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Flexible weapons architecture design

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Daniel A. DeLaurentis
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James Dietz

William A. Crossley

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Approved by: Tom Shih 4/28/2015
Head of the Departmental Graduate Program Date

FLEXIBLE WEAPONS ARCHITECTURE DESIGN

A Thesis

Submitted to the Faculty

of

Purdue University

by

William C. Pyant III

In Partial Fulfillment of the

Requirements for the Degree

of

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I dedicate this thesis to God, my wife and my family who have helped and stood by me throughout my studies and are my rock.

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The views expressed herein are those of the author and do not reflect the position of the Department of the Army or the Department of Defense.

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LIST OF SYMBOLS

- P= Absolute Pressure, N/m^2
- ρ= Density of the Air, kg/m^3
- R= gas constant = 287 J/kg
- T= Temperature, K
- a= acoustic speed of the air, m/s
- k= ratio of specific heats (cp/cv)
- u= local airspeed
- W=Total weight of explosive in the warhead
- c= Charge weight/ unit length of the cylindrical portion of the bomb
- M=metal weight/ unit length of cylindrical portion of the bomb
- N= number of rigid surface in vicinity of the blast
- x= Distance from detonation
- u_y = Blast wave Velocity
- u_p = Blast wind Velocity
- h = current height above ground in meters or feet
- h_0 = initial height above ground in meters or feet
- c_0 = coefficient of drag for the munitions
- v_{0v} = initial vertical velocity in meters or feet per second
- g = gravity in meters or feet per second squared
- D_0= outside diameter of the shell
- D_i= inside diameter of the shell
- P_c= Density of the explosive

- P_m= Density of the metal parts
- m_0 = average mass of fragments (grains)
- C = a constant = 60.10^6
- N = the number of fragments
- M = weight of metal case in grains
- m = weight of smallest fragment considered (grains)
- range= the direction normal to the weapons velocity vector at impact
- deflection= The direction normal to the range direction
- MPI = Mean Point of Impact
- prec = precision error
- σ_{MPI}^2= MPI Error Variance
- σ_{prec}^2 = Precision Error Variance
- σ_{miss}^2= Total Accuracy Error Variance
- CEP = Circular Error Probable
- REP = Range Error Probable
- DEP = Deflection Error Probable
- A_v = Vulnerable Area
- A_p = Presented Area
- i = number of components
- $P_{K/H}$ = Probability of kill if hit
- $P_{S/H}$ = Probability of survival if hit
- Ω = Solid surface angle in steraradians
- A_s=Surface Area of the Fragmentation Wave
- ρ_F = Fragmentation density
- K = fragments per region
- j = groupings of lethal fragment weights
- W_U - equivalent weight of uncased TNT
- W_e= effective weight of tnt accounting for reflection

- R_B = Radius of blast
- P_{S0} $=$ over atmospheric pressure
- Z = scaled blast radius
- A_L $=$ Lethal Area
- MAE_B = Mean Area of Effectiveness Blast Weapon
- MAE_F = Mean Area of Effectiveness Fragmentation Weapon
- PD = Probability of Damage for a Detonation
- L_{ET} $=$ Length of effected target area
- W_{ET} $=$ Width of effected target area
- σ_X $=$ Accuracy Standard Deviation in the x direction
- σ_y = Accuracy Standard Deviation in the y direction
- L_{EP} = Expanded length of effects area
- W_{EP} $=$ Expanded width of effects
- FD = Fractional Damage
- a = aspect ratio
- I = impact angle
- F_R = Fractional Coverage
- v_a = Aircraft Velocity
- v_e= Ejection Velocity
- Δt = intervalometer setting
- TOF = Time of Flight
- L_s $=$ Length of the stick
- W_s $=$ Width of the stick
- φ = horizontal velocity vector of the bomb
- θ $=$ Dive angle of the aircraft
- μ = horizontal angle between the aircraft and the weapons velocities
- d $=$ down range distance of the Weapon in a stick
- L_B $=$ Length of extended blast

- $W_B =$ Length of extended blast
- $L_P =$ Length of total Effects Area with Precision Error
- $W_P =$ Width of total Effects Area with Precision Error
- n_r= Number of Rounds
- $n_{or} =$ Overlap in range direction
- n_p= Number of Pulses
- $n_{od} =$ Overlap in deflection direction
- $P_{CD/d} =$ conditional Probability of Damage deflection
- $P_{CDS} =$ Total Conditional Probability of Damage
- SR = Slant Range
- $\sigma_{bd} =$ Precision error in deflection direction in mils
- $\sigma_{br} =$ Precision error in range direction in
- t = target number

ABSTRACT

Pyant, William C. . M.S.A.A., Purdue University, May 2015. Flexible Weapons Architecture Design. Major Professor: Dr. Daniel DeLaurentis.

Present day air-delivered weapons are of a closed architecture, with little to no ability to tailor the weapon for the individual engagement. The closed architectures require weaponeers to make the target fit the weapon instead of fitting the individual weapons to a target. The concept of a flexible weapons aims to modularize weapons design using an open architecture shell into which different modules are inserted to achieve the desired target fractional damage while reducing cost and civilian casualties. This thesis shows that the architecture design factors of damage mechanism, fusing, weapons weight, guidance, and propulsion are significant in enhancing weapon performance objectives, and would benefit from modularization. Additionally, this thesis constructs an algorithm that can be used to design a weapon set for a particular target class based on these modular components.

CHAPTER 1. INTRODUCTION

1.1 Introduction

The objective of this thesis is to determine the correct architecture design factors that are necessary to design and optimize modular open weapons architecture "flexible weapons" to accomplish the performance objectives of minimizing cost and civilian damage while optimizing fractional damage to the target. Additionally, we will develop and test a problem formulation suited to construct a raid of ‘Flex’ weapons against a list of randomly generated targets. Currently, the United States military uses closed architecture, tightly coupled weapons that mission planners have limited abilities to modify for a particular target. Each weapon is designed, built, and deployed separately for general mission sets. When mission planners begin the mission planning process, they match generic weapons to particular targets based on the required effects and the availability of munitions. Weaponeers can change the fusing of the selected weapons, but other weapons characteristics such as the size of the warhead, the guidance system, the type of warhead used (i.e. blast, fragmentation, explosively formed projectile, etc…), and the propulsion are set based on the how a given weapon is constructed.

This thesis research presumes a flexible weapons design setting where the actual weapon employs an open architecture ‘shell’ that planners customize for each individual mission. The key question to be explored is which weapons architecture design factors provide the most significant boost in mission accomplishment. This thesis theorizes that the weapons design factors of guidance, propulsion, warhead size, damage mechanism, fusing, propulsion, and the total number of weapons will enable the military to improve cost effectiveness and reduce civilian casualties while ensuring target destruction. Of note, there are several important problems that require attention prior to implementation of this concept such as air worthiness of a modular weapons system, but issues such as air-worthiness along with other weapons design issues are outside the scope of this thesis. The primary concern of this thesis is on the architecture design factors within the system of systems, and not solving the design of the modular components. We will also concentrate on creating an algorithm to determine the optimal design for each weapon based on a randomly generated target set.

In the current budget constrained environment, the US Military continues to look for ways to lower cost for weapons acquisition and employments. One of the many benefits of the flex weapons concept is the opportunity for considerable cost savings through tailoring each weapons set for a particular mission. Additionally, the government can save money in the acquisition process by requiring companies to only design components of a given weapon versus designing the whole weapon. Based on the importance of cost as a metric, my algorithm will aim to minimize cost.

Another metric that is vitally important in military planning is civilian casualties. Each unintended civilian casualty can cause an entire population to turn against our military efforts resulting in the political loss of any military gain achieved through destroying a target. Tailorable weapons sets should enable mission planners to select the best combination of weapons to reduce the overall collateral damage in an engagement scenario. This will be the second metric my algorithm will seek to minimize.

Finally, our algorithm will treat destroying the target as an external constraint using a penalty multiplier and the overall fractional damage inflicted by the weapons on the target. Using this construct, we will test the overall effectiveness of Flexible weapons.

CHAPTER 2. WEAPONEERING

2.1 Introduction

Weaponeering is defined as “the process of determining the quantity of a specific type of weapon required to achieve a defined level of target damage considering target vulnerability, weapon effects, munitions delivery error, damage criteria, probability of kill, weapon reliability, etc…” (Driels, Morris, pg. 1) This comprehensive definition describes all of the elements that are taken into account when determining a conventional weapon’s effectiveness in a given situation. Of note, weaponeering is an optimization process from its inception. Weaponeers want to inflict the maximum amount of damage on a target area while using the least amount of resources to achieve that damage.

2.2 Force Application Planning Cycle

It is important to note that weaponeering is part of the larger Force Application Planning cycle consisting of objectives, target development, weaponeering assessment, execution planning, force execution, and combat assessment. Each of these individual phases of the force application planning cycle is vital to the weaponeering process. We will examine each step in detail to gain a better understanding of how each step is used in weaponeering. A typical cycle is as follows:

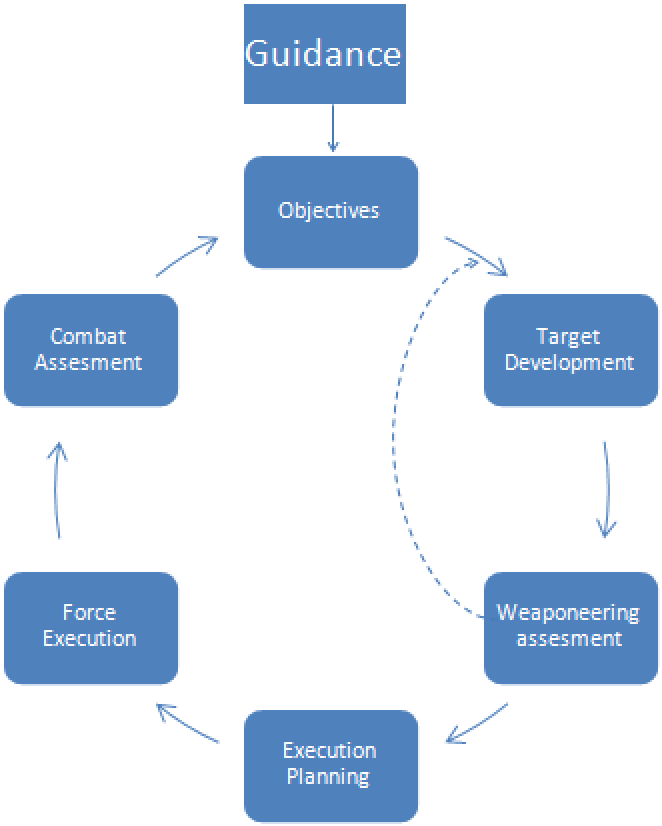

Figure 1: Force Application Planning Cycle, (Driels, Morris, pg. 3)

2.2.1 Guidance and Objectives

Guidance/ Objectives are the purpose of the use of force within the military campaign. These objectives are typically defined by the commander or senior headquarters on when and how force is employed. This guidance will typically highlight the aspects of the enemy activity that the commander wants to effect. (Driels, Morris, pg. 2)

The level of command also greatly impacts the type of guidance given. Within a typical military operation, there are the strategic, operational, and tactical levels of war. The strategic level of war is “an idea or set of ideas for employing the instruments of national power in a synchronized and integrated fashion to achieve theater, national, and/ or multinational objectives.” (JP 3.0, pg. xi) The operational level of war “links tactical employment of forces to national and military objectives.” (JP 3.0, pg. xi) The tactical level of war is the employment and ordered arrangement of forces in relation to each other. This level of war is typically the focus of engagement and battle planning to achieve military objectives. (JP 3.0, pg. xii) The primary focus of the weaponeering process is tactical, but planners ensure they take all strategic and operational objectives into account during the guidance/ objective portion of the force application planning cycle.

Typical guidance and objectives could be the following (using the 1950 -1953 Korean conflict as an example): (Doughty, Robert, pg. 875 - 881)

- Strategic: Protect the Peoples Republic of Korea from North Korean aggression without broadening the war beyond the Korean peninsula.
- Operational: Protect the strategic port of Pusan from being captured and prepare for an amphibious landing at Inchon to cut off the Democratic People's Republic of Korea's army.
- Tactical: Destroy the 3rd DPRK Division located at utm 12345678 using surface to air interdiction and close air support.

The listed guidance and objectives each highlight an important aspect of the mission that need to be taken into account during the force application planning process. If I as a weaponeer decided to develop a force employment solution that destroyed a weapons supply factory in the People's Republic of China, I would directly violate the Strategic objectives thus failing as a mission planner. Ultimately, this portion of the cycle provides the objectives and the limits to the application of force.

2.2.2 Target Development

Target Development is the next step in the force application planning cycle. Target development uses the guidance and objectives established previously and selects what elements are suitable to target. (Driels, Morris, pg. 4) A target is "any entity (person place or thing) considered for possible engagement or action to alter or neutralize the function it performs for the adversary." (JP 3.60, pg. I-1) Targeteers are the group responsible for this step of the planning cycle.

Targeteers typically have knowledge of infrastructure, enemy tactics and enemy weapons that they use to identify the most vulnerable area to attack. Every target has an individual set of characteristics that are essential to describe what a given target is and how it functions. These characteristics can be broken into physical, functional, cognitive, environmental, and temporal characteristics that aid in detection and tracking. (JP 3.60, pg. I-2)

Physical characteristics are items such as location, shape, area, dispersion or concentration of elements that make up the target, degree of hardening, mobility, and any detectable signature. (i.e. heat, reflexivity, radar, etc…) (JP 3.60, pg. I-2) These characteristics will directly affect the number and type of weapons used against it to achieve the desired effects. For example, a fragmentation weapon is extremely effective against personnel in the open, but the same weapon is less effective against an armored vehicle or a bunker. The physical characteristic of each target are vital for this development.

Functional characteristics describe what the target does and how the target does it. A functional characteristic would be a target status, self-defense capabilities (i.e. anti-air missiles, countermeasures), materials a target needs for operation, ability to reconstitute, degree or proportion of functionality, (i.e. tank mobility kill vs destruction), and target physical vulnerabilities. (JP 3.60, pg. I-3) These characteristics are important to identify during the targeting process to determine the kill criteria for a target. Some examples of this are as follows:

- A geographically dispersed air defense system could require multiple individual bombs to destroy the system, but based on analysis of the functional characteristics, a single missile fired at a key component can make the entire air defense system inoperative. (Driels, Morris, pg.)
- For the Korean War example, it could require multiple B-52 sorties to destroy the entire armored division, or a much smaller number of sorties can cause a mobility kill on the entire division. (Driels, Morris, pg.)

Cognitive characteristics are how a targets process information or exercise control functions. (JP 3.60, pg. I-4) Examples of cognitive characteristics are the target's decision cycle, how the target stores information, how the target thinks or operates, and the target's operational norms. Cognitive characteristics aid in identifying targets, predicting how a targets will operate, and identifying weaknesses that can be exploited.

Environmental characteristics describe the effect of the environment on the target and include items such as atmospheric conditions, terrain features, denial and deception measures, physical relationships, and dependencies. (JP 3.60, pg. I-5) These items aid in target identification, weaponeering, and guidance selection. The final characteristic is temporal or time. Time is a characteristic that describes "the targets vulnerability to detection, attack, or engagement in relationship to the time available." (JP 3.60, pg. I-6) Some of the elements of the temporal characteristic are time of appearance, dwell time, time to functionality, and identifiable time. Targeteers do their best to identify as many of the preceding characteristics as possible prior to passing the targeting packet to the weaponeers for weaponeering development.

2.2.3 Weaponeering Assessment

The next step in the force application process, which is the primary focus of this thesis, is the weaponeering assessment. In traditional weaponeering, the weaponeer takes the information gained through the targeting process and selects the quantity and type of weapons needed to produce the required damage on the target. (Driels, Morris, pg.5) Weaponeering assessment typically takes into account the following properties:

- Damage Mechanism of the weapon
- Level of damage the target is to sustain
- Weapon accuracy
- Weapon effectiveness for the particular target
- Type of weapon used
- Release conditions
- Number of weapons used per pass

- Point at which the weapons are aimed
- Required Damage level for the whole mission
- Trajectory of weapon and its impact or arrival state

We will look at each property in greater detail.

2.2.3.1 Damage Mechanism of the Weapon

A weapon can damage a target through a variety of methods, and it is up to a competent weaponeer to decide the best method to attack a target. Some of the most common damage mechanisms employed in modern warfare are blast (over-pressurization), fragmentation, shaped charge/ explosively formed projectile, incendiary, nuclear, and chemical. Each of these mechanisms will affect a target in a particular method, and have potential benefits and weaknesses. Additionally, many weapons have multiple damage mechanisms that occur with each use. A potential example of this is a nuclear weapon will cause fragmentation, blast, and incendiary effects if used on a target. A competent weaponeer must account for all potential damage mechanisms that are associated with a given weapon. For the purpose of this research, I have limited the scope of potential effects to blast, fragmentation, and shaped charges/explosively formed projectiles.

2.2.3.1.1 Blast Warhead

A blast warhead is designed to damage a target primarily through over-pressurization. (Driels, Morris, pg. 9) During a warheads detonation, the explosive is almost instantaneously converted into a gas at around 200 kbars of pressure and 5000^{o} centigrade. (Driels, Morris, pg. 9) The high pressure of this conversion causes the shell surrounding the explosive to rapidly expand thus compressing the air around the warhead. The casing will eventually fracture and the compressed gas will propagate outward from the center of the explosion. As this gas propagates outward, it forms a shockwave along the boundary of the highly pressurized gas that damages whatever is in the path of the explosion. Once the initial shockwave passes the target area, the area behind the shockwave experiences a subsequent under-pressurization that subsequently damages the target. The blast effect concludes when the target area returns to ambient conditions following an explosion.

Blast waves are greatly affected and modified by the targets surrounding environment. Since a blast warhead's primary damage mechanism is the over-pressurization and resulting blast wave, structures and terrain surrounding the impact point will modify the direction of travel, maximum pressure achieved, and the weapons ability to damage a target. A target's vicinity to the blast wave is vitally important to the overall damage the target receives.

If a target is in the vicinity of the initial explosion, which is also described as near field, the blast wave is typically propagating in a spherically, where as if a target is much further away, the blast wave typically propagates in a planar fashion. (Driels, Morris, pg. 811) For the purpose of this research, we will use a far field calculation for prospective damage to a target.

Since a blast wave primarily functions through interacting with the ambient air, the properties of the air surrounding the target will ultimately affect the overall effectiveness of the detonation. The properties of air required are the ambient pressure and the acoustic speed of an ideal gas using the following equations:

Eqn. 2.1: $P = \rho RT$

Eqn. 2.2: $a = \sqrt{kRT}$

Where:

- P= Absolute Pressure, N/m^2
- ρ= Density of the Air, kg/m^3
- R= gas constant = 287 J/kg
- T= Temperature, K
- a= acoustic speed of the air, m/s
- k= ratio of specific heats (cp/cv)
- u= local airspeed

Combining the first two equations we get the following equations:

Eqn. 2.3: $a = \sqrt{\frac{kP}{\rho}}$

The shock wave is also moving at close to the speed of light, and the Mach number is calculated:

Eqn. 2.4: $M = \frac{u}{a}$

Considering a far-field shock wave passing through idea air, we can calculate the air properties up-stream from the blast using the following:

Eqn. 2.5: $p = P_Y - P_x = \frac{7(M_X^2-1)}{6} P_x$ Overpressure

Eqn. 2.6: $\frac{T_Y}{T_X} = \frac{(5+M_X^2)(7M_X^2-1)}{36M_X^2} P_x$ Temperature

Eqn. 2.7: $u_y = u_x - \frac{5a_X(M_X^2-1)}{6M_X^2}$ Velocity of Blast Wave

Eqn. 2.8: $u_p = u_x - u_y = \frac{5a_X[M_X^2-1]}{6M_X^2}$ Blast Wind Velocity

The preceding equations are the primary damage mechanisms for blast type weapons. I will discuss the effects on the target in a future section. The total blast pressure is a function of the characteristics of the weapon used. Basic explosive analysis begins with the assumption that a spherical charge of TNT is detonated in free air. The basic explosive warhead is an explosive charge surrounded by an explosive casing, and it is necessary to equate the cased explosive weight to the uncased explosive weight. The Fano equation listed below equates the cased explosive weight to the uncased explosive weight. If the charge used is not TNT, the resultant weight is multiplied by a multiplier listed in Table 2.1. The explosive weights affect is modified by any rigid surfaces in close proximity to the blast. The total modified weight is Eqn. 2.10, but the modification is only applied if $r \leq 1.5\ w^{\frac{1}{3}}$. (Driels, Morris, pg. 811)

Eqn. 2.9: $W_U = W\left[0.6 + \frac{0.4}{1+2\frac{M}{c}}\right]$

Eqn. 2.10: $W_e = W_U x\ 2^n$

Where

- W=Total weight of explosive in the warhead
- c= Charge weight/ unit length of the cylindrical portion of the bomb
- M=metal weight/ unit length of cylindrical portion of the bomb
- N= number of rigid surface in vicinity of the blast
- x= Distance from detonation

Table 1: EEW Multiplier for Explosive Fill from (Driels, Morris, pg. 816)

Explosive	W_e, Multiplier
TNT	1.00
H-6	1.35
Tritonal	1.07
Comp B	1.11
Comp A3	1.07
Comp C4	1.30
Explosive D	0.92
HBX-1	1.17
HBX-3	1.14
Minol II	1.20

The next point of analysis is to determine the maximum over-pressurization at a given radius. The equation listed below calculates that scaled over-pressurization at a given scaled distance.

Eqn. 2.11: $$Z = \frac{x}{W^{1/3}}$$

Eqn. 2.12: $$P_{S0} = \frac{\hat{P}-P_0}{P_0} = \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\sqrt{1+\left(\frac{Z}{0.048}\right)^2}\sqrt{1+\left(\frac{Z}{0.32}\right)^2}\sqrt{1+\left(\frac{Z}{1.35}\right)^2}}$$

Over-pressurization is the primary destruction mechanism of a blast weapon. (Driels, Morris, pg. 811)

2.2.3.1.2 Fragmentation Warhead

A fragmentation warhead operates in a similar manner to a blast warhead except the primary damage mechanism is the remnants of the metal shell which impact targets at high velocity. Similar to a blast warhead, the explosives in a fragmentation warhead convert to an extremely high temperature and pressure gas inside the warhead. The metal case of the fragmentation warhead then expands two to three times the size of the static shell prior to breaking. Approximately 30% of the energy released by the blast is used to fracture the shell into high velocity fragments. (Driels, Morris, pg. 13)

After the shell fractures, the fragmentation warhead causes damage with the combined effects of the shell case fragments, secondary fragments, and the over-pressurization caused by the explosive. How well a fragmentation weapon performs is based largely on the weight and the shape of the subsequent shell case fragments. In a typical explosion, the breakup of a shell case is hard to predict analytically, and while manufacturers will score the inside of a shell casing to help guide the warhead to break up in a predictable manner, (Driels, Morris, pg. 14) actually defining the kill radius of a fragmentation weapon requires statistical methods to determine the expected performance of a given warhead. (Driels, Morris, pg. 14) Another complication in predicting the performance of a fragmentation warhead is how the weapon interacts with a target. A fragmentation warheads primary destructive mechanism is the shell fragments impacting a target at high speed, but whether the weapon will damage a target fully depends on the hardness of the target it impacts. An example of this is a 10 ounce fragment moving at 5 meters per second will probably kill a human but have little to no impact on a tank. Although the total effectiveness is dependent on the target, I will break this analysis into two primary categories. The first category is the shell performance which encompasses determining the expected mean weight and velocity of individual fragments, while the second portion of the analysis conducted in a future section will discuss how the subsequent fragments will interact with the target.

The best method to determine the effectiveness of a fragmentation weapon on material and personnel targets is through detonation or ‘arena’ testing of the given bomb. (Driels, Morris, pg. 286) A static warhead is placed in the middle of several devices (typically concrete blocks) that measure the number, weight, and initial velocities of the fragments from the test explosion. The process is repeated a statistically significant number of times until the manufacturers determine with statistical certainty the characteristics. Even though this statistical method of determining the fragmentation characteristics of a given warhead is the best, the resultant data is not available for this research because it is often classified and listed in the Joint Munitions Effectiveness Manual (JMEM). WE can however calculate theoretical data using the Gurney equations to help determine an approximate effectiveness of a given weapon. (Driels, Morris, pg.286)

The first step to calculating the effectiveness of a given fragmentation warhead is to calculate the initial velocity of the fragments after the explosion. The equation for a cylindrical shell is as follows:

Eqn. 2.13 $V_0^2 = \frac{2\left(\frac{C}{M}\right)A^2}{2+\left(\frac{C}{M}\right)}$

Eqn. 2.14 $\frac{C}{M} = \frac{P_C}{P_M\left[\left(D_0^2/D_i^2\right)-1\right]}$

Where

- D_0= outside diameter of the shell
- D_i= inside diameter of the shell
- P_c= Density of the explosive
- P_m= Density of the metal parts

Next we will calculate the average fragment size and the number of fragments that have a particular size and weight. This data is calculated using the following equations:

Eqn. 2.15 $m_0 = \frac{CD_0^2}{V_0^2}$

Eqn. 2.16 $N = \frac{M\, exp\left[-\left(\frac{2m}{m0}\right)^{0.5}\right]}{m}$

Where

- m_0 = average mass of fragments (grains)
- C = a constant = 60.10^6
- N = the number of fragments
- M = weight of metal case in grains
- m = weight of smallest fragment considered (grains)

The next element required to calculate the overall effectiveness of a fragmentation weapon is the predicted density of the fragmentation at a given radius. The weapon's fragmentation density is dependent on the geometry and location of the explosion. In a detonation, fragments from a warhead are not evenly distributed because the main fragmentation density is on the side of the warhead whereas the nose has a small number of very large fragments. Additionally, the primary fragmentation is offset about 95^o from the nose for a nose fused weapon and 85^o from the nose for a tail fused weapon. The actual dispersion of the fragments is determined by the arena test discussed above in order to determine the density of fragmentation for each given zone around a detonation. Using the calculated fragmentation data and the results from the arena test, manufacturers are able to determine the likelihood a fragment of a given mass will impact a target within a given area. Weaponeers will use this data, in conjunction with a target vulnerability assessment, to determine the mean affective area for fragmentation for a given detonation.

2.2.3.1.3 Shaped Charge/ Explosively Formed Projectile

Shape charges and explosively formed projectiles are rounds used to penetrate heavily armored vehicles. Although a shape charge and an explosively formed projectile operate in a different manner, (Driels, Morris, pg. 17) their effect on a target is very similar so I will treat the two similarly for this thesis. Here is a brief overview of each weapon.

A shape charge warhead consists of a hollow liner of copper or aluminum formed in a conical or hemispherical shape and backed on the convex side by explosive. The rest of the weapon consists of a container, fuse, and detonator. (Driels, Morris, pg. 15) As the warhead approaches a target, the warhead detonates in the rear of the charge. The explosion melts the metal liner at its apex and forms a high velocity solid jet of liner that that travels at approximately 8,500 meters per second at the tip of the jet and 1,500 meters per second at the tail of the tip. The jet is followed by a solid liner slug that travels at approximately 600 meters per second. As the solid jet impact the armor plate, it produces stress that far exceeds the armors ability to resist impact and penetrates the armor. After the jet pierces the armor, it has sufficient force to cause a fire, injure the crew, or detonate munitions thus destroying the target. (Driels, Morris, pg. 16) An explosively formed projectile operates similarly to a shape charge except it is designed to travel over a longer standoff distance. The major difference between a shape charge and explosively formed projectile however is the shape of the metal liner. In an explosively formed projectile, the metal liner is shaped in a shallow dish and the penetrator is formed into a variety of shapes determined by the design of the liner and the location of the explosive behind the plates. An explosively formed projectile's main advantage over a shape charge however is it can be molded into multiple different penetrator size and it can travel over further distances. Similar to the shape charge, once the explosively formed projectile penetrates the target, its disables the target through harming the crew, causing a fire, or detonating internal ammunition. (Driels, Morris, pg. 17)

The largest difference between the a blast or fragmentation warhead and a EFP/shape charge is that the EFP / shape charge must directly impact its target in order to be affective whereas the blast and fragmentation warhead just need to get into the vicinity of the target to cause damage, but the major benefit of these weapons however is that they are very effective at killing hardened/ armored targets.

2.2.3.2 Level of damage the target is to sustain

The next item that a weaponeer must account for is the level of damage the target must sustain in order to accomplish the goals established in step one. During the course of an engagement, a target can sustain varying degrees of damage that will destroy, degrade, delay, or neutralize a given target for a period of time. During this phase of the force planning cycle, the weaponeer must pick the appropriate damage criteria they will use to define a successful engagement.

Different types of targets have varying damage criteria that we will discuss in throughout the next chapter. The first target we will highlight is personnel or troops. Personnel targets damage is measured in a metric known as casualty criteria. A casualty results when an individual soldier's ability to fight is decreased for a specific period of time after the detonation or wound that the soldier is incapacitated. The actual time associated with the casualty estimate is determined by the tactical situation as follows: (Driels, Morris, pg. 1122)

- Defense – 30 seconds
- Assault- 30 Seconds ~ Defense – 5 minutes
- Assault- 5 minutes ~ Defense - 12 Hours
- Supply 12 hours

The weaponeer must select the appropriate level of damage that is able to accomplish the objectives from phase one of the force planning process and ensure the subsequent weapons selection meets these standards.

Armored vehicles are slightly more complicated with damage criteria due to the multiple ways a vehicle can be affected by a detonation. The different damage criterion for vehicles is as follows:

- Mobility, MO-Kill – Damage that causes a vehicle to be incapable of executing controlled movements and is not repairable by the crew on the battlefield. (Driels, Morris, pg. 1124)

- Mobility, M40-Kill – same as mobility kill but the mobility is lost within 40 minutes(Driels, Morris, pg. 1124)
- Firepower, F-Kill – Defeat the main armament, and the crew cannot repair it. (Driels, Morris, pg. 1124)
- Catastrophic, K-Kill – Damage beyond repair. Damage assumed to occur immediately. (Driels, Morris, pg.1124)
- Passenger, P-Kill – Incapacitation of transport personnel. Incapacitation will be based on 5 min assault. (Driels, Morris, pg. 1125) (for armored personnel carriers)

These damage criteria, similar to casualty criteria, are selected based on the objectives defined in the first phase of the force application planning cycle.

Buildings or structures are a unique type of target because how their damage criteria is directly coordinated with the function of the targeted building. Buildings and structures damage criteria is measured in the percentage of roof or floor area damaged, but the weaponeer is required to delve deeper into the function of the building in order to fully achieve the stated objectives. A building target could be anything from a single family home to a large scale industrial complex. For a typical non-production building, structural damage of 50% or higher renders the building unusable. (Driels, Morris, pg. 1141) Measuring success in industrial complexes however is directly tied to loss production from the building purpose. The following are charts that display lost production in several different types of industrial complexes:

Table 2: Production Loss in Missile and Aircraft Factories (Driels, Morris)

Percentage of Damage	Days Until Full Recuperation	Production Loss (Days)
10	96	46
20	134	74
30	147	91
40	149	100
50	150	104
60	150	105

Table 3: Production Loss in Heavy Vehicle Manufacturing Plant (Driels, Morris)

Percentage of Damage	Days Until Full Recuperation	Production Loss (Days)
20	102	54
30	118	64
50	142	88
60	151	100
70	156	111

Table 4: Production Loss in at Oil Refinery (Driels, Morris)

Percentage of Damage	Days Until Full Recuperation	Production Loss (Days)
30	65	45
50	90	75
70	135	130

The tables display that when weaponeering for a building, it is important that the weaponeer know what effect the targeteer desires from the building, therefore a targeteer should use guidance such as delay production from aircraft factory by 45 days minimum instead of destroy the aircraft factory. The weaponeer needs to establish these criteria prior to proceeding to the next phase of planning. Once the weaponeer establishes the desired effects on a given target, they now move on to selecting the appropriate weapon.

2.2.3.3 Weapon Accuracy

Weapons accuracy is one of the most important aspects of any mission planning cycle because a weapon must hit the desired aim point with a reasonable degree of certainty in order to destroy the target and avoid unnecessary civilian casualties. Modern technology has increased the accuracy of weapons significantly, but the competent weaponeer accounts for the error in even the most accurate bomb. Delivery accuracy is defined as the “quantitative measure of the capability of a weapon system to place ordinance on its intended target.” (Driels, Morris, pg. 127) Manufacturers conduct multiple tests on weapons to statistically determine how, and to what degree each weapon is inaccurate. Upon completion of the test, weapons accuracy error can be broken into the following categories: fixed bias error, occasion to occasion errors (also known as mean point of impact (MPI) error or bias error), and round-to-round, precision or random errors. (Driels, Morris, pg. 1127)

Fixed Bias error is a consistent, systemic error within the weapon itself. An example of this type of error is if a GPS/INS guided bomb always impacts 50 meters to the right of a target, the 50 meters right would be the fixed bias error. A good weaponeer or manufacturer corrects for a weapon’s fixed bias error by just simply aiming the warhead 50 meters the left, and the weapon then impacts the target. Due to the simplistic ability to correct for fixed bias error, weaponeers are not typically concerned with fixed bias error.

Occasion to occasion error or MPI error is the error that occurs randomly during an independent engagement. An occasion is a single, relatively short period of time when one or more weapons are directed at the target. An example of this is an aircraft drops 4 unguided bombs at the exact same drop location and time. These bombs fall to the ground and impact in four separate locations. The central point between where each bomb lands is the mean point of impact (MPI). The mean point of impact error is the distance a given MPI is from the aimpoint. The MPI error will be constant during a given occasion, but it will change during the next occasion. The occasion will change if the release conditions are different and the weapons launch is independent of the first launch.

The final type of error is the variation around the mean point of impact, also known as the precision error. See the diagram below for a visual depiction of the given error.

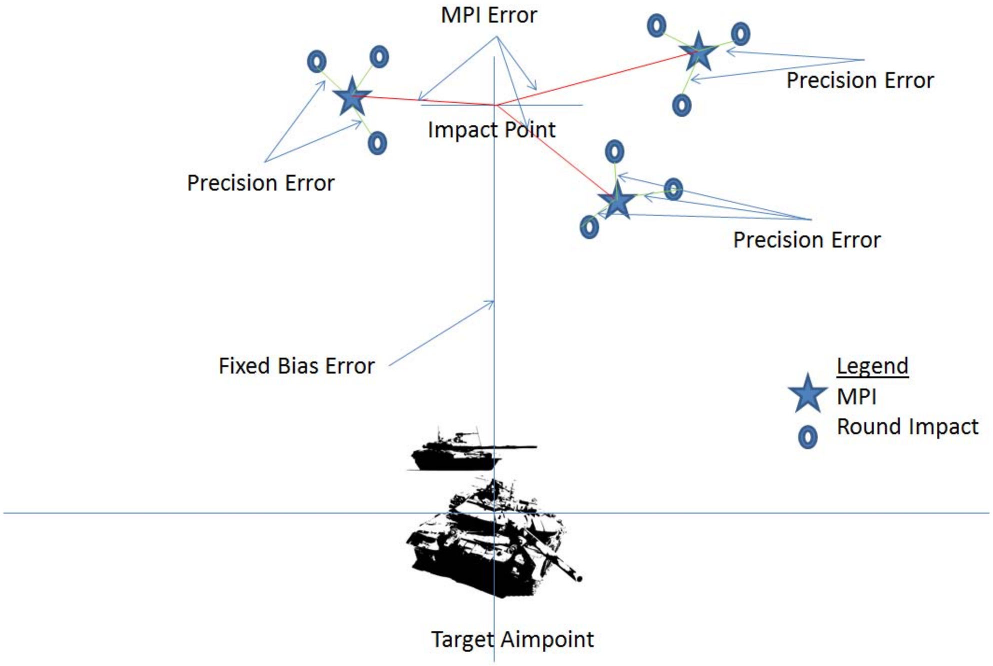

Figure 2: Weapons Impact Error

As the diagram above shows, the individual error in each round is determined by the fixed bias error, the MPI error, and the precision error. Through a simple aiming correction the fixed bias error is eliminated, and the remaining miss distance is a function of the mean point of impact error and the precision error for the total miss distance through the equation below. (Driels, Morris, pg. 133)

Eqn. 2.17: $x_{MPI} + x_{prec} = x_{miss}$

Eqn. 2.18: $y_{MPI} + y_{prec} = y_{miss}$

Eqn. 2.19: $\sigma_{MPI}^2 + \sigma_{prec}^2 = \sigma_{miss}^2$

Although the equations above are excellent ways to measure a weapons accuracy, manufacturers and weaponeers prefer to use the range error probable (REP) and deflection error probable (DEP) as the method to measure accuracy. The measurement of range is defined as the projection of the weapon's velocity vector at impact on the ground plain, and the deflection is perpendicular and to the right of the range vector on the ground at impact.

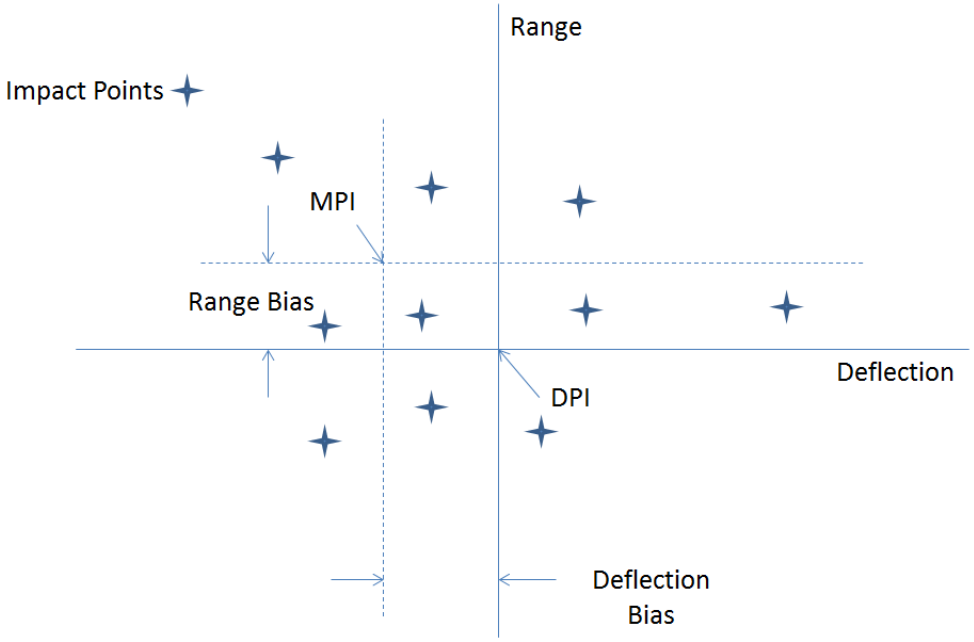

Figure 3: Range and Deflection Error Bias based on diagram 4.8 in (Driels, Morris)

The range error probable and the deflection error probable is the distance from the desired impact point in the range and deflection directions respectively in which 50% of the rounds land. (Driels, Morris, pg. 135) Through thorough weapons testing, each weapon system has a known REP and DEP that weaponeers use in planning missions.

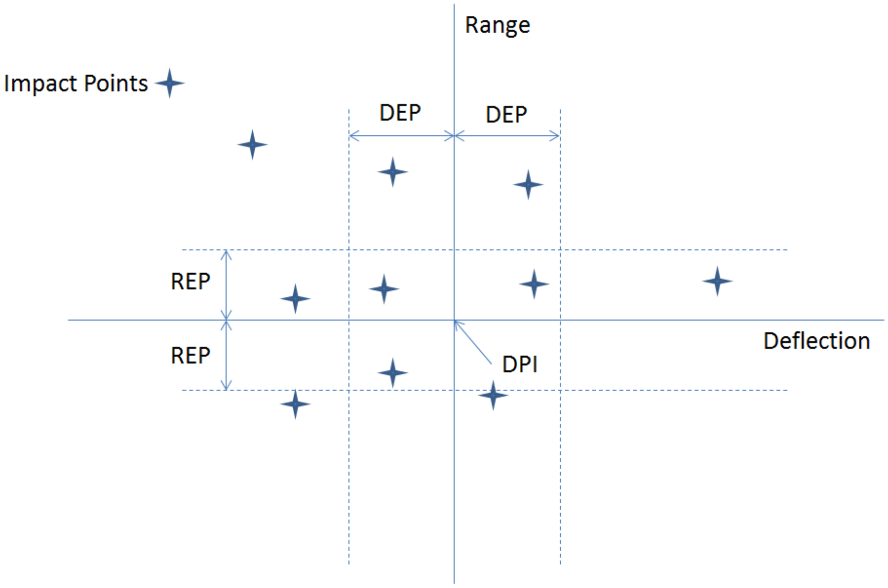

Figure 4: Range and Deflection Error Bias based on diagram (Driels, Morris)

The last and most common measure of error is the circular error probable (CEP). The circular error probable is the radius of a circle in which 50% of the impact points lie within it.

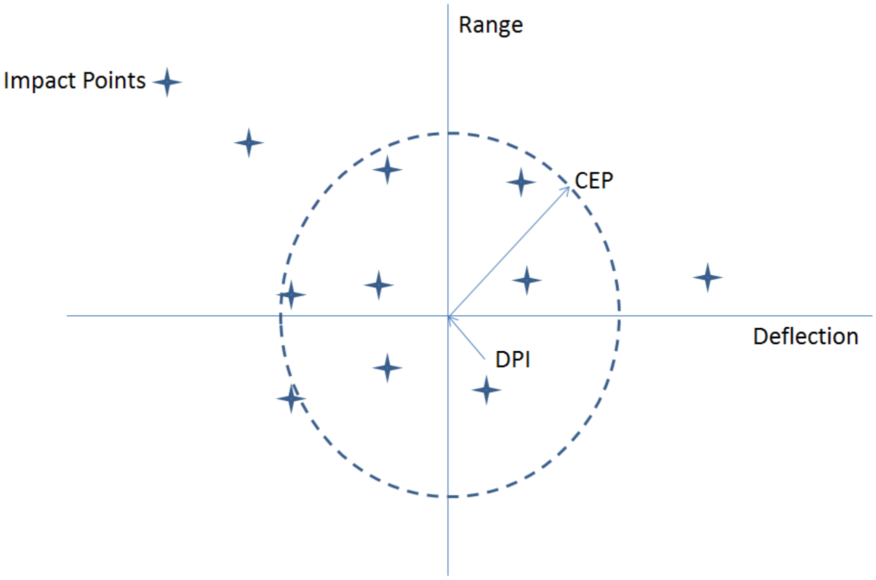

Figure 5: Circular Error Bias based on diagram 4.11 in (Driels, Morris)

The preceding elements are the primary metrics used to estimate weapons accuracy during a given engagement. Weaponeers use the accuracy measurement, in conjunction with the required effects, to determine the appropriate weapons to use in the engagement.

2.2.3.4 Weapon effectiveness for the particular target

The next step is to determine the weapons effectiveness for a particular target. As discussed previously, different types of weapons affect a target in various ways, and different targets have varying degrees of hardness to protect them. During this phase, we will determine the effectiveness of a given weapon on a target.

To determine the effect of a particular weapon on a particular target, two individual studies are conducted to determine the kill criteria for the weapons target pairing. The two studies are a vulnerability assessment on the given target and the effectiveness assessment for the weapon on the particular target. The result of the two studies is known as the effectiveness index which defines the effectiveness for the detonation scenario.

The first step of the vulnerability assessment is to define the effect that will destroy or damage the target. For a fragmentation weapon, the primary destruction mechanism is high velocity particles penetrating and destroying the vulnerable areas of the target. Different targets require different levels of force to penetrate (i.e. a personal target requires much less force to destroy than an armored tank). The targeteer will provide the specific amount of force required penetrating the specified target and the weaponeer will use formula 2.13 -2.16 to calculate the number and velocity of the specified fragments a specified weapon will produce. The weaponeer uses this calculated mass and weight to determine the probability of a kill if the target is hit by this particular particle. (Driels, Morris, pg. 298)

The vulnerable area of a target is defined as the product of the presented area that is normal to the fragmentations velocity vector, and the probability of a kill given a hit. (Driels, Morris, pg. 296) This can apply for individual components or the whole target. The formula is as follows:

Eqn. 2.20: $A_V = A_P x\, P_{K/H}$ for the target

Eqn. 2.21: $A_{Vi} = A_{Pi} x\, P_{Ki/Hi}$ for i components

Where

- A_v – Vulnerable Area
- A_p – Presented Area
- i – number of components
- $P_{K/H}$ – Probability of kill if hit

To better understand the relationship between the vulnerable and the presented areas, take the example of a tank or heavily armored vehicle. A tank is armored to prevent significant damage from a fragmentation weapon, but there are areas where a fragment of the right mass and velocity can cause significant damage and even destroy the tank. One such example is the vehicles ammo cache. A fragment of the right velocity and mass that penetrates the heavy armor of a tank into the ammo cache could cause the ammo to ignite and destroying the tank. The area comprising the ammo cache that is normal to the fragments velocity vector is the vulnerable area, and the area of the tank that is normal to the fragments velocity vector is the presented area. On occasion, a target will have multiple components that is hit will result in target damage or destruction. Using the tank example from earlier, other components that can cause the destruction of the tank are the engine, the fuel bladder, and the crew. The summation of these vulnerable areas will be the total vulnerable area of the vehicle. Additionally, the summation of the individual components probability of kill is equal to the total probability of kill. Using this formulation, the probability of kill as expressed as:

Eqn. 2.22: $P_{K/H} = \frac{1}{A_p} \sum_{i=1}^{s} A_{vi}$

Eqn. 2.23: $P_{K/H} = \sum_{i=1}^{s} P_{Ki/Hi}$ (s is the total number of components)

This formulation allows the weaponeer to form a table of critical components with respective vulnerable areas and the conditional probability of kill. (Driels, Morris, pg. 301)

Following the initial calculation of the probability of a kill based on a hit from a single type of fragment, the weaponeer calculates the probability of a kill resulting from multiple fragmentation hits. The weaponeer will determine the probability if a target survives one hit using the following: (Driels, Morris, pg. 306)

Eqn. 2.24: $P_{Si/Hi} = 1 - P_{Ki/Hi}$ (single hit)

Eqn. 2.25 $P_{Si/Hi}^{(n)} = \left(1 - P_{Ki/Hi}\right)^n$ (multiple hit where n is the number of hits)

Knowing the probability of target surviving after n hits with basic probability the weaponeer can determine the total probability of a kill given n fragmentation hits using the following: (Driels, Morris, pg. 307)

Eqn. 2.26 $P_{Ki/Hi}^{(n)} = 1 - P_{Si/Hi}^{(n)} = 1 - \left(1 - P_{Ki/Hi}\right)^n$

Using the probability of kill for n hits and the pertinent weapons test data, a weaponeer can calculate the total probability of kill for a given warhead. The weaponeer will determine, based on the given test data, the total number of fragments of a given size and weight that are in a given target area. Using the tank example from above, a weapon detonates ‘r’ radius from the target as displayed in the following figure:

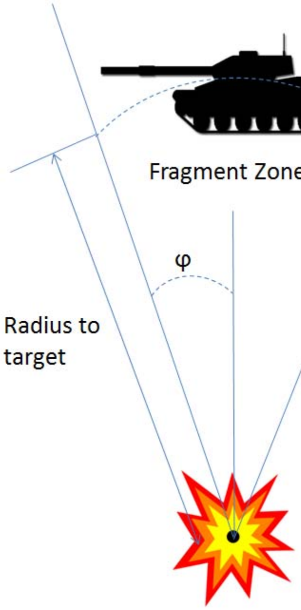

Figure 6: Engagement Geometry top view based on diagram 8.18 in (Driels, Morris)

Additionally, the detonation occurs in three dimensions so the fragmentations total surface area is determined using the solid angle ‘Ω’ as seen below: (Driels, Morris, pg. 309)

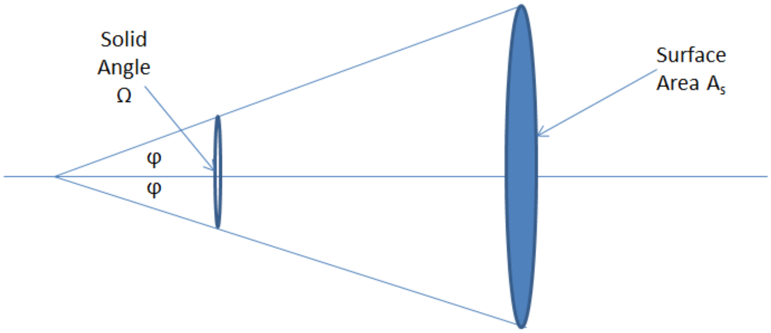

Figure 7: Engagement Geometry side view based on diagram 8.19 in (Driels, Morris)

Eqn. 2.27: $\Omega = 2\pi(1 - \cos\varphi)$ Solid angle in steraradians

Eqn. 2.28 $A_s = \Omega r^2$ Surface Area of the Frag Wave

While this method of determining the total surface area of the fragmentation wave is effective, occasionally a target will be along the boundary of explosion regions. A detonation will have fragmentation spread 360 degrees from the point of detonation, and will have multiple different fragmentation density along the regions surrounding a typical round.

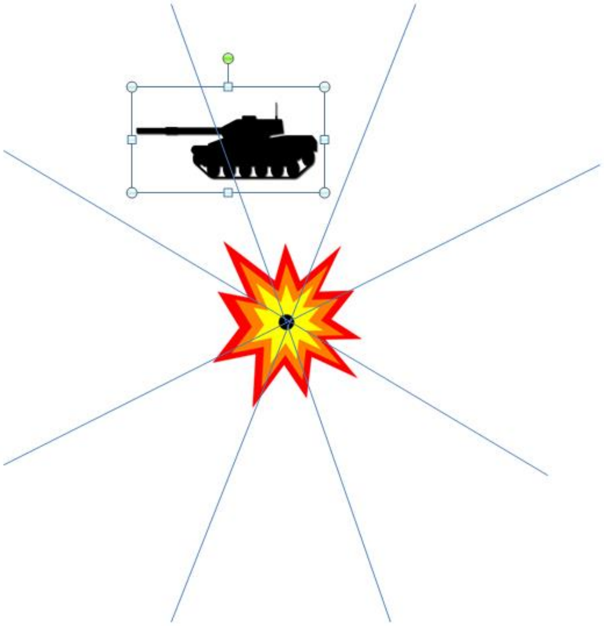

Figure 8: Fragmentation Regions

These different fragmentation regions will result in a different kill probability per detonation for different portions of the target. To account for this, weaponeers use the center of mass of the vulnerable target area also known as the centroid of vulnerability. Using the centroid the weaponeer can calculate the probability of a kill per detonation using the following equations: (Driels, Morris, pg.313)

Eqn. 2.29: $\rho_{F(j)} = \frac{K_{(j)}}{A_S}$

Eqn. 2.30: $P_{K/D(j)} = 1 - exp\left(-\rho_{F(j)}A_{V(j)}\right)$

Where:

- ρ_F – Fragmentation density

- K – fragments per region
- j – groupings of lethal fragment weights (if there are multiple weights that will destroy a target, they are accounted for here)

Extrapolating from the probability of kill for a specific target – detonation geometry, the weaponeer can calculate the probability of kill for the entire target surrounding a given weapon by calculating the probability of kill for all centroid of vulnerabilities surrounding the detonation and summing all non-zero probability of kills. This area, also known as the mean area of effectiveness for fragmentation (MAEf), is the total lethal area (A_L) for a given fragmentation bomb and is derived mathematically using the following equation: (Driels, Morris, pg. 315)

Eqn. 2.31 $A_L = MAE_F = \sum_{x=x_{min}}^{x=x_{max}} \sum_{y=y_{min}}^{y=y_{max}} P_{K/D} \Delta y \Delta x$ in m^2 of ft^2

Determining the effectiveness for blast weapons is much less complicated then determining the effectiveness of fragmentation weapons because blast weapons rely on over-pressurization as the primary damage mechanism. To determine the lethal area (A_L) or mean area of effectiveness for a blast weapon (MAEb), the weaponeer needs to know how much overpressure is required to destroy a given target. The weaponeer will take this information and eqns. 2.1 – 2.13 to determine the weighted radius z for the given detonation. The weaponeer will use the weighted radius to determine the blast radius. The area of the blast radius is the mean area of effectiveness for blast. (Driels, Morris, pg. 316) The equations are as follows:

Eqn. 2.32: $R_B = ZW^{1/3}$ blast radius in feet or meters

Eqn. 2.33: $A_L = MAE_B = \pi(R_B)^2$

Shaped charges and explosively formed projectiles are precision weapons specifically designed to penetrate thick armor and damage a targets internal components. Due to the specific purpose of these weapons, their effectiveness is measure using the projected armor penetration. The damage mechanism produces a metallic penetrator 'jet' that operates as a high velocity, incompressible liquid impacting the target, and Bernoulli's equation relates the pressures, velocities and elevations before and after impact. (Driels, Morris, pg. 378)

Eqn. 2.34: $p_1 + \frac{1}{2}\rho_1 v_1^2 + gz_1 = p_2 + \frac{1}{2}\rho_2 v_2^2 + gz_2$

Where:

- p – pressure
- ρ – density
- v – velocity
- g – gravity
- z – elevation
- v – jet velocity
- L – jet length

A typical shape charge moving at a velocity greater than 1 km per sec will have a stagnation pressure of 3.925 x 10^9 N/m^2, which is much higher than the yield strength of steel. At such high pressure, it is a reasonable assumption to assume the steel armor and penetrator act as a liquid. (Driels, Morris, pg. 378) The leading edge and trailing edge of a shape charge have different velocities that will also determine the depth of penetration. Considering the pressure and elevation between the steel armor and penetrator must be equal, we achieve the following equations. (Driels, Morris, pg. 380)

Eqn. 2.35 $\frac{1}{2}\rho_j(v-u)^2 = \frac{1}{2}\rho_t u^2$

Eqn. 2.36 $t = \frac{L}{(v-u)}$ time in seconds

Eqn. 2.37 $P = u\ x\ t = u\frac{L}{(v-u)}$ penetration length

Eqn. 2.38 $P = L\sqrt{\frac{\rho_j}{\rho_t}}$ Density Law

Eqn. 2.39 $u = \frac{v}{1+\sqrt{\frac{\rho_t}{\rho_j}}}$ Penetration Velocity

The second step of determining the weapon – target effectiveness is to estimate the effectiveness of a given weapon on the specified target. The primary goal of this phase is to determine the probability of damage and the fractional damage expected on a given target. The probability of damage is simply the likelihood a target will be damaged in a given engagement while accounting for the probability of damage if hit and the probability of a hit. (Driels, Morris, pg. 387)

Eqn. 2.40: $Prob_{\{Damage\}} = Prob_{\ \{hit\}}\ x\ Prob_{\{damage\ if\ hit\}}$

For the initial analysis we will use the following assumptions: 1. Single weapon on a unitary (point or area) target; 2. Weapon has known CEP, DEP, and REP (from weapons accuracy estimation); 3. The target has a particular aimpoint (will be assigned in a future step); 4.Blast or fragmentation warheads. The most basic method to estimate the probability of damage is through constructing a Monte Carlo simulation using the weapon's REP, DEP and accuracy standard deviation (σ) and a random number generator to randomly assign weapons impact points. Using the random impact points and the mean area of effectiveness of the given warhead, construct a weapons lethal area around the impact point. If the aimpoint is within the impact area, the trial is a success, and if the aimpoint is outside of the area, it is a miss.

There are three primary methods to analytically solve for the probability of damage, the rectangular cookie cutter, the Carlton damage function, and the lethal area matrix. This thesis will focus on the rectangular cookie cutter and the Carlton damage function. The rectangular cookie cutter models the target - effect area as a rectangle. The sides of the target – effect rectangle are known as the width (W_{et}) and length (L_{et}) of effective target area and are functions of the MAE and the impact angle. (Driels, Morris, pg. 391) The second method of estimating damage, the Carlton damage function, accounts for the geometry of the weapons detonation through accounting for the explosion with the weapons radius in the range (WR_r) and deflection (WR_d) directions. Each damage function accounts for the aspect ratio of the impact angle in calculation the damage. The formulas to determine the probability of damage for the cookie cutter method is: (Driels, Morris, pg. 392)

Eqn. 2.41: $a = max[(1 - 0.8\cos I), 0.3]$ aspect ratio

Eqn. 2.42: $L_{ET} = \sqrt{MAE_f \times a}$ Length of effective target area

Eqn. 2.43: $Wet = \frac{L_{ET}}{a}$ Width of Effective Target Area

Eqn. 2.44: $PD_{1(R)} = \frac{1}{\sqrt{2\pi\sigma}} \int_{\frac{-L_{ET}}{2}}^{\frac{L_{ET}}{2}} exp\left(\frac{x^2}{2\sigma^2}\right)$ Probability of damage in range direction

Eqn. 2.45: $PD_{1(D)} = \frac{1}{\sqrt{2\pi\sigma}} \int_{\frac{-W_{ET}}{2}}^{\frac{W_{ET}}{2}} exp\left(\frac{y^2}{2\sigma^2}\right)$ Probability of damage in deflection direction

Eqn. 2.46: $PD_1 = PD_{1(R)} \times PD_{1(D)}$ Total Probability of damage

The formulation for the Carlton damage function is as follows: (Driels, Morris, pg. 393)

Eqn. 2.47: $P_{(x,y)} = exp - \left[\frac{x^2}{WR_r^2} + \frac{y^2}{WR_d^2}\right]$ Carlton Damage Function

Eqn. 2.48: $L_{ET}^{'} = 2 \times WR_r = 1.128\sqrt{MAE_F \times a}$

Eqn. 2.49: $W_{ET}^{'} = 2 \times WR_d = \frac{L_{ET}^{'}}{a}$

The weaponeer can use these function in a Monte Carlo simulation to get the probability of damage for an engagement scenario. The weaponeer can solve the Carlton damage function analytically by using the expectant value theorem and the assumption that the range and deflection miss distance is independent. (Driels, Morris, pg. 409)

Eqn. 2.50: $PD_1 = PD_{1x} \times PD_{1y} = \frac{L_{ET}^{'} \times W_{ET}^{'}}{\sqrt{\left(17.6REP^2 + {L_{ET}^{'}}^2\right)\left(17.6DEP^2 + {W_{ET}^{'}}^2\right)}}$

The rectangular cookie cutter function requires additional manipulation to solve analytically because in addition to calculating the width and length of the specific target area, the algorithm must also determine if the projected aimpoint is within the bounds of the weapons effects rectangle. To solve this function, the weaponeer uses a normal distribution (ND) based on the expectant mean value and standard deviation of the expectant values to predict the percentage of rounds between normally distributed random samples. This function, although cumbersome is vitally important for calculating the probability of damage for blast weapons because a target outside of the specified blast radius is not be damaged. The other difference between a fragmentation and blast warhead is that the width and length of the effective target area is not affected by the aspect ratio of the weapon when a blast weapon detonates. The subsequent simplified equations area as follows:

Eqn. 2.51: $L_{ET} = W_{ET} = \sqrt{MAE_B}$

Eqn. 252: $\sigma_X = \frac{REP}{0.6745}; \quad \sigma_y = \frac{DEP}{0.6745}$

Eqn. 2.53: $PD_{1x} = \left(ND\left(\frac{L_{ET}}{2}, 0, \sigma_x, 1\right) - ND\left(-\frac{L_{ET}}{2}, 0, \sigma_x, 1\right)\right)$

Eqn. 2.54: $PD_{1y} = \left(ND\left(\frac{W_{ET}}{2}, 0, \sigma_y, 1\right) - ND\left(-\frac{W_{ET}}{2}, 0, \sigma_y, 1\right)\right)$

Eqn. 2.55: $PD_1 = PD_x \times PD_y$

Using the preceding equations, a weaponeer can calculate the predicted damage for a single unguided weapon against a single target, but the formulation changes slightly when a precision weapon is used except due to the precision of the weapons, the probability of hit and the probability of a near miss are accounted for. The P_{NM} and the P_{hit} are weighting factor based on how accurate the weapons are. To calculate the formulation is as follows:

Eqn. 2.56: $PD_1 = [PD_1 \times P_{NM} + PD_2 \times P_{hit}]$

Eqn. 2.57: $CEP = 1.1774\sigma_1$

The preceding vulnerability assessment highlights more about the weapon used on a generic area target, but the weaponeer would have to modify this generic method to fit the proposed target. Examples of some common military targets are buildings, airfields, bridges, bunkers, lightly armored equipment, damns, and troops in various defensive positions. Each of these targets requires specific weaponeering methods to effectively engage the target, and the most common method to modify a given weapon for a given target is fusing. Fusing will be discussed in greater detail in the next chapter.

The final step in the effectiveness assessment is to determine the percent of the target damaged in a given engagement. This concept, also known as the fractional damage, will help the weaponeer determine the amount of weapons required to accomplish the destruction goals of a given sortie. The expectant fractional damage is the measure of the fractional coverage (F_r) of the weapons effects over a target multiplied the probability of damage (PD) within the target area. (Driels, Morris, pg. 437) An example of this concept is a target is spread over a 200 m^2 area with 100 targets in the area. A given sortie will cover 50 m^2 of the target area and has a probability of damage of .97 within the effective area. The resultant fractional coverage is .25% of the target area is covered, and with a .97 percentage probability of damage, the weaponeer can expect a fractional damage of 0.2425 percent or approximately 25 targets damaged. The equation is as follows: (Driels, Morris, pg. 437)

Eqn. 2.58: $FD_1 = F_c \times P_{CD}$

Determining the expected fractional coverage of a target area relies on the expectant value theorem, weapons accuracy, and statistics. For any given engagement, the weaponeer will assume a rectangular lethal area defined by the target area or the weapons effects area. The first step in this process is to ensure the weapons effects area covers the entire target area. To accomplish this, the effects area is expanded to cover the entire target area. If the effects area is already larger than the target area, then the effects area becomes the new target area. Once effects area is expanded to match the target area, the weaponeer will adjust probability of damage by a ratio equivalent to the amount the target area is expanded. The equations are as follows: (Driels, Morris, pg. 443)

Eqn. 2.59: $L_{EP} = max(L_{ET}, L_A)$ Expanded length of effects area

Eqn. 2.60: $W_{EP} = max(W_{ET}, W_A)$ Expanded width of effects area

Eqn. 2.61: $P_{CD} = \left(\frac{L_{ET} \times W_{ET}}{L_{EP} \times W_{EP}} = \frac{A_{ET}}{A_{EP}}\right) \times PD_1$ Conditional damage probability

Once the lethal area is accounted for, the weaponeer will use statistics to determine the expected impact point for a given round within an engagement. The fractional coverage is a ratio of what percentage of the target is covered by the effects.

Eqn. 2.62: $F_R = \frac{\beta}{L_A}$ range direction; $F_R = \frac{\gamma}{L_A}$

deflection direction

Eqn. 2.63: $-\frac{L_A}{2} + \beta = x + \frac{L_{EP}}{2}$ range; $-\frac{W_A}{2} + \gamma = y + \frac{W_{EP}}{2}$

deflection

Eqn. 2.64: $F_R = \frac{L_A + L_{EP}}{2L_A} + \frac{x}{L_A}$ range; $F_R = \frac{W_A + W_{EP}}{2W_A} + \frac{y}{W_A}$

deflection

As the weapon effects area covers more of the target area, the fractional coverage grows until the target area is completely covered. (F_R=1) This pattern occurs on all sides of the target area. To determine the minimum and maximum miss coverage area, the weaponeer will solve for equation 2.64 with F_R equal to zero. See the diagram below: (Driels, Morris, pg. 444)

Eqn. 2.65: $F_R = 0; -s = x_{max} = -\frac{L_{EP} + L_A}{2}$; $F_R = 1;\ -t = x_{min} = -\frac{L_{EP} - L_A}{2}$

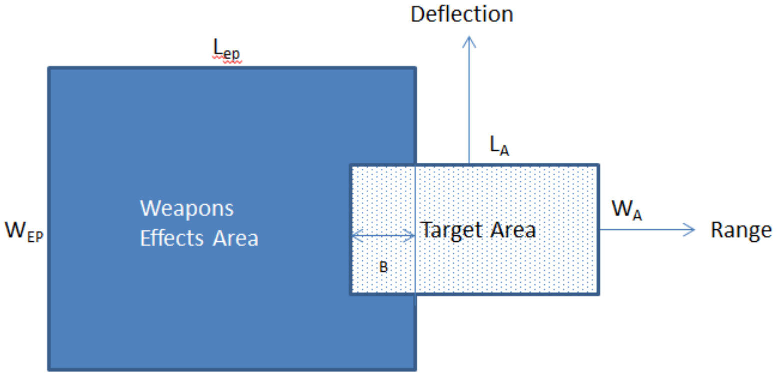

Figure 9: Partial Overlap of target, based on figure 12.13 in (Driels, Morris)

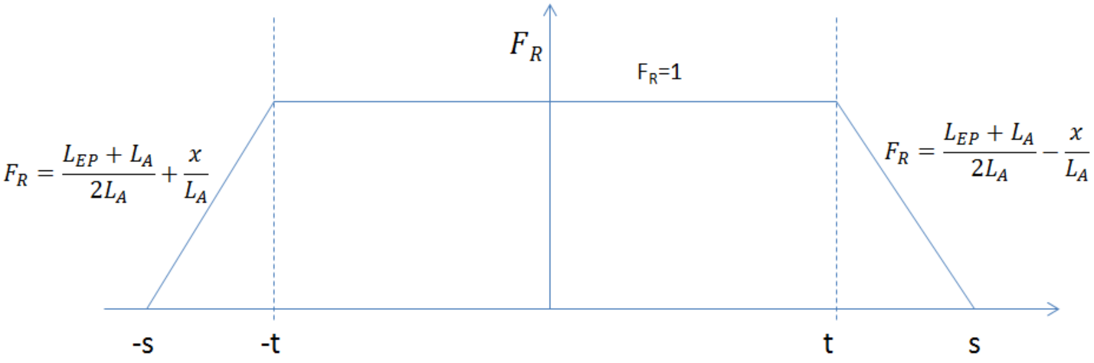

Figure 10: Fractional Coverage Function, Range Direction, from figure 12.17(Driels, Morris)

The expected fractional coverage is obtained by integrating the product of the piecewise continuous function displayed in figure 2.10 with a normal distribution. The resultant expected fractional coverage is used in equation 2.58 to determine the overall fractional damage.

2.2.3.5 Type of weapon used

Once the weaponeer calculates the expected fractional damage from each given weapon the weaponeer will select the type of weapon to use. During this step the weaponeer will select the weapon with the appropriate accuracy and expected fractional damage to accomplish the mission. Conventional weapons are currently built in hard wired, closed architectures that does not allow for modifications, so the weaponeer must pick the entire weapons system even if it does not exactly match the given mission. In the process of picking the weapon, the weaponeer will take the expected collateral damage into account.

“Collateral damage estimation is the process to determine the unintended damage to nearby buildings, material, and personnel when an attack on an intended target is executed.” (Driels, Morris, pg. 1011) The amount of estimated collateral damage can drive the overall weapons selection. Collateral damage estimation (CDE) is a four-tier process including: Tier 1: Information gathering and target material development; Tier 2: Initial assessment; Tier 3: Initial weaponeering assessment; Tier 4: High fidelity weaponeering assessment. (Driels, Morris, pg. 1017)

During the first tier, the weaponeer gathers all available information from intelligence estimates, imagery, and target write ups to develop imagery showing collateral damage concerns overlaid with the worst case weapons range centered on the aimpoint. (Driels, Morris, pg. 1017) This information is passed into the initial collateral damage assessment in tier two. In the tier two assessments, the combatant command reviews the provided imagery and target write ups to determine any significant areas of concern. If there is any high use civilian structure, facility of cultural importance, chemical, biological, radiological, or nuclear facility within the worst case weapons range, the target will require a tier three initial weaponeering assessment. (Driels, Morris, pg. 1018)

The tier three weaponeering assessments is the first calculation of the amount of damage that the civilian facility will incur during the engagement. The weaponeering assessment includes the three levels of: Tier 3A: weaponeering assessment; Tier 3B: bug splat assessment; Tier 3C: casualty assessment. (Driels, Morris, pg.1018 - 1019) During the weaponeering assessment the weaponeer will overlay the rectangular weapons effects area onto the desired aimpoint. The weaponeer will then compare the distance from the edge of the lethal area to the nearest collateral object (CO) to the predefined effective miss distance. The effective miss distance (EMD) is the distance that a weapon can miss a target and still be effective; for example if a bomb misses a petroleum storage facility by ten meters, it would still have the desired effect on the target. The EMD is target and weapon particular, and is accounted for in targeting by adding the EMD onto the length of the target. (Driels, Morris, pg. 542) If the weaponeer determines that the distance to the CO is less than the EMD, the tier 3A CDE risk is high. (Driels, Morris, pg. 1018)

During the Tier 3b assessment, the rectangular target area is replaced by a ‘bug splat’ that represents the area on the map covered by the Carlton damage function. If the collateral object falls within any portion of the ‘bug splat’, the tier 3b CDE estimate is high. (Driels, Morris, pg. 1018) It is of note that changing the attack direction for weapon could subsequently reduce or increase the collateral damage due to the different attack geometry. Weaponeers must ensure they have the optimal attack direction to both increase the overall effect on the target area and decrease the likelihood of collateral damage. The attack direction and overall attack geometry is determined by the release conditions which are set during the next step of the weaponeering process. (Driels, Morris, pg. 1018)

The final step in the tier 3 step is the casually estimate which involves weaponeers determining the population density of the CO in persons per 1000 m^2. Weaponeers will take time when determining the population density because different times during the day will change the overall density. An example of this concept is public fair grounds might have a population density greater than 600 persons per 1000 m^2 during the actual fair, but that same target might decrease to less than 10 persons per 1000 m^2 after the fair. The weaponeer can use this information to propose specific attack times to minimize civilian casualties. Tier 3C is considered high if the population density is greater than the pre-established threshold provided by the upper level commanders. (Driels, Morris, pg. 1019) Of note is the actual casualty levels can be estimated by using the probability of damage and fractional damage equations from the preceding step, and setting the distance from the collateral object to the center of target area as the x and y directions respectively. This will give you the probability of damage and the fractional damage for the collateral area. If you multiply this by the population density, you can get a rough number of civilian casualties.

A tier four CDE analysis uses high fidelity models to estimate to a higher degree of confidence the level of damage to the collateral object. Tier four analysis is typically conducted in the vicinity of highly hazardous materials such as chemicals or nuclear material.

Once the weaponeer establishes the CDE and knows the expected damage from each weapon within the arsenal, the weaponeer will pick the appropriate weapon from to accomplish the mission while avoiding unnecessary collateral damage. An additional factor that also can shape the weaponeers decision is the cost of each individual weapon. An unguided 2000 lb bomb (MK 84) cost around $3000.00, whereas a 2000 lb GPS guided bomb (JDAM) can cost in excess of $20,000.00.(Air Force Budget) In the continuing budget constrained environment, a weaponeer would also account for the overall cost of the weapon when deciding what weapon to use. Using all of these factors, the weaponeer will decide what weapon to use in engaging the target.

The next selection that also greatly impacts the overall effectiveness of the weapon is fusing. A weapons fuse is responsible for determining when and how any given weapon is detonated. A weapon can use proximity, height above impact, impact, delayed impact, and smart fuses to modify when the weapon explodes. A proximity fuse will cause a weapon to detonate at a predetermined distance from an object and is typically used for anti-air weapons. (Driels, Morris, pg. 1045) A height above impact fuse allows for air burst of weapons at a predetermined altitude, and it is typically used with fragmentation weapons for personnel in the open. (Driels, Morris, pg. 1122) An impact fuse causes the weapon to detonate when it makes contact with its target, and it is also used for personnel and anti-tank weapons. (Driels, Morris, pg. 1123) A delayed time fuse will explode a given period of time after it impacts a target. This type of fuse is used to target buildings and bunkers. (Driels, Morris, pg. 1140) The way the fuse works is it allows a munitions to impact with the roof of a building and continue to penetrate to the lower floors of the building. After a predetermined time the fuse will cause the charge to detonate inside the building and increase the likelihood of destruction. Smart fuses are programmable fuses that can operate in multiple roles including impact, delay, and height above impact. These fuses are especially used with penetrator warheads for heavily fortified bunkers to penetrate to a programmed depth prior to detonation. Using these guidelines, the weaponeer will assign the type of fusing for each weapon.

2.2.3.6 Release Conditions

The munitions release conditions depend on the type of weapon used and the required impact geometry of the weapons. The important elements of release conditions will be the velocity, dive angle, and travel direction of the launch platform. For weapons without propulsion or guidance, these elements are essential in determining a munitions trajectory. Additionally, the weaponeer must know the munitions basic flight properties such as the coefficient of drag, air density, and mass to adequately calculate the trajectory. Weapons manufacturers will know each of these parameters, and for throughout this thesis, they will be constants.

There are three basic equations that will govern an unguided munitions trajectory: the vertical motion, horizontal motion, and time of flight. (Driels, Morris, pg. 88-90) The equations for vertical and horizontal motion are as follows:

Eqn. 2.66 $h = h_0 - \left\{\frac{1}{c_0}\left[v_{0v} - \frac{g}{c_0}\right]\left[1 - \exp(-c_0 t) + \frac{gt}{c_0}\right]\right\}$ Height above ground

Eqn. 2.67 $x = \frac{V_{0h}}{c_0}[1 - exp(-c_0 t)]$ Range

To determine the time of flight, we set the height in equation 2.66 equal to zero and solve for time. The equation s as follows: (Driels, Morris, pg. 90)

Eqn. 2.68 $t = \left(\frac{1}{c_0} - \frac{v_{0v}}{g}\right)[1 - exp(-c_0 t)] + \frac{c_0 h_0}{g}$

Unfortunately solving for time is a function of time so the time of flight is numerically solved in MATLAB or some other mathematics program, but these basic equations provide the basic outline for determining the trajectory. The primary parameters used to solve are:

- h – current height above ground in meters or feet
- h_0 – initial height above ground in meters or feet
- c_0 – coefficient of drag for the munitions
- v_{0v} – initial vertical velocity in meters or feet per second
- g – gravity in meters or feet per second squared

- t – time in seconds
- v_{0h} – initial horizontal velocity in meters or feet per second

The last element that is important for the performance of a weapon impact angle. The impact angle can determine if a bomb will hit or miss a building, the fragmentation pattern, and much more about a given engagement. The impact angle is determined through the geometry of the weapon at impact. It is the arctangent of the vertical and horizontal impact velocity. (Driels, Morris, pg. 80) The equations are as follows:

Eqn. 2.69 $v_v = \left[v_{0v} - \frac{g}{c_0}\right] exp(-c_0 t) + \frac{g}{c_0}$ vertical velocity in ft or m/s

Eqn. 2.70 $v_h = v_{0h} exp(-c_0 t)$ horizontal velocity in ft or m/s

Eqn. 2.71 $I = tan^{-1}\left[\frac{v_{iv}}{v_{ih}}\right]$ impact angle in radians

By imputing the calculated time of flight, the weaponeer can determine the impact angle. Using these equations, the weaponeer will calculate the launch platforms desired velocity, altitude, dive angle, approach direction, and drop point to achieve the desired effects. Of note is that an aircraft in a dive would have a higher initial vertical velocity and lower horizontal velocity that would result in a higher impact angle and velocity and more force on impact.

The release conditions for guided munitions depend on the guidance laws of that given munitions. Analyzing the multitude of different guidance laws for guided weapons is beyond the scope of this thesis, but it is important to note that the weaponeer would take these into account when determining the required launch conditions for these guided weapons.

Another consideration the weaponeer will make in conjunction with the threat assessment is any potential enemy weapons that could disrupt the safe launch of a given munitions. These tactical considerations as they are known will greatly limit when and where a given weapon can be launched in addition to restricting the type of weapon the mission requires. The last detail that should be examined is the number of weapons launched in a given sortie. The number of weapons launched in a sortie will adjust the launch conditions of the weapon in order to achieve the desired weapons dispersion. The number of weapons used will be discussed in greater detail in the next section.

2.2.3.7 Number of weapons used per pass

Often a single weapon is will not produce enough damage to accomplish the goals of an engagement. If this occurs, it is common for weaponeers to use multiple weapons together to accomplish the given directives. During this phase of the weaponeering process, the weaponeer decides how many weapons they will need to employ in order to accomplish the stated goals. Modern weaponry employs multiple different munitions with different accuracy, guidance, and propulsion that weaponeers employ in different ways to accomplish their mission.

The goal of this phase is to determine the overall probability of damage for multiple round engagements. Determining the combined probability of damage for a sortie depends on the guidance and the aimpoint of the munitions used during the engagement. The first case is a sortie of multiple unguided weapons released near simultaneously in what is known as a ‘stick.’ Weaponeers use ‘stick’ deliveries to increase the lethal area for a given engagement, and it is the oldest method of delivering multiple air launched weapons. The width and length of a ‘stick’ of weapons increases due to the velocity, position, and ejection characteristics on the delivery platform. A weaponeer must effectively determine and design the impact pattern of the stick to accurately predict its lethality.

A stick’s length in the range direction is determined through the delivery platforms intervalometer settings (Δt) which is the measure of the timer that sends a pulse to the bomb rack to release a pulse of bombs. (Driels, Morris, pg. 461) A pulse of bombs is the number of weapons released at once. The total number of pulses is the variable n_r and the number of weapons per pulse is n_p. The pilot of the aircraft is able to set the intervalometer settings to a fixed value or modern aircraft can enter the desired stick length on the ground and the aircraft will set the intervalometer to achieve the desired stick length (L_s).

The width of a stick (W_s) is determined by the geometry of the delivery platform. Aircraft will carry weapons in a variety of different ways including pylons, attached at hard points, multiple ejection racks, and internally. A round ejected from a multiple ejection rack (MER) will have different initial velocity parameters than a bomb that is allowed to free fall from the internal bomb racks of a B-2. These differences will have a huge impact on the length of a stick. For the purpose of demonstration, this thesis will use a MER delivery demonstrate the calculation of the width of a stick and its effect on lethality.

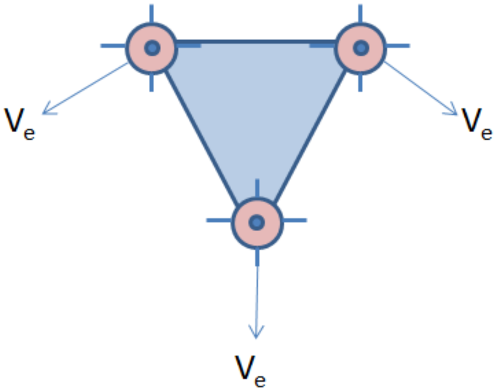

Figure 11: Bomb Ejection from a MER from fig. 13.4 in Driers, Morris

Figure 12: Multiple Ejection Rack attached to an F-4 Fighter from Aviationcorner.net

As the diagrams show, each bomb will be deployed with an initial ejection velocity (V_e) that will impact their position along the ground. Calculating the stick width will require determining the geometry of the weapons in relation to the aircraft. The three angles that will help us determine the width of the stick are the angle between the vertical axis centered on the airplane and the horizontal velocity vector of the bomb (φ), the dive angle of the aircraft (Θ), and the horizontal angle between the aircraft and the weapons velocities (μ). (Driels, Morris, pg. 465) These angles, in addition to the range of the bomb calculated in an earlier section give the weaponeer the width of the stick. The equations for the length and width of the stick are as follows: (Driels, Morris, pg. 466)

Eqn. 2.72: $L_s = v_a(n_r - 1)\Delta t$ Length of the stick

Eqn. 2.73: $\tan\mu = \frac{v_e sin\varphi}{v_a cos\theta}$

Eqn. 2.74: $d = x\tan\mu$

Eqn. 2.75: $W_s = 2 \times d$ Width of the stick

Individual weapons within a stick delivery will still have a certain degree of precision error that is independent of the aim error. In order to fully calculate the enlarged lethal area for a stick of weapons, the weaponeer must account for this increased error. The weaponeer will enlarge the lethal area for each individual bomb and calculate the total lethal area of the stick using the following equations: (Driels, Morris, pg. 469)

Eqn. 2.76: $\sigma_{bd} = \frac{DEP_b \times SR}{1000}$ Precision error in deflection direction in mils (Driels, Morris, pg. 150)

Eqn. 2.77: $\sigma_{br} = \frac{REP_b \times SR}{1000 \sin I}$ Precision error in range direction in mils (Driels, Morris, pg. 151)

Eqn. 2.78: $L_B = \sqrt{L_{ET}^2 + 8\sigma_{br}^2}$ Length of extended blast

Eqn. 2.79: $W_B = \sqrt{W_{ET}^2 + 8\sigma_{bd}^2}$ Length of extended blast

Eqn. 2.80: $L_P = L_S + L_B$; $W_P = W_s + W_B$

The last step to predicting the lethality in this enlarged area is to determine the degree which each weapon overlaps. If the stick has a higher degree of overlap, the lethality would be higher in the contained area, but the overall size would be lower. (vice a versa) The weaponeer must calculate and use this overlap to accomplish the required goals. Overlap can occur in the range (n_{or}) and deflection (n_{od}) direction. (Driels, Morris, pg. 471) Use the following equations to calculate the degree of overlap and the increased probability of destruction.

Eqn. 2.81: $n_{or} = \frac{n_r L_B}{L_P}$ Overlap in range direction

Eqn. 2.82: $n_{od} = \frac{n_p W_B}{W_P}$ Overlap in deflection direction

Eqn. 2.83: $P_{CD/d} = 1 - (1 - P_{CD1})^{n_{od}}$

Eqn. 2.84: $P_{CDS} = 1 - \left(1 - P_{CD/d}\right)^{n_{or}}$

Once the conditional probability of damage is calculated, the stick of weapons is treated as a singular weapon during a bombing run. The total fractional damage of the stick is calculated similar as in the previous chapter, however the L_{EP} and W_{EP} are adjusted to match the stick length and width and a reliability factor (R) is added for the increased number of weapons in the stick. (Driels, Morris, pg. 474) The equation is as follows:

Eqn. 2.85: $L_{EP} = max(L_P, L_A)$

Eqn. 2.86: $W_{EP} = max(W_P, W_A)$

Eqn. 2.87: $FD_1 = E(F_C) \times \left[\frac{A_P}{L_{EP} \times W_{Ep}}\right] \times R \times P_{CDS}$

Calculating the effectiveness for a sortie of multiple precision weapons will operate similarly to a stick delivery except for the dispersion pattern is not based on the geometry of the release conditions. Precision weapons are significantly more accurate and will not automatically disperse in the fashion unguided weapons will. The end result will be a larger overlap of weapons depending on the accuracy of the weapon. The weapons sortie's probability of damage would increase using the following equation: (Driels, Morris, pg. 425)

Eqn. 2.88: $PD = 1 - [1 - PD_1]^n$

The total fractional damage is calculated using the same method listed in earlier sections. The final calculation is the total fractional damage due to multiple, independently aimed sorties. The methodology used to calculate the overall effects of the combined raid will be discussed in the next sections.

2.2.3.8 Aim Points

The aimpoint for a weapon is one of the largest elements that lead to a successful mission. A weaponeer can select multiple aimpoint or a desired mean point of impact (dmpi) within the target area to create the maximum effect. For a single weapon, the weaponeer will select the desired point of impact (dpi) that ensures maximum coverage of the target area and the minimum civilian casualties based on the weapon and target pairing. This process is more complicated for multiple munitions and sorties because the weaponeer must select the appropriate method to increase the fractional damage of the sortie.

Fractional damage consists of the fractional coverage of a target and the damage expected within the target. (Driels, Morris, pg. 442) A weaponeer seeking to improve the overall fractional damage can greatly improve either of these through the selection of appropriate aimpoints. A single DMPI for the entire raid increases the lethality within the target area but it does not increase the fractional coverage of the weapon, whereas multiple aimpoints will increase the fractional coverage without increasing the lethality of the weapons. Most raids will have a combination of single DMPI's and multiple aimpoints resulting in increased coverage area and lethality.

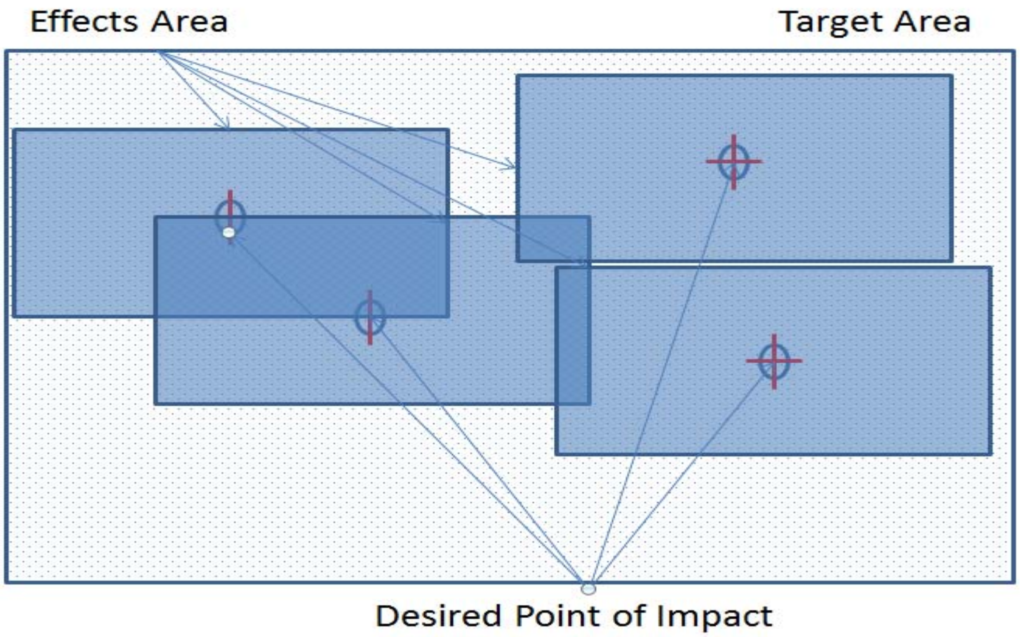

Figure 13: Desired Point of Impact, Lethal Area Overlap

The diagram demonstrates the effect of the overlapping multiple aimpoints. To determine the overall effectiveness of the sortie, the weaponeer will calculate the fractional damage of each rectangle independently then sum the rectangles for the total fractional damage. (Driels, Morris, pg. 478)   The first step will be to calculate the total number of rectangular damage areas and obtain the probability of damage in these individual areas. For the areas with overlapping damage areas, the probability of damage is obtained by equation 2.88 with n being the number of weapons areas overlap.

The weaponeer calculates the total fractional coverage (F_C) for each area independently then the fractional damage for this area is determined with: (Driels, Morris, pg. 478)

Eqn. 2.89: $FD_i = F_{Ci} \times P_{CDi}$

The weaponeer combines all of these areas into one the fractional damage for the entire sortie using:

Eqn. 2.90: $FD_S = \sum_{i=1}^{N} FD_i$

If this final fractional damage does not meet the mission's goals, the weaponeer must implement multiple attack sorties against the target. The weaponeer calculates the total damage for the whole raid sing the following:

Eqn. 2.91: $FD = 1 - (1 - FD_S)^n$

The weaponeer then completes his portion of the planning process by passing the type of weapon required, the number of weapons required, release information, fusing, and the number of sorties required to the mission planners to determine how to execute the mission.

2.2.4 Execution Planning

Execution planning uses the results of the weaponeering assessment to determine the best plan to accomplish the goals. Execution planning is a two tear process incorporating the headquarters and the squadron that will execute the operation. (Driels, Morris, pg. 5) The headquarters assigns the mission to a specific squadron, coordinates the timing, assigns support units, and publishes the air tasking order (or equivalent document). The unit level conducts a thorough study of the target and detailed mission planning including flight routes, refuel locations, aircraft configuration, and crew assignment. The primary aim in this cycle is to have a comprehensive, well-coordinated attack plan. Additionally, planners on the headquarters and unit level concentrate on target identification. Planners and the pilots flying the mission want to ensure positive identification on a target prior to engagement.

2.2.5 Force Execution and Combat Assessment

The last step of the process is force execution and combat assessment. The headquarters controls this phase while communicating and coordinating the strike force in real time to gain positive identification of the target prior to engagement. When the strike force engages the target, headquarters shifts the focus to battle damage assessment. (JP 3.60, II-30)

The headquarters conducts battle damage assessment throughout the execution phase to determine the effectiveness of each individual sortie. Headquarters task either the strike aircraft or other supporting aircraft to assess the actual damage on the target. Based on the level of damage the target sustains, the air component commander can order additional aircraft to strike if the target is still functional, or re-task additional combat sorties slated for the target if the target is destroyed ahead of schedule. While the current strike is ongoing, the air component commander uses the information obtained through thorough battle damage assessments to develop guidance for future targets. (Driels, Morris pg. 4)

The force application planning cycle continues simultaneously throughout the course of the operation. Each group depends on one another to accomplish the assigned mission. The primary aim of this research is to adjust the weaponeering process from having to use the best available weapon to accomplish a goal to designing the best possible weapon to accomplish the assigned mission within the planning process. The real time design will allow weaponeers to provide the best possible weapon for every scenario, and reduce cost and civilian damage through using the minimum required force to accomplish the mission.

CHAPTER 3. FLEX WEAPONS

3.1 Introduction

"Flex" weapons are open architecture weapons systems that allow weaponeers and mission commanders to customize a set of weapons for an individual target. The system will consist of a weapons shell where the weaponeer can interchange various parts of the weapon to achieve the desired effects. The important question is what elements within the flexible weapon system would benefit the mission the most if they were modular. Essentially, by what measure is a weapon good? The goal of this research is to answer these questions.

3.2 Flexible Weapons Performance Metrics

The first step to determine the capability of any new system is defining what qualities determine success for that particular system. What metrics determine the success of flexible weapons? I propose that flex weapons success is a combination of the capability to destroy a target, the ability to avoid civilian casualties, and minimize cost in the process.

3.2.1 Target Destruction

Calculating a flex weapon's ability to destroy a target is similar to all conventional weapons in that weapons developers will test each different variant of flexible weapon to determine the mean area of effectiveness and the guidance error for each model. The major difference however is that a flex weapon has the ability to tailor its configuration significantly immediately prior to a mission. However, the multiple modular components might unintentionally interfere with each other during the mission and cause a degradation of destructive ability. Weapons testers will conduct multiple tests to determine the overall effect of each individual interaction to produce a reliability factor (R) for the weapon system configuration. This thesis will assume that this process has occurred and thus reliability factor as 100%. Although this number is unrealistic, it is constant and thus will not impact the clarity of the results obtained.

The second issue modular weapons have is varying mass properties between modules. Small changes in weight, shape, or density between modules may greatly affect the aerodynamics of a weapon system as it flies in the all flight regime. Any inordinate sensitivity may cause that configuration to be deemed not flight worthy and disrupt the ability to use the weapon. This thesis assumes that each configuration of the weapon will either pass the flight worthiness test or have the same mass properties as a variant that does pass a flight worthiness test.

The primary performance metric within target destruction is the overall damage of a set of flexible weapons on an assigned target. This thesis will measure the overall destructive power of a flexible weapon through the metric of fractional damage, and identify the elements of a weapon system that will positively affect the overall fractional damage and propose those elements as flexible weapons architecture design factors.

3.2.2 Collateral Damage

Collateral damage is a significant issue in the prosecution of any military action, and the level of overall collateral damage inflicted on the local population can negatively impact the local population and the US national support for the military action. Collateral damage also financially affects the war effort through reparations payments the United States pays for families who have love ones killed in military action. A 2012 Army Times article reported that the US distributed $688,000 in condolence payments and $6.8 million in battle repair funds in the first half of fiscal year 2011 alone. (Ryan, John, Army Times) The overall payments in a high intensity conflict are much higher due to the use of more munitions. Reducing the overall collateral damage will greatly increase the US war effort and flexible weapons will help reduce the total collateral damage.

The open architecture of flexible weapons allows weaponers to selectively tailor each weapons package to accomplish the assigned mission while keeping collateral damage to a minimum. This thesis will measure the collateral damage on a simulated civilian object in the vicinity of the assigned target by determining design factors that affect the overall collateral damage and testing to see if each design factor is significant.

3.2.3 Cost

The cost of the weapons system is the next factor that will drive a success or failure of a given design. Congress reduced defense spending of the United States by more than $75 billion over the past two years, and the decrease in spending is projected to continue. (Simeone, 1) Over the same time frame however, the defense department was asked to maintain its current commitments to allies while supporting the wars in Iraq, Afghanistan, and Syria. To address the complicated budgetary constraints while maintaining its combat advantage the Department of Defense mandated all DoD components develop new weapons in a modular open systems approach (MOSA.) The DoD states that" OSA is identified as a key tenet of Better Buying Power, under Promoting Effective Competition, because it enhances system interoperability and the ability to integrate new capabilities without redesign of entire systems or large portions of the enterprise." (Defense Acquisition Guidebook, Ch 4) Flexible weapons are the Air Force's way to reduce cost while increasing lethality through modular weapons design.

In traditional weapons development the weapons developer will design and build the entire weapons system. The weapon will have a closed architecture, and once the weapon is built, the defense department will purchase the whole weapon from the lead contractor. Flexible weapons have an open architecture however, and the government will contract with industry to produce only modules for the system. The defense department can reduce cost by contracting for the smaller, modular components that when changed, change the function of the bomb.

Additionally, flexible weapons can help reduce expenditures through optimally designing each weapon for a given target. The optimal weapons design will help reduce cost through using the minimum force necessary to destroy a given target. Rather than trying to generate an accurate cost forecast, this research instead will examine which factors within a weapons design will positively affect the overall cost of the weapon.

3.3 Flexible Weapons Architecture Design

The previous section discussed the many possible benefits of a modular weapons design, but the true success or failure of the flex weapons concept depends on what elements of the weapon are modular. If the correct elements are modular, mission planners will have the ability to create the optimal weapons set for any target, but if the incorrect elements are modular, the weapon design would provide reduce (or no) additional benefit over conventional weapons. This goal of this thesis is to determine the elements that if modularized would positively affect the development of flexible weapons and change the way weapons are designed.

The previous chapter provided a thorough examination of how conventional weapons function highlighting five key factors: the damage mechanism, size, guidance, propulsion, and fusing. The additional elements such as the type of sensors, communications technology, and computer processing power will also greatly affect a collaborative weapons swarm, but this thesis will concentrate on the first five elements since the intent is to explore the pre-mission execution flex weapon process.

3.3.1 Damage Mechanism

The first element we have selected as a candidate for modularization is the weapons damage mechanism. During the weaponeering process, the damage mechanism of the weapon directly correlates to the overall success of a mission. The correct damage mechanism could mean the difference between using four weapons to destroy a target versus forty weapons to destroy the same target. A fragmentation bomb, for example, would have little effectiveness against a bunker or hardened building because the target is specifically designed/ hardened against this type of weapon. A better choice is to use a penetrator warhead that explodes when the bomb reaches a certain depth within the structure. The simple act of changing the damage mechanism in the bomb greatly increased.

Current weapons have various damage mechanisms that spread from leaflet drops to nuclear weapons. In actual missions, the tactical situation drives the suite of weapons that the joint forces commander allows the air component commander to use. Since the goal of this thesis is not to determine specifically the best weapon, but the best portion of the weapon to modularize, this thesis will limit the number of damage mechanisms to fragmentation, blast, shape charge/explosively formed projectiles, and leaflet drops. This selection of damage mechanisms will provide the necessary variance in type that will help determine if weapons damage mechanism is a significant factor.

3.3.2 Weapons Size

The size of an explosive directly affects the total mean area of effectiveness of the weapon. For example a MK 82 500 lb general purpose bomb has a MAEf of 3000 m^2 against infantry or personnel in the open, and a MK 84 2000 lb general purpose bomb has a MAE_f of 12000 m^2 against infantry or personnel. (Driels, Morris pg. 285) In this example, the bomb that is four times as heavy has four times the effect on that particular target.

The overall resulting effect of a bomb however is not always a mere linear multiplication of the smaller effect, because some weapons target pairings produce unusual results that are not simple multiples of smaller weapons. An example of this is the same MK 82 500 lb general purpose bomb has an MAE_f of 450 m^2 against tanks and the 2000 lb MK 84 bomb has a MAE_f area of 550 m^2. (Driels, Morris pg. 285) The resulting relationship between the two weapons has changed based on the target type.

Due to this target - weapons weight interaction, weapons weight is a factor that we will consider for modularization. Since weapons weight will definitely change the mass property of the flex weapons package, as mentioned previously, the air force would conduct flight testing to determine if the weapon is air worthy. One possible solution to this problem is to flight test the flexible weapon a separate time for each allowed weight. Once the flight tests are complete, the weapon can be employed modularly based on the mission requirements. The weapons size that this thesis tests are 250 lb., 500 lb., 1000 lb., and 2000 lb. bombs.

3.3.3 Fusing

Weapons' fusing has a significant effect on the way munitions detonates on the target, and it will thus be a modular weapons design factor. An example is a 2000 lb blast weapon with a height above burst fuse employed against a building will do minimal damage because the blast mechanism will dissipate prior to causing significant damage to the building, but the same blast weapon employed against a building with a delayed impact fuse will penetrate the roof of the building and explode at a pre-selected time resulting in significant damage if not destruction of the entire building.

Fusing is so important that it is one of the only elements that are modular on current weapons. This research however still includes fusing as a design factor in flex weapons to determine if fusing remains important in the presence of multiple modular components.

3.3.4 Guidance

Weapons guidance is the next element that should be modular in flex weapons because the guidance directly influences the probability that a weapon will impact its target in the correct area. This has the effect of increasing the lethality of an individual strike while decreasing the unnecessary civilian casualties.

Prior to the advent of modern guided weapons, commanders had to use multiple strike aircraft to ensure a target was destroyed. A single bomber was not accurate enough to destroy a target. Modern weaponry however has multiple guidance modes that aid a bomb reach its target with precision. The modes this thesis will concentrate on are unguided, global positioning satellite guided, radar/ laser guided, and TV Optical guidance. These four modes have advantages and disadvantages to each that provide different accuracy and standoff capability when engaging a target.

Unguided munitions typically have a ballistic flight path whose accuracy is based on the aircraft release conditions. GPS guidance uses satellite navigation with a backup inertial navigation system to guide a weapon to its target. This system is excellent because it is accurate and does not require the pilot to have eyes on the target. Radar or laser guided munitions will follow a beam of energy that is either emitted by (e.g. HARM missile) or 'painted' on the target by friendly ground forces or aircraft. The benefit to this method is that it is extremely accurate and the pilot or weapons commander has eyes on the target, but this also places the crew much closer to the target. The last type of missile is also extremely accurate and allows the pilot or mission commander to remotely guide the weapon to impact the target.

Including these different guidance modules will allow the weaponeer to select the appropriate guidance required for the mission in order to destroy the target, reduce civilian casualties, and reduce cost. The guidance mode is typically one of the most expensive elements in a weapons design (US Air Force Budget) , and the ability to tailor the guidance for a particular mission will help address all of these issues.

3.3.5 Propulsion

Propulsion is the last design factor that may be advantageous for modularization. An example of a case where the weapon needs propulsion is when the enemy heavily defends a target with anti-aircraft weapons. The anti-aircraft shield could make the target vulnerable to attack without heavy friendly losses, but the inclusion of propulsion allows the mission commander to engage the target outside the range of the enemy's defensive weapons. This thesis treats propulsion as a binary variable that weaponeers can either choose to equip or not equip with propulsion.

3.3.6 Raid Size

The last factor this thesis will consider as a design factor is the total raid size. Although the total number of weapons employed is also a variable current weaponeers select for each mission, flex weapons also occasionally requires multiple weapons to ensure destruction of a target. The algorithm will use this variable in conjunction with the five other design factors to determine the optimal solution for a random target set. Additionally, by testing this variable in conjunction with the other design factors, we will be able to determine if the other design factors are indeed significant.

CHAPTER 4. METHODOLOGY

4.1 Introduction

The hypothesis of this thesis is that the architecture design factors listed in the previous chapter can be optimized to decrease the cost and civilian casualties while improving the fractional damage of an engagement. To test the hypothesis, we developed a scenario that constructs a random target set for which the flexible weapons engage. Once the scenario begins, an algorithm will optimize the design of a flexible weapon by modifying the architecture design factors listed above to engage the target set. The algorithm seeks to optimize a pseudo-objective function that includes weapons cost, civilian damage, and fractional damage of the weapons sortie. We will run this algorithm multiple times for each scenario using a random seed generator as a variable to count each run. Each scenario will randomly generate the target location, size, elevation, and civilian population prior to the start of the Monte Carlo simulation. Each iteration of the Monte Carlo will randomly generate a starting architecture design factor starting population. We will then use analysis of variance to statistically determine the significance of each architecture design factor. The test is complete when the random seed is no longer significant in determining the value of each run. This is a basic overview of the setup of the experiment.

4.2 Architecture Design Factors

Figure 14: Flex Weapons Modular Design

The architecture design factors are:

- X_1 - Number of Weapons Used
- X_2 - Weapons Damage Mechanism
- X_3 - Weapons fusing
- X_4 - Weapons Weight
- X_5 - Guidance
- X_6 - Propulsion

Each design factor consists of an integer that represents one of the modular components. The number of weapons used is a integer from one to 64 that represents the total number of weapons used for the assigned target. The damage mechanism, fusing, weapons weight, and guidance module are integers between one and four that represents one of the different modular components listed above, and the propulsion is a binary variable that represents with or without propulsion. Additionally a sortie is the individual weapon target pairing, while a raid is all the weapons for the whole mission. For a mission with multiple targets, a subscript of ‘t’ represents the current target, and the total cost is the summation of the cost to engage each target. The assignment is as follows:

Table 5: Architecture Design Factor Assignment

	X_1: # of Weapons	X_2: Damage Mechanism	X_3: Fusing	X_4: Weight	X_5: Guidance	X_6: Propulsion
1		Fragmentation	Impact	250 lb.	Unguided	Propulsion
2		Blast	Time Delay	500 lb.	Laser/ Radar	No Propulsion
3		Shape Charge/ EFP	Height Above	1000 lb.	GPS Guided	
4		Leaflet	Smart Fuse	2000 lb.	TV/ Optical	

Using the above table, a weapons set with the factors X = [12, 2, 3, 4, 2, 1] is equal to 12 GPS guided 2000 lb. blast bombs with propulsion and a time delayed fusing. The limitation with this setup is that it cannot inter mix different components within a sortie. Weaponeers often combine different types of weapons to achieve a desired effect on a target. An example is firing an EFP round at the first tank in a column and following the strike with multiple fragmentation weapons. The combined effects of the highly precise EFP and fragmentation weapons allows the weaponeer to slow or stall the tanks thus increasing their vulnerability to the less precise but larger affective area fragmentation weapons. Although these interactions are essential in an actual engagement, achieving complex interactions to increase the lethality of engagements is outside of the scope of this thesis that is aimed more narrowly on determining the best components to modularize in a weapons design.

4.3 Cost Objective Function

The goal of the cost objective function is to determine the total cost of the mission. To determine the cost of the entire weapon system, the individual cost for each component is added together and multiplied by the total number of weapons employed. The cost objective function is:

Eqn. 4.1: $cost_t = x_{t,1}\left(\left(costw_{(x_{t,2},x_{t,4})}\right) + fuze_{t,3} + guidance_{x_{t,6}} + propulsion_{x_{t,6}}\right)$

'Flex' weapons are currently just a technological concept; no actual cost per weapon exist. Basing cost on similar existing weapons can help, but relating the cost of a total weapon system to the cost of individual weapons is skewed because traditional weapons are purchased as a unit. A more refined solution for estimating flex weapons cost was developed by examining the Air Force's repair part or modification budget. Repair parts or modifications are better analogs for flex weapon modules and were used to develop a baseline cost estimate for most component parts. An example is the JDAM modification kit because this item functions to convert a regular 'dumb' bomb into a GPS guided weapon. The total cost of this modification is an excellent estimate of the cost required to build a modular GPS guidance system.

The cost estimates are stored in the cost objective function and combined on a by component basis to determine the overall cost of the engagement . The 1000 and 2000 lb shape charge cost is also left blank because a shape charges are not build in that size. The cost weight -damage mechanism cost is as follows: (FY 14 Air Force Procurement Budget)

Table 6: Cost of Weapon Damage Mechanism and Weight Pairing

	Fragmentation	Blast	Shape Charge	Leaflet
250 lb	$1000.00	$1000.00	$2000.00	$1000.00
500 lb	$2082.50	$2082.50	$4000.00	$2000.00
1000 lb	$3128.83	$3128.83		$3000.00
2000 lb	$5384.78	$5384.78		$4000.00

The next cost vectors are the fuse and guidance cost. These two costs are independent and they are based on the type of weapon used. The budget listed nine separate fusing systems with different associated cost. Through the course of research, we reduced the total number to four fuses that provide the abilities listed in the previous paragraph. The guidance mode cost list is derived from the conversion smart weapons conversion kits. The cost is as follows:

Table 7: Cost of Fusing and Guidance

Fusing	
Impact	$2145.14
Delay	$2145.14
Air Burst	$1540.7
Smart	$2685.59

Guidance	
Unguided	$0
Radar/ Laser	$64867.62
GPS/INS	$19960.00
TV/Optical	$61178.51

The last cost is the propulsion. To determine the cost of the propulsion, we simply subtracted the cost of a weapons system with propulsion from the same system without propulsion the total cost difference was $ 16758.

The cost of all the components is added together and multiplied by the total number of weapons to generate the total cost for the sortie. If there are multiple targets in the sortie, the algorithm will calculate each associated target's cost for the total missions cost.

4.4 Civilian Damage Objective Function

Civilian casualties are the next metric that the algorithm will minimize using the modular flex weapons architecture. The civilian damage objective function is:

Eqn. 4.2 $$casualties_t = FD_{CO} \times population\ density_t \times area_t$$

Eqn. 4.3 $$cost_{casualties} = casualties_t \times \frac{cost}{casualty}$$

Equation 4.2 estimates the total number of civilian casualties of a given engagement. It multiplies the fractional damage on the collateral object (FD_{CO}) by the population density and the area of the collateral object to determine the total number of casualties. To ensure the pseudo objective function compares like units, the total civilian casualties is converted into the dollar cost of the deaths. The total casualty cost is a dollar value estimate of the total dollar value the United States would pay for the accidental civilian death. While it is impossible to place a value on the life of a human, it is necessary in this case to ensure a viable comparison with the total cost of the mission. The cost per casualty ratio is the total value monetizes the total cost per casualty and the cost of repairing a damaged civilian structure. US labor market data estimates the statistical value of human life to be between $4 million to $9 million dollars. (Viscusi, W. Kip, pg 3) Based on that figure, this research will estimate the total value per person as $5 million. The population density and area of the civilian object are properties of the target.

The total fractional damage of the collateral object is calculated by setting the center of the target area to the center of the collateral object and using the distance to the target as the effective miss distance. The results give the total probability of damage on the collateral object.(Driels, Morris pg. 392) This figure is then multiplied by the expected fractional coverage of the target area through examining the total damage area (Wet and LET) and determining the degree of overlap of the collateral area.

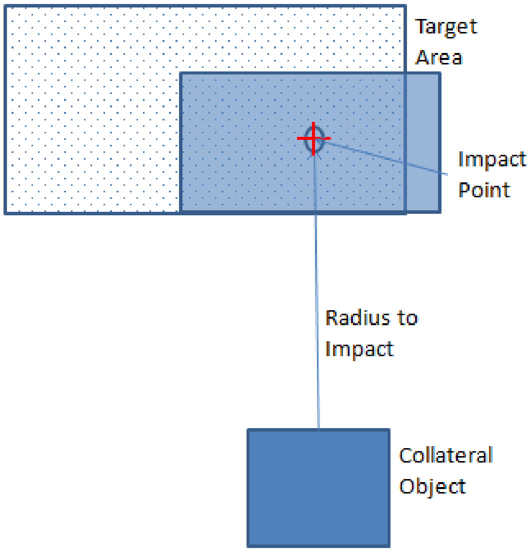

Figure 15: Collateral Object Geometry

As the figure shows, the radius is to the center of the impact area, and the total overlap is determined by the degree the damage area overlaps the collateral area. The probability of damage is determined using equation 2.47 - 2.49, and the total fractional damage is computed with the same function as the fractional damage constraint function.

4.5 Fractional Damage Destruction Constraint

The last metric that determines the performance of the flexible weapons is their ability to engage and destroy a target. Target destruction is measured in the degree of fractional damage a target sustains. This thesis proposes that the six architecture design factors listed above will are essential in predicting and increasing the amount of fractional damage a weapons sortie produces.

This research addresses fractional damage as a constraint based that is based on the goals of the bombing sortie. The constraint is:

Eqn. 4.4 $g_t = 1 - (1 - FD_1)^n \leq required\ damage$

The weaponeer sets the level of damage required prior to the mission needed for mission success. (this research the default value is one) The inequality constraint is converted to the following for use in coding:

Eqn. 4.5 $g_t = 1 - (1 - FD_1)^n - required\ damage$

While this inequality constraint set up is basic it relies on multiple background functions that are discussed in a future section that calculate the total fractional damage and civilian damage for a given scenario.

4.6 Pseudo-Objective Function

The pseudo-objective function is a combination of the cost and CDE function with the fractional damage function as an external penalty. he The cost and CDE functions also have an associated weighting that are between zero and one that total to one. These weights allow the mission designer to decide which is the most important for each particular mission. The cost and the CDE functions are measured in estimated US dollars. The formulation is:

Eqn. 4.6 $\varphi_t = w_1 cost_t + w_2 CDE_t + R_k g_t$

The fractional damage constraint has a penalty multiplier R_k to help scale the constraint to the value of the cost and CDE functions while providing a substantial penalty for not satisfying the constraint. Correctly scaling the penalty multiplier was vital in order to keep a balance between destroying a target and minimizing civilian casualties and cost. If the multiplier is to large, the optimization will attempt to destroy the target at all cost and if it is to small the algorithm will disregard destroying the target and use the least expensive weapons regardless of the mission. After substantial testing we selected the penalty multiplier RK = 200,000,000 because the fractional damage constraint is a value between zero and one and the cost and CDE functions averaged a value of between one million to ten million. The resulting penalty equals between two to four times larger than the cost.

4.7 Target Function

The target function generates a target set that the flex weapon design algorithm seeks to destroy. Each individual target will have the following characteristics:

- T_1 - Priority
- T_2 - Length
- T_3 - Width
- T_4 - Latitude
- T_5 - Longitude
- T_6 - Civilian Population Density
- T_7 - Type
- T_8 - Elevation
- T_9 - Distance to Nearest Civilian Object
- T_{10} - Area of Civilian Object

The priority sets the importance of an individual target within a list of targets. The target file can produce a single target sortie, or multiple targets. The priority gives the importance for each target in a list of multiple targets. The latitude longitude, width, and length of the target establish the target geometry that is used in determining the fractional damage. The civilian population density is the number of persons per 1000 m^2 and it is used in conjunction with the distance and area of the nearest civilian object to help determine the civilian damage estimate of the scenario. The last target property is the target type. The type of target directly determines the effectiveness of a given weapon that engages it. The types of targets are listed in the following table.

Table 8: Target Types

Target Type	Assignment Number
Soldiers in the open	1
Building	2
Armored Vehicle	3
Equipment	4
Civilian Population	5
Bunker	6

Each individual target selected has varying degrees of ‘hardness’ that require different damage mechanisms and fusing combinations to effectively destroy. The target type property will test the optimization algorithm in finding the appropriate level of force to destroy the target.

4.8 Support Functions

There are several support functions that perform essential calculations within the larger design algorithm. This section will give a brief overview of each in detail.

4.8.1 Trajectory

The first function calculates the ballistic trajectory, slant range, time of flight, and range from a designated drop point to the target. The function uses an elliptical earth model and numerically integrates equations 2.66 to calculate the total time of flight. The equation then uses this time of flight to calculate the total range of unguided munitions with no propulsion. The algorithm then uses this range to determine if any guided or unguided free fall munitions can reach the target. The algorithm also calculates the impact angle for a free fall weapon with no propulsion. The outputs of this function are whether a weapon has a trajectory to the target, the time of flight, the slant range, and the impact angle of unguided weapons with no propulsion.

4.8.2 Accuracy

The accuracy function uses conditional statements to determine the overall accuracy of the weapons set within the mission. The functions use the guidance variable to assign the correct accuracy for the guidance mode selected. The output of the function is the range, deflection and error probable in addition to the calculated standard deviation. Each assigned weapon has the following error: (Federation of American Scientist, Military Analysis Network)

Table 9: Guidance Mode Accuracy

	REP	DEP	CEP
Unguided	57.2738	57.2738	100
GPS/ Inertial Guided	4.5819	4.5819	8
Radar/ Laser Guided	0.5727	0.5727	1
TV/ Optical Guided	1.7182	1.7182	3

4.8.3 Effects

The next function calculates the mean area of effectiveness for a given target weapon pairing through evaluating a series of conditional statements to determine the correct pairing. The output is the mean area of effectiveness for fragmentation and blast in m^2. The mean area of effectiveness for fragmentation is a combination of researched values and a regression based on the researched values. The Mean Area of Effectiveness for blast is calculated using the mean over-pressurization that causes target destruction and equations in chapter two. (FEMA document) The mean area of effectiveness for fragmentation is: (Driels, Morris, pg. 285)

Table 10: Mean Area of Effectiveness for Fragmentation - Target Pairing

	Troops	Tanks	Buildings	Civilians	Equipment	Bunkers
250 lb	1500	433.34	0	1500	500	0
500 lb	3000	450	0	3000	600	0
1000 lb	6000	483.3667	0	6000	800	0
2000 lb	12000	550	0	12000	1200	0

4.8.4 Fusing

The fusing function modifies the mean area of effectiveness and the probability of damage function based on the type of fuse used. The function uses conditional statements to compare the damage mechanism, target specification, and selected fusing to adjust the area and probability of damage of each weapon.

The four types of fuses that this algorithm uses are impact, height above burst, time delay, and smart fuses. A greater explanation of how fusing affects the damage of a weapon is in section II.a.3.v. The primary method this algorithm uses to modify weapons damage depends on the weapons type.

4.8.4.1 Impact Fuse

The impact fuse explodes when the weapon impacts the target. Most weapons effects areas are not greatly modified by an impact fuse because the current statistical data is typically gathered at ground level; however there are some notable exceptions. One exception is leaflet drop. If a weapon releases its leaflets when it impacts the ground, the leaflets do not disperse appropriately. While some weapons, such as a shape charge, require impact fuses to activate when it hits the target. The fusing function models these interactions through modifying the total probability of damage and mean effective area of the weapons to enforce the correct fusing pairing.

4.8.4.2 Height Above Impact Fuse

The height above impact fuse explodes at a certain altitude above a target enabling an air burst of the munitions. Some weapon-target pairing are enhanced by the air burst such as fragmentation weapons against all targets except bunkers and buildings because the air burst allows for a larger distribution of fragmentation. Blast weapons effectiveness are actually lowered by an air burst against most targets because the primary damage mechanism is the over-pressurization, The blast radius and intensity increases when it is in close proximity to solid objects that reflect the waves energy. Additionally, a target needs to be within the blast radius of the weapon in order to sustain damage. A height above impact fuse moves the weapon away from reflective surfaces and increases the distance to the target. Shape Charges are greatly diminished by air burst because it causes the weapon to initiate early thus reducing the penetration capability. Leaflets require air burst to ensure proper leaflet distribution.

4.8.4.3 Delay Fuse

Delay fuses cause the weapon to detonate after a pre-established time period after impact resulting in target detonation inside of a target. Delay fuses diminish the effectiveness of fragmentation weapons because the weapon buries itself prior to detonation resulting in a decreased amount of fragments. Blast weapons are generally enhanced by delay fuses. Against soft targets such as troops or equipment, the delay results in the munitions burial in the ground resulting in more fragments. The effect is even larger with buildings and bunkers because the delay allows the weapon to penetrate the first few levels of the building and explode inside resulting in a significant increase in damage because once the fuse is inside of the structure, the over-pressurization required to kill the occupants decreases to the factors required to kill a soft target. Delay fuses are not affective with Shape charges and leaflets.

4.8.4.4 Smart Fuse

A smart fuse can be programmed to perform in the most advantageous method for the weapon target pairing. Smart fuses are even more effective against bunkers because it allows the weaponeer to select a specific penetration depth prior to explosion. The modification factors are below.

4.8.5 Damage Function

The damage function calculates the probability of damage and fractional damage of the engagement. The function receives inputs from the target, effects, and accuracy function to calculate the total probability of damage for one weapon. Once the damage function calculates the probability of damage for a single weapon, it uses a series of conditional statements to determine if the weapons are independent or in a dependent sortie based on the guidance used. The program treats all unguided sorties as dependent and calculates the total damage for the stick of weapons. Guided weapons are considered independent and the probability for damage remains the same as the unitary weapons. (total damage will increase based on the total fractional damage of the sortie)

The algorithm uses the probability of damage for either the stick of dependent weapons or the independent smart weapons to calculate the total fractional damage using the method explained in chapter two. Of note, all sticks are accounted for as whole and not as individual sorties. This fractional damage is the next output of the damage function.

The last output of the damage function is the probability of damage and the total fractional damage to the civilian structure in the vicinity of the target. The program calculates these values by setting the civilian object as the center of target and calculating the actual impact points as the sorties miss distance. The results give the total probability of damage to civilian structures. The program then calculates the width and length of the actual target area to the distance between the collateral area and the target determine if there is any overlap. If there is overlap, the algorithm will calculate the degree of overlap and determine the total fractional damage of the collateral area.

The output of the damage function is a [4 X 4] matrix with row one the probability of damage, row two the fractional damage, row three the probability of damage to the civilian object, and row for the fractional damage to the civilian object. The four columns are the damage mechanism of the weapon.

The fractional coverage and probability of damage for leaflets use the coverage area of MAE_f bombs of the same weight against troops as the total coverage area. The total probability for leaflets is one against civilian targets. The total fractional damage is then calculated based on the probability of one with the coverage area divided by the total target area.

The damage for shape charges is based on the total MAEf or MAEb unless they are employed against tanks or equipment. If the shape charge is used against a tank or equipment, the total probability of damage is equal to one. The fractional coverage area is converted into the total number of tanks within the area, and the fractional coverage is a measure of how many total tanks versus the number of tanks the weapon can destroy. A 250 lb. shape charge bomb will kill one tank per engagement and a 500 lb. shape charged weapon will kill four tanks per engagement. (Simulating a maverick missile with four brilliant anti-tank mines BATs) The last change is that all shape charge fractional damage is directly added together because the weapon is a precision weapon that only attacks an individual vehicle instead of an area effect weapon. This total fractional damage is the last output of the damage function.

4.8.6 Optimization Technique

Optimizing the architecture design factors is difficult because each factor's functionality is determined by a series of variables that represent different component choices for that factor. Additionally, no obvious mathematical relationship exists to explain the behavior of each design choice because each design choice is qualitatively different. Due to these issues, the pseudo objective function requires a zero order optimization algorithm to determine the best design.

After considering several zero order techniques as candidates for the optimizer, a genetic algorithm is selected due to the high number of discrete variables in the design problem. Although a genetic algorithm is one of the most expensive in terms of computation time, it is often effective at finding a solution near the global minimum compared to simulated annealing or the Nelder-Mead simplex optimization techniques. Additionally the genetic algorithm had the added benefit of producing a large selection of feasible designs throughout the optimization that we used to conduct statistical analysis of the design factors.

The genetic algorithm used crossover breading with a generational size of 60 candidate solutions and a maximum number of 200 generations. The design factors had the following configuration:

Table 11: Genetic Algorithm Set Up

	Lower Bound	Upper Bound	Number of Bits
X_1	1	64	6
X_2	1	4	2
X_3	1	4	2
X_4	1	4	2
X_5	1	4	2
X_6	1	2	1

The next step in the optimization is to assign the target. For the purpose of analysis, we started of the first six runs by optimizing against one of every target to gather results on the significance of the design factors against every target type. The algorithm saved the optimal design factors as well as the first generation of each run for statistical analysis.

4.8.7 Monte Carlo Simulation

Once the set up was complete, we set up a Monte Carlo run with a random seed generator to determine if the optimization technique ran a statistically significant number of times. We conducted an analysis of variance with the saved optimal design and the random seed generator. When the random seed value was insignificant in the analysis of variance, the Monte Carlo simulation was complete. Each simulation lasted around 100 total runs per target, and each run was saved in a data array for analysis.

4.8.8 Statistical Analysis

Once the runs were complete, the program evaluated the optimal design and the 60 first generation designs with the cost and CDE objective functions and the fractional damage constraint. Each value and design factor settings were saves in a matrix and evaluated using an analysis of variance to determine which design factors were important in the pseudo objective function, each objective function, and the fractional damage constraint for a particular target type. The results displayed which objective functions were affected by modular weapons and which design factors are significant in that analysis.

CHAPTER 5. RESULTS

5.1 Introduction

The goal of this thesis is to evaluate the elements of a weapon that when modularized will improve the weapons fractional damage while decreasing cost and collateral damage of the mission. We theorized that making the weapons damage mechanism, weight, guidance, propulsion, and fusing modular would improve the cost, CDE, and fractional damage performance. To test this theory, we built an algorithm to test the performance of each design factor against the pseudo objective function consisting of cost, civil damage and the constraint. Civilian damage (CDE) and cost are weighted equally, and each Monte Carlo simulation will be evaluated against a predetermined target type.

5.2 Troops in the open

The first target tested was troops or personnel in the open. The target specifications:

Table 12: Troops Target Information

Priority	Length	Width	Latitude	Longitude	Pop./1000m^2	Type	Elevation	Distance to CO	CO Area
1	141 m	151 m	39.5693	125.6503	259	Troops	20 m	311 m	357 m^2

The Monte Carlo simulation ran a total of 1000 times to ensure a statistically significant number of runs. The median optimal result of the simulation selected 10 laser guided fragmentation bombs with delayed fusing and a mean pseudo objective function value of $430,900. To determine if the genetic algorithm produced the true minimum, we enumerated the entire design space to find the true minimum. There are a total of 32,768 viable designs, and we evaluated each design to determine the true minimum. The results matched the optimal design selected and confirm the genetic algorithms ability to find the global minimum. The optimal results are:

Table 13: Average Objective function Results

Design Factors	Pseudo –Objective Value	Cost	Civilian Casualties	Fractional Damage
[10, 1, 3, 4, 3, 1]	$430,900	$394,220	0	99.98%

Over the course of 1000 runs, the algorithm only changed the design factors for the number of weapons(X_1) and the fusing (X_6) which resulted in miniscule changes to the total pseudo-objective function value as displayed in figure 16. The total change in the pseudo-objective function value where on a scale of -\$1.2 x 10^{-3}.

The primary source of variation in the optimal results was the fusing and the number of weapons used per run. Figure 16 displays that varying each variable will only change the results of the pseudo objective function by a maximum of -\$1.2 x 10^{-3}. This tight grouping of the optimal values displays the validity of the optimization algorithm. Additionally, the target was 99.98% destroyed with no collateral damage.

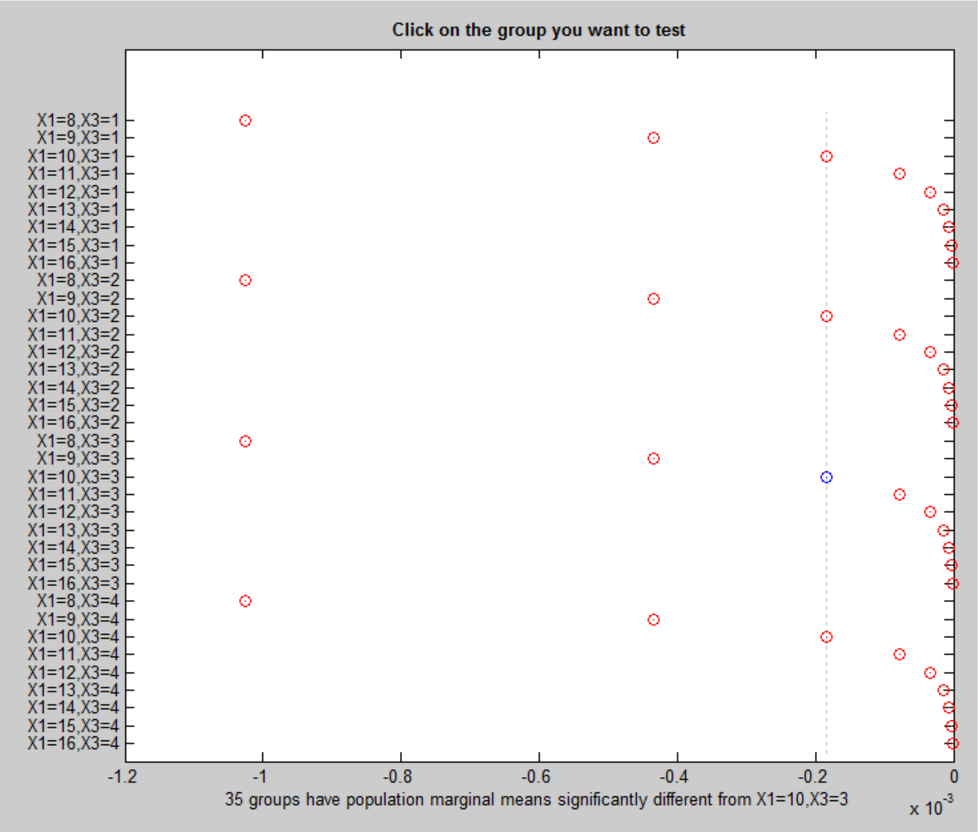

Figure 16: Comparison of Optimal Results with Different Design Variables

The tight grouping of each architecture design factor does not provide enough variance to adequately analyze so we used the random sample of design factors produced for the first generation of the genetic algorithm for each function to analyze the effect of each design factor. Additionally, we analyzed the variance for the pseudo-objective function, the cost, the CDE, and the constraint to determine the significance of each design factor in each function. The analysis of variance for the pseudo-objective function shows that each design factor except the fusing was significant with a p-value less than .05%. The most significant factor (highest F value) was guidance followed by propulsion. Fusing was not as significant and had a P-value of .5758 in evaluating the pseudo-objective function.

Table 14: Analysis of Variance for Pseudo Objective Function with Troops Target

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	1.10563e+19	63	1.75497e+17	2.3	0
Damage Mechanism(X_2)	1.82378+20	3	6.07928e+19	797.59	0
Fusing (X_3)	1.51216e+17	3	3.7872e+17	0.66	0.5758
Weight(X_4)	1.13616e+18	3	4.76552e+20	4.97	0
Guidance (X_5)	1.42966e+21	3	4.76552e+20	6252.27	0.0019
Propulsion (X_6)	1.68526e+20	1	1.68526e+20	2211.02	0
Error	4.56737e+21	59923	7.62207e+16		
Total	6.36343e+21	59999			

Next we evaluated the variance of the design factors against the cost function. This analysis will help determine the how each factor affects the cost of the weapon.

Table 15 Analysis of Variance for Cost Objective Function with Troops Target

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	5.32892e+16	63	8.4586e+14	2858.32	0
Damage Mechanism(X_2)	4.50271e+14	3	1.5009e+14	507.18	0
Fusing (X_3)	8.96679e+12	3	2.98893e+12	10.1	0
Weight(X_4)	4.70735e+14	3	1.56912e+14	530.23	0
Guidance (X_5)	4.70735e+16	3	1.59275e+16	53822.06	0
Propulsion (X_6)	4.415e+15	1	4.415e+15	14919.11	0
Error	1.7733e+16	59923	2.9592e+11		
Total	1.24893e+21	59999			

The analysis of variance for the cost function shows that each variable is significant in predicting the cost of the operation with the Guidance being the most significant and the fusing the least significant. This result is as expected because the guidance modules are the most expensive components while the fusing is the least expensive component. The next analysis of variance determines how each design factor affects the civilian damage estimate.

The CDE ANOVA shows that the fusing and bomb weight were not significant in predicting the civilian casualties in this engagement whereas the number of weapons, damage mechanism, guidance, and propulsion were all significant in predicting the total civilian casualties with propulsion being the most significant followed closely by guidance. The ANOVA table is below. The last analysis is conducted against the fractional damage constraint to determine the design factors total effect on satisfying the constraint.

Table 16 Analysis of Variance for CDE Objective Function with Troops Target

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	458846.9	63	7283.28	2.78	0
Damage Mechanism(X_2)	15178637.6	3	5059545.88	1929.27	0
Fusing (X_3)	4768.9	3	1589.63	0.61	0.6109
Weight(X_4)	2878.4	3	959.46	0.37	0.7777
Guidance (X_5)	46139092.4	3	15379697.46	5864.48	0
Propulsion (X_6)	15699903.5	1	15699903.51	5986.58	0
Error	157149088.7	59923	2622.52		
Total	234808262.4	59999			

Table 17 Analysis of Variance for Fractional Damage Constraint with Troops Target

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	71.82	63	1.14	23.24	0
Damage Mechanism(X_2)	1127.3	3	375.77	7659.66	0
Fusing (X_3)	0.07	3	0.02	0.5	0.6826
Weight(X_4)	24.1	3	8.03	163.76	0
Guidance (X_5)	415.97	3	138.66	2826.43	0
Propulsion (X_6)	1188.96	1	1188.96	24235.89	0
Error	2939.69	59923	0.05		
Total	5790.86	59999			

The constraint analysis of variance once again shows that all of the design factors except fusing were significant in predicting the total amount of fractional damage the target receives. The most significant factor in fractional damage was the propulsion followed by the damage mechanism. The least significant factor across every run was the fusing, however this may change with the target type. It is of note that although this ANOVA shows that fusing is the least important factor, the result is due more to the fidelity of the fusing modeling instead of the actual fusing. This research does not have access to the classified joint munitions effectiveness manual (JMEM) that adequately defines how fusing increases the effectiveness against troops in the open. The next step to improve this result is to more accurately model the fusing.

5.3 Buildings

The next target is a building or industrial complex. The target specifications are:

Table 18: Building Target Information

Priority	Length	Width	Latitude	Longitude	Pop./1000m^2	Type	Elevation	Distance to CO	CO Area
1	166 m	44 m	39.3144	126.8417	352	Building	18 m	369 m	878 m^2

The Monte Carlo simulation ran a total of 1000 times to ensure a statistically significant number of runs. The median optimal result of the simulation selected a median optimal result of 10 GPS guided blast bombs with delayed fusing and a mean pseudo-objective function value of $476950.00. The median optimal results are:

Table 19: Average Objective function Results

Design Factors	Pseudo –Objective Value	Cost	Civilian Casualties	Fractional Damage
[10, 2, 2, 4, 3, 1]	$476,950	$415,940	0	99.97%

There was significantly more variance in with a building target set versus a troops in the open target because buildings are significantly more complex to destroy. The optimal design factors used GPS guidance and propulsion every time while selecting varying the bombs size, fusing, and damage mechanism. Figure 17 compares the total effect of varying the damage mechanism with the fusing. The four groupings of bomb fuse parings are fragmentation weapons with smart fuses, fragmentation with delay fuses, blast weapons with smart fuses, and blast weapons with delay fuses. Out of these four groups, the blast weapons with delay fuses are the cheapest by about $200,000 versus the most expensive pairing. The multi-compare diagram displays the groupings:

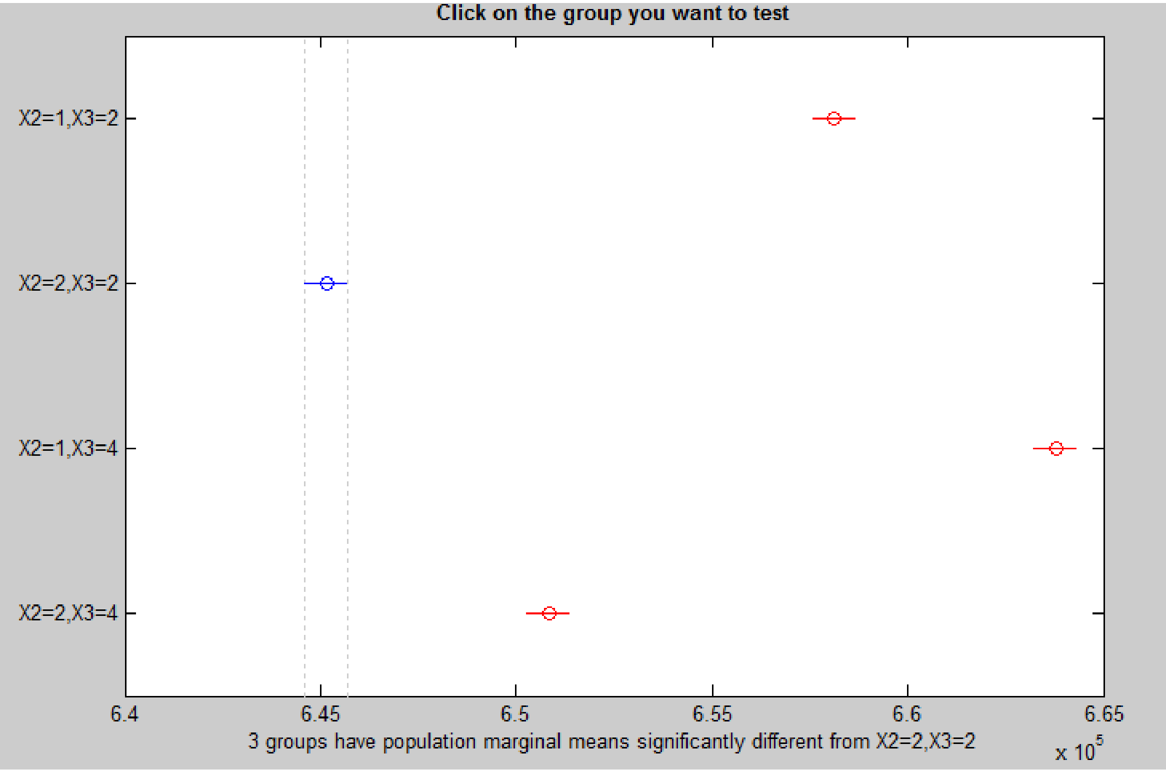

Figure 17: Comparison of Fusing Versus Damage Mechanism

The next grouping is the weapons type versus the weapons weight. Figure 18 displays the groupings of 1000 and 2000 lb fragmentation and blast bombs. The cheapest pairing is the 2000 lb blast bomb while the most expensive is the 1000 lb fragmentation weapons. The spread between the least and most expensive function value is $200,000. Figure 19 shows the total variation across the entire optimal design space. Each grouping is the results of one of the 1000 optimizations.

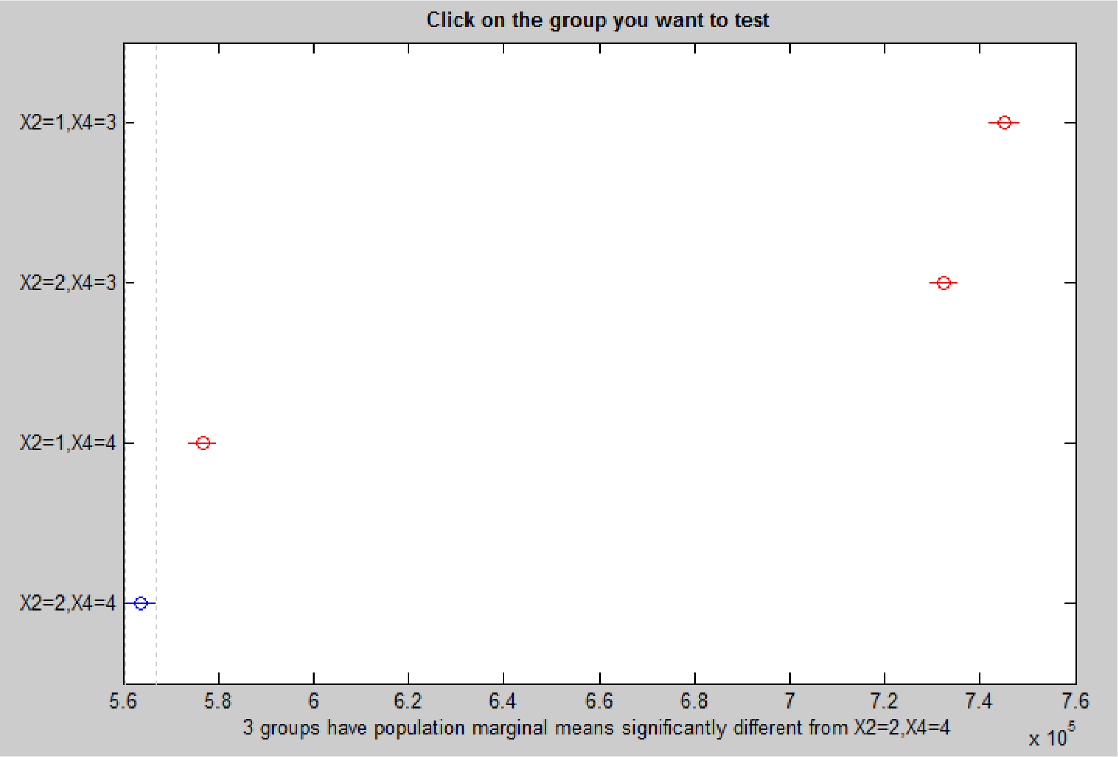

Figure 18: Comparison of Damage Mechanism Weapons Weight

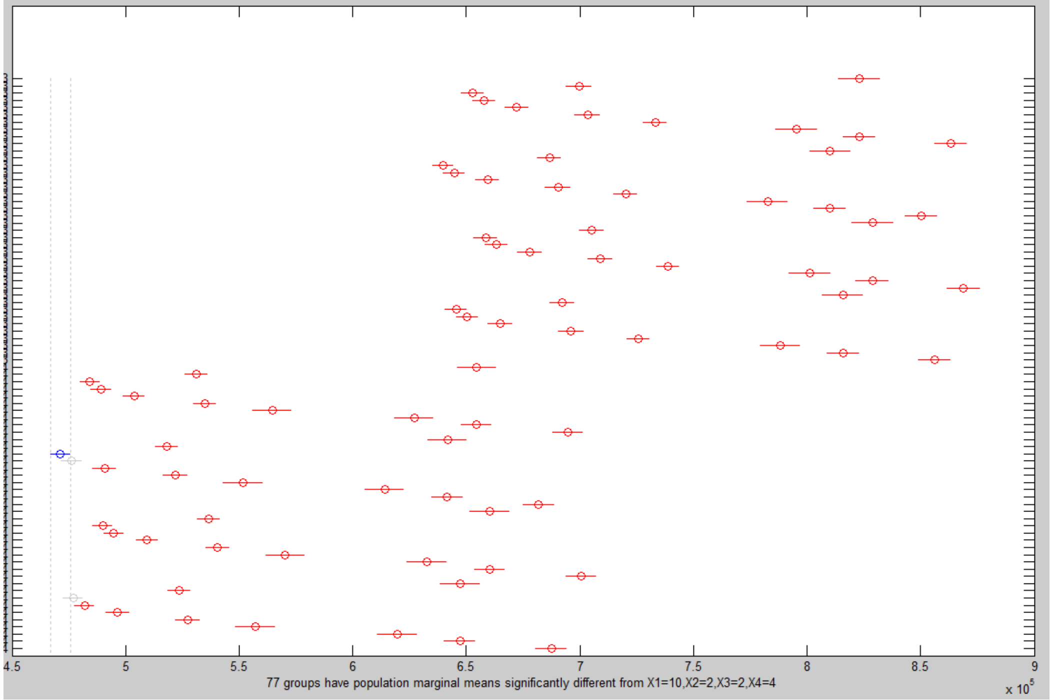

Figure 19: Comparison of Variation Across all Design Factors

The analysis of variance of the pseudo objective function shows that all the design factors were significant except the weapons weight with a p-value of .1001 (compared to p-value of .05). The most significant factor is the guidance module.

Table 20 Analysis of Variance of Buildings Pseudo-Objective Functions

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	1.91955e+19	63	3.04691e+17	2.22	0
Damage Mechanism(X_2)	3.49901e+20	3	1.16634e+20	849.33	0
Fusing (X_3)	2.47163e+18	3	8.23876e+17	6	0.0004
Weight(X_4)	8.5812e+17	3	2.8604e+17	2.08	0.1001
Guidance (X_5)	2.5489+21	3	8.49633e+20	6187.04	0
Propulsion (X_6)	3.70047+20	1	3.70047e+20	2694.69	0
Error	8.22891e+21	59923	1.37325e+17		
Total	1.1524e+21	59999			

The cost function does not change with the target because the weapons cost are independent of the target type, and the previous target proved that all the architecture design factors were significant for decreasing the cost. The civilian damage analysis shows that the fusing and weight are not significant. This result highlights that the civilian damage objective function is a function of the distance away from the target area and the weapons ability to accurately engage the intended target. This result however does not argue that the weight and fusing of a given weapon will have no effect on reducing civilian damage, because they do, but more that in these architecture design factors are not as significant in the presence of the other architecture design factors.

Table 21 Analysis of Variance of Building Civilian Damage Functions

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	846555.7	63	13437.4	2.78	0
Damage Mechanism(X_2)	28004032.1	3	9334677.4	1929.27	0
Fusing (X_3)	8798.4	3	2932.8	0.61	0.6109
Weight(X_4)	5310.5	3	1770.2	0.37	0.7777
Guidance (X_5)	85124940.4	3	28374980.1	5864.48	0
Propulsion (X_6)	28965748.6	1	28965748.6	5986.58	0
Error	28965748.6	59923	4838.4		
Total	433212668.7	59999			

All the architecture design factors were significant in minimizing the fractional damage constraint function.

Table 22 Analysis of Variance of Building Fractional Damage Constraint

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	47.32	63	0.75	12.34	0
Damage Mechanism(X_2)	1505.08	3	501.69	8246.13	0
Fusing (X_3)	34.67	3	11.56	189.95	0
Weight(X_4)	20.95	3	6.98	114.75	0
Guidance (X_5)	516.54	3	172.18	2830.08	0
Propulsion (X_6)	1497.6	1	1497.6	24615.36	0
Error	3645.71	59923	0.06		
Total	7291.32	59999			

5.4 Armored Vehicles

The next target is a group of armored vehicles spread out over a wide area. The target specifications are:

Table 23: Armored Vehicle Target Information

Priority	Length	Width	Latitude	Longitude	Pop./1000m^2	Type	Elevation	Distance to CO	CO Area
1	82 m	30 m	38. 258	125.9103	401	Armor	25 m	391 m	448 m^2

The Monte Carlo simulation ran a total of 1000 times to ensure a statistically significant number of runs. The median optimal result of the simulation selected a median optimal result of 27 TV/ Optical guided fragmentation bombs with air burst fusing and a mean pseudo-objective function value of $2548900.00. The median optimal results are:

Table 24: Average Objective function Results

Design Factors	Pseudo –Objective Value	Cost	Civilian Casualties	Fractional Damage
[27, 1, 3, 4, 4, 1]	$2,548,900	$2,211,500	0	99.83%

Tanks are harder targets to kill because they are particularly designed to protect the occupants from attack. Due to these facts, there is significant variance in the architecture design factors however the design factors did not significantly affect the mean value. Since the mean value did not change with the variation of the design factors, we moved on to analyzing the variance of a random set of design factors to test their significance.

The first ANOVA will analyze the pseudo-objective function. From the analysis, the architecture design factors of fusing and weight were not important while the other values were important. The most important factor was guidance and the least important was fusing with a p-value of .2987. Table 26 is the analysis of variance of the civilian casualty objective function. The analysis of each architecture design factor shows the same pattern as the other targets and shows that universally, minimizing civilian damage is a function of missing the civilian objects.

Table 25 Analysis of Variance of Armored vehicle Pseudo-Objective Function

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	2.58757e+19	63	4.10726e+17	2.42	0
Damage Mechanism(X_2)	6.40383e+20	3	2.13461e+20	1256.65	0
Fusing (X_3)	6.24394e+17	3	2.08131e+17	1.23	0.2987
Weight(X_4)	9.38636e+17	3	3.12879e+17	1.84	0.1371
Guidance (X_5)	3.01733+21	3	1.00578e+21	5921.02	0
Propulsion (X_6)	6.85608+20	1	6.85608e+20	4036.18	0
Error	1.01788e+22	59923	1.69865e+17		
Total	1.45603e+22	59999			

Table 26 Analysis of Variance of Armored Vehicle Civilian Casualty Function

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	1095917.8	63	17395.5	2.78	0
Damage Mechanism(X_2)	36252918.7	3	12084306.2	1929.27	0
Fusing (X_3)	11390.1	3	3796.7	0.61	0.6109
Weight(X_4)	6874.7	3	2291.6	0.37	0.777
Guidance (X_5)	110199400	3	36733133.4	5864.48	0
Propulsion (X_6)	37497919.1	1	3749719.1	5986.58	0
Error	375337581.3	59923	6263.7		
Total	560820084.9	59999			

The last ANOVA compares the fractional damage constraint with the architecture design factor and all of the values were important with propulsion being the most important.

Table 27 Analysis of Variance of Armored Vehicle Fractional Damage Constraint

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	26.79	63	0.425	5.08	0
Damage Mechanism(X_2)	1185.45	3	395.149	4720.8	0
Fusing (X_3)	3.49	3	1.165	13.92	0
Weight(X_4)	45.98	3	15.326	183.1	0
Guidance (X_5)	184.87	3	61.625	736.22	0
Propulsion (X_6)	506.27	1	506.273	6048.38	0
Error	5015.79	59923	0.084		
Total	6979.49	59999			

5.5 Equipment

The next target is general equipment spread out over a wide area. The target specifications are:

Table 28: Equipment Target Information

Priority	Length	Width	Latitude	Longitude	Pop./1000m^2	Type	Elevation	Distance to CO	CO Area
1	183 m	9 m	39.9015	126.1128	189	Equipment	2.4m	259 m	304 m^2

The Monte Carlo simulation ran a total of 1000 times to ensure a statistically significant number of runs. The median optimal result of the simulation selected a median optimal result of 45 GPS guided blast bombs with air burst fusing and an mean pseudo objective function value of $2,096,200. The median optimal results are:

Table 29 Average Objective function Results

Design Factors	Pseudo –Objective Value	Cost	Civilian Casualties	Fractional Damage
[45, 2, 3, 4, 3, 1]	$2,096,200	$1,812,800	0	99.86%

This target is unique because the dimensions are very long and thin. (Simulating a runway) To optimize destruction for this target, the algorithm used the approach of an air burst fused blast weapons to saturate the length of the target with weapons that detonate well above the ground so the effected ground area is not as large. The algorithm had very little variance in the design factor choices so we will go straight to the analysis of variance.

Table 30 Analysis of Variance of Equipment Pseudo-Objective Function

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	7.79373e+18	63	1.2371e+17	2.76	0
Damage Mechanism(X_2)	6.79127e+19	3	2.26376e+19	505.06	0
Fusing (X_3)	8.71061e+16	3	2.90354e+16	0.65	0.5842
Weight(X_4)	1.33565e+18	3	4.45216e+17	9.93	0
Guidance (X_5)	8.94444+20	3	2.98148e+20	6651.89	0
Propulsion (X_6)	3.02625+19	1	3.02625e+19	675.18	0
Error	2.68584e+21	59923	4.48215e+16		
Total	3.68845e+21	59999			

The ANOVA shows that all of the design factors are significant for the pseudo-objective function except the fusing. Although these results suggest that fusing is not an important factor, the lower significance is a result of a high fidelity fusing model. The most significant factor was guidance for the pseudo-objective function.

Table 31 Analysis of Variance of Equipment Civilian Casualty Function

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	244397	63	3879.32	2.78	0
Damage Mechanism(X_2)	8084642.3	3	2694880.77	1929.27	0
Fusing (X_3)	2540.1	3	846.69	0.61	0.6109
Weight(X_4)	1533.1	3	511.04	0.37	0.7777
Guidance (X_5)	24575200.2	3	8191733.39	5864.48	0
Propulsion (X_6)	8362285.7	1	8362285.68	5986.58	0
Error	83702780.3	59923	1396.84		
Total	125066613.9	59999			

The ANOVA table for the civilian casualties shows that the size of the bomb was insignificant in predicting the civilian deaths for this target type, while the most significant factor was propulsion followed closely by guidance.

The final ANOVA tested the architecture design factors against the Fractional damage constraint. The ANOVA shows that every architecture design factor is important against equipment (except the fusing caveat from above). This result, although interesting shows one of the improvements and areas for future work for this algorithm. This run's required damage is 100% so the algorithm is trying to destroy the entire runway, when a single weapon dropped in the center of the runway with delay fusing for cratering would also make a runway un-usable. Future iterations of this work will separate the equipment category into the actual target type and account for the unique damage mechanism required for each target type.

Table 32 Analysis of Variance of Equipment's Fractional Damage Constraint

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	136.11	63	2.16	34.58	0
Damage Mechanism(X_2)	1068.13	3	356.04	5698.36	0
Fusing (X_3)	0.11	3	0.04	0.56	0.6402
Weight(X_4)	23.11	3	123.27	123.27	0
Guidance (X_5)	732.11	3	244.04	3905.71	0
Propulsion (X_6)	2035.87	1	2035.87	32583.38	0
Error	3744.09	59923	0.06		
Total	7774.32	59999			

5.6 Civilian Population

The next target is meant to stretch the algorithm to ensure it picks the appropriate weapon for the target. The weapons algorithm should not pick any lethal weapons to use against a civilian population so if this happens, the algorithm does not function correctly. The target specifications are:

Table 33 Civilian Population Target Information

Priority	Length	Width	Latitude	Longitude	Pop./1000m^2	Type	Elevation	Distance to CO	CO Area
1	143 m	141 m	39.7014	126.0016	486	Civilian	7.7m	116 m	1584 m^2

The Monte Carlo simulation ran a total of 1000 times to ensure a statistically significant number of runs. The median optimal result of the simulation selected a median optimal result of 64 unguided leaflets dispersion bombs with air burst fusing and an mean pseudo objective function value of $12052000.00. The median optimal results are:

Table 34 Average Objective function Results

Design Factors	Pseudo –Objective Value	Cost	Civilian Casualties	Fractional Damage
[64, 4, 3, 4, 1, 1]	$12,052,000	$1,599,000	0	94.77%

The algorithm worked exactly as designed. It effectively designed a leaflet drop over a large civilian area, and did not use any casualty causing weapons. The overall cost of the pseudo-objective function very high because algorithm could only cover 95% of the target resulting in a large penalty. Figure 20 perfectly displays the effect of the penalty multiplier because the cost decreases as the number of weapons used increases.

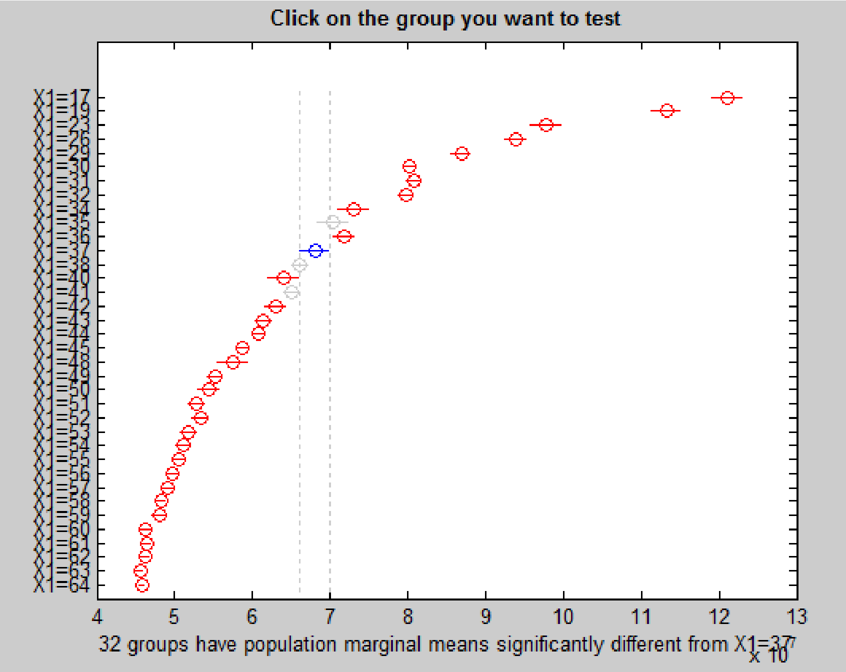

Figure 20 Pseudo-Objective Function Price vs Sortie Size

With each additional weapon, the actual cost of the sortie increases while the total pseudo objective functions penalized cost value decreases. In addition to validating the algorithm performs well with multiple divergent target types, the analysis of variance proves that for this target, every architecture design factor is important for the pseudo-objective function.

Table 35 Analysis of Variance for the Civilian Population Pseudo-Objective Function

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	3.41969e+20	63	5.42808e+18	21.76	0
Damage Mechanism(X_2)	5.94825e+21	3	1.98275e+21	7848.57	0
Fusing (X_3)	4.26684e+18	3	1.42228e+18	5.63	0.0007
Weight(X_4)	1.06129e+20	3	3.53763e+19	140.03	0
Guidance (X_5)	2.14386e+20	3	7.14621e+20	2828.77	0
Propulsion (X_6)	5.82974e+21	1	5.82974e+21	23076.57	0
Error	1.51381e+22	59923	2.52626e+17		
Total	2.96272e+22	59999			

The most important value was propulsion while the least important value was the fusing but each value was significant.

Table 36 shows the significance of each architecture design factor in calculation the civilian damage for the target. Each architecture design factor in the ANOVA of the civilian casualty objective function except the fusing was significant in predicting the total civilian casualties. The most important factor was propulsion.

Table 37 displays the ANOVA of the fractional damage constraint. For the civilian target fractional damage is a measure of the total fractional coverage of the target area with leaflets at a given density. All of the architecture design factors were significant in predicting the fractional 'damage' of the civilian target. The most significant factor was once again propulsion while the least significant was number of bombs. Although the number of bombs was the least significant, it still had a p-value of less than zero.

Table 36 Analysis of Variance of Civilian Casualty Function for Civilian Target

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	17060341.6	63	270799.1	23.05	0
Damage Mechanism(X_2)	269468728.8	3	89822909.6	7643.97	0
Fusing (X_3)	17661.6	3	5887.2	0.5	0.6816
Weight(X_4)	5495076.5	3	1819692.2	154.86	0
Guidance (X_5)	101160191.7	3	33720063.9	2869.59	0
Propulsion (X_6)	289150108.2	1	289150108.2	24606.8	0
Error	704144509.8	59923	11750.8		
Total	1392021958.5	59999			

Table 37 Analysis of Variance for Civilian Target Fractional Damage Constraint

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	143.23	63	2.27	41.31	0
Damage Mechanism(X_2)	732.15	3	244.05	4434.08	0
Fusing (X_3)	64.23	3	21.41	389	0
Weight(X_4)	48.07	3	16.02	291.13	0
Guidance (X_5)	436.13	3	145.38	2641.3	0
Propulsion (X_6)	1907.86	1	1907.86	34663.17	0
Error	3298.16	59923	0.06		
Total	6659.19	59999			

5.7 Bunker

The last target, a bunker, is perhaps the hardest to kill because it is hardened to prevent all weapons from destroying it. A flex weapon needs the right combination of damage mechanism, size, guidance, and fusing to do a bunker.

Table 38 Civilian Population Target Information

Priority	Length	Width	Latitude	Longitude	Pop./1000m^2	Type	Elevation	Distance to CO	CO Area
1	143 m	141 m	39.7014	126.0016	486	Bunker	7.7m	116 m	1584 m^2

The Monte Carlo simulation ran a total of 1000 times to ensure a statistically significant number of runs. The median optimal result of the simulation selected a median optimal result of 14 GPS guided fragmentation bombs with delay fusing and an average pseudo objective function value of $646420.00. The median optimal results are:

Table 39 Average Objective function Results

Design Factors	Pseudo –Objective Value	Cost	Civilian Casualties	Fractional Damage
[14, 1, 2, 4, 3, 1]	$646,420	$569,950	0	99.96%

The algorithm worked extremely well in building an weapons set to destroy the bunker complex. The one shocking selection is the algorithm chose a fragmentation bomb to attack the complex versus a blast weapon, but fragmentation weapons have blast and fragmentation affects. Figure 21 compares the optimal results between 1000 and 2000 lb. blast weapons show that the 2000 lb. blast weapon does perform slightly better. (note: the value above is the median value of 1000 total runs) Next we continue with the analysis of variance for the pseudo-objective function.

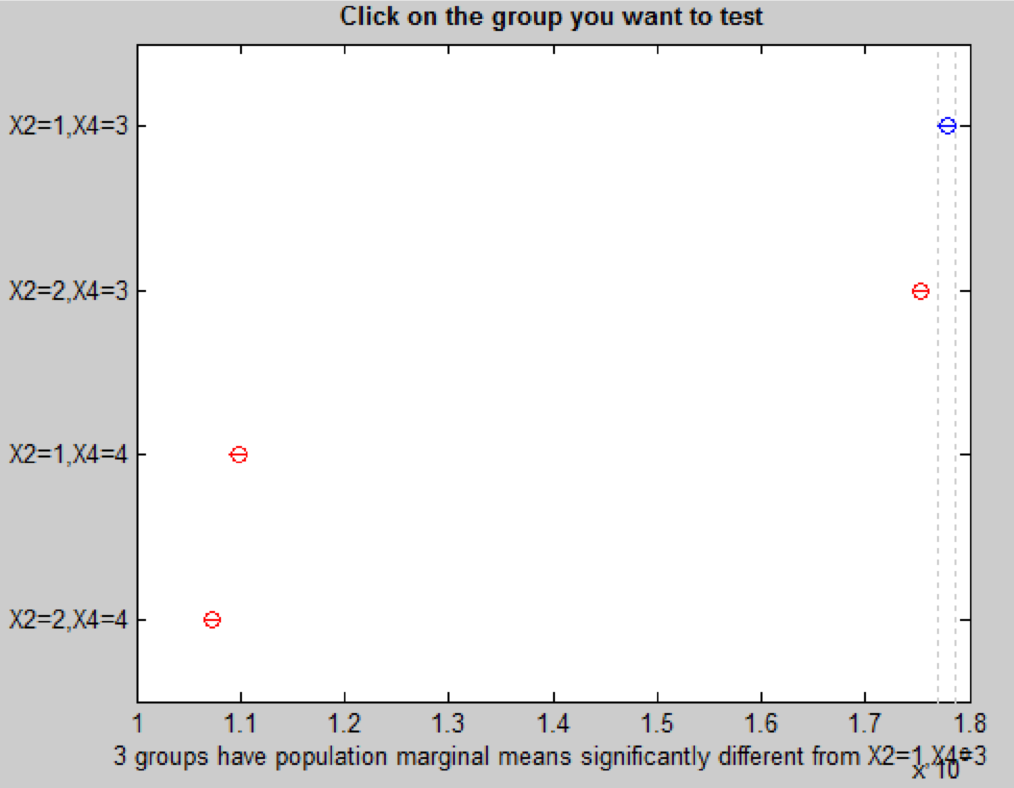

Figure 21 Comparisons of Bomb Weight and Damage Mechanism

Table 40 Analysis of Variance for Bunker Target Pseudo-Objective Function

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	3.86577e+19	63	6.13614e+17	2.52	0
Damage Mechanism(X_2)	1.0426e+21	3	3.47533e+20	1427.11	0
Fusing (X_3)	2.21872e+19	3	7.39572e+18	30.37	0
Weight(X_4)	3.21172e+17	3	1.07057e+17	0.44	0.7247
Guidance (X_5)	4.36853e+21	3	1.45618e+21	5979.67	0
Propulsion (X_6)	1.08618e+21	1	1.08618e+21	4460.29	0
Error	1.45925e+22	59923	2.43522e+17		
Total	2.11606e+22	59999			

All of the design factors except weapons weight were significant against the pseudo-objective function with guidance as the most significant. Table 41 displays the ANOVA determined the significance of the architecture design factors versus the civilian casualties.

The ANOVA for civilian casualties is similar the previous targets because fusing and weapons weight are not as important in predicting the civilian casualties. The most significant factor was the propulsion. The last ANOVA compare the architecture design factors and the fractional damage constraint and all the design factors are significant.

Table 41 Analysis of Variance for Bunker Target of Civilian Casualty Function

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	1616463.5	63	270799.1	2.78	0
Damage Mechanism(X_2)	53473173.3	3	89822909.6	1929.29	0
Fusing (X_3)	16793.9	3	5887.2	0.61	0.6111
Weight(X_4)	10142.5	3	1819692.2	0.37	0.7776
Guidance (X_5)	162542571.2	3	33720063.9	5864.47	0
Propulsion (X_6)	289150108.2	1	289150108.2	5986.64	0
Error	704144509.8	59923	11750.8		
Total	1392021958.5	59999			

Table 42 Analysis of Variance of Bunker Fractional Damage Constraint

Source	Sum Squares	d.f.	Mean Square	F	Prob.>F
# of Weapons(X_1)	14.9	63	0.237	4.81	0
Damage Mechanism(X_2)	455.11	3	151.702	3084.87	0
Fusing (X_3)	437.79	3	145.929	2967.47	0
Weight(X_4)	2.77	3	0.925	18.8	0
Guidance (X_5)	158.72	3	52.908	1075.89	0
Propulsion (X_6)	461.05	1	461.053	9375.53	0
Error	2946.78	59923	0.049		
Total	6659.19	59999			

CHAPTER 6. CONCLUSION

6.1 Thesis Conclusion

The goal of this thesis was to identify the elements of flexible weapons that should be modularized to improve fractional damage, cost, and civilian damage estimates. We reviewed general weaponeering to determine the elements within a weapons system that effect weapons-targets solutions. The primary factors we identified that may affect the success of a mission were the weapons damage mechanism, fusing, size (weight) of explosive, guidance, propulsion, and the number of weapons in the engagement. Our hypothesis was that these elements should be modularized to significantly affect the performance of flexible weapons against a variety of representative targets.

We developed a pseudo-objective function encompassing cost, monetized civilian damage, and target fractional damage to test the validity of each design factor. Additionally, we optimized the pseudo-objective function with a genetic algorithm to determine the best weapon set to engage a specified target. We found that all of the architecture designs factors are significant in optimizing cost, civilian damage, or fractional damage when used against a deterministic set of targets.

The pseudo-objective function was evaluated against six representative target types and the results determined that the design factors of raid size, damage mechanism, guidance, and propulsion were significant against all target types. Fusing was significant against buildings, civilian populations, and bunkers, and the weapon weight was significant against troops, equipment, and the civilian population. In addition, the optimization algorithm was extremely effective at determining a cost-optimal solution for destroying the target near the global minimum of the pseudo-objective function. Although we cannot prove the genetic algorithm solution is the global minimum due to not fulfilling the Kuhn-Tucker conditions, each run of the weapons optimization runs a minimum of 200 generations until it approaches the global minimum. Additionally, we enumerated the entire design space for troops in the open and the genetic algorithm produced the true global minimum. Finally the optimal results for each target’s 1000-iteration Monte Carlo had extremely low variance, and further validate the genetic algorithm.

Table 43 Summary of Pseudo Objective Function ANOVA P-Values

	Troops	Building	Armor	Equipment	Civilian	Bunker
# of Weapons(X_1)	0	0	0	0	0	0
Damage Mechanism(X_2)	0	0	0	0	0	0
Fusing (X_3)	0.5758	0.0004	0.2987	0.5842	0.0007	0
Weight(X_4)	0.0019	0.1001	0.1371	0	0	0.7247
Guidance (X_5)	0	0	0	0	0	0
Propulsion (X_6)	0	0	0	0	0	0

The work in this thesis sought to establish a foundation for further work with this nascent concept. Thus, the scope of this research is limited due to the deterministic target set and limited access to actual weapons and target test data. A weapons designer or weaponeer who has access to the joint munitions effectiveness manual (JMEM) can use this work and methodology as a tool to further research the viability of modular weapons. Additionally, a weapons designer will have better access to production cost data to compare the flexible weapons cost to current weapons cost effectiveness.

6.2 Future Work

Although this thesis provides a firm foundation in flexible weapons research, additional work remains to improve the overall effectiveness for flexible weapons design. First we should re-examine the propulsion architecture design factor. Currently propulsion is treated as a binary variable (a weapon is built with or without propulsion). A richer range of settings would be beneficial, for example: no propulsion, 10 km range, 50 km range, 100 km range, etc. The different levels of propulsion would give the mission commander a wider range of options and improve the realism of the scenario.

The next area that requires additional work is development of a higher-fidelity fusing model. Currently the fusing design factor was only occasionally significant, but this result is due to the lack of fidelity in the fusing model. For weapon-target pairings that require the correct fusing, (i.e. bunkers, buildings, and leaflet drops) the fusing variable is always significant; while with targets where fusing just enhances the effects, the variable is not significant due to modeling. A higher fidelity model would enable an examination of fusing as a design factor to a more refined level.

The introduction of additional damage mechanisms, targets, and damage criteria (such as cratering) are also recommended enhancements. The additional inputs would increase the usefulness of the algorithm in an actual weaponeering scenario. We would also like to examine the additional design factors of sensors, processors, and communications to increase the autonomy of the weapons in searching for targets in a real-time scenario. Additionally, this algorithm should be tested for additional levels of damage. The algorithm currently tests for 100% fractional damage, but the algorithm’s performance is unknown if the level of damage is lowered.

The addition of these elements should be tested in a real-time, agent-based simulation, where each weapon and target is modeled as agents in a collaborative engagement scenario. The collaborative engagement scenario simulation will further validate the concept of flexible weapons while exploring the effectiveness of a flexible weapons swarm in engaging an enemy defended area.

Finally, replacing the genetic algorithm with integer programming may very well improve the functionality of the approach. Integer programming is similar to linear programming except it optimizes integer variables instead of continuous variables. Since each design factor is represented by an integer, integer programming might arrive at the same solution without the computational cost of the genetic algorithm.

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APPENDIX

APPENDIX

1. Runner Code

```
% Develop a loop to run multiple function runs
clear
clc
global T t w1 w2
%t=randi(8);
t=1;
cons_sol={};       % Constraint Solution
cost_sol={};       % Cost solution
CDE_sol={};        % CDE Solution
T_sol={};          % T Solutions
ftot_sol={};       % Phi Solutions
x_sol={};          % x Solutions
fgen_sol={};       % First generation
stats_sol={};      % Stats solution
X_sol={};          % x Solutions
vlb1 = [1 1 1 1 1 1];  %Lower bound of each gene - all variables
vub1 = [64 4 4 4 4 2];  %Upper bound of each gene - all variables
bits1 =[6 2 2 2 2 1];  %number of bits describing each gene - all variables
vlb=repmat(vlb1,1,t);   % Repeat the matrix for each weapon for lower bound
vub=repmat(vub1,1,t);   % Repeat the matrix for each weapon for uper bound
bits=repmat(bits1,1,t);  % Repeat the matrix for the bits

T=target(t);
T(:,7)=6;          % Set target type

for l=1:1
%    w1=(l-1).*.1;
%    w2=1-w1;
%T=target(t);
%T(:,7)=l;          % Set target type
w1=1;
w2=1;
  for seed=1:1000
%      T=target(t);
%      T(:,7)=l;          % Set target type
    T_sol{l,seed}=T;
    [ftot_sol{l,seed},x_sol{l,seed},fgen_sol{l,seed},stats_sol{l,seed}]=Script2(seed,T);
    % Run the code Several times
```

```
        cons_sol{l,seed}=cons(x_sol{l,seed},T,t);       % Constraint Solution (Percentage of target
destroyed)
        cost_sol{l,seed}=cost(x_sol{l,seed},T,t);       % Cost Solution (Dollars)
        CDE_sol{l,seed}=civilian(x_sol{l,seed},T,t);    % CDE Solution (Civilian Casualties)
        [phi{l,seed},ftot2_sol{l,seed} ] = phi3( x_sol{l,seed} );   %Function matrix total
        seeds(l,seed)=seed;
    end
end
%[b,bint,r,rint,stats] = regress(Sol,Var);
% [p,tbl,stats2] = anovan(Var,Sol);

for l=1:1
    for seed=1:1000
        fgens((1+(60.*(seed-1)))+(100.*(l-1)):60+(60*(seed-1))+(100.*(l-
1)),:)=decode(fgen_sol{l,seed}, vlb, vub, bits);
        design(((1+(t.*(seed-1)))+(100.*(l-1))):t+(t*(seed-1))+(100.*(l-1)),:)=x_sol{l,seed};
        constraint((1+(t.*(seed-1)))+(100.*(l-1)):t+(t*(seed-1))+(100.*(l-1)),:)=cons_sol{l,seed}';
        civcas((1+(t.*(seed-1)))+(100.*(l-1)):t+(t*(seed-1))+(100.*(l-1)),:)=CDE_sol{l,seed}';
        phitotal((1+(t.*(seed-1)))+(100.*(l-1)):t+(t*(seed-1))+(100.*(l-1)),:)=ftot2_sol{l,seed}';
        costtotal((1+(t.*(seed-1)))+(100.*(l-1)):t+(t*(seed-1))+(100.*(l-1)),:)=cost_sol{l,seed}';
        S((1+(t.*(seed-1)))+(100.*(l-1)):t+(t*(seed-1))+(100.*(l-1)),:)=seeds(l,seed);

%         design(((1+(t.*(seed-1)))+(100.*(l-1))),:)=x_sol{l,seed};
%         constraint((1+(t.*(seed-1)))+(100.*(l-1)),:)=cons_sol{l,seed}';
%         civcas((1+(t.*(seed-1)))+(100.*(l-1)),:)=CDE_sol{l,seed}';
%         phitotal((1+(t.*(seed-1)))+(100.*(l-1)),:)=ftot2_sol{l,seed}';
%         costtotal((1+(t.*(seed-1)))+(100.*(l-1)),:)=cost_sol{l,seed}';
    end
end

DD=[design, S];
y=length(fgens);
for q=1:y
    FS(q)=q;
    phiA(q,:)=phi3(fgens(q,:));
    consA(q,:)=cons(fgens(q,:),T,t);
    costA(q,:)=cost(fgens(q,:),T,t);
    civilianA(q,:)=civilian(fgens(q,:),T,t);
end
DDD=[fgens,FS'];
[p1,tbl1,stats1] = anovan(constraint,design);
[p2,tbl2,stats2] = anovan(costtotal,design);
[p3,tbl3,stats3] = anovan(civcas,design);
[p4,tbl4,stats4] = anovan(phitotal,design);
[p5,tbl5,stats5] = anovan(phitotal,DD);
[p6,tbl6,stats6] = anovan(phiA,fgens);
[p7,tbl7,stats7] = anovan(consA,fgens);
[p8,tbl8,stats8] = anovan(costA,fgens);
[p9,tbl9,stats9] = anovan(civilianA,fgens);
```

```
[b,bint,r,rint,stats] = regress(phitotal,design);
save ('C:\Users\William Pyant\Documents\Thesis\MATLAB\Results6.mat');
```

2. Optimizer Code

```
% William C. Pyant III
% % Thesis Script
% clc
% clear all
% Weapons Effects Matrix
function [ftot,X, fgen, stats,x]=Script2(seed,T)
setRandomSeed(seed);                % Call Random Number Generator
global T t Range I ToF traj SR
T=T;
t=length(T(:,1));
ftot=0;
[ Range, I, ToF, traj, SR ] = trajectory(T,t);
options = goptions([]);
vlb1 = [1 1 1 1 1 1];   %Lower bound of each gene - all variables
vub1 = [64 4 4 4 4 2];  %Upper bound of each gene - all variables
bits1 =[6 2 2 2 2 1];   %number of bits describing each gene - all variables
vlb=repmat(vlb1,1,t);    % Repeat the matrix for each weapon for lower bound
vub=repmat(vub1,1,t);    % Repeat the matrix for each weapon for uper bound
bits=repmat(bits1,1,t);  % Repeat the matrix for the bits
%keyboard
[xopt,fbest,stats,nfit,fgen,lgen,lfit]= GA550('phi3',[],options,vlb,vub,bits);
ftot=fbest;
x=xopt;
X=transpose(reshape(xopt,6,t));
X(:,4)=round(X(:,4));
end
% Random Seed Generator
function setRandomSeed(rng_seed)
  % Use a fixed seed for the PRNG
  s = RandStream.create('mt19937ar','seed',rng_seed);
  RandStream.setGlobalStream(s);
end
```

3. Pseudo Objective Function Code

```
function [ phi, phi2 ] = phi3( x )
% Pseudo objective functions
global T t w1 w2
x=transpose(reshape(x,6,t));
f1 = cost(x,T,t);        % Call cost objective function
CDE1=civilian(x,T,t);    % Call CDE Objective
g = -cons(x,T,t);        % Call destroyed constraint function
r_p=200000000;           % Penalty Multiplier
% exterior penalty function
ncon = length(g);        % number of constraints
P = 0;                   % intialize P value to zero
J=1;
```

```
% Optional Weighting Coeeficients

for j = 1:ncon
   P = P + max(0,g(j));  % note: no c_j scaling parameters
end
CDE=sum(CDE1).*5000000;
f=sum(f1);
phi = w1.*f + w2.*CDE + r_p*P;
for l=1:t
   phi2(l)=w1.*f1(l)+w2.*CDE1(l)+ r_p.*g(l);
end
end
```

4. Cost Objective Function Code

```
function [ f ] = cost( x,T,t )
%UNTITLED7 Summary of this function goes here
%   Detailed explanation goes here
costw=[1000,1000,2000,1000;           % 250 lb cost
   2082.50,2082.50,4000,2000;         % 500 lb
   3128.83,3128.83,10000,3000;        % 1000 lb
   5384.40,5384.40,20000,4000];       % 2000 lb
fusing=[2145.14,2145.14,633.63+907.07,2685.59];
%Fusing cost in dollars
% [Impact (FMU-143G/B), Impact Delay(FMU-143H-B), Air Burst(FMU-56D/FMU139)
% Proximity (FMU56D), Hard Target Smart Fuse (FMU-152/B),HTSF(FMU-152/B) ]
guidance=[0,64867.62,19960,61178.51];   % Guidance cost
% [unguided, Laser guided (WGU-36), GPS Guided (JDAM KIT), TV/OPT(DSU-27)]
propulsion= [(81626.58-64867.62),0];   % Propulsion Cost
% [ No Propulsion, propulsion (cost achieved by subtracting WGU 36 from
% WGU-42 )]
for l=1:t

   f(l)=x(t,1).*((costw(x(t,2),x(t,4))+fusing(x(t,3))+guidance(x(t,5))...
      +propulsion(x(t,6))));
end
end
```

5. Civilian Damage Objective Function Code

```
function [ CDE, E] = civilian( x,T,t )
% This module will calculate the civilian damage estimate from a given
% target run Using methedology from Weaponeering: Conventional Systems
% Effectiveness chapter 30
[PD, FD, CD] = destroyed( x,T,t );       % Collateral Damage estimates
Etot=0;
for l=1:t
   E(l)=T(l,6);             % Expectant Population multiplied
                              % by the target area
   if x(l,2)== 1
      p(l)=max(CD(l),[],2);
      CDE(l)=p(l).*E(l);
```

```
    elseif x(l,2)== 2
        p(l)=CD(l,2);
        CDE(l)=p(l).*E(l);
    elseif x(l,2)== 3
        p(l)=CD(l,3);
        CDE(l)=p(l).*E(l);
    elseif x(l,2)== 4
        p(l)=CD(l,3);
        CDE(l)=p(l).*E(l);
    end
    Etot=Etot+E(l);
    if T(l,7)==5              % If the target is a civilian population
        if x(l,2)==4          % If the weapon type is leafelets
            CDE(l)=0;         % 0 collateral damage
        else                  % If any other type of weapon
            f=max(FD,[],2);     % Fractional Damage
            CDE(l)=(1-(1-f(l)).^x(l,1)).*E(l);    % Total Damage
        end
    end
end
end
```

6. Fractional Damage Constraint Code

```
function [ g ] = cons( x,T,t )
% This constraint is put in place to ensure the target is destroyed
% Method is in Weaponeering: Conventional Weapons Systems Effectiveness
[PD, FD]=destroyed(x,T,t);
for l=1:t
    f=max(FD,[],2);
    if T(l,7)== 3 || T(l,7)==5
        if x(l,2)==3
            g(l)=-abs(1-(f(l).*x(l,1)));
        else
            g(l)=1-(1-f(l)).^x(l,1)-1;
        end
    else
        g(l)=1-(1-f(l)).^x(l,1)-1;
    end
end
end
```

7. Target Function Code

```
function [ T ] = target(t)
%UNTITLED Summary of this function goes here
%   Detailed explanation goes here
T=zeros(t,10);          % Develop a [t,7] target matrix
w1=rand(t,1);           % Develop a random weighting for each target
w=w1/sum(w1);             % Normalize the weighting
T(:,1)=w;             % Set the weighting as the first element in the
                      % Target matrix
```

```
T(:,2)=randi([1,200],t,1);   % Establish the legnth of the target area
T(:,3)=randi([1,200],t,1);   % Establish the width of the target area
% Randomly assign Lat and Long coordinates for Targets
lat=38 + (40-38).*rand(t,1);    % Randon Latitude points
long=125 + (127-125).*rand(t,1);% Random Longitude points
T(:,4)=[lat];                   % Assign Random Lat points bounded
                                % between (38,40) degrees north
T(:,5)=[long];                  % Assign Random Long points bounded
                                % between (125,127) degrees east
T(:,6)=randi(500,t,1);          % Establish the population density in the
                                % target Area
T(:,7)=randi(6,t,1);            % Randomly select the 'hardness' of each
                                % target in the Target Matrix
elev= 1 + (25-1).*rand(t,1);    % Randon Latitude points
T(:,8)=[elev];                  % Randomly select the elevation of each
                                % target in the Target Matrix
T(:,9)=randi(500,t,1);          % Establish the population civilian facility
                                % Offset from the target area in meters
T(:,10)=randi([250,2000],t,1);  % Determine the area of the civilian
                                % structure in meters squared
end
```

8. Destroyed Function Code

```
function [ PD,FD, CD ] = destroyed( x,T,t )
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here
global Range traj SR I
h0=20000;                   % release altitude in ft
%h0=6096;                   % release altitude in meters
vt=500;                     % aircraft speed, knots
vek=7;                      % ejection velocity (knots)
ve=vek.*0.5144;             % ejection velociy (m/s)
theta_i=0;                  % dive angle
theta0=theta_i*pi/180;      % convert dive angle to radians
va=vt*0.5144;               % convert knots to meters/sec
%va=vt;                     % use m/s
d = 10.78/12;               % diameter Mk-82 (inches)
%d=0.2738;                  % Diameter of mk-82 (meters
mass=500/32.2;              % mass of Mk-82
%mass=226.796;              % mass of mk-82 in kg
g = 32.2;                   % define gravitational constant
%g=9.8337;                  % gravitational constant in m/s
rho = 0.07488/32.2;         % air density psi
%rho= 516.2794;             % air density pascals
Cd=0.2;                     % constant drag coefficient
MAE=effects(x,T,t);         % Accuracy
%MAE(:,1)=0.092903.*MAE(:,1);      % Convert ft^ to m^2
Acc=accuracy(x,T,t);        % Determine the accuracy of the weapons
Range=Range.*.3048;         % Convert Range to meters
nr=2;                       % number of weapons released per pulse
dt=20;                      % time in seconds to release weapons
```

```
PD=zeros(t,4);                  % Establish probability matrix
FD=zeros(t,4);                  % Fractional Probability matrix
CD=zeros(t,4);                  % Collateral damage matrix


for l=1:t
if x(l,6)==2 && traj(l)==2            % No propulsion
PD=zeros(t,4);                  % Establish probability matrix
FD=zeros(t,4);                  % Fractional Probability matrix
else
% ----------------------------Unitary weapon-----------------------------
if x(l,1)==1              % Unitary Weapon
a=max(1-cosd(l),0.3);       % ratio of weapons Radii
WRr=sqrt(MAE(l,1).*a./pi);  % Weapons Radii range
WRd=WRr/a;                % Weapons Radii Deflection
Letf=1.128.*sqrt(MAE(l,1).*a);% Legnth of Effective Target area
Wetf=Letf/a;              % Width of effective target area
PD1xf=Letf/sqrt(17.6.*Acc(l,2).^2+Letf^2);  % Probability of damage
% in X direction
PD1yf=Wetf/sqrt(17.6.*Acc(l,3).^2+Wetf^2);  % Probability of damage
% in Y direction
PD(l,1)=PD1xf.*PD1yf;       % Total probability of damage (frag)
Letb=sqrt(MAE(l,2));       % Legnth of effective target area (blast)
Wetb=sqrt(MAE(l,2));       % Width of effective target area (blast)
PD1xb=Letb/sqrt(17.6.*Acc(l,2).^2+Letb^2);  % Probability of damage
% in X direction
PD1yb=Wetb/sqrt(17.6.*Acc(l,3).^2+Wetb^2);  % Probability of damage
% in Y direction
PD(l,2)=PD1xb.*PD1yb;       % Total probability of damage (blast)
% Collateral Damage Estimates
CD(l,1)=exp(-((4.*T(l,9).^2./Letf^2)+(4.*T(l,9).^2./Wetf^2)));
% Collateral Damage estimate of a civilian facility close to the
% target area from fragmentation
CD(l,2)=exp(-((4.*T(l,9).^2./Letb^2)+(4.*T(l,9).^2./Wetb^2)));
% Collateral Damage estimate of a civilian facility close to the
% target area from fragmentation
%----------------------------Salvo Unguided Weapons------------------------
else                    % Salvo
if x(l,5)==1          % Unguided weapons
a=max(1-cosd(l),0.3);       % ratio of weapons Radii
WRr=sqrt(MAE(l,1).*a./pi);  % Weapons Radii range
WRd=WRr/a;                % Weapons Radii Deflection
Ws=1.414.*Range.*ve/(va.*cos(theta0));  % Width of Stick
Ls=va.*(nr-1).*dt;  % Legnth of the stick
% Stick of Frag Weapons
Letf=sqrt(MAE(l,1).*a);     % Legnth of Effective Target area
Wetf=Letf/a;              % Width of effective target area
PD1xf=Letf/sqrt(17.6.*Acc(l,2).^2+Letf^2);  % Probability of damage
% in X direction
PD1yf=Wetf/sqrt(17.6.*Acc(l,3).^2+Wetf^2);  % Probability of damage
% in Y direction
PD(l,1)=PD1xf.*PD1yf;       % Total probability of damage (frag)
```

```
sigmar=Acc(l,2)./.6746;    % Standard Deviation in Radius
sigmad=Acc(l,3)./.6746;    % Standard Deviation in deflection
sigmabr=SR(l).*sigmar./1000;% Precision Area Standard Deviation (m^2)
sigmabd=SR(l).*sigmad./1000;% Precision Area Standard Deviation (m^2)
Lbf=sqrt(Letf^2+8.*sigmabr.^2);% Legnth of expanded lethal area with precision error
Wbf=sqrt(Wetf^2+8.*sigmabd.^2);% Width of expanded lethal area with precision error
Wpf=Ws+Wbf;              % Total Pattern width in meters
Lpf=Ls+Lbf;              % Total Pattern Legnth in meters
np=round(x(l,1)./nr);      % Number of Pulses
Pcd1f=PD(l,1).*Letf.*Wetf./(Lbf.*Wbf);    % Preserved lethality of the weapon
nodf=np.*Wbf/Wpf;          % Degree of overlap in deflection
if nodf<1
Pcddf=np.*Pcd1f.*Wbf./Wpf;% Probability of damage in the
% deflection range for no overlap
else
Pcddf=1-(1-Pcd1f).^nodf; % Probability of damage in the
% deflection range for overlap
end
norf=nr.*Lbf./Lpf;         % Overlap in the range
if norf<1
Pcdsf=nr.*Pcddf.*Lbf./Lpf;% Probability of damage in the
% deflection range for no overlap
PD(l,1)=Pcdsf;        % Save probability of destruction
else
Pcdsf=1-(1-Pcddf).^norf; % Probability of damage in the
% deflection range for overlap
PD(l,1)=Pcdsf;        % Save probability of destruction
end
% Stick of Blast Weapons
Letb=sqrt(MAE(l,2));       % Legnth of effective target area (blast)
Wetb=sqrt(MAE(l,2));       % Width of effective target area (blast)
PD1xb=Letb/sqrt(17.6.*Acc(l,2).^2+Letb^2);  % Probability of damage
% in X direction
PD1yb=Wetb/sqrt(17.6.*Acc(l,3).^2+Wetb^2);  % Probability of damage
% in Y direction
PD(l,2)=PD1xb.*PD1yb;       % Total probability of damage (blast)
Lbb=sqrt(Letb^2+8.*sigmabr.^2);% Legnth of expanded lethal area with precision error
Wbb=sqrt(Wetb^2+8.*sigmabd.^2);% Width of expanded lethal area with precision error
Wpb=Ws+Wbb;              % Total Pattern width in meters
Lpb=Ls+Lbb;              % Total Pattern Legnth in meters
Pcd1b=PD(l,2).*Letb.*Wetb./(Lbb.*Wbb);    % Preserved lethality of the weapon
nodb=np.*Wbb/Wpb;          % Degree of overlap in deflection
if nodb<1
Pcddb=np.*Pcd1b.*Wbb./Wpb;% Probability of damage in the
% deflection range for no overlap
else
Pcddb=1-(1-Pcd1b).^nodb; % Probability of damage in the
% deflection range for overlap
end
norb=nr.*Lbb./Lpb;         % Overlap in the range
if norb<1
```

```
Pcdsb=nr.*Pcddb.*Lbb./Lpb;% Probability of damage in the
% deflection range for no overlap
PD(l,2)=Pcdsb;        % Save probability of destruction
else
Pcdsb=1-(1-Pcddb).^norb; % Probability of damage in the
% deflection range for overlap
PD(l,2)=Pcdsb;        % Save probability of destruction
end
% Collateral Damage Estimates
CD(l,1)=exp(-((4.*T(l,9).^2./Lbf^2)+(4.*T(l,9).^2./Wbf^2)));
% Collateral Damage estimate of a civilian facility close to the
% target area from fragmentation
CD(l,2)=exp(-((4.*T(l,9).^2./Lbb^2)+(4.*T(l,9).^2./Wbb^2)));
% Collateral Damage estimate of a civilian facility close to the
% target area from fragmentation
else
%-------------------------Stick of precision Weapons----------------------
a=max(1-cosd(l),0.3);      % ratio of weapons Radii
WRr=sqrt(MAE(l,1).*a./pi);  % Weapons Radii range
WRd=WRr/a;                 % Weapons Radii Deflection
Letf=1.128.*sqrt(MAE(l,1).*a);% Legnth of Effective Target area
Wetf=Letf/a;               % Width of effective target area
PD1xf=Letf/sqrt(17.6.*Acc(l,2).^2+Letf^2);  % Probability of damage
% in X direction
PD1yf=Wetf/sqrt(17.6.*Acc(l,3).^2+Wetf^2);  % Probability of damage
% in Y direction
PD(l,1)=PD1xf.*PD1yf;        % Total probability of damage (frag)
Letb=sqrt(MAE(l,2));       % Legnth of effective target area (blast)
Wetb=sqrt(MAE(l,2));       % Width of effective target area (blast)
PD1xb=Letb/sqrt(17.6.*Acc(l,2).^2+Letb^2);  % Probability of damage
% in X direction
PD1yb=Wetb/sqrt(17.6.*Acc(l,3).^2+Wetb^2);  % Probability of damage
% in Y direction
PD(l,2)=PD1xb.*PD1yb;       % Total probability of damage (blast)
Letb=sqrt(MAE(l,2));       % Legnth of effective target area (blast)
Wetb=sqrt(MAE(l,2));       % Width of effective target area (blast)
PD1xb=Letb/sqrt(17.6.*Acc(l,2).^2+Letb^2);  % Probability of damage
% in X direction
PD1yb=Wetb/sqrt(17.6.*Acc(l,3).^2+Wetb^2);  % Probability of damage
% in Y direction
PD(l,2)=PD1xb.*PD1yb;       % Total probability of damage (blast)
% Collateral Damage Estimates
CD(l,1)=exp(-((4.*T(l,9).^2./Letf^2)+(4.*T(l,9).^2./Wetf^2)));
% Collateral Damage estimate of a civilian facility close to the
% target area from fragmentation
CD(l,2)=exp(-((4.*T(l,9).^2./Letb^2)+(4.*T(l,9).^2./Wetb^2)));
% Collateral Damage estimate of a civilian facility close to the
% target area from fragmentation
end
end
%--------------------Fractional Damage per Sortie------------------------
```

```
% Determine the Fractional Damage of the weapons
% Fragmentation Weapons
a=max(1-cosd(l),0.3);         % ratio of weapons Radii
WRr=sqrt(MAE(l,1).*a./pi);      % Weapons Radii range
WRd=WRr/a;                  % Weapons Radii Deflection
Letf=1.128.*sqrt(MAE(l,1).*a);    % Legnth of Effective Target area
Wetf=Letf/a;                % Width of effective target area
Lepf=max(Letf,T(l,2));       % Effective pattern legnth (meters)
Wepf=max(Wetf,T(l,3));          % Effective pattern legnth (meters)
Atf=Lepf*Wepf;              % Effective pattern Area (meters^2)
Waf=Letf.*Wetf;             % Weapons Effective Area (meters^2)
Fcf=Waf/Atf;                % Fractional Coverage Area
FD(l,1)=Fcf.*PD(l,1);       % Fractional Expected Damage
% Blast Weapons
Letb=sqrt(MAE(l,2));         % Legnth of effective target area (blast)
Wetb=sqrt(MAE(l,2));          % Width of effective target area (blast)
Lepb=max(Letb,T(l,2));        % Effective pattern legnth (meters)
Wepb=max(Wetb,T(l,3));          % Effective pattern legnth (meters)
Atb=Lepb*Wepb;                % Effective pattern Area (meters^2)
Wab=Letb.*Wetb;               % Weapons Effective Area (meters^2)
Fcb=Wab/Atb;                % Fractional Coverage Area
FD(l,2)=Fcb.*PD(l,2);        % Fractional Expected Damage
% Account for EFP Weapons against tanks
if x(l,2) == 3 && T(l,7)== 3        % Anti Armor Weapon against tanks
tanks=round((Atf./250).*4);        % Establish the total number of tanks
if x(l,4)==1                % 250 lb bomb
if x(l,3)==1 || x(l,3)==4      % If Impact fuse or smart fuse
if x(l,5)==2 || x(l,5) == 4  % Laser/Radar guided
PD(l,3)=1;          % Establish the total probability of kill
FD(l,3)=1/tanks;       % Establish the Fractional probability
else                % GPS or no guidance
PD(l,3)=0;          % Establish the total probability of kill
FD(l,3)=0/tanks;       % Establish the Fractional probability
end
else                  % No impact fuse or propulsion
PD(l,3)=0;          % Establish the total probability of kill
FD(l,3)=0/tanks;       % Establish the Fractional probability
end
elseif x(l,4)==2              % 500 pound bomb
if x(l,3)==1 || x(l,3)==4      % If Impact fuse or smart fuse
if x(l,5)==2            % Laser/Radar guided
PD(l,3)=1;          % Establish the total probability of kill
FD(l,3)=4/tanks;       % Establish the Fractional probability
elseif x(l,5)==4          % TV/Optical/IR Guidance
PD(l,3)=1;          % Establish the total probability of kill
FD(l,3)=4/tanks;       % Establish the Fractional probability
else                % GPS or No Guidance
PD(l,3)=0;          % Establish the total probability of kill
FD(l,3)=0/tanks;       % Establish the Fractional probability
end
else                  % No impact fuse or smart fuse
```

```
PD(l,3)=0;                % Establish the total probability of kill
FD(l,3)=0/tanks;             % Establish the Fractional probability
end
else                          % Not 250 or 500 lb bomb
PD(l,3)=0;                    % Establish the total probability of kill
FD(l,3)=0;                    % Establish the Fractional probability
end
end
% Account for EFP Weapons against equipment
if x(l,2) == 3 && T(l,7)== 4
tanks=round((Atf./250).*4);           % Establish the total number of tanks
if x(l,4)==1                      % 250 lb bomb
if x(l,3)==1 || x(l,3)==4          % If Impact fuse or smart fuse
if x(l,5)==2                 % Laser/Radar guided
PD(l,3)=1;                 % Establish the total probability of kill
FD(l,3)=1/tanks;           % Establish the Fractional probability
elseif x(l,5)==4             % TV/ Optical/ IR guidance
PD(l,3)=1;                 % Establish the total probability of kill
FD(l,3)=1/tanks;           % Establish the Fractional probability
else                      % GPS or no guidance
PD(l,3)=0;                 % Establish the total probability of kill
FD(l,3)=0/tanks;           % Establish the Fractional probability
end
else                         % No impact fuse or propulsion
PD(l,3)=0;                 % Establish the total probability of kill
FD(l,3)=0/tanks;           % Establish the Fractional probability
end
elseif x(l,4)==2                   % 500 pound bomb
if x(l,3)==1 || x(l,3)==4          % If Impact fuse or smart fuse
if x(l,5)==2                 % Laser/Radar guided
PD(l,3)=1;                 % Establish the total probability of kill
FD(l,3)=4/tanks;           % Establish the Fractional probability
elseif x(l,5)==4             % TV/Optical/IR Guidance
PD(l,3)=1;                 % Establish the total probability of kill
FD(l,3)=4/tanks;           % Establish the Fractional probability
else                      % GPS or No Guidance
PD(l,3)=0;                 % Establish the total probability of kill
FD(l,3)=0/tanks;           % Establish the Fractional probability
end
else                         % No impact fuse or smart fuse
PD(l,3)=0;                % Establish the total probability of kill
FD(l,3)=0/tanks;             % Establish the Fractional probability
end
else                          % Not 250 or 500 lb bomb
PD(l,3)=0;                    % Establish the total probability of kill
FD(l,3)=0;                    % Establish the Fractional probability
end
end
% Account for Leaflets
if x(l,2) == 4 && T(l,7)==5
if x(l,3)==3 || x(l,3)==4
```

```
PD(l,4)=1;              % Establish the total probability of kill
ATE=T(l,2).*T(l,3);
FD(l,4)=x(l,4).*250./ATE;        % Establish the Fractional probability
PD(l,1)=0;
PD(l,2)=0;
PD(l,3)=0;
FD(l,1)=0;
FD(l,2)=0;
FD(l,3)=0;
else
PD(l,4)=0;              % Establish the total probability of kill
ATE=T(l,2).*T(l,3);
FD(l,4)=0;              % Establish the Fractional probability
PD(l,1)=0;
PD(l,2)=0;
PD(l,3)=0;
FD(l,1)=0;
FD(l,2)=0;
FD(l,3)=0;
end
end
CD(l,3)=0;                % CDE for Tank weapons
CD(l,4)=0;                % CDE for leafelets

end
end
end
```

9. Effects Function Code

```
function [ MAE ] = effects( x, T, t )
%UNTITLED3 Summary of this function goes here
%   Detailed explanation goes here
% MAE is Mean Area of Effectiveness
p0=101;                        % Standard/Initial air pressure in kPa
MAE=zeros(t,2);
for l=1:t
%------------------------ Fragmentation Munitions--------------------------
   if x(l,2)==1                 % Fragmentation Munition
      if x(l,4)==1              % 250 lb bomb (MK 81 Exmple)
         massb=118;                % Total mass in kg's
         legnthb=1.88;             % Total legnth of bomb in m
         diameterb=.228;           % Total diameter of bomb in m
         masse=27.9067;            % Mass of explosives in kg
         M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
         % portion of th bomb in kg/meters
         c=masse./legnthb;          % Charge Weight per cylindrical
         % Portion of the bomb in kg/meters
         Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
         % TNT equivalent in kg/meters
         We=Wu.*2.^4;               % euivalent weight based on
         %surfaces
```

```
    if T(l,7)==1              % Target Type Troops
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)= 1500;         % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
    elseif T(l,7)==2          % Target Type Building
      if x(l,3)==2 || x(l,3)==4
        op=.6894;             % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
      else
        op=.6894;             % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
      end
    elseif T(l,7)==3          % Target Type Armored Vehicles
      op=13.7895;             % Max overpressure in bar (200 PSI)
      z=0.8581;
      MAE(l,1)=433.3417;      % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==4          % Target Type Equipment
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)= 500;          % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==5          % Target Type Civilian Population
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=1500;          % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==6          % Target Type Bunker
      if x(l,3)==2 || x(l,3)==4
        op=.6894;             % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
      else
        op=20.6842;           % Max overpressure in bar (300 PSI)
        z=.7036;
        MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
      end
    end
  elseif x(l,4)==2            % 500 lb bomb (MK 82 Example)
    massb=241;                % Total mass in kg's
    legnthb=2.21;             % Total legnth of bomb in m
    diameterb=.2731;          % Total diameter of bomb in m
    masse=89;                 % mass of explosives in kg
    M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
```

```
% portion of th bomb in kg/meters
c=masse./legnthb;          % Charge Weight per cylindrical
% Portion of the bomb in kg/meters
Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
% TNT equivalent in kg/meters
We=Wu.*2.^4;               % euivalent weight based on
%surfaces
if T(l,7)==1             % Target Type Troops
   op=.6894;              % Max overpressure in bar (10 PSI)
   z=3.2348;
   MAE(l,1)=3000;       % MAE Fragmentation (in ft^2)
   MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
elseif T(l,7)==2          % Target Type Building
   if x(l,3)==2 || x(l,3)==4
      op=.6894;              % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
   else
      op=.6894;              % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
   end
elseif T(l,7)==3          % Target Type Armored Vehicles
   op=13.7895;           % Max overpressure in bar (200 PSI)
   z=0.8581;
   MAE(l,1)=450;        % MAE Fragmentation (in ft^2)
   MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
elseif T(l,7)==4          % Target Type Equipment
   op=.6894;              % Max overpressure in bar (10 PSI)
   z=3.2348;
   MAE(l,1)=600;        % MAE Fragmentation (in ft^2)
   MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
elseif T(l,7)==5          % Target Type Civilian Population
   op=.6894;              % Max overpressure in bar (10 PSI)
   z=3.2348;             %
   MAE(l,1)=3000;        % MAE Fragmentation (in ft^2)
   MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
elseif T(l,7)==6          % Target Type Bunker
   if x(l,3)==2 || x(l,3)==4
      op=.6894;              % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
   else
      op=20.6842;           % Max overpressure in bar (300 PSI)
      z=.7036;
      MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
   end
```

```
   end
elseif x(l,4)==3              % 1000 lb bomb (MK 83 Example)
   massb=447;                 % Total mass in kg's
   legnthb=3;               % Total legnth of bomb in m
   diameterb=.3571;           % Total diameter of bomb in m
   masse=191.2881;            % mass of explosives in kg
   M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
   % portion of th bomb in kg/meters
   c=masse./legnthb;          % Charge Weight per cylindrical
   % Portion of the bomb in kg/meters
   Wu=masse.*(.6+(.4/(1+2.*(M./c)))); % Un-cased charge weight in
   % TNT equivalent in kg/meters
   We=Wu.*2.^4;               % euivalent weight based on
   %surfaces
   if T(l,7)==1              % Target Type Troops
      op=.6894;              % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=6000;         % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
   elseif T(l,7)==2          % Target Type Building
      if x(l,3)==2 || x(l,3)==4
         op=.6894;              % Max overpressure in bar (10 PSI)
         z=3.2348;
         MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
         MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
      else
         op=.6894;              % Max overpressure in bar (10 PSI)
         z=3.2348;
         MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
         MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
      end
   elseif T(l,7)==3          % Target Type Armored Vehicles
      op=13.7895;            % Max overpressure in bar (200 PSI)
      z=0.8581;
      MAE(l,1)=483.3667;     % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
   elseif T(l,7)==4          % Target Type Equipment
      op=.6894;              % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=800;          % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
   elseif T(l,7)==5          % Target Type Civilian Population
      op=.6894;              % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=6000;         % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
   elseif T(l,7)==6          % Target Type Bunker
      if x(l,3)==2 || x(l,3)==4
         op=.6894;              % Max overpressure in bar (10 PSI)
         z=3.2348;
         MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
```

```
      MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
    else
      op=20.6842;          % Max overpressure in bar (300 PSI)
      z=.7036;
      MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
    end
  end
elseif x(l,4)==4           % 2000 lb bomb (MK 84 Example)
  massb=924.8748;          % Total mass in kg's
  legnthb=3.2766;          % Total legnth of bomb in m
  diameterb=.4572;         % Total diameter of bomb in m
  masse=428.645;           % mass of explosives in kg
  M=(massb-masse)./legnthb;  % Metal Weight per cylidrical
  % portion of th bomb in kg/meters
  c=masse./legnthb;        % Charge Weight per cylindrical
  % Portion of the bomb in kg/meters
  Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
  % TNT equivalent in kg/meters
  We=Wu.*2.^4;             % euivalent weight based on
  %surfaces
  if T(l,7)==1             % Target Type Troops
    op=.6894;              % Max overpressure in bar (10 PSI)
    z=3.2348;
    MAE(l,1)=12000;        % MAE Fragmentation (in ft^2)
    MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
  elseif T(l,7)==2         % Target Type Bunker
    if x(l,3)==2 || x(l,3)==4
      op=.6894;            % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
    else
      op=.6894;            % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    end
  elseif T(l,7)==3         % Target Type Armored Vehicles
    op=13.7895;            % Max overpressure in bar (200 PSI)
    z=0.8581;
    MAE(l,1)=550;          % MAE Fragmentation (in ft^2)
    MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
  elseif T(l,7)==4         % Target Type Equipment
    op=.6894;              % Max overpressure in bar (10 PSI)
    z=3.2348;
    MAE(l,1)=1200;         % MAE Fragmentation (in ft^2)
    MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
  elseif T(l,7)==5         % Target Type Civilian Population
    op=.6894;              % Max overpressure in bar (10 PSI)
    z=3.2348;
```

```
        MAE(l,1)=12000;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
      elseif T(l,7)==6          % Target Type Bunker
        if x(l,3)==2 || x(l,3)==4
          op=.6894;             % Max overpressure in bar (10 PSI)
          z=3.2348;
          MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
          MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
        else
          op=20.6842;           % Max overpressure in bar (300 PSI)
          z=.7036;
          MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
          MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
        end
      end
    end
%------------------------------ Blast Munitions----------------------------
  % Typical building destruction occurs at 10-12 psi
  elseif x(l,2)==2                  % Blast Munition
     if x(l,4)==1                  % 250 lb bomb (using 50% Explosive Value)
      massb=118;                 % Total mass in kg's
      legnthb=1.88;              % Total legnth of bomb in m
      diameterb=.228;            % Total diameter of bomb in m
      masse=59;                  % Mass of explosives in kg
      M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
      % portion of th bomb in kg/meters
      c=masse./legnthb;           % Charge Weight per cylindrical
      % Portion of the bomb in kg/meters
      Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
      % TNT equivalent in kg/meters
      We=Wu.*2.^4;                % euivalent weight based on
      %surfaces
      if T(l,7)==1              % Target Type Troops
        op=.6894;               % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
      elseif T(l,7)==2          % Target Type Building
        if x(l,3)==2 || x(l,3)==4
          op=.6894;             % Max overpressure in bar (10 PSI)
          z=3.2348;
          MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
          MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
        else
          op=.6894;             % Max overpressure in bar (10 PSI)
          z=3.2348;
          MAE(l,1)=0;           % MAE Fragmentation (in ft^2)
          MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
        end
      elseif T(l,7)==3          % Target Type Armored Vehicles
        op=13.7895;             % Max overpressure in bar (200 PSI)
```

```
        z=0.8581;
        MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==4          % Target Type Equipment
        op=.6894;            % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)= 0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==5          % Target Type Civilian Population
        op=.6894;            % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==6          % Target Type Bunker
        if x(l,3)==2 || x(l,3)==4
            op=.6894;            % Max overpressure in bar (10 PSI)
            z=3.2348;
            MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
            MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
        else
            op=20.6842;          % Max overpressure in bar (300 PSI)
            z=.7036;
            MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
            MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
        end
    end
elseif x(l,4)==2              % 500 lb bomb
    massb=241;                % Total mass in kg's
    legnthb=2.21;             % Total legnth of bomb in m
    diameterb=.2731;          % Total diameter of bomb in m
    masse=120.5;              % mass of explosives in kg
    M=(massb-masse)./legnthb;  % Metal Weight per cylidrical
    % portion of th bomb in kg/meters
    c=masse./legnthb;         % Charge Weight per cylindrical
    % Portion of the bomb in kg/meters
    Wu=masse.*(.6+(.4/(1+2.*(M./c)))); % Un-cased charge weight in
    % TNT equivalent in kg/meters
    We=Wu.*2.^4;              % euivalent weight based on
    %surfaces
    if T(l,7)==1              % Target Type Troops
        op=.6894;            % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==2          % Target Type Building
        if x(l,3)==2 || x(l,3)==4
            op=.6894;            % Max overpressure in bar (10 PSI)
            z=3.2348;
            MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
            MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
        else
```

```
         op=.6894;              % Max overpressure in bar (10 PSI)
         z=3.2348;
         MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
         MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
      end
   elseif T(l,7)==3           % Target Type Armored Vehicles
      op=13.7895;             % Max overpressure in bar (200 PSI)
      z=0.8581;
      MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
   elseif T(l,7)==4           % Target Type Equipment
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;          % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
   elseif T(l,7)==5           % Target Type Civilian Population
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
   elseif T(l,7)==6           % Target Type Bunker
      if x(l,3)==2 || x(l,3)==4
         op=.6894;              % Max overpressure in bar (10 PSI)
         z=3.2348;
         MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
         MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
      else
         op=20.6842;            % Max overpressure in bar (300 PSI)
         z=.7036;
         MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
         MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
      end
   end
elseif x(l,4)==3               % 1000 lb bomb
   massb=447;                  % Total mass in kg's
   legnthb=3;                % Total legnth of bomb in m
   diameterb=.3571;            % Total diameter of bomb in m
   masse=223.5;              % mass of explosives in kg
   M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
   % portion of th bomb in kg/meters
   c=masse./legnthb;           % Charge Weight per cylindrical
   % Portion of the bomb in kg/meters
   Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
   % TNT equivalent in kg/meters
   We=Wu.*2.^4;                % euivalent weight based on
   %surfaces
   if T(l,7)==1              % Target Type Troops
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
```

```
    elseif T(l,7)==2          % Target Type Bunker/Building
        if x(l,3)==2 || x(l,3)==4
            op=.6894;              % Max overpressure in bar (10 PSI)
            z=3.2348;
            MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
            MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
        else
            op=.6894;              % Max overpressure in bar (10 PSI)
            z=3.2348;
            MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
            MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
        end
    elseif T(l,7)==3          % Target Type Armored Vehicles
        op=13.7895;            % Max overpressure in bar (200 PSI)
        z=0.8581;
        MAE(l,1)=0;    % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==4          % Target Type Equipment
        op=.6894;              % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;        % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==5          % Target Type Civilian Population
        op=.6894;              % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
        MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==6          % Target Type Bunker
        if x(l,3)==2 || x(l,3)==4
            op=.6894;              % Max overpressure in bar (10 PSI)
            z=3.2348;
            MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
            MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
        else
            op=20.6842;            % Max overpressure in bar (300 PSI)
            z=.7036;
            MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
            MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
        end
    end
elseif x(l,4)==4              % 2000 lb bomb
    massb=924.8748;            % Total mass in kg's
    legnthb=3.2766;            % Total legnth of bomb in m
    diameterb=.4572;           % Total diameter of bomb in m
    masse=462.4374;            % mass of explosives in kg
    M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
    % portion of th bomb in kg/meters
    c=masse./legnthb;          % Charge Weight per cylindrical
    % Portion of the bomb in kg/meters
    Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
    % TNT equivalent in kg/meters
```

```
        We=Wu.*2.^4;              % euivalent weight based on
        %surfaces
        if T(l,7)==1              % Target Type Troops
           op=.6894;              % Max overpressure in bar (10 PSI)
           z=3.2348;
           MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
           MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
        elseif T(l,7)==2          % Target Type Bunker
           if x(l,3)==2 || x(l,3)==4
              op=.6894;              % Max overpressure in bar (10 PSI)
              z=3.2348;
              MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
              MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
           else
              op=.6894;              % Max overpressure in bar (10 PSI)
              z=3.2348;
              MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
              MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
           end
        elseif T(l,7)==3          % Target Type Armored Vehicles
           op=13.7895;            % Max overpressure in bar (200 PSI)
           z=0.8581;
           MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
           MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
        elseif T(l,7)==4          % Target Type Equipment
           op=.6894;              % Max overpressure in bar (10 PSI)
           z=3.2348;
           MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
           MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
        elseif T(l,7)==5          % Target Type Civilian Population
           op=.6894;              % Max overpressure in bar (10 PSI)
           z=3.2348;
           MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
           MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
        elseif T(l,7)==6          % Target Type Bunker
           if x(l,3)==2 || x(l,3)==4
              op=.6894;              % Max overpressure in bar (10 PSI)
              z=3.2348;
              MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
              MAE(l,2)=pi.*(z.*We^(1/3))^2; % MAE Blast (in ft^2)
           else
              op=20.6842;            % Max overpressure in bar (300 PSI)
              z=.7036;
              MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
              MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
           end
        end
      end
%------------------------- Explosive Formed Projectiles------------------
  % Typical EFP will penetrate armor to the equal to the diameter of the
  % round
```

```
elseif x(l,2)==3                  % Explosive Formed Munition
   if x(l,4)==1                 % 250 lb bomb (using 50% Explosive Value)
     massb=45.3592;              % Total mass in kg's
     legnthb=1;                % Total legnth of bomb in m
     diameterb=.1778;            % Total diameter of bomb in m
     masse=9.07185;              % Mass of explosives in kg
     M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
     % portion of th bomb in kg/meters
     c=masse./legnthb;           % Charge Weight per cylindrical
     % Portion of the bomb in kg/meters
     Wu=masse.*(.6+(.4/(1+2.*(M./c)))); % Un-cased charge weight in
     % TNT equivalent in kg/meters
     %We=Wu.*r.^n;               % euivalent weight based on
     %surfaces
     if T(l,7)==1              % Target Type Troops
       op=.6894;               % Max overpressure in bar (10 PSI)
       z=3.2348;
       MAE(l,1)=10;            % MAE Fragmentation (in ft^2)
       MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
     elseif T(l,7)==2          % Target Type Building
       op=13.7895;             % Max overpressure in bar (10 PSI)
       z=3.2348;
       MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
       MAE(l,2)=0;             % MAE Blast (in ft^2)
     elseif T(l,7)==3          % Target Type Armored Vehicles
       op=.6894;               % Max overpressure in bar (200 PSI)
       z=0.8581;
       MAE(l,1)=10;            % MAE Fragmentation (in ft^2)
       MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
     elseif T(l,7)==4          % Target Type Equipment
       op=.6894;               % Max overpressure in bar (10 PSI)
       z=3.2348;
       MAE(l,1)=10;            % MAE Fragmentation (in ft^2)
       MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
     elseif T(l,7)==5          % Target Type Civilian Population
       op=.6894;               % Max overpressure in bar (10 PSI)
       z=3.2348;
       MAE(l,1)=10;             % MAE Fragmentation (in ft^2)
       MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
     elseif T(l,7)==6          % Target Type Bunker
       op=20.6842;              % Max overpressure in bar (300 PSI)
       z=.7036;
       MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
       MAE(l,2)=0;             % MAE Blast (in ft^2)
     end
  elseif x(l,4)==2              % 500 lb bomb
     massb=135;                 % Total mass in kg's
     legnthb=2.21;              % Total legnth of bomb in m
     diameterb=.2731;            % Total diameter of bomb in m
     masse=39.0089;              % mass of explosives in kg
     M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
```

```
    % portion of th bomb in kg/meters
    c=masse./legnthb;          % Charge Weight per cylindrical
    % Portion of the bomb in kg/meters
    Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
    % TNT equivalent in kg/meters
    %We=Wu.*r.^n;              % euivalent weight based on
    %surfaces
    if T(l,7)==1               % Target Type Troops
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=20;            % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==2           % Target Type Building
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
      MAE(l,2)=0;             % MAE Blast (in ft^2)
    elseif T(l,7)==3           % Target Type Armored Vehicles
      op=.6894;               % Max overpressure in bar (200 PSI)
      z=0.8581;
      MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
      MAE(l,2)=0;             % MAE Blast (in ft^2)
    elseif T(l,7)==4           % Target Type Equipment
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=20;            % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==5           % Target Type Civilian Population
      op=.6894;               % Max overpressure in bar (10 PSI)
      z=3.2348;
      MAE(l,1)=20;            % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2;% MAE Blast (in ft^2)
    elseif T(l,7)==6           % Target Type Bunker
      op=20.6842;             % Max overpressure in bar (300 PSI)
      z=.7036;
      MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
      MAE(l,2)=pi.*(z.*Wu^(1/3))^2; % MAE Blast (in ft^2)
    end
  elseif x(l,4)==3               % 1000 lb bomb
    massb=447;                 % Total mass in kg's
    legnthb=3;                 % Total legnth of bomb in m
    diameterb=.3571;           % Total diameter of bomb in m
    masse=223.5;               % mass of explosives in kg
    M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
    % portion of th bomb in kg/meters
    c=masse./legnthb;          % Charge Weight per cylindrical
    % Portion of the bomb in kg/meters
    Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
    % TNT equivalent in kg/meters
    %We=Wu.*2.^4;              % euivalent weight based on
    %surfaces
```

```
      if T(l,7)==1             % Target Type Troops
        op=.6894;               % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;             % MAE Blast (in ft^2)
      elseif T(l,7)==2          % Target Type Bunker/Building
        op=.6894;               % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;             % MAE Blast (in ft^2)
      elseif T(l,7)==3          % Target Type Armored Vehicles
        op=13.7895;              % Max overpressure in bar (200 PSI)
        z=0.8581;
        MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;             % MAE Blast (in ft^2)
      elseif T(l,7)==4          % Target Type Equipment
        op=.6894;               % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;             % MAE Blast (in ft^2)
      elseif T(l,7)==5          % Target Type Civilian Population
        op=.6894;               % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;             % MAE Blast (in ft^2)
      elseif T(l,7)==6          % Target Type Bunker
        op=20.6842;              % Max overpressure in bar (300 PSI)
        z=.7036;
        MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;             % MAE Blast (in ft^2)
      end
    elseif x(l,4)==4              % 2000 lb bomb
      massb=924.8748;              % Total mass in kg's
      legnthb=3.2766;             % Total legnth of bomb in m
      diameterb=.4572;            % Total diameter of bomb in m
      masse=462.4374;              % mass of explosives in kg
      M=(massb-masse)./legnthb;   % Metal Weight per cylidrical
      % portion of th bomb in kg/meters
      c=masse./legnthb;           % Charge Weight per cylindrical
      % Portion of the bomb in kg/meters
      Wu=masse.*(.6+(.4/(1+2.*(M./c))));  % Un-cased charge weight in
      % TNT equivalent in kg/meters
      %We=Wu.*r.^n;                % euivalent weight based on
      %surfaces
      if T(l,7)==1             % Target Type Troops
        op=.6894;               % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;             % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;             % MAE Blast (in ft^2)
      elseif T(l,7)==2          % Target Type Building
        op=.6894;               % Max overpressure in bar (10 PSI)
```

```
        z=3.2348;
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==3    % Target Type Armored Vehicles
        op=13.7895;        % Max overpressure in bar (200 PSI)
        z=0.8581;
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==4    % Target Type Equipment
        op=.6894;         % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==5    % Target Type Civilian Population
        op=.6894;         % Max overpressure in bar (10 PSI)
        z=3.2348;
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==6    % Target Type Bunker
        op=20.6842;        % Max overpressure in bar (300 PSI)
        z=.7036;
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      end
    end
%----------------------------Leaflet Drop----------------------------------
  % Typical EFP will penetrate armor to the equal to the diameter of the
  % round
  elseif x(l,2)==2                % Blast Munition
     if x(l,4)==1               % 250 lb bomb (using 50% Explosive Value)
      if T(l,7)==1              % Target Type Troops
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==2    % Target Type Building
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==3    % Target Type Armored Vehicles
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==4    % Target Type Equipment
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==5    % Target Type Civilian Population
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      elseif T(l,7)==6    % Target Type Bunker
        MAE(l,1)=0;       % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;       % MAE Blast (in ft^2)
      end
    elseif x(l,4)==2              % 500 lb bomb
      if T(l,7)==1              % Target Type Troops
```

```
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==2      % Target Type Building
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==3      % Target Type Armored Vehicles
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==4      % Target Type Equipment
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==5      % Target Type Civilian Population
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==6      % Target Type Bunker
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      end
    elseif x(l,4)==3        % 1000 lb bomb
      if T(l,7)==1        % Target Type Troops
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==2      % Target Type Bunker/Building
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==3      % Target Type Armored Vehicles
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==4      % Target Type Equipment
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==5      % Target Type Civilian Population
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==6      % Target Type Bunker
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      end
    elseif x(l,4)==4        % 2000 lb bomb
      if T(l,7)==1        % Target Type Troops
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==2      % Target Type Bunker
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==3      % Target Type Armored Vehicles
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
      elseif T(l,7)==4      % Target Type Equipment
        MAE(l,1)=0;         % MAE Fragmentation (in ft^2)
        MAE(l,2)=0;         % MAE Blast (in ft^2)
```

```
         elseif T(l,7)==5          % Target Type Civilian Population
            MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
            MAE(l,2)=0;            % MAE Blast (in ft^2)
         elseif T(l,7)==6          % Target Type Bunker
            MAE(l,1)=0;            % MAE Fragmentation (in ft^2)
            MAE(l,2)=0;            % MAE Blast (in ft^2)
         end
      end
   end
end
% [MAEm]=fuse( x,T,t, MAE );               % Modify the MAE value for the fuse
% MAE=MAEm;                           % Modified MAE values
end
```

10. Accuracy Function Code

```
function [ Acc ] = accuracy( x, T, t )
% Accuracy Matrix
% Values taken from FAS website at http://fas.org/man/dod-101/sys/smart/index.html
global Range I ToF traj SR
for l=1:t
   if x(l,6)==0                        % No Propulsion
      if traj(t)==0                    % Bomb cannot reach target and
         Acc(l,1)=10000;                 % No propulsion so value is high
         Acc(l,2)=10000./(2.*.873);      % miss distance
         Acc(l,3)=10000./(2.*.873);      % miss distance
      else
         if x(l,5)==1                  % Unguided bomb
            Acc(l,1)=100;                % CEP
            Acc(l,2)=100./(2.*.873);     % REP
            Acc(l,3)=100./(2.*.873);     % DEP
         elseif x(l,5)==2         % Laser Guided Bomb
            if x(l,2)==3
               Acc(l,1)=1;            % CEP
               Acc(l,2)=1./(2.*.873);  % REP
               Acc(l,3)=1./(2.*.873);  % Deflection Error Projection
            else
               Acc(l,1)=8;            % GPS/ INS Guided Weapon
               Acc(l,2)=8./(2.*.873);  % From Laser Guided Bombs FAS
               Acc(l,3)=8./(2.*.873);  % From Laser Guided Bombs FAS
            end
         elseif x(l,5)==3              % GPS/ INS Guided Weapon
            Acc(l,1)=13;               % Circular Error Probability in meters
            Acc(l,2)=13./(2.*.873);     % From JDAM FAS
            Acc(l,3)=13./(2.*.873);     % From Laser Guided Bombs FAS
         elseif x(l,5)==4              % TV/IR Guided
            Acc(l,1)=3;                % Circular Error Probability in meters
            Acc(l,2)=3./(2.*.873);      % From GBU-15 FAS
            Acc(l,3)=3./(2.*.873);      % From Laser Guided Bombs FAS
         end
      end
   else                                % Propulsion
```

```
    if x(l,5)==1                    % Unguided bomb
        Acc(l,1)=100;               % CEP
        Acc(l,2)=100./(2.*.873);    % REP
        Acc(l,3)=100./(2.*.873);    % DEP
    elseif x(l,5)==2                % Laser Guided Bomb
      if x(l,2)==3                  % EFD Projectile
        Acc(l,1)=1;                 % CEP
        Acc(l,2)=1./(2.*.873);      % REP
        Acc(l,3)=1./(2.*.873);      % Deflection Error Projection
      else                          % Other Projectile type
        Acc(l,1)=8;                 % GPS/ INS Guided Weapon
        Acc(l,2)=8./(2.*.873);      % From Laser Guided Bombs FAS
        Acc(l,3)=8./(2.*.873);      % From Laser Guided Bombs FAS
      end
    elseif x(l,5)==3                % GPS/ INS Guided Weapon
      Acc(l,1)=13;                  % Circular Error Probability in meters
      Acc(l,2)=13./(2.*.873);       % From JDAM FAS
      Acc(l,3)=13./(2.*.873);       % From Laser Guided Bombs FAS
    elseif x(l,5)==4                % TV/IR Guided
      Acc(l,1)=3;                   % Circular Error Probability in meters
      Acc(l,2)=3./(2.*.873);        % From GBU-15 FAS
      Acc(l,3)=3./(2.*.873);        % From Laser Guided Bombs FAS
    end
  end
end
end
```

11. Trajectory Code

```
function [ Range, I, ToF, traj, SR ] = trajectory(T,t)
%-----------------------------------------------------------------------
% This program calculates an air-launched weapon trajectory using a
% simplified high-fidelity model. It does NOT take into account the
% variation of temperature and density with altitude, hence density and
% drag coefficient are constants.
%-----------------------------------------------------------------------
h0=20000;                   % release altitude in ft
%h0=6096;                   % release altitude in meters
vt=500;                     % aircraft speed, knots
%vt=843.905;                % aircraft speed, m/s
ve=7;                       % ejection velocity (knots)
%ve=11.8147;                % ejection velociy (m/s)
theta_i=0;                  % dive angle
theta0=theta_i*pi/180;      % convert dive angle to radians
va=vt*1.688;                % convert knots to ft/sec
%va=vt;                     % use m/s
d = 10.78/12;               % diameter Mk-82 (inches)
%d=0.2738;                  % Diameter of mk-82 (meters
mass=500/32.2;              % mass of Mk-82
%mass=226.796;              % mass of mk-82 in kg
g = 32.2;                   % define gravitational constant
%g=9.8337;                  % gravitational constant in m/s
```

```
rho = 0.07488/32.2;               % air density psi
%rho= 516.2794;                   % air density pascals
Cd=0.2;                           % constant drag coefficient

v_0h = va*cos(theta0)-ve*sin(theta0);
v_0v = va*sin(theta0)+ve*cos(theta0);
vt=sqrt(v_0h*v_0h+v_0v*v_0v);
x=0;
y=0;
dt=0.0001;
n=0;
Cd=0.5;
thetat=theta0;
k=0.5*0.25*pi*d*d*rho*Cd;

vx=v_0h;
vy=v_0v;
h=h0;
range=0;

while(h>=0)
   n=n+1;
   Fd = k*vt^2*Cd;                  % get drag force
   %Fd=0;
   ax = -Fd*cos(thetat)/mass;        % compute the x acceleration
   ay = g-Fd*sin(thetat)/mass;       % compute the y acceleration
   vx1 = vx+ax*dt;                  % compute x velocity in t+dt
   vy1 = vy+ay*dt;                  % compute y velocity in t+dt
   dx=vx1*dt;                       % change in x position
   dy=vy1*dt;                       % change in y position
   h=h-dy;                          % new altitude
   range=range+dx;                  % new down range
   vx=vx1;                          % initialise Vx for the next loop
   vy=vy1;                          % initialise Vy for the next loop
   thetat=atan2(vy,vx);             % new bomb angle
   vt=sqrt(vx^2+vy^2);              % new bomb velocity

   alt(n)=h;                        % plotting varaibles
   dr(n)=range;
end

time=n*dt;
Range = range.*0.3048;              % Range in Meters
Final_alt = h;
I = thetat*180/pi;
Impact_velocity = vt;
ToF = time;
%plot(dr,alt);grid;title('Trajectory'); xlabel('downrange');ylabel('altitude');
for l=1:t
   lla1=[T(l,4),T(l,5),T(l,8)];
```

```
    lla2=[38,127,6096];
    [a,b,c]=convert_lla2azelr(lla1,lla2);
    hm=0.3048.*h0;
    A=sqrt(c^2-hm^2);
    SR(l)=c;
    if range>=A
        traj(l)=1;
    else
        traj(l)=2;
    end
end
end
```