ALLIED RANGE SAFETY PUBLICATION - 1 VOLUME I
(ARSP-1 VOL I)

WEAPON DANGER AREAS / ZONES FOR UNGUIDED WEAPONS IN A GROUND ROLE - DETERMINISTIC METHODOLGY -

FACTORS AND PROCESSES

MARCH 2007

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NORTH ATLANTIC TREATY ORGANIZATION

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Major General, POL(A)
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CHAPTER 1

Introduction

0101 Range Safety

1. The Range is a two- or three dimensional space (area or zone) reserved, authorised and normally equipped for hazardous firings. The aim of Range Safety is to minimise risk to the general public, civilian and military personnel arising from hazardous range activities to an acceptable level. Range Safety is the summation of a series of different issues that guarantee on the whole a safe procedure of firing. A survey is given in Annex A. Exterior safety (see para 103) is a main issue of Range Safety.

0102 Risk

1. The dimensions of a Weapon Danger Area/Zone (WDA/Z) can be calculated by deterministic and/or by probabilistic methodologies. The development of WDA/Z involves the line between acceptable (tolerable) and non-acceptable (non-tolerable) risk. Risk is the combination of the probability and the consequence of a hazard. The level of acceptance is a national issue and prescribed in national policies. Acceptance of risk does not mean that risk is non existent. It refers to a willingness to live with a risk of a particular technical process or condition that is regarded as acceptable (tolerable) in the circumstances in question.

0103 Exterior Safety

1. This safety relates to people who are not involved in the firing. To ensure exterior safety on the range surface and in the height appropriate WDA/Z are to be applied. Any WDA/Z directly marks the line between acceptable risk and non-acceptable risk when its development is based on risk analysis. Each WDA/Z is designed to allow a specific level of risk outside its two- or three dimensional boundary and in this way it is a proper subset of the Total Energy Area/Zone (TEA/Z). The control of WDA/Z boundaries is a responsibility of Range Safety.

0104 Interior Safety

1. Interior Safety relates to personnel performing the firing. Special safety procedures are used to protect those persons.

0105 Other Issues

1. Noise- and overpressure and toxicity hazards fall into this category. Safety in operation and operation controlling, pollution and contamination control and open fire protection, medical coverage, clearing duds and blinds as well as the training and exercising of personnel are other components of Range Safety.

0106 Hazards Of A Firing

1. A key element of Range Safety is the application of WDA/Z. To establish WDA/Z possible hazards involved in each firing have to be identified and analysed. The consequences and characteristic parameters of the ballistic flight of any projectile will influence the design and dimension of WDA/Z in relation to the expected hazards. The various connections and related factors are displayed in a diagram in Chapter 2 (Figure 2.1).

0107 Scope Of This Publication

1. This publication will relate only to factors and processes which govern the development of range independent (overall valid) WDA/Z for unguided weapons used in the direct or indirect firing mode. It is the aim to make the description of the factors calibre/weapon independent whenever it is appropriate. Numerical values for factors will be given in ARSP-1 Volume II.

2. Publishing an air danger height for the range or each weapon will ensure aircraft safety.

3. Certain features of range design will affect the dimensions of the required WDA/Z. Protective structures (e.g. stop butts or special infrastructure like baffled ranges or indoor ranges) may be used to reduce WDA/Z dimensions to a minimum in a safe way. To go into detail on these options is not the subject of the ARSP-1 Volumes.

0108 Producing The Wda/Z

1. The way a WDA/Z for a specific weapon will be developed is subject of ARSP-1 Volume II "Applications".

0109 The Volumes Of Arsp-1

1 The ARSP-1 Volumes are only concerned with weapon systems currently in use by the armed forces of member nations and not with experimental systems or weapons, which have not completed their development.

2. The WDA/Z models developed in these Volumes will be based on deterministic methodologies. In addition, the error budget for the free flight will be considered.

3. The WDA/Z will be developed for spin- or fin stabilised projectiles of all calibres (small, medium, large) and of all kinds including mortars, artillery rockets and sub-munitions released from carriers. The WDA/Z will cater for ricochets and fragmentation every time those events occur.

4. Direct fired (indirect fired) rockets will be treated as fin-stabilised projectiles (artillery munition). Mortars are treated as fin-stabilised projectiles, rifled mortars (spin-stabilised) as artillery projectiles.

5. The diagram in Figure 1.1 gives an overview of the 3 Volumes of ARSP-1. The third Volume (in preparation) will contain the deterministic part of STANAG 3606 (Laser Hazards).

0110 The Series Of ARSPs

1. The diagram in Figure 1.2 shows the position of the ARSP-1 Volumes (Deterministic Methodology) in relation to the drafted/planned ARSP-2 Volumes (Probabilistic Methodology), ARSP-3 Volumes (Data Acquisition and Analysis) and ARSP-4 Volumes (Software).

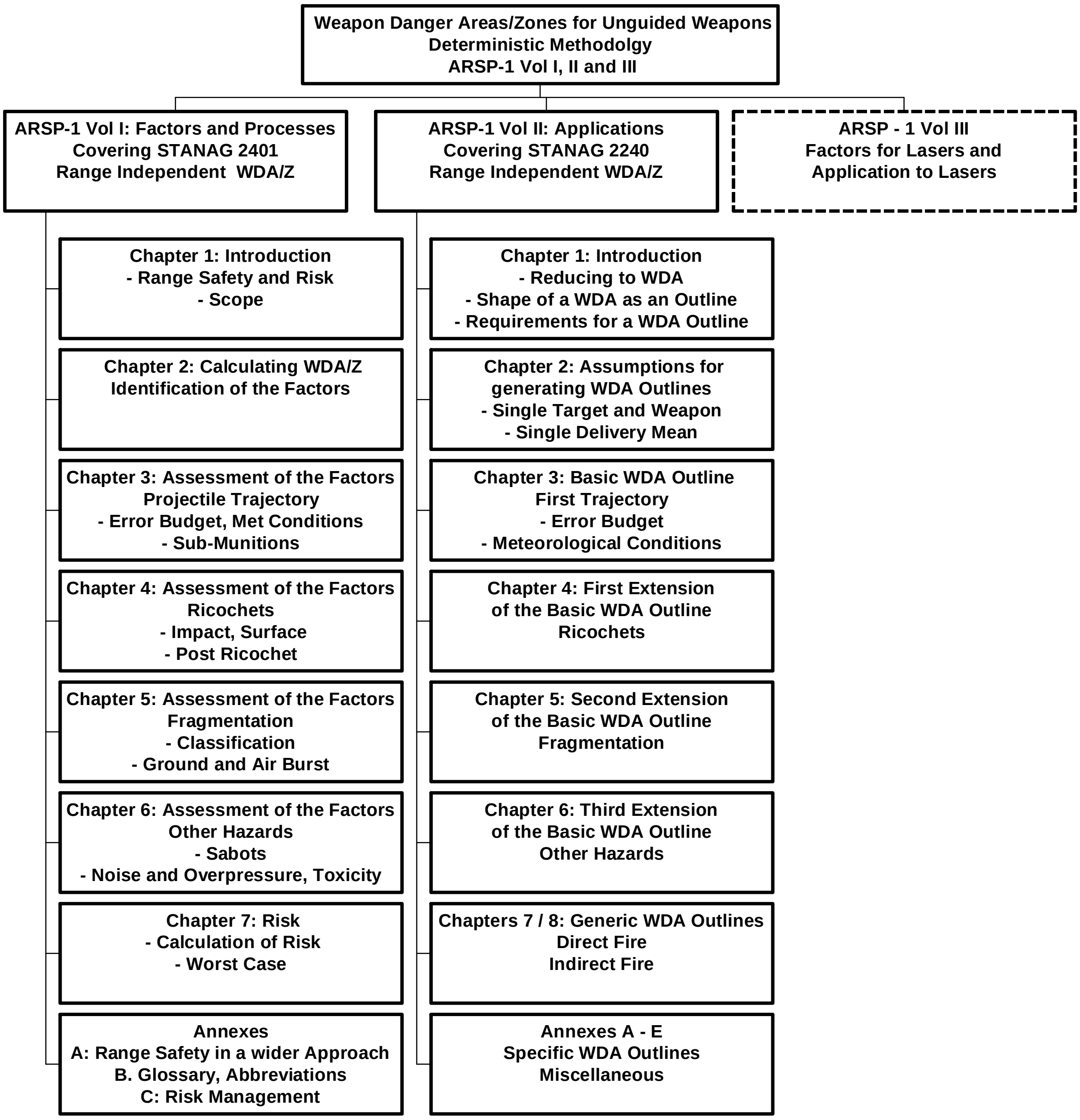
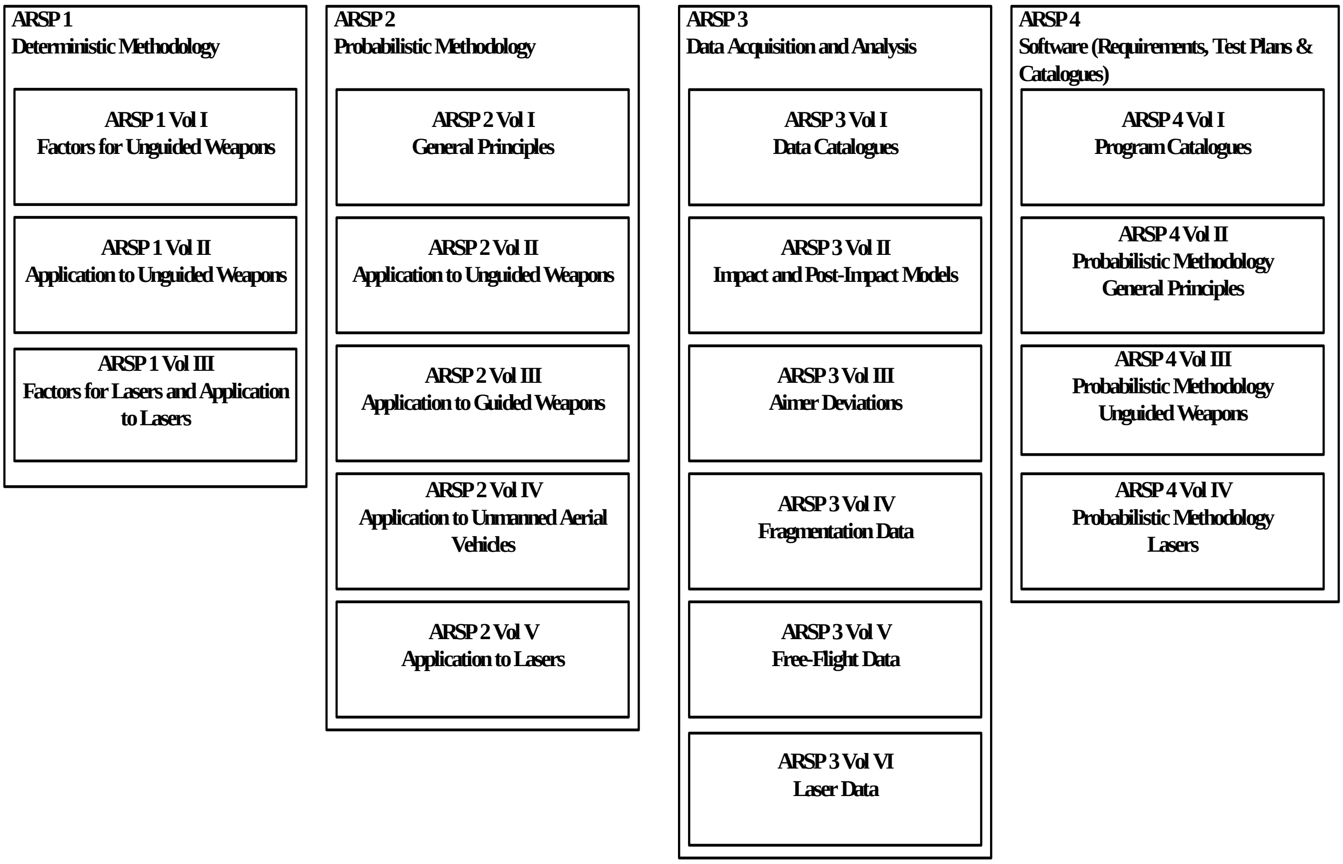


Figure 1.1: The Volumes of ARSP-1 for the Deterministic Methodology



The status of the ARSPs (July 2006). ARSP-1 Vol I and II are finished in their first edition. ARSP-2 Vol I and II are completely drafted. ARSP-1 Vol III, ARSP-3 Volumes I and II are under development. The others have not yet started.

Figure 1.2: The Series of ARSPs and their Volumes

CHAPTER 2

Calculating WDA/Z: Identification Of The Factors

0201 Sources of Hazards and associated Factors

1. There are a number of main sources for hazards a fired projectile may cause: the projectile's trajectory, possible ricochets, sub-munitions and fragmentation. The following flow chart shows these characteristic sources besides other ones and their associated factors that have to be considered when developing WDA/Z. The assessment of the factors related to these flow charts is the subject of the Chapters 3 - 6. In Chapter 7 and Annex C special factors regarding risk assessment (in the wider area of risk management) for WDA/Z calculation will be presented.

2. Three digit numbers in the individual blocks refer to the paragraphs in which these factors are addressed. A selection of often-used terms, definitions and abbreviations is contained in Annex B (Lexicon).

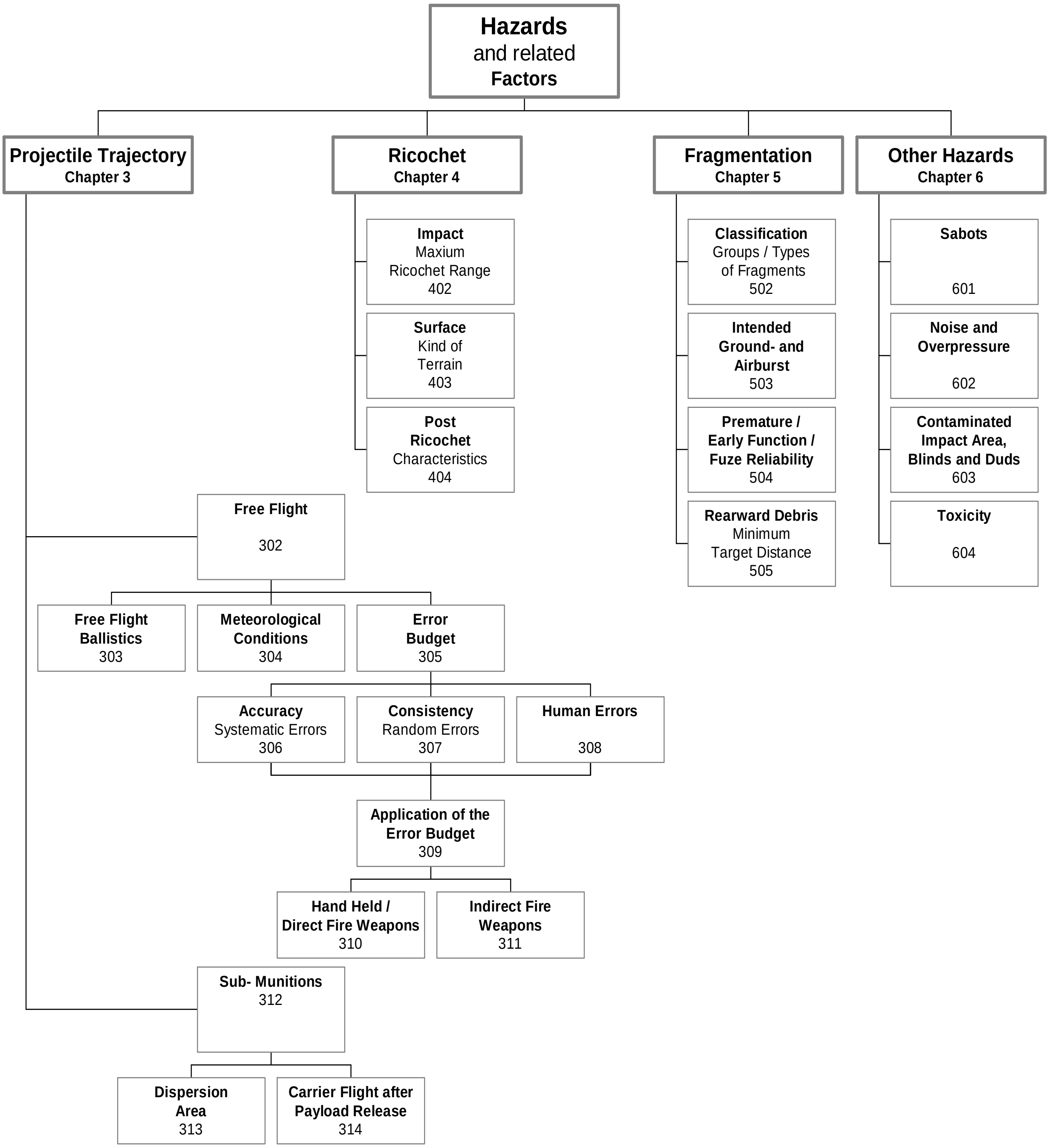


Figure 2.1: Hazard Diagram

CHAPTER 3

Assessment Of The Factors: Projectile Trajectory

0301 Introduction

1. The ballistic flight of a projectile results in a sequence of possible hazardous events, which contribute to the WDA/Z. Following the diagram, Figure 2.1, the first step is to examine the free flight of the projectile and their sub-munitions if designed for. The most attention is given to indirect fired projectiles.

0302 Free Flight

1. The free flight (first trajectory) of a projectile starts at the muzzle of the barrel or tube (for sub-munitions at the point of release) and terminates when hitting the target or impacting the surface (including PD fuzes), in the proximity of the target (PROX fuzes), after a pre-set time (TIME fuzes) or when destroying itself when designated for.

2. The trajectory of a carrier in the event of a fuze failure (payload not ejected) must also be calculated for the WDA/Z. For base-burn, rocket-assisted projectiles and artillery rockets a special WDA/Z has to cater for the possibility of motor failure or reduced effects.

0303 Free Flight Ballistics

1. No reliable WDA/Z for general use can be published, unless the ballistic properties of the projectile in free flight have been accurately determined during development. To take into account the effects of free flight it is necessary to have the ability to calculate the complete trajectory of the projectile for any given sets of ballistic data, meteorological conditions and topographical data. Trajectories can be calculated by specific software programs (based on common ballistic models as Point Mass Model (PMM), Modified Point Mass Model (MPMM, STANAG 4355) or six Degrees of Freedom Model (6 DoFM) whatever is appropriate). Those programs must be proved to deliver reliable results. The input/output data and the software programs have to be at least as good as the calculated WDA/Z. The general use of standardised software is optional. For example the **N**ATO **A**rmament **B**allistic **K**ernel (NABK) - software may be used (STANAG 4537) to obtain specific output data for calculating WDA/Z.

2. A selection of <u>ballistic input data</u> (not all relevant for the variety of considered projectiles) is:

a. Weapon system and type of projectile (e.g. shell, rocket, sub-munitions)
b. Muzzle velocity (and number of charge) or releasing velocity (sub-munitions)
c. Quadrant/super-elevation
d. Azimuth of fire
e. Fuze setting (time of flight)
f. Ballistic coefficients (e.g. drag coefficients)

g. Meteorological conditions (esp. range wind (speed and direction))
h. Relative height to sea level.

3. For calculating WDA/Z additional data are required (data to be produced by using International Civil Aviation Organisation (ICAO) or special weather conditions):

a. Maximum ordinate (vertex, for determining air danger height)
b. Maximum range or range for given elevations (a contribution to the WDA length)
c. Time of flight
d. Angle of impact (for estimates of possible ricochets)
e. Maximum Ricochet Range (MRR) or critical elevation (QE_{crit}), see Chapter 4, para 402
f. Range of the projectile in case of no burner/motor function (artillery, only for Base Burn (BB) projectiles and Rocket Assisted Projectiles (RAP))
g. Ejection point, including height (carriers)
h. Range of empty carriers after ejecting the payload
i. No fuze function (trajectory without ejection point)

4. Further inputs for trajectory calculations of indirect fired projectiles are

a. Weapon and target co-ordinates, range (or elevation) and azimuth to target
b. Meteorological data (METCM STANAG 4082, METB STANAG 4061)
c. Fire Control Input (FCI) data or data from firing tables (STANAG 4119).

5. For WDZ vertical hazards must be taken into account for aircraft safety (see Figure 3.1). Vertical hazards encompass the vertex (maximum ordinate) of the free flight and following ricochets, and fragment heights (normal burst safety distance, see Chapter 5, para 503).

6. A common practice is to set a fixed level above the entire range for airspace safety. The altitude will be calculated by the maximum vertex of all expected trajectories.

a. For indirect fired projectiles including artillery rockets it is recommended to use the vertex of the free flight trajectory of the highest elevation on which the firing is planned or the vertex of the Maximum Ricochet Range trajectory (see Chapter 4, para 402) whatever is greater. For HE projectiles the maximum fragment radius (Chapter 5, para 503) related to the maximum vertex height may be added to that vertex depending on the fuze design.

b. For direct fire weapons the maximum vertex of all first trajectories and possible ricochets after impact are necessary. This method requires real post-impact data from trials. In case of lack of data, for direct fire weapons the vertex of the Maximum Ricochet Range belonging to that kind of weapon, will give a safe choice for example.

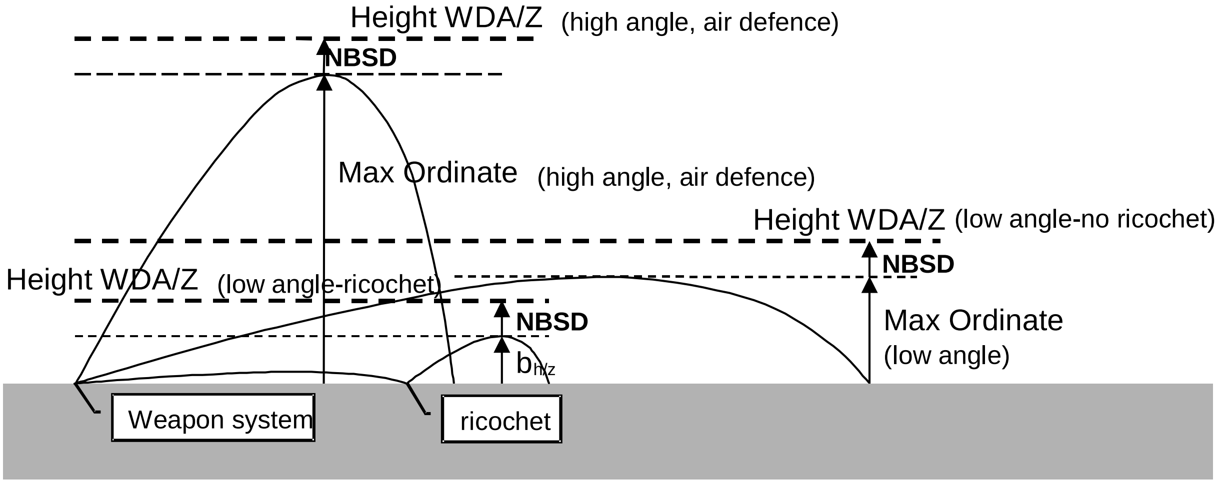


Figure 3.1: Air Danger Height

0304 Meteorological Conditions

1. The trajectory of a projectile is influenced by atmospheric conditions, which is a major effect for indirect fired projectiles. Air density and wind are the most significant. A tail wind will increase the range of a projectile fired at a given elevation and similarly, a cross wind will cause a lateral deviation; and a head wind will reduce the range. All other wind directions between them are also important for WDA/Z calculations. When firing rocket propelled projectiles, special care should be taken to have updated information about the wind conditions in the boost phase part of the trajectory. Rockets are especially susceptible to crosswind during this phase. Low air pressure and high temperatures will result in a greater projectile range. When firing at increased altitudes air pressure and temperature are also significant. All these effects need to be considered when calculating WDA/Z.

2. Generally, meteorological (met) conditions will be incorporated into the fire-input control if applicable. Basic met conditions will meet the requirements of the ICAO standards. Local orders and procedures will determine the sources from which to take the meteorological data.

3. For weapons without fire control systems (e.g. hand held weapons) the firer will make adjustments for met conditions, otherwise extra margins of safety will often be added. For direct fire weapons utilising fire control systems, and indirect fire weapons it is assumed that some data on wind speed, wind direction, temperature and atmospheric pressure will be available before firing, and that the effects of meteorological data will have been accounted for during trajectory calculation. An extra safety allowance needs to be added for the variability of meteorological data (cf. sub-para 311.4d).

0305 Error Budget

1. The error budget encompasses different sources of errors mainly for first trajectories. The errors are divided into random and systematic errors which are described below and displayed in a scheme (Figure 3.2) in sub-paragraph 307.4. Generally the error budget is laid down the NATO Armaments Error Budget (NAEB) [1]). Originally developed for indirect artillery fire the NAEB will be suitable for all NATO armaments.

0306 Accuracy

1. For a mission, accuracy is a systematic error and measured by the distance between the mean point of impact (MPI) and the aiming point. This distance is called bias or MPI error. From occasion to occasion the bias may have its own distribution which means the dispersion of the MPI around the aiming point.

2. The bias originates in irregularities, which are specific to each weapon system. Systematic errors in met conditions also contribute to the bias. When firing the same gun under identical conditions, zeroing can reduce the bias.

0307 Consistency

1. The consistency or round-to-round error (RTR error) of a firing is determined by the dispersion of the impacts around the mean point of impact (MPI). The finite number of projectiles fired on a single occasion under identical conditions being distributed around the MPI will produce precision errors in range and deflection. This dispersion is due to random variations in meteorological and firing conditions (e.g. weapon system, projectile, charge). Thus, RTR errors are random errors.

2. Generally, RTR errors are based on normal distributions. For direct fire the RTR errors are measured in standard deviations sd (in range and deflection), which may be transformed into a single standard deviation (circular distribution). For indirect fire the precision errors are normally characterised by probable errors (PE) in range and in deflection. PE data are laid down as one PE (equivalent to 0.6745 x sd) data (in range and deflection) in firing tables. As opposed to MPI errors RTR errors cannot be reduced by zeroing. For details see ARSP-1 Volume II (Annex E, Appendix 1).

3. When systematic errors are known, they may be combined with RTR errors by standard formulas as a total error, and included in the WDA/Z calculations.

4. A diagram (Figure 3.2) displays relations between RTR and MPI errors and the resulting total error $\sqrt{RTR^2 + MPI^2}$.

[1] NAAG AC/225(LG/4-SG/2)/D10 Revised 1998 (Accuracy of Tube Artillery Fire at Extended Ranges) – also Draft STANAG 4635 Ed.1 on the NATO ARMAMENTS ERROR BUGDET MODEL (2006) (for direct and indirect fire)

- The RTR error varies with each projectile causing the dispersion around the MPI. This is known as consistency.
- The MPI error is the same for each projectile of the series and causes the bias. This is known as accuracy.
- Firing a series of n projectiles on

  one Occasion $x \leq n$

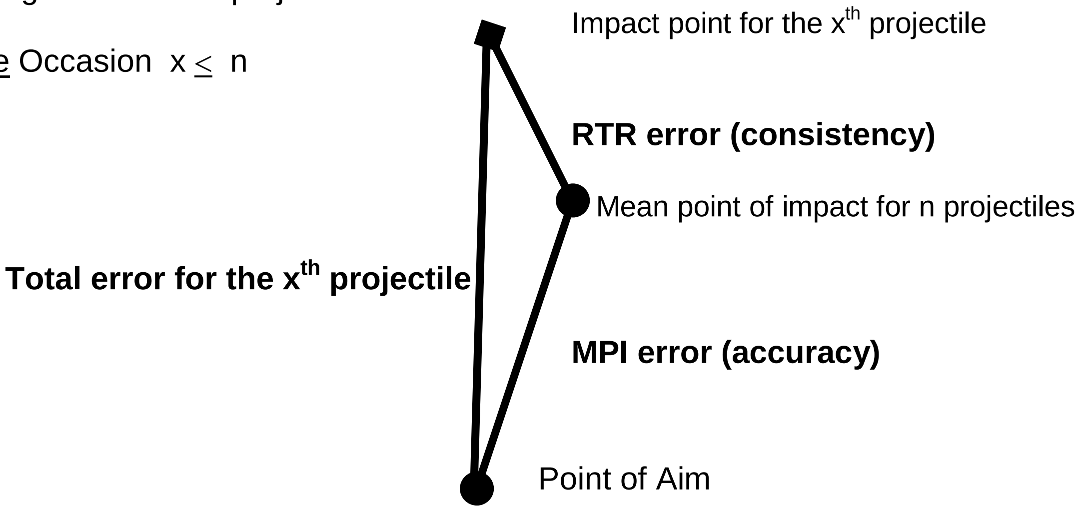


Figure 3.2: Total Error

0308 Human Error

1. Unpredictable human error is the inevitable consequence of having a human component in most weapon systems (deliberate human error is not considered in this agreement). The problem of unpredictable human action is greatest for weapon systems where the largest single safety factor is the allowance made for gross human error. These considerations are mostly applicable to small calibre projectiles.

2. For direct fire (mounted weapons) the task of aligning sight and target is largely mechanised. When firing from a static position, the aiming error will be small and is best combined with weapon system errors as an overall system error. When firing from a moving vehicle/platform, the aiming error will be much greater and a separate allowance should be made. For indirect fire, weapon systems may be subject to gross error from a variety of causes: wrong charge loading, incorrect ammunition data for the aiming system, wrong target or gun position, inaccurate meteorological data.

3. For the ARSP-1 Volumes I and II misdirected shots or wrong target engagements, wrong charge loading, incorrect ammunition data, or wild firing will not be taken into account. Range control, skill and discipline are described in Annex A.

0309 Application of the Error Budget

1. When error budgets are used for the development of WDA/Z it is advisable to distinguish between two different modes of engagement: Firing with hand held/direct fire weapons or firing in an indirect mode (c.f. artillery and mortar weapons).

0310 Hand Held/Direct Fire Weapons

1. Predictable but inevitable human errors, especially for beginners, have to be taken into account. The error budget for mounted direct fire weapons will normally be smaller than that for hand held weapons (see para 308). In either case a measure for aimer error can be determined by evaluating aimer error statistics. For overall valid WDA/Z a maximum deviation is to be established.

0311 Indirect Fire Weapons

1. Because of extended ranges up to 40 km and more of artillery firings the error budget for indirect fire is a significant issue. The NAEB (see para 305) lists MPI and RTR errors (see sub-para 4) which affect the projectile's accuracy and consistency for different delivery techniques. The NAEB is only valid for the first trajectory and does not cater for any ricochet. In comparison ricochets significantly contribute to the size of the WDA/Z, the NAEB has minor significance for its dimensions (only if ricochets are expected).

2. For indirect fire it may be assumed that the delivery of the first projectiles is not accurate because of some missing or incorrect/old data. Limited to one occasion the total error of the first shots can be handled by identifying a sufficiently large target area, and firing these shots into its centre to enable adequate corrections for the following shots (corrected fire technique). In this case RTR and MET errors are contributions for calculating artillery WDA/Z.

3. Indirect fire WDA/Z can be delivered as ready-to-use (they will not be influenced directly by applying real data for the NAEB). However, prior to the development of WDA/Z the NAEB is used to calculate RTR-errors in range and deflection (STANAG 4144). Another method is to give extra allowances for the (unknown for the first shots) RTR and MPI errors to be incorporated into a basic WDA/Z calculation. By applying the methods of the NAEB in an iterative process during firing, the fitting WDA/Z will then be developed step by step by using true data for the errors.

4. The following basic errors of NAEB and their type (ME (= MPI Error) or RE (= RTR Error)) may not apply to the whole of the variety of the considered projectiles and mostly they are applied to indirect fire weapons.

   a. **Launch Errors** resulting from variations in weapon locations (gun point) [ME], firing direction [ME], verification of the gun [ME], aiming data of the gun [RE], muzzle velocity [ME, RE], tip-off errors [RE]

b. **In-flight Errors** resulting from variations in MET conditions [ME; RE], projectile aerodynamic data [ME, RE], fuze setting parameters [RE], propulsion errors (e.g. BB-element burn time error) [ME, RE].

c. **Muzzle Velocity** variations occur for the following reasons: Barrel wear [ME], charge composition (type) [ME], new propellant (lot) [ME], charge temperature [RE], round to round variation [RE], projectile mass/size [RE], ram depth inconsistency [RE].

d. **Error Sources** in the indirect fire MET messages are instrumentation errors [ME]; errors in measuring wind, temperature, pressure, humidity [all ME]. Modelling error: error from modelling of the MET messages [ME]. Spatial error: Error from the distance (space staleness) between sonde measurement and the actual trajectory of the projectile for each height zone [ME]. Time error: Error from time staleness between the sonde measurement and the real trajectory of the projectile for each height zone [RE].

5. Joint RTR/MPI error formulas (for standard normal distributions) for some indirect fire delivery models are listed in Draft STANAG 4635 (see para 305) and ARSP-1, Volume II (Annexes C and E).

6. Often, only the standard deviation data from trials or PE data from firing tables are known, from which the WDA/Z have to be determined. In that case it is recommended to add an extra margin of safety to accommodate those above-described errors which are not covered by those data.

0312 Sub-Munitions

1. Certain projectiles are designed to function as a carrier. Improved Conventional Munitions (ICM), carrier shells or particular rockets unload special devices (c.f. bomblets/grenades, smoke or illumination canisters) which have a portion of the inherent velocity of its carrier. The trajectories of those devices originate at the point of unloading (e.g. fuze setting) and are called secondary trajectories. They have adherent the error budget of the carrier and their subsequent own error budget which is similar to the above one. The calculation of the secondary trajectories often requires special simulation models that are adapted to the payload. These models deliver additional data for the design of the WDA/Z for the carrier shell and its payload. Other particular issues as failure modes at different stages, in addition to proper functioning, must be considered.

0313 Dispersion Area

1. Released bomblets/grenades produce an elliptically shaped pattern around the impact point of the central bomblet/grenade. The covered area is part of the WDA/Z. The dimension of the pattern depends on the parameters of the ejection point (height, trajectory angle, carrier velocity, ejection velocity and error budget, met conditions and sub-munition trajectories).

2. Special artillery carrier shells release sensor fuzed sub-munitions that also produce dispersion areas on the range surface. Those sub-munitions may descend on parachutes and thus their error budget is strongly affected by meteorological conditions. At a pre-set height the detection will begin and further on the sub-munitions will be armed. It is recommended to use the detection radius as basis for calculating the WDA/Z. Sensor fuzed sub-munitions may have a self-destroying mechanism, which will be activated when the sub-munitions is on the range in an undefined position. The maximum range of the explosively formed penetrator determines the radius of the circle to protect against this hazard.

3. Illumination, smoke devices or the like are treated similarly.

4. In the following Figures 3.3 and 3.4 those points are displayed, which have to be considered when developing WDA/Z for ICM projectiles and carrier shells with sensor-fuzed sub-munitions. Only the range components are shown. Deflection/lateral components are also required (see ARSP-1 Volume II).

0314 Carrier Flight After Payload Release

1. The trajectory of an empty carrier (cf. ICM) and its base plate after unloading can be seen as secondary. The empty carrier may be unstable and will have a different impact point than the same projectiles with fuze malfunction. When calculating WDA/Z for carrier shells it is necessary also to take into account the free flight of the complete carrier (no unloading) up to the point of impact and associated ricochets.

2. Some carriers (cf. mortars, rockets) will break apart by fuze activation with help of detonation devices. The WDA/Z has then to cater for the carrier parts which will travel like large fragments and other debris.

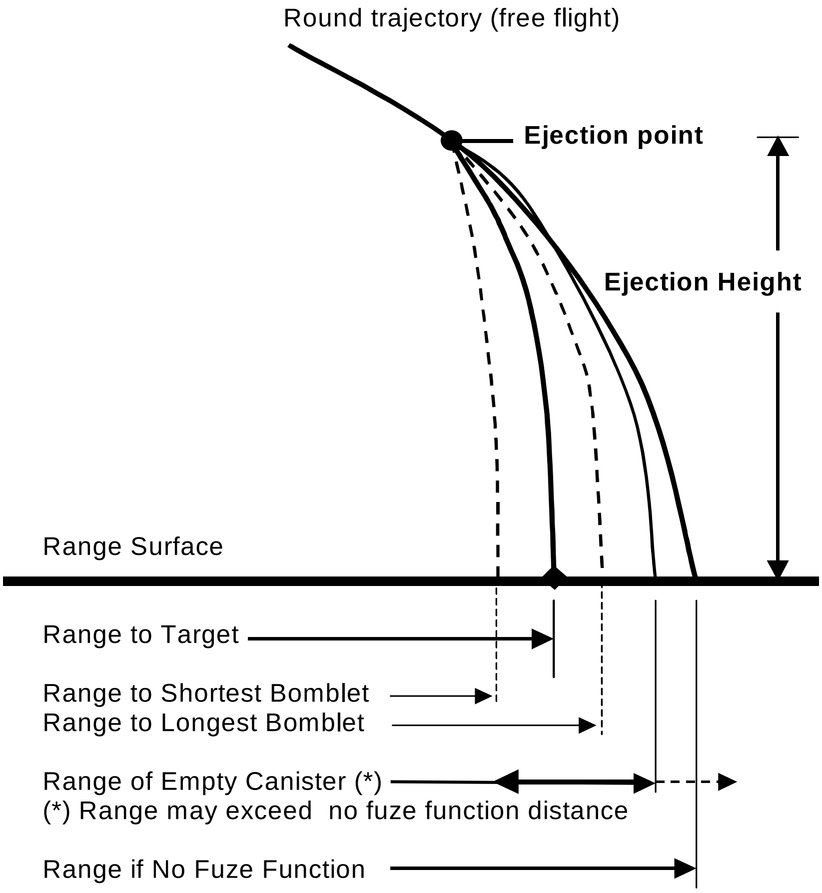


Figure 3.3: ICM Projectiles

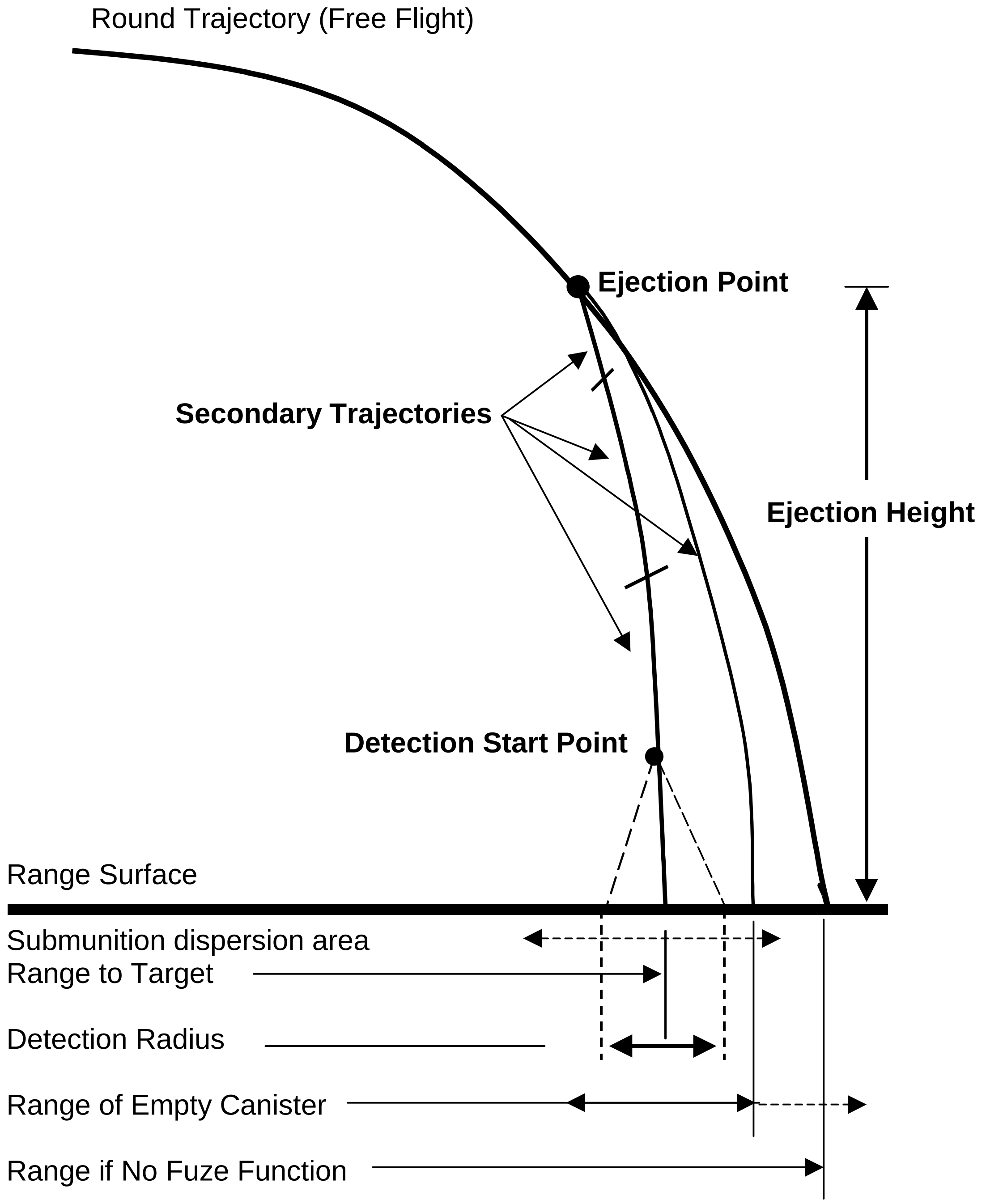


Figure 3.4: Sensor Fuzed Sub-Munitions

CHAPTER 4

Assessment Of The Factors: Ricochets

0401 Introduction

1. When a projectile impacts the surface or a target ricochets may occur. The range, deflection and height of possible ricochets are to be combined with the WDA/Z of the first trajectories. Whether or not ricochet can occur has a major effect on the size and shape of the required WDA/Z.

0402 Impact

1. A ricochet occurs when a projectile impacts on a surface or target and the subsequent change of direction and speed results in a second trajectory. The term *break-up* is used where pieces of a projectile, which are not formed through explosively induced fragmentation, occur upon impact. Ricochet and break-up behaviour is influenced by the impact surface, and the projectile calibre, rigidity, nose shape, stabilisation mode and impact velocity. It is also influenced by the type of the projectile (e.g. ball or hard-core projectile, HE/KE - projectile, empty carrier of a base ejection projectile).

2. Ricocheting is associated more with direct fire than indirect fire weapons because of the shallow angle of impact coupled with the predominantly inert nature of direct fire projectiles. Each weapon/munition has its generic ricochet danger area dependent on the type of terrain or target engaged and on the data of the first trajectory at impact. For the deterministic methodology the full length and width of the ricochet danger area can be estimated by applying the Maximum Ricochet Range (MRR), that is the greatest range of a projectile at which ricochets may occur.

3. The gun quadrant elevation (QE) required to reach the MRR on flat ground is weapon system and charge dependent (only artillery and mortars) and is defined as the Critical Quadrant Elevation (QE_{crit}). The QE_{crit} is the quadrant elevation that results in an angle of descent equal to the Critical Impact Angle (IA_{crit}). IA_{crit} is the angle at which the probability of ricocheting is taken to be zero. For spin stabilised projectiles, it is common to take 533 mils for that angle as a conservative choice. The QE_{crit} for fin stabilised projectiles will be smaller as they have a different ricochet behaviour. Further advice on estimating the MRR or QE_{crit} of spin and fin-stabilised munitions will be given in ARSP-1 Volume II.

4. When a projectile ricochets the distance to which it might travel will depend on several factors, which include :

a. Projectile related factors:
   (1) Physical properties: mass, velocity, rigidity.
   (2) Mode of stabilisation.
   (3) Yaw angle and yaw rate.

b. Target related factors:
   (4) Nature of target surface and surrounding area.
   (5) Slope of surface.

c. Engagement related factors:
   (6) Angle of descent.
   (7) Angle of incidence with the target surface.
   (8) Post ricochet stability and drag (and degree of damage to the projectile).

5. Forward ricochet travel. Theoretical prediction of forward ricochet distance takes the above variables into account. It is assumed that no combination of first trajectory followed by one or more ricochets will cause a projectile to travel further than the MRR. If the ricochet length is expected to be significant then meteorological conditions should be considered when calculating the MRR (a free flight trajectory). Note: The MRR distance of a projectile is always shorter than its maximum range.

6. If the projectile does not completely break up upon impact, it may ricochet. For small deflections in elevation and azimuth, the more stable and rigid projectiles may travel, after ricochet, with low yaw and with levels of drag not significantly greater than before impact, such a process is described as ‘stable ricochet’. Ranges several times greater than for a normal, high drag, ricochet may be possible. The impacts on the surface for a spinning projectile will not be symmetrical and will be distorted due to gyroscopic and frictional forces.

7. Fin stabilised HE/KE ammunition and cone stabilised training ammunition may not have such complicated behaviour after ricocheting. The degree of damage when impacting and shallow ricochet angles only will affect the MRR length.

8. Fin stabilised mortars, fired in the high register role, do not normally produce ricochets. New mortar systems will also fire in the low register. In this case mortars, handled as fin stabilised projectiles, may ricochet as well as rifled mortars.

9. The **maximum ricochet width** can be determined by experiment. Ricochet trials are costly and time consuming and only a few appropriate data are currently available. In the absence of data, it is recommended to take specific fractions of MRR for that parameter (see ARSP-1 Volume II, Chapter 4, Table 4.1).

10. When a projectile detonates/breaks up at impact a **fragment danger area** is the only consequence. For HE projectiles the normal burst safety distance (see Chapter 5) may be applied.

0403 Surface

1. The slope of the ground in the impact area will affect the construction of the WDA/Z. No natural surface is uniform and therefore all MRR calculations are estimates. Forward slope at the impact point will increase the impact angle so that the IA_{crit} will be reached at a

range shorter than the MRR for horizontal ground. Reverse slope will have the opposite effect, increasing the MRR. The majority of slopes on the range surface will have no significant effect on range safety. However, when engaging targets in a mountainous region, MRR calculations need to take account of the effects of significant slope in the WDA/Z determination.

2. The nature of the impact surface will affect the distance to which ricochets may travel. Indirect fire weapons will strike both hard and ground surfaces, direct fire weapons will often have first strike against hard targets. If MRR is being used as contribution for the WDA/Z length the target material will have no effect for range. The lateral displacement, however, will change depending on the strike velocity, angle of strike and the amount of deformity that the projectile undergoes.

0404 Post Ricochet

1. For special engagements or for using non-deterministic approaches post ricochet trajectories have to be determined. This problem applies mostly to spin-stabilised ammunition. Typically a point mass model is applied to calculate the post ricochet trajectory if the projectile remains stable after ricocheting. The choice of model parameters depends on various factors including the availability of post ricochet data (from trials; as in the case of free flight) and predicted degree of damage to the projectile.

CHAPTER 5

Assessment Of The Factors: Fragmentation

0501 Introduction

1. When the projectile impacts fragments are created by the effect of the explosive filler or by the effect of its kinetic energy. The overall spread of fragments has to be contained in the WDA/Z.

0502 Classification

1. Fragments encompass all parts of a projectile and can be grouped as follows:

   a. **Natural Fragments.** Variable sized parts of a projectile body, which are the results of the high explosive filler. Those fragments are thrown out with a high velocity.

   b. **Controlled (pre-formed) Fragments.** Defined geometrical structures, such as cubes/balls which are designed to be propelled outward at high velocity by the effect of the explosive filler.

   c. **Projectile Fragments.** Variable sized parts of a kinetic energy projectile that are produced as a result of high-speed impact (c.f. Frangible, PELE or APFSDS projectiles).

   d. **Other Hazardous Objects** that can be treated as fragments:

      (1) Slugs and explosively formed penetrators. These come from shaped charge warheads or sub-munitions. The range of those particular projectiles can be large. In the case of sub-munitions their direction may not be predictable when self-destroying.

      (2) Primary debris. Debris of a projectile (mostly HE, HEAT) that is not designed for any assignment may also be hazardous. Parts of the debris can have longer ranges than other fragments. Depending on the kind of the projectile this group may include for example bolts, nuts, pins, screws, parts of electronic devices, fuze debris, carrier shell debris (bottom, metal plates, interior hulls, fuze parts, etc).

      (3) Secondary debris. Debris generated from the impact is called secondary.

2. Calculations of fragment trajectories are usually based on the database of static detonations in specific semi-circular arenas or similar facilities. Also simulation models may give the necessary fragment data. It is recommended to select for each zone of the arena the most dangerous fragment (called the representative fragment) and to use this set of fragments for calculating the fragment danger area/zone.

3. The lack of data for fragment trajectories (e.g. suitable drag) is a major issue. Significant data are the fragment shape, mass and initial velocity. The velocity has to be fitted for the in-flight bursting projectile with data of the projectile (e.g. velocity, angle of trajectory) at the point of detonation. Generally, for WDA/Z purpose, the determination of trajectories of fragments or explosively formed penetrators will be calculated by a plain 2-dimensional point mass model. Parameter variations of the input data are recommended for simulating the fragment WDA/Z.

4. It is a national prerogative to classify fragments as hazardous or not or to set thresholds. In this way fragments classified as non-hazardous may be excluded from fragment danger areas. Applying of risk assessment (see Annex C) is then recommended.

0503 Intended Ground And Airburst

1. The fragment danger area/zone around the intended point of burst (ground or air) is the envelope of all computed fragment trajectories having their termination points on the range surface. For simplification it is recommended to draw a circle around the point of burst (surface co-ordinates) with a radius of the maximum range of all fragments (this radius is called Normal Burst Safety Distance (NBSD)) as danger area, and to take the maximum vertex as air danger height. This danger area/zone is the containment of all fragments. A reduced fragment range can be adopted if adequate protection for personnel is provided, or if a hazardous fragment threshold is established and accepted based on risk management.

0504 Premature/Early Function/Fuze Reliability

1. The reliability of fuzes is an issue with indirect firing of mortars or artillery, or firing over troops. When firing fuzes suspected of having an unacceptable probability of functioning while in-flight consideration must be given to the potential fragments generated along the trajectory and the WDA/Z must take account of this. For example, the NBSD may be increased due to enhanced fragment spread if detonation occurs at any significant height above the ground (early function). If a premature function occurs at fuze arming distance the forward velocity of the projectile will reduce the rearward NBSD and increase the forward NBSD.

0505 Rearward Hazards (DEBRIS)

1. When engaging hard targets back splash effects can occur. Fragments may be parts of the projectile itself and/or of the target and other material. To make the firing position safe a minimum engagement distance may be advised for each direct fire weapon. That distance can be established by definite trials or by worst case analysis. This distance also takes into account if the projectile has explosive filling. If the minimum distance cannot be applied, appropriate protection must be provided for the weapon system serving personnel for firing at shorter distances.

2. Recoilless weapons and rockets will produce rearward debris, which has to be taken into account when determining the WDA/Z.

CHAPTER 6

Assessment Of The Factors: Other Hazards

0601 Sabots

1. Sabots, needed for spin or fin-stabilised ammunition of smaller calibre than the bore of the barrel, are hazardous objects. They are discarded in range and deflection directly in front of the weapon system. Normally, sabots will have their own special danger area.

2. When firing at high angle sabots can have a wide spread, also rearwards, depending on wind direction and speed. The firing position and its neighbourhood could be exposed to danger. Thus, the WDA/Z has to cater for this effect.

0602 Noise And Overpressure

1. Firing noise has three main sources

   a. The weapon (noise spreads spherically)
   b. The projectile noise when travelling through the air
   c. The detonation noise (HE munitions) or impact noise at high energy (e.g. KE projectiles)

2. The type of noise produced from the firing is weapon system dependent. The amplitude, or peak pressure, of the noise and its duration are the main factors in assessing potential damage. In general terms hearing damage to personnel in the area of the firing weapon systems will be greatest if hearing protection is not worn, or worn incorrectly.

3. Personnel involved with live fire activities must wear ear protection when the level of noise is equal to or greater than set forth in national standards.

4. Using Noise Prediction Programs combined with a good knowledge of the meteorological conditions and the local topography can reduce noise to the surrounding communities. The following is advised:

   a. Not to fire large calibre HE projectiles in state of inversion layers at atmosphere.

   b. Taking into account the possibility of unexpected reflections of the noise.

5. Generally, these programs can give useful indicators to avoid worst cases, based on available data. This will enable decisions to be made as to whether the weapon, which will produce the noise, should be fired from a particular location and at a particular time.

6. Damage from overpressure has to be taken into account. Personnel exposed to overpressure will normally suffer ear and lung damage.

7. Before a new weapon system enters service the position of the crew has to be investigated in order to be sure that the pressure level is acceptable. During this investigation reflections from the area/zone around the weapon system have to be examined.

0603 Contaminated Impact Area

1. Procedures for blind/dud disposal are laid down in STANAG 2143.

2. Impact areas for carriers may be contaminated with bomblets or sub-munitions, which may not have self-destructed and may be activated in a (un)-defined time frame. The WDA/Z has to account for the maximum range of fragments and explosively formed projectiles (see Chapter 5, 502d).

0604 Toxicity

1. Toxic hazards may arise on the firing point from propellant combustion products and in the target area from the operation/no-operation of the projectile. Range safety instructions and WDA/Z should specify the hazard(s) where necessary and provide clear directions to be taken to mitigate the risk.

CHAPTER 7

Risk

0701 Introduction

1. The term risk is addressed in Chapter 1, paragraph 102. In the wider area of Range Safety the application of Risk Management is a major tool (see para 702 and Annex C). An example for risk calculation is in para 703. Also addressed are worst case applications (see para 704).

0702 Risk Management

1. Risk management is the process of identifying, assessing, and controlling risks. Risk management is a **five-step process**. The five steps are:

   a. Step **1**:Identify hazards
   b. Step **2**:Assess hazards
   c. Step **3**:Develop controls to determine residual risk and make risk decisions
   d. Step **4**:Implement controls
   e. Step **5**:Supervise and evaluate

2. The risk management process is addressed in detail in Annex C.

0703 Calculation Of Risk

1. If a person knows about the level of risk and takes the decision of controlling that risk, nevertheless, and suffers injuries or death, he is responsible for his actions. The risk to be considered when developing WDA/Z is the **residual risk (R)** that personnel or material involved or not involved in the process the hazards are coming from causes loss, injury, or damage. The following issues give information for WDA/Z development.

2. The following two different probabilities may characterise a WDA/Z:

   a. The **probability of escapement** (P_{esc}) stands for the probable event that a hazardous object will escape from a defined area/zone.

   b. The **probability** of **hitting a specific area** (P_{hsa}) will assess that area outside the defined area with a graduated (specific) level of probability of being hit by a hazardous object leaving that defined area.

3. The residual Risk **R** is a **joint probability** of three **independent** probabilities **P, T** and **C** (as defined in the following table):

R = P * T * C		
P	**T**	**C**
$P = P_{esc}$: probability of escapement $P = P_{hsa}$: probability of hitting a specified area	T = Tr: probability that a person (or object) is outside the range T = Ts: probability that a person (or object) is inside a specified area	C (= Consequence or Effect, taken as a probability) is the severity of an incident outcome expressed in personnel or asset (object) loss.
P will be provided by procedures to calculate the WDA/Z	T will be an individual measure given by the user. T may be time dependent.	An explanation for C can be found in Annex C, Figure C.2 "Hazard Severity".
Those methods can be applied to compute the WDA/Z	Those calculations will depend on the range on which the firing takes place and the surrounding areas. It is a range specific measure.	

Table 7.1: Risk Formula

For the measures **Tr** and **Ts**, persons and objects are rated by different levels. Further information is given in Annex C, especially by Figure C.3.

4. The risk **R** is often a specific measure for a fixed located danger area/zone (except the trivial cases T = 0 or T = 1).

5. The probability P_{esc} is an upper boundary for P_{hsa} that means $\mathbf{P_{hsa} \leq P_{esc}}$. The measure P_{esc} is the sum of all P_{hsa}.

6. Remark on the probabilities Tr and Ts: It takes time and manpower to provide sufficient good data for computing the probability T. Usually, Tr and Ts will be hardly known which is the reason why it is difficult to calculate the risk **R** exactly. Often, the only way is to set T = 1 and consequently C = 1. In doing so it is reasonable to give P_{esc} an adequate high level in its absolute value (which is recommended for practice). If P_{hsa} and Ts (Tr) are not known the probability of escapement P_{esc} should be set by national standards (e.g. 10^{-6}) to ensure a low risk level outside the WDA/Z.

0704 Worst Case

1. In paragraph 703 the risk R (in its meaning as a residual risk) is defined as the product of three independent probabilities: **R = P * T * C**. There are two simple special cases of R (P and T taken as in the table of paragraph 703):

a. R = 0 if P = 0 and/or T = 0 and/or C = 0

b. R = 1 if P = 1**,** T = 1 and C = 1

2. The risk R is zero if the probability T is zero (if a projectile escapes from the danger area hitting a definitely empty (specific) area there will be no risk). In case it is assured P = 0 the measures C and T can take values between 0 and 1.

3. If the WDA/Z is calculated after **worst case methods** (fully deterministic without any probability) then P can be seen as a 0 - 1 probability (P = 1 inside the defined space and P = 0 outside). T and C can be taken arbitrary.

4. In various cases, because of absence of essential data for probabilistic models, WDA/Z have to be calculated after worst case methods by applying the 0 -1 probability. For almost all cases it is impossible to calculate **the** worst case danger area/zone (which is equivalent to the TEA/Z). It is only possible to create a WDA/Z for **a** worst case. The real worst case is often not known. Parameter variations could help to get closer to a reasonable worst case.

ANNEX A

A Survey of Range Safety under the Aspect of Applying WDA/Z

1. Range Safety is the combination of organisational, training and technical measures taken to ensure that there are no unacceptable effects of the weapon and/or its associated munitions outside the designated **WDA/Z** which marks the boundaries for an acceptable level of risk/danger around the corresponding firing range (weapon system and expected impact/target area).

2. The Range Safety Organization (RSO) consists not only of the (safety and operational) personnel of the training / firing area, but also includes the designated safety personnel of the troops / units using the ranges. The responsibility of the units safety personnel is mostly directed toward the proper use of the weapons and its associated ammunitions. The Ranges Safety personnel have overall responsibility, including safeguarding that no unauthorised persons enter the danger areas. Organisational measures taken by the RSO are for example:

   a. Issuing Range Safety Instructions/Manuals to the troops using the training area;

   b. Marking the danger and/or target area in the field and on maps;

   c. Co-ordinating between multiple users of the same training area;

   d. Ensure that the units / troops use the correct firing range in combination with the designated weapon and ammunitions combination or munitions;

   e. Incident/accident report system.

3. Training measures taken by the RSO are for instance:

   a. Ensure that the troops/weapon crews/units have the required level of training;

   b. Instruct troops and safety personnel on Range Safety Instructions.

4. Technical measures taken by the RSO are for instance:

   a. Construction of baffles and/or restrictions so that weapons can only be aimed in the desired/safe directions if necessary;

   b. Limit the use of munitions-types to (for instance) training or short-range munitions.

5. The Weapon Danger Area / Zone (developed in the series of ARSPs) does not guarantee 100% safety. There remains an area/zone outside in which the risk is below an acceptable level. The RSO is there to ensure that the conditions set for that WDA/Z are met. The WDA/Z (transformed into an outline of its shape – see ARSP-1 Volume II) gives the area/zone in which the (dangerous/harmful and underlying) effects of the (weapon systems and its ammunitions or) munitions are to be expected when used in a proper way. This means that the RSO has to ensure that any weapon is aimed at its assigned target, loaded with the correct munitions (cf. projectile and charge) and that all corresponding settings (e.g. fuzes, fire control computers, etc) are correct.

ANNEX B

Lexicon and Abbreviations

Selected Definitions used in ARSP-1 Volumes I and II (partly from AAP-6 and the IRSAG Glossary of Terms (GoT)).

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)

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. (GoT)

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

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

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. (GoT)

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. (GoT)

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

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. (GoT)

Indoor Range. An indoor range is one, which is fully contained in a building or other structure. (GoT)

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

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. (GoT)

Premature. A premature is the complete or partial function of a munition before the completion of the required arming delay of the fuzing system. (GoT)

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. (GoT)

Probability of Escapement. The probability of escapement is the chance of ammunition, a fragment or propelled debris leaving a defined space, often stated as chance or probability per operation or event, expressed as a percentage or as a decimal. (GoT).

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)

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

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

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, not involved personnel and the public.

Open (outdoor) Range. An open range is one which is exposed to the natural effects of light, wind and weather. The range may be completely open or contained partially by a structure. (GoT)

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

Risk. Risk is the combination of the probability and the consequence of a hazard. (GoT)

Risk Assessment. Risk Assessment is the systematic identification of hazards, severity and probability. It is used to estimate the risk to individuals or population, property or the environment.

Risk Analysis. Risk analysis is part of the overall process of risk management. It contains hazard assessment and determination of risk level.

Risk Management. Risk Management is the systematic application of management policies, procedures and practices to the task of analysing, evaluating and controlling risk. (GoT)

Tolerable (Acceptable) Risk. Tolerable (Acceptable) risk is the level of risk with which society is prepared to accept so as to secure certain benefits, provided the risk is properly controlled. (GoT)

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. (GoT)

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.

Weapon System. The weapon system encompasses the delivery means and the munitions (cf. charge, primer, projectile) used.

List of Abbreviations

ADH	Air Danger Height
APFSDS	Armour Piercing Fin Stabilised Sabot Discarding
ARSP	Allied Range Safety Publication
$\mathbf{IA_{crit}}$	Critical Angle of Impact
MRR	Maximum Ricochet Range
MPI	Mean Point of Impact
NAEB	NATO Armaments Error Budget
NBSD	Normal Burst Safety Distance
PE	Probable Error
PELE	Projectile with Enhanced Lateral Effect
$\mathbf{P_{esc}}$	Probability of Escapement
$\mathbf{P_{hsa}}$	Probability of hitting a specified area
QE	Quadrant Elevation
$\mathbf{QE_{crit}}$	Critical QE
R	Residual Risk
RSO	Range Safety Organization
RTR	Round to Round
SD	Standard Deviation (normal distribution)
TEA/Z	Total Energy Area/Zone
WDA/Z	Weapon Danger Area/Zone

ANNEX C

Risk Management

From US FM 100-14: Risk Management, April 1998

1. Risk management is the process of identifying, assessing, and controlling risks. Risk management is a five-step process. The five steps are:

   a. Step **1**: Identify hazards
   b. Step **2**: Assess hazards
   c. Step **3**: Develop controls to determine residual risk and make risk decisions
   d. Step **4**: Implement controls
   e. Step **5**: Supervise and evaluate

2. Steps **1** and **2** together comprise the risk assessment for WDA/Z development. In step **1** the hazards that may be encountered are identified. In step **2** the direct impact of each hazard is determined. Step **2** is completed in sub-steps.

3. Sub-step A assesses each hazard in relation to the probability of a hazardous incident. Figure C.1 (see next page) provides a summary of the five degrees of probability. The letters in parentheses following each degree (A through E) provide a symbol for depicting probability.

FREQUENT (A) Occurs very often, continuously experienced	
Single item	Occurs very often in service life. Expected to occur several times over duration of a specific mission or operation. Always occurs.
Fleet or inventory of items	Occurs continuously during a specific mission of operation, or over a service life.
Individual soldier	Occurs very often in career. Expected to occur several times during mission or operation. Always occurs.
All soldiers exposed	Occurs continuously during a specific mission or operation
LIKELY (B) Occurs several times	
Single item	Occurs several times in service life. Expected to occur during a specific mission or operation.
Fleet or inventory of items	Occurs at a high rate, but experienced intermittently (regular intervals, generally often).
Individual soldier	Occurs several times in career. Expected to occur during a specific mission or operation.
All soldiers exposed	Occurs at a high rate, but experienced intermittently.
OCCASIONAL (C) Occurs sporadically	
Single item	Occurs some time in service life. May occur about as often as not during a specific mission or operation.
Fleet or inventory of items	Occurs several times in service life.
Individual soldier	Occurs some times in career. May occur during a specific mission or operation, but not often.
All soldiers exposed	Occurs sporadically (irregularly, sparsely, or sometimes).
SELDOM (D) Remotely possible; could occur at sometime	
Single item	Occurs in service life, but only remotely possible. Not expected to occur during a specific mission or operation.
Fleet or inventory of items	Occurs as isolated incidents. Possible to occur some time in service life, but rarely. Usually does not occur.
Individual soldier	Occurs as isolated incident during a career. Remotely possible, but not expected to occur during a specific mission or operation.
All soldiers exposed	Occurs rarely within exposed populations as isolated incidents.
UNLIKELY (E) Can assume will not occur, but not impossible	
Single item	Occurrence not impossible but can assume will almost never occur in service life. Can assume will not occur during a specific mission or operation.
Fleet or inventory of items	Occurs very rarely (almost never or improbable). Incidents may occur over service life, but rarely.
Individual soldier	Occurrence not impossible but may assume will not occur in career or during a specific mission or operation.
All soldiers exposed	Occurs very rarely, but not impossible.

Figure C.1: Hazard Probability

4. **Sub-step B** addresses the severity of each hazard. It is expressed in terms of degree of injury or illness, loss of or damage to equipment or property, environmental damage, and/or other mission impairing factors such as lost combat power. The degree of severity estimated for each hazard may be based on knowledge of the results of similar past events. There are four degrees of hazard severity (I through IV). Figure C.2 provides a summary of the four degrees of hazard severity.

CATSTROPHIC (I)
Loss of ability to accomplish the mission or mission failure. Death or permanent disability. Loss of major or mission critical system or equipment. Major property damage. Severe environmental damage. Mission critical security failure. Unacceptable collateral damage.
CRITICAL (II)
Significantly (severely) degraded mission capability or unit readiness. Permanent partial disability, temporary total disability. Extensive (major) damages to equipment or systems. Significant damage to property or the environment. Security failure. Significant collateral damage.
MARGINAL (III)
Degraded mission capability or unit readiness. Lost day due to injury or illness. Minor damage to equipment or systems, property or the environment.
NEGLIBLE (IV)
Little or no adverse impact on mission capability. First aid or minor medical treatment. Slight equipment or system damage. Little or no property or environmental damage.

Figure C.2: Hazard Severity

5. **Sub step C** combines the results of sub steps A and B to create an estimate for the overall initial risk. This can be depicted on a risk assessment matrix as shown in Figure C.3 on the next page.

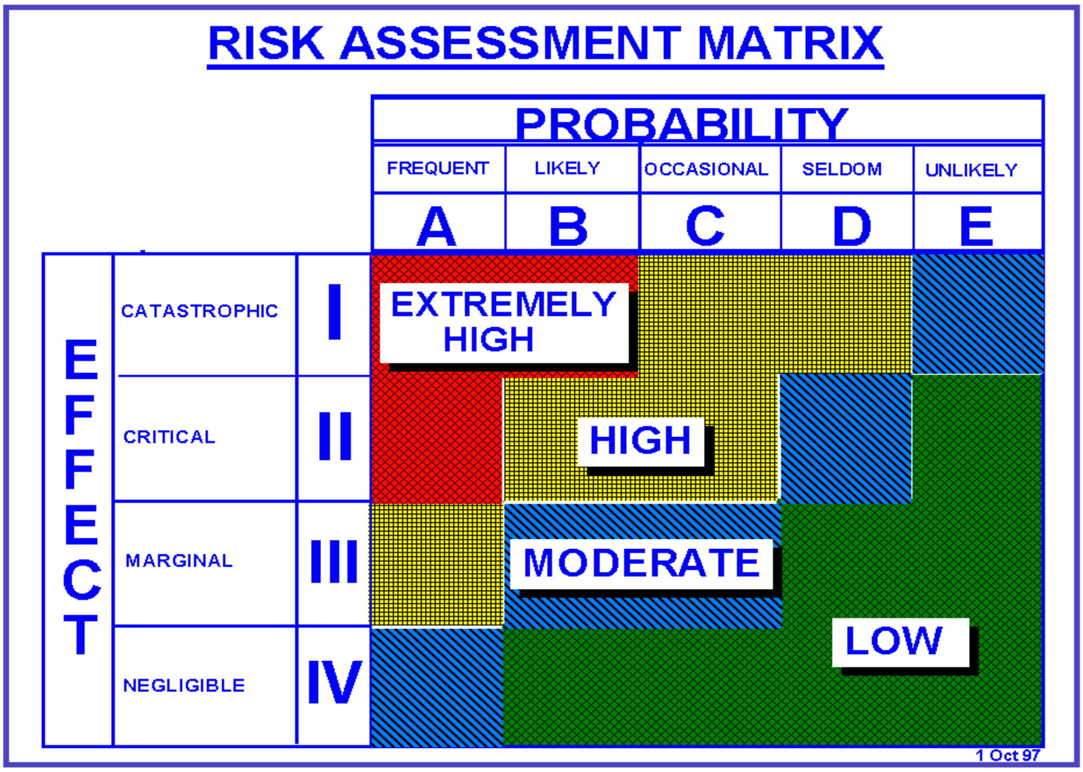


Figure C.3: Risk Assessment Matrix

6. Step **3** is accomplished in **2 sub-steps**: <u>develop controls and make risk decisions</u>.

7. <u>Sub-step **A** - Develop Controls</u>. After assessing each hazard, leaders develop one or more controls that either eliminate the hazard or reduce the risk (probability and/or severity) of a hazardous incident. When developing controls, they consider the reason for the hazard not just the hazard itself.

a. <u>Types of Controls</u>. Controls can take many forms, but fall into three basic categories educational controls, physical controls, and avoidance.

(1) *<u>Educational controls</u>.* These controls are based on the knowledge and skills of the units and individuals. Effective control is implemented through individual and collective training that ensures performance to standard.

(2) *<u>Physical controls</u>.* These controls may take the form of barriers and guards or signs to warn individuals and units that a hazard exists. Additionally, special controller or oversight personnel responsible for locating specific hazards fall into this category.

(3) *<u>Avoidance.</u>* These controls are applied when leaders take positive action to prevent contact with an identified hazard.

b. Criteria for Controls. To be effective, each control developed must meet the following criteria:

(1) *Suitability.* It must remove the hazard or mitigate (reduce) the residual risk to an acceptable level.

(2) *Feasibility.* The unit must have the capability to implement the control.

(3) *Acceptability.* The benefit gained by implementing the control must justify the cost in resources and time. The assessment of acceptability is largely subjective.

c. Residual Risk. Once the responsible leader develops and accepts controls, he determines the residual risk associated with each hazard and the overall residual risk for the mission. Residual risk is the risk remaining after controls have been selected for the hazard. Residual risk is valid (true) only if the controls for it are implemented. As controls for hazards are identified and selected, the hazards are reassessed as in Step 2 and the level of risk is then revised. This process is repeated until the level of residual risk is acceptable to the commander or leader or cannot be further reduced.

d. Overall residual risk. This type of risk must be determined when more than one hazard is identified. The residual risk for each of these hazards may have a different level, depending on the assessed probability and severity of the hazardous incident. Overall residual mission risk should be determined based on the incident having the greatest residual risk. Determining overall mission risk by averaging the risks of all hazards is not valid. If one hazard has high risk, the overall residual risk of the mission is high, no matter how many moderate or low risk hazards are present.

8. Sub-step **B** - Make Risk Decision. A key element of the risk decision is determining if the risk is justified. The commander must compare and balance the risk against mission expectations. He alone decides if controls are sufficient and acceptable and whether to accept the resulting residual risk. If he determines the risk level is too high, he directs the development of additional controls or alternate controls, or he modifies, changes, or rejects the recommended course of action.

9. Step **4**, implementing controls, requires that controls are integrated into appropriate verbal and written orders and instructions. Controls must be clear and simple and understood at all levels.

10. Step **5**, supervision and evaluation, requires that standards and controls be enforced. Evaluation is used to determine the effectiveness of each control measure and identifying and accurately assessing the probability and severity of hazards, as well as determining whether the level of residual risk was accurately estimated. **Figure C.4** (see next page) provides an overview of the risk management cycle as a continuous process (application).

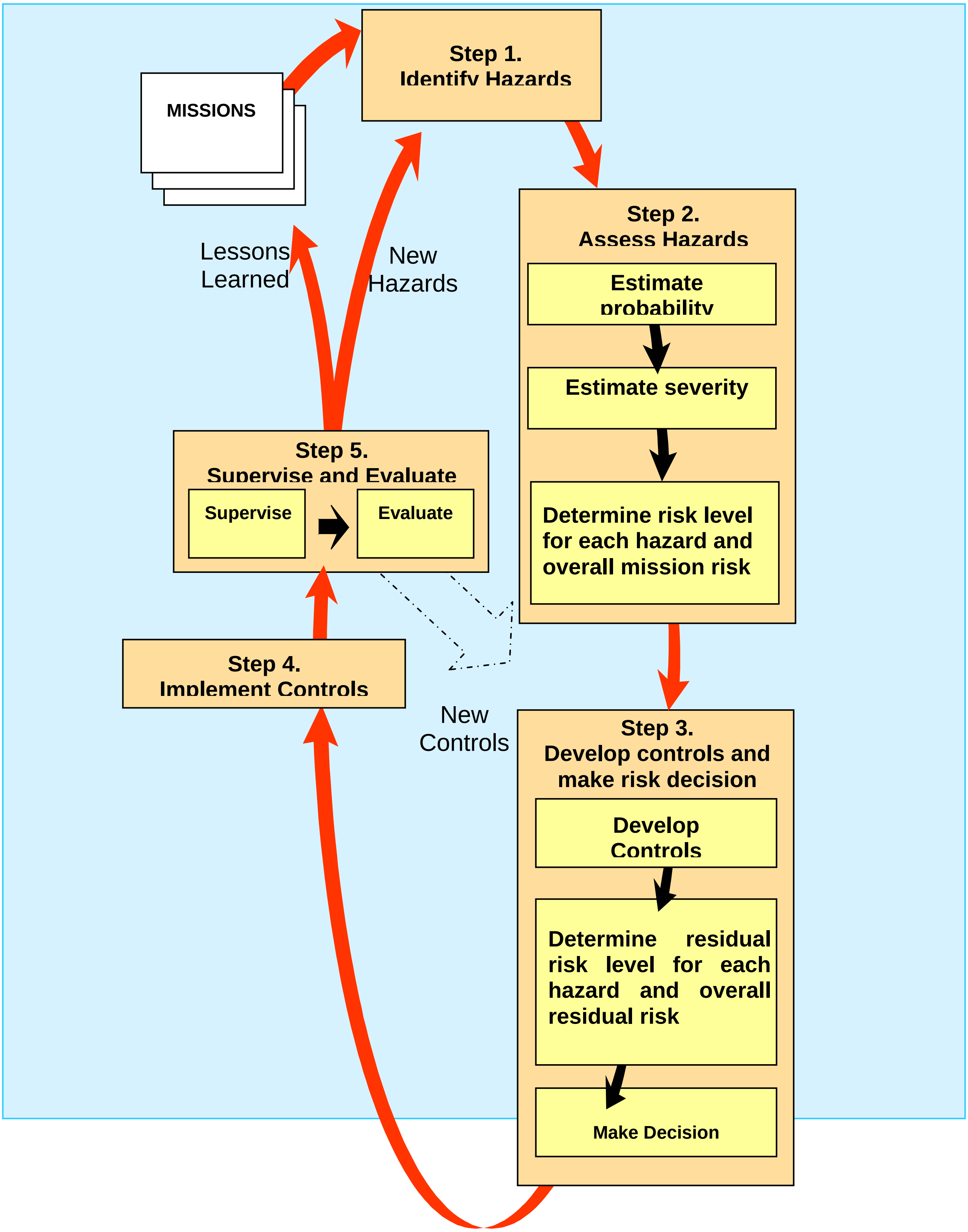


Figure C.4: Continuous Application of Risk Management