CAPT MAJOR

USAF/GAF Fighter Weapons School

F-104G

COURSE NO. 111504MD

Non-Nuclear Weapons Delivery

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INTRODUCTION

Effective close air support and interdiction sorties are dependent on timely and accurate weapons delivery. Force structure planning and methods of formating strike forces will not be treated in this text; however, improving the skill level of the individual pilots making up these forces is the primary objective of this course.

This author's hypothesis is that scientific analysis and concentrated training of gunnery fundamentals is a prerequisite to effective ordnance delivery in a combat environment. Since each pilot's non-nuclear weapons delivery capability is readily assessable from range sheets or strike film, the challenge to prospective weapons officers or interested pilots is to master the fundamentals of weapons delivery and effectively communicate techniques to fellow pilots.

I wish to acknowledge the USAF Fighter Weapons School for generously providing source material for this text, both through FWS textbooks and Fighter Weapons Newsletters.

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NON-NUCLEAR WEAPONS DELIVERY

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Chapter I

GROUND ATTACK THEORY

This chapter is the introduction to air-to-ground conventional ordnance delivery. The information presented will be discussed in terms of bombs for ease of presentation and continuity; however, the concepts apply to rockets and guns.

The air-ground problem, definitions, harmonization, angle of attack, ballistics, errors, wind effects, and hazards of delivery will be considered.

1. THE AIR-GROUND PROBLEM.

The air-ground deliveries considered in this text will deal with three catagories of munitions: free fall bombs, unguided rockets, and cannon projectiles. Each type of munition has peculiar ballistic variations; however, the basic delivery problem remains unchanged. That is, determine your desired release parameters, compute a depressed sight line, and then fly the predetermined flight path to release.

Wind effect, ordnance and loading induced errors, aircraft sight system errors, and pilot-induced errors are variables that must be considered for consistently accurate hits. You, as a competent weapons officer, must understand the delivery problem to be able to develop efficient training programs and to recommend techniques that will make your fellow fighter pilots better bombers.

2. DEFINITIONS.

The following terms are defined for use in ground attack study:

1. Angle of Attack: The angle between a base reference line and the relative wind. The relative wind is opposite in direction to the aircraft's flight path. The base reference line may be the fuselage reference line, in which the angle is termed the zero sight line angle of attack.

2. Ballistic Trajectory: The path of a munition from release to impact. This trajectory is a result of ballistics, release velocity, release angle and release height above the target.

3. Air Mass Effect: The flow of an air mass, both direction and velocity, relative to the aircraft.

4. Parallax Error: The error induced by the linear separation of the sight and the gun as it is installed in the aircraft, or the error induced by the separation of the sight and the ordnance mounted on pylons.

5. Mil: A unit of angular measurement used in gunnery computations. There are 17.45 mils (technically milliradians) in 1°, and the accepted working definition is: 1 mil subtends 1' at 1000'.

6. ADL: Armament Datum Line or Zero Sight Line. The zero mil sight reference line (determined by 1800' harmonization) used in gunnery computations.

7. Harmonization: The orientation of three reference lines - ADL (both sight & radar), and theoretical mean fixed boreline - so a fully computing tracking index will predict bullet impact at harmonization range only.

8. OPSL: Zero Prediction Sight Line. A sight line which has been depressed to correct for parallax and becomes the base, or zero line for all sight computations. (coincident with ADL)

9. FRL: Fuselage Reference Line or Water Line 100: A reference line extending through the fuselage parallel to the longitudinal axis of the aircraft.

10. Gun Line: A line extended through a gun's bore to infinity.

11. Theoretical Mean Fixed Bore Line: Gun line corrected for tangential throw.

12. Harmonization Constant: The relative position of the zero mil sight line and the FRL. This is approximately 40 mils.

13. Trajectory Shift: The angle swept by a bullet as its direction changes from the theoretical mean fixed bore line toward the flight path.

14. Gravity Drop: The amount of drop of a bullet toward the earth due to gravity. Gravity drop is a function of time.

15. Velocity Jump: The angle through which a rocket rotates due to the launcher line being at an angle to the relative wind.

16. Trajectory Drop: The amount of drop of a rocket toward the earth due to gravity and thrust.

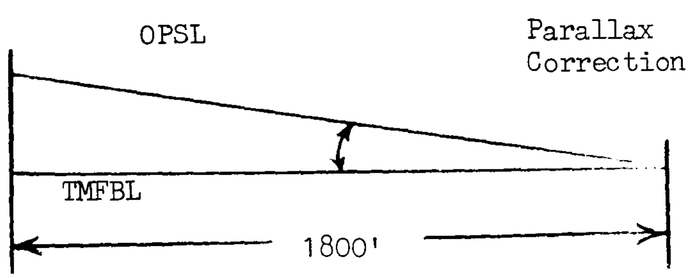
17. Effective Depression: Depression from intended aircraft flight path.

3. HARMONIZATION.

Harmonization is the process that enables the computing tracking index to predict bullet impact at a given range. For air-ground deliveries, the position of the harmonized zero sight line or ADL is important so proper depression angles can be selected for a variety of weapons and delivery parameters. A discussion of harmonized range and harmonization constant follows.

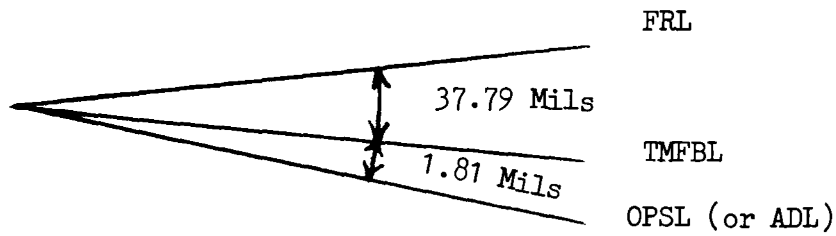
A. HARMONIZED RANGE.

Harmonized range is defined as the range where the theoretical mean fixed bore line (TMFBL) intersects the Zero Prediction Sight Line (OPSL). The selected harmonization range used at Luke is 1800'. (See Figure 1).



(Figure 1)

On the ground, an F-104G sight in the manual, zero mil position, is harmonized with the following references:



(Figure 2)

The angle between the FRL and TMFBL is 2° 09' 56" (37.79 Mils). This is the result of gun depression below the FRL and tangential throw.

The angular distance between the TMFBL and the OPSL can be approximately calculated by using the formula:

$$\frac{x}{1000} = \frac{\text{Gun Parallax (ft)}}{\text{Range (ft)}}$$

For 1800 feet harmonization:

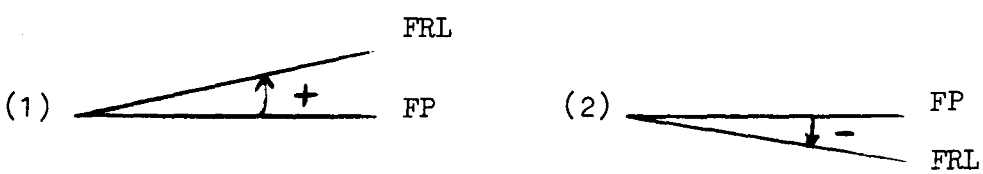
$$\frac{x}{1000} = \frac{3.27}{1800} \qquad x = 1.8 \text{ Mils}$$

B. HARMONIZATION CONSTANT.

The total distance between the FRL and the ADL can be called a harmonization constant. The angle of attack charts in the Dash 34 manual are based on a harmonization constant of 40 Mils. If any circumstances arise to alter the 40 Mil relationship, the difference between 40 Mils and the new FRL/ADL relationship must be applied to all Dash 34 figures.

4. ANGLE OF ATTACK.

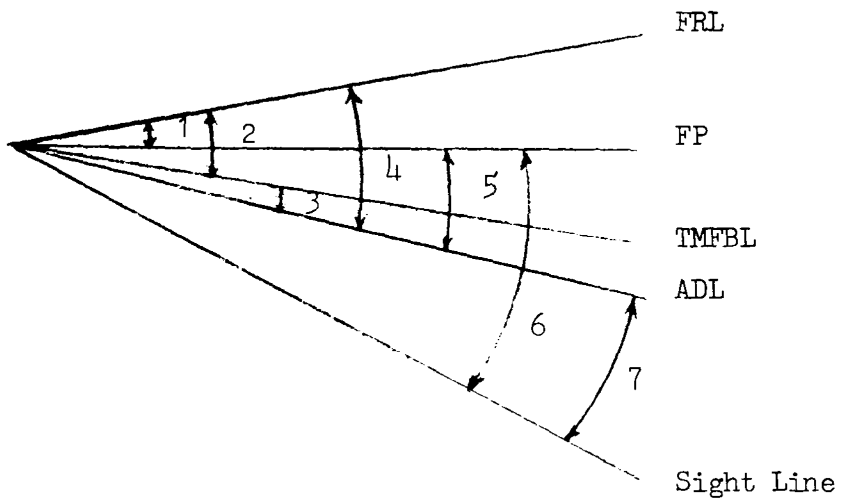
The angular distance between the fuselage reference line and the aircraft's flight path is defined as the angle of attack. Angle of attack is dependent on "G", calibrated airspeed, and aircraft gross weight. It may be either positive (1) or negative (2).



Since we know that the zero sight line is a constant 40 mils below the FRL, an angle of attack chart can be constructed showing the relative position of the zero sight line to aircraft flight path. This is done for us in the Dash 34 manual. Zero sight line angle of attack is computed by entering the Dash 34 Zero Sight Line Angle of Attack Chart (p 6-5) with airspeed, reading up to gross weight, over to dive angle, and down to the desired angle of attack in mils. It was previously stated that angle of attack was dependent on "G". Release G is actually a function of the cosine of dive angle and is expressed this way in the Dash 34 chart.

The Dash 34 bombing tables list sight depression from flight path. If we algebretically add the zero sight line angle of attack to this listed depression, we have the depression required in the sight. Rocket and gun tables list sight depression as a function of angle of attack for one step computation ease.

The entire sight depression problem looks like this:



(Figure 3)

1. Aircraft angle of attack
2. Gunline below FRL
3. Sight-gun parallax

$$\frac{x}{1000} = \frac{\text{Parallax}}{1800'}$$

4. Harmonization constant (approximately 40 mils)
5. Zero sight line angle of attack
6. Depression from flight path
7. Sight depression

For daily practical use:

Dash 34 depression + ZSL angle of attack = Sight Setting

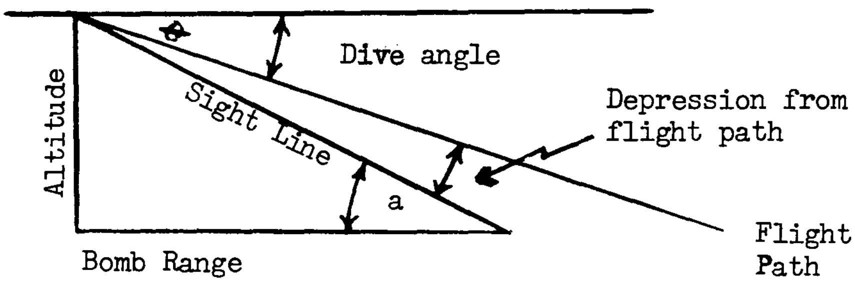
5. BALLISTICS.

Ballistic data is figured by a computer through a series of equations. The equations consider such factors as: atmosphere, release conditions, retarding device (if any), the drag coefficient, physical properties, ejection velocity, forward velocity of rockets and 20mm, trajectory shift, velocity jump, trajectory drop, and gravity drop. The computer can give a more accurate solution to the trajectory curve since it integrates the time rate equation about 16 times per second of time of flight of the munition.

This information appears in the ballistics tables of the Dash 34 manual. Also, the Dash 34 provides a series of sight depression charts to adapt raw data from any source to F-104 sight depression from flight path figures.

A. BALLISTICS TABLES.

Perhaps the keys to the bombing problem are the horizontal component of the trajectory curve, called Bomb Range (Br), and the munitions time of flight (Tf). The reasons for this is that bomb range enables us to compute depression from flight path, and the time of flight enables us to determine how much effect wind will have on bomb impact.



(Figure 4)

Using trigonometric relationships, angle "a" in Figure 4 can be computed:

$$\text{Cot "a"} = \frac{\text{Bomb Range Corrected for Parallax}}{\text{Release Altitude Corrected for Parallax}}$$

Slant range can be computed using the Pythagorean Theorm.

$$\text{Slant Range} = \sqrt{(\text{Bomb Range})^2 + (\text{Altitude})^2}$$

After angle "a" has been computed, the sight depression from flight path can be determined and converted into a mil value.

$$\text{Depression from FP} = (a - \delta)\ 17.45$$

B. DEPRESSION CHARTS.

The solution in paragraph A is quite time consuming and normally unnecessary since the Dash 34 bombing tables list depression from flight path corrected for parallax. However, as a weapons officer, you may have occasion to compute sight settings for munitions that do not appear in the F-104 Dash 34. If this happens, all you will need to know is bomb range for the desired release altitude. Enter the appropriate Dash 34 sight depression angle chart (p 6-7 through p 6-19) with bomb range, project up to release altitude, and then over to sight depression from flight path.

The solution obtained by this method will have a reasonable amount of accuracy. The one variable not considered is ejection velocity of the store. Figure 5 shows comparative ejection velocities of the F-104, F-100, and F-105.

EJECTION VELOCITIES IN FEET PER SECOND

Munition	F-104	F-100	F-105	
			Pylon	Mer
M-117	15	18	12	6
M-82	18	22	14	7
M-83	21	14	11	5
M-84	14	0	10	
BLU-27	16	--	12	6
MLU-10B	16	20	13	7

(Figure 5)

(1) Sample Problem:

Munition	BLU 27-B (Finned)
A/C Gross Wt	21000#
Dive Angle	10°
Release Alt	500'
Release A/S	450 KIAS (460 TAS)
Bomb Range	1974'

FIND:		
	Depression from Flight Path	77 mils
	ZSL Angle of Attack (TO Flaps)	-22.5
	Sight Setting	54.5 mils

6. ERRORS (NON-PILOT FACTORS).

It has been shown that the ballistic tables take into account many variable factors. How much these factors affect the accuracy of the bomb can be computed mathematically and allowances made in the tables. However, there is a group of errors that could produce relatively small miss distances but cannot be computed in advance. These may be divided into four catagories: Inherent Dispersion, Munitions Installation, Aircraft Systems, and Miscellaneous.

A. INHERENT DISPERSION.

The errors resulting from dispersion are many, varied, and to a large extent, unpredictable. They are a result of such things as bent bomb fins, misalignment of structural parts, variations in size of projectiles, thrust variation and burn rate in rockets and 20mm and many other variables. One of the key inputs to the computer for figuring the ballistic trajectory is the coefficient of drag. The coefficient of drag is determined mathematically and by actual flight test of that munition. A fairly old munition has had the drag coefficient determined many times, so it is probably extremely accurate; however, a new munition's drag may be based on a relatively small sampling, so after continued testing, a new drag coefficient may be obtained and consequently, the ballistic tables may change. This drag coefficient is also only an average, so each munition may vary a bit, and each separate bomb may take a slightly different trajectory than predicted.

B. MUNITIONS INSTALLATION.

The second source of impact error is found in munitions installation. The pilot must know the orientation of guns, gun pods, rocket launchers, and base sight references as closely as possible. The fuselage mounted gun in the F-104 does not present a great deal of difficulty. It is stable with reference to the airframe and is boresighted with the reference sight line; however, externally mounted gun pods are only as stable as the mounting hardware. Gun pods and rocket launchers have been observed to become misaligned when jarred, especially during rough takeoffs and landings, and when submitted to large drag forces at high airspeeds.

Any misalignment causes a deterioration in the overall system accuracy.

Rocket launchers are usually not boresighted. They are suspended from hooks, tightened to prescribed torque, and left as a headache to pilots. The true orientation of the launcher is not really known, and it is merely assumed that it is pointed in the proper direction.

C. AIRCRAFT SYSTEMS.

Any portion of the aircraft release system may become worn and induce slight electrical delays or distorted separation of munitions from aircraft.

D. MISCELLANEOUS.

One miscellaneous factor is target height. The ballistics tables assume that a target has no vertical development; therefore, if a target is about 100 feet higher than the ground, the pilot should take this into consideration when planning the mission or a bomb range error may result. A second miscellaneous factor is non-standard atmosphere. The ballistic trajectories are based on a standard atmosphere. If this atmosphere is not standard, as is usually the case, the munition will take a slightly different trajectory. The non-standard atmosphere could, naturally, result from temperature and pressure deviations, but perhaps a more important deviation would be caused by target altitude. When releasing low drag munitions, this error is usually quite small; however, high drag munitions with their associated high times of flight will produce correspondingly larger errors. A recent test indicates that Snakeye weapons delivered against a target at 3000 feet altitude may produce a range miss distance of 150 feet if sea level ballistic charts are used.

7. ERRORS (PILOT FACTORS).

Previously mentioned errors are generally small in magnitude. As a weapons officer, you will have limited control over these variables, but you can assist in a good quality control program in your unit. However, the area of pilot induced errors is one over which you may have a great deal of control. These errors can result in very large miss distances, and must be basically and logically understood if you are to instruct effectively. The following errors will be considered:

- Pipper not on the aimpoint
- Proper setting (ballistics corrected for wind)
- Release dive angle
- Release airspeed
- Release "G"
- Wings level
- Coordinated flight

A. PIPPER NOT ON THE AIMPOINT.

More pilots have missed more targets for the simple reason that they didn't have the pipper on the aimpoint. This error is caused by 2 factors, improper aircraft control and not knowing where the aimpoint is. Why would a pilot, knowing full well that he will miss the target if his pipper is not positioned properly, release the bomb anyway? The first answer is obvious--that he flew the aircraft incorrectly; however, the second answer is not quite so obvious--that is, he didn't know exactly where the aimpoint was. He might be attempting to correct his aimpoint to make up for other errors, such as being shallow or slow. Another reason that he may not know the correct aimpoint is that the wind is unknown or incorrect. At slant ranges greater than 3000 feet from the target, it is difficult to estimate 10 or 20 feet to determine the proper aimpoint. Thus, even though the biggest error results from not having the pipper on the aimpoint, this is frequently not the pilot's fault, but is due to the human inability to guess 100% correctly.

If bombing was always done in a no-wind condition and the aimpoint was always the target, the only reason for a pilot to not have his pipper positioned properly would be caused by improper flying. This factor alone still probably causes most of the misses. So, when analyzing a target miss, either by yourself or another pilot, try to determine if the pipper was really on the aimpoint. Gun camera film can be a great help in analyzing this error.

B. PROPER SETTING (BALLISTICS CORRECTED FOR WIND).

The pilot must have the proper setting, if he is going to consistently hit the target. Also, the wind problem is of such magnitude that it will be discussed at length later in this chapter.

C. RELEASE DIVE ANGLE.

Sight depression is computed for one particular dive angle. The dive angle before and after the bomb release will not affect the bomb. It is important only at the moment of release. The following analysis holds true, no matter if a dive delivery or level delivery is used. If the munition is released at the wrong dive angle, two partially concelling errors will result--a release point range error and a trajectory error. (See Figure 6).

(1) Release Point Range Error. If the release is accomplished while approaching the target in a dive steeper than planned, an overshoot will result. This is caused by a reduction in the aircraft angle of attack, resulting in more effective depression and a decreased slant range. A shallower-than-planned dive angle will produce an undershoot.

(2) Trajectory Error. Besides the release point range error, the steeper dive angle will affect the bomb trajectory, causing it to be shorter and flatter and the bomb range will be less than planned. This will partially cancel out the release point range error but will always be the lesser of the two errors.

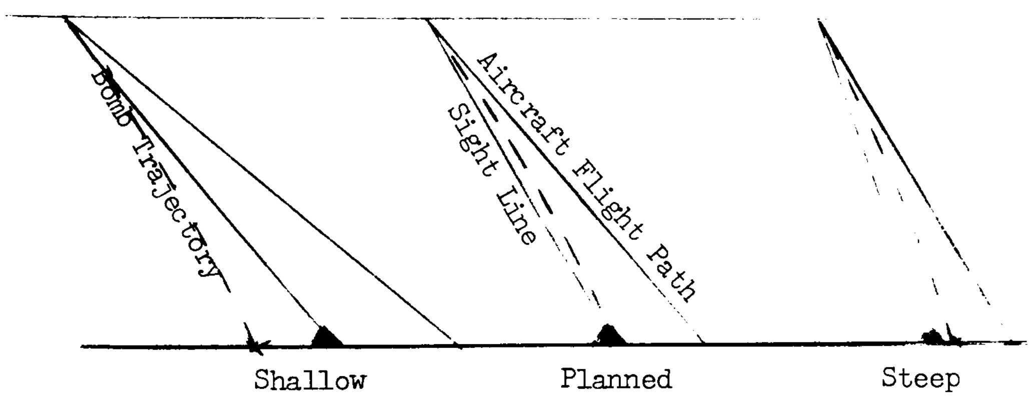


Figure 6

D. RELEASE ALTITUDE.

Sight depression is computed for one particular release altitude. Only at this altitude and slant range will the sight line and ballistic trajectory intersect. If the release is made at an altitude different from planned, two partially cancelling errors will result--a release point range error and a bomb trajectory error.

(1) Release Point Range Error. If the weapon is released lower than planned, an overshoot will result because the aircraft is closer to the target at release. If the release is made high, an undershoot will result.

(2) Trajectory Error. In addition to the release point range error, a lower-than-planned release will result in a shorter bomb range. This will partially cancel out the release point error, but will be the lesser of the two.

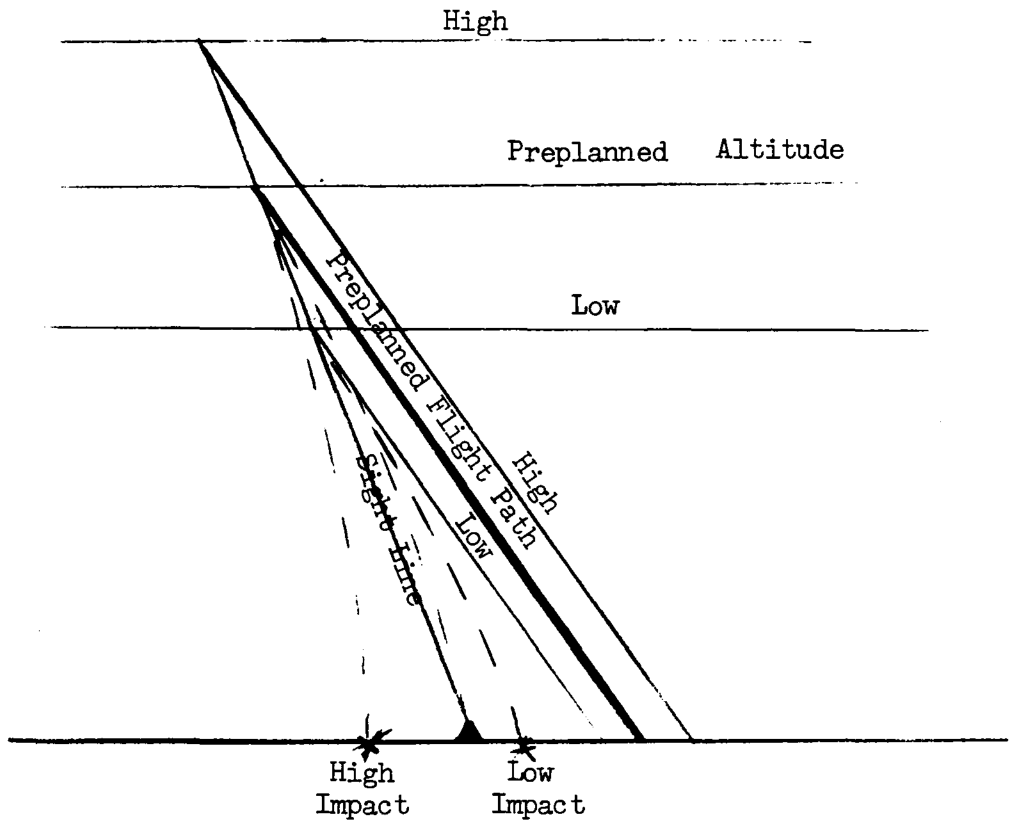
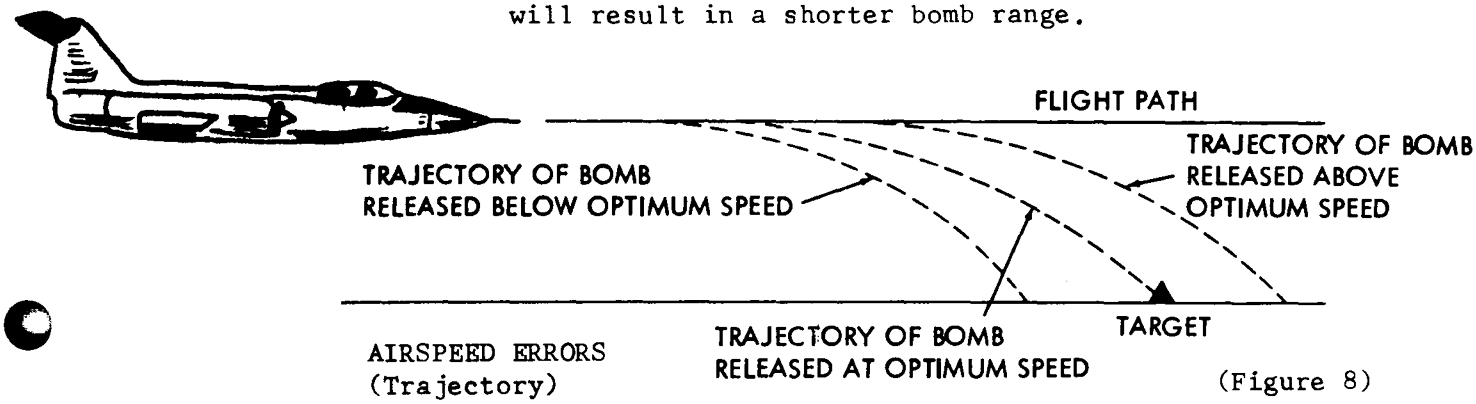


Figure 7

E. RELEASE AIRSPEED.

Sight depression and angle of attack are calculated for one particular airspeed. If the delivery airspeed varies from the planned airspeed, the trajectory of the bomb changes and the sight setting is no longer valid. These two errors are cumulative.

(1) Trajectory Error. At the moment of release, the bomb's horizontal velocity is equal to that of the delivery aircraft. Releasing at an airspeed greater than planned will impart a greater speed to the bomb resulting in a longer, flatter trajectory and a resultant overshoot. Conversely, a release made at an airspeed lower than planned will result in a shorter bomb range.



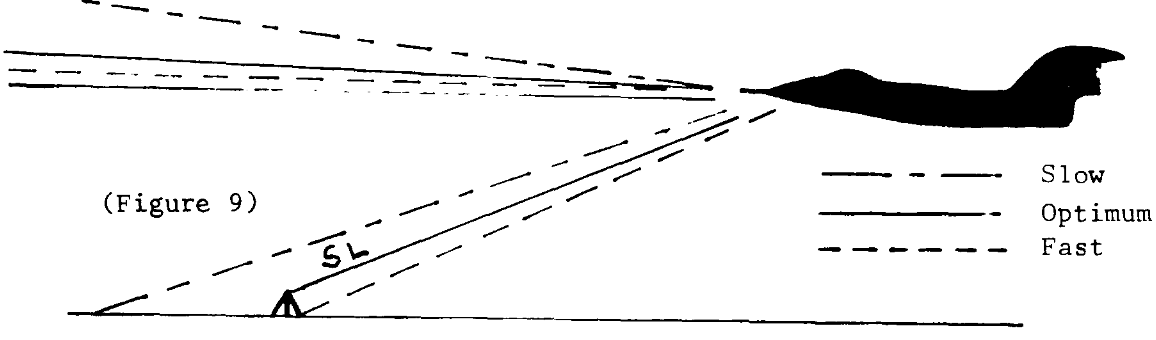
AIRSPEED ERRORS (Trajectory)

(Figure 8)

Effect of Airspeed

(2) Release Point Range Error. In addition to changing the bomb's trajectory, an increase in airspeed will decrease the aircraft's angle of attack, which increases the effective sight depression, causing an overshoot. Conversely, a decrease in airspeed decreases the effective sight depression causing an undershoot. The trajectory error and release point range error add to each other.

RELEASE POINT RANGE ERROR



(Figure 9)

F. RELEASE "G".

As was mentioned previously, bomb ballistic tables are based on a release "G" equal to the cosine of the dive angle. At a 30° dive angle, this would be .866 G.

An increase in "G" loading on the aircraft results in an increase in angle of attack which, in effect decreases sight depression relative to the flight path. The result will be an undershoot. Conversely, a negative "G" will decrease the aircraft angle of attack and produce an overshoot.

G. WINGS LEVEL.

If a bomb is released in a bank with the pipper on the target, pendulum effect will cause less effective depression and a resultant short impact. Releasing in a bank also results in the pipper moving forward and opposite to the bank. This in effect places the aircraft to the side of the target. If the bomb is released in a left bank, it will impact left and short of the target. Released in a right bank, it will impact right and short of the target.

BANK EFFECT

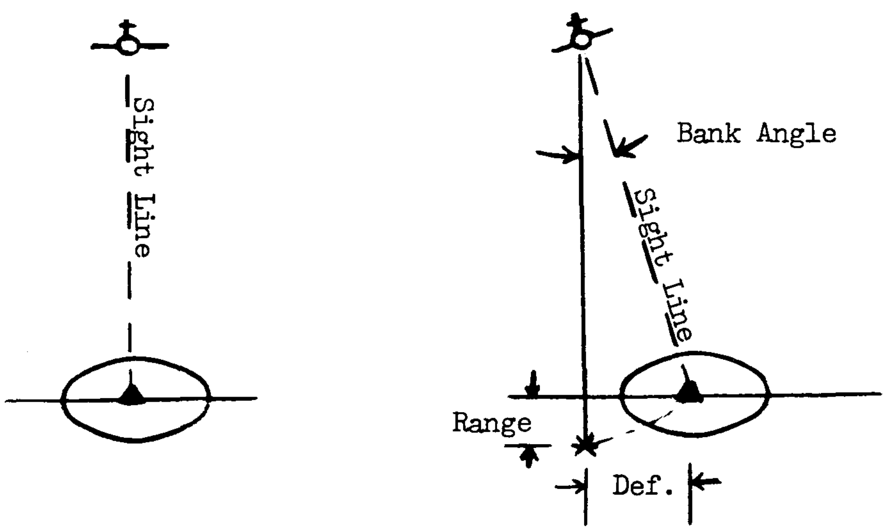
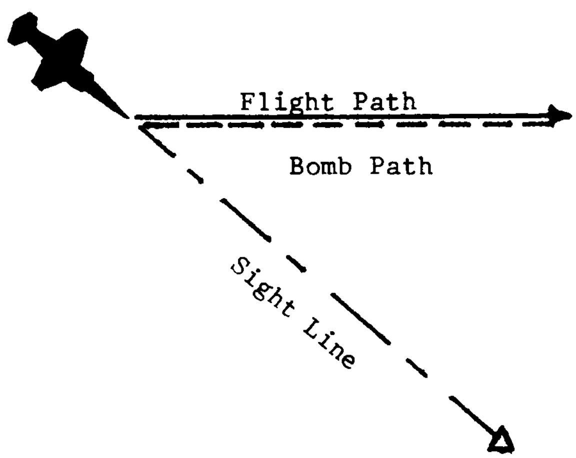


Figure 10

H. COORDINATED FLIGHT.

At the moment of release, the bomb has only the speed and direction of the aircraft. So, at release, the bomb doesn't recognize skid and aligns itself with the aircraft's flight path. Thus, the impact error is in the direction of the skid. If the ball is left, the skid is left. The impact will also be slightly long because the aircraft is closer to the target at release than computed.



SKID EFFECT

(Figure 11)

8. WIND.

Wind, or air mass movement, influences every piece of ordnance dropped or shot from an aircraft. In order to examine wind effects, a series of situations using bombs will be presented. They are: a perfect (no drag) bomb in a no wind situation, a no drag bomb released in a constant wind, a high drag bomb in a no wind situation, and a high drag bomb with wind. Also, the drift and crab methods of offset aiming will be considered.

The following assumptions will be made for this text book discussion:

All fin-stabilized objects are released in coordinated flight.

The air mass in which the aircraft and the bomb are moving is infinite in all horizontal directions and extends from anywhere above the aircraft down to the earth's surface.

The air mass moves with any velocity (speed and direction) although for any given problem, velocity is constant.

The bomb is released from the aircraft centerline. A bomb released from some other station requires additional consideration. This is a simple correction and easily understood.

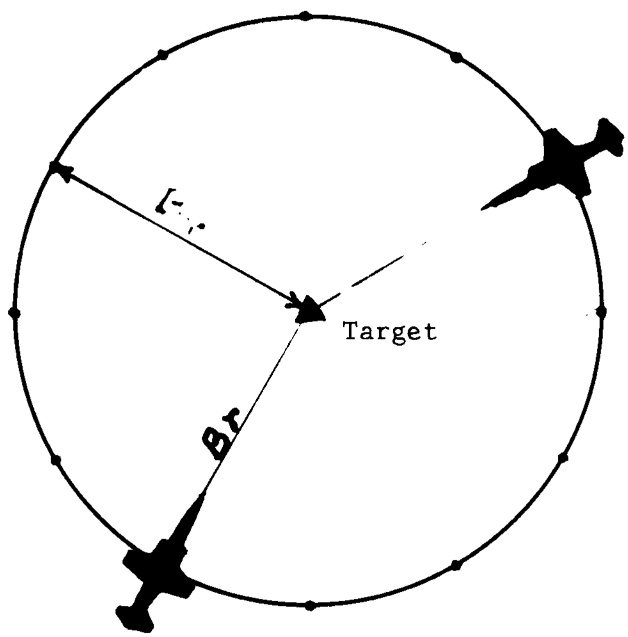
The aircraft maintains a constant velocity after release. This is not necessary and does not affect what happens to the bomb after release, but is used to show vector relationships from release to impact.

A. PERFECT BOMB - NO WIND.

First, we will consider an aircraft flying in level unaccelerated flight with no wind. We'll assume that this aircraft releases a perfect bomb that has absolutely no drag. Where will this bomb go? The bomb and the aircraft certainly had the same horizontal velocity at release, and since the bomb has no device to accelerate it, and no drag to decelerate it, the bomb will always have the same horizontal velocity as the aircraft. The force of gravity will cause the bomb to accelerate toward the ground, but this is a vertical vector and has no effect on the horizontal velocity. So as the aircraft and bomb continue with the same horizontal velocity vector after release, the bomb will remain vertically below the aircraft until impact.

The aircraft must pass directly over the target if the bomb is to impact the target in this hypothetical no-drag situation. In actual practice, we know this to be very nearly true with bombs that have extremely low drag.

If we change only the direction of run-in in this hypothetical situation, the same conditions will still apply. Gravity will accelerate the bomb toward the ground, the bomb will remain vertically below the aircraft until impact, and the aircraft must pass directly over the target if the bomb is to impact on target. The bomb time of fall and horizontal bomb range stay the same. With the same no-wind sight depression, the pipper will be on the target at release for any release heading. Thus, there are an infinite number of release points around a no-wind target for given release conditions. These release points transcribe a circle of radius B_r with the target at its center.



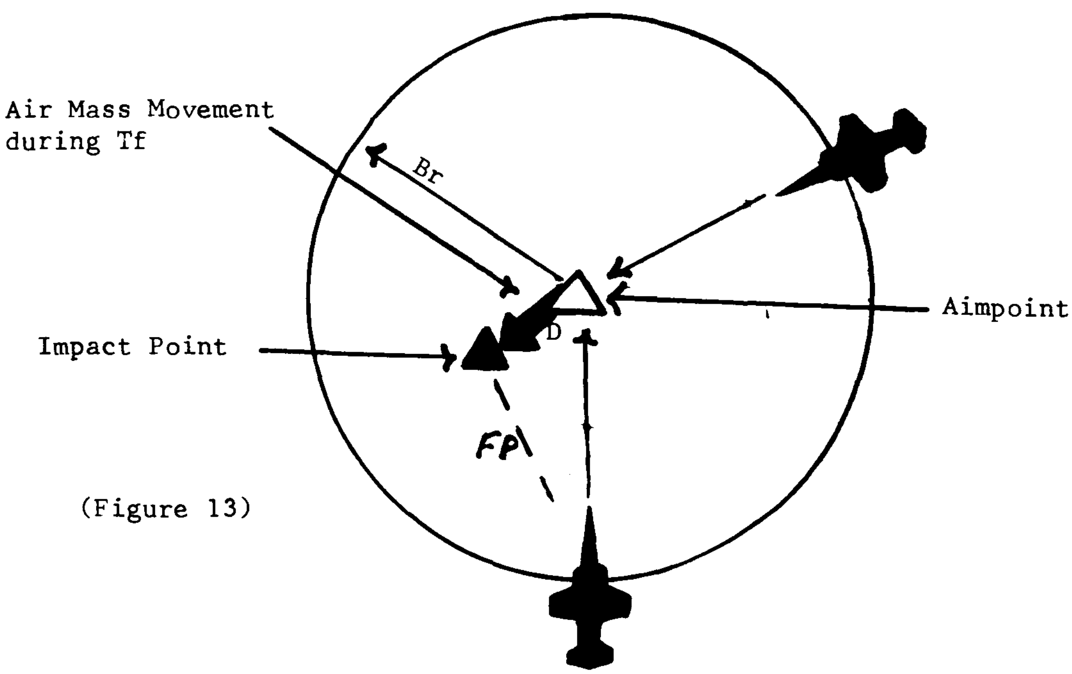
PERFECT BOMB - NO WIND

(Figure 12)

A bomb released anywhere on this circle with the aircraft headed towards the center will impact the target. What the aircraft does before or after reaching a release point on this circle does not affect the results. The bomb will impact on the target, which is the aimpoint.

B. PERFECT BOMB - WIND.

Now suppose that we have the same situation and conditions except the air mass is moving with a constant horizontal velocity above the ground. The air mass is merely moving above the ground and everything that occurs in this air mass will be exactly the same as occurred in the previous "no wind" air mass. The bomb will accelerate toward the ground due to gravity, and will remain vertically below the aircraft until impact. The horizontal air travel distance B_r will be the same for any release heading, but the impact point will move during the bomb's time of flight because the air mass is moving. The bomb will impact on some ground point other than the aimpoint, but its flight path through the air mass will not change.



(Figure 13)

PERFECT BOMB - WIND

(1) Wind Effect (D). Air mass velocity (V) and time of flight (t_f) are known constants for any given release conditions; therefore, the bomb will impact a predictable distance and direction from the target, regardless of the release heading. The miss distance is computed in the following manner:

$$\text{Distance} = V \times t_f$$

If: $\text{Velocity} = 1 \text{ knot} = 1\frac{NM}{HR} = \frac{6080 \text{ Ft}}{3600 \text{ sec}} = 1.69 \frac{\text{Ft}}{\text{Sec}}$

$$D = 1.69 \times t_f \text{ (for 1 knot of wind velocity)}$$

NOTE: The constant 1.69 has the units $\frac{\text{Ft}}{\text{Knot} \cdot \text{Sec}}$

This $1.69 \times t_f$ is the computation used to arrive at the Dash 34 manual "cross Ft/Kt" column. This is the distance in feet for one knot of wind. The distance for any velocity is computed by multiplying the cross Ft/Kt times that velocity in knots; therefore, it we should encounter a new munition and only t_f is known, cross Ft/Kt can easily be computed.

In Figure 13, if you released with the pipper on the target, D would represent a miss. However, if you precomputed D and aimed upwind that distance, you would be using an upwind aimpoint, and bomb impact would be on target.

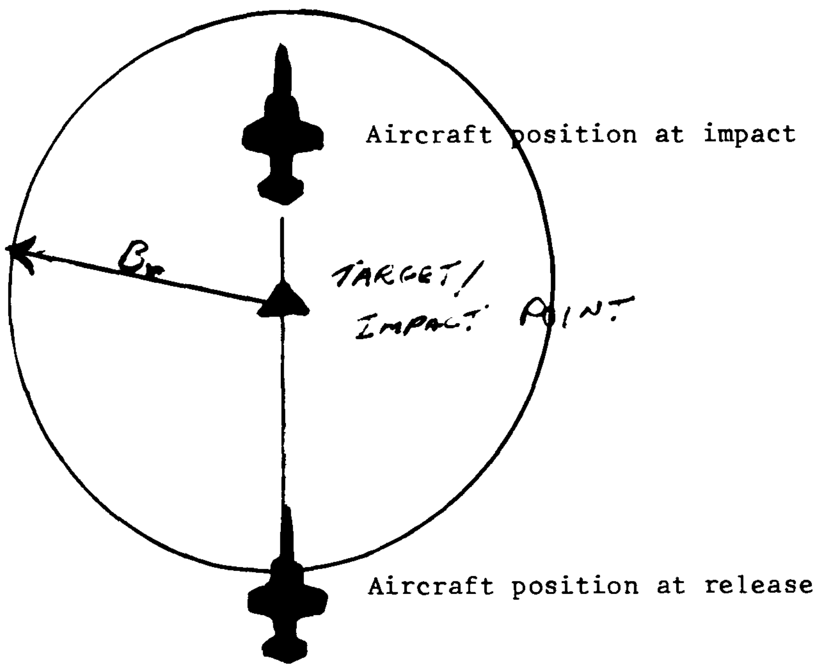
$$\underline{\text{Upwind Aimpoint} = 1.69 \times t_f \times \text{wind velocity (kts)}}$$

If the Dash 34 figures are used:

$$\underline{\text{Upwind Aimpoint} = \text{Cross Ft}/_{\text{Kt}} \times \text{wind velocity (kts)}}$$

C. HIGH DRAG BOMB - NO WIND.

Now, let's consider a more realistic situation, a bomb with high drag and a no-wind condition. The difference occurs when this high drag bomb is released from the aircraft. Gravity still accelerates the bomb towards the ground, but due to the high drag, the time of flight is greatly increased and the bomb does not continue with a constant horizontal velocity as does the aircraft. The bomb decelerates with a constantly changing velocity until it either impacts or has a negligible horizontal velocity. The bomb's horizontal velocity vector is still in the direction of the aircraft's horizontal velocity vector, but the bomb's speed is decreasing. The high drag bomb in a no-wind situation will not remain directly below the aircraft, but will always be a predictable distance behind and below the aircraft. When the bomb impacts, it will have traveled a shorter distance and the aircraft will have passed directly over the no-wind target. This is true regardless of run-in heading.

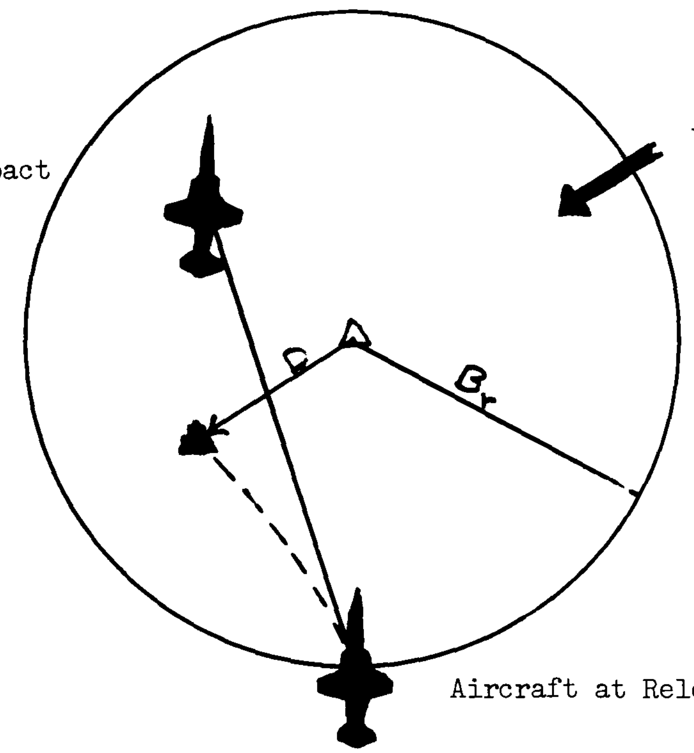


HIGH DRAG BOMB - NO WIND (Figure 14)

D. <u>HIGH DRAG BOMB - WIND</u>.

In the no-drag situation, it was noted that the air mass moved with a constant horizontal velocity above the ground. It was then concluded that what happened in this air mass was not affected by this motion. This is equally true for a high drag bomb; therefore, for bombing in a wind, all we need is an aimpoint measured some precomputed distance against the air mass direction of motion.

The air mass will then move this distance during t_f, and the bomb will impact on target. Release heading is still not a consideration and the bomb will stay below and behind the aircraft until impact. This will apply to a bombing problem of any dive angle.



(Figure 15)

E. <u>WIND CORRECTION.</u>

From the discussion in the previous paragraphs, we can draw the following conclusions:

The bomb is always directly behind the aircraft.

The "Upwind Aimpoint" is against the direction of the wind, and the distance is equal to 1.69 x T_f x wind speed.

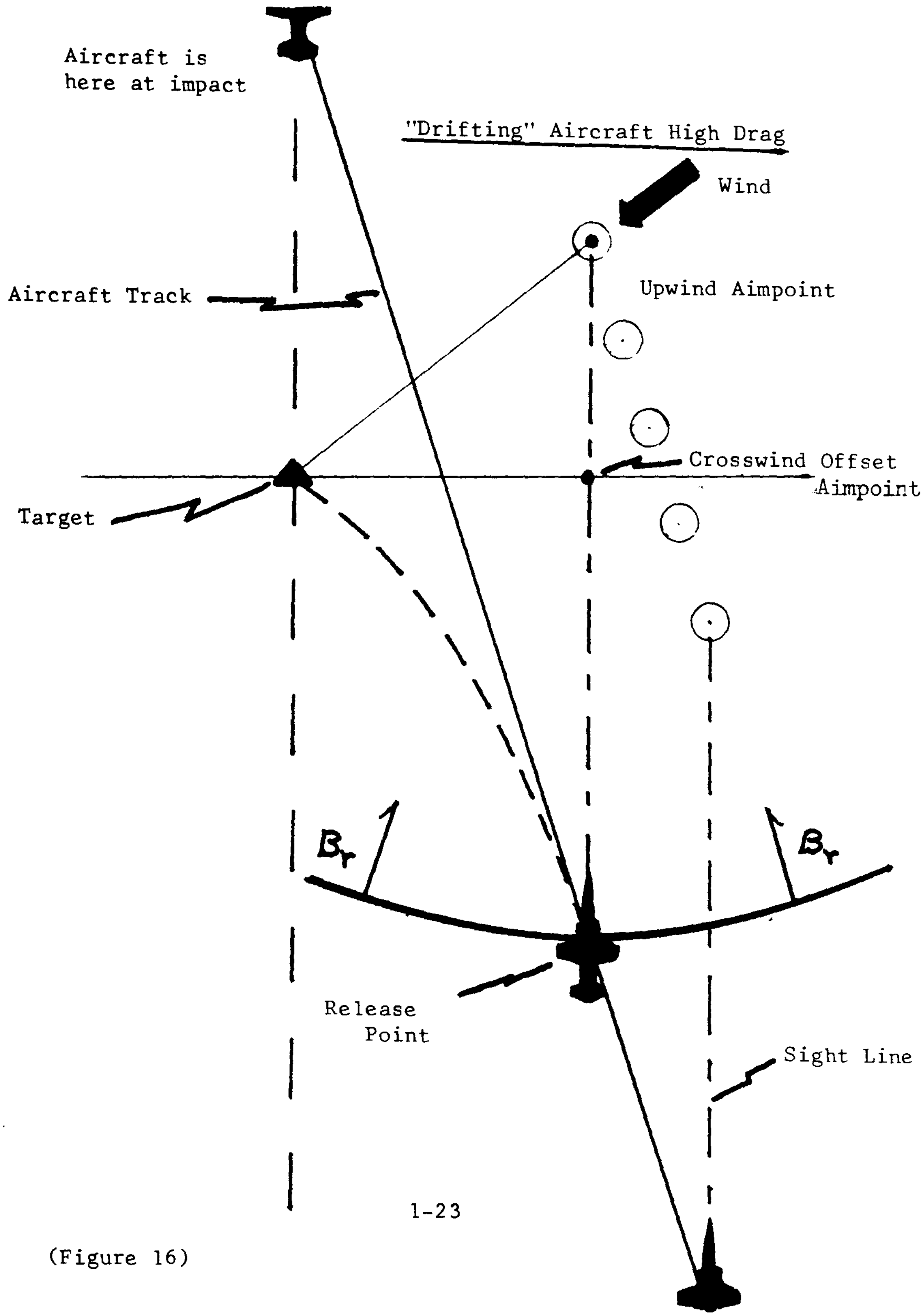
The aircraft can be coming from any direction. If the tracking index is on the aimpoint, the proper release point is equal to the bomb range (B_r) from the aimpoint.

The "Upwind Aimpoint" method may be applied to a bombing problem of any dive angle.

From these conclusions, we can arrive at some techniques to use for different bombing problems. There are two basic methods used to correct for wind: "Drifting" and "Crabbing". These terms are not exactly definitive; however, in fighter pilot language, drifting is thought of as flying a constant heading and allowing the wind to move the aircraft while crabbing is turning into the wind to make good a constant track across the ground. The drifting technique is usually used when delivering munitions from higher dive angles, while crabbing is used to deliver munitions from lower dive angles and level. In some cases, crabbing must be used; however, it usually makes no difference which of the two methods is used.

(1) Drift Method. The technique employed when using the drift method of release is: roll in upwind of the computed upwind aimpoint, allow the pipper to drift toward the upwind aimpoint as a final correction for airspeed and dive angle is made, and then "pickle" the instant the exact B_r is attained from the aimpoint. If, at that exact instant, all the release parameters have been satisfied, the bomb will impact on target.

Another way to arrive at the proper release point is to use a "crosswind offset aimpoint". In this method, the wind is broken down into range and crosswind components. The sight depression is corrected by multiplying the Mils/Knot figure in the Dash 34 by the cross component of wind, then offsetting perpendicular to the aircraft heading a distance equal to the cross Ft/Kt figure times the cross component of the wind. Though this method is frequently used on training ranges, it is not recommended for two reasons: first, the pilot is restricted to a single run-in heading. If he is not on this heading, his solution is wrong and an error will result. Second, this method requires more complicated computations and still requires the pilot to release with the tracking index off the target.



(Figure 16)

(2) Crab Method. The technique employed when using the crab method is to roll in approximately on track with the tracking index slightly upwind of the upwind aimpoint. As the aircraft starts to drift, turn into the wind to "kill the drift" while attempting to keep the pipper track on or slightly upwind of the upwind aimpoint. Trial and error turns will eventually place you on the proper aircraft track and enable you to use the upwind aimpoint for bomb release. (The upwind aimpoint remains the same when either the drifting or crabbing technique is employed).

Some of the guesswork can be removed from this method if a crab offset distance is computed. This enables the pilot to establish the proper aircraft offset track distance early, and then concentrate on killing drift to maintain that distance.

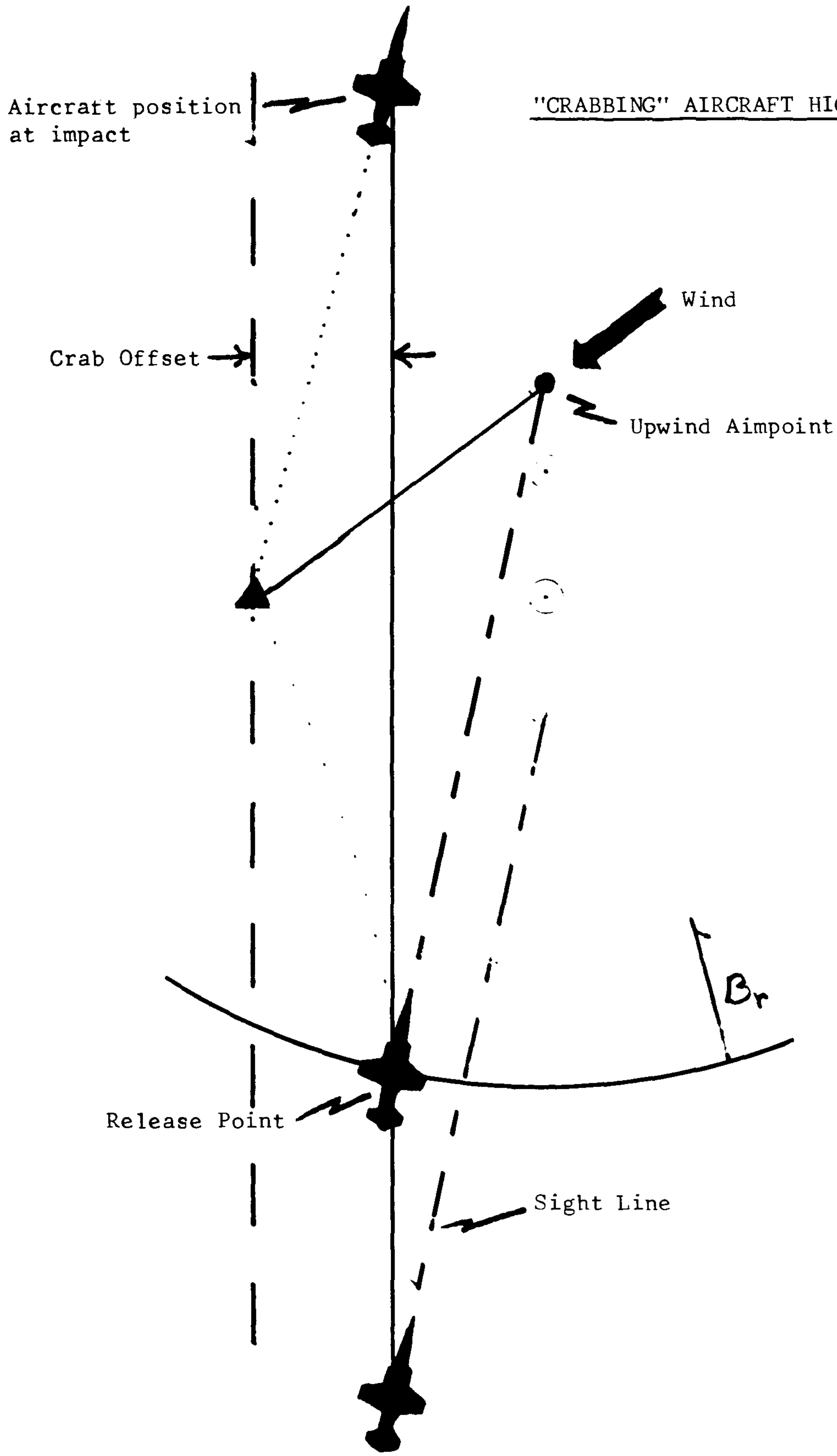
The crab offset formula is:

$$\text{Crab Offset (Ft/Kt)} = \text{Cross Ft/Kt} - \frac{B_r\ \text{(Ft)}}{\text{TAS (Kts)}}$$

This formula gives the distance the aircraft is offset for one knot of wind. A practical use of the equation is to use only the crosswind wind component and offset the track for each knot of wind.

It is not recommended that sight depression be corrected for wind for the same reasons mentioned in the "drifting" discussion, with one additional factor. In order to compute the crabbing crosswind offset aimpoint, we would have to know aircraft heading and divide the wind into a shorter crosswind component and another component along the sight line. Also, since the crosswind offset aimpoint for crabbing is different from the crosswind aimpoint for drifting, if a pilot were to use this method, he would have to be completely "drifting" or completely "crabbing" or have an aimpoint error and a resultant bomb impact error.

"CRABBING" AIRCRAFT HIGH DRAG



(Figure 17)

9. <u>HAZARDS OF AIR-GROUND DELIVERY</u>.

The hazards of air-ground delivery must be considered by each pilot attempting to deliver ordnance effectively. The very fact that much of the mission is flown at rather high speeds while maneuvering close to the ground requires alert airmanship and preplanning. High gross weight pull-outs over uneven terrain can be critical. Any aircraft emergency requires immediate and proper action.

In addition to the items mentioned above, enemy defensive action and possible ricochet or fragmentation damage present real problems.

Know your aircraft and systems, understand the air-to-ground delivery problems, and fly professionally!

NON-NUCLEAR WEAPONS DELIVERY

Chapter II

LEVEL BOMBING

Level bombing can be done from a variety of altitudes, and a general explanation of medium and high altitude level bombing is given. However, the major points of discussion in this chapter treat low level level bombing. This includes advantages and limitations, applicable weapons, delivery techniques, and computations.

1. GENERAL.

Bombs may be dropped from level flight at three different arbitrary groups of altitudes:

Low altitudes - Below 300 feet
Medium altitudes - Between 300 feet and 1500 feet
High altitudes - Above 1500 feet

Level bombing encompasses those dive angles between 0 and 5°. For simplicity, this chapter will discuss only the 0° dive angle portion of level bombing. Chapter 3, Dive Bombing, considers the problems and techniques associated with 5 to 45° dive angles, and the considerations at 5° are similar to those at less than 5°.

A. LOW ALTITUDES.

The low altitude grouping is used most extensively for the simple reason that it is easier to get precisely accurate hits. Relatively short bomb ranges put the pilot close to the target and he can see his aimpoint better. Also, at 300 feet and less, there is sufficient sight depression available for most of the weapons used.

Probably the greatest advantage of the low altitude delivery is accurate altitude estimation. The F-104 altimeter has inherent errors that make the altimeter method of altitude estimation unreliable. Therefore, pilot estimation (or guessing) becomes the primary method. Experience has proven that pilots are very good at guessing altitudes up to 100 feet AGL. However, above 200 feet it is extremely difficult to consistently estimate altitude correctly.

B. MEDIUM ALTITUDES.

Medium altitude level deliveries (EMR) have long been associated as a back up method of nuclear weapons delivery. Because of the altitude estimation problem and the tremendous difference between nuclear and non-nuclear yields, this delivery mode is not recommended except for area weapons such as CBU.

If target acquisition or enemy defenses require a higher approach, the best solution would be to use a low angle dive delivery rather than a medium altitude level delivery.

For freefall general purpose bombs, this is almost exclusively a back up mode. Besides the accuracy problem, there are two additional factors: Safe Separation and Ricochet.

(1) Safe Separation. When dropping a freefall GP bomb, it will probably be necessary to perform some type of escape maneuver to get out of the bomb's fragmentation envelope. One procedure is to make a 90° turn in the horizontal plane as soon as the bomb is released; another is a 4 G pull up in the vertical plane.

(2) Ricochet. Unless general purpose bombs impact at an angle greater than about 30°, there is a high probability that they will skip or ricochet. Also, in marshy or soft earth, they may broach. In certain cases, this skip or broach distance may be as much as 5000 feet.

C. HIGH ALTITUDES.

The delivery of freefall general purpose bombs from high altitudes in a level attitude is valid though less accurate than other modes of delivery. Ground radar, flying the wing of a sophisticated radar equipped aircraft, or in some specialized instances using the F-104G radar are methods of determining the correct release point.

When using ground radar as a source, the pilot is required to fly a constant altitude and airspeed, and follow the directions of the radar controller to establish the proper release track.

The use of the 24000 foot bomb cursor and aircraft timers is possible in the F-104G, but the expected accuracy would be similar to a pilot's NWD average. Formation drops on an area target could yield acceptable hits.

2. ADVANTAGES OF LEVEL BOMBING.

Accuracy, surprise, ease of delivery, and low weather capability are four major advantages of low level bombing.

A. ACCURACY.

Accuracy in visual bombing is directly dependent on slant range from the target. The closer the aircraft is to the target, the more accurate the bomb's impact will be. Careful matching of ordnance to specific release conditions can yield relatively short delivery ranges. In such cases, accuracy should be very high.

B. SURPRISE.

Of all the delivery modes, low level bombing affords the best opportunity for achieving some degree of surprise. This is particularly true if the delivery is preceded by low level navigation to the target.

C. DELIVERY EASE.

In level bombing, the pilot's problems are simplified to a great extent because, at the moment of release, the attitude, altitude, and airspeed are not changing. In combat, this delivery usually doesn't have the long flat approach to the target which is usually used in training on a scoreable range. An experienced pilot will be straight and level for only a few seconds prior to release, but still, at the moment of release, the aircraft should be stabilized at the proper airspeed, altitude and attitude.

D. WEATHER.

Low level bombing yields the best chance of success under low cloud ceilings. Bombs can be delivered with comparative ease below a 500 foot ceiling. At times, it is possible to bomb below a 200 foot ceiling provided the visibility is good enough to acquire the target.

3. LIMITATIONS OF LOW LEVEL BOMBING.

Low Level Bombing has three major limitations: Target Acquisition, Exposure to Small Arms Fire, and Weapon Adaptability.

A. TARGET ACQUISITION.

If the target has no vertical development, or is well camouflaged, it may be extremely difficult to see from low altitudes. Also, natural factors such as mountains or heavy tree coverage may obscure the target. These factors alone may make it necessary to use a low angle dive rather than a level delivery.

B. SMALL ARMS FIRE.

The very nature of the low level delivery puts the aircraft directly at the altitudes where it is vulnerable to all types of small arms or automatic weapons fire.

C. MUNITIONS.

Not all munitions are suited to a low level delivery. Rockets and 20mm ammunition cannot be accurately delivered level. Also, GP bombs, because of ricochet characteristics, usually aren't dropped from low levels. Additionally, there are only certain fuzes capable of the necessary fast arming times required for the comparatively short time of fall. Most of the munitions that are delivered at low altitudes have been expressly designed for this delivery.

4. WEAPONS.

There are three series or types of munitions usually associated with low level bombing: Fire Bombs, Snakeye Bombs, and the CBU series. All have been designed for low level delivery accuracy.

A. FIRE BOMBS.

Napalm filled Fire Bombs may also be delivered at low dive angles; however, the level delivery will spread the fire damage over a longer range. Since almost no damage will be done short of the bomb impact, the bomb impact should be planned to hit slightly short of the target. This will insure that some flaming napalm is spread over the target. The pattern length of the napalm is about 250 feet, so the acceptable release point error is also about 250 feet. Additionally, any vertical or horizontal dimension to the target will increase the acceptable release point error.

B. SNAKEYE BOMBS.

Delivery of the Snakeye series bombs and the M117 warhead with a retarded tail do not pose any unusual problems. Settings should be planned for an on-target impact. Since time of flight of these weapons is comparatively high, wind corrections become very important.

C. CBU.

The CBU series (except CBU-24 and CBU-29) pose some unique problems:

(1) Time of Flight. The time of flight of retarded bomblets is comparatively long, therefore, wind will affect these bombs for a longer period of time, so wind corrections must definitely be made. Also, since it is desirable to lay these bombs down in a pattern (straight line), it is usually insufficient for the pilot to drift with the wind to arrive at the proper release point. He should crab to make sure that the aircraft track across the ground is parallel to the line along which he wants the CBU to impact.

(2) Sight Depression. Like Fire Bombs, CBU's will produce very little results unless they hit the target. For this reason, sight depression should be based on a 500 or 800 foot short impact for the first bomblet in the string.

(3) Altitude. The inherent characteristics of each type of bomblet determine the proper altitude at release. An examination of fuze arming time, dud rate, etc., of BLU series bomblets will indicate the best release altitude to use.

(4) Airspeed. Airspeed is critical when dropping CBU. This is true not only from a delivery standpoint but from a dispensing standpoint. The minimum recommended airspeed is 500 knots to insure proper dispensing of the bomblets from the SUU-7/A dispenser.

(5) Spacing. Because of the long time of fall of the BLU bomblets, it is necessary for the aircraft to have a minimum of 30 seconds spacing behind an aircraft which is dispensing BLU bomblets.

5. DELIVERY TECHNIQUES.

The delivery techniques used in combat are basically the same as on a scorable range. The apparent difference is the varied approaches necessary in combat to minimize the defensive threat.

Basic techniques and a sampling of combat situation approach techniques follow.

A. BASIC TECHNIQUES.

Many elements of basic flying and professionalism apply to bombing. Preplanning and thorough knowledge of aircraft handling characteristics and switch settings is vitally important. Also, check your sight setting computations and aircraft sight system so you know they are correct and you are mentally confident that if you fly the maneuver properly, you will hit.

Enroute to your target, attain release speed if possible and trim the aircraft. Many people prefer a slight nose heavy feeling. All yaw must be trimmed out and this should be rechecked periodically throughout flight. Also adjust attitude indicator to level flight at release speed. This is more important in diving deliveries than low level, but is a good habit to establish.

The actual delivery (scorable range training) is a matter of establishing a fairly long final approach (1-2 miles) while staying slightly high to enable you to see the target and get correctly aligned. After alignment is established, slowly ease down to release altitude and attain delivery airspeed.

Depending on the time of flight of ordnance delivered and wind, either fly your body directly over the center of the target or track upwind the correct offset distance.

Keep your eyes on the target, anticipate the "pickle" as the pipper approaches the target, and maintain level flight. "Pickle" the instant you have the correct sight picture.

After release, maintain stable flight a short distance and then pull up. This is an initial training aid to prevent "climbing" before release and inducing an early sight picture.

After delivery maneuvers are practiced several times, pilots get a feel for the proper bomb range and release altitude and do well without thinking about the details mentioned above. However, the basic criteria mentioned must be achieved if a pilot is to become a consistently good bomber.

B. COMBAT APPROACHES.

Enemy defenses dictate the approach technique a pilot must use to hit accurately and survive. For instance, an attack on a target defended by SA-2's only could probably be best executed by a low level navigation/low level bomb delivery and escape.

Another example, a combination SA-2 and light AAA defense, would pose a different problem. First, initial navigation and entry would be high enough to avoid the small arms fire. The actual attack should be a letdown consisting of unpredictable turns and altitude changes until reaching a predetermined point just short of release. If everything worked out well, the pilot could stabilize a couple of seconds, get a good release, and then make an escape maneuver.

Areas not defended by sophisticated missile or radar tracking guns can be attacked using curvilinear approaches. This minimizes the effect of visually sighted small arms fire.

The combat release could be summed up by saying: if the defenses permit, stabilize early; if not, jink until just prior to release point, stabilize, pickle, and escape. Use an upwind aimpoint combined with a crab offset when necessary.

6. COMPUTATIONS.

The following steps are necessary to compute a valid low level bomb sight setting:

Determine release conditions (altitude and TAS)
Compute Zero Sight Line angle of attack
Find depression from flight path and bomb range
Determine offset aimpoint and sight depression

A discussion on determining release conditions and other factors pertinent to the low level bombing problem follows.

A. DETERMINE RELEASE CONDITIONS.

This first step in computing weapons settings is very important. The weapons officer must be familiar with the limitations of the selected weapon for weapons effects, safe separation, and fuzing. This knowledge can be applied to the tactical situation, i.e., you would like to release as low and slow as possible for accuracy, but survival in a target area is easier if you have a high airspeed. Therefore, an optimum release condition can be logically determined.

Safe separation and fuze arming time are the two factors that mechanically limit minimum release altitude. Table 6-4a in the Dash 34 gives minimum release altitudes for safe escape for GP bombs. Table 6-4b lists minimum altitude required for fuze arming. If a table is not available for fuze arming, a minimum altitude can still be computed by taking the desired fuze setting plus manufacturers tolerances (± 20% for 904), and entering the applicable weapons chart in the Dash 34. Compare time of flight figures with your computed fuze setting to determine minimum release altitudes.

B. OTHER FACTORS.

Gross weight, zero sight line angle of attack, depression, bomb range, and offset aimpoint computations will be considered in the sample problem. This paragraph will mention some other background information.

(1) Weather. Weather information is provided by a forecast facility. Release temperatures, pressure altitude and wind flow are necessary inputs to the bombing problem. Many times experience in flying in a particular area enables a pilot to make some accurate last minute changes. Also, smoke from a previous strike could reveal inversions and/or general wind direction and speed.

(2) Ballistics. Dash 34 ballistics are standard day figures. Variations from standard have little effect on low drag bombs. However, it has been proven that target altitude variations yield significant bomb range variations for high drag bombs. The F-100 Dash 34, for instance, has amended ballistics charts for Snakeye.

(3) Altimeter Technique. Another point of discussion is altimeter setting technique. Should you set 1013.2 and use pressure release altitudes, or use forecast target area pressure? Either method is correct, but using target pressure is more convenient since you can use map altitudes for terrain clearance and indicated release altitude computations.

C. SAMPLE PROBLEM.

Plan a 100 ft. AGL level attack using BLU-27/B (Finned)

Given: Desired impact - 100' short of target
Release airspeed - 450 KIAS (T.O. Flaps)
Target altitude - 900 feet
Gross weight - 21,000#
Release temp - 15° C
Release wind - 030°/10 kts

Find: True airspeed - 458
Zero sight line angle of attack - -20.5 mils
Release indicated altitude - 1275'
Sight depression from flight path - 64 mils
Bomb range - 1572 + 100 = 1672'
Sight depression - 44 mils
Upwind aimpoint - 030°/35 ft.
Cross ft per knot - 3.5
Crosswind crab offset - 0

(1) True Airspeed. Enter chart 6-4 (p. 6-20) with 450 KCAS. Project up to 1000 feet pressure altitude, across to 15° C and down to TAS (458).

(2) Zero Sight Line Angle of Attack. Enter chart 6-2a (p 6-5) with 450 KCAS. Project up to 21,000#, across to 0° dive angle, and down to angle of attack.

(3) Release Indicated Altitude. Enter chart 6-6b (p. 6-23) with 450 KIAS. Project up to 21,000# and across to the altimeter correction error of 275'. Add this to planned release altitude of 900 + 100 + 275 = 1275'.

(4) Sight Depression from Flight Path. Enter table 6-13 (p. 6-231) for 100' release at 458 TAS. Interpolate for bomb range between 440 and 460 KIAS - 1572'. Bomb time of flight equals 2.06 secs and crosswind drift is 3.5 ft per knot.

The depression from flight path listed in table 6-13 is for an impact on target. Since we want a 100' short impact, the bomb range must be changed to 1572' + 100' = 1672' and figure 6-3a (p. 6-7) used to compute depression from flight path. Enter with 1672', project up to 100' AGL and across to 64 mils.

(5) Sight Depression Setting. Algebraically add 64 mils and -20.5 mils. Final setting equals 44 mils depression.

(6) Wind Solution. Using an upwind aimpoint of 030^{o}/35 feet, you can attack from any heading. Also, because of the time of flight of this munition, you can fly your body over the target after killing drift, pickle on the upwind aimpoint, and get a hit.

PROBLEMS

LEVEL NAPALM

Given: A/C Configuration 2xBLU - 1/B + Tips
Weapon - Unfinned BLU-1/B
Impact - On target
Release altitude - 200 feet AGL
Release airspeed - 400 KIAS (T.O. Flaps)
Target altitude - 1800 feet
Gross weight - 22,000 #
Release temp - +10°C
Release wind - 090°/20

Find: True airspeed
Zero sight line angle of attack
Release indicated altitude
Sight depression from flight path
Bomb time of flight
Bomb range
Manual reticle depression
Upwind aimpoint
Cross ft per knot
Crosswind crab offset

If you plan to attack on a 360^{o} heading, what methods of determining release point could you use? Draw a simple diagram showing possible methods and your best choice.

If the wind was really 270^{o}/10, where would your bomb impact if you used the forecast aimpoint?

LEVEL CBU

GIVEN: A/C Configuration SUU-21/A + Tips
Weapon - MK-106
Impact - 500' short of target
Release altitude - 400 ft AGL
Release airspeed - 500 KIAS (no flap)
Target altitude - SEA LEVEL
Gross weight - 20,000 #
Release temp - +20° C
Release wind - 360°/15
Attack from East to West

Find: True airspeed
Zero sight line angle of attack
Release indicated altitude
Sight depression from flight path
Bomb time of flight
Bomb range
Manual reticle depression
Upwind aimpoint
Crosswind crab offset

LEVEL MK-82

Given: A/C Configuration 2xMK-82 + Tips
Weapon - MK-82 with M-904 (4 sec) Fuze
Impact - On target
Release altitude - 500' ft AGL
Release airspeed - 400 KIAS (T.O. Flaps)
Target altitude - 1000' ft
Gross weight - 21,000 #
Release temp - +25°C
Release wind - 045°/7

Find: True airspeed
Zero sight line angle of attack
Release indicated altitude
Sight depression from flight path
Bomb time of flight
Bomb range
Manual reticle depression
Upwind aimpoint

What are the safe separation and fuze arming criteria for this problem?

Would you advise making this delivery? Why?

NON-NUCLEAR WEAPONS DELIVERY

Chapter III

DIVE BOMBING

Dive Bombing is the most flexible and widely used method of conventional bombing. This flexibility is extremely useful, but its price is increased delivery difficulty. Therefore, a weapons officer's most difficult task is to help increase his units dive bombing accuracy. This chapter will consider the dive bombing problem, advantages, limitations, weapons applicable, delivery techniques, and computations.

1. GENERAL.

Visual dive bombing technically includes all angles from 1° to 90°. In most instances, dive angles of from 5° to 45° are used, although some situations exist for 60° attacks. For discussion purposes, we will classify three catagories of dive bombing:

5° - 20° Low Angle
20° - 35° Medium Angle
Over 35° High Angle

Low angle bombing is sometimes called glide bombing.

A. LOW ANGLE BOMBING.

In the previous chapter, it was inferred that delivery accuracy could be directly related to bomb slant range at release. Low angle bombing enables us to more easily acquire many targets in a combat situation and still deliver ordnance from reduced slant ranges.

The types of ordnance most suitable for low angle bombing are: fire bombs, snakeyes, and bluff nose bombs.

Low drag GP bombs can be delivered from shallow angles if weather dictates, and some pilots get very good results. However, it is more difficult to compensate for deviations from preplanned release conditions, and relatively easy to get gross error misses. If you had a choice, high drag bombs would be a better weapon in this delivery envelope.

B. MEDIUM ANGLE BOMBING.

Medium dive angles are used almost exclusively for low drag general purpose bombs. Finned fire bombs can be accurately delivered, but the effective ground pattern is generally quite small.

Medium angles are popular with many pilots, but again enemy defense posture must be considered. Also, fuze arming and safe separation altitudes must be carefully examined. It is easy to press and release below minimum arming altitude and still recover from the dive; however, dud bombs could result.

C. HIGH ANGLE BOMBING.

Most combat bombing in a non-permissive environment falls into this catagory. Aircraft survivability and relative accuracy are the main reasons this is true.

2. ADVANTAGES OF DIVE BOMBING.

The advantages discussed in this paragraph are the advantages of visual dive bombing over visual low level bombing. They are: target acquisition, survivability, and weapon flexibility.

A. TARGET ACQUISITION.

The problem of finding the target is one of the major disadvantages of the low level attack. Many times for this single, simple reason the combat pilot will be forced to use a low angle attack rather than a low level attack. This may be necessary for reasons of camouflage, concealment, or dense foliage.

B. SURVIVABILITY.

The dive attack offers a better change of survival from enemy gun defenses than does the low level attack. Dependent on the enemy gunners maximum effective range, it may be possible to recover from the delivery out of range of all enemy gun defenses.

C. WEAPONS FLEXIBILITY.

Not only is the dive attack adaptable to almost all existing weapons, but it will also provide safe escape distance, fuze arming time, and is the only delivery that provides the separation required for an airburst.

3. LIMITATIONS OF DIVE BOMBING.

Dive bomb limiting factors are critical. An unskilled pilot will have difficulty performing correctly, weather (ceiling and visability) must be considered, and the long range enemydefense threat must be analyzed.

A. ACCURACY.

Dive bombing is generally less accurate than low level bombing. Longer release slant ranges and the requirement for a higher degree of pilot skill are the reasons.

In dive bombing, the pilot has little opportunity to stabilize before release. He must judge a roll-in point that will establish the desired release angle, use an initial sight position that is pretty much of a guess, and then detect drift rate in time to make a correction if necessary. The sight picture, altitude, and airspeed are constantly changing and the pilot must estimate the correct release slant range with very limited aid from his cockpit instruments. In addition, he must be wings level and in coordinated flight for a true sight picture.

The best way to increase accuracy? Practice!

B. WEATHER.

In addition to the accuracy limitation of dive bombing, the delivery is weather limited. Generally speaking, the following ceilings are needed to obtain the indicated dive angles.

CEILING	MAX DIVE ANGLE
10,000 ft	45°
8,000 ft	40°
6,000 ft	30°
4,000 ft	20°
2,000 ft	15°
1,000 ft	5°
500 ft	0°

C. VULNERABILITY.

Dive angles and release altitudes can be selected to completely avoid small arms fire, but longer range AAA and surface to air missiles are always a threat. Although listed as a limitation to be considered, dive bombing is probably the best way to survive in a sophisticated environment (standoff weapons not considered), and approach tactics can be used to decrease the exposure time during a delivery.

4. DELIVERY TECHNIQUES.

The basic delivery techniques addressed in this course are the result of a comprehensive analysis of the trigonometry associated with a bombing maneuver. An understanding of this basic information, combined with diligent practice, develops proper habits and enhances proficiency. Then, as a pilot develops his "feel" or "eyeball", combat tactics applications become meaningful and attack variations (without significantly degraded accuracy) that increase survival probability in an unfriendly environment become practical.

A. THE FLIGHT PATH METHOD.

The Flight Path Method is designed as an instructional aid for studying ground attack. It will be used as the source of information from which basic delivery techniques are rationalized and developed, and is easily adapted to scorable range training.

A mathematical explanation, trim techniques, roll-in, final approach, wind, and some common pilot problems will be considered.

(1) The Math. For each preplanned bomb delivery, a specific point in space (release point) is defined based on bomb range, selected dive angle, true airspeed, and release altitude above ground (Figure 1).

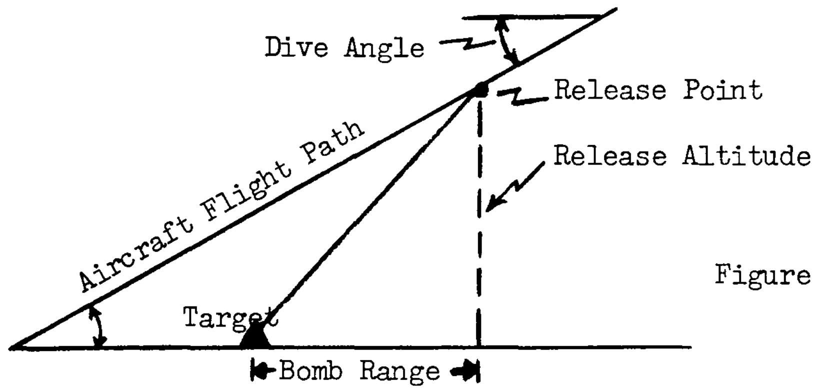
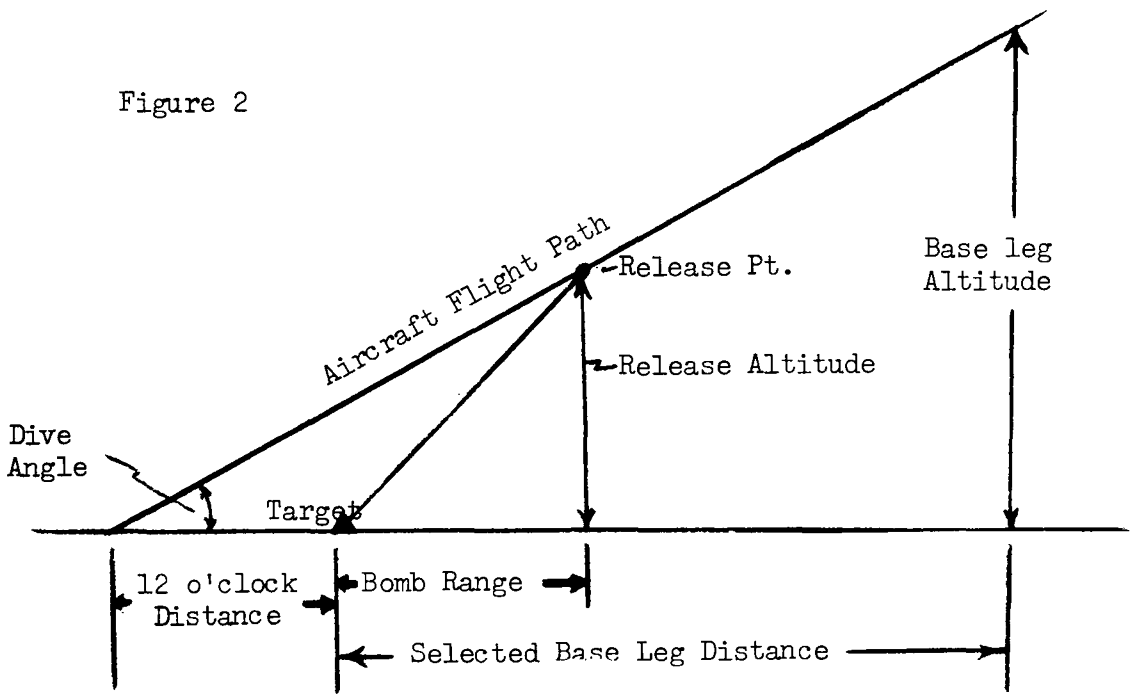


Figure 1

The obvious objective of all gunnery training is to discuss and practice techniques that will enable pilots to consistently arrive very close to this preplanned point in space with the preplanned release conditions. If this is successfully accomplished, the tracking index (pipper) will be precisely on the aimpoint at release and the ordnance impacts will be consistently accurate.

An expanded view of Figure 1 (Figure 2) serves as a study guide for base leg positioning, altitude, and roll-in technique. Note that the aircraft flight path intersects the ground at some distance 12 o'clock to the target. This distance is determined by the preplanned release criteria.

Figure 2



Also, for any selected base leg position on a controllable range, a base leg altitude can be computed that will represent an extension of the preplanned aircraft flight path.

The method for computing the point at which the aircraft flight path intersects the ground is:

$$\frac{\text{Release Altitude}}{\text{Tangent Dive Angle}} - \text{Bomb Range} = \text{Dist. 12 o'clock to tgt.}$$

The base leg altitude computation is:

(Selected base leg dist. + 12 o'clock dist.) Tan Dive Angle = Base Leg Altitude.

(2) Trim. Enroute to the target, attain release speed if possible and trim the aircraft. All yaw must be trimmed out. In addition, the delivery will be easier if release airspeed pitch trim is maintained throughout the pattern. This requires more stick pressure during roll-in, but keeps the nose from rising too rapidly as the release point is approached. Also, adjust the attitude indicator for release airspeed. This important step helps a pilot to accurately assess each pass and make corrections or release adjustments as required.

(3) Roll-in. This is undoubtedly the key to dive bombing, and is particularly important during initial training. On controlled ranges, a predetermined base leg distance and altitude enables a pilot to set himself up so he can practice "looking" at the target in proper perspective. After this proper perspective for each specific delivery is learned, he can rely on his cockpit to target reference and not need ground reference base leg points.

Roll-in airspeed varies with desired attack angles and release airspeeds, but should always be high enough for positive aircraft control. Also, it is good idea to use as high a roll-in airspeed as practical for application to a combat situation.

The lead point for roll-in depends on angle off and individual technique. Each pilot should be consciously aware of his technique and strive to be consistent. This simple point helps prevent overshoots or undershoots and enables pilots to be set up for good final approaches.

Aircraft pitch control during roll-in is a matter of flying some portion of the sight head or a flight path reference to the preplanned 12 o'clock flight path reference point. This distance can either be estimated or premarked on your home range for practice. The method of roll-in described above can be used for all dive deliveries. The only time a pilot would vary this technique is when he recognizes a deviation in base leg positioning, and either dives off excess altitude or holds his nose nearly level to generate the proper dive angle. From a training viewpoint, by the time a pilot is able to recognize base leg deviations and adjust his roll-in, his roll-in proficiency is acceptable and he is probably already scoring well.

(4) Final Approach. Initial roll out on final approach should be accomplished by using the sight head or flight path reference, with the aircraft laterally offset upwind of the upwind aimpoint. It is imperative that a pilot roll wings level to determine true aircraft offset. Pendulum effect is very noticeable in dive bombing because of the relatively large effective depression angles.

Immediate reference to the attitude indicatior is essential. If the aircraft is on the proper flight path and the dive angle is correct, the final turn was properly executed. It is important to associate the dive angle reading and correct flight path.

Figure 3 depicts the presence of an infinite number of parallel flight paths associated with each delivery. If a pilot is indicating the proper dive angle, but is not on the correct flight path, the preplanned release conditions plus an optimum sight picture can not be attained. However, if the pilot is approximately on the correct flight path, the pipper will arrive at the proper aimpoint at the proper time.

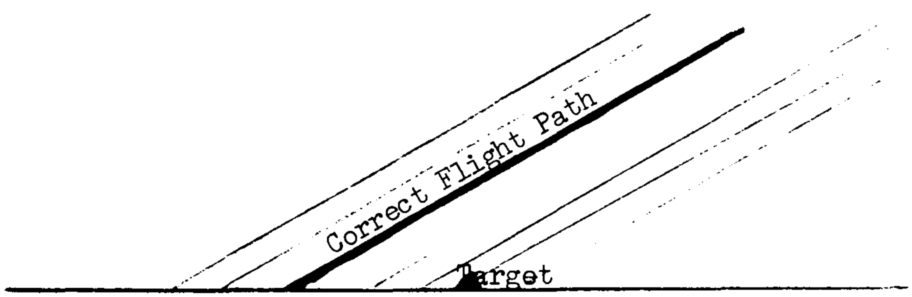


Figure 3

Many pilots prefer to generate a 5° steeper than planned dive initially, and then "fly off" the excess dive angle as the maneuver progresses. This technique is acceptable for experienced pilots doing familiar maneuvers; however, scorable range test flights with experienced pilots has shown that the flight path method speeds proficiency when new maneuvers and/or unfamiliar release criteria are used.

Speed of crosscheck is important at this point in the delivery. Immediate corrections to adjust airspeed and dive angle with power changes and rate of pipper placement give a pilot an opportunity to be very close to preplanned release conditions or be planning error compensations.

When making offset corrections, fly the sighthead, not the pipper. Pendulum effect occurs because the sight line is depressed below the aircraft's longitudinal axis. As a bank is started, the pipper initially moves opposite to direction of roll, and if you place the pipper on your desired track, it will overshoot when you roll out. Also, do not use rudder to place the pipper on the desired offset aimpoint. You will get 100% line error since free fall bombs follow the aircraft flight path at release.

The eariler a pilot can get established on final approach, the easier it is to recognize drift and deviations from preplanned release conditions. Corrections can be made as required and a few seconds will be left for tracking before release.

The term tracking may be misleading in a dive bombing discussion. It is <u>not</u> a matter of holding the pipper on a point, but rather controlling rate of pipper movement so the precise offset aimpoint is achieved at the same instant release slant range, dive angle, and airspeed are attained.

Since a pilot has difficulty looking at a precise point on the ground and his altimeter at the same time, some method must be used to inform the pilot of proper release altitude. An accepted practice in medium and high angle bombing is to compute vertical rate of descent in feet per second, cross check the altimeter until you are 1 to 2 seconds above release altitude, and then count one or two seconds and release while precisely on the desired aimpoint.

Low angle bombing yields relatively slow rates of descent. Since altitude at release is critical, a pilot can usually get better results by dividing his crosscheck between altimeter and aimpoint, and release on indicated altitude.

A typical dive bomb run can best be described in time. The pilot rolls in and assesses his initial dive angle and airspeed; he has time for one large or possibly two minor corrections to be attempted; at this time he must decide if he can accurately release on this pass; he now has time to track a few seconds, release, and start his recovery.

(5) Wind. Wind is a difficult problem in dive bombing. Ten knots of unknown wind can negate a perfect delivery and result in little damage to a pinpoint target.

Offset aimpoint is computed using release altitude wind, the assumption being that a low drag bomb will accept little wind in addition to aircraft flight path. Wind at other altitudes should be examined for shear or flow pattern and velocity.

When preplanning a mission, figure on using only ½ to 2/3 of the forecast wind. This generally results in an acceptable miss distance for the first pass. In addition, while enroute to the target area, look for indications of actual wind flow such as smoke drift, navigation errors, etc. If more than one pass is made, correct for obvious wind effect from the first bomb. Crosswind is especially noticable, but head or tailwind is usually difficult to pinpoint.

(6) Common Pilot Problems. Initial flight path placement, judging distance, coordinated flight, and error recognition are fairly common pilot problems.

If a pilot rolls out on final and places the pipper too near his offset aimpoint, he will probably end up in a "bunt". This requires forward stick pressure and makes tracking difficult. It is best avoided by starting the pipper short of the target.

Judging distance depends very much on pilot proficiency and experience. A controlled range is usually no problem because footage markers are available. In combat situations, however, errors are easily made. Different dive angle approaches and terrain slope induce errors of judgment.

Coordinated flight can be a problem. It is natural for a pilot to place his aircraft where he wants it with rudder. The best advice for this common problem is to consciously think about coordinated flight and possibly consider removing your feet from the rudder pedals on the final portion of a delivery to see if the pipper "jumps".

Error recognition is a constant and difficult problem. Perfect dive bomb passes are seldom flown, but some pilots are better at recognizing deviations and correcting than others. You must develop a technique that allows assessment of a run before release and make pipper offset corrections based on error analysis knowledge. Another possibility that should be considered is not releasing if the situation permits and try a better delivery the next time.

B. COMBAT TECHNIQUES.

Combat techniques require an increased skill level. The target area approach is dictated by the enemy defenses and could be low, medium, or high altitude.

The low and medium altitude approaches require a climbing and turning maneuver to the roll-in point while the high altitude attack could be a descending turn to roll-in or a high altitude roll-in using a steep dive angle.

Final approach technique will also be modified in most combat situations. Flight members will usually attack from varying headings and may use a curvilinear approach until just short of the release point. At the time, roll wings level, release, and begin an immediate pull out. A wings level pull out will get you out of small arms more quickly, but in dense AAA fire, unpredictable turns during recovery will increase probability of survival.

5. COMPUTATIONS.

The following steps are necessary to compute a valid dive bomb setting:

Determine release conditions (dive angle, altitude and TAS).
Compute Zero Sight Line Angle of Attack.
Find Depression from flight path and bomb range.
Compute release indicated altitude.
Compute offset aimpoint and sight depression.

A discussion on determining release conditions and some Dash 34 manual chart information follows.

A. DETERMINE RELEASE CONDITIONS.

Determining release conditions contains three selectable variables: delivery airspeed, dive angle, and release altitude. It is essential that a weapons officer understand the limitations of the selected weapon for weapons effects, safe separation, and fuzing.

Selecting a delivery airspeed and dive angle depends on enemy defenses and the weapon being used. For instance, Snakeyes or napalm would probably be delivered from low dive angles to take advantage of reduced slant ranges and increase accuracy. Conversely, a heavily defended target would probably be attacked with general purpose low drag bombs from a 45° or higher dive angle. In all situations, it is a good idea to compute more than one delivery parameter in the event there is weather in the target area or the mission is diverted to another target.

Determining release altitude is based on the airspeed and dive angle previously selected. Factors such as desired terrain clearance, altitude loss during recovery, and recovery "G" forces must be considered. In addition, weapon limitations such as minimum impact angle and fuzing limitations must be considered. Another very important factor is safe escape from both weapons effects and possible secondary explosions from the target.

When examining fuze arming criteria, it is advisable to check dive angles on either side of the selected one to insure arming. For instance, if a pilot is 5 ° shallow and uses the indicated release altitude preplanned, will the bomb arm? These questions must be examined and planned for by the weapons officer.

B. DASH 34 MANUAL INFORMATION.

Dash 34 manual references necessary for dive bomb computations are included in the sample problem. However, a weapons officer must be familiar with the chart limitations. For instance, minimum release altitude for fuzing is just that. If a pilot uses such a parameter and presses, he will probably get a dud. Altitude loss charts provide no ground clearance, and fragmentation charts provide no margin of safety from secondary explosions.

6. PROBLEM.

Plan a 3000 ft AGL 30° dive attack using an M-117 750 pound bomb.

Given: A/C Configuration 2 x M-117 + Tips
Fuze M-904 with 4 sec safe separation.
Desired impact - On target
Release airspeed - 450 KIAS (T.O. Flaps)
Target altitude - SEA LEVEL
Gross weight - 22,000 #
Release temperature - +10° C
Release wind - 090°/12

Find: True airspeed
Zero Sight Line Angle of Attack
Release indicated altitude
Sight depression from flight path
Bomb range
Sight depression
Upwind aimpoint

NON-NUCLEAR WEAPONS DELIVERY

Chapter IV

BUNT BOMBING

Bunt bombing is a technique employed to enter low angle dive bomb deliveries under low ceilings, and also a technique that can be used during normal dive bomb delivery. The objective is to generate desired released conditions by placing the pipper very close to the desired release aimpoint and let the aircraft "G" load reduce and dive angle increase as the maneuver progresses. Bunt bombing will be discussed from a level entry and from a dive entry. In each case, a desired release "G" of 0.5 will be assumed.

Bunt bombing is a specialized application of ordnance delivery developed to keep improve hard bomb accuracy. It should not be considered for delivering high drag weapons, napalm, or other ordnance that is optimized for accuracy at relatively short slant ranges.

1. LEVEL ENTRY BUNT BOMBING.

The computations for bunt bombing from a level entry are straightforward. That is, a dive angle (usually 10°), release airspeed, and release altitude are selected to insure safe separation and bomb arming.

The sight setting is computed from the Dash 34 manual. Since experience has shown that most pilots arrive at a release "G" of 0.4 to 0.6 when bunting, a 0.5 "G" release angle of attack (60° dive) is used in the computation.

The approach to a target is planned that puts the aircraft about 800 feet above release altitude, straight and level, and at an airspeed approximately 40 knots below desired release airspeed.

As the target passes under the pitot boom of an F-104, forward stick pressure and trim are applied to place the pipper upwind and directly abeam the target. Holding the pipper on this abeam line induces a bunt. As release altitude and airspeed approach, the "G" load on the aircraft smoothly approaches 0.5 and a 10° dive angle is established. Since altitude progression is relatively slow, the altimeter can be used to judge the precise time to release the bomb.

After release, a positive recovery should be initiated.

2. DIVE ENTRY BUNT BOMBING.

The computations for dive bunt bombing are the same as normal dive bombing with one exception. That exception is the use of a 60° dive angle of attack quantity for Zero Sight Line Angle of Attack (release "G" is function of the cosine of dive angle). This figure will be valid for a 0.5 "G" release.

The bunt pattern is similar to regular dive bombing. The technique desired is to roll out a few degrees shallow with the pipper on a line abeam the upwind aimpoint.

As the maneuver progresses, slight forward pressure and trim are required to keep the pipper from "running" toward the 12 o'clock position. The result of holding the pipper abeam the target is an increased dive angle and decreased "G" force. Desired release conditions would be the predetermined release dive angle, precomputed release indicated altitude, 0.5 "G", precomputed airspeed, and pipper placement precisely abeam the 3-9 o'clock position of the upwind aimpoint.

Pilot proficiency and preference determine whether the drifting method or bunt method is more desirable. An advantage of bunt bombing is more precise pipper aimpoint control since the pilot is concentrating on holding the pipper on a precise point.

Some possible disadvantages of the bunt delivery are the requirement for a relatively stable and wings level approach to the release point and ordnance limitations that preclude a 0.5 "G" release. While planning for a 0.5 "G" release, it can be assumed that a pilot may overshoot his bunt and get close to a zero "G" condition. If this occures, certain weapons or loading stations may not provide safe clearance from the aircraft at release.

NON-NUCLEAR WEAPONS DELIVERY

Chapter V

ROCKETS

Air-to-ground rockets can be delivered from a variety of dive angles and slant ranges. They are more accurate than bombs and contain more power than 20mm ammunition. This chapter will treat rocket firing theory, delivery techniques and computations.

1. ROCKET THEORY.

Rockets are unique when compared to bombs and 20mm ammunition. The acceleration profile, temperature effect, elements of trajectory, launcher orientation, and accuracy factors will be discussed.

A. ACCELERATION.

Sustained acceleration makes a rocket trajectory different from bombs and bullets. A bomb has only the velocity of the delivery aircraft imparted to it and gravity accelerating it toward the ground. A bullet is accelerated to its maximum velocity in the distance of barrel length, and is constantly decelerating during its time of flight. A rocket, however, is accelerated while in flight. Its initial velocity as it leaves the aircraft is extremely slow when compared to a 20mm bullet. This initial velocity is only slightly higher than the velocity of the launching aircraft, but since the rocket is accelerating and the bullet is decelerating, their velocities will be equal at some point and eventually the rocket's velocity will be greater than the bullet's. This point of equal velocity occurs at about 2000 feet, and at about 4000 feet, the rocket's velocity is much greater than the bullet's. A comparison of times of flight is given in Figure 1.

F-104 30° DIVE 400 KTAS

RELEASE ALTITUDE	ROCKETS T_f	20MM T_f	M-117 T_f
2000	1.97	1.58	4.75
2500	2.33	2.27	5.74
3000	2.73	3.12	6.67
3500	3.15	4.04	7.56
4000	3.60	5.02	8.42
4500	4.09	6.02	9.24
5000	4.61	7.06	10.03

(Figure 1)

B. TEMPERATURE.

Propellant temperature has an important effect on rocket velocity. An increase in the temperature of the propellant prior to ignition increases the burning rate, which results in an increased gas pressure within the motor. Since the rocket is propelled by gas pressure, the greater pressure causes an appreciable increase in the rocket velocity, which in turn effects the time of flight and the impact velocity. Conversely, if fired when the propellant is below the stipulated minimum, the rockets flight will be slow and erratic. Burning time for various temperatures is depicted in Figure 2.

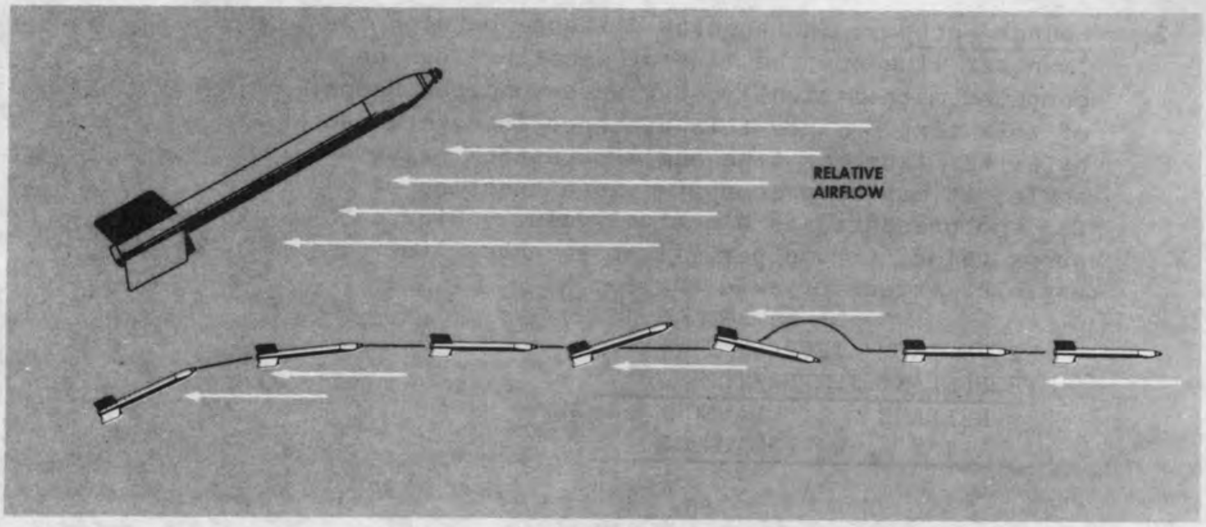
Propellant Temp, Degrees F	-50°	10°	70°	130°
Burning Time, Seconds	2.92	2.12	1.69	1.42

(Figure 2)

The Ballistic Tables in the Dash 34 manual are based on a propellant temperature of 70° F. Any deviation from this temperature will result in an impact error. This error will be quite small if only surface temperatures are considered. However, if rockets are flown at extremely high altitudes for long periods of time, the resultant cold soaking could produce quite a large error.

C. TRAJECTORY.

The rocket's trajectory is not a smooth path through the air. Rather, it is an oscillating path. This is because the rocket center of gracity is located near the front, and the center of pressure is near the rear. Air loads acting upon the rocket act upon the center of pressure, but the rocket turns or revolves around its center of gravity. As shown in Figure 3, a rocket will tend to weathervane into the relative airflow.

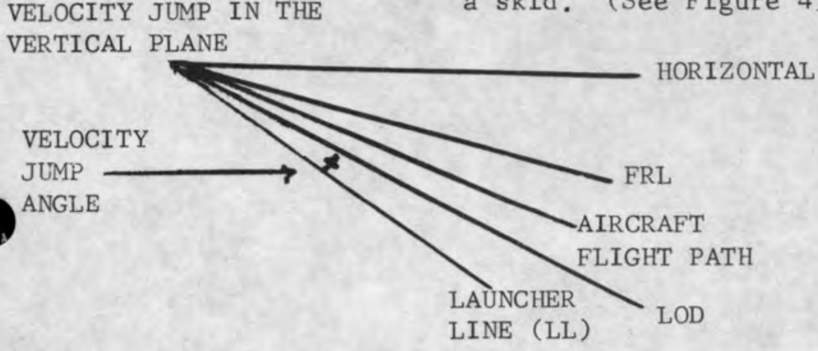


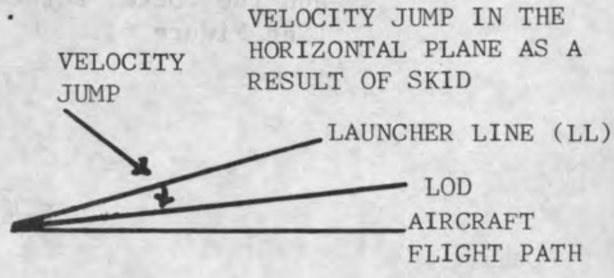
Rocket Stability

(Figure 3)

When discussing the trajectory of a 20mm projectile, two of the factors considered were gravity drop and trajectory shift. In rocket calculations, there are also two factors to be considered. These are called trajectory drop and velocity jump. For explanation purposes, trajectory drop may be likened to gravity drop and velocity jump compared to trajectory shift.

(1) Velocity Jump. The angle through which the rocket rotates due to the launcher line being at an angle to the relative wind is velocity jump. Whenever the launcher is displaced from the flight path, the rocket will leave the launcher and turn into the relative wind. The resultant path that the rocket takes is called the line of departure (LOD). Velocity jump may take place in the vertical plane as a result of either a positive or negative angle of attack, in the horizontal plane as a result of firing in a skid. (See Figure 4).





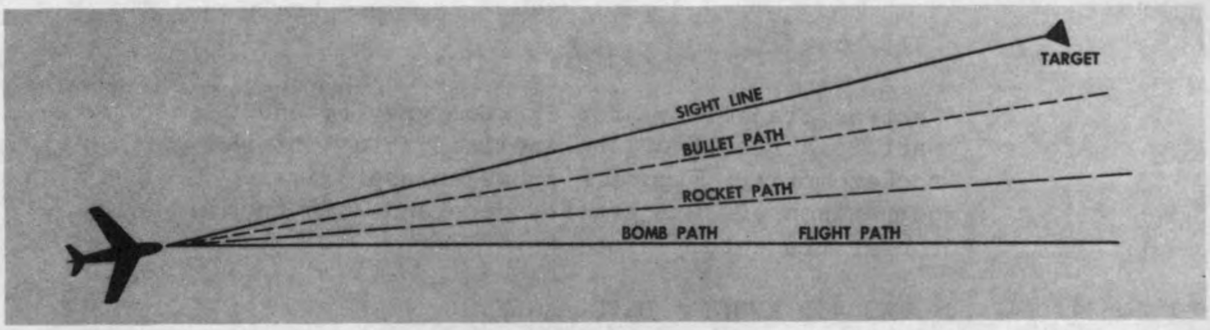
(2) Launch Factor. The angular distance between the launcher line and the line of departure can be computed mathematically, but is beyond the scope of this text. Since this distance is determined by either launcher line angle of attack or skid angle, it may be precomputed as a function of TAS and presented as a decimal value. Figure 5 shows velocity jump per mil of launcher line angle of attack or skid angle.

2.75 INCH AIRCRAFT ROCKET
PROPELLANT TEMPERATURE 70° F

RELEASE TAS	LAUNCH FACTOR (F)
350	.766
400	.793
450	.817
500	.836
550	.852
600	.865

(Figure 5)

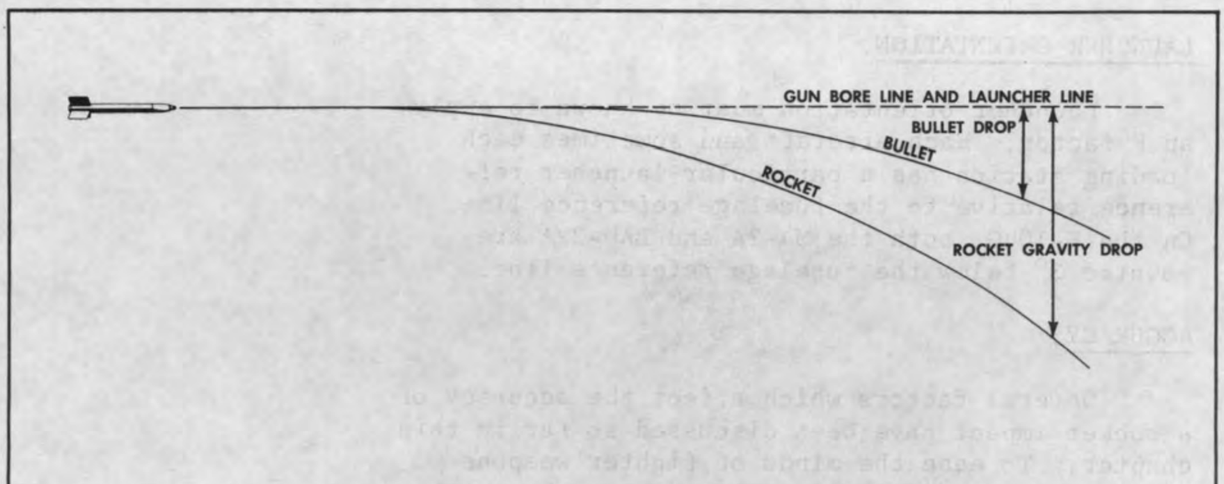
To arrive at this F Factor, such things as airspeed, propellant temperature, rocket type, launcher design, and relative air density were considered. The rocket always departs the launcher and turns toward the aircraft flight path. If the firing airspeed was 500 KTAS and the launcher angle of attack was 10 mils, the rocket's line of departure (LOD) would be 83.6% of the distance or .836 mils per mil of LL angle of attack. Thus, the LOD would be 8.36 mils from the launcher line and 1.64 mil from the flight path. Because of the low initial velocity of the rocket, its velocity jump will be greater than a 20mm projectile's trajectory shift. Comparing a bullet, a rocket, and a bomb impact when released in a skid, the bullet would hit closest to the target, the bomb farthest away, and the rocket between the bullet and the bomb. (See Figure 6).



Effects of Skid on Bullet, Rocket, and Bomb Impact

(Figure 6)

(3) Trajectory Drop. In the preceding paragraph, it was seen that because of low initial rocket velocity, velocity jump was greater than trajectory shift. Because of this low initial velocity, a rocket's trajectory drop is also greater than a bullet's gravity drop.



Comparison of Bullet and Rocket Trajectories

(Figure 7)

Since the rocket's initial trajectory is more vertical, the thrust of the motor is also more vertical and the rocket is accelerated earthward by its thrust in addition to gravity.

Part of trajectory drop is from gravity and part is a result of the inclined thrust of the rocket motor. Figure 8 shows an approximate comparison of 20mm gravity drop and 2.75 inch rocket trajectory drop.

TAS 400 KNOTS - DIVE ANGLE 0°

RANGE FEET	20MM GRAVITY DROP INCHES	2.75 INCH ROCKET TRAJECTORY DROP INCHES
600	6	78
1200	28	245
1800	68	454
2400	128	663
3000	216	936
3600	338	1167

(Figure 8)

D. LAUNCHER ORIENTATION.

Launcher orientation must be known to apply an F factor. Each aircraft and sometimes each loading station has a particular launcher reference relative to the fuselage reference line. On the F-104G, both the MA-2A and LAU-3/A are mounted 3° below the fuselage reference line.

E. ACCURACY.

Several factors which affect the accuracy of a rocket impact have been discussed so far in this chapter. To ease the minds of fighter weapons instructors, the following factors have been taken into consideration in the ballistic tables in the Dash 34 manual: Rocket acceleration, change of mass, velocity jump, trajectory drop, launcher line orientation, and parallax correction. The ballistic tables are based on a 70° propellant temperature and no correction is applied for temperature variation. Although pilots should be aware of the effect of propellant temperature variations, they should not attempt to aggravate the problem by flying at high altitudes for long periods of time. There are two factors which are not considered in the ballistic tables of the Dash 34 manual with which the weapons officer should be familiar. These are dispersion and rocket launcher alignment.

(1) Dispersion. The mean dispersion of individually fired rockets is approximately 7.5 mils. Damage to fins and other superficial parts of the rocket can cause dispersion to increase greatly. Dispersion of undamaged rockets is caused primarily by thrust misalignment and variations in the propellant temperature. These factors frequently result in a misalignment between the direction of thrust and the rocket's longitudinal axis. When fired from podded launchers, the dispersion increases to 9.5 mils. This is due to two reasons: Supersonic shock wave and launcher controlled ignition. The supersonic shock wave generated by a rocket will alter the course of rockets following it. The delay between pairs of rockets from a LAU-3A is 1/100 of a second. The aircraft will have moved approximately 60 feet (over the ground) closer to the target by the time the last rocket in a pod is fired. If the 9.5 mil dispersion pattern is measured against a target perpendicular to the flight path of the aircraft, the pattern would be a circle; but if the target was horizontal and had no vertical development, the 9.5 mil dispersion would form an elipse on the ground. The dimensions of this elipse would vary by the sine of the dive angle. Assuming a constant slant range of 5000 feet from the target, the impact pattern of a pod of rockets would have the following dimemsions. (See Figure 9).

SLANT RANGE 5000 FEET
9.5 MIL DISPERSION

DIVE ANGLE	ELIPSE DIMENSIONS IN FEET
5°	95 x 1090
10°	95 x 548
15°	95 x 367
20°	95 x 278
25°	95 x 225
30°	95 x 190
35°	95 x 166
40°	95 x 148
45°	95 x 134
50°	95 x 124
55°	95 x 116
60°	95 x 109

(Figure 9)

(2) Launcher Alignment. Rocket launchers, unlike 20mm cannons are not harmonized. Instead, the lugs are tightened to a prescribed torque and the pilot presses on. Actual tests have proven that launcher lateral alignment can be varied as much as 40 mils, and elevation alignment as much as 10 mils by improper launcher torquing procedures during loading. A visual inspection of the launcher may not detect any misalignment. Also, dynamic forces in flight could cause appreciable alignment distortion resulting in increased miss distance.

2. DELIVERY TECHNIQUES.

Delivery techniques will be discussed as basic techniques and combat techniques. The goal of basic techniques is to develop proper habits and gain proficiency. Combat techniques will simply state some roll-in and tracking variations that may increase survival probability in an unfriendly environment.

A. BASIC TECHNIQUES.

As stated in previous chapters, preplanning, thorough aircraft system knowledge, accurate computations, a good ground sight check, and pilot confidence enhance success. Enroute trim procedures remain unchanged; however, roll-in, final approach, and wind corrections are slightly different and will be treated in detail.

(1) Roll-In. In rocketry, as in dive bombing, the key to a good delivery is the roll-in. Judgment of the correct roll-in point and the ability to recognize deviations quickly enough to adjust the roll-in comes with training, practice, and experience.

For initial training, a fixed base leg position enables a pilot to develop a cockpit reference that is applicable to any target (at least for that particular dive angle). The base leg airspeed should be high enough for comfortable aircraft control.

Pendulum effect is not as pronounced in rocketry as in dive bombing, but it is present. Therefore, some portion of the sighthead or a flight path reference should be used to roll-out.

The method for flight path reference point calculations is the same as that described in the dive bomb chapter. The ballistic trajectory of rockets is such that relatively little depression from flight path is required for rocketry. Therefore, the flight path reference points are closer to the target.

(2) Final Approach. Proper roll-out reference for rocketry is a combination of correct flight path reference plus dive angle. A cross check of the attitude indicator immediately enables a pilot to make a judgment of his roll-in technique, but more important, enables him to assess his pass and make corrections and to plan error compensation.

Pipper movement is much slower in rocketry than in dive bombing, and can be controlled much more easily. In fact, since the effective depression angle is small, the pipper may actually appear to "back up" as airspeed increases and the angle of attack decreases. Also, the pipper should initially be placed upwind if the upwind aimpoint and drift controlled with small rapid banks, if required.

As release attitude is approached, a pilot should concentrate on precisedly tracking the aimpoint. Remember, rockets are aimed and fired, while bombs are released from a position in space.

If release conditions are not being met, decide immediately if you can adjust the aimpoint with a reasonable degree of confidence or go through dry. After firing, initiate your recovery immediately.

(3) Wind. Wind presents a problem in rocketry, although the relatively short time of flight makes offsets much less than for dive bombing.

If the winds being used are forecast, offset for ½ to 2/3 of the predicted wind velocity. Drift is fairly easy to pinpoint, but head and tail wind factors are difficult to judge. When firing pods of rockets, it is good to remember the size and shape of the impact pattern. It would be wise to release with a pure head or tailwind, if possible to minimize the probability of missing laterally. Rudder application gives approximately 80% line error and is not effective for killing drift.

B. COMBAT TECHNIQUES.

Combat techniques vary from basic training techniques only in the manner of approach, tracking time allowed, and recovery.

A turning approach to roll-in (to include climbing or descending) while maintaining a high energy level enables a pilot to react to defenses and still make his desired attack.

Curvilinear approaches with varying headings complicate defenses against flight attacks. However, still roll-out just prior to release, track momentarily, and fire. Recover immediately using turns as necessary.

3. COMPUTATIONS.

The following steps are necessary to compute a valid rocket setting:

Determine release conditions (dive angle, altitude and TAS).
Compute Zero Sight Line Angle of Attack.
Compute release indicated altitude.
Find sight setting.
Find crosswind correction.

A discussion on determing release conditions and some Dash 34 manual information follows.

A. DETERMINE RELEASE CONDITIONS.

Determining release conditions contains three selectable variables: delivery airspeed, dive angle, and release altitude. A weapons officer must understand the capabilities and limitations of rockets to insure desired weapons effects as well as safe delivery parameters.

(1) Delivery Airspeed. Delivery airspeed is usually a matter of combat conditions. For the F-104, 400 KIAS is a reasonable minimum airspeed, and 560 true airspeed TAS is the rocket table upper limit.

(2) Dive Angle. In dive bombing, dive angle was considered mostly from the viewpoint of survivability and ease of delivery. In rocketry, another important consideration appears - weapons effects. As mentioned in the paragraph on accuracy, the pattern of pod launched rockets is an ellipse whose range axis varies with dive angle. Considering the 9.5 mil dispersion cone, the area (A) of an ellipse can be computed if slant range and dive angle are known: $A = (\frac{1}{2}X)\ (\frac{1}{2}Y)$.

Using the formula above, the density of rockets or square feet per rocket can easily be computed and compared with the desired weapons effects. Density is more dependent on dive angle than number of pods fired or slant range up to about 30° of dive.

The final choice of dive angle will be based on weather, enemy defenses, and the weapons officer's calculation of pattern size necessary to destroy a given target.

(3) Release Altitude. Release altitude determination is very important to insure adequate safe separation and aircraft recovery. Also, enemy defenses, weather expected, type of terrain, and possible secondary explosion effects must be accounted for.

As in dive bombing, deviations from planned flight path must be examined. For instance, using Table 6-4c of the Dash 34 manual, if a 25° dive angle were selected for a 440 KTAS attack, 1500 feet would be needed to avoid fragmentation damage. If a pilot attacked using a 30° dive angle and released on his 25° selected altitude, he would be 200 feet below the safe recovery altitude for 30°.

It is a good idea to build in a reasonable buffer or safety margin when planning attacks for a combat situation. Also, a weapons officer should brief the parameters of his selected settings so pilots can make accurate judgments during delivery.

B. DASH 34 MANUAL INFORMATION.

Ballistics information in the Dash 34 manual is presented in an easily usable format. Table 6-4c lists safe escape data, and the rocket sight setting tables list sight settings as a function of zero sight line angle of attack. Also, slant range and wind correction figures are provided.

ROCKET PROBLEM

Given: Warhead M-151
Rocket Launcher-LAU-3/A
Dive Angle-30°
Release Altitude-1500 Feet AGL
Release Airspeed-400 KIAS (T.O. Flaps)
Target Altitude-SEA LEVEL
Gross Weight-20,000 #
Release Temp +5° C
Wind-290/15

Find: TAS
ZSL Angle of Attack
Sight Setting
Slant Range
Upwind Aimpoint
"F" Factor

Do these conditions give adequate safe separation?

What would be the error resulting from a 1° right SKID?

NON-NUCLEAR WEAPONS DELIVERY

Chapter VI

STRAFE

The gun is the basic weapon of tactical fighter aircraft. It is versatile, accurate, can concentrate firepower, and is conveniently installed inside the F-104. This chapter will treat strafing theory, both low and high angle strafe techniques, wind effects, and computations.

1. THEORY.

A 20mm projectile ballistics profile differs from bombs and rockets in that a 20mm round attains its maximum velocity as it leaves the gun. This results in relatively small trajectory shift angles and enables a pilot to hold the pipper on a target with rudder and get a concentrated and accurate burst of firepower. A discussion of projectile velocity, gravity drop, trajectory shift, and bullet density patterns follows.

A. VELOCITY.

The 20mm projectile's initial velocity is the sum of aircraft velocity and muzzle velocity. The aircraft velocity component is simply true airspeed times 1.69 feet per knot second.

The average muzzle velocity for the M-61 Cannon, when firing the 20mm HEI M56 E2 cartridges, has been calculated to be 3295 feet/second. New barrel muzzle velocity at 21° C (70° F) was calculated to be 3380 feet/second; however, for fighter aircraft, where the average environmental temperature is 5° C (40° F), a loss of approximately 35 feet/second in muzzle velocity is experienced due to the temperature of the propellant. An additional loss of 50 feet/second is experienced as a result of barrel wear. For trajectory computations, the muzzle velocity for the M-61 Cannon is rounded off to 3300 feet/second.

Figure 1 shows a comparison of launch velocity and time of flight.

LAUNCH VELOCITY 400 KTAS

Time of Flight Sec	.1	.3	.5	.7	.9	1.1
Velocity Ft/Sec 10° Dive	3692	3196	2802	2473	2198	1966

(Figure 1)

An examination of Figure 1 shows that the 20mm projectile loses almost 50% of its launch velocity during the first second of flight. An interesting result of this examination and a comparison of rocket and bomb times of flight is that a strafing burst preceding rocket firing or dive bombing does not yield effective flak suppression. In some cases the rockets hit the target before the 20mm impact. The exception to the above observation is delivering napalm and high drag bombs at relatively short slant ranges.

B. GRAVITY DROP.

Gravity drop is defined as the amount of drop of a 20mm projectile (in the vertical plane) caused by the gravitational force of the earth. Gravity drop is usually measured in inches and is simply a function of time of flight. ($S = \frac{1}{2} a t^2$). Time of flight is a function of muzzle velocity and two variables: range and launch airspeed. The projectile starts decelerating the instant it leaves the barrel of the gun and gravity drop increases approximately by the "square" in proportion to range; i.e., gravity drop for 1000 feet is about 17 inches (5° dive and 400 KTAS), but for twice the range or 2000 feet, the gravity drop is about 75 inches.

Dive angle does not effect gravity drop, but the drop below the TMFBL is maximum at 0° dive and zero at 90° dive. However, dive angle does effect projectile deceleration and consequently time of flight.

C. TRAJECTORY SHIFT.

Trajectory shift is defined as the angle in the plane of symmetry swept by a projectile as its direction changes from the TMFBL toward the aircraft flight path. Trajectory shift is measured in mils from the TMFBL to the line of departure (LOD).

Examining the definition, it can be seen that trajectory shift angle is dependent on angle of attack.

The M-61 Cannon is depressed 1° 56' to partially compensate for trajectory shift. With tangential throw added in, the TMFBL is 2° 09' 56" or 37.79 mils below the fuselage reference line.

When strafing with wings level, the trajectory shift vector is vertical; but if a bank is used, the shift will be in the plane of symmetry. Trajectory shift also occurs when firing in a skid and is termed lateral trajectory shift.

The trajectory shift formula is:

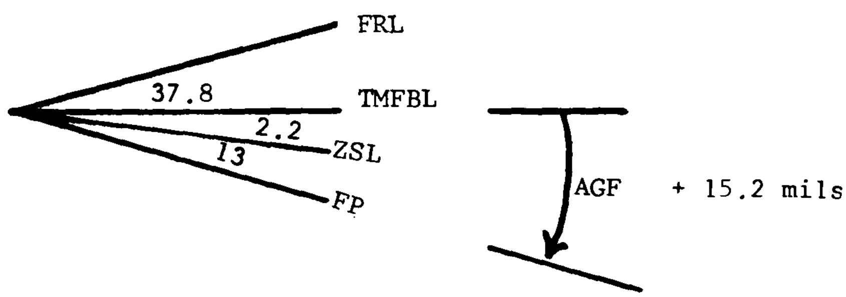
$$E = \frac{(Vf)\ (AGF)}{Vf + Vm}$$

E = Trajectory shift in mils
Vf = Velocity of the fighter (feet per second)
Vm = Muzzle velocity (feet per second)
AGF = Angle of gunfire (mils) measured from TMFBL to flight path.

Three examples of trajectory shift, illustrating positive, negative, and lateral shift follow:

(1) Positive. The conditions listed below give a positive trajectory shift value.

Gross weight - 22,000 #
True airspeed (flaps up) - 450 knots
Dive Angle - 10°

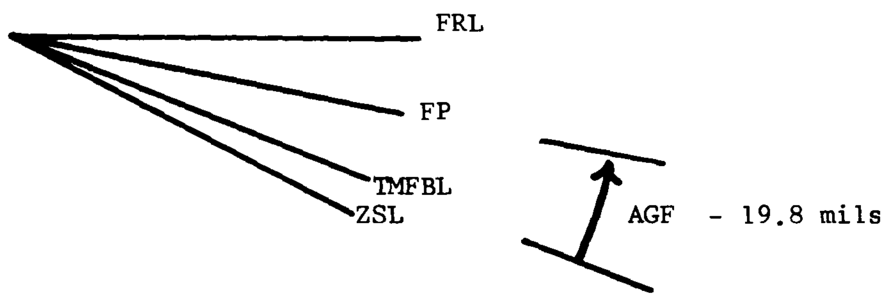


$$E = \frac{(760)\ \ (15.2)}{3300 + 760}$$

E = 2.8 mils

(2) Negative. The conditions listed below give a negative trajectory shift value.

Gross weight - 21,000 #
True airspeed (T.O. flaps) 450 knots
Dive Angle - 10°



$$E = \frac{(760)\ \ (-19.8)}{3300 + 760}$$

E = - 3.7 mils

(3) Lateral Shift. The skid conditions listed below show the effect of lateral trajectory shift.

True airspeed - 450 knots
Skid/yaw angle - 9 mils

$$E = \frac{(760)\ \ (9)}{3300 + 760}$$

E = 1.7 mils

In this example, the bullets would hit 3.4 feet from the pipper toward the flight path at 2000 feet of range. However, if the same conditions were present and the pilot did not put the pipper on the target with rudder, the bullets would impact 14.6 feet farther off the target (the entire 9 mil value is 18 feet).

D. BULLET DENSITY.

Bullet density may be defined as the number or rounds per square foot and may be directly related to bullet dispersion. A study of 20mm bullet dispersion patterns reveals that the 20mm cannon is not a precision instrument. Consequently, all projectiles fired do not hit the aiming point. This pattern is a cone, measured in mils from the gun muzzle to the circumference of a circle containing all the hits. The dispersion criteria when harmonizing an M-61 cannon are: At least 75% of the projectiles fired must hit within a 4-mil cone and 100% must hit within an 8-mil cone. It is assumed that the dispersion pattern after proper harmonization will be the same when firing against a target. As the slant range is increased, the dispersion increases and the bullet density decreases inversely proportional to the square of the range. Figure 2 depicts the bullet density for 150 rounds (75%) of a 200 round burst that can be expected to impact in a 4-mil diameter circle.

Slant Range (Ft)	2000	2500	3000	3500	4000	4500	5000	5500	6000
Impact Radius (Ft)	4	5	6	7	8	9	10	11	12
Pattern Area (Sq Ft)	50	79	113	154	200	254	314	380	450
Bullet Density (Impacts per Sq Ft)	3.0	1.9	1.3	.98	.75	.59	.48	.40	.33

(Figure 2)

It must be emphasized that the 4-mil dispersion pattern will be a circle only if the target is perpendicular to the flight path. In firing against a horizontal target, the dispersion pattern would be an ellipse with a minor axis equal to 4 mils and the major axis greater than four mils. The actual dimension of the major axis is a function of the sine of the dive angle as well as the range.

2. LOW ANGLE STRAFE.

If target defenses permit, low angle strafing is the most effective method of attack. Low angle strafe includes angles of 5° - 20° for the purpose of this discussion. Within these parameters, a minimum of preplanning is required because varying dive angle and airspeed does not affect the impact point appreciably. Proper range estimation is the most difficult problem to overcome, but practice on a controlled range provides experience.

Controlled range techniques will be discussed. The assumption is made that pop-up maneuvers, jinking attacks, or curvilinear approaches will be used in a combat situation.

A. ROLL-IN.

Attacks on controlled ranges are usually made from a base leg position approximately 10,000 feet from the target at 2000 - 2500 feet AGL. Airspeed should be about 50 knots below desired firing airspeed.

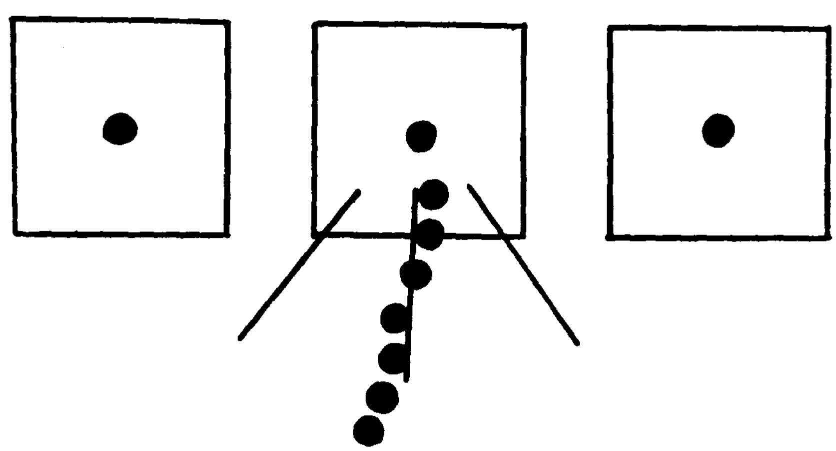
As in other deliveries, the roll-in is the key to a precise and accurate pass.

Lead the turning point enough to insure rolling out straight down the lead in line (no wind), and control the rate of nose movement to generate an initial 12 - 15° dive angle.

B. FINAL APPROACH.

Initial final approach technique is to place the pipper 200 - 300 feet short of the target while aligning the aircraft with the lead in line. Check airspeed progression and adjust power as necessary. As the aircraft progresses down final, the pipper will appear to "walk" toward the aimpoint.

If the pass is properly flown, the pipper will arrive at the aimpoint just before the aircraft reaches desired firing range (2000 - 1600 feet). Hold the pipper on the aimpoint while firing and then execute an immediate smooth 4 G wings level recovery.



(Figure 3)

Figure 3 depicts pipper movement during a nearly perfect run. If a pilot visualizes a small cone eminating from his aimpoint and controls lateral pipper movement to stay in the cone, he will avoid overcorrecting and have a smooth run.

Many pilots prefer a little nose down trim to prevent the pipper from overshooting the aimpoint with resultant forward stick force while firing. Also, if the pilot starts fine tracking a couple of hundred feet too soon, it is recommended to fire a burst rather than continue trying to track. Experience has shown that after a couple of seconds the pipper starts moving and most pilots would score better if they fired with good tracking and accepted the couple of missed rounds due to dispersion.

Another technique that aids smooth tracking is to look at the target and slowly move the pipper instead of looking at the pipper and trying to stop it on an aimpoint.

3. <u>HIGH ANGLE STRAFE</u>.

High angle strafe (20^{o} and higher) technique are similar to rocket techniques. Roll-in and initial pipper placement are the same as for rockets. Wind techniques are slightly different and will be covered later.

The major technique problem arises from the nature of the impact pattern. As a strafing burst is being fired from high angles, aircraft horizontal movement causes the pattern of impacts to form a line. The distance between adjacent impacts will not be equal since the aircraft slant range is constantly decreasing with a resulting decreased time of flight. If no attempt is made to control pipper movement during the burst (simply maintaining dive angle and airspeed), a predictable pattern will occur, but the density of impact on a pinpoint target will be relatively small.

The technique recommended to get better concentration is to bunt the aircraft as required to hold the pipper on the aimpoint. The impact pattern will still be a line, but it will decrease in length with a resulting increase in bullet density. A further refinement of this technique would be to compute a sight setting for impact on target with the first round, and then bunt the pipper toward 6 o'clock as range decreases.

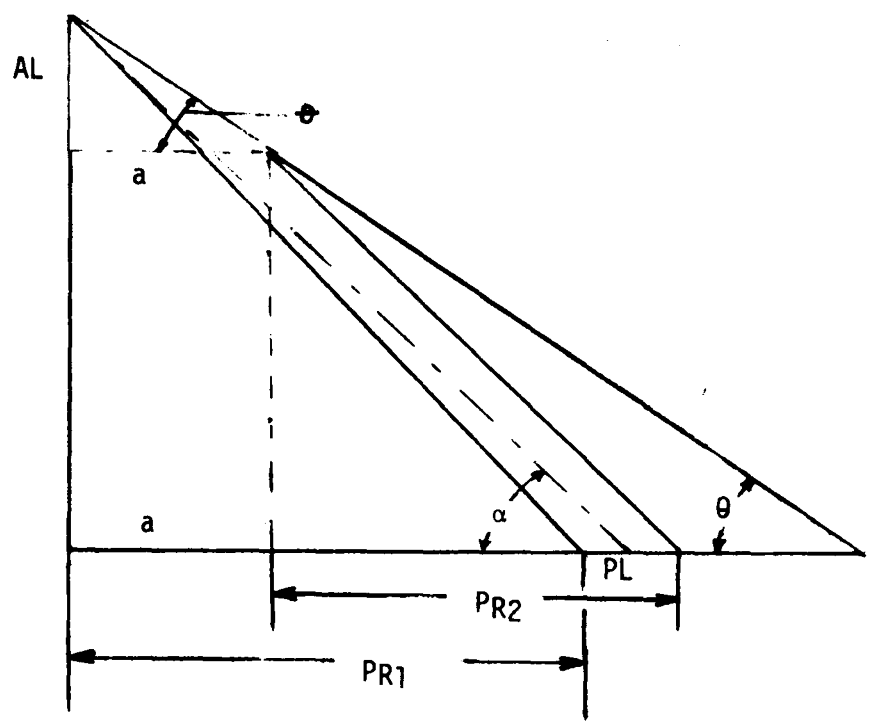
An examination of pattern length computation follows. It is based on maintaining dive angle and altitude - any bunt applied will decrease pattern length (PL) and increase density.

A. PATTERN LENGTH.

The trigonometric method for computing PL is shown in Figure 4. Determine altitude loss (AL) using the equation AL = Sin θ (Vf) (t)

~~θ~~ = Dive angle
Vf = Fighter velocity (feet per second)
t = Time of fire (secs)

Subtract AL from initial firing altitude to determine cease fire altitude.



(Figure 4)

Use Table 6-22 to find the horizontal projectile range at both open fire and cease fire. The Dash 34 manual strafe tables give the impact point for the first round for each flight condition. This makes this method of computation valid.

By inspection of Figure 4.

$$PL = (PR_2 + a) - PR_1$$

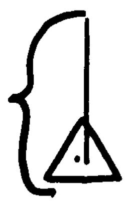
NOTE: $a = \cos \theta \, (V_f) \, (t)$

PR_1 = Horiznotal range at open fire (feet)
PR_2 = Horizontal range at cease fire (feet)
$-\theta-$ = Dive angle (degrees)
V_f = Fighter velocity (feet per second)
t = Time of firing (sec)

B. <u>ADJUSTED SIGHT SETTING</u>.

The firing pattern discussed in A would look like Figure 5.

PL

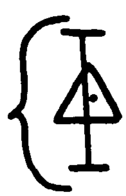


AIMPOINT ON TARGET

(Figure 5)

To insure hits on a target, a pilot could initially aim short ½ the PL distance and let the sight move through the target. Another method that could be used would be to compute an adjusted sight setting that would effectively move the pattern toward 6 o'clock. (See Figure 6).

PL



ADJUSTED SIGHT USING TARGET AS AIMPOINT

(Figure 6)

The method of computation used is to tell the sight that the initial horizontal range PR_1 is $\frac{1}{2}$ PL longer than it really is. Refering to Figure 4,

$$\tan \alpha = \frac{\text{Release Altitude AGL}}{PR_1 + \frac{1}{2} PL}$$

DFP = Depression from flight path
α = Degrees
θ = Dive Angle (degrees)

$$DFP = (\alpha - \theta) \; 17.45$$

4. WIND.

Wind effect on 20mm is similar to other ordnance. A correction into the wind (or ahead of a moving target) is a function of projectile time of flight and wind velocity. Since 20mm time of flight, trajectory shift, and depression angles are relatively small, "bank" as well as "drift/crab" methods of wind correction can be used. Low and high angle wind correction methods will be treated individually.

A. LOW ANGLE BANK CORRECTION.

The bank correction method of attack is ideal for low angle strafe. The pipper is controlled by bank and rudder so that it "walks" directly toward the aimpoint as described in a no wind condition. Bank and pendulum effect errors are present but negligible.

Aimpoint is adjusted for wind using the following formula:

$$D = (TF) \; (1.69) \; (V_w)$$

The most important part of this maneuver is to smoothly hold the pipper on the aimpoint with bank and rudder as necessary until cease fire.

B. LOW ANGLE DRIFT CORRECTION.

The drift technique is similar to dive bombing deliveries. That is, use an initial upwind offset that will allow the aircraft to drift to the proper aimpoint at firing range. This is difficult to judge and offers no advantage over the bank correction method. If the aircraft is flown in a wings level position, rudder must be applied while firing.

In strong crosswind conditions, this results in excessive rudder deflection and appreciable lateral trajectory shift.

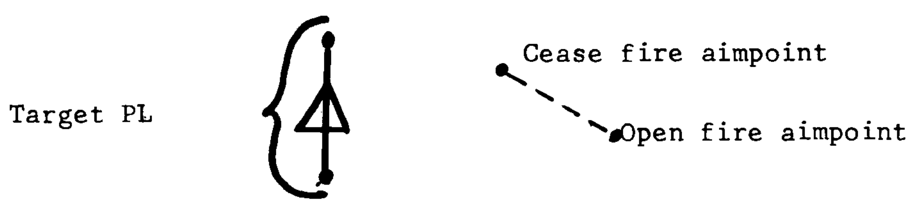
Most pilots probably use a combination of the two methods in strong crosswinds. Roll out upwind and slowly establish the proper bank angle to offset drift and then hold the pipper on the aimpoint with a combination of bank and rudder pressure.

C. HIGH ANGLE BANK CORRECTION.

This method is not recommended because the slant ranges and pendulum effect errors generate significant impact deviations.

D. HIGH ANGLE DRIFT/CRAB CORRECTION.

The high angle drift correction method is similar to rocket firing. However, an upwind aimpoint is computed for both open fire and cease fire conditions. During roll out on final approach, position the pipper upwind of the upwind aimpoint so that it arrives at the upwind aimpoint precisely at firing altitude. While firing, control rate of pipper movement so that it arrives at the cease fire aimpoint at the proper time. (See Figure 7).



(Figure 7)

The aircraft will not always drift at the same rate as desired pipper movement. In these situations, apply rudder pressure to slow apparent rate of drift.

5. COMPUTATIONS.

The following steps are necessary to compute a gun sight setting:

Determine release conditions (dive angle, altitude, and TAS).
Compute Zero Sight Line Angle of Attack.
Find sight setting
Find crosswind correction

A. DETERMINE RELEASE CONDITIONS.

Enemy defenses and the type of target will dictate what airspeed, dive angle, and release altitude should be used. The weapons officer must be completely familiar with strafe theory and ballistics to select the optimum release conditions for target destruction and safe escape.

(1) Dive Angle. Target size, terrain, and camouflage will limit the minimum dive angle usable, and enemy defenses will determine an optimum angle to survive.

(2) Length of Firing Burst. Bullet dispersion and number of hits desired in the target will determine the length of burst.

(3) Airspeed. As high as practical, consistent with accurate delivery.

(4) Release Altitude. Release altitude is dependent on terrain clearance, length of firing burst, dive angle, and recovery parameters. Most important is escape distance - both from enemy defenses and secondary explosion effects.

B. SAMPLE PROBLEM.

The following sample problem will demonstrate the use of Dash 34 manual tables and high angle strafe computation procedures.

Given: Dive Angle - 30°
Release airspeed (T.O. Flaps) - 480 KTAS
Target elevation - SEA LEVEL
Minimum recovery altitude - 1650 feet
Release wind - 360°/10
Gross weight - 21,000 #
Recovery "G" - 4
Time of burst - 2 seconds

Find: Open fire altitude - 3811 ft
Cease fire altitude - 3000 ft
Zero Sight Line Angle of Attack - -26 mils
Upwind aimpoint (open fire)
Upwind aimpoint (cease fire)
Pattern Length

(1) Cease Fire Altitude. Cease fire altitude is determined by adding altitude loss during recovery (1350 feet) to minimum altitude given (1650 feet).

Cease fire altitude = 1350 feet + 1650 ft = 3000'

(2) Altitude lost during firing (AL). Use the formula: $AL = \sin\theta\,(Vf)\,Tb$

$$AL = \sin(30^\circ)\,(480 \cdot 1.69)\,(2)$$
$$AL = (.5)\,(811.2)\,(2) = 811 \text{ feet}$$

(3) Open Fire Altitude. Open fire altitude is equal to cease fire altitude plus altitude lost during firing.

Open fire altitude = 3000' + 811' = 3811'

(4) Pattern Length. Pattern length is computed using: $PL = PR_2 + \cos\theta\,(Vf)\,(t) - PR_1$

$$PL = 4857 + 1395 - 6036$$
$$PL = 216 \text{ feet}$$

(5) Upwind Aimpoint. Upwind aimpoints for open and cease fire conditions are:

Open fire = (Tf) (1.69) (10 knots)
= (4.5) (1.69) (10) = 76 feet

Cease fire = (2.99) (1.69) (10) = 50 feet

6. PROBLEMS.

Solve the following problems:

Given: Dive angle - 10°
Release airspeed - 440 KTAS (430 KCAS)
Gross weight - 20,000 #
Slant range - 2100 feet

Find: Sight setting ________
Wind offset/knot ________

Given: Dive angle - 30°
Release airspeed (no flaps) - 450 KIAS
Minimum recovery altitude - 1500 ft AGL
Target elevation - SEA LEVEL
Gross weight - 21,000 #
Recovery "G" - 4
Release temp - +12°C
Release wind - 090/10
Attack heading - 360°

Find: Cease fire altitude ________
AL ________
Open fire altitude ________
Zero Sight Line Angle of Attack ________
Upwind aimpoint
Open Fire ________
Cease fire ________
Pattern length ________
Sight setting to put the center of PL on Tgt ________

NON-NUCLEAR WEAPONS DELIVERY

Chapter VII

RIPPLE BOMBING

This chapter provides an introduction to ripple bombing. Although the F-104 does not presently have the capability to ripple release, information on ripple bombing may be of future value to weapons officers. Theory of ripple bombing and an introduction to ripple computations follow.

1. RIPPLE THEORY.

Ripple bombing is not a new concept. Strings of bombs have been dropped by large aircraft for many years. More recently, the increased carrying capability of some fighters and the requirement to make only one pass in a sophisticated environment has generated interest in fighter ripple releases. Another important consideration for ripple bombing is the capability to deliver a string of bombs in such a manner as to increase the probability of a hit on a difficult target.

Selecting delivery parameters is a matter of adapting the aircraft equipment (i.e., timer interval capability) and release conditions to produce a desired distance between impacts. The technique of delivery is to compute a sight setting for the first desired bomb impact and then concentrate on flying a constant dive angle and airspeed. The pipper will move toward 12 o'clock from the initial release point and the bombs will string out. It may be desirable to adapt a bunt delivery technique if it is desirable to concentrate the impacts for target destruction.

2. RIPPLE FORMULAS.

The following three ripple delivery formulas are presented for information.

1. $$Ir = \frac{D\ [\cos \phi \pm (K) \sin \phi]}{V\ (1.69)\ [\cos \theta - K \sin \theta]}$$

Ir = Interval timer in seconds
D = Distance between adjacent bomb impacts
Ø = Ground slope
Θ = Delivery dive angle
K = Constant (number of feet change in bomb range per foot change in release altitude above detonation point)

2. PL = D (N-1)

Pattern Length on level terrain

D = Distance between impacts

N = Number of bombs dropped

3. $$K = \frac{(\text{Br at initial rel alt ADP}) - [\text{Br at (Initial rel alt ADP} - F]}{F}$$

K = Number of feet change in bomb range per foot change in altitude above detonation point.

Br = Bomb range (ft).

ADP = Above detonation point

F = Minimum difference between listed release altitudes in Dash 34.

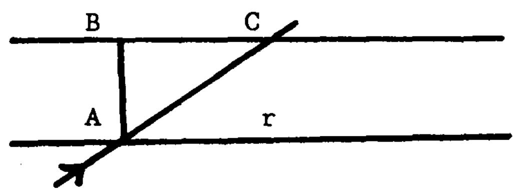
Formula one looks complicated at first glance, but is really easy to understand if the target is considered level. For instance, if $\emptyset$ is 0°, the quantity $[\cos \emptyset \pm (K) \sin \emptyset]$ becomes 1. Likewise, if a level delivery is made, the quantity $[\cos \Theta - (K) \sin \Theta]$ becomes 1 and the formula tells us that for a given time interval $Ir = \frac{D}{\bar{V}\,(1.69)}$ the distance between impacts depends on aircraft velocity.

Formula three is computed directly from the Dash 34. If, for example, bomb ranges and release altitudes were chosen as follows:

Alt	Rng
3500	4573
4000	5101

the constant $K = \frac{5101 - 4573}{500} = 1.057$

An additional consideration when ripple bombing is selecting an attack heading that will insure target destruction while providing a relatively safe approach.



(Figure 1)

In Figure 1, if an aircraft attacks a bridge along axis AC, the interval between bombs could be larger while still assuring destruction than if an attack was made on axis AB.

Another application of Figure 1 is to determine how many (N) hits are required to destroy a target, and then compute a minimum range dimension that must be used.

Range Dimension = (N) (D)

NON-NUCLEAR WEAPONS DELIVERY

Chapter VIII

ERROR MAGNITUDE

Error magnitude or error analysis is a study of the results of deviations from preplanned release conditions. These errors can be stated in general terms or quantitatively. This chapter demonstrates error analysis computations for various deliveries, and includes a discussion of parallax corrections and the range error formula.

1. PARALLAX.

Chapter 1 of this text briefly discussed parallax. The ballistic tables in the Dash 34 manual and the sight depression charts have taken parallax correction into consideration and provide valid sight depression from flight path information. However, the formulas used for determining error magnitude consider parallax correction changes. Therefore, a weapons officer must be able to use and explain parallax corrections.

Parallax distance is measured both horizontally and vertically from the munition to the sight. In the F-104, parallax distance varies from the centerline and wing stores. Figure 5-2 in the Dash 34 manual gives bomb range and altitude correction for parallax for wing pylon stores. The sight is 4.4 feet above the wing pylons and 25.6 feet forward. The centerline store distances are 5 feet above and 14 feet forward. The vertical parallax factor is expressed as Y parallax and horizontal as X parallax.

There is one other separation between bomb and sight - lateral separation. It is not mathematically corrected for; however, when delivering ordnance from short slant ranges, 1500 feet and less, a slight offset may be made to correct for bomb position. This correction has little consequence in the F-104; however, future German aircraft may have larger wingspans.

A. PARALLAX CORRECTION FOR ALTITUDE.

Parallax correction is the process that mathematically places the bomb at the sight head. If a level delivery is considered with a centerline bomb 50 feet above the ground, the sight is 55 feet above the ground. Considering a 90° dive, the sight would be 14 feet below the bomb. At intermediate dive angles, the sight is some resultant distance (a portion of X plus a portion of Y) from the bomb. The altitude parallax correction for centerline stores is:

Altitude parallax = 5 Cos θ - 14 Sin θ

θ = dive angles in degrees

The data for centerline store correction to release altitude is presented in Figure 1.

DIVE ANGLE	X PARALLAX FACTOR	Y PARALLAX FACTOR	CORRECTION TO RELEASE ALTITUDE
0°	0	5	5
5°	-1.22	4.98	3.8
10°	-2.43	4.92	2.5
15°	-3.62	4.83	1.2
20°	-4.79	4.7	-0.1
25°	-5.92	4.53	-1.4
30°	-7.0	4.33	-2.7
35°	-8.03	4.09	-3.9
40°	-9.00	3.83	-5.2
45°	-9.9	3.53	-6.4
50°	-10.7	3.21	-7.5
55°	-11.5	2.87	-8.6
60°	-12.1	2.5	-9.6

(Figure 1)

B. PARALLAX CORRECTION FOR RANGE.

Parallax correction for range always places the bomb aft of the sight head. The formula is:
Parallax correction for range = (14 Cos θ + 5 Sin θ)

The data for centerline store correction for range is presented in Figure 2.

DIVE ANGLE	X PARALLAX FACTOR	Y PARALLAX FACTOR	CORRECTION TO BOMB RANGE
0°	-14	0	-14
5°	-13.9	-0.4	-14.3
10°	-13.8	-0.9	-14.7
15°	-13.5	-1.3	-14.8
20°	-13.2	-1.7	-14.9
25°	-12.7	-2.1	-14.8
30°	-12.1	-2.5	-14.6
35°	-11.5	-2.9	-14.4
40°	-10.7	-3.2	-13.9
45°	-9.9	-3.5	-13.4
50°	-9.0	-3.8	-12.8
55°	-8.0	-4.1	-12.1
60°	-7.0	-4.3	-11.3

(Figure 2)

2. RANGE ERRORS.

The formula for range errors determines miss distance for ordnance released at other than planned conditions. The formula assumes that the preplanned sight depression was used and that the pipper was on target at release. It may be used to compute individual deviations or any combination of dive angle, airspeed, and altitude variations at release. Care must be exercised when treating positive and negative signs in the formula because positive values indicate long errors while negative values are short errors.

From page 4-10 in the Dash 34 manual, the range error formula is:

$$A = R_p - Y_p \cot \left[\theta + \frac{\phi - \alpha A + \alpha P}{17.45} \right]$$

R_p = New bomb range corrected for parallax and range correction if used.

Y_p = New sight head altitude corrected for parallax.

θ = Dive angle in degrees

Examining $\frac{\phi - \alpha A + \alpha P}{17.45}$ we can see that ϕ (depression from flight path) + αP (preplanned angle of attack) is actually the sight setting in mils. Therefore, if we substitute SD and use the new ZSL angle of attack, the formula becomes:

$$A = R_p - Y_p \cot \left[\theta + \frac{SD - ZSL\alpha}{17.45} \right]$$

where ZSL α equals the new conditions of release. The preceding formula can be used with bombs, rockets, and high angle strafe.

3. LOW LEVEL BOMB ERRORS.

The following sample problem demonstrates low level bombing error analysis.

Sample Problem:

Munition	MK-106 (SUU-21/A)
Impact	100 feet short of target
Release IAS	400 KIAS (w/T.O. Flaps)
Release altitude	50 feet AGL
Dive angle	0^o
Gross weight	21,000 #

Release temperature	$+5^{o}$ C
Target altitude	1000 feet
Wind	Calm
TAS	400 KIAS
ZSL Angle of Attack	-10.5 mils
Depression from flight path	70.5
Sight depression	60 mils

A. <u>RELEASE AIRSPEED ERRORS</u>.

Using the preceding sample problem and the formula $A = Rp - Yp \cot \left[\theta + \frac{SD - ZSL}{17.45} \right]$ a release airspeed of 380 KIAS would result in a miss distance of:

$$A = 665 - 14 + 100) - (50+5) \cot \left[0^{o} + \frac{60 - (-4.5)}{17.45} \right]$$

$$= 751 - 55 \cot \left[\theta^{o} + \frac{64.5}{17.45} \right]$$

$$= 751 - 55 \cot 3.69^{o}$$

$$= 751 - 853$$

= 102 feet <u>short</u>

A release airspeed of 420 KIAS would yield the following error:

$$A = (722 - 14 + 100) - (50+5) \cot \left[0^{o} + \frac{60 - (-15)}{17.45} \right]$$

$$= 808 - 55 \cot 4.3^{o}$$

$$= 808 - 55\ (13.3)$$

$$= 808 - 732$$

= 76 feet <u>long</u>

B. RELEASE ALTITUDE ERRORS.

Using the sample problem criteria, the following release altitude errors occur:

A release 10 feet lower than planned or 40 feet AGL:

$$A = (615 - 14 + 100) - (40+5) \cot \left[0^\circ + \frac{60 - (-10.5)}{17.45}\right]$$

$$= 701 - 45 \cot 4.04^\circ$$

$$= 701 - 45\ (14.16)$$

$$= 701 - 637$$

= 64 feet long

A release 10 feet higher than planned or 60 feet AGL:

$$A = (762 - 14 + 100) - (60 + 5) \cot 4.04^\circ$$

$$= 848 - 65\ (14.16)$$

$$= 848 - 921$$

= 73 feet <u>short</u>

C. CLIMB/DIVE ERRORS.

Using the sample problem criteria, the following dive angle errors occur:

1° dive

$$A = (609 - 14 + 100) - (50 + 4.75) \cot \left[1^\circ + \frac{60- (-10)}{17.45}\right]$$

$$= 695 - 54.75 \cot 5.02^\circ$$

$$= 695 - 54.75\ (11.38)$$

$$= 695 - 623$$

= 72 feet <u>long</u>

1^{o} climb

$$A = (786 - 14 + 100) - (50 + 5.24) \cot \left[-1^{o} + \frac{60 - (-10.5)}{17.45}\right]$$

$$= 872 - 55.2 \cot 3.04^{o}$$

$$= 872 - 55.2\ (18.83)$$

$$= 872 - 1040$$

= 168 feet <u>short</u>

In the above solutions, bomb ranges were extracted from MK-106 error analysis tables, and 1^{o} parallax corrections were disregarded.

D. LOW LEVEL BOMB ANALYSIS.

A comparison of the errors computed in paragraphs A through C yields these facts:

1. For airspeed errors of the same magnitude, a slow airseed will produce an error greater than a fast airspeed.

2. A high release will produce a larger error than a low release.

3. A climb produces much larger errors than a dive.

Release errors for the preceding sample problem are listed in chart form in Figure 3.

RELEASE ERROR	IMPACT ERROR
20 Knots Slow	102 Feet Short
20 Knots Fast	76 Feet Long
10 Feet Low	64 Feet Long
10 Feet High	73 Feet Short
20 Feet High	154 Feet Short
1^{o} Climb	168 Feet Short
2^{o} Climb	639 Feet Short
1^{o} Dive	72 Feet Long
2^{o} Dive	105 Feet Long

(Figure 3)

4. DIVE BOMB ERRORS.

The following sample problem demonstrates dive bomb error analysis:

Munition	BDU-33A/B
Impact	On target
Release airspeed	400 KIAS (w/T.O. Flaps)
Release altitude	3000 feet AGL
Release dive angle	30°
Gross weight	21,000 #
Release temperature	+7°
Target altitude	1000 feet
Wind	Calm

TAS	420
ZSL Angle of Attack	-18
Depression from flight path	143 mils
Sight setting	125

A. RELEASE AIRSPEED ERRORS.

Using the sample problem criteria in paragraph 4 and the range error formula, a release airspeed of 380 KIAS will result in a miss distance of:

$$A = (3750 - 14.6) - (3000 - 2.7) \cot \left[30^\circ + \frac{125 - (-13)}{17.45}\right]$$

$$= 3735.4 - 2997.3 \cot 37.91^\circ$$

$$= 3735.4 - 2997.3\ (1.284)$$

$$= 3735.4 - 3845$$

$$= -110$$

= 110 Feet short

The bomb range is corrected for parallax, and the new angle of attack of the ZSL is -13 mils.

A release airspeed of 420 KIAS will result in the following miss distance:

$$A = (3895 - 14.6) - (3000 - 2.7) \cot \left[30^\circ + \frac{125 - (-22)}{17.45}\right]$$

$$= 3880.4 - 2997.3 \cot 38.43^\circ$$

$$= 3880.4 - 2997.3\ (1.260)$$

$$= 3880.4 - 3770$$

= 110 feet long

B. RELEASE ALTITUDE ERRORS.

Using the sample problem criteria, a release altitude error of 500 feet high (all other criteria unchanged) will result in a miss distance of:

$$A = (4325 - 14.6) - (3500 - 2.7) \cot \left[30^\circ + \frac{125 - (-18)}{17.45}\right]$$

$$= 4310.4 - 3497.3\ (\cot 38.19^\circ)$$

$$= 4310.4 - 3497.3\ (1.271)$$

$$= 4310.4 - 4445$$

= 135 Feet short

A 500 foot low release:

$$A = (3297 - 14.6) - (2500 - 2.7) \cot \left[30^\circ + \frac{125 - (-18)}{17.45}\right]$$

$$= 3282.4 - 2497.3 \cot 38.19^\circ$$

$$= 3282.4 - 2497.3\ (1.271)$$

$$= 3282.4 - 3170$$

= 112 Feet long

C. RELEASE DIVE ANGLE ERRORS.

Using the sample problem criteria, a 5° shallow release will result in a miss of:

$$A = (4409 - 14.8) - (3000 - 1.4) \cot \left[25^{\circ} + \frac{125 - (-16.5)}{17.45} \right]$$

$$= 4394.2 - 2998.6 \cot 33.12^{\circ}$$

$$= 4394.2 - 2998.6 (1.533)$$

$$= 4394.2 - 4600$$

= 206 Feet short

A 5° steep release

$$A = (3315 - 14.4) - (3000 - 3.9) \cot \left[35^{\circ} + \frac{125 - (-20.5)}{17.45} \right]$$

$$= 3300.6 - 2996.1 \cot 43.4^{\circ}$$

$$= 3300.6 - 2996.1 (1.057)$$

$$= 3300.6 - 3162$$

= 138 Feet long

D. DIVE ANGLE ERROR ANALYSIS.

Comparing the error computations confirms the following statements:

1. A slow airspeed produces a slightly larger error than a fast airspeed.

2. A high release produces a slightly larger error than a low release.

3. A shallow dive angle produces a larger error than a steep dive angle, and of all the errors, a shallow dive can produce the greatest miss distance.

Based on a 400 KIAS release 3000 feet AGL, the BDU-33 A/B dropped from a SUU-21/A dispenser yields the errors in Figure 4.

RELEASE ERROR	IMPACT ERROR
5^{o} Shallow	206 Feet Short
5^{o} Steep	138 Feet Long
20 Knots Slow	110 Feet Short
20 Knots Fast	110 Feet Long
500 Feet High	135 Feet Short
500 Feet Low	112 Feet Long

(Figure 4)

5. HIGH ANGLE STRAFE EXAMPLE.

A short sample problem identifies high angle strafe computation procedures.

Munition	20mm from M-61 gun
Impact	On target
Firing airspeed	400 KIAS (w/T.O. Flaps)
Firing altitude	3000 feet AGL
Gross weight	21,000 #
Release temperature	5^{o} C
Wind	Calm
TAS	400 knots
Angle of Attack	-18 mils
Sight setting from Dash 34	7.5 mils

A 20 knot slow airspeed error will be:

$$A = 4952 - 3000 \cot \; 30^{o} + \frac{7.5 - (-13)}{17.45}$$

$$= 4952 - 3000 \; (\cot 31.18^{o})$$

$$= 4952 - 3000 \; (1.652)$$

$$= 4952 - 4960$$

= 8 Feet short

An examination of Dash 34 strafe charts shows that the projectile range is sensitive to ZSL angle of attack changes, and the range variations very nearly cancel out the effective sight depression changes. The sample problem shows that 20 knots gives only an 8 foot deviation.

6. ROCKET ERROR ANALYSIS.

An examination of the Dash 34 rocket tables indicates a need to interpolate rocket horizontal ranges for varying ZSL angles of attack and airspeeds. The procedure is the same as dive bomb computations, and as mentioned in the Dash 34 error analysis narrative, rocket miss distances are smaller than dive bomb miss distances for similar circumstances.

Figure 5 shows rocket error analysis for 1500 feet AGL firing, 15° dive angle, and 400 KTAS.

RELEASE ERROR	IMPACT ERROR
5° Shallow	229 Feet Short
5° Steep	31 Feet Long
20 Knots Slow	110 Feet Short
20 Knots Fast	80 Feet Long
250 Feet High	44 Feet Short
250 Feet Low	25 Feet Long

(Figure 5)

7. RELEASE "G" ERRORS.

Release "G" errors are computed exactly like other range deviations. An assumption must be made as to the effect of the release "G" on the particular pass: i.e., the release "G" for a 30° dive may be ½ G - if those criteria are used, simply substitute 60° dive angle ZSL angle of attack into the range error formula and compute the miss distance.

As in all error analysis, a deviation in release "G" was probably accompanied by a dive angle change and/or release altitude deviation. These combinations of deviations many times result in gross miss distances that are seemingly unexplainable since film assessment may show that a proper aimpoint was used.

8. BANK ANGLE ERRORS.

As an aircraft banks, the depressed pipper rolls about a point centered on the aircraft flight path. If the pipper is placed on the target while releasing in a bank, two errors will occur: one will cause the weapon to hit short, and the other will cause the weapon to hit in the direction of bank. These range and deflection errors can be computed using the following formulas.

A. RANGE/DEFLECTION ERROR FORMULAS.

$$E\ rng = Y - r \cos B$$

$$E\ def = r \sin B$$

where E rng - Range error (Ft)

E def = Deflection error (Ft)

$r\ (Ft) = Y - \frac{B}{90}(Y - X)$ = Ellipse radius interpolated between major and minor axis

B = Bank angle (Degrees)

$Y = RA \cot \theta - B_r$

$X = \frac{(DFP)\ (RA)}{1000 \sin \theta}$

RA = Release Altitude

B_r = Bomb range

θ = Dive Angle (Degrees)

DFP = Depression from flight path

NOTE THAT BOTH BANK ERROR EQUATIONS WILL NOT GIVE ACCURATE RESULTS FOR ROCKETS AND STRAFE EXCEPT FOR CONDITIONS THAT PRODUCE ZERO VELOCITY JUMP OR ZERO TRAJECTORY SHIFT.

ALSO NOTE THAT THE FORMULAS ABOVE SHOULD TECHNICALLY BE CORRECTED FOR PARALLAX. HOWEVER, THE RESULTING DEVIATIONS ARE QUITE SMALL AND PARALLAX CORRECTIONS NEED NOT BE CONSIDERED WHEN COMPUTING BANK ERRORS.

B. SAMPLE PROBLEM.

The following problem demonstrates bank error computation.

Munition	BDU-33 A/B (SUU-21/A)
Release altitude	3000 feet AGL
Release airspeed	400 KTAS
Dive angle	30°
Bomb range	3750'
Deflection from flight path	153 mils

Find the errors resulting from a 15° left bank:

$$E\ rng = Y - r \cos B$$

$$Y = RA \cot \theta - B_r$$

$$= 3000 \cot 30^{\circ} - 3750$$

$$= 3000\ (1.732) - 3750$$

$$= 5196 - 3750 = 1446'$$

$$X = \frac{(DFP)}{1000}\ \frac{(RA)}{\sin \theta}$$

$$= \frac{(153)}{1000}\ \frac{(3000)}{(.5)}$$

$$= \frac{459}{.5} = 918'$$

$$r = Y - \frac{B}{90}\ (Y - X)$$

$$= 1446 - \frac{15}{90}\ (1446 - 918)$$

$$= 1446 - \frac{1}{6}\ (528) = 1358'$$

$$E\ rng = 1446 - 1358\ (.966)$$

$$= 134'\ \text{short}$$

$$E\ def = r \sin B$$

$$= 1358\ (.259)$$

$$= 352'\ \text{left}$$

9. UNCOORDINATED FLIGHT.

Deviations in ordnance impact due to skid are dependent on the nature of the ordnance trajectory. For instance, bombs follow an aircraft's flight path at release and the skid error is 100%. However, 20mm projectiles and rockets have some resultant error due to lateral trajectory shift and velocity jump respectively.

The formula for skid error is:

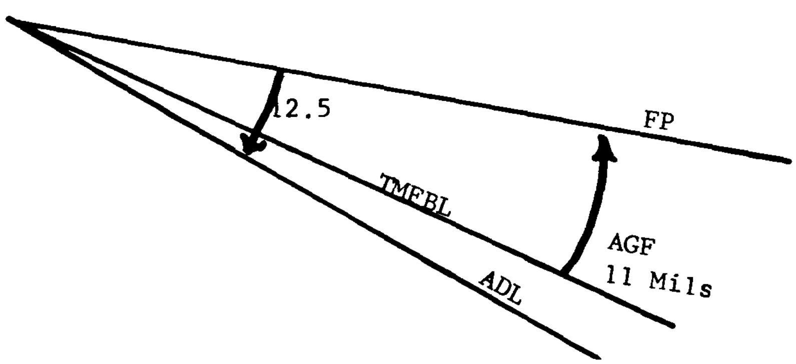
$$E = \frac{(\text{Skid})\ (\text{Slant Range})\ (\text{F. or T.})}{1000}$$

where: E = Error (ft)
Skid = Skid angle (mils)
F = F factor for rockets only
T = T factor for strafe only = $\frac{Vf}{Vf + Vm}$

10. LOW ANGLE STRAFE ERROR ANALYSIS.

The following sample problem demonstrates strafe error analysis:

Given: M-61 cannon/20mm
True airspeed - 400 knots (T.O. Flaps)
Dive angle - 10^{o}
Gross weight - 21,000 #
Temperature - $+15^{o}$ C
Altitude - SEA LEVEL
ZSL Angle of Attack - 12.5 mils
Flight Condition Diagram - See Figure 6



(Figure 6)

The trajectory shift resulting from the given flight conditions is:

$$E = \frac{Vf\ (AGF)}{Vf + Vm} \qquad E = \frac{676\ (11)}{676 + 3300} = 1.87 \text{ mils } \underline{\text{UP}}$$

Using the rule of thumb 1 mil = 1 foot @ 1000 feet, the trajectory shift portion of the low angle strafe problem can be graphically plotted. To compute the actual bullet impact point relative to the ADL, gravity drop must be applied to trajectory shift. Figure 7 depicts the graphic solution to the sample problem. Subsequent paragraphs will deal with deviations from preplanned release conditions.

A. <u>DIVE ANGLE ERROR</u>.

Varying the dive angle will change the aircraft angle of attack and result in a slight change of trajectory shift.

A 5° shallow dive angle will change the ZSL angle of attack from -12.5 mils to -11.5 mils. The new trajectory shift angle is:

$$E = \frac{676\ (10)}{676\ 3300} = 1.7 \text{ mils } \underline{\text{UP}}$$

A 5° steep approach will change the trajectory shift value to:

$$E = \frac{676\ (12)}{676\ 3300} = 2.04 \text{ mils } \underline{\text{UP}}$$

Considering no change in gravity drop, the resultant bullet impact for the above deviations at a range of 2000 feet would be:

5° shallow = 4 inches lower than planned

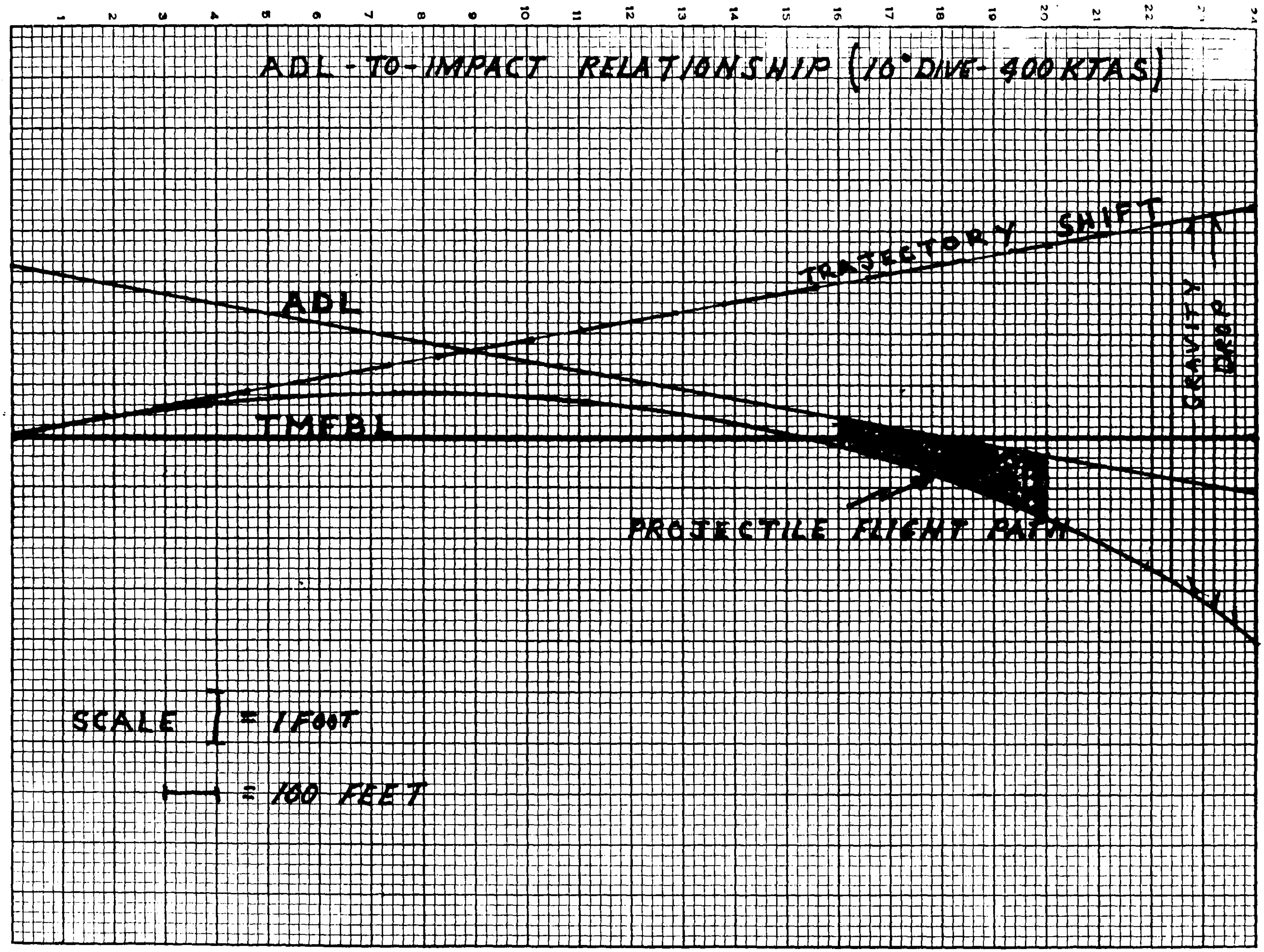
5° steep = 4 inches higher than planned

B. <u>AIRSPEED DEVIATIONS</u>.

Airspeed deviations cause a change in trajectory shift angle. A slight change in dynamic gravity drop also occurs, but is not considered because the value is only about 0.1 mil for 50 knots airspeed change.

A firing airspeed of 380 KTAS gives a ZSL angle of attack of -7 mils. The trajectory shift angle is:

$$E = \frac{(642)\ \ (5.5)}{642 + 3300} = .89 \text{ mils } \underline{\text{UP}}$$


ADL-TO-IMPACT RELATIONSHIP (16° DIVE-400 KTAS)
TRAJECTORY SHIFT
ADL
TMFBL
GRAVITY
DRAG
PROJECTILE FLIGHT PATH
SCALE = 1 FOOT
= 100 FEET

(Figure 7)

A firing airspeed of 420 KTAS gives a ZSL angle of attack of -17.5 mils. The trajectory shift angle is:

$$E = \frac{(710)\ \ (16)}{710 + 3300} = 2.84 \text{ mils } \underline{\text{UP}}$$

The resultant bullet impact points for airspeed deviations at a 2000 foot firing range are:

20 Knots Slow - 36 Inches Low

20 Knots Fast - 3 Inches High

C. SLANT RANGE.

Increased slant range increases projectile time of flight with a resultant increase in gravity drop.

In the example problem, if a pilot fires from 2900 feet, the bullets would impact about 5.6 feet below the pipper position.

D. SKID EFFECT.

Skid induces lateral trajectory shift, resulting in bullet impact some distance from the pipper toward the flight path. Assuming that one ball width displacement at 400 knots gives about 0.8 degrees of skid, the trajectory shift angle would be:

$$E = \frac{(676)\ \ (13.9)}{676\ \ \ 3300} = 2.16 \text{ mils}$$

At 2000 feet, the impact would be 4.3 feet from the pipper towards the flight path.

E. BANK EFFECT.

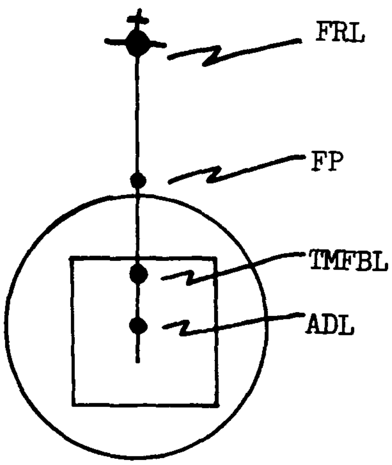
Firing in a bank produces lateral and range errors. These errors are relatively small in low angle strafe; however, they will be demonstrated since the problem solving technique is similar to one you could use on rocket analysis.

Bank effect error for strafe and rockets differs from bomb analysis because of trajectory shift. Remember, trajectory shift occurs in the plane of symmetry while gravity drop is perpendicular to the earth's surface.

The bank problem and sample problem quantities will be discussed.

(1) The Bank Error Problem. To solve a bank error problem, three factors must be considered: trajectory shift, gravity drop, and the relative positions of the TMFBL and the pipper or ADL.

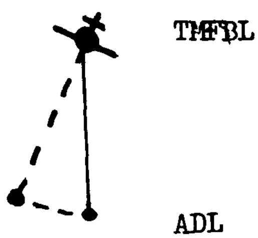
The strafe targets on ranges are constructed at a 10^{o} angle from perpendicular. The effect of this is to present a perpendicular surface if the strafe flight path is a 10^{o} dive. Assuming a 10^{o} dive approach, the relative positions of the FRL, FP, TMFBL, and ADL are shown in Figure 8.



(Figure 8)

The positions of the FRL, FP, TMFBL, and ADL remain constant. Since the pilot is assumed to place the pipper on the target, only the TMFBL and ADL positions need be considered to compute miss distance. (See Figure 9).

(Figure 9)



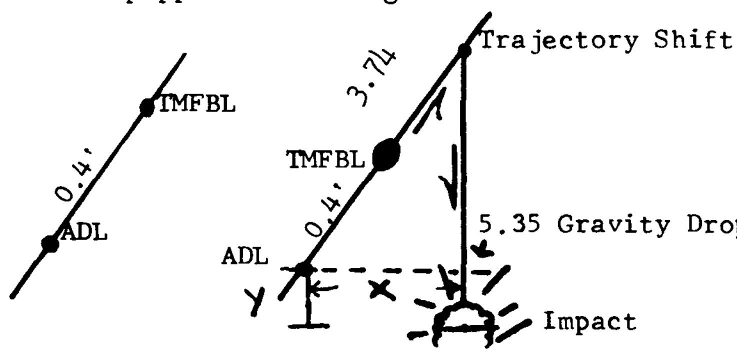
(2) Sample Computation. Assuming a 30° bank angle and a range of 2000 feet, the method of computation is:

Determine the relationship of the TMFBL and ADL for wings level flight. (See Figure 7).

Plot position of the pipper for a 30° bank angle.

Determine gravity drop and trajectory shift for sample conditions: Gravity drop equals 5.35 feet; trajectory shift equals 3.74 feet. (See Figure 7).

Plot impact of projectiles in relation to the pipper. (See Figure 10).



(Figure 10)

Lateral error = 4.14 Sin 30° = 2.07 feet right

Range error = 5.35 - 4.14 Cos 30° = 1.81 feet low

The wings level impact point for this sample would be 1.25 feet below the pipper (See Figure 7).

Applying the same method of computation for ranges of 1800 feet, 2000 feet, and 2400 feet yields the following relationships.

	1800'	2000'	2400'	
Gravity Drop	4.15'	5.35'	8.5'	
Trajectory Shift	3.35'	3.74'	4.5'	
ADL/IMFBL Relation	0	-.4'	-1.1'	
Impact relation to Pipper (30° bank)	1.67' 1.28'	2.07' 1.81'	2.8' 3.7'	In direction of bank Low
Impact point for wings level	.8'	1.25'	2.9'	Low

(Figure 11)

The following conclusions can be made:

1. As firing range increases (constant bank), the impact point moves in the direction of bank and low.

2. If bank angle is increased (constant range), the impact point moves in the direction of bank and low.

3. Strafe impact errors are small whenever bank is used to correct drift.

NON-NUCLEAR WEAPONS DELIVERY

Chapter IX

ERROR COMPENSATION

Error compensation is the application of error analysis information to the attack situation before release. Aimpoint adjustment and altitude adjustment are two methods of error compensation. This chapter will discuss these two methods of error compensation plus important facts that must be considered when making adjustments.

1. ADJUSTED AIMPOINT METHOD.

To use the adjusted aimpoint method of error compensation, a pilot must recognize a deviation from preplanned release conditions plus know the error magnitude involved. He then must plan the rest of the delivery so his pipper is offset a distance equal and opposite to the expected miss distance.

As an example, if a preplanned 30° dive bomb release in fact turned out to be a 25° dive pass, an error of approximately 240 feet at 6 o'clock would occur if the pilot met all other release conditions. Knowing this error, the pilot could aim 240 feet at 12 o'clock and expect to get a reasonably accurate impact.

Two limitations to the adjusted aimpoint method are: judging distance on the ground, and tracking a point other than the target.

A. JUDGING DISTANCE.

Judging distance on the ground is difficult in a combat situation (no range circles on the targets) and the difficulty is compounded at dive angles of less than 90°. The apparent offset distance will be less than the actual distance for 6 and 12 o'clock and is portrayed by the formula: $X = Y \sin \theta$.

X = Apparent Distance
Y = Actual Distance
θ = Dive Angle

B. <u>OFFSET TRACKING</u>.

Another limitation of the adjusted aimpoint method is trying to track a point some distance off target. Depending on the degree of error in the pass, offset tracking is just like using an upwind aimpoint. However, for rather large errors (a couple of hundred feet), precise tracking may be virtually impossible. Some situations that might be good examples are: jungle, forrested terrain, or water. All these backgrounds make precise off-target tracking very difficult.

2. <u>ALTITUDE ADJUSTMENT METHOD</u>.

The altitude adjustment method is simply a matter of using the target as a tracking reference and adjusting release altitude as necessary to insure a hit. The computations for this method match depression available to the actual dive angle and airspeed attained by using Dash 34 tables. There are four steps in these computations:

1. Find ZSL angle of attack for the actual release condition and subtract this value from the preplanned sight setting.

2. Enter Dash 34 tables with depression from flight path and release conditions attained. (Dive angle and airspeed).

3. Apply altimeter errors to obtain indicated release altitude. The difference between this altitude and the preplanned is the altitude adjustment required.

4. The new release altitude must be checked for adequate fuzing and fragmentation clearance plus safe recovery.

The major advantage to this correction method is being able to use the target as the aimpoint. Also, for any given preplanned set of release conditions, some rules of thumb can be established as guides for release altitude corrections.

3. FUZE ARMING - FRAGMENTATION CLEARANCE.

Regardless of the error compensation technique used, a pilot must know the fuzing, fragmentation clearance, and recovery criteria for the preplanned delivery. If the preplanned conditions were near the minimum allowable, a pilot would know not to press his release altitude.

The altitude adjustment method appears to be the best method for compensating for errors. Although the release altitude is varied, the resultant time of flight for the selected ordnance stays practically constant, and the minimum recovery altitude is close to preplanned.

Considering the adjusted aimpoint method, it is possible to exceed minimum release criteria. If a steeper than planned dive angle is attained, the pilot may correctly release at some 6 o'clock distance; however, if he used preplanned release altitude, the bomb time of flight would be smaller and could place the aircraft in a dangerous fragmentation envelope or a dud bomb situation.

In the final analysis, the pilot who is close to his preplanned release conditions, understands fuzing and fragmentation limitations, and applies some correct error compensation will achieve better results.

NON-NUCLEAR WEAPONS DELIVERY

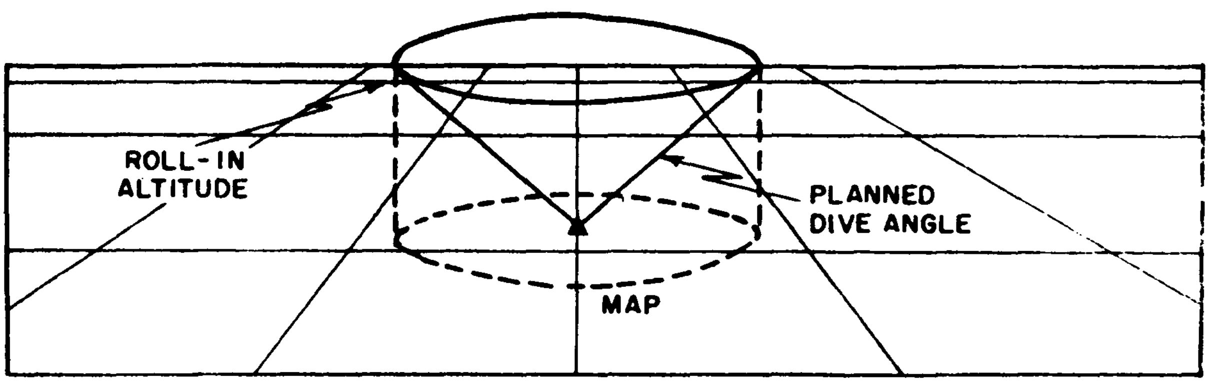
Chapter X

RANDOM MANEUVERS

Part of a fighter pilot's "full spectrum" capability is the ability to penetrate enemy defenses at low altitudes to help achieve deception and tactical surprise. Evasion of early warning radar, minimizing ground controlled intercept capability, and survival in a sophisticated SAM environment can be accomplished through low level penetration; however, maximum exposure to small arms and automatic weapons fire can be anticipated. Special situations exist where a low level approach and pop-up maneuver is the best tactic. This chapter will discuss the mechanics of pop-up maneuvers and repositioning maneuvers.

1. GENERAL.

A successful attack on a ground target, using pop-up tactics, depends on the pilot's ability to maneuver his aircraft to a precise position in space relative to the target. This position in space is determined by the type ordnance carried, the precomputed delivery conditions for the ordnance, and the maneuvering characteristics of the aircraft. In combination, these factors define an imaginary circle centered on the target, from within which the predetermined release conditions cannot be attained with final turns of 90^{o} or less. This circle is the Minimum Attack Perimeter (MAP). (See Figure 1).



(Figure 1) MINIMUM ATTACK PERIMETER

If the tactical fighter aircraft is within the Minimum Attack Perimeter, during the initial attack phase, the pilot cannot successfully accomplish his primary attack without repositioning the aircraft outside the Minimum Attack Perimeter. Two basic types of primary maneuvers, accomplished from outside the Minimum Attack Perimeter, will be discussed in this chapter with primary consideration being given to impact accuracy, safe escape from weapons effects, keeping the target in sight during the maneuver, and survivability (exposure time).

Because the vulnerability of the delivery aircraft to ground defenses increases rapidly as exposure time increases, only delivery maneuvers initiated from minimum approach altitudes are considered. Several backup maneuvers, performed from inside and outside the Minimum Attack Perimeter, will be outlined for combat use. It is recognized that there are many other possible methods of attacking a target from a low level approach; however, most of these do not meet the above criteria.

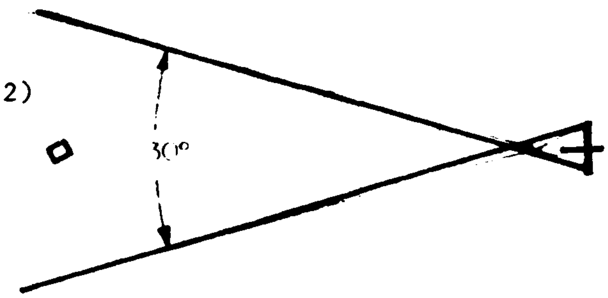
The attack maneuvers described in this chapter have been tested on a tactical range complex. In an actual combat area there will be numerous target complexes which are protected by natural terrain features and difficult approaches. Some of the maneuvers described would be difficult, if not impossible to employ in such an environment; therefore, these maneuvers must be considered basic additions to the fighter pilot's weapon delivery capability. (In the final analysis, the fighter pilot must destroy the target where he finds it and must use the tactics and delivery conditions dictated by the nature and environment of the target).

When preplanning for delivery maneuvers described herein, a major requirement is that a significant initial point (IP) and pop-up point must be selected. The IP can be any point easily recognized by aircrews. The distance from the IP to the target is not critical, but should be within 10 to 20 miles from the target. The pop-up point should be located 2 - 4½ nautical miles from the target. The distance is dependent upon the type maneuver planned. If a suitable pop-up point is not available the IP location becomes critical and should be as close to the desired pop-up point as possible to prevent a serious run-in navigation error.

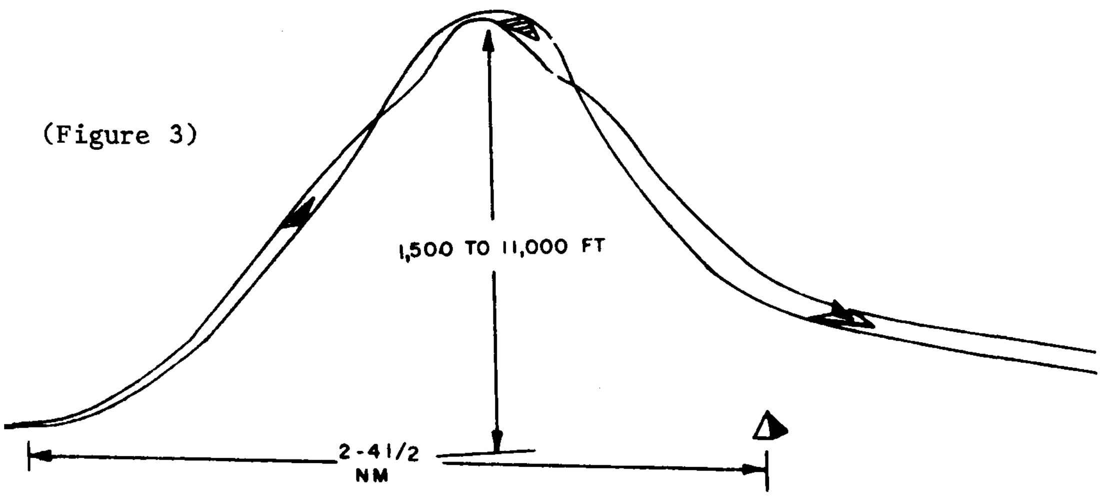
2. DIRECT POP-UP DELIVERY.

The approach to the target is on a preplanned final attack heading at minimum altitude and optimum cruise airspeed for low-level navigation. When the target or pop-up point is identified, airspeed is increased, and the aircraft is maneuvered until the target falls within a 30° cone extending from the nose of the aircraft. (See Figure 2). At a pop-up point 2 - 4½ miles short of the target, initiate a wings-level pullup. Climb to an apex altitude 500 - 1000 feet above the target elevation for low angle strafe; 1000 - 1500 feet for shallow dive angles (10 - 15°) for glide, napalm, CBU or land mind; 5000 - 7000 feet for rockets/30° glide bomb; or 9000 - 11,000 feet for high-angle dive bomb. Prior to the desired apex altitude, initiate a 180° roll to inverted flight, pull the aircraft nose through the horizon to the desired dive angle and return the aircraft to a wings level, upright attitude. (See Figure 3). Prior to expending munitions, attain the preplanned release conditions. After weapons release, withdrawal will be dictated by target environment and subsequent intentions.

(Figure 2)



(Figure 3)



DIRECT POP-UP ATTACK PARAMETERS

A. APPROACH.

Accelerate the aircraft to 420 - 480 KIAS prior to arrival at the pop-up point. The power setting used for the pop-up will depend on the entry airspeed, aircraft configuration and apex altitude necessary to establish the desired dive angle. Normally, full military power will suffice for dive angles of less than 30^{o}, while after-burner use is desirable for dive angles of 30^{o} or more. The distance from the target where pop-up is initiated varies with pilot experience and desired dive angle. Dive angles of 15^{o} or less will require pop-up from about 2 nautical miles (NM), while 3 NM are adequate for 15 - 30^{o} dives and 4 NM for dive angles above 30^{o}. The distance from the target at which the pop-up is commenced will directly affect the climb-angle required to reach the maneuver apex. As a rule-of-thumb, the climb-angle should be within $\pm$ 5^{o} of the dive angle.

B. CLIMB AND ROLL-IN.

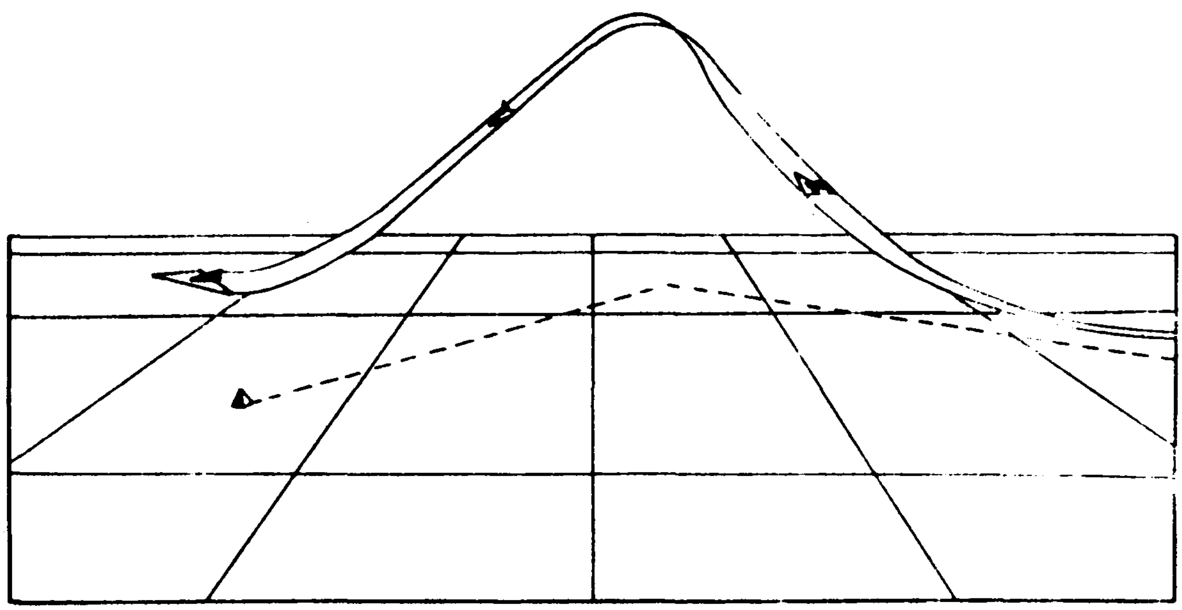
During the climb, the aircraft should be rolled to inverted flight at an altitude half-way between the desired release altitude and apex altitude. After the target is visually acquired, the nose of the aircraft is maneuvered to a point below the target where initial tracking can begin. While in an inverted position at the apex of the maneuver, corrections can be accomplished as required to achieve the desired dive angle. When properly positioned, execute the reversal to a wings-level upright attitude. Do not allow indicated airspeed at the maneuver apex to fall below 300 KIAS for any dive angle. When the final roll reversal is accomplished, standard delivery techniques and tracking should be employed to obtain the desired release conditions and sight picture.

C. DISADVANTAGE OF DIRECT POP-UP.

The major disadvantage of this maneuver is the blanking of the target by the delivery during the pop-up to reversal altitude. All reference to the target is lost at one of the most critical parts of the delivery maneuver. Consequently, adequate visual reference is not available to the pilot as an aid in accomplishing the adjustments required to attain the desired release conditions. An approach offset from the final attack heading at pullup will enable the pilot to maintain visual contact with the target throughout the approach and delivery maneuver.

3. ANGLE-OFF POP-UP DELIVERY.

In this maneuver, the preplanned pop-up point is approached at low level from 15 to 90^{o} either side of the final attack heading. The approach angle-off is varied according to delivery dive angle to permit the pilot visual contact with the target from pop-up until completion of weapon delivery. The delivery maneuver is initiated over the preplanned pop-up point at an airspeed of 420 to 480 KIAS by simultaneously selecting the desired power setting and accomplishing the pop-up to the preplanned apex altitude. Corrections are made during the maneuver in order to arrive on the final attack heading with the desired release conditions. The release conditions are attained and the recovery maneuver is accomplished in the same manner as in the direct pop-up maneuver. (See Figure 4).

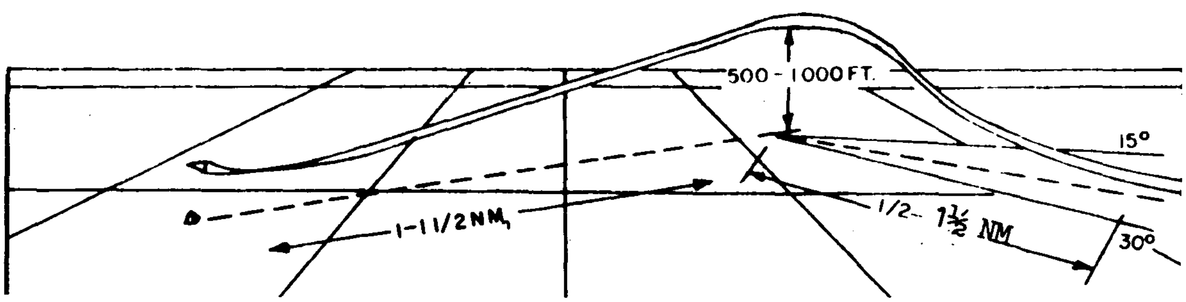


(Figure 4) ANGLE-OFF POP-UP

Although this maneuver accommodates any dive angle from 0^{o} - 60^{o} at an approach angle of 90^{o} to the final attack heading, certain approach angles and pop-up distances will result in minimum exposure time to enemy defenses, insure compatibility with the planned dive angle, and permit the pilot to easily see the target at all times. Optimum approaches are discussed in the following five paragraphs.

A. LOW-ANGLE STRAFING.

Approach the target on a run-in heading 15 - 30^{o} from the desired attack heading at 420 - 450 KIAS. Start a 2 G pop-up at a point one-half to one nautical mile from the intersection of the run-in heading and the attack heading, so as to arrive at an apex altitude of 500 - 1000 AGL, one nautical mile from the target. Select full military power upon initiating the pop-up to preserve airspeed for maneuvering. (See Figure 5).



(Figure 5) POP-UP LOW-ANGLE ATTACK

Control rate of turn at the apex to establish the desired dive angle 5 - 10^{o}. Roll out on final with the pipper practically on the target. Rate of turn and pitch change can be mose easily controlled if the roll-in is made in a partially inverted attitude. The roll-in can be "played" by floating over the top or by increasing G while partially inverted to compensate for any positioning errors. This desired firing envelope extends from a maximum slant range of 3000 feet to the minimum slant range which will provide safe escape from weapons effects and terrain. Total exposure time from pop-up to open fire is 10 - 14 seconds.

B. LOW-LEVEL BOMBING.

For low-level bombing, the apex point should be kept to 500 feet AGL or lower. A gentle pull-up is made approximately 1½ nautical miles from the Minimum Attack Perimeter, and a descent to approach is made as soon as the target is sighted. Approach speed is the same as for a strafing attack (420 - 450 KIAS).

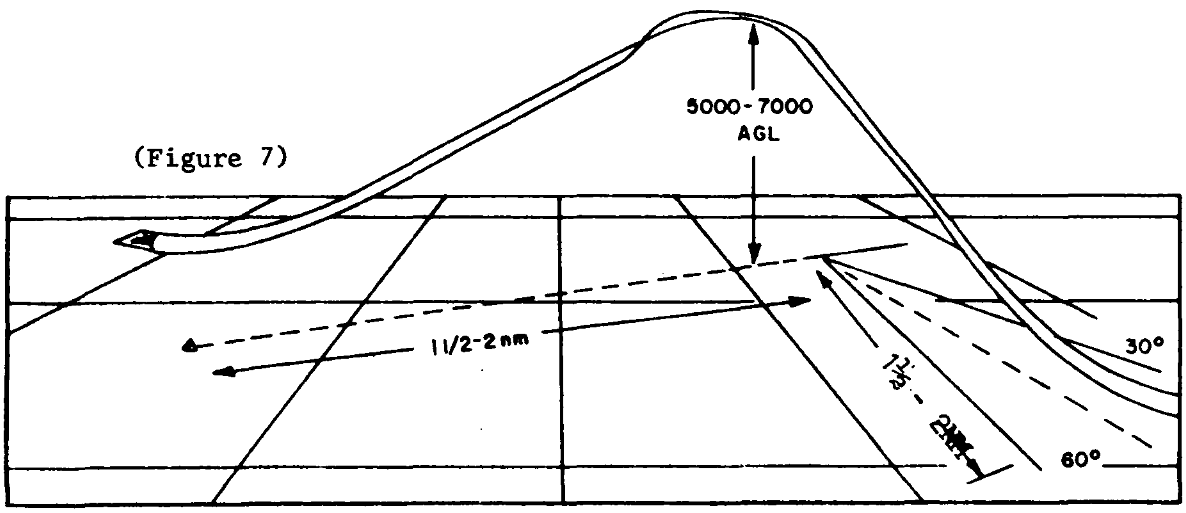
C. LOW ALTITUDE GLIDE (5 - 15°).

Low altitude glide deliveries of Snakeye or napalm should start 15 - 30° from the desired attack heading. Start a 2 G pop-up or a point one to one and one-half nautical miles from the intersection of the run-in and attack headings so as to arrive at a 1000 - 1500 foot AGL MAP one to one and one-half nautical miles from the target. Control roll out on final to establish desired dive angle and alignment. Release and recovery are the same as any low angle delivery.

D. LOW-ANGLE ROCKETS AND GLIDE BOMBING.

Approach the target on a run-in heading 30 - 60° from the desired attack heading at 420 - 480 KIAS. Start a 2 - 3 G pop-up, 1½ - 2 NM from the intersection of the attack and run-in headings, and strive for an apex point 5000 - 7000 feet AGL, 1½ - 2 NM from the target. The climb-angle should be approximately 25 - 35°. Play the pop-up and roll-in, according to distance from the target, to establish a 30° dive angle. The point at which the roll-in toward the target is begun will vary with release altitude, dive angle, climb angle, and climb airspeed. Generally, the turn-in should be initiated 1500 feet prior to the apex altitude. When the aircraft is established on the final attack heading, the nose is maneuvered to a point below the target and roll-out is accomplished. The aircraft should now be in position to commence the tracking process. The minimum airspeed at the apex point should be 300 KIAS. Average exposure time for a rocket attack with a 400 KIAS release, 4000-foot slant range, is 35 - 45 seconds from pop-up to firing. (See Figure 6).

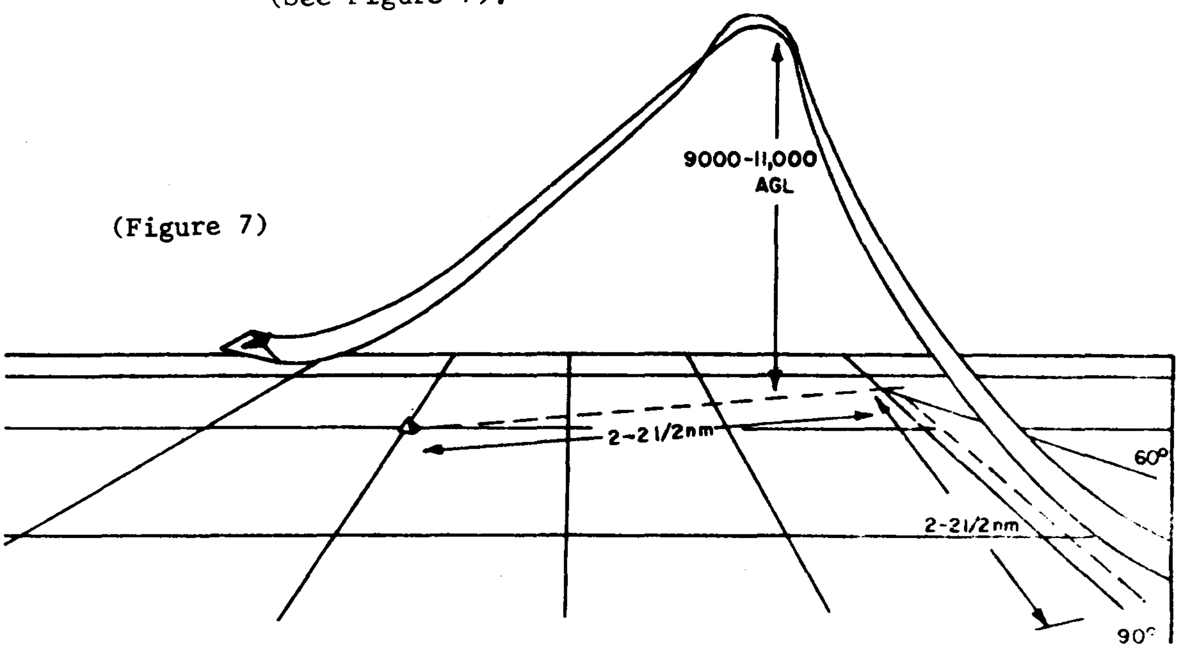
(Figure 7)



E. HIGH-ANGLE DIVE BOMB.

Approach the pop-up point 60 - 90° from the desired attack heading. The pop-up point is 2 - 2½ NM from the intersection of the attack and run-in headings. Over the pop-up point, simultaneously select afterburner and initiate a 2 - 4 G pullup to a climb angle of approximately 45° . Fly to the apex point 2 - 2½ NM from the target at 9000 - 11,000 feet AGL and roll-in, establishing a 45° dive angle. The minimum desired airspeed at the maneuver apex is 300 KIAS. Average exposure time, from pop-up to release at 4000 feet AGL, is 45 - 60 seconds. (See Figure 7).

(Figure 7)



POP-UP HIGH ANGLE DIVE BOMB

F. ADVANTAGES OF THE ANGLE-OFF DELIVERY.

This delivery maneuver offers excellent versatility with continuous visibility of the target from pullup to release. Using the target as a reference, constant adjustments can be made, if necessary, to attain the preplanned release conditions. The major advantage of this maneuver is that the attack heading can be altered after pullup to permit an attack on a more vulnerable area of the target or to correct for any errors induced by popping-up at other than the desired point. Additionally, if a change in attack heading is required and cannot be accomplished prior to rolling out on final or if the target is not located during the pop-up, the aircraft can be returned to low altitude and the maneuver begun from a new pop-up point.

4. BACK-UP DELIVERY MANEUVERS.

In any combat situation, the probability of attaining the desired approach or delivery position is less than 100 percent; therefore, specified back-up or repositioning maneuvers should be planned. Two back-up maneuvers and one repositioning maneuver will be discussed. They are: the indirect angle-off delivery, the 180^{o} reversal (pop-up) and low-level repositioning.

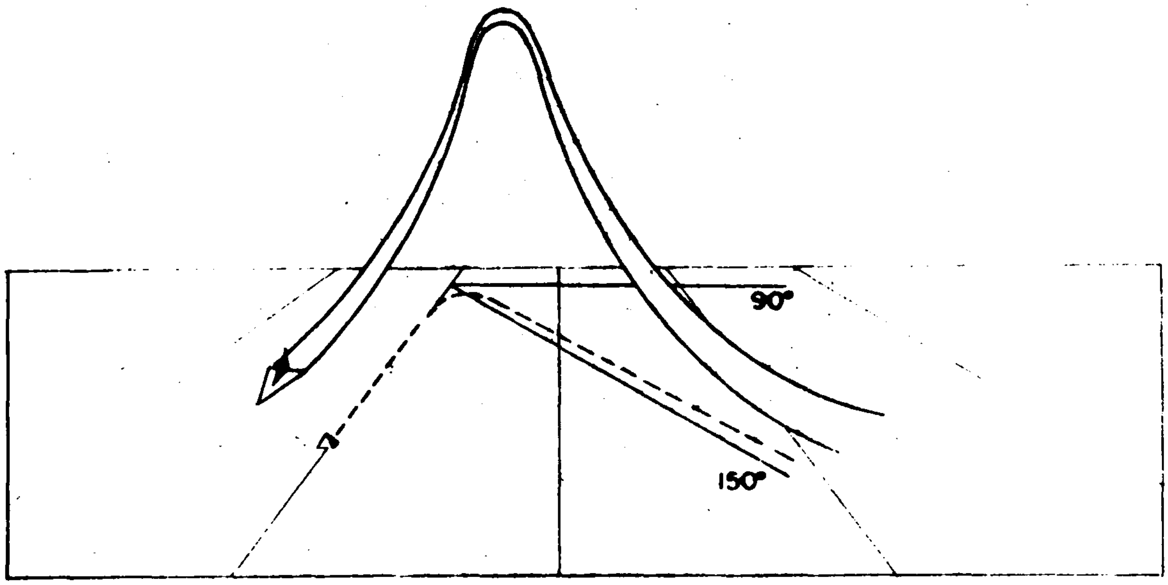
A. INDIRECT ANGLE-OFF DELIVERY.

The indirect angle-off maneuver may be used if the pilot misses the desired pop-up point or is too near the target to accomplish an angle-off maneuver. The delivery maneuver is similar to the angle-off maneuver except that the low-level approach to the pop-up point is 90 - 150^{o} from the final attack heading, either side of the target. The initial portion of the pop-up is accomplished straight ahead. Approaching the desired apex altitude, a wingover reversal is performed. The maneuver resembles the first half of the lazy-eight maneuver except for a varying rollout (See Figure 8). The distance from the target at the apex of this maneuver should be slightly greater than that established for the angle-off maneuver. This will compensate for the increased turn required to align the the aircraft with the target.

If the angle-off delivery maneuver cannot be accomplished due to the geographic location of the target, enemy defenses, or similar reasons, this maneuver may be useful. It should only be used as an alternate or back-up to the angle-off approach because of certain inherant disadvantages. First, the aircraft is exposed to enemy defensive fire longer than in some of the other maneuvers. Second, the element of surprise may be lost when the aircraft passes near the target area. Also, the increased angle-off requires that the pilot initially look rearward in order to continuously maintain visual contact with the target. The amount of arc necessary to return to the attack heading requires skillful aircraft handling and increased time to accelerate to the release airspeed. Finally, the pop-up and apex points are more difficult to estimate than in other maneuvers.

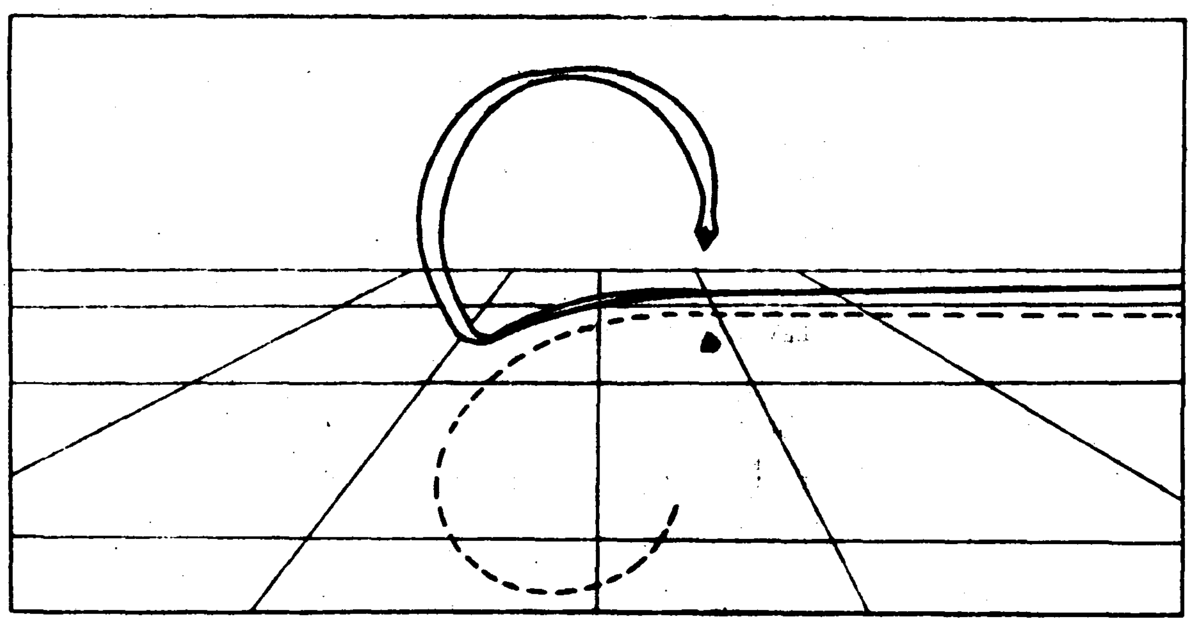
B. 180^{o} REVERSAL (POP-UP).

This maneuver can be used if the aircraft has been inadvertently flown inside the Minimum Attack Perimeter. (See Figure 9). When the target has been identified, turn



(Figure 8)

INDIRECT ANGLE-OFF POP-UP



(Figure 9)

180° REVERSAL

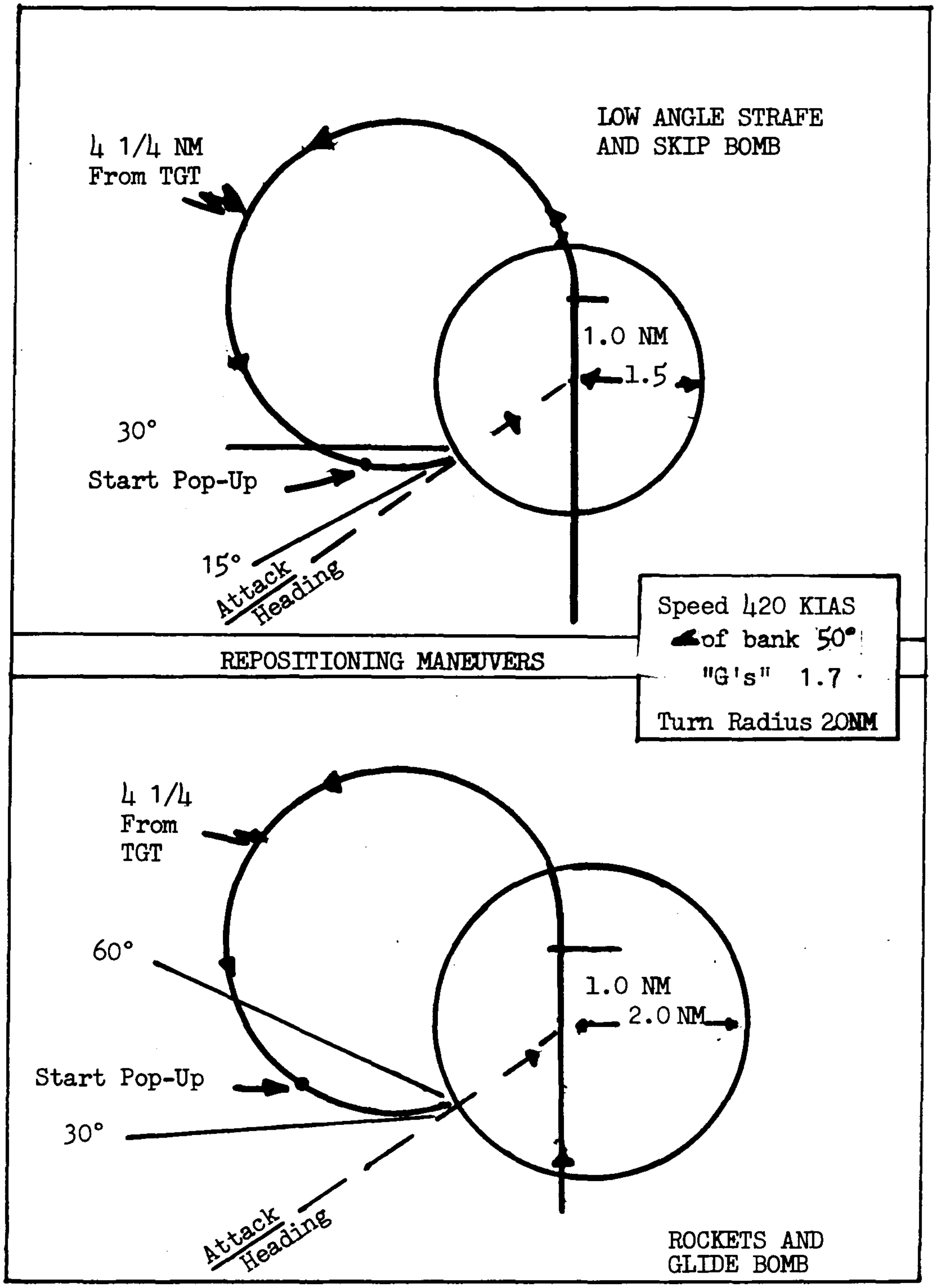
the aircraft to a heading that will take it over, or close to, the target. After the aircraft passes the target, execute a standard rate turn in either direction. This will place the aircraft approximately $1\frac{1}{4}$ miles past the target and at an angle-off which will permit the pilot to keep the target in sight. Upon completion of 30^{o} of turn, initiate a pop-up and begin reducing the angle of bank. Vary the climb and rate of turn throughout the pop-up to attain the desired attack heading. The aircraft is turned continuously from pull-up until roll-out on final. Final attack heading will be 210^{o} - 270^{o} from the original approach heading. The exact heading will depend on rate of turn and altitude gained in the pop-up. The complete maneuver is similar to the lazy-eight maneuver. The delivery parameters and recovery maneuver are as previously described for the other maneuvers. The major advantage of this maneuver is that the target can be kept in sight during the pop-up. The attack can be completed in a shorter period of time than is required to reposition for a primary attack. The disadvantages are similar to those listed for the indirect angle-off maneuver.

C. REPOSITIONING MANEUVER.

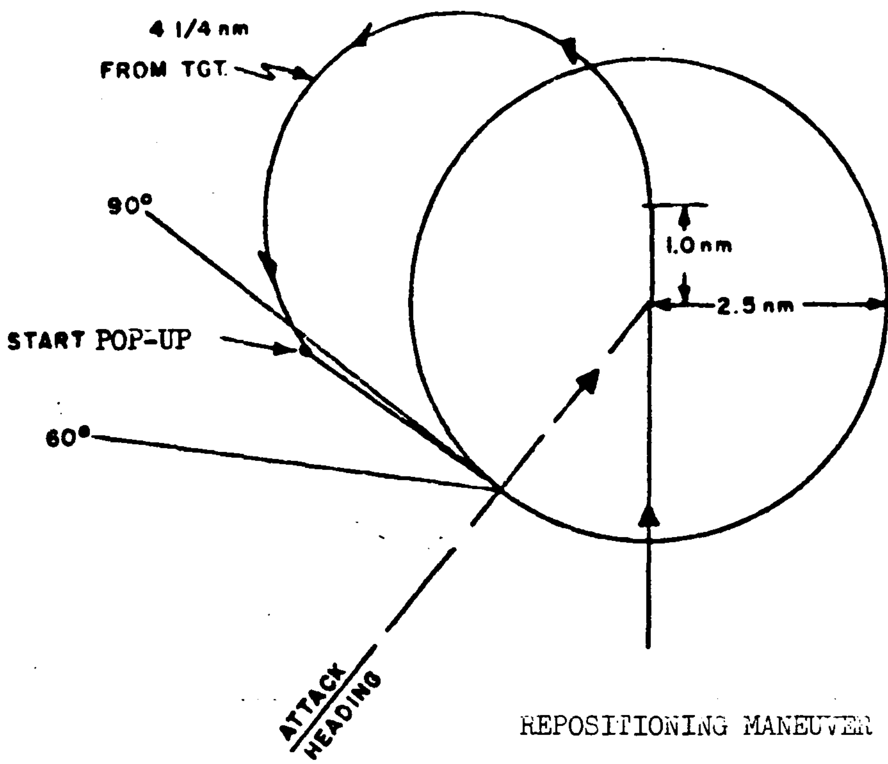
If the aircraft has inadvertently passed too close to, or over, the target and enemy defenses dictate a maneuver with minimum exposure time, the aircraft must be repositioned for the attack. It would be impossible to specify procedures to cover all conditions; however, some guidelines are presented for maneuvering tactical fighters at extreme low level. Turn radius is dependent upon true airspeed and radial G forces. Radial G will determine the angle-of-bank to be used during a turn. The following data were computed for an airspeed of 420 KTAS:

LEVEL TURN RADII

RADIUS NAUTICAL MILES	ANGLE OF BANK (Nearest 5^{o})	TOTAL G FORCES	RADIAL G FORCES
1/2	80^{o}	5.2	5.1
3/4	75^{o}	3.6	3.5
1	70^{o}	2.9	2.7
1 1/4	65^{o}	2.3	2.1
1 1/2	60^{o}	2.0	1.8
2	50^{o}	1.7	1.2
2 1/2	45^{o}	1.5	0.6


LOW ANGLE STRAFE
AND SKIP BOMB
4 1/4 NM
From TGT
1.0 NM
1.5
30°
Start Pop-Up
15°
Attack
Heading
REPOSITIONING MANEUVERS
Speed 420 KIAS
of bank 50°
"G's" 1.7
Turn Radius 2.0NM
4 1/4
From
TGT
60°
1.0 NM
2.0 NM
Start Pop-Up
30°
Attack
Heading
ROCKETS AND
GLIDE BOMB

The degree of turn selected for repositioning will depend on aircraft performance limitations. In this selection, the following factors must be considered; aircraft configuration, gross weight, and desired airspeed for initiation of the attack. These factors will determine turning performance. The repositioning maneuver is used to place the aircraft in position to initiate a primary maneuver. Figures 10 and 11 (drawn to scale) show that it is necessary to perform a 1.7 "G" turn (minimum) in order to roll out within the desired approach cone at, or prior to, the pop-up distance. Before initiating the turn, fly past the target for 10 seconds (about 1 NM). The aircraft will be $4\frac{1}{4}$ NM from the target at the farthest point in the maneuver. The level turn is initiated by simultaneously pulling up slightly and establishing bank angle and G. Once the G-load is established, the nose of the aircraft is positioned on the horizon and the turn is completed. Using this technique, turns can be made comfortably as low as 100 feet AGL. Approaches made within $1\frac{1}{4}$ NM to either side of the target will permit the pilot to turn in either direction using 1.5 - 2.0 G turns. A turn away from the target will cause the pilot to momentarily lose sight of the target. Use of the repositioning maneuver for initiation of the direct pop-up maneuver is not recommended. Depending upon the final approach dive angle, the pilot will have to fly at lease $2\frac{1}{4}$ NM past the target before initiating any turn inbound. The target will be more than 5 NM away at the farthest point in the maneuver.



HIGH ANGLE DIVE BOMB

(Figure 11)

SPEED	420 KIAS
∠ OF BANK	50°
"G's"	1.7
TURN RADIUS	2.0 nm

REPOSITIONING MANEUVER