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GUIDANCE ON THE DEVELOPMENT OF WEAPON DANGER AREAS/ZONES FOR GUIDED WEAPONS

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NATO LETTER OF PROMULGATION

Date

1. The enclosed Allied Range Safety Publication ARSP-02, Volume III, Edition A, Version 1, GUIDANCE ON THE DEVELOPMENT OF WEAPON DANGER AREAS/ZONES FOR GUIDED WEAPONS, which has been approved by the nations in the Military Committee Land Standardization Board, is promulgated herewith. The agreement of interested nations to use this publication is recorded in STANAG 2470.

2. ARSP-02, Edition A, Volume III, Version 1, is effective upon receipt.

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS
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RECORD OF SPECIFIC RESERVATIONS

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

1. Introduction. Guided weapons (GW) systems are fired for practice on designated military land and sea ranges with defined boundaries or on the high seas. A GW system includes the missile, firing platform, guidance and control equipment. Outside the range boundaries the general public have freedom of access. Where a range utilises sea danger areas, shipping of any nationality may freely enter these designated danger areas. Similarly, civil and military aircraft may fly over ranges where GW are being fired. The hazards to personnel operating the weapons, those working within range areas and the general public must be assessed to ensure that the risk of them being injured by missiles fired on those ranges is reduced to a level which is as low as reasonably practicable (ALARP). A key element in this process is the identification of the weapon danger areas (WDA) associated with each type of GW being fired. A WDA contains 2 groups of hazards which need to be evaluated: launch hazards and in-flight hazards.

1.2 GUIDED WEAPON (GW) WEAPON DANGER AREA/ZONE (WDA/Z)

1. The GW WDA/Z template is three-dimensional but is normally displayed as two dimensional template with a height restriction. Traditionally, GW WDA/Z have been developed using deterministic methodology and WDA are extended into WDZ by using a constant height above the WDA. The level of risk associated with the WDA or WDZ has been assessed as tolerable but has not been explicitly quantified. In order to quantify the levels of risk we have to use a probabilistic methodology.

2. There are 2 types of WDA associated with GW systems:

   a. Total Energy WDA. Total Energy WDAs are applicable to GW which are not fitted with a Flight Termination System (FTS) and are designed usually to contain all the missiles and their associated debris during firing. Such WDA are used for those missiles with a short range. The WDA will differ depending on whether the missile has an inert, telemetry or operational payload.

   b WDA derived for GW Systems with a FTS Fitted. For longer range and more agile GW it may be impossible to contain the total energy WDA within designated range danger area. Consequently, FTS are used to allow a reduced WDA.

3. GW WDA/Z developed using deterministic principles, where a number of worst-case assumptions are used, are usually more conservative in size. This often results in the use of large areas or zones and can constrain training. As probabilistic methodologies are developed they can be used to provide a more accurate assessment on the area required to contain failures of any component of the GW. Improved accuracy of the estimation of the area required can lead to a reduction in the overall size of the WDA. Also, probabilistic analyses can provide information that can be used to diagnose problems for conceptual or existing ranges. The principles for the development of probabilistic WDAs are contained in ARSP 2 Vol I.

4. It is important to note that the use of a probabilistic methodology is not a universal remedy. Whilst it has many advantages over deterministic methodology, probabilistic models have to be developed and data needs to be gathered and analyzed for use in these models and this may not be a simple process.

1.3 OUTLINE OF ACTIVITY

1. To derive a WDA some or all of the following activity is required:

a. Development of a GW system performance model.

b. Analysis of the guided missile flight failure modes and the resultant hazards.

c. Derivation of the Air Danger Height (ADH).

d. Derivation of the Total Energy WDA.

e. Derivation of the Launch Danger Area.

f. Identification of the flight termination/destruct boundaries.

g. Derivation of the WDA when a FTS is fitted.

h. Assessment of the reliability of the FTS (where applicable).

i. Conducting a risk assessment.

J. Considering the method of wind correction if applicable.

1.4 AIM

1. The aim of this document is to describe the general methodology that may be applied to develop an appropriate WDA/Z for use on ranges. The principles are necessarily general to enable them to be used for all GW.

1.5 SCOPE OF THIS PUBLICATION

1. This publication will replace STANAG 2921 (Reference 5) and is concerned primarily with:

a. Assessing the various hazards associated with launch, flight, and recovery of land launched GWs.

b. Assessing the risk to personnel operating on military ranges and the general public.

c. Discussing the factors for which allowance should be made when determining the extent of the WDA/Z.

2. It is intended to give guidance on some methods that have been used in the past and to give an indication of the detail and quality of information required.

3. Figures regarding required reliability and tolerable risk are not given as it is considered that the responsibility for setting them lies with the country in which the GW is to be launched.

4. The application of WDA in order to define GW Range Danger Area is the responsibility of the appropriate national authority.

5. This agreement is concerned with the determination of GW danger areas and all references to danger areas indicate GW danger areas unless otherwise stated.

1.6 VOCABULARY AND ABBREVIATIONS

1. The following terms are defined for the purpose of this ARSP only. No formal agreement exists for their employment in any other context:

   a. Buffer zone is the three-dimensional area between a weapon danger boundary and a range danger boundary designed to increase the margin for error in WDA calculations.

   b. Debris zone is the three-dimensional area between the flight termination boundary and the weapon danger boundary.

   c. Launch danger area is the space around the GW Launcher in which personnel are at risk from system launch hazards and therefore the presence and protection of personnel is closely controlled.

   d. Flight Termination System is a system fitted to a GW used to terminate flight in the event of a designated 'flight terminate' line being transgressed.

2. Other technical terms and abbreviations used in this publication are provided in the Lexicon.

1.7 RELATED DOCUMENTS

1. This is one of a sequence of Allied Range Safety Publications (ARSPs) that are concerned with the development of WDA/Z for a variety of weapon systems. The proposed framework is shown in Figure 1. The colours represent the following:

   Green – Ratified documents

   Yellow – In construction

   Red – To be written

2. Brief descriptions of each ARSP are given below:

   a. Volumes in ARSP-1 cover the deterministic methodology:

      (1) Volume I (Reference 1) contains a description of the factors that are relevant to the use of unguided weapons.

      (2) Volume II (Reference 2) contains a description of the application of the factors from Volume I, and provides generic danger area outlines together with nation dependent numerical values for the factors.

b. Volumes in ARSP-2 cover the probabilistic methodology:

(1) Volume I (Reference 3) contains a description of the application of these principles to unguided weapons.

(2) Volume II (Reference 4) will contain the methodologies for the construction of probabilistic weapon danger areas.

(3) Volume III (this Volume) a description of the application of these principles to guided weapons (GW)

(4) Volume IV will contain a description of the application of these principles to unmanned aerial vehicles (UAV).

3. Some of the volumes described will be derived from existing STANAGs:

a. ARSP-2 Volume IV will be produced by updating STANAG 2402 (Reference 6).

1.8 IMPLEMENTATION OF THE AGREEMENT

This ARSP is implemented when the necessary orders/instructions putting the principles and procedures detailed in the agreement into effect have been issued to the forces concerned.

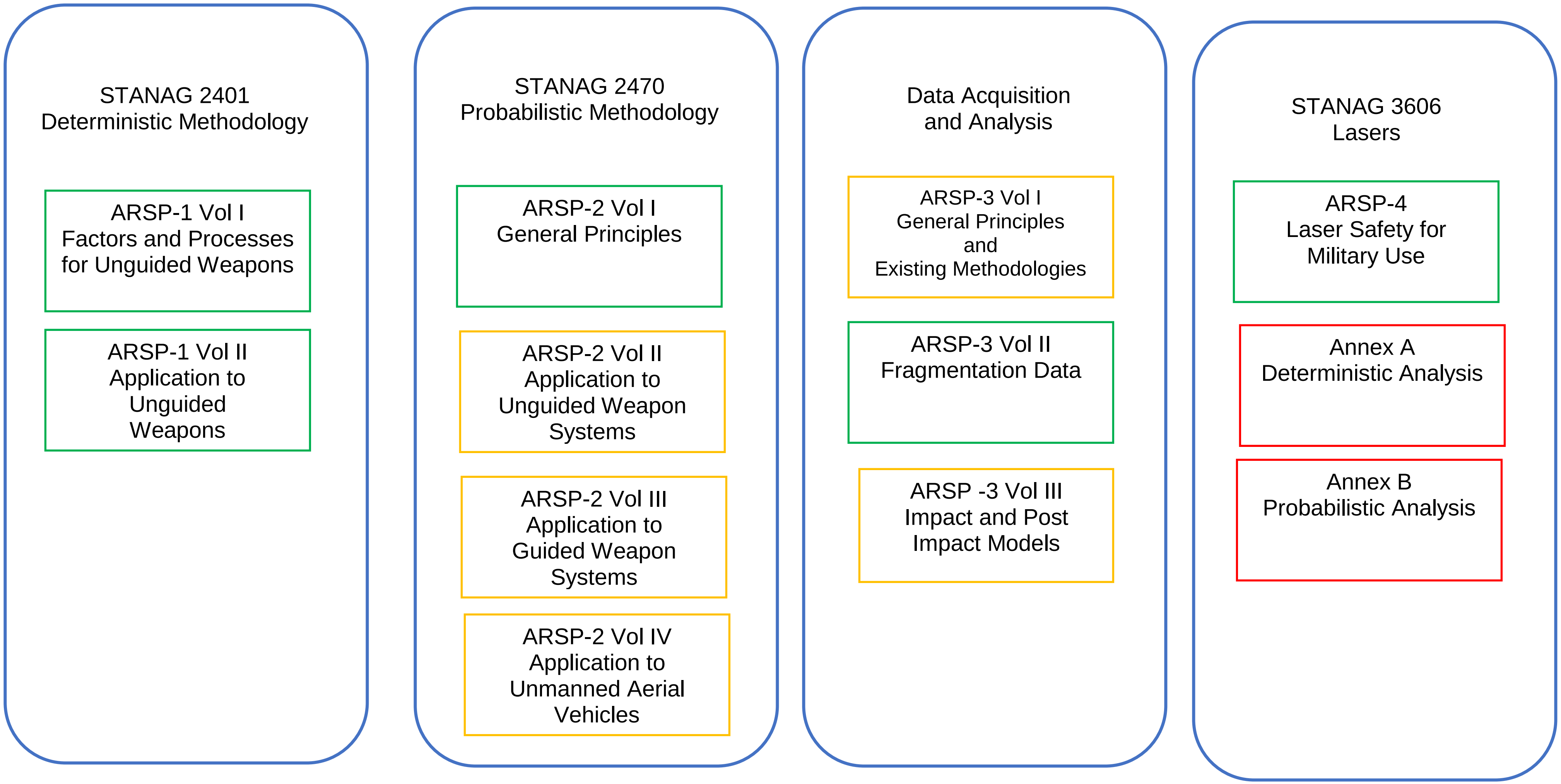

Figure 1. Framework of each Allied Range Safety Publications (ARSP).

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CHAPTER 2

PERFORMANCE MODEL

2.1 INTRODUCTION

1. General. When developing modern GW systems, use is made of performance models allowing data to be processed by computer. These are usually 6 degrees-of-freedom (DOF) models whose outputs are in the X, Y and Z positional axis and the yaw, pitch and roll rotational axis set. These models are essential tools in calculating the trajectories of correctly functioning and “rogue” missiles Where appropriate these models will be supplemented with others that represent warhead effects (e.g. point mass models). If a 3 DOF model (i.e. three spatial DOF only) or 4 DOF model (i.e. three spatial DOF plus axial spin) is used, it should be validated against a 6 DOF model. The safety criticality/safety significance of the model, if used to examine potential hazards, should be established. Since some models may be safety critical/safety significant it therefore follows that they should be written using high integrity software and be subjected to an independent validation and verification process, which provides confidence in the results obtained, in accordance with appropriate national/international standards.

2.2 MODEL INPUTS

1. Model Inputs. The inputs to models can be divided into 7 groups, with sub-paragraphs a. to f. used to obtain the total energy WDA, and data under sub-paragraph g. included where a FTS is fitted:

   a. Launch variables.

   b. Missile in-flight characteristics.

   c. Missile in-flight failure modes.

   d. Engagement geometry.

   e. Range and environmental factors.

   f. Payload effects.

   g. Additional factors introduced as a result of the introduction of a FTS.

2. Launch Variables. Some of the variables that can be introduced at launch and which should be considered are:

   a. Launch platform altitude and position.

   b. Launch platform velocity.

   c. Launch platform heading.

   d. Launch platform quadrant elevation (QE) or pitch attitude in the case of aircraft.

e. Launch platform roll angle.

f. Launcher tip-off effects.

g. Propulsion motor charge temperature and its effect on motor performance.

h. Launch mass.

i. The relative position of missile launch points on a multiple launcher to the line of fire.

j. In the case of long range missiles consideration should be given to latitude, curvature of the earth and the Coriolis effect.

3. Missile Flight Characteristics. The following are examples of missile flight characteristics that should be considered:

a. Propulsion motor thrust misalignment.

b. Asymmetric thrust resulting when one or more launch motors, fired as a cluster, fail to function.

c. Missile thrust/time profile of both the launch and flight motors.

d. Propellant mass and burn-out time of both launch and flight motors.

e. Earliest and latest Safety and Arming Unit (SAU)/Flight Termination System (FTS) Arming Unit times and distances.

f. Missile centre of gravity including changes in this parameter in flight, e.g. when fuel is expended, and its effect on the static margin.

g. Missile aerodynamics, kinematics, and coefficients.

h. Maximum lateral acceleration (latax) which the missile can achieve.

i. Maximum velocity.

j. Missile trajectory; on occasions this will be the output of the programme.

k. Fault tolerance and correction.

l. Variations in build standard.

4. Missile Flight Failure Modes (FM). As a result of an analysis of the GW system, missile flight FM should be identified with their probability of occurrence and then incorporated, at set time in the missile flight, within the performance model so that their effect on the missile trajectory can be assessed.

5. Engagement Geometry. The relative positions of modules of the GW system and the target will affect the operation of the system and therefore need to be considered. Examples are:

a. Target location including consideration of moving targets.

b. The displacement of the GW system sight from the missile launch position.

c. Movement of the launch platform (e.g. vehicle, ship, or aircraft (including helicopters)).

6. Range and Environmental Factors. Range and environmental factors contribute to the size of WDAs and may impose limitations on their application. Examples are:

a. In the application of range safety measures there is usually an element of delay such as:

(1) Reaction times of the range safety staff.

(2) Range safety equipment (RSE) functional delays.

b. Meteorological effects (including temperature, air density, wind direction and speed).

c. Errors in measuring missile position.

d. The accuracy of range sensors.

e. The physical lay-out of the range.

7. Payload Effects. A warhead/payload event could occur at an unplanned time in the flight of a missile, e.g. a missile warhead may detonate on arming. This will affect the shape of a WDA. Whenever possible these effects, which will be dependent on the type of warhead used e.g. blast, fragmentation or shaped charge, should be included within the model. This information should be available from component trials. If such empirical data is not available, the effect should be modelled and whenever possible the effects should be confirmed by live firing. The payload may not be explosive (e.g. it may be a chaff dispenser) nevertheless the effects of desired and premature operation, on range safety, need to be assessed and quantified.

8. Additional Factors to be Considered as a Result of the Introduction of a FTS. When a FTS is fitted the following additional factors may need to be considered and incorporated within the performance model:

a. Pre-defined destruct boundaries (azimuth and elevation)

b. Position of the Visual Flight Safety Officer (VFSO) with respect to the launcher.

c. Position of the VFSO with respect to the nominal line of fire.

d. FTS interfaces with the missile control systems.

e. The VFSO's reaction times.

f. Delays in the operation of the FTS.

g. The reliability of the FTS.

h. Missile and debris scatter after the FTS has been initiated.

i. GW system and functional delays.

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CHAPTER 3

FLIGHT FAILURE MODES AND HAZARD ANALYSIS

3.1 INTRODUCTION.

1. It is first necessary to assess the probability of a GW of going "rogue". The GW may behave in a variety of ways:

a It may crash within the WDA, thereby should not pose a risk to personnel.

b. In the event of FTS failure there are 3 possibilities which could present a level of risk to personnel:

(1) It could become a ballistic projectile, continue on course but, in the event of a FTS failure, crash beyond the WDA boundary.

(2) It may turn and crash outside the left and right WDA boundary or within areas defined as low risk where the population density is controlled.

(3) Under certain failure conditions it may loop over the launcher and crash outside the WDA rear boundary.

3.2 FAILURE MODES.

1. General. When assessing the probability of a "rogue" missile flight a whole-system approach should be taken. An analysis should be made of the GW system's FM and their effect on the missile trajectory should be identified. Additionally, when fitted and used, the RSE and the FTS are part of the system. The method used to assess the probability of a "rogue" missile flight varies with the size, complexity and cost of the weapon system. When a small, comparatively cheap missile system is being considered, a large amount of data from firing trials may be available. An assessment based upon actual results may be made, supplemented by theoretical analysis of the system. When a large, costly system is assessed, it is unlikely that sufficient missiles will have been fired to produce adequate data and a purely theoretical assessment will have to be made. However, all available firing data should be used.

2. Possible Effects of Failure. A missile failure after launch may have serious consequences for range safety if the operator/ system loses control of the missile. The length of time the missile remains airborne will depend on the nature of the failure and the nature of the missile engagement. For example: removal of all control signals by wire-break may be designed to result in a wire-guided missile flying ballistically to the ground whilst a failure of system electronics or missile control hardware which results in the control surfaces remaining in a fixed position may cause an aerodynamically stable missile to travel a considerable distance.

3. Types of Failure. The types of failure to be considered depend on the GW system used, e.g. the FM associated with a Command to Line-of-Sight (CLOS) system will be different to a fire and forget system. Examples of FMs that have been identified in the past are:

a. Autopilot failures such as gyro topple and drift.

b. GPS/IMU failure.

c. Control surfaces jamming (fins, jetavators or vanes).

d. SAU/FTS arming unit failures.

e. A break in, or interference with, the command link.

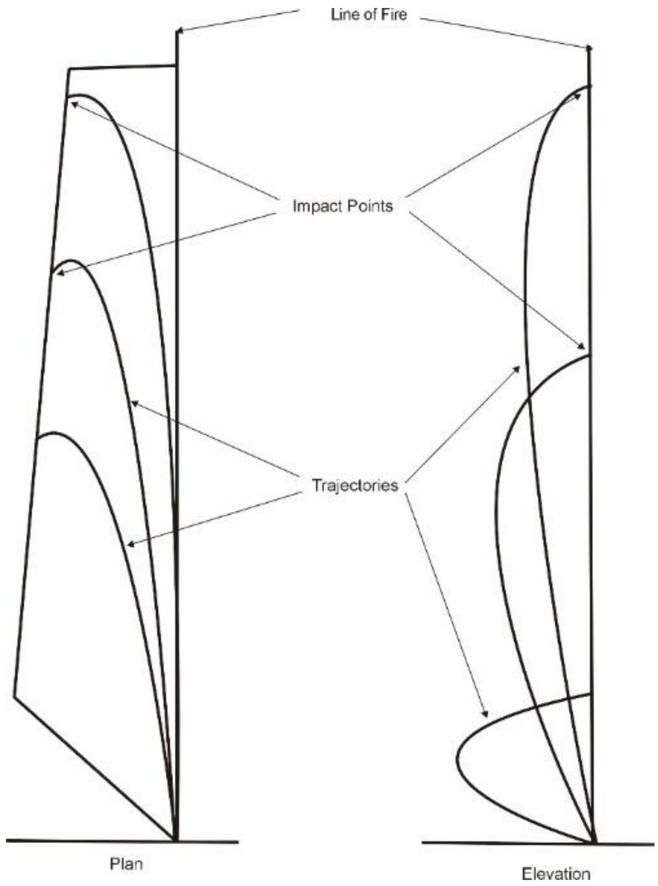
4. Component Reliability. The first stage of FM analysis is to establish the failure rate for each component of the GW system including RSE. This information should be available from manufacturers or other databases e.g. MIL HDBK 217. These figures are usually theoretical, being based on reliability data obtained during development and the ground testing of components. Difficulty may be experienced in obtaining these figures when GW and components are purchased from foreign manufacturers. Useful tools in support of this work are reliability block diagrams, Fault Tree Analysis (FTA), Failure Modes Effects and Criticality Analysis (FMECA) and quantified hazard analysis techniques. Care should be taken to ensure that the information is relevant in the particular application being considered. Figures used should be justified and sources stated. If information is unavailable it may be necessary to rely on the qualitative assessments made by guided weapons engineers. A number of worst-case assumptions may have to be made; this will at least ensure that the resultant WDA has a high safety factor.

5. Failure Mode (FM) Analysis. Using reliability data it is necessary to identify each failure separately on a FM list, an outline of which is given at Annex A. The FM list should then be used as the basis of a FM Log, an explanation is given at Annex B. Each FM should be allocated a discrete number for cross reference purposes. The FM should then be described in reasonably simple terms. The missile behaviour resulting from the failure should be analyzed and described. The FMs should then be simulated at any time in a missile flight to identify possible "rogue" trajectories. The method of simulation should be described in the FM Log with any conclusions to be drawn.

6. Impact Analysis. The approach used to conduct this analysis is dependent on the principles which form the basis of the design of the GW system. It follows that there is no prescribed method to be followed. Two possible methods are described below:

a. Using data gathered as a result of the FM analysis it is possible, using a performance model, to analyze the fall of shot for each FM. An example of a possible form of output is shown in Figure 2.

Figure 2. Model output



b. This should be incorporated within the FM Log (Annex B). A line can then be drawn around the plots thus defining an impact area associated with that specific failure, Figure 3. This procedure is followed for all the identified FMs and all the impact areas are then combined to produce an overall impact area, as shown in Figure 4. Using this information it is possible to produce an impact trace based on the line of fire in which areas of high and low risk, based on impact analysis, can be identified, Figure 5. Confidence levels and assumptions should be agreed with the appropriate national authorities.

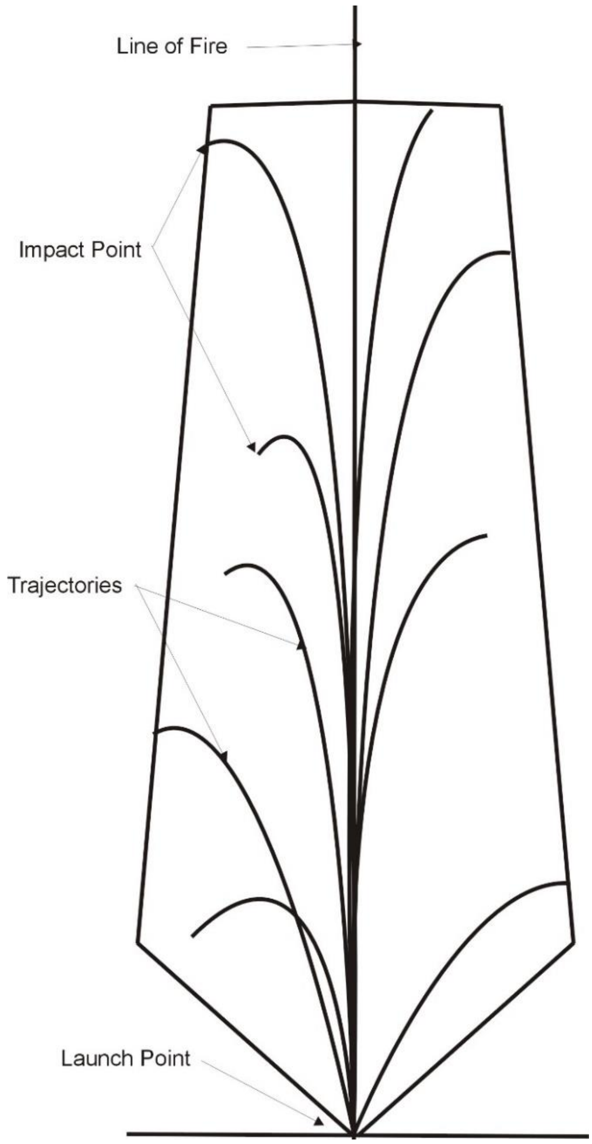


Figure 3. Example failure mode impact area trace

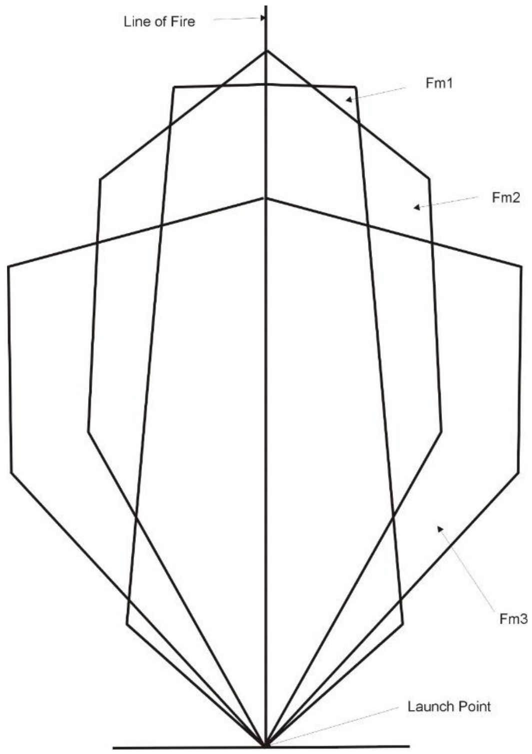
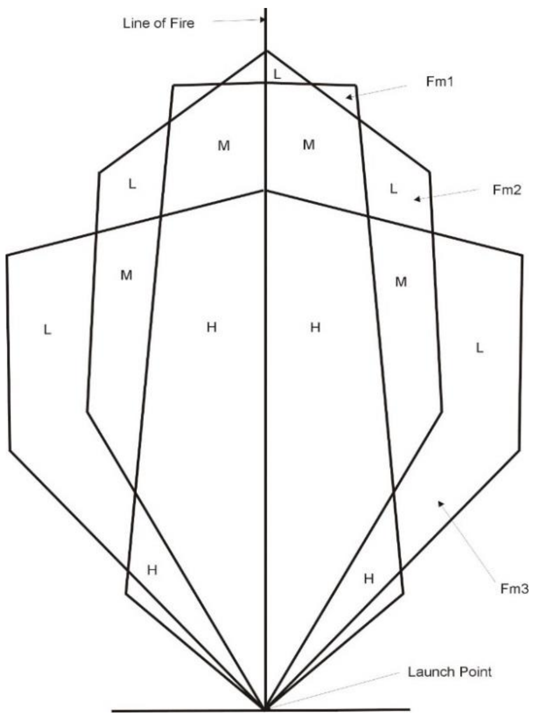


Figure 4. Example of FM traces overlaid to create a composite WDA



Legend:
L: - Area of Low Risk
M:- Area of Medium Risk
H: - Area of High Risk

Figure 5. Example showing areas of low and high risk within a WDA as a result of impact analysis

Alternatively, it is possible to analyze where the majority of the missiles will land using modelling techniques such as Monte Carlo simulations. The likely impact area is divided into small squares and the impact of a large number of simulated firings (e.g. 100,000) is plotted in the squares. The distribution can then be used to create a WDA identifying areas of high and low risk. An example of the results derived from this form of analysis is given In Figure 6. Confidence levels and assumptions should be agreed with the appropriate national authorities.

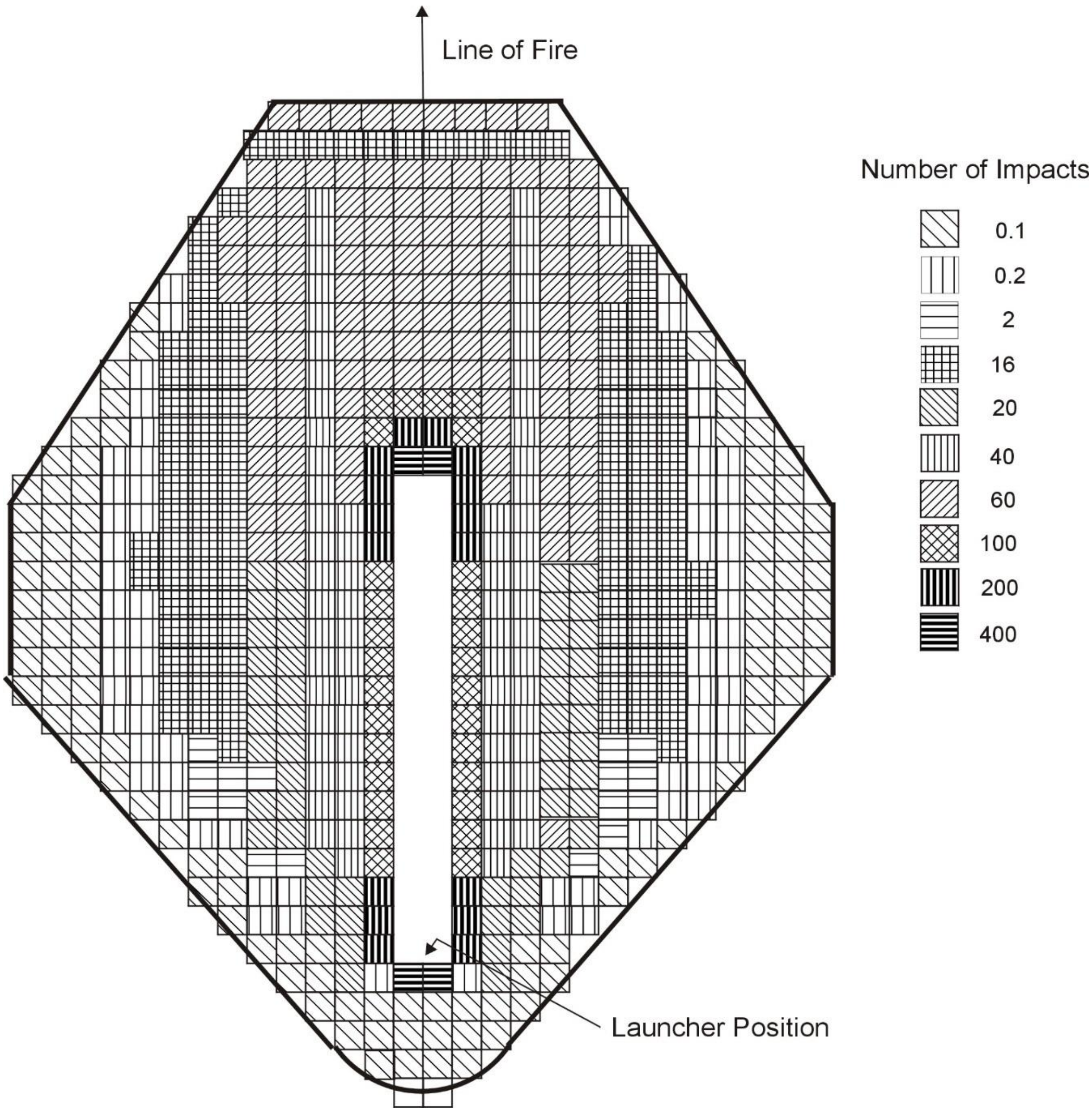


Figure 6. WDA generated by using Monte Carlo techniques

7. Frequency. The relationship between the various FMs need to be established and the chance of their occurring assessed so that their individual and cumulative effect may be evaluated. Using flight records and theoretical assessments it should be possible to establish the probability of a failure occurring. Care should be taken to ensure that the environment in which this data was obtained is known. This ensures that the application of this data is appropriate to future firing. It may be necessary to adjust the figures using technical judgement. This should confirm the high and low risk areas inside a WDA which were identified as a result of the impact analysis and refine the risk assessment. A possible basis for this analysis is to create an event tree, Figure 7, assigning probabilities to each FM.

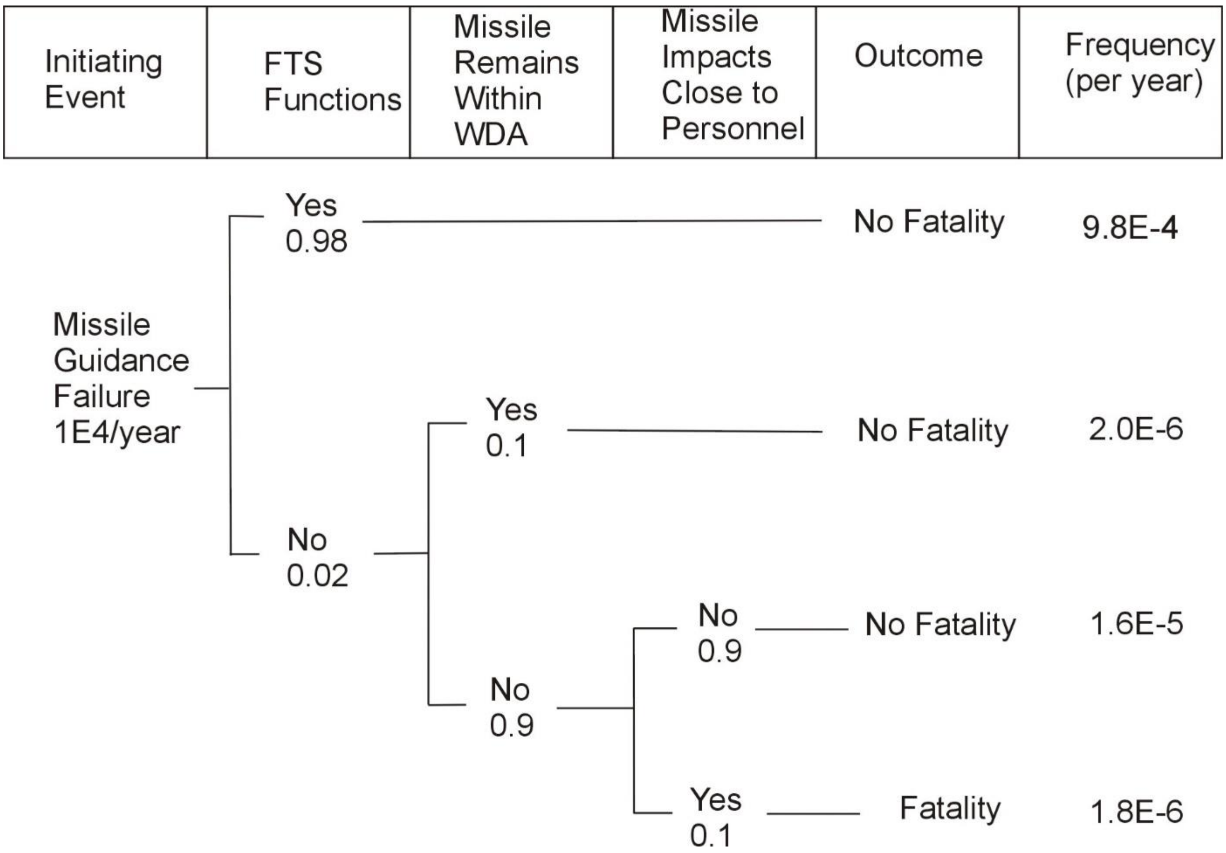
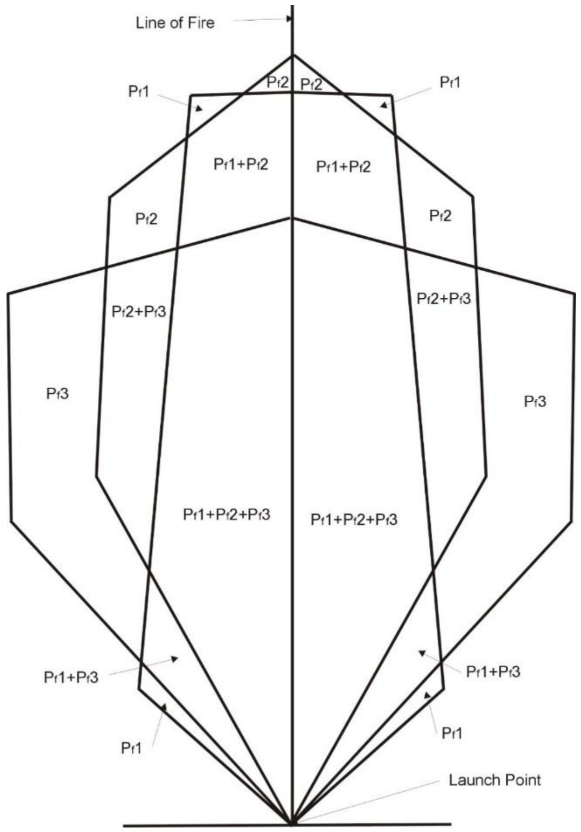


Figure 7. Example of event tree showing probabilities

8. An example of output from this form of quantified analysis is given in Figure 8. In this case, the designation of areas of high, low and medium risk is dependent on the order of probabilities i.e. $P_{f}1<P_{f}2<P_{f}3$. It may be necessary to make some worst-case assumptions.



P_f1: Probability of Failure Mode (FM) 1 occurring.
P_f2: Probability of FM 2 occurring
P_f3: Probability of FM 3 occurring.
Probabilities are summed where FM areas overlap

Figure 8. Example of areas of risk with assigned probabilities

9. Problems Associated with Air Launched GW. The exact position, velocity and heading of the aircraft is not known at the instant of launch. Therefore, extra allowance has to be made when calculating the boundaries of WDAs based on the probability of a missile FM occurring. Consideration should be given to:

a. Launch. A launch box in which the missile can be fired should be defined. The pilot should not be permitted to fire when outside the box and should be constrained to fire within prescribed limits of altitude, heading, angle of attack and roll angle.

b. Engagement. A WDA should be defined when firing an air launched GW at a target such as an Unmanned Aerial Vehicle (UAV). It should contain a danger area for each target engagement because of the variations which are possible in engagement conditions, such as altitude, speed and attitude.

A WDA can then be produced including both launch and engagement areas.

CHAPTER 4

DERIVATION OF THE WDA

4.1 DERIVATION OF THE WDA

1. Derivation of the ADH. In order to minimise the risk to aircraft flying over range areas it is necessary to calculate the maximum height which a guided missile, and its debris, may achieve. Three cases should be examined:

a. A complete guided missile.

b. A guided missile that has broken up as a result of FTS initiation.

c. A missile that achieves its maximum height which then breaks up. In these circumstances the distance to which the warhead fragments may reach must be considered and added to the apogee of the missile trajectory.

2. Derivation of the Total Energy WDA. In order to assess whether a GW system needs to be fitted with a FTS and identify possible areas where people may be at risk, the total energy WDA needs to be determined using a performance model. This is the area which will contain the missile and its debris in any eventuality. It takes into account the maximum motor burn time and minimum missile drag and is dependent on worst case missile launch QE and missile biases, which will cause the missile to fly the maximum distance from the launcher. To this is added the total energy effects of the warhead, including re-ignition and secondary launch if the motor can still produce thrust. The resultant shape of the total energy WDA is dependent on the missile aerodynamic characteristics; particular account should be taken of the maximum lateral acceleration (latax) to which the missile can be subjected before its structure fails. Consideration should also be given to meteorological effects.

4.2 DERIVATION OF THE LAUNCH DANGER AREA

1. General. During the development of a GW, hazards associated with launch areas may be identified. These launch hazard distances must be contained within the GW designated WDA. Examples of such hazards are blast overpressure, noise, debris, efflux, high velocity erosive gases, motor malfunctions and inadvertent captive firing. Consideration should also be given to the missile going "rogue" and causing a hazard to personnel on or near the firing point. Personnel should normally be excluded from these areas, with the exception of those deemed essential for the safe operation of the weapon.

2. Blast Overpressure. Motor ignition generates a pressure wave which may cause injury to human internal organs e.g. lungs. During development, trials should be conducted using remote firing techniques and instrumentation to establish the hazard area.

3. Noise. Noise generated at missile launch and in flight may cause damage to the hearing of persons located in the area of the launcher. In order to establish a hazard area, trials should be conducted to establish the noise hazard distance to the protected and unprotected ear.

4. Debris. Missile launch may result in:

a. Primary Debris. When the missile is launched from a tube or canister items, such as blow out panels, may be ejected. Normally this debris rapidly loses kinetic energy and would not be a hazard to personnel though it could cause the operator to be distracted. During firing trials it is recommended that the position of these items is identified so that areas of potential hazard can be derived and contained within the WDA.

b. Secondary Debris. The missile efflux can disturb loose stones and gravel in the area at the rear of the launcher. This hazard area should be identified and quantified.

5. Toxic Effects. A missile efflux frequently contains toxic fumes and particles. Trials should be conducted to measure the toxic content of the efflux and assess its effects. Trials should be conducted to measure the effect on persons located close within or close to the launcher and a hazard area identified.

6. High Velocity Erosive Gases. When launched, missiles emit a plume of very hot gases which could cause injury to persons. Trials should be conducted to measure any hazard area.

7. Motor Malfunctions. A missile motor design should follow the appropriate published national design principles. Range safety submissions should include details of the performance of the motor. Consideration should also be given to a number of possible motor hazards.

a. Hang Fire and Misfire. A hang fire is an undesired delay in the functioning of a firing system, a misfire is the failure of the ignition system of the rocket motor of a round to function wholly or in part. The hazards associated with a misfire or hang fire in either the 1st Stage or 2nd Stage Motor should be assessed.

(1) 1st Stage Motor. The hang fire/misfire waiting period should be defined and justified by the GW manufacturer. During the safety wait period the range clearance procedures for the weapon are to remain in force and the equipment and associated range systems must be set to demand flight termination in the event of a missile being launched. During this period, the risk to operators is reduced by the adoption of well-defined safety drills. Usually these are designed to ensure that the missile is kept at all times, during the designated waiting period, pointing in the centre line of the firing arc. In the case of handheld weapons a suitable secure mounting is required.

(2) 2nd Stage Motor. Unless the hang fire is of short duration it is likely that both hang fire and misfire events will result in the missile impacting with the ground. Subsequent action will depend on the location and state of the missile. Neither the missile nor any fragments should be approached until the waiting period associated with the missile has expired and then only after the appropriate safety rules published in National Ammunition Safety Regulations have been complied with.

b. Late Light-up of the 2nd Stage Motor. There is no direct hazard to personnel on the firing point, providing the missile does not ground prior to or shortly after light-up. If the missile grounds there is the possibility that the missile will break up on impact, with the debris being projected forward. There is, however, a remote possibility that a burning motor section might ricochet or turn so that it may be projected rearwards. A protective wall should reduce the risk from this hazard. If the missile does not break up, the possibility exists that the missile may resume flight, in which case the missile flight shall be terminated and the resultant debris should fall within the designated WDA. The situation could occur that the FTS is damaged during groundstrike and would not be able to terminate missile flight. This should be considered when designing the FTS and deriving the WDA.

8. Inadvertent Captive Firing. Some missile systems use the packaging as part of the missile launcher. On occasions an error of drill or system failure may cause the missile not to be released from the retaining packaging furniture at launch. This may result in the missile and packaging flying down range. A hazard area should be identified with this failure mode which should be included within the WDA.

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CHAPTER 5

IDENTIFICATION OF FLIGHT TERMINATION/DESTRUCT BOUNDARIES

5.1 FTS REQUIREMENT

1. General. If a FTS is fitted to a GW system the position of the flight termination boundary should be considered, in both plan and elevation. The following factors should be considered:

   a. The user requirement.

   b. The debris zone or warhead fragmentation area.

   c. The range topography.

   d. The buffer zone.

   e. Meteorological effects.

2. The User Requirement. In the case of long-range weapons, e.g. terrain following and sea skimming missiles, the free flight zone must be large enough to allow the user to achieve the trial/ training aims. In the past the destruct boundary has been based on the 3σ (3 SD) contour around the planned missile trajectory to allow for variations in GW system performance, i.e. it is the area in which 99.7% of missiles will travel.

3. Fitting a FTS. To ensure that "rogue" missiles fall within their designated WDA they are fitted with a FTS. Whilst this produces a degree of confidence that a missile will not fly outside a designated WDA it follows that the reliability of the FTS must be assessed. The method used will depend on how frequently the system has been used in flight. If insufficient empirical data is available from trials, a theoretical assessment based on a reliability analysis (such as FMECA and FTA) of its components supported by good engineering judgement will have to be completed. The probability of a dangerous "rogue" missile occurring in these circumstances may be calculated by compounding the probability of a missile failure with the probability of the FTS failing.

5.2 ZONES AND ARCS.

1. The Debris Zone. Associated with a FTS fitted GW is a debris zone, which is defined as the zone between the destruct boundary and the weapon danger boundary. It is designed to contain all the debris that results from the activation of the FTS and is based upon the conclusions of the hazard and impact analyses discussed above. As part of the computer modelling process the throw, or distance travelled, of major missile components, including the payload, after break-up (which is assumed when the missile is destroyed) may be assessed using worst case assumptions, such as:

   a. The missile is at the elevation destruct boundary altitude as used by the VFSO.

   b. The missile crosses the azimuth destruct boundary at right angles.

c. The missile is travelling at the maximum velocity.

d. The missile body attitude is such that which the worst case throw conditions will be produced.

2. The Range Topography. If a GW is to be fired on a specified range it is possible to tailor the destruct boundary and hence the WDA. In this case the WDA will be designed to avoid the possibility of missile debris impacting in specific areas such as ammunition compounds, range technical facilities, maintenance and administrative areas.

3. The Buffer Zone. On occasions it may be necessary to include an extra margin for error to ensure that there is a low risk to any person close to, but outside, the range boundary. This may be dependent on the confidence levels associated with the performance model. In this case a buffer zone may be inserted between the WDA boundary and the range boundary. Figure 9 demonstrates the concept in plan view.

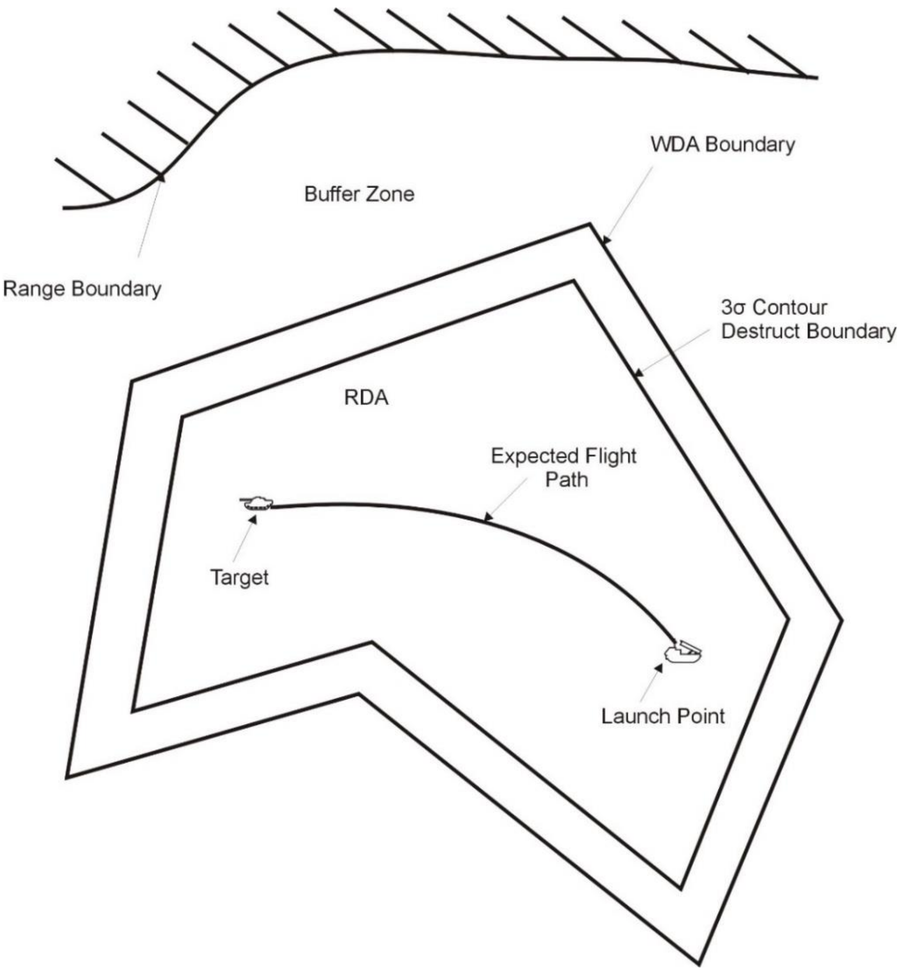

Figure 9. FTS based WDA

5. Engagement Arcs. When a FTS is used and depending on the type of GW system, precautions may need to be taken to inhibit the firing of the missile so that it cannot be launched outside clearly defined azimuth and elevation engagement arcs. If

it were to be launched it would be destroyed on arming. It is therefore essential to define engagement arcs that are within the associated flight termination/destruct boundaries.

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CHAPTER 6

RISK ANALYSIS – PERSONNEL

6.1 GENERAL. It is possible to postulate multiple fault conditions which, if they occur, could lead to a missile or parts of a missile impacting outside the WDA. However, it must be demonstrated that the probability of this occurring is reduced to a level such as to be ALARP. A risk analysis should be completed taking into account the following groups of people:

a. Exercise participants.

b. Personnel on the range who are not participating in the exercise.

c. The general public.

6.2 RISK CRITERIA.

1. General. Risk criteria are agreed from time to time by the appropriate national authorities. The risk analysis should, if possible, be quantitative in nature and should address both individual (I_{risk}) and individual cumulative risk (C_{risk}) resulting from a person being exposed to a large number of firings.

a. Individual Risk. The risk of injury to an individual per firing within a given area is given by:

$$I_{risk} = \frac{E.P}{A}$$

where: E is the missile debris area in sq.m.
P is the probability of missile impact in Area A.
A is the area at risk (usually the WDA) in sq.m.

This overestimates the risk to an individual when the missile debris is a scatter of pieces smaller than a person with the spacing between them larger than the person. In these conditions a more accurate method is to replace E with A_p.B.

where: A_p is the area represented by one person.
B is the number of discrete debris pieces.

Casualty expectation (C_{exp}) from a single firing is related to the 'risk' by the formula:

$$C_{exp} = I_{risk}.^{n}$$

where: n is the number of persons in area A.

b. Individual Cumulative Risk. The formula used for calculating C_{risk} is as follows:

$$C_{risk} = \frac{N.E.P}{A}$$

where:

N is the number of missiles fired annually.
E is the debris area in sq.m.
P is the probability of missile impact in area A.
A is the area at risk in sq.m.

2. Risk to the General Public. Many ranges are located close to centres of population. An analysis shall be conducted into the possibility of a missile impacting outside the WDA and the risk of injury to a member of the general public. Consideration should be given to all known FMs and should not be based upon the assumption of a single FM. A number of methods may be used to assess and present the risk levels in the area surrounding a range. Two such methods are:

a. Method 1. Establish contours of constant risk based on the probability of a "rogue" missile crossing a line where it is assumed that a person on that line will be fatally hit. As a general rule, this probability value will decrease as the radius from the missile launch point increases. The gradual decrease is due to the probability of missile fragments reaching a given distance decreasing with increasing radius. A step change in the probability figures may occur where an additional failure occurs. The probability of causing a fatality during a firing (P_f) is given by the expression:

$$P_f = P_r.P_{hk}.A_p.D_{pop}.P_a.R.$$

where:

P_r is the probability of a "rogue" event.
P_{hk} is the probability of a lethality given a hit. (If this information is unavailable a value of 1 should be assumed.)
A_P is the area represented by 1 person, (1 m^2 or 10^{-6} sq.km.).
D_{pop} is the population density per sq.km.
P_a is the probability of the missile being in an area with a (sensibly) uniform distribution of hit chance that contains the population cluster.
R is the ratio of the area of the population cluster to the area with the probability P_a.

b. Method 2. Conduct a detailed analysis based upon the known population densities in particular areas and calculate a discrete risk figure for that particular area. The formula used to calculate the total probability of causing 1 fatality per firing, P_f is given by:

$$P_f = P_r.A_p.D_{pop}.P_a.R$$

where:

P_r is the probability of a "rogue" event.
A_P is the area represented by 1 person (1 m^2 or 10^{-6} sq.km.).
D_{pop} is the population density per sq.km.
P_a is the probability of the missile reaching the nearest and furthest point of the population cluster being considered.
R is the ratio of the area cluster to the total area of an annulus (see Figure 10) with the same nearest and furthest distances.

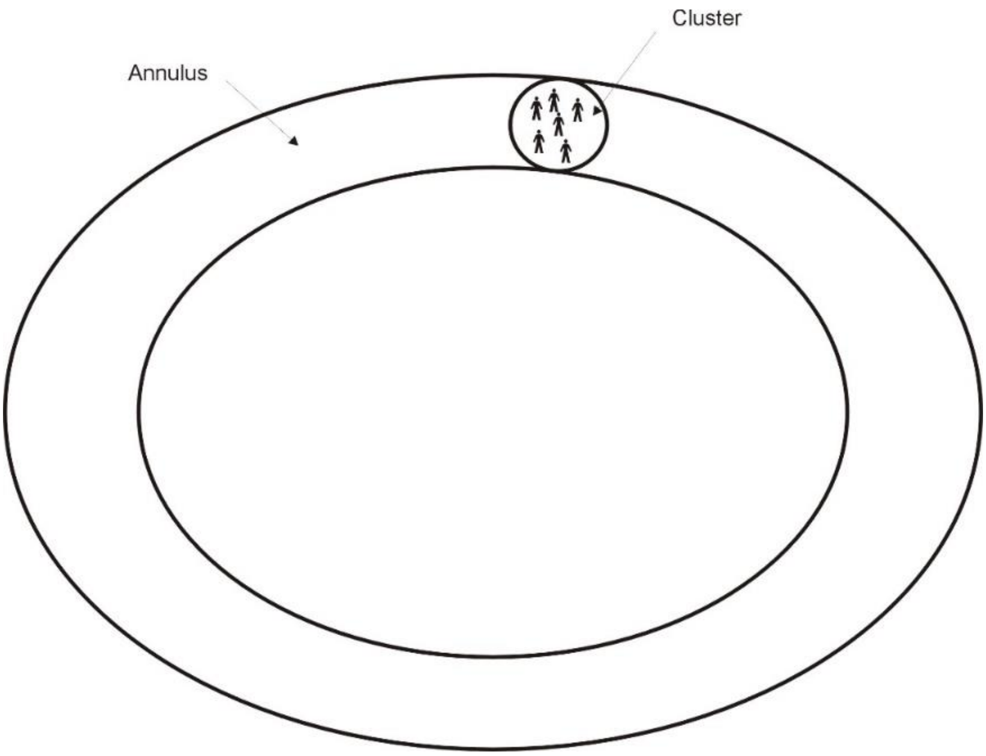

Figure 10. - Diagrammatic Representation of Method 2

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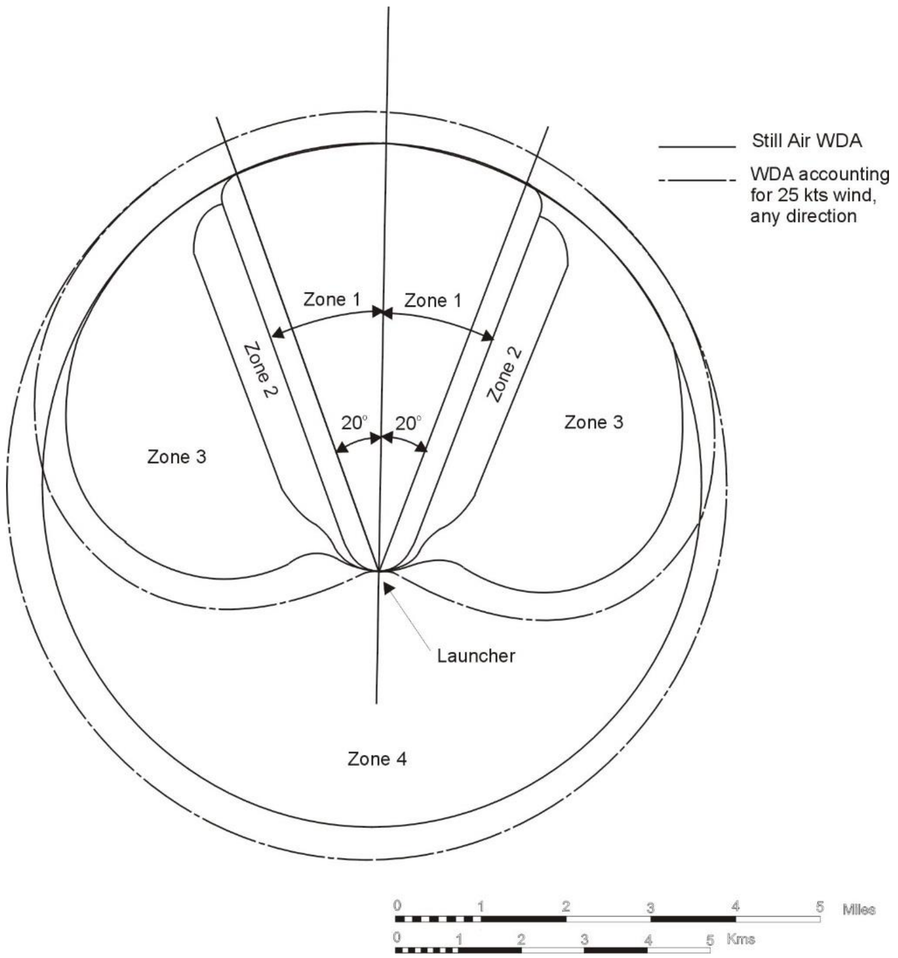
CHAPTER 7

METEOROLOGICAL CORRECTIONS

7.1 GENERAL.

1. Missile flight is subjected to meteorological effects. Usually a guided missile's auto pilot will compensate for normal variations. A strong gusting wind, however, may cause excessive yaw or pitch and as the missile's auto pilot seeks to compensate, the gyro may topple. If the missile has a long ballistic or unguided phase of flight, wind drift may become a significant problem. After a warhead event occurs, the debris dispersion will be affected by the meteorological conditions. Therefore, limitations will be placed on missiles being fired under specified meteorological extremes and/or procedures developed to compensate for them.



Engagement arc 20º
Zone 1: Should contain no unprotected personnel
Zone 2: Should lie within the Range Boundary and contain a limited number of people.
Zone 3: may contain unprotected personnel and may be permitted to cross the range boundary.
Zone 4: may contain large concentrations of population.

Figure 11. Application of an 'omni-directional' wind correction

2. In the case of short range anti-tank missiles, an omnidirectional approach might be taken (as shown in Figure 11, with a 25 kts wind). Provided the missile is planned to be fired close to the ground, surface wind speed may be applied. It should be noted that a constant radial distance added for wind is only correct if the missile flight time to impact around the WDA boundary remains constant.

3. In the case of longer range weapon systems, a true meteorological correction may be applied to the downwind WDA boundary. In the case of ground to air missiles, a mean ballistic wind correction should be obtained and applied to the trace. If the missile passes through a number of risk zones at different heights (such as a diving anti-ship missile) it may be necessary to establish discrete wind corrections for each zone and apply them to individual parts of the trace.

ANNEX A

FAILURE MODE LIST

Failure Mode	Item/Component	Description of Failure
0001 etc.	Control Surface etc.	Fins driven to stops etc.

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ANNEX B

1. The failure mode (FM) list forms the basis of the FM log.

Failure Mode Number	Item/ Component	Description of Failure	Reference	FM Sequence	Simulation Method	Severity	Likelihood	Risk Class	Risk Reduction Measures
0001 etc.	Control Surface etc.	Fins driven to stops etc..							

FAILURE MODE LOG SHEET

a. FM Number. A unique number cross referenced to the hazard list which is used to identify this FM throughout all the analyses.

b. Item/Component. A concise description of the FM that would result in a hazard being created. Initially a loosely worded statement may be made which can be expanded at a later date.

c. References. References made to source documents such as FTAs and FMECAs or cross references to other FMs.

d. FM Sequence(s). The sequence of events necessary for the FM to result in an accident. This should include a description of the missile behaviour that would result from the FM.

e. Simulation Method. The method used to simulate the FM should be described.

f. Classification of Severity. The severity of the accident will be classified i.e. catastrophic or negligible, etc.

g. Classification of Likelihood. The probability of the specified FM occurring should be stated with an associated confidence level.

h. Classification of Risk. Where appropriate this can follow the guidance given in appropriate national documents.

i. Risk Reduction Measures. Where appropriate risk reduction measures should be identified and described.

LEXICON

Air Danger Height (ADH). The Air Danger Height (ADH) is the maximum height Above Ground Level (AGL) at which hazards may exist. ADH is measured in feet.

As Low As Reasonably Practicable (ALARP). This involves weighing a risk against the trouble, time and money needed to control it. Thus, ALARP describes the level to which risks should be controlled to be considered tolerable.

Buffer zone. The three-dimensional area between a weapon danger boundary and a range danger boundary designed to increase the margin for error in WDA calculations.

Debris Zone. The three-dimensional area between the flight termination boundary and the weapon danger boundary.

Flight Termination System (FTS). The system fitted to a GW used to terminate the flight. The FTS will normally be activated to ensure the WDA boundary is not transgressed.

Frequency The number of occurrences of a given event or the number of observations falling into a specified class.

Hazard. Potential source of harm.

> Note: The term hazard can be qualified in order to define its origin or the nature of the expected harm
> (e.g. electric shock hazard, crushing hazard, cutting hazard, toxic hazard, fire hazard, drowning hazard).

Individual Risk (IR) The risk to a single person.

> Notes:
> 1. Annual individual risk has units of deaths per person per year.
> 2. Event individual risk has units of deaths per person per event.
> 3. Inidividual risk can be calculated for other consequences such as hit or injury.

Launch Danger Area. The space around the GW Launcher in which personnel are at risk from system launch hazards and therefore the presence and protection of personnel is closely controlled.

Monte Carlo simulation. A method utilising random sampling to obtain inputs for computer simulation trials and obtaining approximate solutions in terms of a range of values each of which has a calculated probability of being the solution to the problem.

Probability. A real number in the scale 0 to 1 attached to a random event.

Note: It can be related to a long-run relative frequency of occurrence or to a degree of belief that an event will occur. For a high degree of belief, the probability is near 1.

Risk. Combination of the probability of occurrence of harm and the severity of that harm.
Note: Frequency rather than probability may be used in describing risk.

Risk analysis. Systematic use of available information to identify hazards and to estimate the risk.

Rogue Missile. A rogue missile is one which when in flight, goes out of control and flies an unintended trajectory.

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

Unmanned Aerial Vehicle (UAV). An aircraft which is designed to operate with no human pilot on board and which does not carry personnel. Moreover, a UAV:

a. Is capable of sustained flight by aerodynamic means.

b. Is remotely piloted or automatically flies a pre-programmed flight profile.

c. Is re-usable.

d. Is not classified as a Guided Weapon or similar one shot device designed for the delivery of munitions.

Visual Flight Safety Officer (VFSO). A nominated person who is responsible for the termination of UAV flight if the UAV is observed to cross a flight termination boundary.

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.

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