spread of sub-munitions in range
(h)	sb_z	Spread of sub-munitions in deflection
(i)	d_{PF}	Range in case of propulsion failure
(j)	d_{ei}	Expected position for cargo ejection
(k)	MRR	Maximum ricochet range
(l)	s	Maximum range of fragments (NBSD)
(m)	d_{EC}	Expected point of impact for empty carrier
(n)	d_{NFF}	Position of impact at no fuze function
(o)	w_R	Maximum lateral spread of ricochets
(p)	$PE_{x,EC}$	Probable error (alternatively standard deviation $sd_{x,EC}$) for round-to-round error in range for the empty carrier impact
(q)	$PE_{x,NFF}$	Probable error (alternatively standard deviation $sd_{x,NFF}$) for round-to-round error in range for impact at no fuze function

2. The last two items are needed for munitions with time fuzes because the range probable error may be very different from the normal RTR error in range.

3. Most of the above terms are range dependent. A ballistic calculation of the particular case is necessary to determine the value of the terms.

C305 Representation Of WDA

1. There are several possible ways of representing the components of WDA based on the dimensions of the EBA, the FDA, etc. (see Table C3.2)).

2. A representation made up of ellipses is usually the most correct way, but may be the most difficult to construct. The shape of the RDA will be in addition to these. The approach with modified segments is used in the following paragraph.

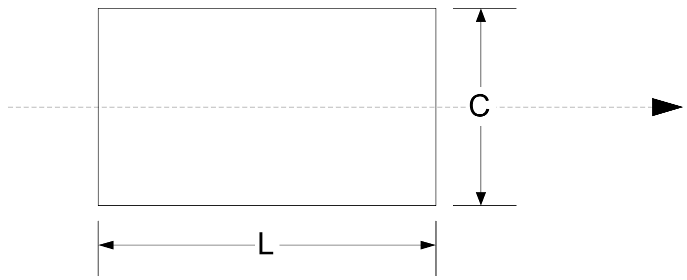
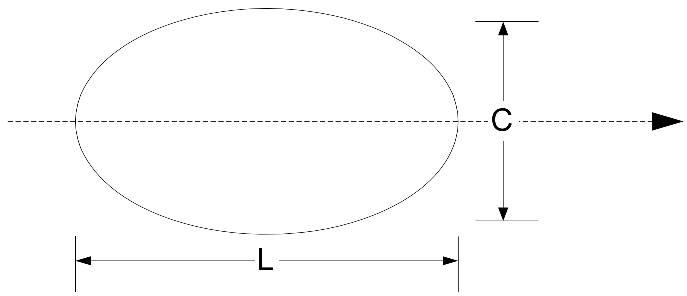
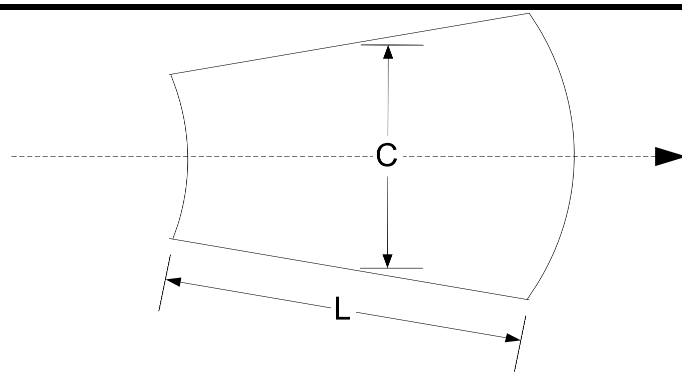
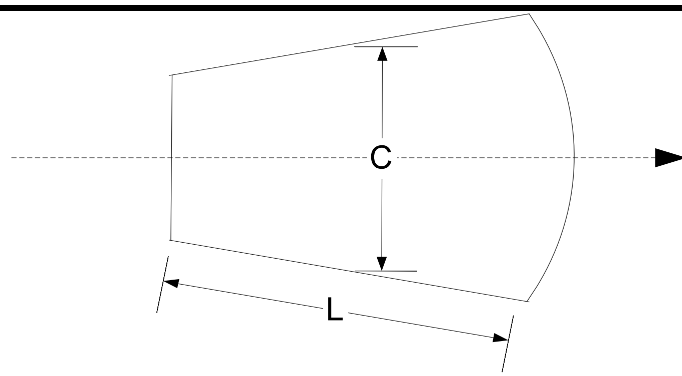
Rectangles	
Ellipses	
Segments	
Modified segments	

Table C3.2: Representation of WDA

C306 Procedure For Constructing The WDA Outlines

1. Pattern. In the following figures, these patterns will be used.

	The gun or the launcher (FP)	------------▶	The intended line of fire
	Error budget area (EBA). (For cargo, the area for mean impact points)		Fragment Danger Area (FDA)
	Cargo dispersion / impact area		Empty carrier EBA
	Ricochet Danger Area (RDA)		No-fuze-function EBA

Table C3.3: Pattern for WDA Outlines

2. The specific WDA outlines referring to the components are below. In the following examples, factors and WDA specific angles and other numbers are presented with real numbers which may differ from national specifications.

a. **Shot noise and overpressure.** Areas centred at the muzzle of the weapon accounting for meteorological conditions.

b. **Launch debris.** Two fans extending forward and backward around the intended line of fire: Applies to rocket artillery or to selected 155mm artillery (e.g. *Excalibur*).

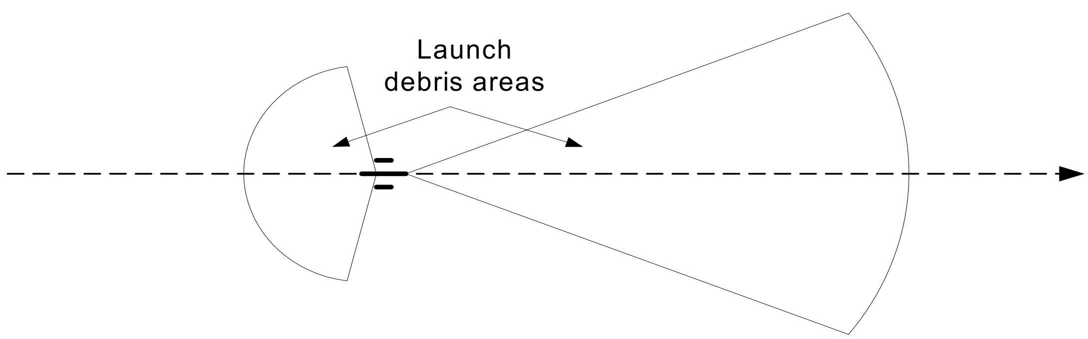


Figure C3.1: Specific WDA Outline for Launch Debris

c. **Stabilisation failure.** This area is intended to contain the hazards created if there is a stabilisation failure. It is a fan extending from the muzzle with a half angle of δ (mils) and a radius of U (m).
Example: For MLRS, U = 12500 m and δ = 1000 mils (56.3°).

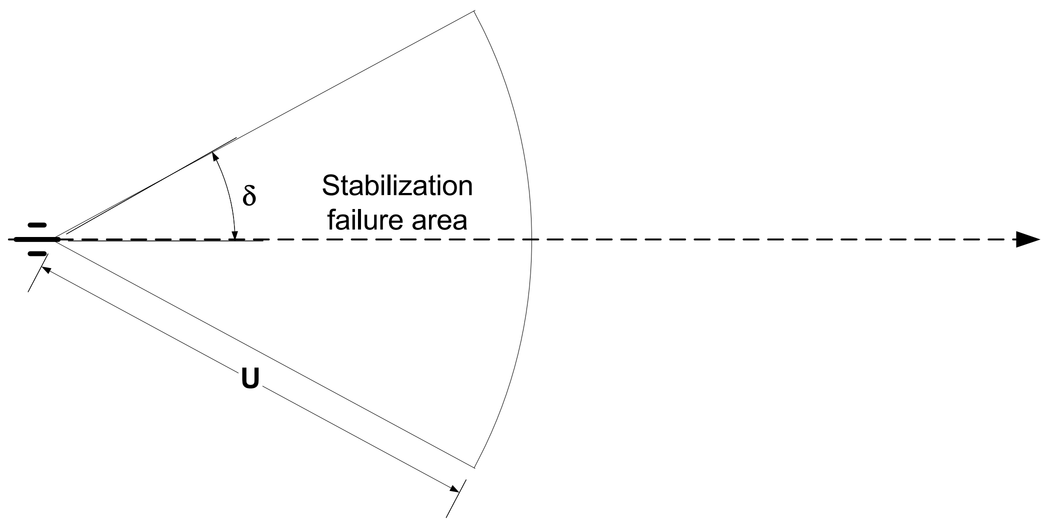


Figure C3.2: WDA Outline for Stabilization Failure

d. **The round-to-round deviation.** The probable error in range and deflection are usually found in the firing tables. Otherwise the following values may be used to calculate range dependent PE values:

(1) The lateral deflection (z axis) to each side is

Mortars	2 mils
Tube artillery	1 mil
Rocket artillery	3 mils

(2) The range spread (x axis) forward or backward from the mean point of impact is

Mortars	$0.04d_t \tan(IA)$
Tube artillery	$0.02d_t \tan(IA)$
Rocket artillery	$0.05d_t \tan(IA)$,

where IA is the angle of fall at impact.

e. **The mean point of impact (MPI) deviation.** This calculation may be complex, taking into consideration the age and quality of the available meteorological data in addition to several munition parameters. Normally, the MPI deviation is of the same order of magnitude as the round-to-round deviation. It may be reduced if information from preceding shots is taken into account.

f. **The error budget area (EBA).** The Error Budget will be presented by PE data and corresponding m values (see Chapter 3 (0302.4, 5) and Appendix E1), using RTR and MPI components. The EBA is given by a modified segment centred at the aiming point and with a length of

(1) $$L = 2m\sqrt{PE_{x,RTR}^2 + PE_{x,MPI}^2}$$

and a width of

(2) $$C = 2m\sqrt{PE_{z,RTR}^2 + PE_{z,MPI}^2}$$

The measure C is related to the centre of EBA.

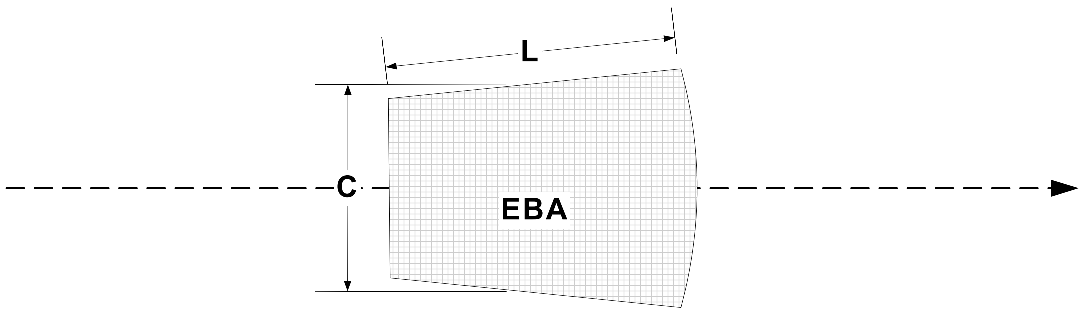


Figure C3.3: A WDA Outline for the EBA

g. **Early fuze function.** If there is any danger for early fuze function, the possible impact area is a fan extending from the muzzle with a half angle of

(3) $$\tan\alpha = \frac{m\sqrt{PE_{z,RTR}^2 + PE_{z,MPI}^2}}{d}$$

and with a length of

(4) $$D = d + m\sqrt{PE_{x,RTR}^2 + PE_{x,MPI}^2}$$

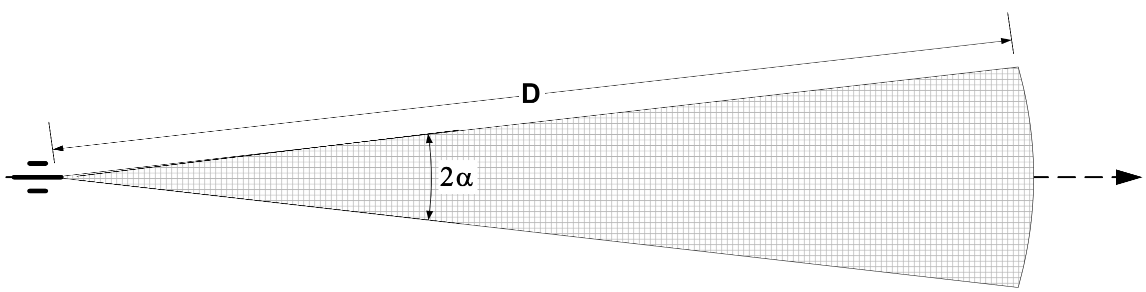


Figure C3.4: Possible Impact Area for early Fuze Function

Early fuze function applies to projectiles with mechanical time (MT) fuze, proximity fuze or any non-qualified fuze (fuze in an experimental phase). The event will lead to a premature warhead fragmentation or a premature cargo ejection. The fan-shaped area spanning the EBA is then a part of the WDA. If the carrier ejects fragments or sub-munitions in the event of fuze function a cargo dispersion area (sub-paragraph i below) and a fragment danger area (sub-paragraph j below) must be added accordingly.

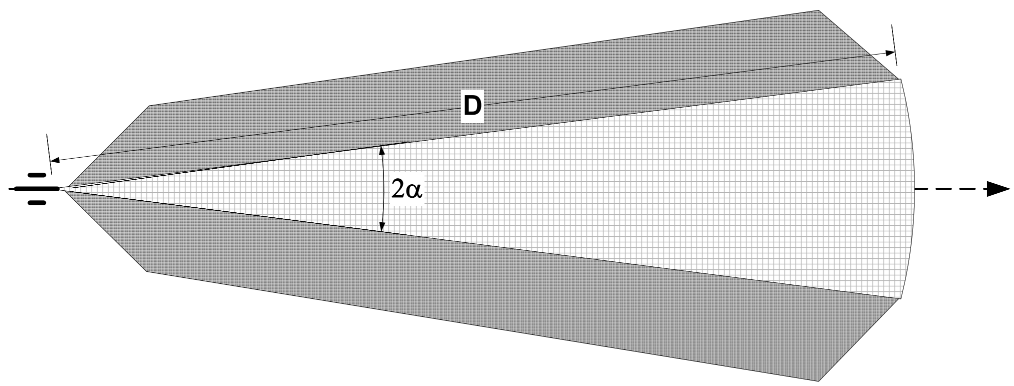


Figure C3.5: WDA Outline for early Fuze Function

h. **Failure in rocket assistance or base burn.** If there is a significant chance for propulsion failure, a WDA should be made for this case along the same principles as any other projectile. The danger area in case of propulsion failure could be of the same shape as for normal functioning, but with the dimensions scaled by the factor d_{PF}/d_t. Propulsion failure does not have to be considered if premature fuze functioning is a danger. Any intermediate area between the two EBA with and without propulsion failure should also be a part of the WDA.

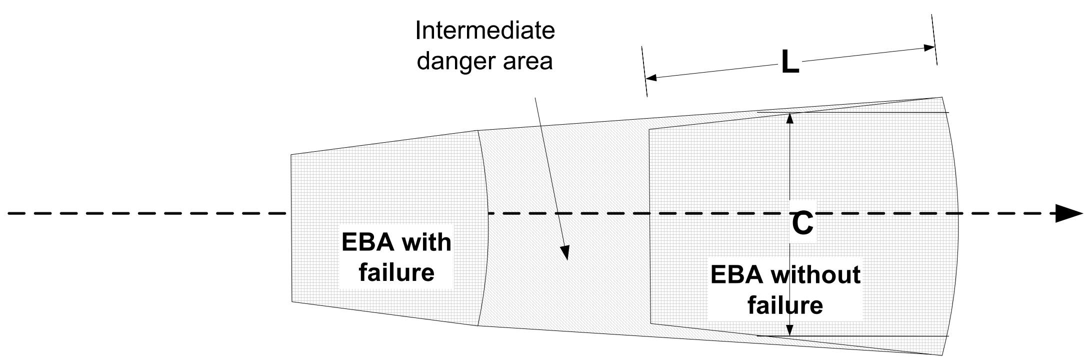


Figure C3.6: WDA Outline for Failure of Rocket Assistance or Base Burn

i. **Cargo dispersion area (impact area).** The extent of the dispersion is determined by the ejection process. The danger area should be determined by calculating the maximum dispersion in range and deflection multiplied by a safety factor. The extent of dispersion, given by sb_x and sb_z, may be found in the firing tables. They are added to the EBA.

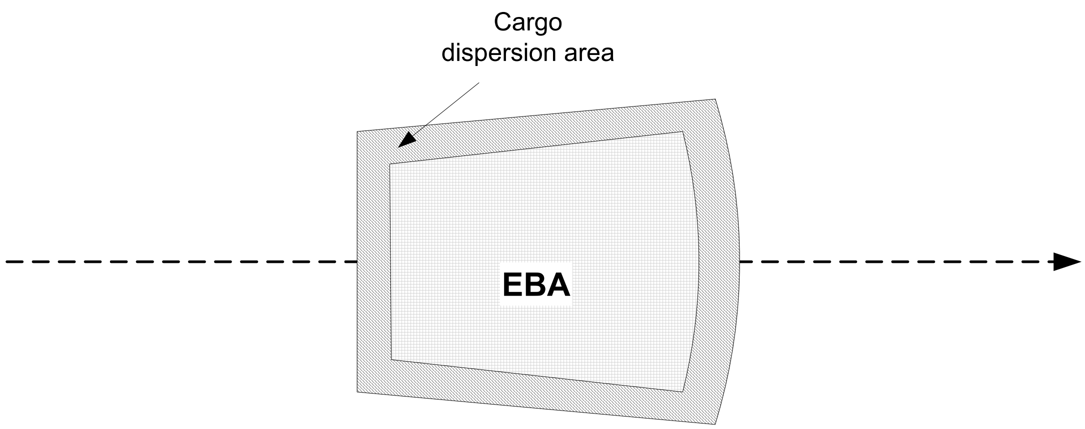


Figure C3.7: WDA Outline for Cargo Dispersion

For non-cargo warheads the EBA and the impact area are equivalent.

j. **Fragment Danger Area (FDA).** Fragment generating warheads will spread fragments in all directions around the impact point. In addition, sensor fuzed munition may eject a heavy, high velocity fragment (projectile-like) being capable of flying up to 4000 m.

The fragment radius should be added to the impact area at all sides and will appear as a rounded rectangle:

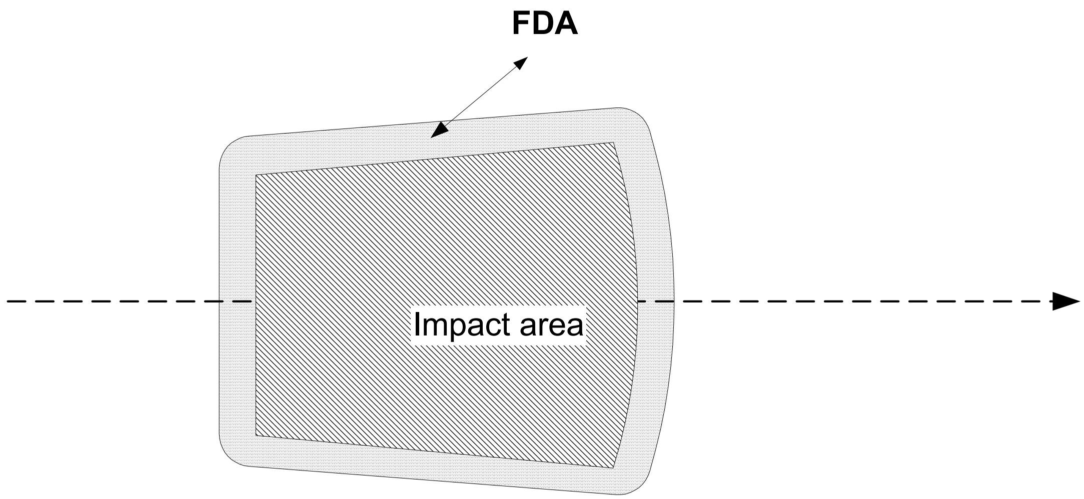


Figure C3.8: Fragment Danger Area around the Impact Area

k. **No-fuze-function impact.** This covers the area around the expected point of impact for no-fuze-function. The width of the area is

(6) $$C_{NFF} = 2m \frac{d_{NFF}}{d} \sqrt{PE_{z,RTR}^2 + PE_{z,MPI}^2},$$

and the length is

(7) $$L_{NFF} = 2m \sqrt{PE_{x,NFF}^2 + PE_{x,MPI}^2}$$

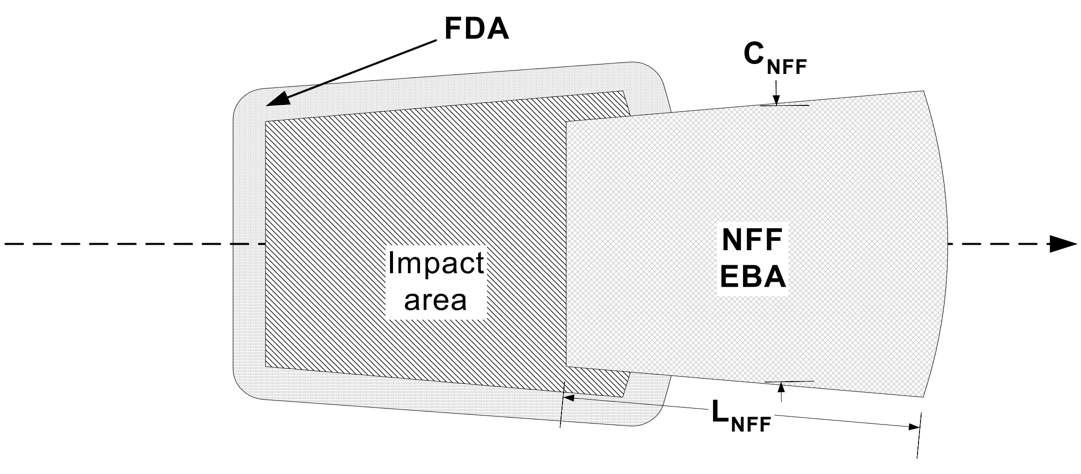


Figure C3.9: WDA Outline for No-Fuze-Function Impact

l. **No-fuze-function fragmentation.** The NFF fragmentation area has a distance *s* in all directions from the possible no-fuze-function area.

m. **The Ricochet Danger Area (RDA).** This area extends from the near corners of the possible impact area for no-fuze-function and to a distance beyond the far corners. This distance should be determined according to Chapter 4. The width of the area is found by adding an angle β (e.g. 800 mils (45°)) to each side (Figure C3.10), but limited laterally by w_R as shown in Chapter 8 (0803). The distance from the gun to the far end of RDA is MRR.

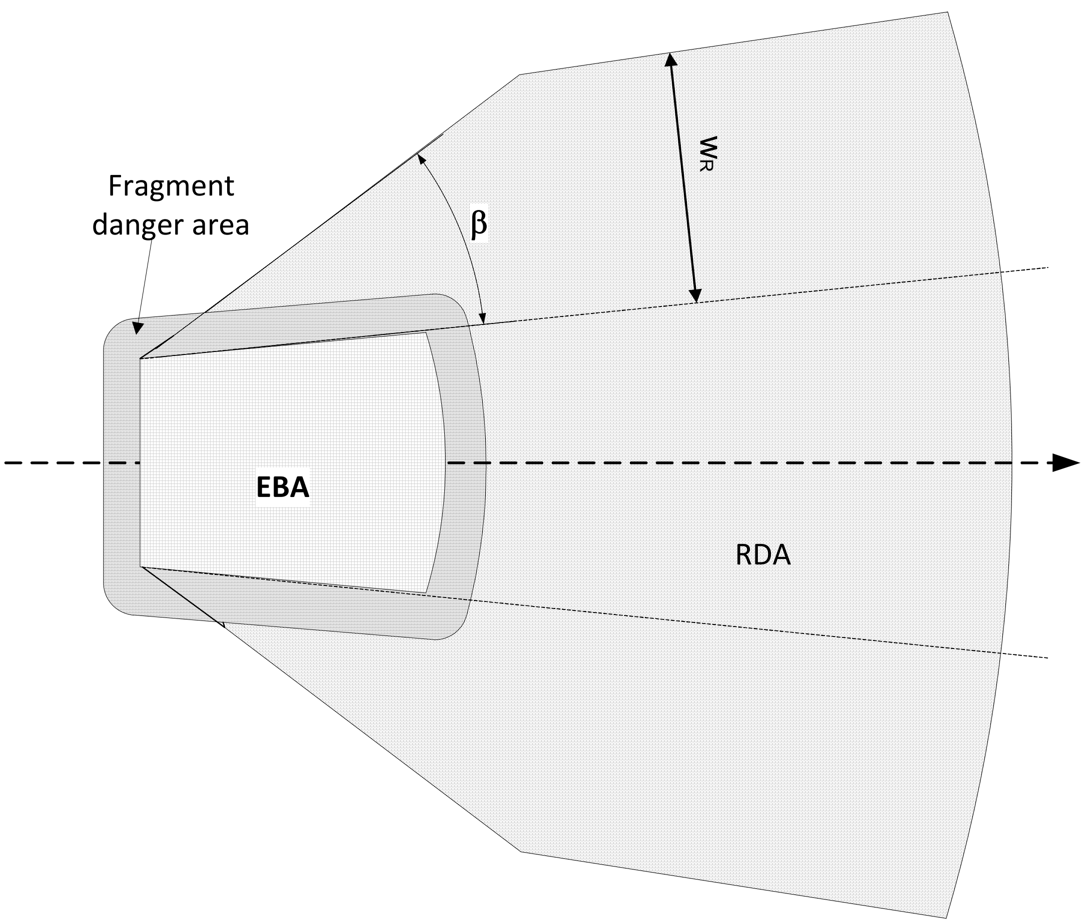


Figure C3.10: Ricochet Danger Area

n. **Empty carrier.** Assuming a stable flight, the impact point for an empty carrier may be calculated. High spinning open tube carrier may get an extra aerodynamic lift bringing them beyond this point. It is recommended to multiply the calculated additional distance by a number greater than one. The width of the area is

(8) $$C_{EC} = 2m\frac{d_{EC}}{d}\sqrt{PE_{z,RTR}^2 + PE_{z,MPI}^2}$$

and the length is

(9) $$L_{EC} = 2m\sqrt{PE_{x,EC}^2 + PE_{x,MPI}^2}$$

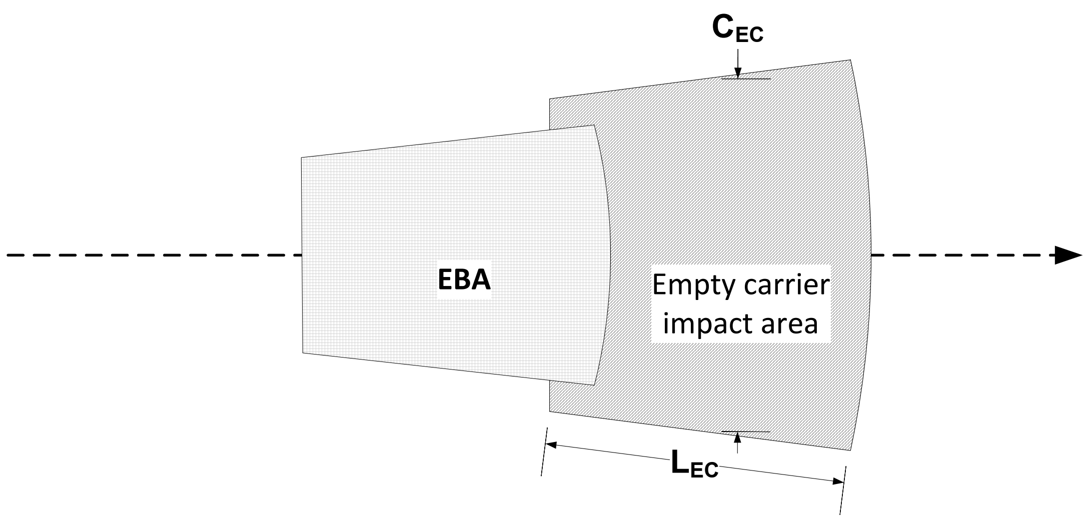


Figure C3.11: WDA Outline for the empty Carrier Impact

o. **Empty carrier ricochet and RDA.** This area extends from the near corners of the possible empty carrier impact area to a distance beyond the far corners that is determined according to Chapter 4. The RDA for the empty carrier is determined in the same way as for the complete round above. The distance from the gun to the far end of the empty carrier RDA is normally MRR of the full round, but may be modified based on the ballistic behaviour of the empty carrier.

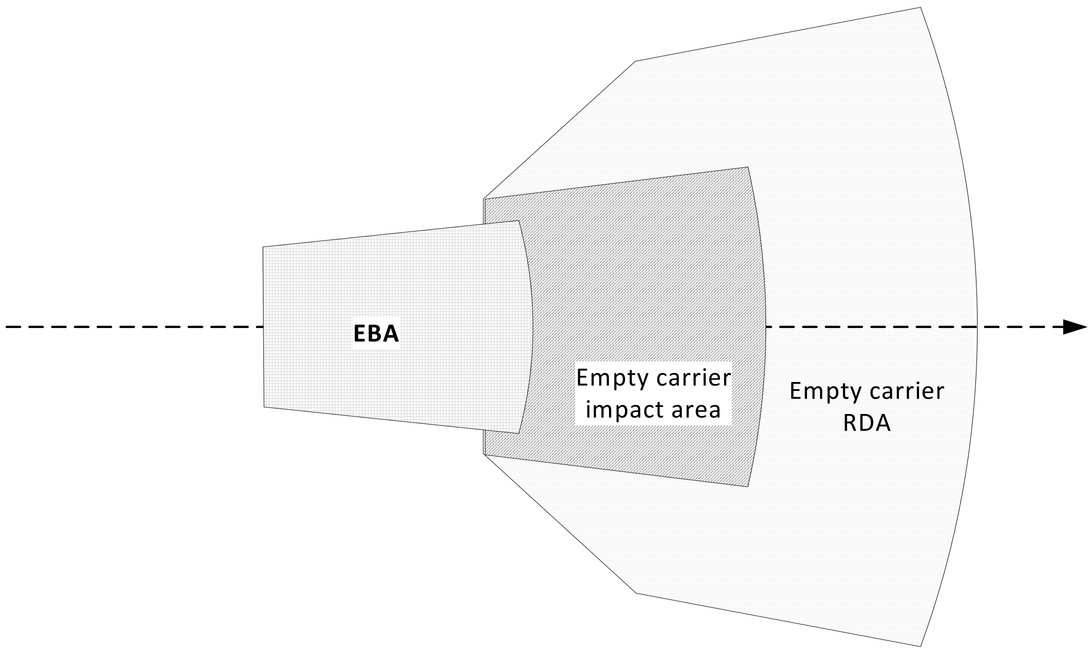


Figure C3.12: WDA Outline for the empty Carrier Impact and RDA

C307 A Worked Example

1. Consider the firing of a 155 mm cargo bomblet munition. The round is not supposed to have any propulsion assistance. The following data (see Table C3.4 and Figure C3.13) as required in paragraph C304 are available.

d	13500 m	d_{ei}	13070 m
d_{max}	19050 m	MRR	16900 m
$PE_{x,RTR}$	31 m	s (NBSD)	120 m
$PE_{z,RTR}$	12 m	d_{EC}	13960 m
$PE_{x,MPI}$	45 m	d_{NFF}	13870 m
$PE_{z,MPI}$	26 m	$PE_{x,EC}$	60 m
sb_x	110 m	$PE_{x,NFF}$	55 m
sb_z	90 m		

Table C3.4: Data Set for the Example

2. Any danger for premature fuze functioning will not be considered here. Nor will shot noise be considered.

3. According to equations (1) and (2), using m = 8, the dimensions of the error budget area is L = 874 m, C = 458 m. The angle α thus becomes (458/2)/13.5 = 17 mils.

4. Thus the EBA will start at 13500 - 874/2 = 13063 m from the gun and end at 13500 + 874/2 = 13937 m from the gun, and has a width of 229 m to both sides of the intended line of fire.

5 The cargo dispersion area will extend 110 m outside the EBA in the x-direction and 90 m outside EBA in the z-direction. The area for cargo dispersion area is 874 + 2 • 110 = 1094 m in length and 458 + 2 • 90 = 638 m in width.

6. Adding the fragment danger range *s* to all sides of cargo dispersion area, the size of the FDA will be 1334 • 878 m.

7. Considering no-fuze-function using equations (6) and (7) the impact area will be 1010 m long and 471 m wide. It will extend from 13365 m to 14375 m from FP.

8. Using equations (8) and (9) the impact area for the empty carrier is found to be 1200 m in length and 474 m in width starting 13360 m from the FP.

9. Considering empty carrier ricochet, the ricochet danger area will start at the near part of the empty carrier impact area and extend to MRR.

10. Assuming a hard surface, the lateral spread of the ricochet is found to be (16900 – 13500)/4 = 850 m. This distance is added outside the lines originating at FP and touching EBA.

11. The ricochet deflection angle is taken as 45º relative to the EBA limiting lines. These RDA border lines are tangents to the empty carrier impact area.

12. The following figure shows the components mentioned in this example disregarding the no-fuze-function impact area which becomes more or less covered by the empty carrier impact area. An elliptical representation of the impact areas is used.

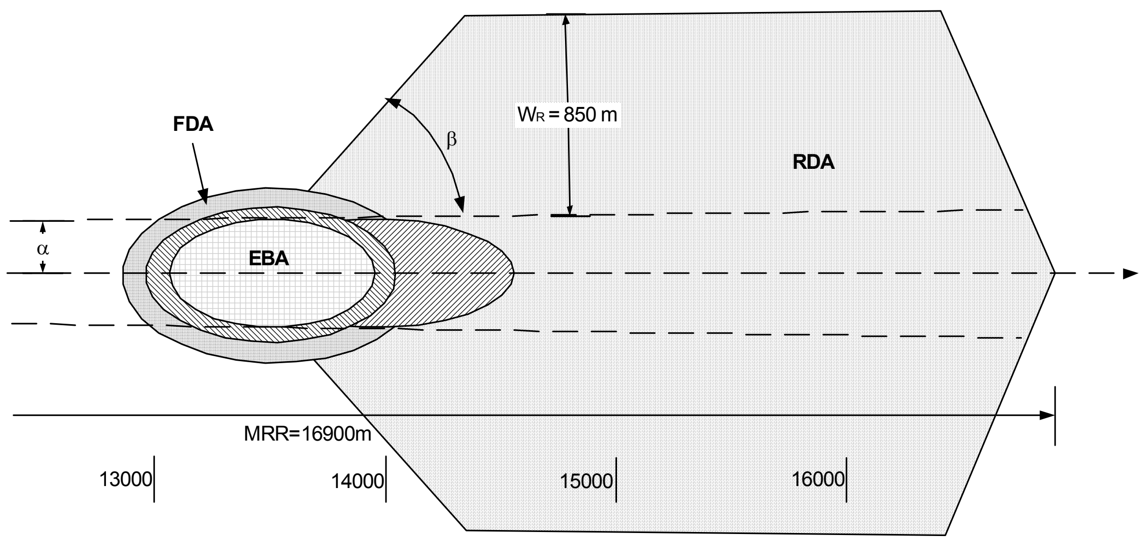


Figure C3.13: Example of considered Components for ICM Projectiles

ANNEX D

WDA Outlines For Ground-To-Air and Air-To-Ground Weapons

D001 Introduction

1. This Annex is divided into Appendices D1 and D2 for calculation of WDA related to two different aspects of engaging targets:

   a. From ground to air (engaging aerial targets with earthbound weapon systems) in Appendix D1.

   b. From air to ground (engaging earthbound targets from weapon systems on elevated moving platforms – excluding bombs and parachute systems). From the variety of elevated weapon platforms in Appendix D2 rotary wing - aircrafts are selected firing unguided small and medium calibre munition.

2. In both Appendices of this Annex adapted and modified WDA outlines from the Annexes A and B are used.

3. WDA/Z for firings air-to-air (air combat) will not be considered.

APPENDIX 1

WDA Outlines For Ground-To-Air Weapons

D101 Introduction

1. This Appendix covers WDA outlines for air defence weapons engaging aerial targets. Those weapons can also be used in a ground support role for which the results of Annexes A and B are applicable.

D102 Assumptions For A WDA Outline

1. The WDA for employing aerial targets is fundamentally the WDA for engaging earth-bound targets of Annexes A and B, because of the possibility of employing aerial targets of low height. For firing also at targets of high altitude in accordance with high QE the WDA is to be enlarged under the following aspects.

a. The extended range and deflection of a projectile fired with high QE is significant for strong wind. The range and lateral dimensions of the WDA outline may be calculated by simulation of first trajectories with wind (according to SMC) coming from tail to head (a step size of 15° is sufficient). The lateral deviation should include spin deviation if spin stabilised projectiles are used (see Appendix E2). For the length of the EB Fan this procedure directly results in the maximum range (with met conditions (see Annexes A and B)).

b. The additional area to cover the lateral deviations from the outermost line of the EB Fan may be covered by an additional area Wind Influence Area (WIA), which is designed similar to FDA. The width w_d results from the simulation as well as the opening angle β_d. An example is given with Figure D1.1.

c. The air danger height h (which defines the WDZ) depends on the maximum allowed QE (for example 70°), and the value of h is the height of the vertex for the trajectory of that greatest QE. A possible fragmentation radius of the normal burst safety distance (NBSD) has to be added to that vertex.

d. Fragmentation may occur when the projectile hits the aerial target. Also, a self-destruction or command distraction mechanism may detonate the projectile on its trajectory. These effects normally occur during the first third of the flight of the projectile, thus a specific FDA is not required.

e. In case of strong head winds and high angle fire the firing position may be endangered by backward travelling fragments or sabots.

f. An aerial target is a moving target. Thus, the aiming error may be enlarged, which leads to a higher half opening angle α (a minimum of 4° is recommended) of the EB fan. For engaging aerial targets of low height ricochets may occur. The ricochet length is contained in the maximum range. Low angle fire is less sensitive to met influence, thus the lateral ricochet spread may be already covered by the area WIA (see b.)

g. For firing at aerial targets specific safety measures are to be applied (e.g. regarding the servicing personnel, the towing aircraft), which are laid down in national safety regulations.

D103 Developing The WDA Outline

1. In Figure D1.1 an example of a simulation result of the lateral spread and maximum range of a 12.7 mm calibre projectile is shown. The line starting at the origin reflects the angle β_d (in this example 25°). The outer line of the EB fan is the plot-axis in direction of line of fire. For each wind direction the ground impacts related to the selection of elevations are connected by a polygon. A 60° downrange closure is indicated. In addition, the lateral spread contains the spin deviation.

2. In Figure D1.2 a typical WDA outline for air defence weapons is demonstrated. The outline length l is the maximum range (including met). The RDA and FDA may not be needed because of the statements made in section D102 (those areas should be covered by the WIA).

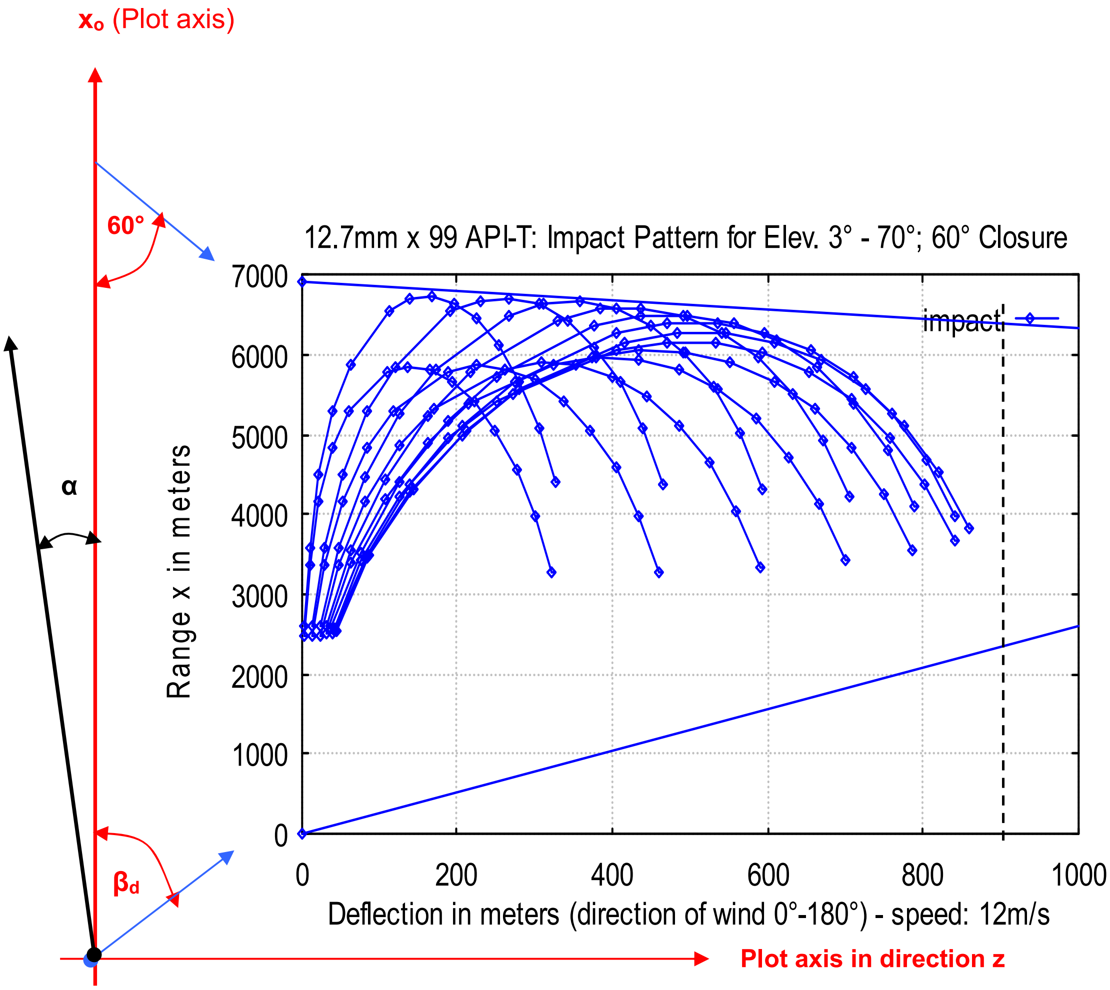


Figure D1.1: Impact Pattern due to Wind (and Spin) Influence of all Directions from 0° to 180°

Wind direction in steps of 15°,
Elevations are: 3°, 6°, 10°, 15°, 20°, 30°, 35°, 40°, 45°, 50°, 55°, 60°, 65°, 70°
Height of muzzle = height of impact; the resulting width w_d is about 900 m.

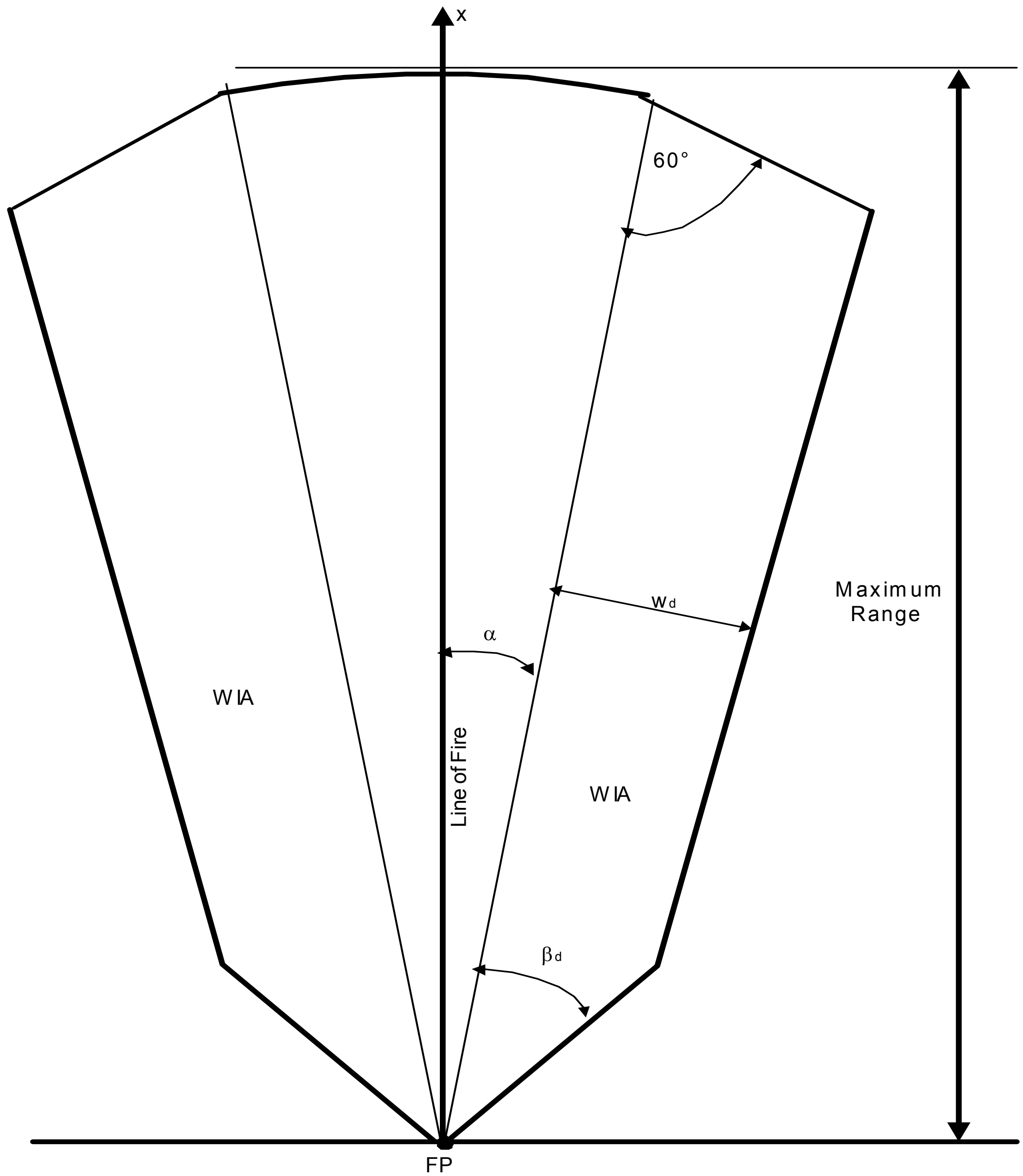


Figure D1.2: WDA Outline for Firing against Aerial Targets

APPENDIX 2

WDA Outlines For Air-To-Ground Weapons

D201 Introduction

1. Fixed or rotary wings aircraft mounted weapons (firing from elevated platforms) will be considered, generally, in a different way than for earthbound weapons because of abnormal ricochet behaviour (lateral and in height) which was observed by test firings.

a. It will be shown that the Maximum Ricochet Range may not be unique under certain circumstances. In the following WDA for rotary wings (helicopters) will be considered in this way without loss of generality.
b. In this context firing from elevated platforms or on descending areas (hilly areas) the WDA outline length, which is calculated for flat ranges, is to be enlarged in a way as shown.
c. The way of establishing the error budget in range, deflection (and height) is sketched.

D202 The Error Budget

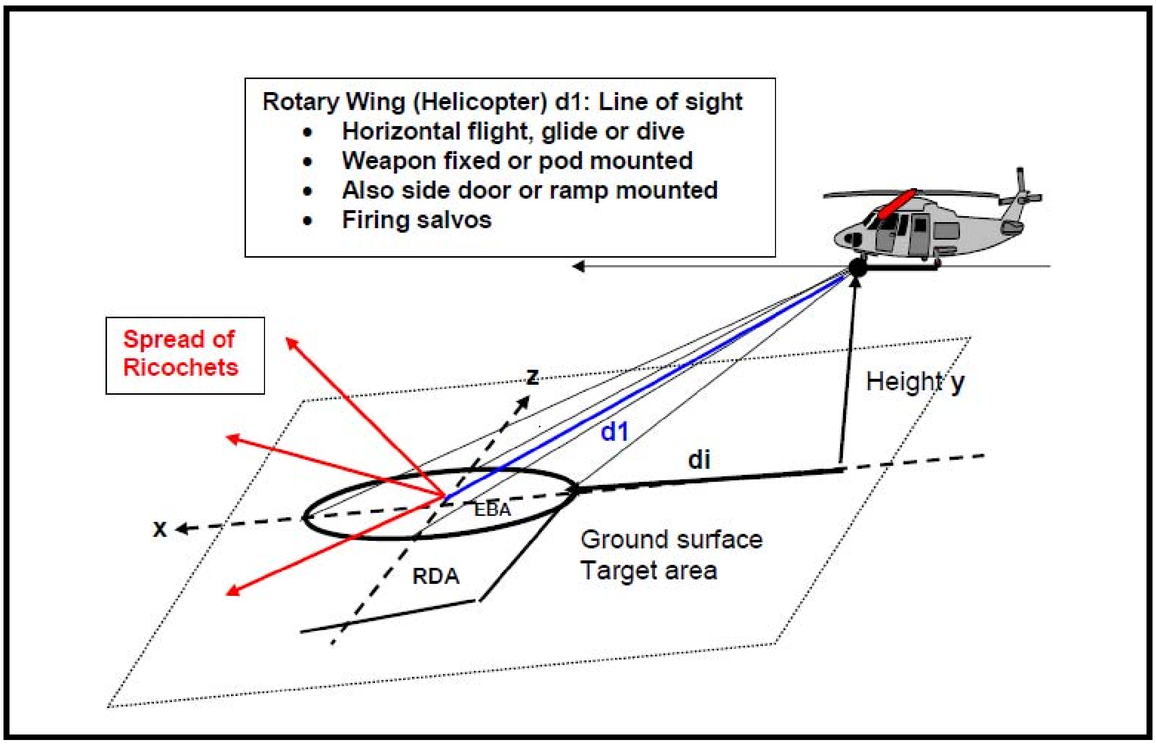


Figure D2.1: Firing salvos from a helicopter and coordinate system

1. For a helicopter in a hovering position the total errors around PT are greater than for a helicopter in flight (stabilised by gyroscopic effects). Depending on the stability of the mount the joint errors are bigger for the elevation (variation of range) than for the azimuth (variation of deflection), which results in an elliptical shaped cone of fire (see cone of fire in Chapter 7 (0702.2)) with different EB angles for range and deflection representing sd_x and

sd_z respectively. The value of the EB angle in range influences the overall length of the WDA outline.

D203 The Maximum Ricochet Ranges For Elevated Platforms (Helicopters)

1. The following graphic shows easily that the Maximum Ricochet Range (MRR) is not unique when firing from elevated platforms to the ground level. Two options for direct fire are possible: attacking with steep angle (trajectory C1) or with lower angle (trajectory C2). Normally the first one will be used because of limited firing distances d1 (e.g. less 2500m). The problem is that in some cases two MRR exist which makes it difficult to find a similar formula as given in Chapter 7 (0706). Besides ground levels other ones lower than the elevated platform are possible but will not be considered.

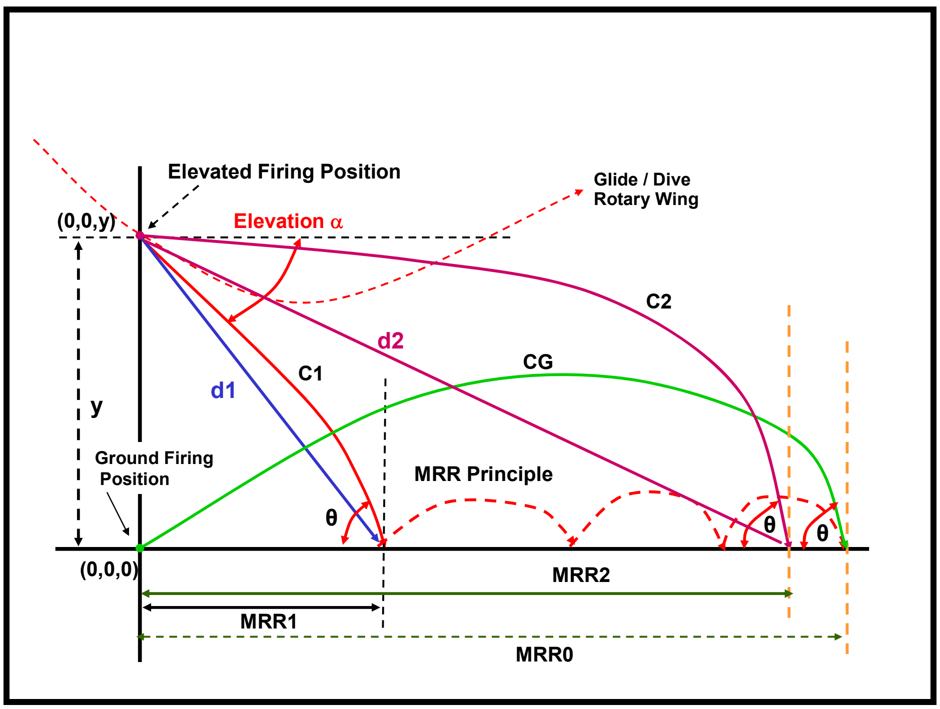


Figure D2.2: The situation for two MRR values

2. Shown in the graphic of Figure D2.2 are three trajectories having the same impact angle ϴ but different QE (= α). Let the angle ϴ be the critical impact angle (IA_{crit}) of Chapter 4, 0402.2. Then the ground-to-ground trajectory CG represents the MRR (= MRR0) as described in ARSP-1 Vol. I, Chapter 3. Firing from an elevated platform may deliver two trajectories C1 and C2 with IA_{crit} = ϴ in consequence two MRR values (MRR1 and MRR2) exist in the sense of ARSP-1 Vol. I. However, depending on the height y either both values may have a significant differing distance or they converge to one value which is a continuous process. Is this limit known for a specific height yc then for y > yc all impact angles will be bigger then ϴ which is obvious. Thus, two maximum ricochet ranges (MRR1 and MRR2) are possible when considering the ground level.

3. Let the height y be fixed. For each of MRR1 or MRR2 there are alternative MRR which are just the line-of-sights (d1 [MRR1(y)] and d2 [MRR2(y)) to the ground targets. It is MRRi (y) = SQRT ($[MRRi]^2 + y^2$), i = 1, 2. In the following Table D2.1the value MRR2(y) is

listed and it is seen that MRR2(y) is always smaller than MRR0. Partly d1 = MRR1(y) is also listed.

4. In this context see as an example Table D2.1 which shows this convergence for a set of fixed parameters. The critical angel Θ is 30°, the weapon is the 27 mm gun with training ammunition. The weather condition is a ballistic wind of 15 m/s speed and a 100 hPa reduction to ICAO. The trajectories are calculated by a simple point mass model. The height of the platform varies from 0.0 Meter (ground level) up to height yc, where the convergence happens. The following table shows values for this set of parameters.

0504	**Trajectory C1; IA_{crit} = 30°**			**Trajectory C2; with IA_{crit} = 30°**		
0505 *y*	**MRR1**	**QE_{crit}**	**MRR1(y)**	**MRR2**	**QE_{crit}**	**MRR2(y)**
0506 *m*	**m**	**Degree**	**m**	**m**	**Degree**	**m**
0.0 *)	0	-	**0**	***7335 *)***	+11.8	**7335**
10	17	*-30*	-	7335	+11.72	7335
25	43	*-30*	-	7333	+11.55	7333
50	87	*-30*	-	7332	+11.29	7332
100	173	*-30*	**200**	7326	+10.75	7327
200	346	*-30*	**400**	7317	+9.7	7320
400	696	-29.785	**918**	7269	+7.5	7280
600	1048	-29.62	**1207**	7203	+5.25	7228
800	1406	-29.39	**1618**	7112	+2.93	7157
1000	1771	-29.09	**2033**	6993	+0.51	7064
1220	2190	-28.62	**2507**	6818	-2.32	**6926**
1250**)	2248	-28.55	**> 2500**	6791	-2.72	6905
1500	2771	-27.65	-	6502	- 6.35	6673
1750	3431	-25.8	-	6051	-10.8	6299
1950	4427	-21.465	-	5246	-16.8	5597
1970	4774	-19.8	-	4946	-18.7	5324
1971	4798	-19.5	-	4900	-18.9	5282
1971.32	4843	-19.245	-	4855	-19.18	5240
1971.325	**4849**	**-19.21**	**-**	**4849**	**-19.21**	**5234**

*) This is the ground firing MRR according to ARSP-1 Vol. 1 Chapter 3 related to the given fixed set of parameters: MRR0 = MRR = 7335m with IAcrit = 30° and QEcrit = 11.8°. At ground level trajectories C1 and C2 are identical resp. trajectory C1 makes no sense.

**) The data for heights > 1250m are of theoretical nature but needed for understanding the problem. For firing from fixed or rotary wings the first trajectory and the line of sight d1 is relevant. In the example d1 is to be less than 2500m (therefore the red line in the above table).

Table D2.1: Example for the variety of MRR values
(firing from elevated platforms)

D204 The WDA Outline For Firing From Elevated Platforms

1. Even if munition is fired from elevated platforms the corresponding WDA is located on the ground level. To find a convenient solution for the WDA dimensions in length and width is in the deterministic case rather impossible except for worst case assumptions. In consequence probabilistic methods are recommended.

2. It was shown by a high number of test firings that firing salvos from elevated platforms produce uncontrollable ricochets (see photo below). This effect may be caused by the fact that ground based targets are attacked by projectiles having high velocity (the platform may also be moving) and a steep impact angle. This leads obviously to high range ricochets also to the left and the right with high azimuth angles up to 75°. This effect is known for small and medium calibre projectiles (e.g. 12.7 mm and 27 mm) – a series of incidents are known where ricochets left the WDA or damaged the own air craft or even friendly fire was observed. However, to go further into detail is beyond this ARSP-1.

Figure D2.3: Live firing with salvos at night from a hovering helicopter

a. This live firing was preformed with 12.7 mm tracer ammunition (burning rate 4.7 s) at a sand target with impact angle > 20°. Despite of spinning projectiles ricochets occur to the left and right side with high range.

3. The WDA Outline. It is standard for firing air-to-ground to start the WDA at the planned point of impact. Taking into account the error budget the WDA will be shaped as in Figure D2.1 sketched. For HE projectiles a fragment danger area around the rectangle (or ellipse) is to be added (fragment radius s).

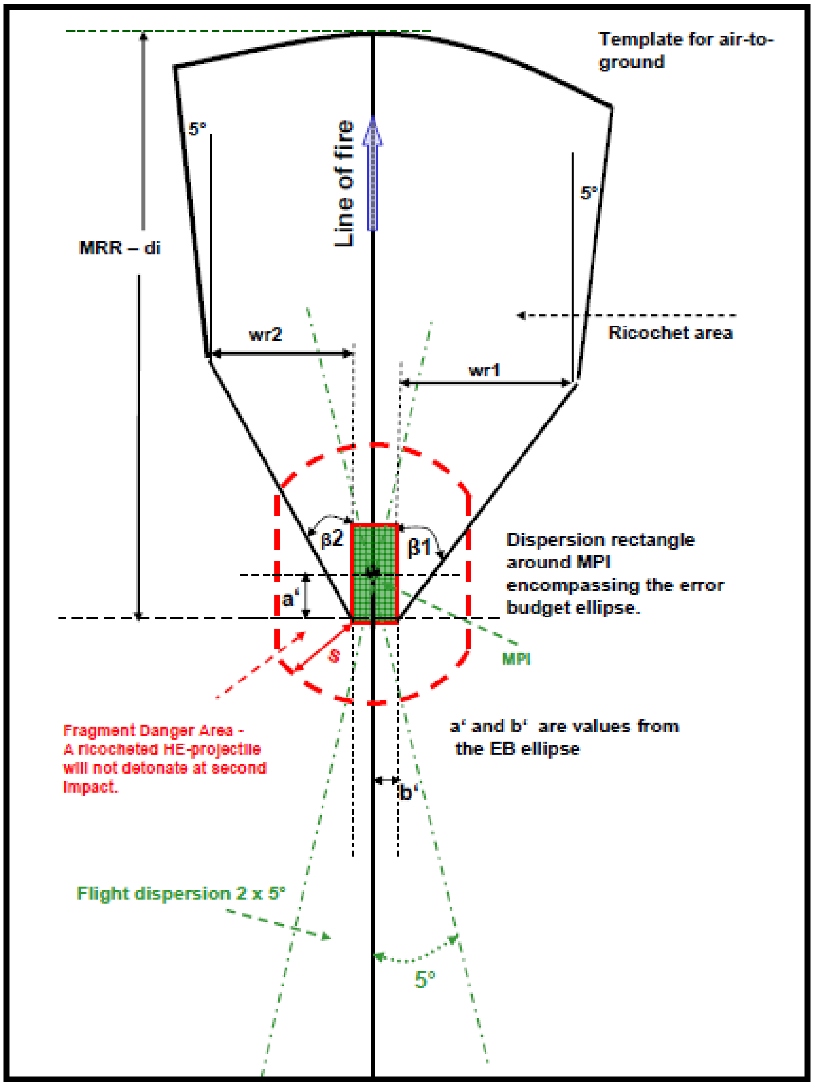


Figure D2.4: Example for a WDA template for firing from elevated moving platforms

a. The WDA length MRR - di. For the scope of this ARSP-1 Volume it is recommend using simply the corresponding formulas of Chapter 4: MRR - di – for di see Figure D2.1. Thus, the value of MRR may be taken as the “ground value” (MRR0) which would lead in some cases to an overrated but conservative WDA length. Another option may be to use the height depend MRR2(y) calculated as in Table D2.1. Taking the MRR1 can lead to WDA length which may be to short in comparison with test results (not shown here), efficient solutions are not possible.

Let **lm(y)** be the maximum range of the projectile for height y and ground level impact then lm(y) - di is a more conservative choice for MRR - di – see paragraph D205 for a quick calculation of lm(y).

b. The WDA opening angles and width. To cater for expected high range ricochets with high azimuth the opening angles of the WDA outline should be much greater (e.g. doubled) than for the ammunition fired ground-to-ground. In addition, taking into count observation results and known incidents with ricochets the opening angle β1 (ricochets to the right) should be bigger than β2 (ricochets to the left), in the same way the width wr1 should be bigger than wr2 for right spinning projectiles (vice versa for left spinning projectiles).

Example: To get a feeling for numbers test results of 12.7mm tracer lead to the following WDA data: β1 = β2 = 75° and wr1 = wr2 = 1400m.

c. Due to experience from live firings (high angle ricochets remaining over 8s above the target) it is recommend to take the maximum possible ordinate for the WDZ height, which means the height of the projectile fired perpendicular into the air (may be overrated but conservative).

d. In a convenient way the extra additions for HE- projectiles have to be done if needed (see Figure D2.4).

D205 The Effect Of Elevated Platforms On The WDA Length

1. In the following it is shown how a given WDA outline length is to be enlarged if the firing platform is located above the surface. This is illustrated for helicopters in a stationary position (without error budget) and positive QE as an example. The shown method is also applicable when firing downhill

a. As the helicopter gains altitude the maximum range $\mathbf{l_m}$ will increase as illustrated in Figure D2.5. The angle of descent at the target PT will always be greater than the equivalent ground mounted engagement. This is a function of the difference in altitude of the firing point.

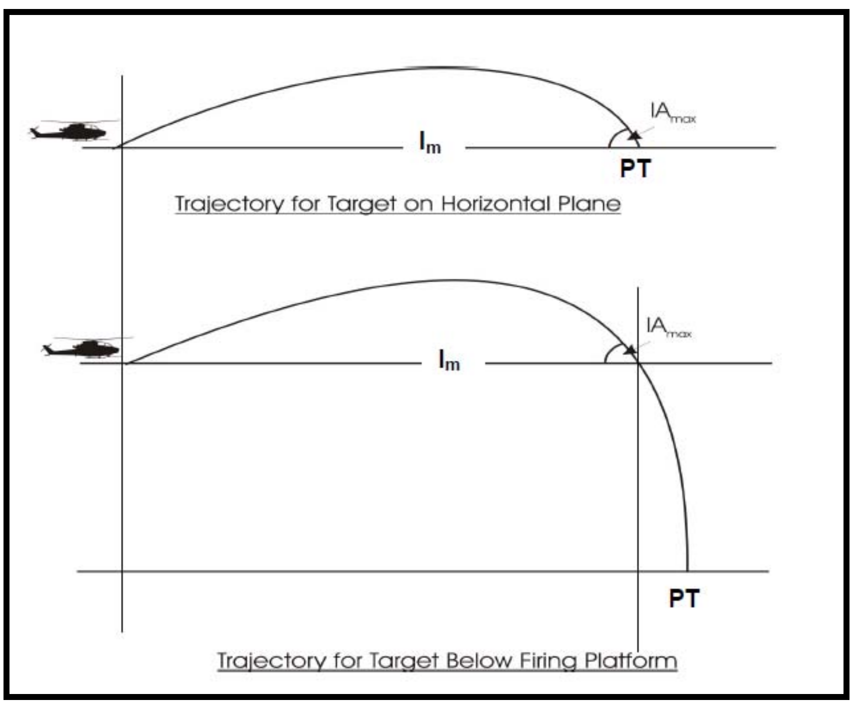
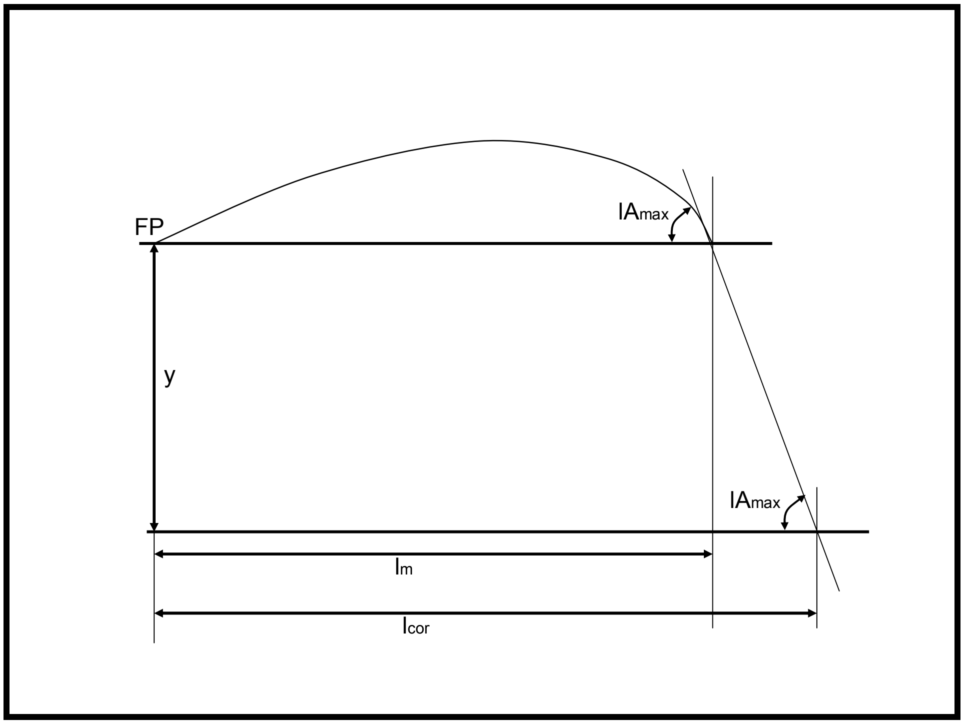


Figure D2.5: Change of the Trajectory Length with increased Altitude

b. A simple calculation of the maximum range for elevated platforms is given with the following considerations. The distance to be added to the normal WDA outline length will depend on the altitude of the firing aircraft. The extension can be calculated by applying the IA_{max} on the horizontal plane to the aircraft, as if it were on the ground and deducing the difference in range if the trajectory were consistent at that angle until it strikes the ground. The corrected maximum range is called l_{cor} and is illustrated in Figure D2.6.



l_m Maximum range at ground level
IA_{max} Impact angle at l_m
y Difference in altitude between the ground and firing platform
l_{cor} WDA length at firing altitude for a ground target

Figure D2.6: Producing corrected maximum Range (l_{cor})

c. The new maximum range l_{cor} can be calculated as follows:

$$l_{cor} = l_m + y / \tan IA_{max}$$

d. If a QE restriction ⩽ QE_{crit} (at ground level) can be applied, such that an MRR can be achieved, then l_m and IA_{max} can be replaced by MRR and IA_{crit} respectively.

l_{cor} = MRR + y /

ANNEX E

Miscellaneous

E001 Introduction

1. Hit probabilities of targets will be assessed using normal distributions, probable errors and circular error probable as well as dispersion rectangles or ellipses. For one and two dimensions those parameters are developed in detail in Appendix E1.

2. For spin stabilised ammunition the line of fire has to be considered for the lateral deviation due to drift, which is shown in Appendix E2.

3. There are some options to close a WDA outline downrange as indicated in Figure 4.1 of Chapter 4. In Appendix E3 perpendicular, arc and steep angle closures will be shown.

4. Active and reactive targets require specific danger areas. A short survey is given in Appendix E4.

5. Appendix E5 contains a lexicon (selected definitions used in this document) including a list of abbreviations.

APPENDIX 1

Probable Errors In One And Two Dimensions

E101 Introduction

1. Normal distributions provide standard data for estimating hit probabilities of targets. Essential parameters like probable errors (PE) and circular error probable (CEP) as well as dispersion rectangles or ellipses will be developed in detail.

E102 Probable Error For An Interval

1. Let f(x) be the density function of a (μ, σ) uncorrelated one dimensional normal distribution and X a random variable in the interval (a, b] . Then the probability of X to be in this interval given by

$$P = P(a < X \leq b) = \int_a^b f(x)\,dx = (\sigma\sqrt{(2\pi)})^{-1} \int_a^b \exp(-0.5((x - \mu)/\sigma)^2)\,dx$$

Q = 1 - P is the complementary probability.

Let $\Theta(x) = (\sqrt{(2\pi)})^{-1} \int_{-\infty}^{x} \exp(-0.5t^2)\,dt$ a (0, 1) normal distribution. Then the probability P can be expressed by (a f(x) **(μ, σ)** normal distributed density function can be transformed into a Θ((x - μ)/σ)) **(0, 1)** normal distributed density function):

$$P(a < X \leq b) = \Theta((b - \mu)/\sigma) - \Theta((a - \mu)/\sigma) \qquad \text{(I)}$$

2. Let a = μ - m σ and b = μ + m σ, m>0, then the probability of X to be between μ - m σ and μ + m σ is dependent on the factor m only

$$P(\mu - m\sigma < X \leq \mu + m\sigma) = \Theta(m) - \Theta(-m) \qquad \text{(II)}$$

With this important relation PE data will be defined. Some data of m and P are listed in Table E1.1 (page E1-4). For a given P the factor m can be found by a root finding method. For the following all data are taken from Table E1.1.

3. Examples. Taking m = 0.6745 in formula (II), then P is 0.5. That means that 50% of all X are between μ - 0.6745σ and μ + 0.6745σ. This value of m is called Probable Error (PE) (or ONE PE).

Taking m = 5.3959 (= 8PE) it results P = 0.999999966 or $Q = 0.34 \times 10^{-7}$. Therefore choosing 8 PE results in a complementary probability of about 10^{-8}.

4. Remark. These data are only valid in the one-dimensional case. To get comparable results in the two-dimensional case, different data of m have to be taken (see Table E1.1). For the two-dimensional case rectangles and ellipses will be analysed.

E103 Probable Error For A Rectangle (R)

1. Without correlation the analogous formula for two dimensions is simple, because the solution of the double integral is the product of two one-dimensional density functions

f(x) [(μ, σ_x) normal distributed] and f(z) [(λ, σ_z) normal distributed]. The following described function is the probability P_R of hitting a rectangle where the MPI is its centre (= centre of the 2dim. normal distribution). Let f(x, z) be the density function of a 2-dim ((μ, σ_x), (λ, σ_z)) normal distribution. Let X and Z be two random variables, then

$$P_R = P(a_1 < X \le b_1, a_2 < Z \le b_2) = \int_{a_1}^{b_1}\int_{a_2}^{b_2} f(x, z)\,dx\,dz = \int_{a_1}^{b_1} f(x)\,dx \int_{a_2}^{b_2} f(z)\,dz =$$

$$P(a_1 < X \le b_1)\, P(a_2 < Z \le b_2) =$$

$$[\Theta((b_1 - \mu)/\sigma_x) - \Theta((a_1 - \mu)/\sigma_x)]\,[\Theta((b_2 - \lambda)/\sigma_z) - \Theta((a_2 - \lambda)/\sigma_z)] \text{ (as shown in E102.1)}$$

2. Let $a_1 = \mu - m\,\sigma_x$ and $b_1 = \mu + m\,\sigma_x$ and $a_2 = \lambda - m\,\sigma_z$ and $b_2 = \lambda + m\,\sigma_z$ then it follows equivalent to formula (II) the only dependence of the factor m

$$P_R(\mu - m\,\sigma_x < X \le \mu + m\,\sigma_x,\ \lambda - m\,\sigma_z < Z \le \lambda + m\,\sigma_z) = [\Theta(m) - \Theta(-m)]^2 \qquad \text{(III)}$$

a. For given values of m the probability P_R of the random variable (X, Z) to be in the rectangle $[-2a_1,2b_1]$ x $[-2a_2,2b_2]$ is given by formula (III). The complementary probability is the probability of hits outside that rectangle. The factors m to a given probability $\mathbf{P_R}$ can be found by solving the equation $P_R = [\Theta(m) - \Theta(-m)]^2$. The solution requires an iteration process (root finding method). With the factor m the half axes of the dispersion rectangle to a given probability P_R or P_R x 100 in percent and for given sd data can be calculated.

b. <u>**Examples for a Rectangle**</u> (all data are from Table E1.1). Taking m = 0.6745 (the <u>one dimensional</u> PE data), then only **25%** of all (X, Z) are in that specific rectangle. To have 50% of all (X, Z) inside the rectangle, a higher factor is to be chosen: m = **1.0518**. Taking 8PE of the one-dimensional PE data (m = 5.3959), then $\mathbf{0.137 \times 10^{-6}}$ of all (X, Z) are outside the rectangle (a smaller value than in the one-dimensional case). The resulting rectangle is called 8PE rectangle (with a_1,a_2,b_1,b_2 as above with m = 5.3959).

E104 Probable Error For An Ellipse (E) And CEP

1. Given a two-dimensional ((μ, σ_x), (λ, σ_z)) normal distribution. The analogue probability P_E over an ellipse E is then given by the integral (for two-dimensional normal distributions the figure of constant densities (c^2 = constant) are ellipses)

$$P_E = (2\pi\,\sigma_x\,\sigma_z)^{-1} \iint_{(x-\mu)^2/\sigma^2_x + (z-\lambda)^2/\sigma^2_z \le c^2} \exp(-0.5((x-\mu)^2/\sigma^2_x + (x-\lambda)^2/\sigma^2_z))\,dx\,dz$$

This integral has the analytic solution: $P_E = 1 - \exp(-c^2/2)$ which comes from the <u>Rayleigh distribution</u> (not shown here). The same relation is valid for circles ($\sigma_x = \sigma_z$).

2. The value m has the meaning of c and is easily calculated by $m^2 = 2 \ln(1 - P_E)$. With m the half axes of the dispersion ellipse around MPI = μ to a given probability P_E or P_E 100 in percent and for given sd data can be calculated (see Figure E1.1).

c. **Examples for Ellipses** (all data from Table E1.1). Taking m = 0.6745 (the one dimensional PE data), then no more than **20.35%** of all (X, Z) are in that specific ellipse. To have 50% of all (X, Z) inside the ellipse, a higher factor is to be chosen: m = **1.1774**. Taking 8PE (m = 5.3959) of the one-dimensional PE data, then **0.476×10^{-6}** of all (X, Z) are outside the ellipse (a smaller value as in the one-dimensional case and as the analogous rectangle).

d. **Examples for Circles and CEP Value.** The area A_E of the dispersion ellipse is given by $A_E = \pi m^2 \sigma_x \sigma_z$ (see Figure E1.1 for sd from samples). If $\sigma_x = \sigma_z$ this area is the dispersion circle. To estimate a dispersion ellipse by a dispersion circle set a new number $\sigma_c = 0.5(\sigma_x + \sigma_z)$ and $r = m\ \sigma_c$ is the radius of that circle. Taking m from Table E1.1 for P = 0.5 then m = 1.1774. This is the **one CEP** (circular error probable) value with the following attributes:

(1) The circle of radius 1.1774 σ around the MPI contains 50% all hits.

(2) Taking $1 - P = 10^{-6}$ then m = 5.2565 (Table E1.1) and the resulting circle has the radius 5.2656 σ containing 99.99990 % of all hits.

(3) The sniper weapon systems are assumed to have a high accuracy of hitting, so that resulting CEP is small. Thus the radius f_s (5.2656σ) may be seen as a recommendation for the size of the stop butt (factor f_s is taken as a margin for safety; e.g. $f_s = 2$). Note that the value $\sigma_c = 0.5(\sigma_x + \sigma_z)$ is target distance dependent and so the size of the stop butt depends on the target distance.

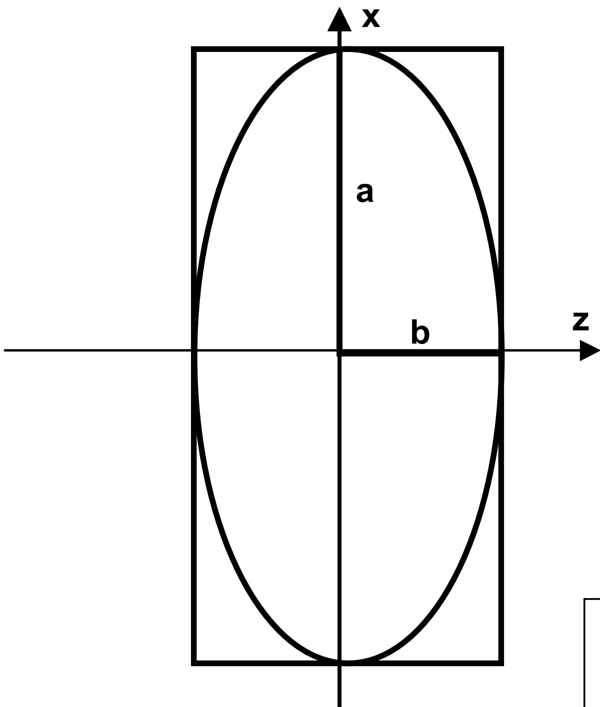
E105 Table Of Probabilities For Rectangles And Ellipses

1. For some given probabilities P factors m are listed in Table E1.1 for intervals, ellipses and rectangles. It is seen by Figure E1.1 and the data in the table, that the complementary probability (Q = 1 - P) for the same probability P is smaller for rectangles because they encompass the ellipse. Vice versa, to achieve a given P the factor m of the dispersion ellipse is bigger than for a dispersion rectangle. With the corresponding factors m the area of dispersion for ellipses or rectangles (see Figure E1.1) may be calculated.

P	m			1 - P
	Interval	Ellipse	Rectangle	
0.100000000	0.1257	0.4590	0.4073	0.9
0.203450000	0.2578	**0.6745 (1PE (*))**	0.5993	0.79655
0.250000000	0.3186	0.7585	**0.6745 (1PE (*))**	0.75
0.500000000	**0.6745 (1PE (*))**	1.1774	1.0518	0.50
0.650000000	0.9346	1.4490	1.2995	0.35
0.900000000	1.6449	2.1460	1.9488	10^{-1}
0.990000000	2.5758	3.0349	2.8062	10^{-2}
0.999000000	3.2905	3.7169	3.4807	10^{-3}
0.999900000	3.8906	4.2919	4.0556	10^{-4}
0.999990000	4.4172	4.7985	4.5648	10^{-5}
0.999999000	4.8916	5.2565	5.0263	10^{-6}
0.999999524	5.0358	**5.3959 (8PE (*))**	5.1654	**0.476 10^{-6}**
0.999999863	5.2698	5.6222	**5.3959 (8PE (*))**	**0.137 10^{-6}**
0.999999966	**5.3959 (8 PE (*))**	5.8637	5.6412	**0.34 10^{-7}**

(*) the specific factors producing one or 8 PE intervals, ellipses or rectangles

Table E1.1: Probabilities of Rectangles versus Ellipses and PE-data



P 100 [%] (area)
Dispersion Rectangle (R) or

P 100 [%] (area)
Dispersion Ellipse (E)

for a sample:
E: a = m (Ellipse) sd_x
E: b = m (Ellipse) sd_z
R: a = m (Rectangle) sd_x
R: b = m (Rectangle) sd_z
P 100 [%] (area)

Area of Dispersion Rectangle (R):
$A_R = 4\ a\ b$

Area of Dispersion Ellipse (E):
$A_E = \pi\ a\ b$

for a given P and corresponding m; see examples in Table E1.1

Figure E1.1. Dispersion Ellipses and Rectangles

APPENDIX 2

Correction To Bearing – Orientation Of The Outline

E201 Introduction

1. Correction to bearing is related to spin stabilised ammunition. If no correction is made, the line of fire is directed towards the target point PT (line of sight). For a clockwise spinning projectile the drift due to spin is to the right side of the line of fire and the point of impact is located as shown in Figure E2.1. The slant distance to the impact point gives the angle **ε**, which is called the correction angle to bearing (drift correction angle). This angle will be obtained by trajectory simulations.

E202 The Correction

1. To correct the spin deviation, that angle will be taken to the left side of the line of sight to define a new line of fire (see Figure E2.1). In this way, the real target point PT will be hit.

2. The Figure E2.1 shows also the different orientations of the dispersion ellipses for no correction and for correction.

3. When taking WDA outlines symmetrical to the line of fire (of sight), then both cases are covered: correction and no correction because the angle **ε** will be at the right and left side of the line of sight (the angle ε should be contained in the angle α of the EB Fan – see Chapter 3).

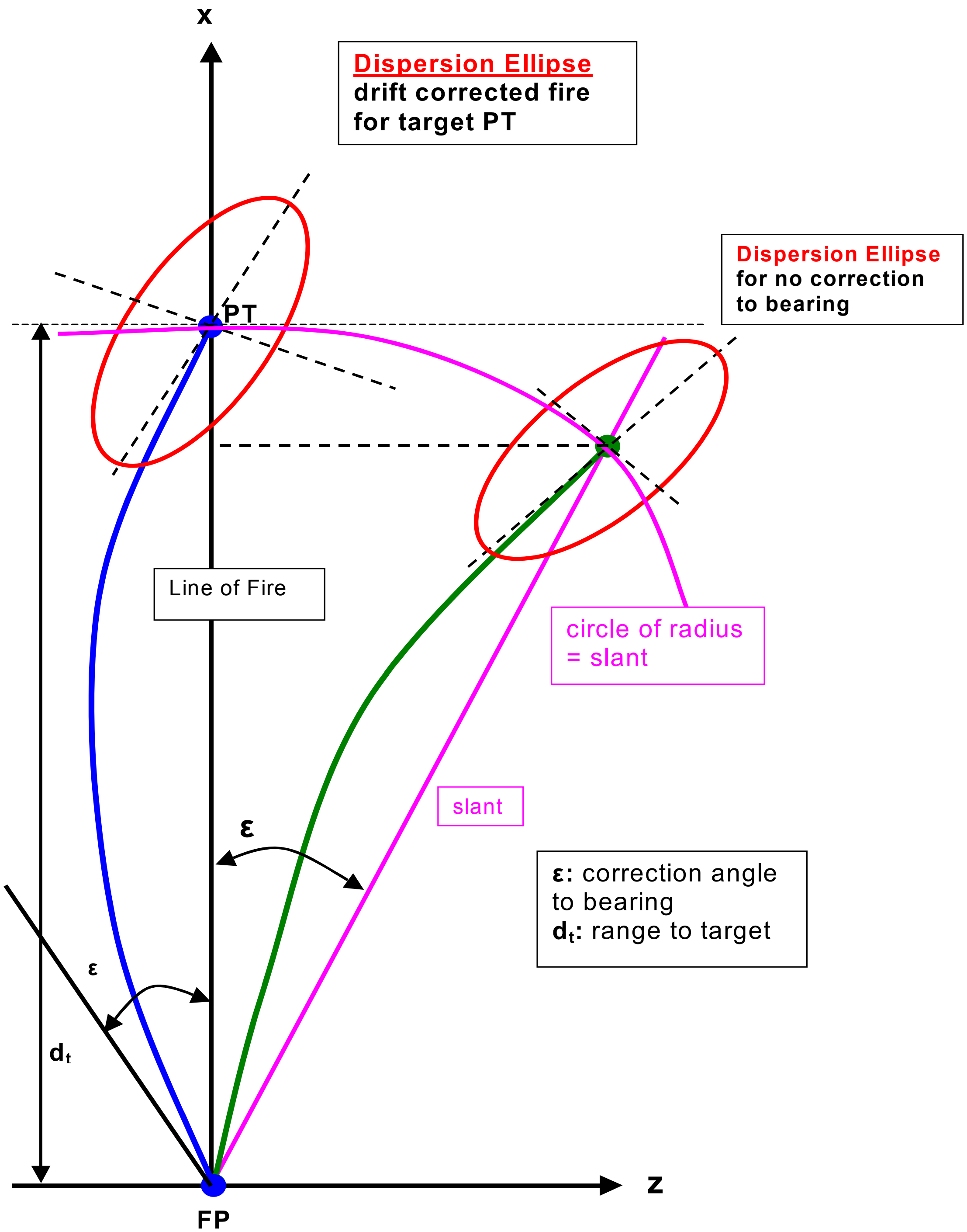


Figure E2.1: Spin-stabilised Munition Correction to Bearing

APPENDIX E3

Downrange Closures For WDA Outlines

E301 Introduction

1. If the total width of the WDA outline is small, the simplest closure may be a straight line perpendicular to the line of fire (LoF). However, if the width is significant, the use of an alternative shape will assist the application of the danger area to a firing range. The alternatives will be shown below.

E302 Downrange Closures: Perpendicular, Arc And Steep Angle

1. There are different methods of a downrange shape. A straight line perpendicular to the line of fire is less used because by definition it is not probable that a projectile will travel further than its maximum range (Figure E3.1). But it is a conservative choice.

2. Another common way is to cut back from the MRR on the outmost line of the EB Fan under a specific steep angle λ left and right, under the assumption that ricochets to the side will have less energy and therefore will not go to maximum range. A common choice for λ is 60° (measured as indicated in Figure E3.1). Also this kind of closure is convenient for the downrange closure of the FDA when it encompasses the RDA. An option is to cut back from the line of fire (for small angles α) for easy drawing.

3. The error budget fan may go up to the maximum range (if used) and is closed by an arc determined by the opening angle α (Chapter 3: the EB Fan is assumed to be a sector of a circle). To have a part of a circle as a closure is realistic, because for changing the azimuth in the interval (-α, +α) the maximum range will be the same (neglecting strong weather conditions).

4. To close downrange with an arc for the RDA and/or FDA is always correct (in this way all outlines of Chapters 3 - 8 are drawn).

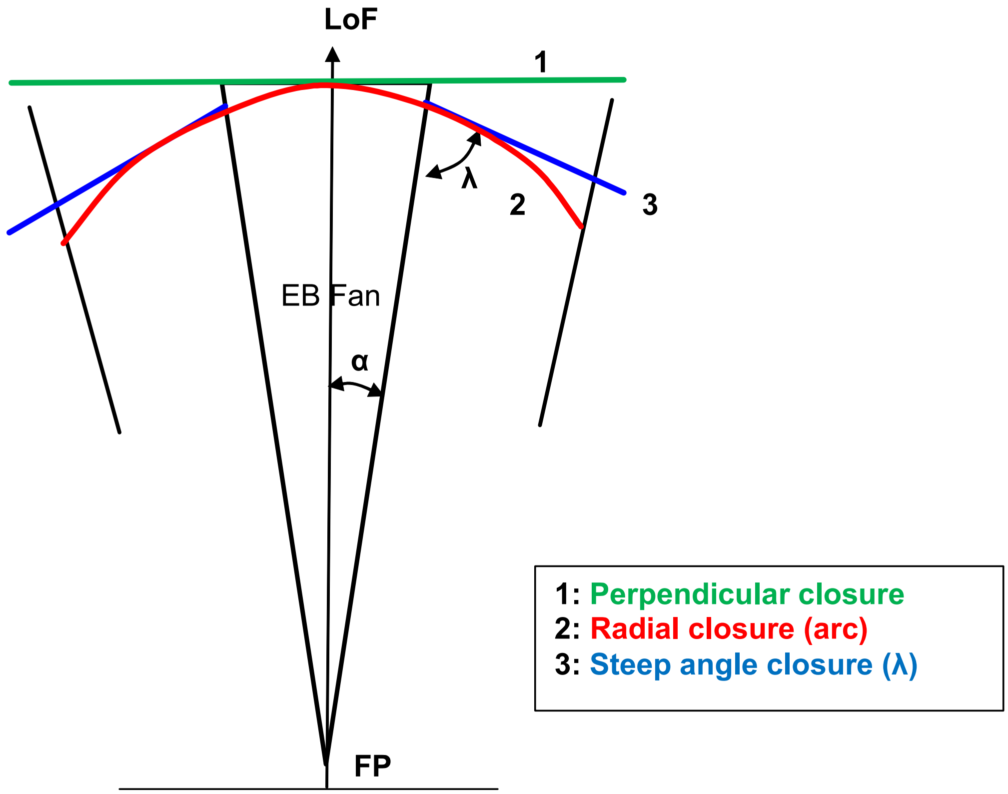


Figure E3.1: Different WDA Outline Downrange Closures

APPENDIX 4

WDA For Active And Reactive Protection Systems

E401 Introduction

1. This Annex covers the use of active and reactive protection systems as used against unguided projectiles and missiles. Using such systems the overall WDA outline consists of two independent parts:

   a. The WDA outline of the missile or projectile being used.

   b. The WDA outline covering the hazards of the protective system.

This Annex covers the last part only. The first part is determined by corresponding WDA outlines developed in this document.

2. Reactive systems are devices that are activated by the intended action of the incoming missile or projectile.

3. Active systems are devices that act and destroy the incoming missile or projectile before it hits the target.

E402 Reactive Systems

1. Reactive systems are mainly of three kinds:

   a. Explosive reactive armour (ERA) consisting of sandwiches of metal plates separated by a high explosive material,

   b. Inert or non-explosive reactive armour (NERA) consisting of sandwiches of metal plates separated by a non-energetic materials (usually a polymer),

   c. Combinations of the two above.

2. When the incoming missile or projectile hits the reactive armour, the interlaid material expands by a detonation wave (ERA) or a shock wave (NERA). The rate of expansion results in an ejection of the metal plates that interact with the incoming projectile.

3. The ejection velocity **v** is determined by the properties of the interlaid material and the mass of the metal plates. For systems with symmetric design (two metal plates of equal mass) Gurney's equation may be applied

$$v = \frac{\sqrt{2E}}{\left(\frac{2m}{c} + \frac{1}{3}\right)^{1/2}}$$

where *m* is the mass of a single plate, *c* is the mass of the explosive and *E* is the gravimetric energy content of the explosive released during detonation. The numerator $\sqrt{2E}$ has the unit of velocity and is 3 km/s for the most powerful explosives. For asymmetric sandwich configurations the equation becomes slightly more complicated.

4. Advises for developing a WDA outline:

a. The plates will be ejected in a direction normal to the surface of the sandwich.

b. The extension of the danger area should be determined based on a ballistic calculation of the plate. As the plate is aerodynamic unstable, its trajectory will be erratic and unpredictable. The maximum range of the plate should be determined by the vacuum trajectory or with a constant drag coefficient not greater that 0.05 referring to the plate area.

c. The range of the vacuum trajectory is $r = \frac{v^2}{g} \sin 2\xi$ where ξ is the ejection angle and *g* is the acceleration of gravity.

d. A possible deviation of the ejection angle of 60º in all directions should also be accounted for.

e. Ricochets of the plates from the ground do not have to be considered if the directions above are followed.

f. Unintended initiation of reactive systems caused by small fragments or small-arms projectiles should be accounted for.

g. An additional circular safety area based on considering the ERA system as an explosive fragmenting shell should also be accounted for.

E403 Active Systems

1. Active protection systems are generally classified as either

(a) *hard-kill systems* that physically destroy the incoming missile or projectile or

(b) *soft-kill systems* that disturb or jam the guidance system of the incoming missile. This effect may increase the WDA of the attacking system.

2. It is not possible to formulate a general description of the WDA for such devices. The WDA has to be determined based on an adequate knowledge of the working principles of the actual device taking into account the possibilities of guidance failure, unpredictable behaviour of the object to be attacked and ejection of fragment and other objects in unintended directions.

APPENDIX 5

Lexicon And List Of Abbreviations

E501 Lexicon: Selected Definitions Used In ARSP-1 Volume I And II

1. The definitions are partly from AAP-6. See also in addition the lexicon in ARSP-1 Volume I (Annex B). For indirect fire a collection of specific terms is collected in Appendix C3 (C302, THE COMPONENTS).

a. **Accuracy of Fire.** Accuracy of fire is the component of precision of fire, which is expressed by the closeness of the MPI, of groups of shots, at and around the point of aim. (AAP-6)

b. **Air Danger Height.** The Air Danger Height (ADH) is the maximum height above ground level (AGL) at which hazards may exist ADH is measured in feet.

c. **Back Splash.** Back splash is fragmentation or target debris thrown back towards the firing point as a result of projectile impact.

d. **Consistency/Dispersion.** Dispersion is the scatter pattern of hits around the Mean Point of Impact (MPI) of weapons fired under identical conditions. (AAP-6)

e. **Carrier.** A carrier (or carrier/cargo shell) is a specially designed, base or nose ejection, hollow projectile which carries cargo (sub-munitions, illumination flares, smoke canisters or other material).

f. **Critical Impact Angle (IA_{crit}).** The IA_{crit} is the acute angle between the line of arrival of a weapon and the horizontal plane above which a ricochet should not occur.

g. **Debris:** Debris consists of scattered fragments from munitions which are not considered for any assignment.

h. **Deterministic development of WDA/Z**. That means an analytical approach for the outline using fixed formulas for calculation. Normally this leads to worst case scenarios.

i. **Direct Fire.** Direct fire is an engagement in which the target can be seen by the firer. (AAP-6)

j. **Early Burst.** An early burst occurs if the fuze, set to the proximity role, initiates the shell beyond the position in the trajectory where proximity arming is complete, but before the intended burst height. It may also be the result of a malfunctioning mechanical time fuze.

k. **First Trajectory.** This is the flight pass from the muzzle to the first impact or point of functioning.

l. **Frangible Ammunition.** Ammunition without explosives which breaks apart when impacting due to its kinetic energy.

m. **Fragment Danger Area/Zone.** The space around a burst of a projectile or shell in which its fragments are expected to travel and impact.

n. **Hard Target.** Hard target refers to all material or surfaces which posses sufficient strength and surface hardness in relation to a given ammunition that when impacted suffers little or no deformation. Severe backsplash effects may be generated (target and ammunition parts).

o. **Hazard.** A hazard is any real or potential condition that can cause injury, illness, or death of personnel and general public, or damage to or loss of equipment or property.

p. **Indirect fire.** Indirect fire is an engagement in which the target cannot normally be seen by the firer; the delivery means is laid mechanically or electronically using data derived from tables or computation (AAP-6)

q. **Maximum Ricochet Range.** The Maximum Ricochet Range (MRR) is the range corresponding to the angle of descent, which produces the $\mathbf{IA_{crit}}$ for the projectile.

r. **Normal Burst Safety Distance (NBSD).** The Normal Burst Safety Distance from the point of burst beyond which it is improbable that any fragment from a bursting weapon will travel.

s. **P**rojectile with **E**nhanced **L**ateral **E**ffect **(PELE - projectile)**. This is a multi purpose inert fin- or spin-stabilised projectile. Due to the difference in density between the internal core (base) and the projectile body an extremely high internal pressure develops when the projectile impacts a target. This internal pressure causes the projectile to fracture producing for instance a cone of fragments.

t. **Probable Error (PE).** The probable error of a random variable is that deviation from the mean which is as likely to be exceeded as not (GoT). **One** PE is the unit of measurement of the horizontal error lying wholly on one side of the mean point of impact both in range and deflection, i.e. plus, minus, left or right.

u. **Projectile.** A projectile is an object, capable of being propelled by a force, normally from a gun and continuing in motion by virtue of its kinetic energy. Projectiles are divided in Kinetic Energy Projectiles and Shells. (AAP-6)

v. **Range (Distance).** The range is the distance between any given point and an object or target. (AAP-6)

w. **Range (Area/Zone).** The Range is a space reserved, authorised and normally equipped for hazardous firing (weapon/laser). (AAP-6)

x. **Range Safety.** Range Safety is the means by which the risk of injury or damage when firing authorised weapons on a range is reduced to an acceptable level. It is achieved by procedures which provide an accepted level of safety for personnel involved in firing, non-involved personnel and the public.

y. **Ricochet.** Ricochet is the change of velocity, and hence speed and direction, induced in a projectile, missile or fragment caused by its impact with a surface.

z. **Ricochet Danger Area/Zone.** The space, in which ricocheted rounds may travel and impact. Multiple ricocheting may be included.

aa. **Sabot.** A sabot is a lightweight carrier in which a sub calibre projectile is centred, to permit firing and projection from within the larger calibre barrel of the delivery means. The carrier fills the bore of the weapon from which the projectile is fired and is normally discarded a short distance from the muzzle. (AAP-6)

bb. **Slug.** A slug is an irregular shaped fragment occurring by shaped charge detonations.

cc. **Soft Target (or Ground Target).** Soft target refers to all surfaces or material which, when impacted will be penetrated or hold up the projectile (earth, sand, wood, thin aluminium or steel plates, canvas, cardboard) depending on the use of ammunition. Backsplash effects will not be generated.

dd. **Total Energy Area/Zone (TEA/Z).** The TEA/Z is the maximum possible two / three dimensional space around a firing point into which it is possible for weapons, fragments or impact debris to pass or fall.

ee. **Weapon Danger Area/Zone (WDA/Z).** The WDA/Z as a proper subset of the TEA/Z, is a defined 2/3-dimensional space on the range, which is exposed to hazardous impacts or functioning of munitions, their fragments, or their sub-munitions, under normal firing conditions. There is an accepted low probability that munitions, fragments, sub-munitions or propelled debris may escape. The WDA/Z excludes gross human errors.

ff. **Weapon Danger Area/Zone Outline**. This outline is the contour of the template or the technical drawing of a WDA/Z.

E502 List Of Most Used Abbreviations

1. Partly in brackets is given the place of first occurrence in this volume.

AP	Armour Piercing
ARSP	Allied Range Safety Publication
APDS	Armour Piercing Discarding Sabots (B001.2)
APEI	Armour Piercing Explosive Incendiary (A001.3)
APFSDS	Armour Piercing Fin Stabilised Discarding Sabots (B001.2)
API	Armour Piercing Incendiary (A001.3)
CEP	Circular Error Probable (E104)
EB	Error Budget
EBA	Error Budget Area (0302.1)
FAPDS	Frangible APDS (B001.2)
FDA	Fragment Danger Area (0501)
HE	High Energy (0501)
HEAT-MP	High Energy Anti Tank - Multi Purpose (0501)
IA_{crit}	Critical Angle of Impact (0402)
ICM	Improved Conventional Munition
IMA	Intermediate Area (0302.7)
KE	Kinetic Energy (B001.2)
KETF	Kinetic Energy Time Fuze (B001.2)
ICAO	International Civil Aviation Organisation
Met	Meteorology or meteorological
MRR	Maximum Ricochet Range (0402)
MPI	Mean Point of Impact (0302.2))
MV	Muzzle Velocity
NAEB	NATO Armaments Error Budget (0302)
NBSD	Normal Burst Safety Distance (0501.1)
PE	Probable Error (0302.2)
PELE	Penetrator with Enhanced Lateral Effect
PT	Point Target (single target) (0202)
QE	Quadrant Elevation
QE_{crit}	Critical QE (in combination with MRR)
RDA	Ricochet Danger Area (0401)
RWDA	Rearward Danger Area (0502.2)
RTR	Round to Round (0302.2)
SCA	Semicircular Arena (for fragmentation tests)
SMC	Special Met Conditions (0705)
SE	Systematic Error (0302)
sd	Standard Deviation (normal distribution) (0302)
SMP	Sub-munition Pattern (C302)
TEA/Z	Total Energy Area/Zone
TPCSDS	Training Projectile (Purpose) Cone Stabilised Discarding Sabot (B002)
WDA/Z	Weapon Danger Area/Zone

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