SNAP-SHOOT GUNSIGHT FOR FIXED-GUN FIGHTER AIRCRAFT

by

MAJOR STEPHEN W. GILBERT, USAF
MAJOR ALBERT E. PREYSS, USAF
MAJOR RICHARD E. WILLES, USAF

TECHNICAL REPORT 69-3
DECEMBER 1969

UNITED STATES AIR FORCE ACADEMY
COLORADO 80840

SNAP-SHOOT GUNSIGHT FOR
FIXED-GUN FIGHTER AIRCRAFT

by

MAJOR STEPHEN W. GILBERT, USAF
MAJOR ALBERT E. PREYSS, USAF
MAJOR RICHARD E. WILLES, USAF

UNITED STATES AIR FORCE ACADEMY
TECHNICAL REPORT 69-3
DECEMBER 1969

Editor: Lt Colonel Robert B. Weaver, USAF

The research reported in this document was made possible in part by support extended to the faculty of the United States Air Force Academy by Hq. Aerospace Defense Command and the Office of Aerospace Research.

Additional copies of this document may be obtained by writing to the Director of Faculty Research, United States Air Force Academy, Colorado 80840

TABLE OF CONTENTS

List of Figures iii

Abstract iv

I. The Need for Improvement 1
Fixed Depression or "Iron" Sight 1
Lead-Computing Optical Sight 3
Snap-Shoot Gunsight 4

II. Lead-Computing Gunsight Theory 6
Lead-Angle Computation 8
Angular Velocity Measurement and Smoothing 13

III. Snap-Shoot Gunsight Theory 14

IV. Simplified Snap-Shoot Analysis 18

V. Comparison of Lead-Computing Optical Sight and
the Snap-Shoot Concept 22

VI. Conclusions and Recommendations 26

LIST OF FIGURES

Figure		Page
1	Prediction Angle Components	7
2	Lead Angle for a Maneuvering Target	9
3	Lead Angle for Non-Maneuvering Target	11
4	Snap-Shoot Gunsight Geometry	19
5	Steering Components	23
6	Lead-Computing Gunsight Simulation Results	24
7	Snap-Shoot Gunsight Simulation Results	24
8	Time on Target Comparison	25

ABSTRACT

The design philosophy, mechanization and employment of three types of air-to-air gunsights are discussed from the standpoint of their effectiveness in providing a fighter pilot with accurate and usable steering information during an aerial engagement. Two of the gunsights, the so-called "iron sight" and the Lead-Computing Optical Sight (LCOS), are common to most modern fighter aircraft. The third system is a radically new concept in fire control computation called the "snap-shoot" gunsight.

The snap-shoot concept is an attempt to arrive at a more realistic division of responsibility between man and machine than either the lead-computing optical sight or the iron sight. With the lead-computing optical sight, the pilot is relieved of all computational and most of the measurement responsibilities, requiring only that he "track" a target with a dynamic visual cue (a pipper). The authors contend that the pilot is in a much better position than is the computer to determine future target motion. All existing computing gunsights, however, relieve the pilot of this responsibilit; The snap-shoot gunsight concept relies heavily upon the pilot's natural predictive ability, while the computer is given the task of determining accurate projectile trajectories and displaying them to the pilot.

Although the snap-shoot solution to the fire control problem has essentially zero settling time and is far more accurate than either of the existing systems, it also creates an inherently difficult manual control task for the human operator. Simulation results indicate that, although the steering task is more difficult than for the lead-computing optical sight, the snap-shoot gunsight provides the pilot with accurate and positive indications of firing opportunities. The simulation also shows conclusively that a lead-computing gunsight is easily defeated by a maneuvering target.

The authors, realizing the difficulty of the manual control task involved with the proposed snap-shoot technique, suggest a possible combination of the three gunsights, employing the favorable characteristics of each and compensating for each of their weaknesses.

THE NEED FOR IMPROVEMENT

Experience of our pilots in Southeast Asia has clearly shown that although rockets and guided missiles extend the lethal radius of a fighter aircraft, these weapons are often ineffective during a close-in, maneuvering air battle. During such an encounter, the time required to lock-on, prepare, launch, and guide a missile may exceed the duration of the encounter. Even if a successful launch were possible, appropriate evasive maneuvers on the part of the target aircraft can defeat the missile guidance systems. So clear is the evidence that the gun is still the most versatile air-to-air weapon that most of our first-line fighter aircraft are being fitted with the General Electric Vulcan, M-61. This gun, capable of firing up to 6000 rounds per minute, provides the fast reaction and target area saturation needed for the close-in, maneuvering engagement. The gun, however, is only as accurate as the method used to aim it. One method is provided by the fixed depression sight.

Fixed Depression or "Iron" Sight

A fighter pilot engaged in aerial combat is faced with an extremely difficult manual control task during a firing pass. In an aircraft fitted with fixed forward firing guns, he must maneuver his aircraft so that the weapon line is correctly positioned relative to the target. The correct firing position of the weapon line is normally determined by some form of on-board computation. Weapon line aiming information so generated is presented to the pilot on a heads-up display (a gunsight) in the form of a steering dot or "pipper." Maneuvering to place the pipper on-target constitutes a solution to the fire control problem and is the manual control task challenging the pilot.

At extremely short ranges, when the bullet time of flight to the target is only a fraction of a second, miss-producing effects such as gravity drop are negligible compared to the parallax caused by the physical location of the gunsight relative to the gun. In addition, the short time of flight permits a reasonable pilot estimate of the required lead angle. In circumstances such as these, it is usually sufficient to fix the pipper on the gunsight, adjusting its depression from the weapon line to compensate for minor ballistic and parallax effects. If the pilot flies a near nominal attack path, for which the compensation has been determined and preset into the sight, and uses "Kentucky windage" for the lead angle, he can effect a reasonably accurate solution to the fire control problem.

The fixed depression or "iron" sight is easily maintained and inexpensive, and the mechanization is simple. More important, the iron sight is easy to use and is accurate at the short ranges for which it was designed. No external or internal measuring equipment is required other than the pilot observing and predicting target motion. Also, since the pipper is "caged," that is, it has no dynamics, the steering task closely resembles that encountered in formation flying and is consequently easy to perform.

As target range increases, the corresponding increase in bullet time of flight requires the pilot using an iron sight to predict target motion further into the future. Kentucky windage and a fixed depression gunsight soon fail to provide a satisfactory solution to the problem, becoming totally inadequate as the range opens to a thousand feet or so. At these ranges, ballistic corrections can no longer be ignored and some type of mechanized bullet trajectory computation must be substituted for a nominal pipper depression. One solution to the long range fire control problem has been to relieve the pilot of all computational and most of the measurement responsibilities, requiring only that he track with the pipper on target.

A lead-computing optical sight (LCOS) is designed to provide this kind of computational aid to the pilot.

Lead-Computing Optical Sight

In a lead-computing gunsight, the prediction angle (i.e., the angle between the present line of sight and the weapon line accounting for ballistic corrections and predicted target motion during the bullet time of flight) is continuously computed and displayed as a deflection of the pipper relative to a fixed reference on the gunsight. Unfortunately, the mechanization of this gunsight presents several problems and the resolution of these difficulties has produced some undesirable characteristics which limit its effectiveness. For instance, the lead-angle computation requires the measurement of present target motion and prediction of the future target position after the bullet time of flight. Prediction involves an assumption concerning the future target motion. It is accepted practice to assume that the angular velocity of the line of sight will remain constant at its present value over the bullet time of flight. When the gunsight is employed against a target using evasive tactics such as the "scissor" or "jink," this assumption is not valid. Furthermore, the pipper dynamics, if undamped, make tracking extremely difficult because of the coupling of relative target and attacking aircraft motion.

Introducing pipper damping necessitates a finite tracking time with the pipper on target to allow the computer to "settle" to a solution. Even then, the solution will be in error if the target is accelerating or if the attack geometry requires the attacker to continuously change his own turn rate to track the target. Consequently, the lead-computing gunsight, which was introduced to eliminate the limitations of human computation and measurement, introduces a new set of limitations which are just as undesirable as those it was intended to remove.

The need for an improved gunsight system is even more evident when one considers the increased speed and maneuverability of modern aircraft. Many approaches such as the flexible gun and helmet mounted optical displays are being studied to improve and expand the lethal radius of the gun. But these elaborate and complex systems will be only as good as the fire control computations make them. In an effort to eliminate the shortcomings of the lead-computing optical sight and find a more satisfactory division of responsibility between man and computer, we propose what we call the "snap-shoot" gunsight.

Snap-Shoot Gunsight

Because of his unique ability to perceive motion, the pilot is better able to predict target motion than is a computer using noisy sensor data. Since the pilot can directly observe the major component of the target's acceleration vector (i.e., he sees the target's bank angle and knows that the lift vector is normal to the wingspan), he is essentially in a pursuit tracking situation with good knowledge of the second derivatives of both components of the error.

Since lead-angle is usually the major component of the prediction angle, we contend that target motion prediction should be the pilot's responsibility not the computer's. The computer is assigned the task of determining bullet trajectories relative to the firing aircraft. We envision, therefore, a gunsight displaying a computer "tracer" pattern representing the bullet pattern that the pilot would see had he actually fired.

In practice, it appears that the entire tracer stream need not be displayed, although its value as a trend indicator has not been thoroughly established. The possible confusion resulting from display of too much information is a subject for further investigation. It may be sufficient to display only that portion of the bullet stream corresponding to the bullet fired one time of flight ago which is now at the range of the target. Thus, the gunsight pipper would represent that particular point on the tracer path.

Computation of pipper deflection depends only upon measurements of attacking aircraft motion and target range, either estimated or measured. Target motion does not affect the computation, requiring no weak assumption concerning future target position. The pilot has this responsibility.

A correct solution to the fire control problem is obtained whenever the pipper is on target regardless of the control used to get it there. Of course, a complete solution requires that the pilot, anticipating this occurrence, actually depressed the trigger a bullet time of flight ago. Conversely, if the pipper is held on-target for at least one time of flight and the trigger is depressed during that time, the problem is solved. In fact, this would constitute a solution to the lead-angle prediction problem, including the higher order acceleration effects neglected in conventional lead-computing gunsight computations.

It is the former case, in which the pilot anticipates the crossing of pipper and target, that gives the "snap-shoot" gunsight its name. The pilot can fire in advance of an indicated solution, which is clearly snap-shooting, since it does not require finite on-target teaching times. In effect, therefore, this gunsight would have zero settling time.

A pilot engaging an optimally evading target must devote his full attention to optimum performance of his own aircraft and cannot, therefore, adequately compensate for gunsight inaccuracies. During a brief encounter, there may be only a few momentary firing opportunities. A gunsight which accurately indicates when these opportunities occur is mandatory. The lead-computing gunsight, because of the minimum tracking time required and the weak lead angle prediction assumptions, cannot meet these requirements. In fact, the lead-computing gunsights in use today often indicate firing opportunities when none exist. Conversely, the sight may indicate an aiming error when a hit could actually be scored.

The following discussion more clearly illustrates the inherent weaknesses of the lead-computing gunsight and highlights the improvements afforded by the proposed snap-shoot concept.

LEAD-COMPUTING GUNSIGHT THEORY

Wrigley and Hovorka (Fire Control Principles. New York, McGraw Hill Book Co., 1959) treat the general problem of fire control systems and lead computation in considerable detail. Following is a brief summary of their work as it applies to the problem of air-to-air gunnery:

> Underlying the theory of a lead-computing gunsight is a certain element of probability; the target position at the time of hit must be predicted, and there is a certain interval between the launching and the hit, called the time of flight, during which the projectile is wholly or partly . . . under the influence of natural phenomena outside the launcher's control.

The computed prediction angle (the angle between the present line of sight and the weapon center line) is displayed to the pilot as the deflection of a "pipper" on a heads-up optical sight. To obtain a correct solution, the pilot must superimpose the pipper on the target, using smooth, coordinated turns, for up to one second prior to the firing instant. The turning rate required to accomplish this tracking task is a measure of the target's velocity and is used to compute the prediction angle.

The computed prediction angle consists of three angular corrections as illustrated in Figure 1:

1) Jump correction - a function of angle of attack and velocity at the firing instant accounting for the apparent change in direction of the projectile as it leaves the muzzle;

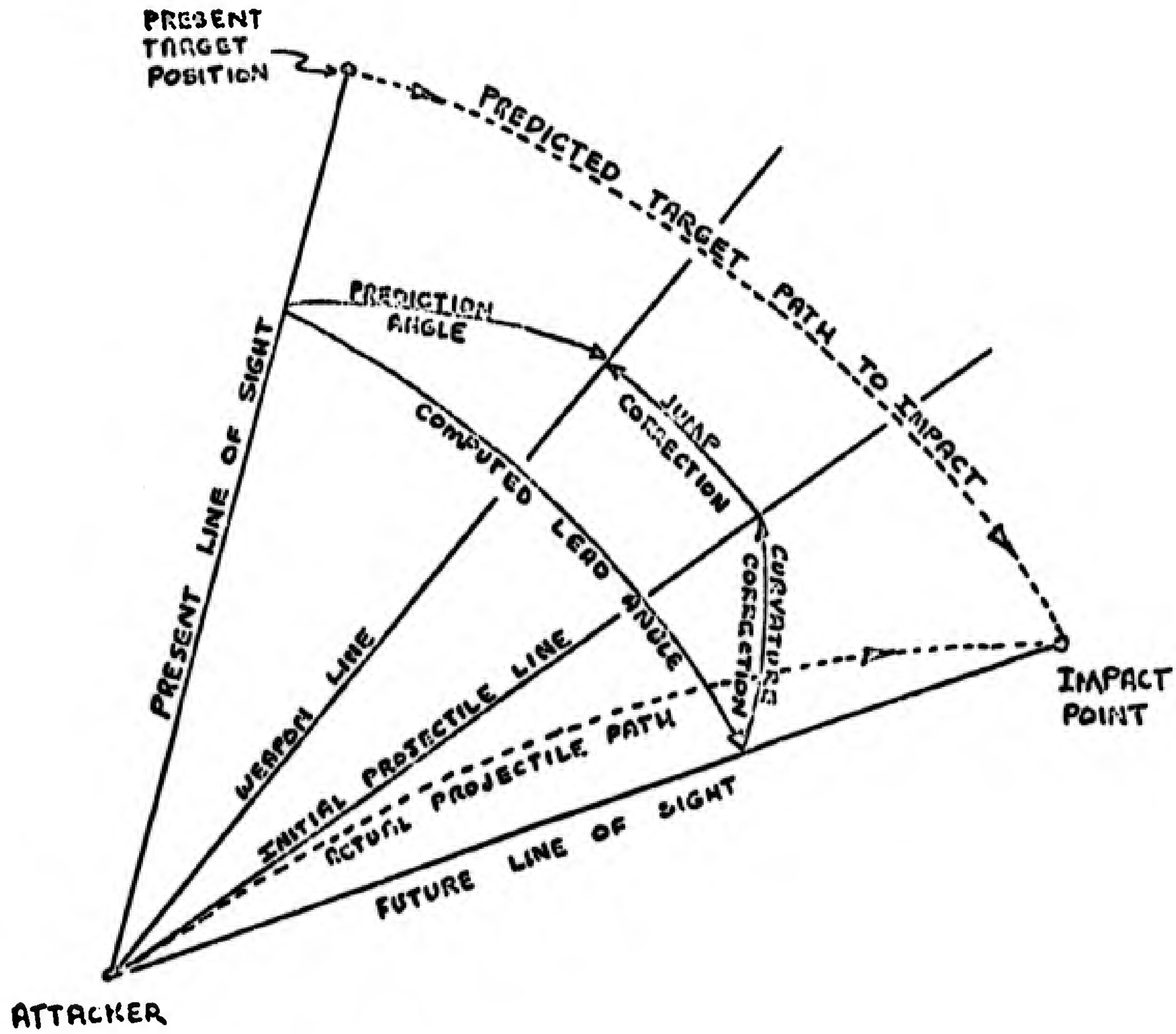

Figure 1. Prediction Angle Components

2) Curvature correction - a function of aerodynamic drag and gravitational forces acting on the projectile during the time of flight;

3) Lead angle correction - the predicted angular travel of the target during the time of flight.

These corrections represent the physical problem to be solved by all existing lead-computing gunsights. Curvature and jump corrections must be applied to any ballistic trajectory accounting for the projectile behavior after it leaves the muzzle. It is the lead angle correction which characterizes the lead-computing gunsight, implying knowledge of future, predictable target motion.

Lead Angle Computation

Figure 2 illustrates the lead angle geometry. Lead angle is defined as the angle between the present line of sight and the predicted line of sight at impact.

To determine the relative position of the predicted line of sight, future target motion must be assumed. The simplest and most widely used assumption is that the target will continue in unaccelerated flight (i.e., in a straight line at constant speed). Next in order of increasing complexity, the target is assumed to maintain constant acceleration (i.e., a constant turn rate) as measured at the firing instant. This assumption, of course, means that target acceleration must be a measurable quantity, which it generally is not. Finally, the probability that the target will perform any one of several maneuvers may be determined and the most probable maneuver used to estimate future target position. Clearly, during any maneuvering air battle, none of these will be correct.

From the standpoint of measurability and design simplicity, the first order approximation of a constant speed, straight line target path is by far the most easily implemented. All known gunsights use

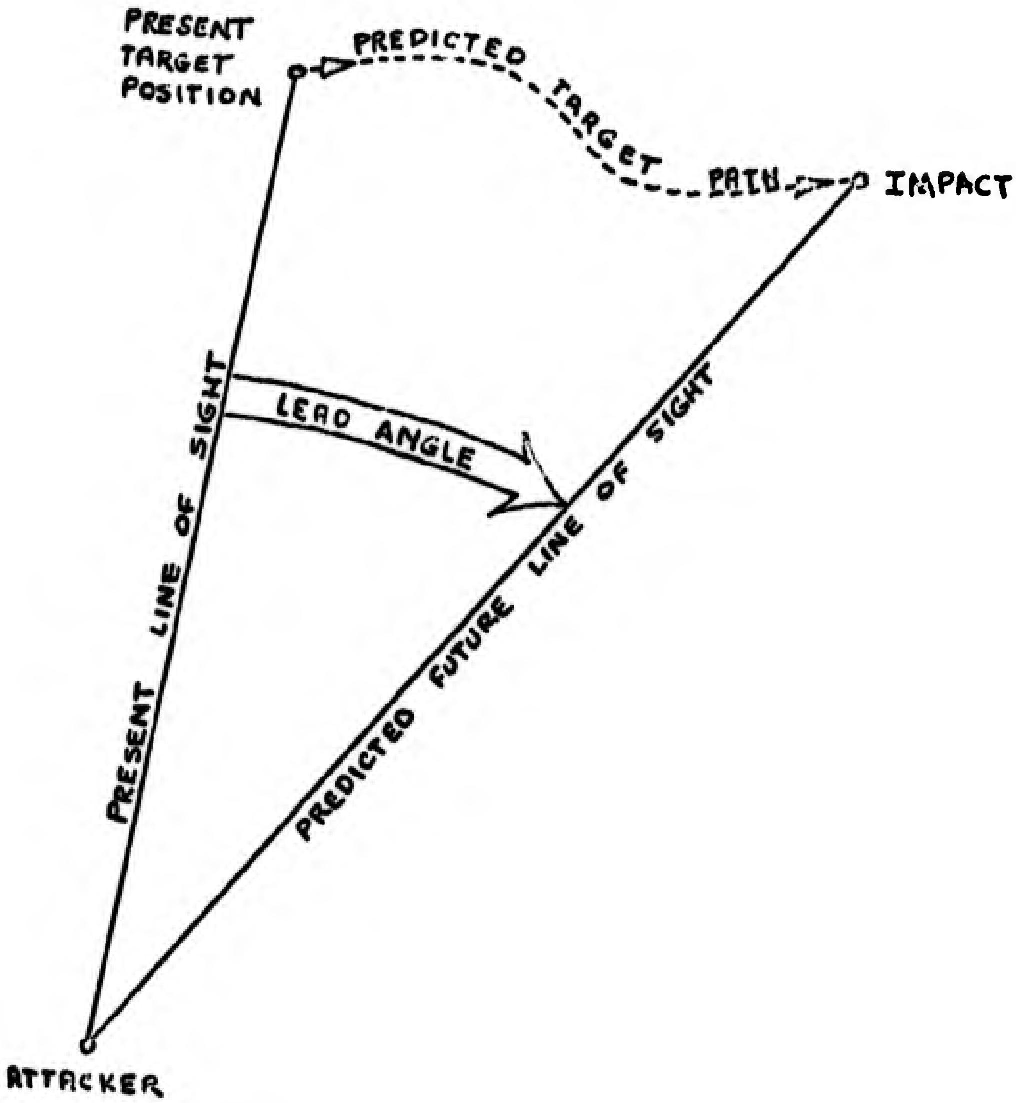

Figure 2. Lead Angle for a Maneuvering Target

this assumption for computing lead angle. The snap-shoot concept discussed later eliminates the need for these necessarily weak assumptions.

Having made the required simplification, we find that the lead angle computation is relatively simple. Figure 3 shows how the lead angle is determined for an un-accelerated target. In the figure, let:

$\bar{V}_T$ = the target velocity vector (magnitude and direction) relative to a fixed coordinate frame.
V_{TN} and V_{TR} are components of $\bar{V}_T$ perpendicular to and along the line of sight respectively.

$\bar{V}_A$ = the attacking aircraft velocity vector relative to the same fixed coordinate frame.
V_{AN} and V_{AR} are components of $\bar{V}_A$ perpendicular to and along the line of sight respectively.

R_o = the present target range either manually estimated or radar derived.

R_f = the distance to the computed impact point.

T_f = computed time of flight to impact.

V_M = the average projectile velocity relative to the attacking aircraft. (Note: It is common practice to use an average projectile velocity determined from nominal muzzle velocity, air density, firing attitude and time of flight.)

Since target speed and direction are assumed constant during the time of flight, T_f, the target should travel $V_{TN}T_f$ perpendicular to the line of sight during that time. During the same time interval, a projectile fired along the future line of sight, neglecting gravity, will travel a distance

$$R_f = (V_A + V_M)\, T_f$$

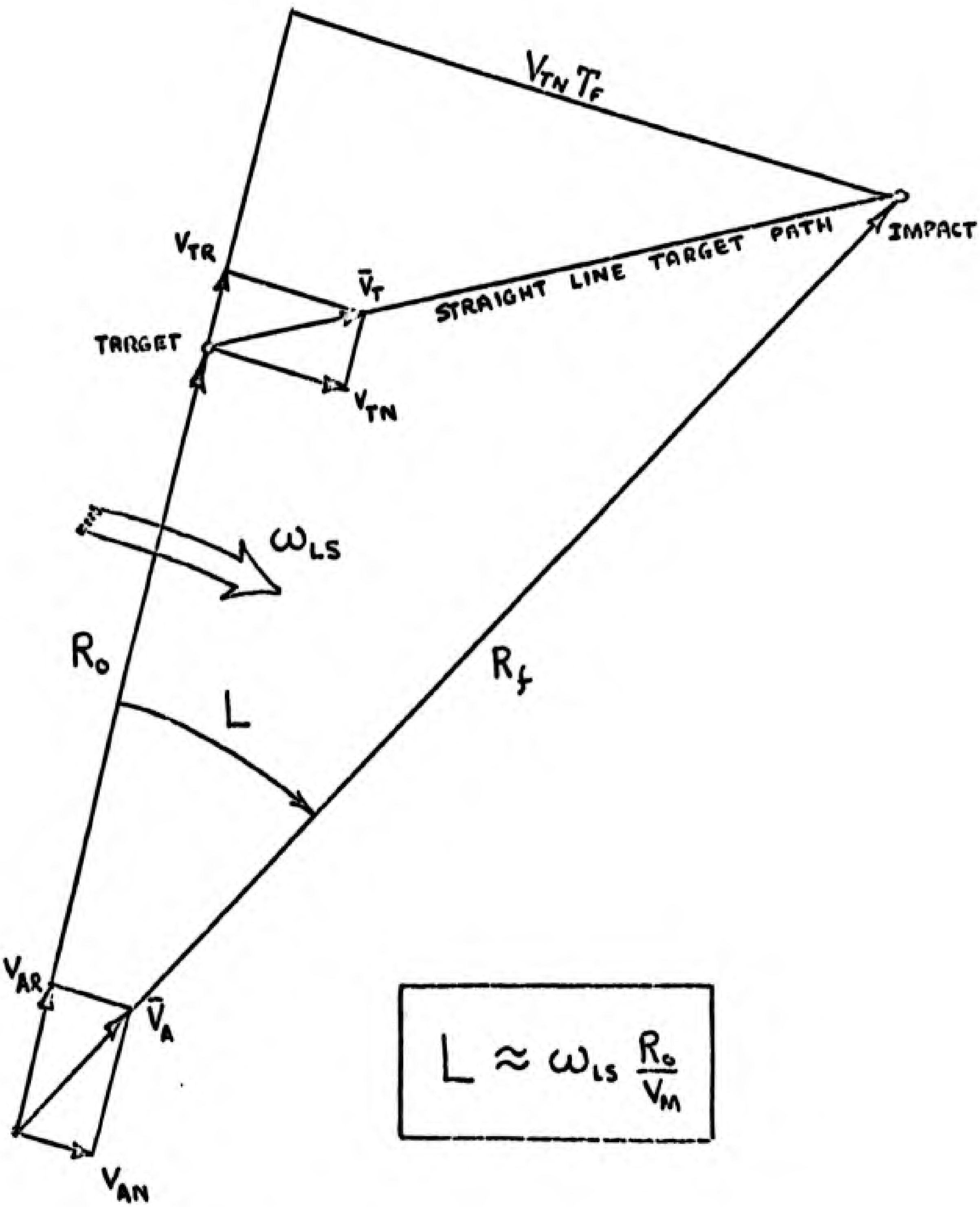

Figure 3. Lead Angle for Non-Maneuvering Target

From the problem geometry an expression for the lead angle, L, is simply

$$\sin(L) = \frac{V_{TN}T_f}{(V_A + V_M)\,T_f} = \frac{V_{TN}}{V_A + V_M} \tag{1}$$

Approximating $\sin(L) \approx L$, for small values of L, we have

$$L = \frac{V_{TN}}{V_A + V_M} \tag{2}$$

The target's velocity components are not directly measurable from the attacking aircraft so that V_{TN} must be derived from other, measurable quantities. The tracking process described earlier, in which the pilot superimposes a pipper on the target, is a means of measuring the rate of change of direction of the line of sight. In terms of the lead angle geometry, the line of sight angular velocity, ω_{LS}, is

$$\omega_{LS} = \frac{V_{TN} - V_{AN}}{R_o} \tag{3}$$

Since $V_{AN} = V_A \sin L$ and the small angle approximation still apply,

$$V_{AN} \approx V_A L \tag{4}$$

Substituting Eq. 4 into 3 and rearranging

$$V_{TN} = \omega_{LS} R_o + V_A L \tag{5}$$

Finally, substituting Eq. 5 into Eq. 2 and rearranging we have

$$V_{/A}L + V_M L = \omega_{LS} R_o + V_{/A}L \tag{6}$$

or

$$L = \omega_{LS} \times \frac{R_o}{V_M} \tag{7}$$

which is the simplest form of the lead angle equation in terms of the measurable quantities, R_o, V_M, and line of sight angular velocity.

Although this is not the exact form of the lead angle equation mechanized in the lead computer, it is useful to point out some interesting and important facts.

First, the computed lead angle is only accurate if the target is non-maneuvering and if the lead angle is small. It is unlikely during combat that either of these conditions will be satisfied. Line of sight turning rates may exceed 30 degrees per second, resulting in lead angles exceeding the limits of the optical sight. Furthermore, since the lead angle computation is strongly dependent upon the line of sight angular velocity, even small tracking errors may cause relatively large errors in the computed lead angle.

Angular Velocity Measurement and Smoothing

There are basically two types of systems designed to measure the line of sight angular velocity, the difference being the location within the systems of the rate-sensing gyroscopes.

The so-called "director" systems have the rate sensing elements located on the tracking element, usually an angle tracking radar antenna. One of the main disadvantages of this system is that it usually requires the pilot to lose visual contact with his target while he acquires a radar lock-on. In addition, target scintillation (especially for a maneuvering target) and the error nulling process used for angle tracking cause significant variations in the angular velocity measurement. This problem is partially eliminated by smoothing the data but at the price of system response time.

The more common "disturbed" systems have the rate sensing gyroscopes fixed to the airframe. The pilot "tracks" the target with a pipper and the resulting aircraft turn rate is a measure of the line of sight angular velocity. Long training and a great deal of experience are required to accomplish this manual tracking task smoothly and accurately. The need for data smoothing is not as obvious as it was for the director system. Consider an encounter in which the target aircraft crosses directly in front of the attacker. As the attacker turns to track his opponent, the pipper would be deflected in the opposite direction by an equal amount. Any attempt to superimpose the pipper on the target would aggravate an already impossible situation. To compensate for this effect, the mechanized gunsight retards the pipper movement by a fraction of the rate of change of lead angle. That is, as the turn develops, the lead angle will increase as a function of time, the rate of change being directly proportional to the turn rate. The actual lead angle displayed to the pilot, however, is reduced by a small fraction of this rate of change. The resulting mechanized equation has the form

$$L = (\omega_{LS} - \sigma \dot{L}) \frac{R_o}{V_M} \tag{8}$$

where σ is the smoothing factor (usually between .25 and .35). The net effect of the smoothing process is to retard the pipper deflection so that a tracking solution is possible. The system delay time resulting from this process, however, causes the pilot to over-correct. The pilot must be intimately familiar with the system dynamics and compensate for the time lags introduced. To effectively employ this type of system, the target must be tracked smoothly for up to one second to arrive at a steady state solution. A maneuvering target can easily defeat either of the systems described above, the common scissors maneuver being one of the more effective methods since line of sight angular velocities are never constant and the smoothing time delays cause incorrect lead angles to be displayed. It is not surprising that many pilots would rather cage the gunsight and fire at close range.

SNAP-SHOOT GUNSIGHT THEORY

It has already been pointed out that during a maneuvering encounter there may be only a few momentary firing opportunities. It is important that the pilot know when these opportunities exist without having to second-guess the computer. It is often difficult, if not impossible, to smoothly track the target long enough to allow the computer to settle to an accurate solution. The snap-shoot gunsight discussed in this section eliminates the element of probability thereby eliminating one of the major miss-producing factors of the lead-computing gunsight. Furthermore, the proposed concept requires only target range data (either manually estimated or radar derived) so that target tracking is not a prerequisite for accurate aiming information.

We originally envisioned a computed "tracer pattern" displayed on a heads-up display similar to the actual tracer pattern a pilot would see had he been firing. The F-106 (or any other aircraft having an on-board digital computer and inertial platform) was considered since data storage and accurate position information would allow extremely accurate trajectory computations to be made. It is assumed that heading, pitch and roll angles are available as inputs to the digital computer. An air data computer is used to determine angle of attack, speed, and ambient air density.

At some time, t_o, the above data are used as initial conditions for actual trajectory computations of a projectile. It should be noted that an actual bullet need not be fired to perform the necessary calculations. Using the heading, pitch, roll, angle of attack, and aircraft speed along with the nominal muzzle velocity of the gun, the initial velocity vector of the bullet in inertial space may be determined. The effects of gravity and aerodynamic drag on the projectile after it leaves the muzzle are well established and may be used to numerically integrate the equation of motion of the projectile to determine its position in space after any time interval, Δt. Let $\bar{r}_B(t)$ denote the position vector of a bullet fired at t_o after the elapsed time interval, Δt. The equation of motion to be integrated then is

$$\bar{r}_B(t) = \bar{v}_B(t_o)\,\Delta t + \int_{t_o}^{t_o + \Delta t} \bar{v}_B\, dt \qquad (9)$$

where the reference frame is chosen with its origin at the point of firing.

The aircraft position relative to the initial starting point may be determined in a similar manner by numerically integrating the equation

$$\bar{r}_A(t) = \int_{t_o}^{t_o + \Delta t} \bar{v}_A\, dt \qquad (10)$$

where $\bar{v}_A$ is determined as a function of time from the inertial platform and air data computer outputs. Thus, at any time $t=t_o + \Delta t$, the position of the projectile relative to the firing aircraft is simply

$$\bar{r}_{B/A}(t) = \bar{r}_A(t) - \bar{r}_B(t) \qquad (11)$$

The next step is to perform a coordinate transformation into "pilot" coordinates through the pitch, roll, and heading angles as measured at time, t. The resultant vector would be the relative position of a bullet fired "Δt" ago as seen by the pilot, and would be displayed on the heads-up sight as a pipper deflection from the fuselage reference line.

At time, t, a new set of initial conditions is taken for another computed bullet; the process just described begins again, but now for two bullets. If the time increments taken are small enough, say 1/20-second or less, the resulting display will represent a tracer path. The computations on any one bullet need only be carried out to the effective range of the gun at which time the data is dropped from the computer storage file.

At this point, the pilot has no way of telling which portion of the entire tracer path to use since target range has not yet been determined. If it is desirable to have completely autonomous operation of the gunsight, target range would be manually estimated by the pilot. Stadiometric ranging has been used successfully in the past to determine the approximate target range. This method requires that the pilot set into the computer the estimated wingspan of the target, which in turn establishes the size of a reticle display coupled to the pipper deflection. The pilot slews this reticle to the apparent wingspan of the target (usually by twisting the throttle grip) thereby manually inserting an estimated target range into the computer. An identical method could be used here in which the range reticle follows the computed tracer pattern to the correct location. Another possibility, which would relieve the pilot of the manual ranging task, is to display a number of reticles at selected ranges, say every one-thousand feet, along the tracer pattern. The reticle size at each point would be inversely proportional to the range. The pilot would use the appropriate ring corresponding to the observed target wingspan to determine the portion of the tracer pattern to be used.

If automatic radar ranging is available, identical computations are made for the relative bullet position; however, only that point of the computed tracer pattern which is at the correct range is displayed to the pilot. This would eliminate possible confusion resulting from the complete display of tracer pattern and range reticles. With the simplified display the pilot has an exact indication when a firing opportunity occurs. He must, of course, anticipate when these opportunities will occur by observing the pipper motion relative to the target and actually commence firing soon enough to have a bullet at the indicated point. If he is able to keep the pipper on target for the time of flight of a projectile while actually firing the hit probability is significantly increased.

Furthermore, if the pilot tracks the target in this manner, he is actually solving the lead angle prediction problem including the higher order acceleration effects. It should be noted, however, that tracking is not a prerequisite of this system. The pipper may momentarily pass through the target and if the pilot has fired soon enough, at least one hit will be scored. In a maneuvering battle, where there may be only one such firing opportunity during the entire engagement, the advantage afforded by the snap-shoot gunsight is obvious.

The accuracy of the technique just described is limited only by the accuracy of the on-board equipment used to obtain the data and upon the capacity and speed of the computer facility used to process the data. Unfortunately, not all fighter aircraft are so equipped. A simplified approach to the snap-shoot concept is described in the next section. Although not as accurate as the previous method, the simplified approach could easily be implemented by modifying an existing lead-computing optical sight system.

SIMPLIFIED SNAP-SHOOT ANALYSIS

Figure 4 represents a typical attack situation considering only the horizontal plane. Gravity, drag, and angle of attack effects are ignored so that the projectile when fired is assumed to continue in a straight line path depending on the heading and speed of the aircraft at the time of firing. In the figure, let

x_o, y_o = the present aircraft position measured relative to a fixed coordinate reference;

Ψ_o = the present aircraft heading;

V_A = speed of the attacking aircraft;

V_M = average projectile velocity during the time of flight;

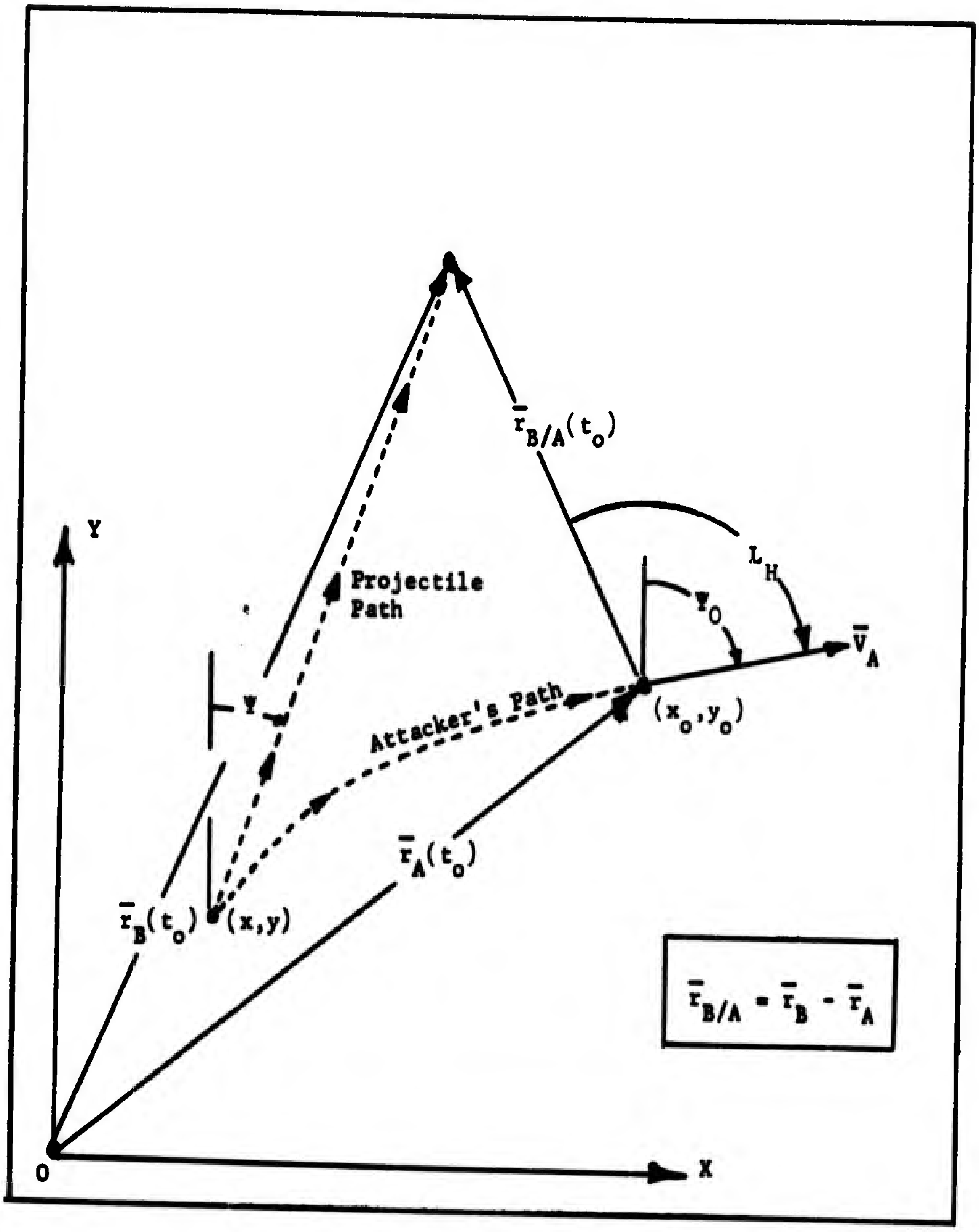

Figure 4. Snap-Shoot Gunsight Geometry

T_f = projectile time of flight

R_o = present target range (either manually estimated or radar measured)

The present aircraft position written in vector form is

$$\bar{r}_A(t_o) = x_o \bar{I} + y_o \bar{J} \tag{11}$$

and the present position of a bullet fired T_f ago is given by

$$\begin{aligned} \bar{r}_B(t_o) = & \left\{ x_{-T_f} + (V_A + V_M) T_f \sin \Psi_{-T_f} \right\} \bar{I} \\ & + \left\{ y_{-T_f} + (V_A + V_M) T_f \cos \Psi_{-T_f} \right\} \bar{J} \end{aligned} \tag{12}$$

where the subscript, $-T_f$, refers to position and heading of the aircraft a time of flight ago. The present bullet position relative to the firing aircraft is Eq. 11 minus Eq. 12,

$$\bar{r}_{B/A}(t_o) = \bar{r}_A(t\ ) - \bar{r}_B(t\ ) \tag{13}$$

Since T_f was the time of flight required for a previously fired bullet to reach the measured target range, R_o, the magnitude of $\bar{r}_{B/A}(t_o)$ must equal R_o. Thus

$$\begin{aligned} R_o^2 = & \left\{ x_o - x_{-T_f} - (V_A + V_M) T_f \sin \Psi_{-T_f} \right\}^2 \\ & + \left\{ y_o - y_{-T_f} - (V_A + V_M) T_f \cos \Psi_{-T_f} \right\}^2 \end{aligned} \tag{14}$$

An approximate solution for the time of flight, T_f, may be obtained if the heading change is assumed small so that

$$x_o - x_{-T_f} \approx V_A T_f \sin \Psi_o \tag{15}$$

and

$$y_o - y_{-T_f} \approx V_A T_f \cos \Psi_o \tag{16}$$

Substituting Eqs. 15 and 16 into Eq. 14 and solving for T_f gives

$$T_f = \frac{R_o}{V_M} \tag{17}$$

Again using the approximation that the heading change during the time of flight is small, the horizontal pipper deflection, L_H, will be approximately

$$L_H = \Psi_o - \Psi_{-T_f} \tag{18}$$

A similar argument would hold for maneuvers in the vertical plane and the corresponding vertical pipper deflection, L_V, would be

$$L_V = \Phi_o - \Phi_{-T_f} \tag{19}$$

where Φ represents aircraft pitch attitude.

These angles (i.e., L_H and L_V) along with curvature and jump correction angles identical to those used on existing lead-computing gunsights constitute the total pipper deflection angle, which is similar to the prediction angle discussed earlier. It must be noted that there is in fact a very subtle difference between this and the lead-computing gunsight; lead angle prediction has been replaced by actual heading and pitch angle changes, both of which are measurable quantities. The weak assumption concerning future target motion has been eliminated. Additionally, target tracking requirements have been eliminated since the computations are based only upon the motion of the attacking aircraft. Thus, when the pipper is on target, even momentarily, a hit could have been scored.

In the next section the snap-shoot and lead-computing schemes are compared in a simulated attack against a scissoring target. This comparison illustrates vividly the relative effectiveness of both gunsights, showing both the inadequacy of the lead angle computation and the tracking problem associated with the snap-shoot concept.

COMPARISON OF LEAD-COMPUTING OPTICAL SIGHT AND THE SNAP-SHOOT CONCEPT

In the preceding sections we have derived equations governing the behavior of the lead-computing optical sight pipper and the snap-shoot pipper under certain simplifying assumptions. These approximate dynamic models are adequate for a comparison of their performance and permit an evaluation of the snap-shoot steering logic.

For a lead-computing gunsight, ignoring jump and curvature corrections, the pipper deflection is given by

$$L = (\omega_{LS} - \sigma \dot{L}) \frac{R_o}{V_M} \qquad (8)$$

and the corresponding snap-shoot pipper deflection is

$$L_H = \Psi_o - \Psi_{-T_f} \qquad (18)$$

The steering error (see Figure 5) is

$$e(t) = \delta_T(t) - L \qquad (20)$$

where $\delta_T(t)$ is the target motion relative to the attacker's weapon line and L represents snap-shoot or lead-computing gunsight pipper deflection.

Using Eq. 20, the appropriate pipper expression and a steering law, a simulation to determine the tracking error and bullet miss distance during a constant range stern attack on a scissoring target was conducted. For the lead-computing optical sight simulation, it was assumed that the pilot's steering was perfect, that is, the pipper

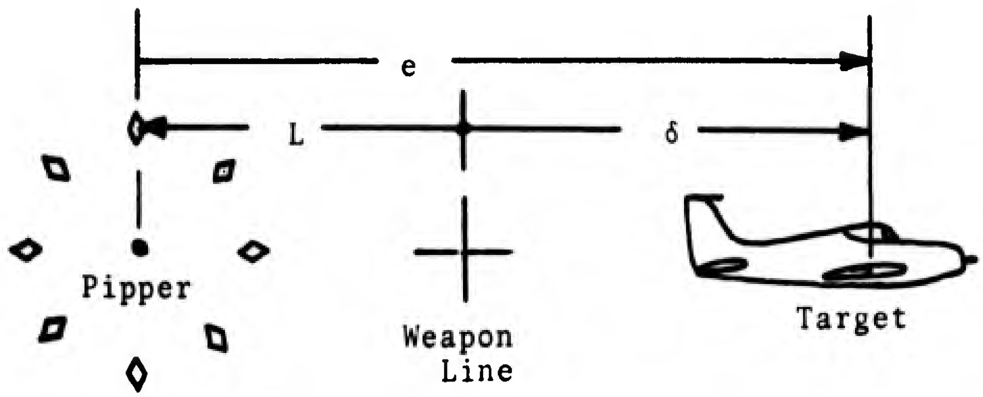

Figure 5. Steering Components

was always on target indicating a continuous aiming solution. In the case of the snap-shoot gunsight, an iron sight plus vernier steering law was postulated. This steering law has the form

$$\dot{\Psi} = K_1 \dot{\delta}_T + K_2 e \tag{21}$$

where $\dot{\Psi}$ is the turn rate of the attacking aircraft. The $K_1\dot{\delta}_T$ term is what has been called iron sight steering since it represents the pilot's attempt to track the target with the weapon line. The K_2e term is vernier steering since it represents the pilot's attempt to null the error between pipper and target. Results of the simulation are presented in Figures 6 and 7.

It is readily apparent that the lead-computing gunsight, even with perfect steering on the part of the pilot, is easily defeated if the target maneuvers. The scissors tactic, simulated by a sinusoidal variation in the line of sight direction, results in a continuously changing line of sight angular velocity upon which the lead-angle computations are based. The resulting miss distance is significant considering that the computer is actually indicating that the solution is always correct. The pilot has no way of knowing when the solution is actually correct and would probably expend a considerable amount of

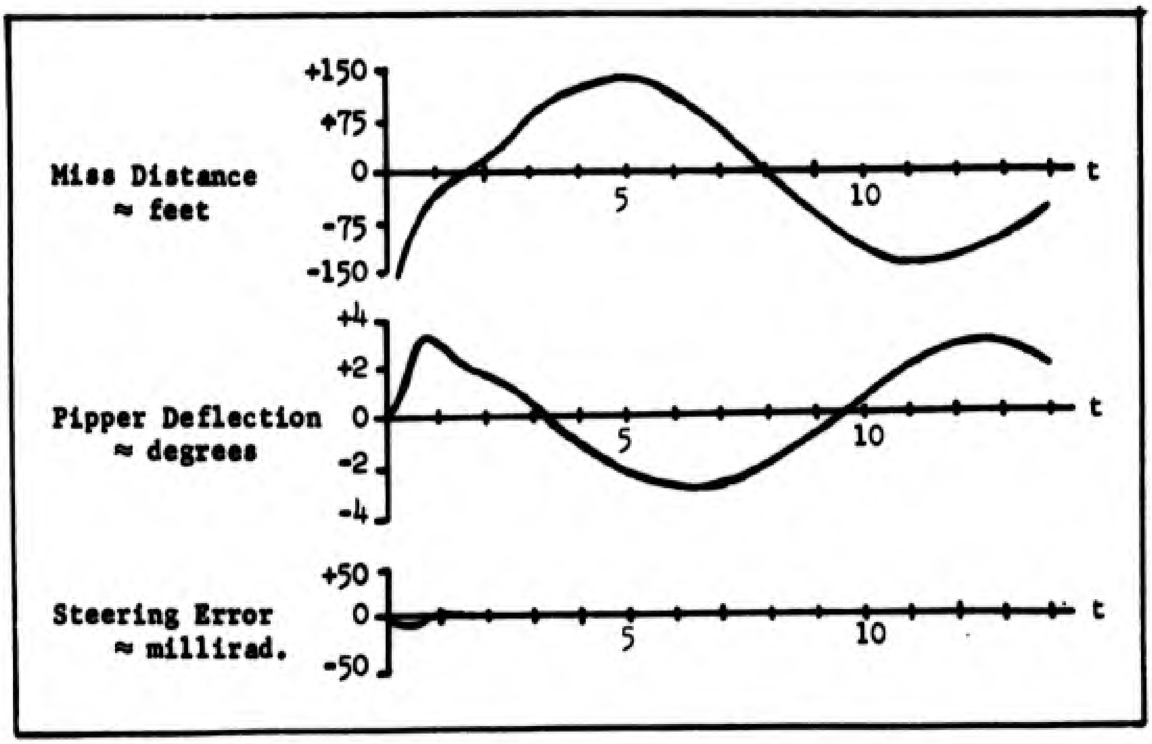

Figure 6. Lead-Computing Gunsight Simulation Results.
Sinusoidal Target Motion - 300 sin(.5t) ft.

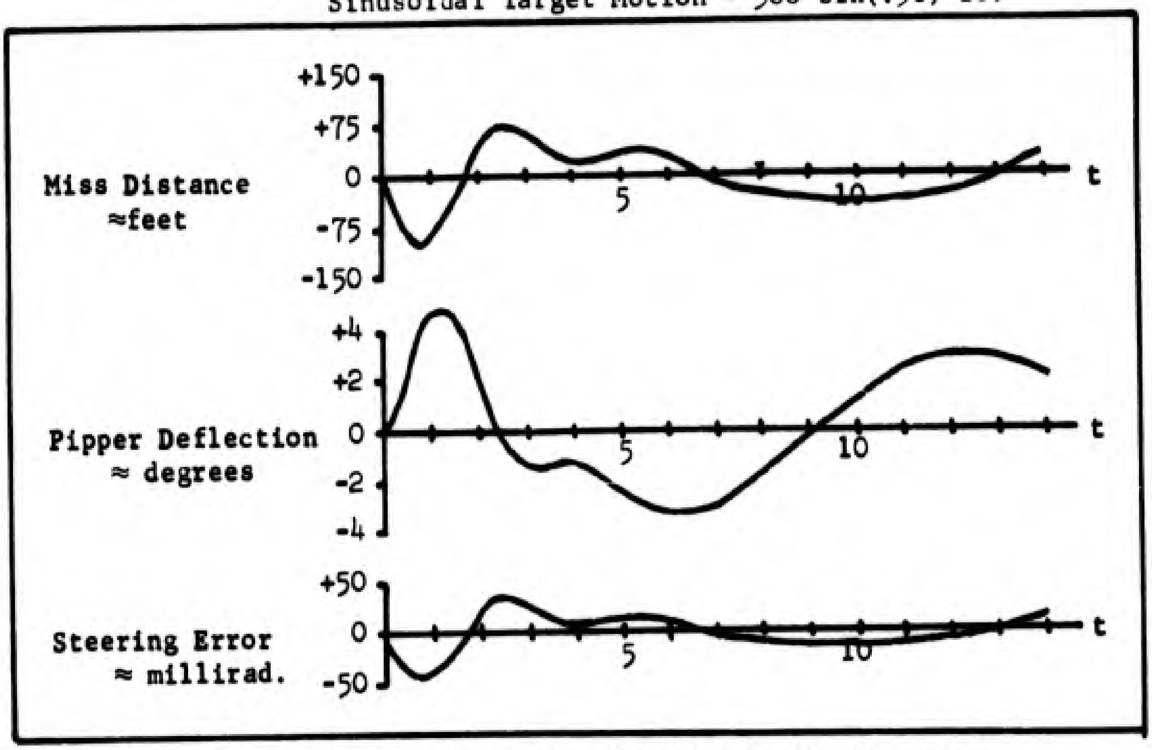

Figure 7. Snap-Shoot Gunsight Simulation Results.
Sinusoidal Target Motion - 300 sin(.5t) ft.

ammunition hoping to second guess the computer.

In contrast to the lead-computing gunsight results, Figure 7 shows that the undamped snap-shoot pipper only indicates a firing opportunity, that is, the pipper passing through the target, when the miss distance is essentially zero. Thus, the pilot is not deceived by the computer as was the case for the lead-computing gunsight. In Figure 8, it is assumed that miss distances within -15 feet of the target qualify as possible hits and the total time "on-target" for both gunsights is compared. The snap-shoot gunsight results indicate nearly 50% more time on target than the lead-computing gunsight during one complete excursion of the target. Even though the lead-computing sight has the advantage of perfect steering, the first hit opportunity occurs at nearly the same time for either gunsight. Even more important, the pilot using a snap-shoot gunsight under these conditions would have a positive indication when a hit could be scored.

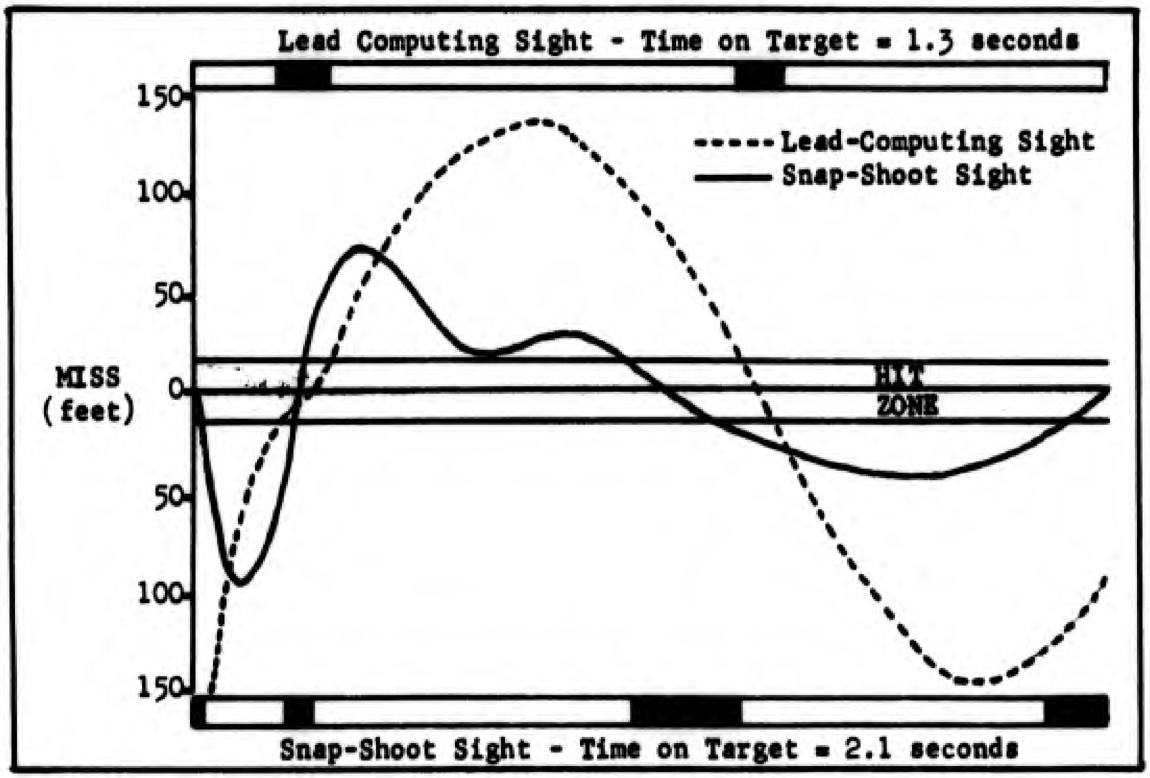

Figure 8. Time on Target Comparison. Lead-Computing Sight vs Snap-Shoot Sight.

CONCLUSIONS AND RECOMMENDATIONS

In this paper we have described three approaches to the mechanization of a gunsight for air-to-air fire control. Each of the gunsights discussed has a different philosophy underlying its mechanization. These philosophies differ in their division of responsibility between man and machine. Each sight, therefore, imposes different requirements on human compensation during the manual control task of tracking the target with the gunsight pipper. For example, an iron sight requires the pilot to make up for the absence of on-board computation by doing his own lead angle estimation.

Depending on the attack conditions, one of these sights will have certain advantages over the others. At close range, the iron sight's simplicity weighs strongly in its favor. At longer ranges, against non-maneuvering targets, the lead-computing optical sight provides reasonable estimates of the required prediction angle. Against aggressively maneuvering targets, when engagement times are short and only momentary firing opportunities exist, the zero settling time and positive indication of a firing opportunity are important features and are characteristics of the snap-shoot gunsight. This fact was vividly demonstrated in the simulation. Therefore, it would appear that a marriage of the best features of the three gunsights might provide a more effective solution to the airborne fire control problem.

A composite of the three gunsights would incorporate the favorable characteristics of each and compensate for each of their shortcomings. The composite gunsight having a fixed reference (an iron sight) and two dynamic pippers, one corresponding to the prediction angle in a lead-computing gunsight and the other pipper representing the snap-shoot solution, would provide the pilot with usable information during the most severe circumstances. The lead angle pipper, damped to simplify the tracking problem, provides coarse aiming data, while the snap-shoot pipper, representing actual bullet position, provides instantaneous indications of firing opportunities. In effect, the snap-shoot pipper indicates errors in the computed prediction angle.

In practice, the pilot learns to compensate for the inaccuracies of the lead-computing gunsight during standard passes against targets flying standard patterns. However, when attack conditions are non-standard (i.e., during actual combat), the pilot is no longer able to make accurate compensation. The suggested scheme, in which the gunsight displays an estimate of future target position at the same time it indicates the error in this estimate, would be a more meaningful approach to the tracking and aiming task now facing the pilot and would be a logical division of responsibility in solving the fire control problem.

Specific recommendations for further study on this proposal include realistic, three dimensional simulation with the "man-in-the-loop" to determine sight stability during maneuvering flight. The simplified snap-shoot approach could be instrumented by modifying an existing gunsight to incorporate the change from lead angle computation to computation of actual heading and pitch changes during the time of flight.

BLANK PAGE

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Hq USAFA (Directorate of Faculty Research) USAF Academy, Colorado 80840	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

SNAP-SHOOT GUNSIGHT FOR FIXED-GUN FIGHTER AIRCRAFT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report

5. AUTHOR(S) (First name, middle initial, last name)

Major Stephen W. Gilbert, USAF
Major Albert E. Preyss, USAF
Major Richard E. Willes, USAF

6. REPORT DATE December 1969	7a. TOTAL NO. OF PAGES 36	7b. NO. OF REFS 1
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) TR 69-3 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) none	

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Directorate of Faculty Research (DFSFR) USAF Academy, Colorado 80840

13. ABSTRACT

The design philosophy, mechanization and employment of three types of air-to-air gunsights are discussed from the standpoint of their effectiveness in providing a fighter pilot with accurate and usable steering information during an aerial engagement. Two of the gunsights, the so-called "iron sight" and the Lead-Computing Optical Sight (LCOS) are common to most modern fighter aircraft. The third system is a radically new concept in fire control computation called the "snap-shoot" gunsight.

The snap-shoot concept is an attempt to arrive at a more realistic division of responsibility between man and machine than either the lead-computing optical sight or the iron sight. With the lead-computing optical sight, the pilot is relieved of all computational and most of the measurement responsibilities, requiring only that he "track" a target with a dynamic visual cue (a pipper). The authors contend that the pilot is in a much better position than is the computer to determine future target motion. All existing computing gunsights, however, relieve the pilot of this responsibility. The snap-shoot gunsight concept relies heavily upon the pilot's natural predictive ability, while the computer is given the task of determining accurate projectile trajectories and displaying them to the pilot.

Although the snap-shoot solution to the fire control problem has essentially zero settling time and is far more accurate than either of the existing systems, it also creates an inherently difficult manual control task for the human operator. Simulation results indicate that, although the steering task is more difficult than for the lead-computing optical sight, the snap-shoot gunsight provides the pilot with accurate and positive indications of firing opportunities. The simulation also shows conclusively

DD FORM 1 NOV 65 1473

(Cont)

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
air-to-air gunsights Lead-Computing Optical Sight snap-shoot gunsight fire control computation computing gunsights						

Continuation of abstract of "Snap-Shoot Gunsight for Fixed-Gun Fighter Aircraft. Unclassified

that a lead-computing gunsight is easily defeated by a maneuvering target.

The authors, realizing the difficulty of the manual control task involved with the proposed snap-shoot technique, suggest a possible combination of the three gunsights, employing the favorable characteristics of each and compensating for each of their weaknesses.