2

Basic Fighter Maneuvers

> I fly close to my man, aim well and then of course he falls down.
>
> Captain Oswald Boelcke
> Probably the World's First Ace
> German Air Service, WW-I

Basic fighter maneuvers (BFMs) are the building blocks of fighter tactics. They may be classified as primary maneuvers, which can be performed without regard to an adversary (e.g., accelerations, climbs, turns), and relative maneuvers, which must be described or performed in relation to another aircraft. The physics and techniques involved in most primary maneuvers are discussed in the Appendix and therefore are not covered here.

> No guts, no glory. If you are going to shoot him down, you have to get in there and mix it up with him.
>
> Major Frederick C. "Boots" Blesse, USAF
> 10 Victories, Korean Conflict

Pursuit Curves

Pursuit curves were discussed previously in relation to missile trajectories; they are equally relevant to fighter maneuvering. The three forms of pursuit—lead, pure, and lag—are technically defined by the orientation of the attacking aircraft's velocity vector ahead of, directly toward, or behind the target aircraft, respectively. Since the fighter pilot does not always have an indication of the precise direction of his velocity vector, his nose position is usually substituted as a reference. In maneuvering situations these two references (velocity vector and nose position) vary by the amount of the attacker's angle of attack and sideslip, which are generally not great enough to be of importance. So, what is called "pure pursuit," for instance, may actually involve a small amount of lag.

Lead Pursuit

A lead-pursuit path is followed by positioning the aircraft's nose ahead of the target, or "bogey," fighter. As discussed in the gun-employment section, the practical maximum lead when the attacker is maneuvering near the target's plane of turn is often limited by the attacker's over-the-nose visibility and the requirement that he maintain sight of the bogey. "Blind" lead turns may be appropriate under some circumstances, but they are inherently dangerous, both because of the possibility of a collision and because of the potential for losing sight of the bogey and allowing it to gain a more threatening position or to escape. Larger amounts of lead can often be generated by turning in a parallel plane with the target, so that sight may be maintained over the side of the attacker's nose.

The purpose of lead pursuit is primarily to increase closure on the target by use of geometry. The ideal lead angle for greatest closure depends on relative aircraft positions, relative speeds, and target maneuver. As with missiles, a proportional-navigation course usually maximizes closure, and can be estimated visually as the lead angle that causes the target to appear to remain stationary against the distant horizon. If the target's drift appears to be toward the attacker's nose, more lead is called for, and vice versa.

The lead-collision or lead-pursuit curve may even allow an attacker to close on a much faster target, particularly if that target turns toward the attacker at a rate that places the attacker at a large AOT.

Figure 2-1 depicts a fighter using lead pursuit to close on a faster target from a rear-hemisphere position. Note that in this example the target aircraft is turning toward the attacker, inscribing a rather large arc in the sky, while the attacker keeps his nose in front of the target's position and turns inside its flight path to close the range. The attacking fighter is not maintaining a perfect proportional-navigation (lead-collision) track in this case, since the LOS to the target is rotating throughout the maneuver, but

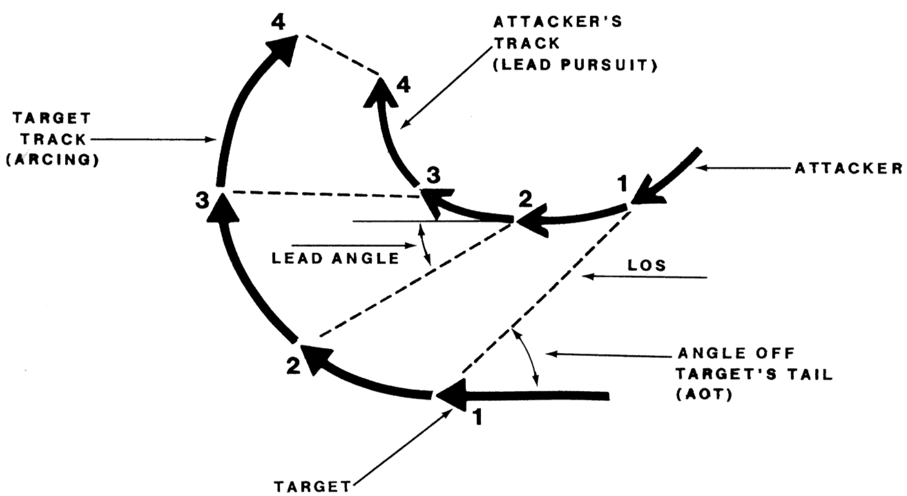

Figure 2-1. Effects of Arcing and Lead Pursuit

the combination of its position at high AOT and lead pursuit allows it to close the range continuously, even with inferior airspeed. In general, a fighter cannot maintain a lead-collision course from a position near the target's beam without equal or superior speed, but lead pursuit can provide closure at a reduced rate.

Two other points are worth mentioning about this example. It illustrates that, in using lead pursuit, the attacker must turn with a decreasing radius and increasing rate as he closes the range. Eventually he may have to turn much tighter and faster than the target in order to maintain lead pursuit. Also note that lead pursuit results in increasing AOT, thereby reducing the attacker's angular position advantage in the target's rear hemisphere.

Figure 2-2 depicts two possible defenses against a lead-pursuit maneuver performed by an attacker still out of firing parameters, one appropriate for a defender with a speed advantage (solid path), the other for a defender with a speed disadvantage (broken path). In the first case the defender turns away from the attacker to decrease AOT as much as practical, and then uses his superior speed to increase range by an extension maneuver as described earlier. This may allow him to disengage, or it may provide enough separation eventually to enable him to come back at the attacking fighter and meet it head-on, negating the attacker's angular position advantage. This option may not be appropriate against a missle-equipped attacker, since the turn-away could place the opponent within his firing envelope.

In the second case slower speed enables the defender to turn tightly enough to prevent the detrimental effects of arcing, and he meets the

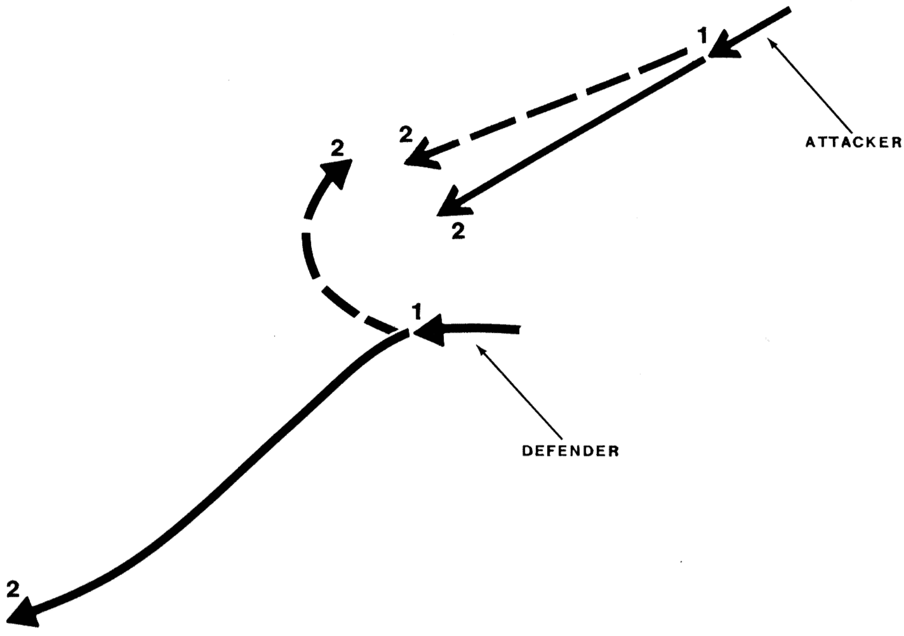

Figure 2-2. Defenses against Lead Pursuit

attacker with high AOT. It may not be possible for the defender to complete this option before a guns or missile defense maneuver is required, depending on the actual ranges and weapons involved. The attacker's angular position advantage may be reduced or eliminated in this manner if he can be met with high AOT.

Pure Pursuit

Holding the attacking aircraft's nose directly on the target also provides closure, unless the target has a significant speed advantage and AOT is very small. Although pure pursuit does not generate as much closure as lead pursuit under most conditions, neither does it cause AOT to increase as rapidly. In addition, pure pursuit presents the minimum frontal area of the attacking fighter to the target pilot, increasing the defender's visual problems.

> Months of preparation, one of those few opportunities, and the judgement of a split second are what makes some pilot an ace, while others think back on what they could have done.
>
> Colonel Gregory "Pappy" Boyington, USMC
> 28 Victories, WW-II

Lag Pursuit

In lag pursuit the attacker places his nose at an angle behind the target aircraft. This tactic is useful in slowing or stopping closure to maintain a desired separation from the target while simultaneously maintaining or decreasing AOT. Using lag pursuit, even a faster fighter can maintain a position in the rear hemisphere of a maneuvering target aircraft. Figure 2-3 illustrates the use of lag pursuit to attain a stabilized position in the rear hemisphere of a slower opponent. In this example the attacker finds

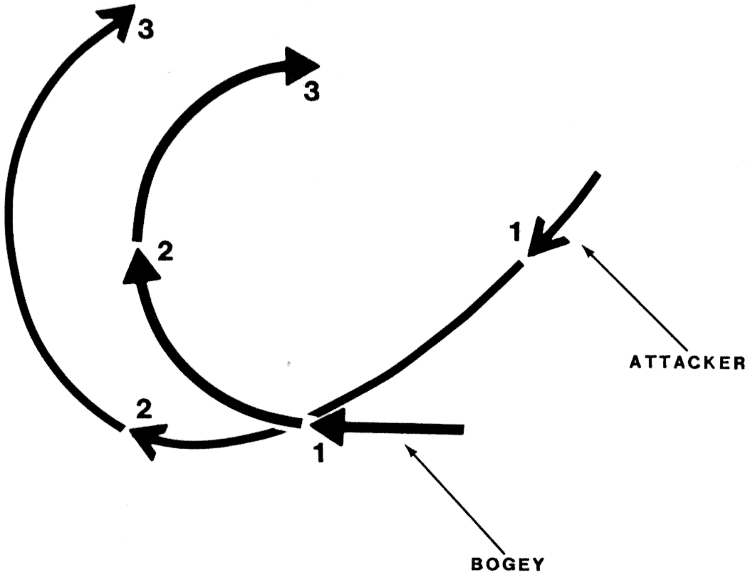

Figure 2-3. Lag Pursuit

himself on the inside of the target's turn at high AOT and presumably out of firing parameters. His turn capability will not allow him to pull enough lead for a gun snapshot (or perhaps he is equipped with rear-quarter missiles only). One option is to relax the turn, allowing the nose to drift to a point behind the bogey for lag pursuit. This reduced turn rate also offers the attacker a good opportunity to increase his energy by accelerating. (See the Appendix for a discussion of energy.) Eventually this fighter approaches the bogey's flight path and reinitiates a hard turn back toward the target, achieving a fairly stable position behind the bogey and outside its turn. This position, which affords the attacker a view of the underside of the hard-turning bogey, is termed "cold-side" lag.

As long as the fighter has a speed advantage over its opponent and can achieve the same turn rate, stabilized lag pursuit is possible in the bogey's rear hemisphere. However, there are several very strict constraints on combinations of range, relative speed, turn radii, and relative fighter positions which must be met for stabilized lag pursuit. All these parameters are very difficult to meet in practice, even with a cooperative target, so lag pursuit is generally a temporary state of affairs. Nevertheless, this tactic does allow a fighter to maintain a speed advantage over a maneuvering target while remaining in its rear hemisphere.

Lag also may make it very difficult for the bogey pilot to maintain sight of the attacker, particularly when the attacker is on the cold side or near the bogey's six o'clock (i.e., dead astern); this forces the defender to turn harder or to reverse his turn direction. If the attacker is equipped with an off-boresight weapon, one that can be fired at a target that is not directly ahead, there may be a shot opportunity regardless of the bogey's maneuver. If the bogey pilot cannot safely reverse without giving his attacker a shot opportunity, the continued turn occupies his attention and forces him to be predictable, making him easy pickings for a second fighter.

Likewise, however, an attacker is also predictable and vulnerable while performing prolonged lag pursuit. When using this tactic a pilot should attempt to gain a position from which a shot opportunity will be presented with his available weapons if the bogey reverses. Unless the attacker is gun equipped, lag, particularly cold-side lag, at close range with the nose well off the bogey may allow the bogey to reverse with impunity, possibly gaining an offensive position. At the very least this condition does not make the bogey predictable. It also may result in a difficult position from which to disengage should disengagement be necessary. Additionally, sustained lag pursuit can be very taxing physically to the attacking pilot, since his greater speed requires a higher load factor than that of his opponent.

Stabilized lag pursuit with its many constraints may not offer the optimum offensive position for the attacker considering his weapons system and relative maneuvering capabilities. It is usually desirable for the attacker to stabilize within the boundaries of his weapons envelope, possibly only having to satisfy aiming requirements for a valid shot. If the attacker can reach such a position even temporarily, especially if he is out of the defender's field of vision, the bogey pilot is forced to react in order to regain sight.

Effective defense against lag pursuit involves simply changing the defender's speed, turn direction, or G. For hot-side lag this generally means tightening the turn, sometimes with a gravity assist by turning nose-low. Cold-side lag is usually countered by a turn reversal, which places the attacker on the inside of the defender's turn in lead pursuit. Such a maneuver results in a rapid decrease in range and may actually cause the attacker to fly out in front of the defender, reversing the roles. This reversal is often more effective when performed nose-high, causing a reduction in the defender's forward velocity and increasing closure. Reversals are quite effective against missiles-only fighters, as these fighters will often quickly pass through the min-range missile boundary unless the lag geometry is just right. For gun-equipped fighters, however, a bogey reversal usually results in at least a snapshot opportunity for the attacker.

> Fighting spirit one must have. Even if a man lacks some of the other qualifications, he can often make up for it in fighting spirit.
>
> Brigadier General Robin Olds, USAF

Lag Displacement Rolls

In the lag-pursuit discussion one method was mentioned for achieving a lag position from a point inside the defender's turn at medium AOT (about 30° to 60° AOT), when the range is only slightly greater than that desired for lag. This method involves relaxing the turn and allowing the nose to drift behind the target, remaining essentially in the same maneuver plane as the target until approaching the desired lag position. When he sees this maneuver, the bogey pilot may assume that the attacker cannot match his turn performance and is about to overshoot. Such an assumption may induce the defender to reverse his turn direction to gain a position advantage on the overshooting attacker—but this often presents the attacker with a gun-shot opportunity instead.

Other initial conditions require different tactics for reaching a lag position. For instance, when approaching the target at close range with high overtake and low AOT (less than about 30°), simply relaxing the turn may not slow the closure fast enough to prevent overshooting. Should the defender reverse in this situation, the attacker could be in real trouble. Figure 2-4 illustrates this case, which begins much like that described in Figure 2-3, except at closer range and with less AOT. Here, the attacker's high closure causes him to fly out in front of the target after the reversal. Technically, any time the attacker crosses behind the target an overshoot has occurred; but this is usually not dangerous unless the target is moving at a slower speed or has a tighter turn radius. Such a situation often results when a missed gun shot is pressed to minimum range with high closure.

Position "1" in Figure 2-4 assumes that the attacker cannot pull sufficient lead for a gun shot (or is not gun equipped) and is inside minimum missile range (or is not missile equipped). To avoid a dangerous overshoot in such a situation it is necessary to stop the closure rapidly. This may be accomplished by a speed reduction, by a hard turn away from the target (reducing the component of velocity in the direction of the target), or by an out-of-plane maneuver. A speed reduction may not be desirable since a

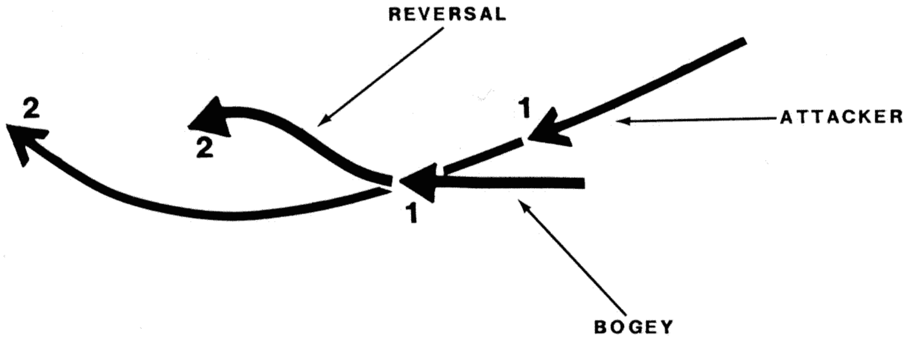

Figure 2-4. Results of an Overshoot

speed advantage often provides a maneuverability advantage (particularly below corner speed), and the attacker may lose maneuvering potential. A hard turn away from the target (pulling toward its extended six o'clock region) in the bogey's plane of turn may cause the attacker to lose sight of the bogey, and also may bleed off valuable energy (speed). Additionally, such a maneuver would make it unlikely that lag pursuit could be reinitiated, and it probably would result in loss of the offensive.

An out-of-plane maneuver is often the best alternative in this situation. Figure 2-5 illustrates one such maneuver, called the lag roll. At point "1" the attacker, in lead pursuit at close range, levels his wings and pulls nose-up out of the defender's plane of turn. The resulting climb reduces speed and the component of velocity in the defender's direction (reducing closure). The attacker continues to pull up, possibly also pulling somewhat toward the bogey's flight path in a rolling-pull maneuver, to ensure

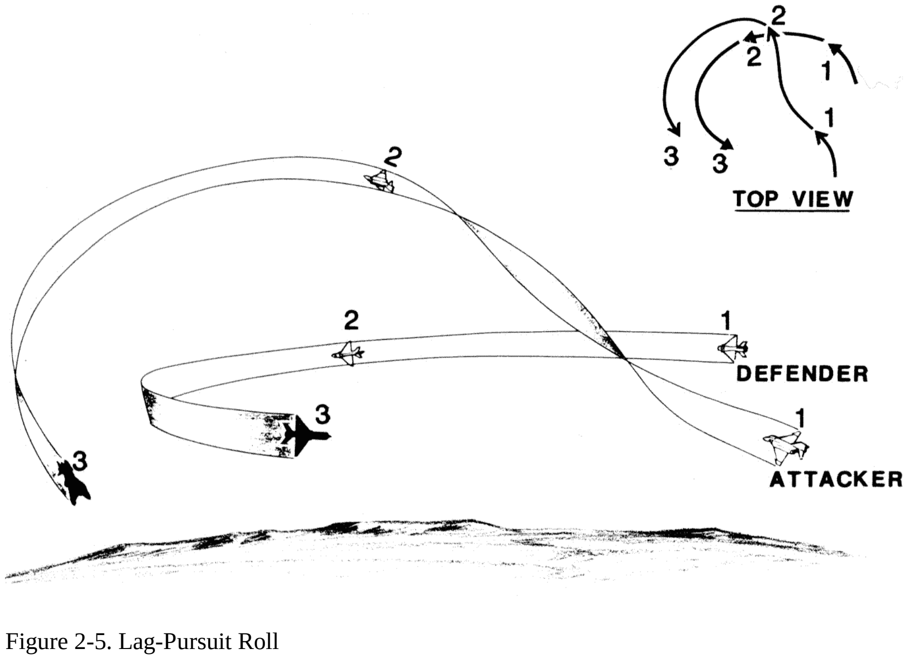

Figure 2-5. Lag-Pursuit Roll

that he passes above and behind the defender as he crosses the bogey's flight path. A slow, continuous roll toward the bogey (here to the right) during this phase of the maneuver enables the attacker to maintain sight throughout, and he passes above and behind the defender essentially inverted, as depicted at point "2." Trading airspeed for altitude in this maneuver allows the attacker to maintain his total energy better than if he had simply pulled more G in a level turn, and low-G conditions once the climb is established may even allow energy addition. From position "2" the attacker benefits from a gravity assist in the nose-low turn, allowing him to pull the bogey closer to the nose and position offensively in lag pursuit.

Should the defender reverse at point "2," the attacker has the options (depending on speed) of performing a second lag roll in the opposite direction or continuing to roll around the bogey's flight path, passing underneath and back into lag on the other side.

The displacement roll is similar to the lag roll, except that it is used in close-range, low-closure situations to reduce AOT and increase range, rather than to prevent an overshoot. This maneuver tends to "displace" the attacker's flight path from inside the bogey's turn toward or to the other side of the defender's flight path. In such nearly co-speed situations lag pursuit is not generally advantageous, so this tactic is primarily of value for positioning the attacker within a missile envelope. It allows the attacker to increase nose-tail separation with the defender (possibly to meet min-range constraints) without reducing speed. After completion of the displacement roll, the attacker will usually be in lag pursuit, requiring him to turn faster than the bogey to point at the target for a boresight missile shot. Essentially the displacement roll trades some angular advantage for increased nose-tail separation and possibly reduced AOT.

After the foregoing description of the lag roll, the following narrative by Colonel Robin Olds, USAF, should have a familiar ring.

> I had another |MiG] in sight at my 10 o'clock, in a left turn ... I pulled sharp left, turned inside him, pulled my nose up about 30 [degrees] above the horizon,... barrel rolled to the right, held my position upside down above and behind the MIG until the proper angular deflection and range parameters were satisfied, completed the rolling maneuver, and fell in behind and below the MIG-21 at his seven o'clock position at about .95 mach. Range was 4500 feet, angle off 15. The MIC obligingly pulled up well above the horizon and exactly down sun. I put the pipper on his tailpipe, received a perfect [missile] growl, squeezed the trigger once, hesitated, then once again. The first Sidewinder leapt in front and within a split second, turned left in a definite and beautiful collision course correction. . . . Suddenly the MIG-21 erupted in a brilliant flash [of] orange flame.[1]

Another variation of the lag roll is known as a barrel-roll attack. This maneuver is useful in making the transition from lead pursuit in the target's beam area or forward hemisphere to a rear-hemisphere position. Such a situation may develop when an attacker is performing lead pursuit against a bogey at fairly long range and the defender turns toward the attacker. At some point the attacker may realize that continued lead pursuit would result in passing the bogey at very high AOT (i.e., in his forward hemisphere). A barrel-roll attack is initiated with a wings-level pull-up and a roll toward the bogey, as with the lag roll. Since the range to the target is considerably greater, however, the climb established is continued for a longer time, resulting in a greater altitude advantage over the defender. Again the rolling pull is timed with the target's motion so the attacker arrives at a position well above the bogey, inverted, before passing slightly behind the defender. As the attacker approaches the overhead position his altitude advantage and gravity assist may provide the opportunity for him to pull hard down toward the target, remaining inside the horizontal boundaries of the bogey's turn, for a "high-side" (i.e., coming down from above and to one side) gun-firing pass. Or, depending on relative aircraft performance, available weapons, or bogey maneuvers, the attacker can delay and moderate his pull-down slightly to arrive at a lag-pursuit position. An illustration of this second option would look much like Figure 2-5, except that, because of the starting conditions, most of the initial phases of the manuever (i.e., the pull-up and roll) would take place in the defender's forward hemisphere. Often there will be a greater heading difference between the fighters at position "2," making lag pursuit impractical. In this case, between times "2" and "3," the attacker may turn steeply nose-low, using lead pursuit to pull inside the bogey's turn. This maneuver keeps nose-tail separation from increasing greatly.

One of the common mistakes made in the employment of lag rolls and barrel-roll attacks is attempting to use them without sufficient initial lead pursuit. Returning to Figure 2-5, note that the attacking and defending aircraft are aligned nearly parallel at time "1." Visualize what would happen if the attacker's nose at time "1" were pointed at, or only slightly ahead of, the bogey. First, as the attacker started his pull-up, the bogey would disappear beneath the nose, requiring the attacker to perform a very quick roll just to maintain sight, and greatly reducing any altitude advantage which may be achieved over the bogey. Without the climb between times "1" and "2," the attacker's forward velocity component may cause him to overshoot the bogey's flight path grossly, or force him to pass too far behind the target, allowing nose-tail separation to increase greatly. The lack of sufficient altitude advantage at time "2" also reduces the gravity assist available to the attacker for pulling his nose back toward the bogey to maintain an angular advantage.

Another common error is beginning the pull-up too late. In order for the attacker to gain the required vertical separation in this case, he must attain a rather high nose attitude. This situation may allow the defender to dive away and gain separation before the attacker can pull back down. Or the bogey may wait until about time "2" and pull sharply up toward the attacker, meeting him on the way down with high AOT, and causing a vertical overshoot.

The attacking fighter may also need a speed advantage over the defender for lag displacement rolls (except for the barrel-roll attack) to work well. If the pull-up is begun in the bogey's rear hemisphere as depicted in Figure 2-5, the attacker must cover considerably more distance than the defender to arrive at position "3" and therefore needs a considerable speed advantage. But if at time "1" the attacker was closer to the target's beam or even slightly into its forward hemisphere, as described for the barrel-roll attack, then the attacker would require less speed to complete the maneuver.

One of the effective defenses against lag displacement rolls and barrel-roll attacks is to dive away in an extension maneuver as the attacker approaches his maximum climb attitude. The defender should simply unload while maintaining his original bank angle, as though he were still turning, during the early part of this extension. Otherwise, the attacker may recognize the tactic and pull back down before sufficient separation can be achieved. The extension may generate enough separation for escape, or it may provide room for a hard turn back into the attacker to negate his position advantage.

Another effective tactic, especially against a barrel-roll attack, is for the defender to execute a simultaneous barrel roll in the opposite direction, i.e., toward the attacker. If he can get his nose higher than the attacker's between times "1" and "2," the defender may be able to reach a rear-hemisphere position on the attacker after completing the roll.

High Yo-Yo

> The Yo-Yo is very difficult to explain. It was first perfected by the well-known Chinese fighter pilot Yo-Yo Noritake. He also found it difficult to explain, being quite devoid of English.
>
> Squadron Leader K. G. Holland, RAF
> Fighter Pilot

Both the lag-roll and the barrel-roll attack may be used to prevent overshooting the flight path of a maneuvering target or to reduce AOT under various conditions. The high yo-yo is also useful for preventing overshoots and reducing AOT, and it is best suited to conditions of moderate AOT (about 30° to 60°), when the attacker is more nearly co-speed with the defender and lacks the excess lead required for lag rolls. As with the various lag displacement rolls, the high yo-yo uses three-dimensional maneuvering rather than increased load factor to reduce horizontal turn radius, thereby allowing the attacker to retain greater energy. Figure 2-6 depicts this maneuver.

At position "1" the attacker is turning in the bogey's plane of maneuver in pure pursuit with rapidly increasing AOT and closure. If this course is continued it could result in an overshoot of the bogey's flight path and loss of the offensive. Therefore, the attacker rolls his wings level (sometimes called a quarter roll or quarter-plane roll) and pulls up, out of the defender's plane of turn. This climb reduces the component of the attacker's velocity which is oriented toward the bogey, eventually stopping the closure, and if it is begun soon enough, it will prevent an overshoot. As the closure slows to nearly zero, the attacker should be high in the defender's rear hemisphere in a nose-high attitude. At point "2" the attacker rolls toward the bogey to place his lift vector ahead of, on, or behind the defender to establish lead, pure, or lag pursuit, respectively. The choice depends pri-

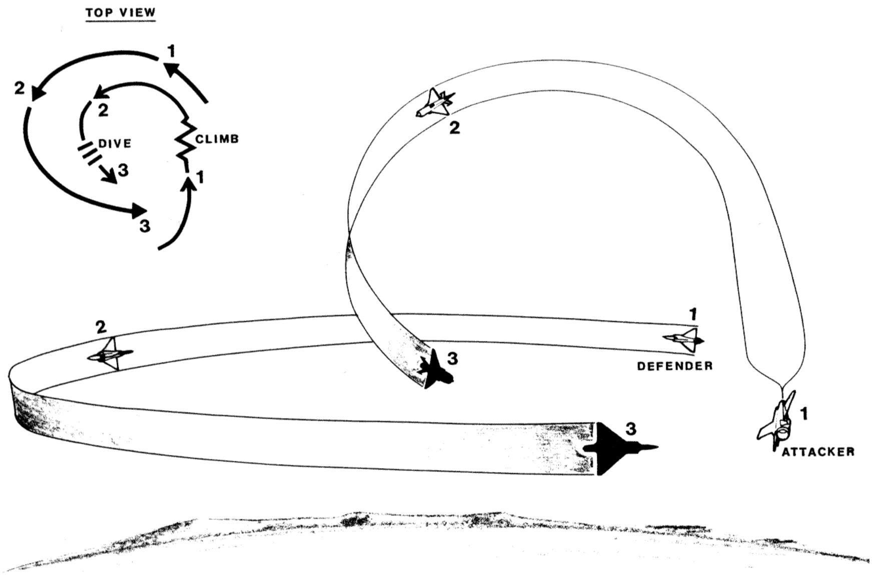

Figure 2-6. High Yo-Yo

manly on the present nose-tail separation and the desired range once the attacker's nose is pointed back toward the defender. In the case depicted the attacker wishes to close the range for a guns pass at point "3," so he pulls for a point ahead of the target's position at point "2" and keeps his nose ahead of the defender throughout the remainder of the rolling, nose-low turn toward point "3."

The lead-pursuit option depicted generally results in the attacker reaching a higher peak altitude, losing more airspeed, and approaching the bogey in a rather steep dive across the circle at point "3." Choosing lag pursuit at point "2" usually will result in the attacker maintaining greater speed but scooping out below the bogey's altitude. The result of this option is usually a hot-side lag-pursuit position looking up at the defender across the circle.

A common error in most out-of-plane offensive maneuvers which have been discussed is to generate excessive pitch attitudes relative to the defender, either nose-up or nose-down. Excessive nose-high pitch may result from beginning a high yo-yo too late. The short range then requires greater pitch attitude to avoid a horizontal overshoot. Once the attacker is very nose-high in the bogey's rear hemisphere, range begins to open very rapidly, affording the defender an opportunity to dive away and gain separation in an extension maneuver.

The excessive nose-down situation usually results from greed on the part of the attacker, when he chooses the lead-pursuit option from the top of a high yo-yo or barrel-roll attack in an attempt for a quick gun shot. If the defender pulls hard up into the plane of this high-side attack after the attacker is committed to being excessively nose-low, the bogey can often generate a vertical overshoot, with the attacker losing the offensive after he passes through the target's altitude. It is important to note that these out-of-plane maneuvers generally will prevent an overshoot and often will improve the attacker's offensive position; but without a significant turn-performance advantage the attacker should not expect an immediate lethal firing position with a boresight weapon.

> The lead *Messcrschmitt* suddenly stopped smoking. It was a complete givcaway; I knew that at this instant he'd cut power. I chopped the throttle to prevent overrunning the enemy fighter. I skidded up to my right, half rolled to my left, wings vertical. He turned sharply to the left; perfect! Now—stick hard back, rudder pedals co-ordinating smoothly. The *Thunderbolt* whirled around, slicing inside the *Messcrschmitt.* I saw the pilot look up behind him, gasping, as the *Thunderbolt* loomed inside of his turn, both wings flaming with all eight guns. This boy had never seen a *Thunderbolt* really roll; he was convinced I'd turned inside him.[2]

Low Yo-Yo

The out-of-plane maneuvers so far discussed have been designed to slow closure and decrease AOT by pulling the attacker's nose (velocity vector) away from and behind the target in the initial phases. The purpose of the low yo-yo is to increase closure and angular advantage with a lead-pursuit out-of-plane maneuver.

A typical scenario for use of this tactic is represented by a fairly long-range (i.e., probably hot-side) lag-pursuit situation, where the attacker does not have the turn capability to pull his nose to the target quickly for a shot, or where doing so would cause excessive speed loss. Figure 2-7 depicts this situation. Here the attacker would like to pull his nose to the bogey for a gun shot, but he lacks the turn capability to accomplish this rapidly in the horizontal plane. The attacker can increase the horizontal component of his turn rate by pulling the nose down toward the inside of the turn. The gravity assist and the ability to generate a horizontal turning component by rolling the aircraft once it is established in a nose-low attitude allow the attacker to position his nose well in front of, but considerably below, the bogey's position. Ideally, the attacker should generate excess lead at point "2" so that he can level his wings, pull up, and fly essentially a straight path to intercept the bogey at the desired range. At point "3" the attacker approaches the bogey's altitude from below and reestablishes his turn in the defender's plane of maneuver as gun-firing range and lead are reached simultaneously.

Obviously, in practice, it is very difficult to make all these events occur at the same time, at point "3." The greater the nose-tail distance at point "1," the more lead will be necessary at point "2" in order to close the range. But the larger the lead angle, the greater the AOT will be at intercept, so there is obviously a practical limit to the available lead angle. At excessive range the attacker can make up all the distance with one low yo-yo only by flying out in front of the defender. Generally, it is more prudent to close the range a little at a time in several steps. The first low yo-yo can close the range somewhat and can be followed by a high yo-yo or barrel-roll attack from position "2" to reduce excess AOT. This sequence can be repeated as necessary. In general, two small yo-yos (high or low) are safer than one big one.

An attempt to make up too much range in one maneuver leaves the

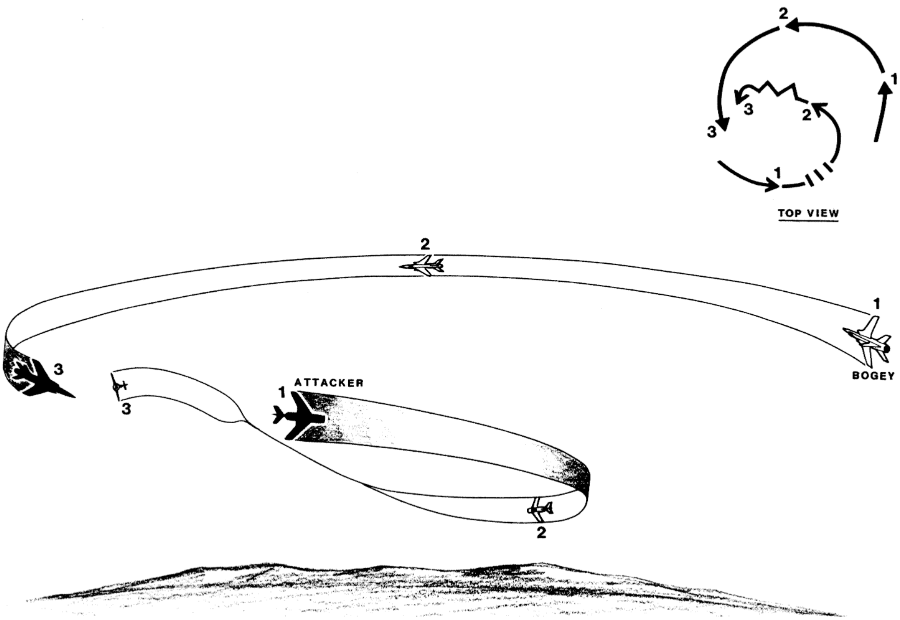

Figure 2-7. Low Yo-Yo

attacker vulnerable to countermoves by the defender. Generally, an attempt to generate large amounts of lead in the low yo-yo results in an excessively nose-low attitude. With sufficient range, greater AOT, and a gravity assist, the defender may be able to pull nose-low down toward the attacker and meet him nearly head-on, neutralizing the attacker's position advantage. Or, if the defender has sufficient energy, he may choose to pull up as the attacker commits his nose too low, and by performing a rolling-pull toward the attacker (essentially a barrel-roll attack) actually achieve a position advantage high in the attacker's rear hemisphere.

> The winner (of an air battle) may have been determined by the amount of time, energy, thought and training an individual has previously accomplished in an effort to increase his ability as a fighter pilot.
>
> Commander Randy "Duke" Cunningham, USN

Lead Turn

The lead turn was discussed in the gun-employment section of Chapter 1 in connection with preparing for a snapshot. In this section "lead" turn is defined as an "early" turn that is started by the attacker before he passes the opponent in a forward-hemisphere approach situation. It does not necessarily connote lead pursuit, and in fact it may be a lag maneuver. Figure 2-8 depicts a lead-turn scenario.

At point "1" the aircraft are converging on opposite headings with offset flight paths. Before the two fighters pass abeam, one of them begins a lead turn toward the flight path of the other (solid tracks), while its opponent

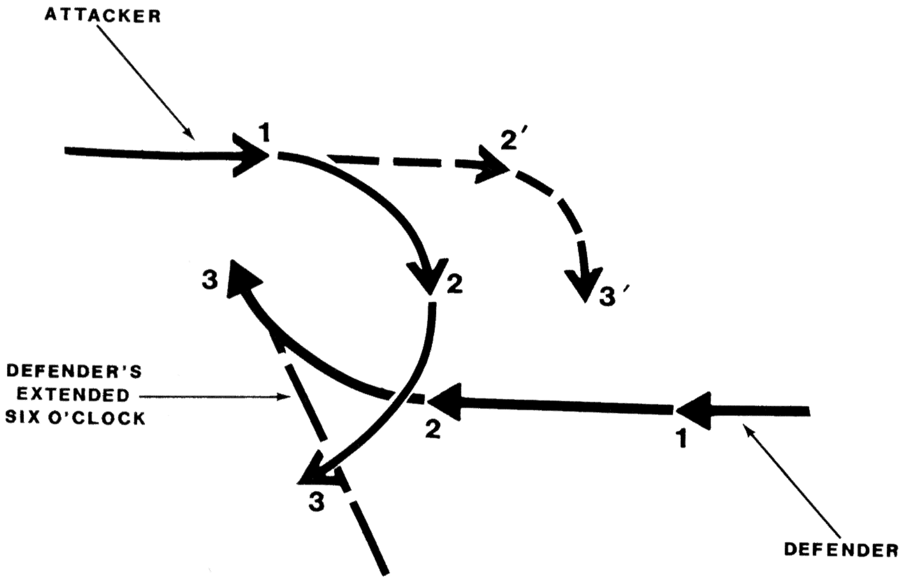

Figure 2-8. Lead Turn

continues straight ahead to point "1" At point "1" the early-turning fighter has a considerable advantage over its opponent. This position may allow a high-angle gun snapshot. At time "2" the defender turns toward the attacker, who then overshoots the defender's six o'clock at time "3" and assumes a temporary lag-pursuit position deep in the defender's rear hemisphere.

For comparison, the broken track shows the result if both pilots wait until they pass abeam before beginning to turn (points "1" and "2’"). At time "3"-"3'," the fighters are still abeam, essentially neutral.

Although the lead turn can be a very effective offensive maneuver, it is not without limitations. The earlier the turn is begun, the greater the potential rewards, but obviously if it is started too soon the attacker will pass in front of the defender's nose. This can be dangerous if the defender is equipped with a short-range, all-aspect weapon such as a gun. It also results in the other blind-lead-turn problems mentioned in the previous chapter. One possible solution to this problem is a slightly out-of-plane lead turn, so that the attacker passes above or below the defender's nose, avoiding a boresight weapons-firing solution.

Another danger of the lead turn is the overshoot potential. In Figure 2-8 the attacker delayed his turn to pass behind the defender, but he overshot the bogey's extended six o'clock position at long range with a track-crossing angle (TCA) of about 90°. TCA is defined as the angular difference in velocity vectors at any instant. As long as turn radii and speed are about equal between the opponents, there is little danger in such an overshoot. If the defender reverses near point "3," he places the attacker on the inside of his turn in lead pursuit and subjects himself to a guns pass. If, however, the defender has a tighter turn-radius capability or slower speed at the time of the overshoot, a reversal may place him inside the attacker's turn, on the offensive, as depicted in Figure 2-4.

The potential danger of an overshoot situation is dependent on many factors, including range, relative turn performance, TCA, and relative speeds. In general, the greatest danger exists for the attacker when overshoots result at close range and low TCAs against a slower bogey with a tighter turn radius, as in Figure 2-4. Against a slower or tighter-turning opponent, the attacker should use caution in employment of the lead turn.

The earlier a lead turn is started, assuming the attacker passes behind the defender, the closer the resulting range and the smaller the TCA at overshoot; both of these conditions can increase the attacker's risk. If the attacker is at a slower speed or has a smaller turn radius, the overshoot risk is reduced and the lead turn may be begun sooner, resulting in greater offensive advantage.

A further consideration in lead turns is a factor called flight-path separation. As shown in Figure 2-9, this is the perpendicular distance from the attacker to the extended flight path of the defender at any moment. In both cases depicted in this figure, the attacker and the defender are co-speed and approaching on opposite courses with each fighter having the same flight-path separation relative to its opponent. In case 1, the attacker's turn radius (RA) is approximately half the flight-path separation, while in case 2 the attacker's turn radius is doubled, about equalling the flight-path separation. In each case the attacker begins a lead turn (time "1") against the nonmaneuvering defender so as to arrive on his flight path with identical nose-tail separation (time "2"). Note that in case 1 the attacker achieves about a 180° angular advantage, while in case 2 (larger turn radius) he gains only about a 90° advantage. In general, the potential angular advantage of a lead turn against a nonmaneuvering opponent is proportional to the ratio of flight-path separation to attacker turn radius when the turn is commenced. The effect of greater attacker turn rate is to allow the lead turn to be started at closer range, while the attacker still achieves maximum angular advantage. This allows less time for the opponent's defensive counter, which usually involves turning toward the attacker to reduce flight-path separation.

Because of these principles, fighters with tight turn radii stand to benefit most from a given flight-path separation. It therefore behooves less-maneuverable fighters to reduce flight-path separation to a minimum by attempting to pass as closely as possible to an opponent in forward-quarter

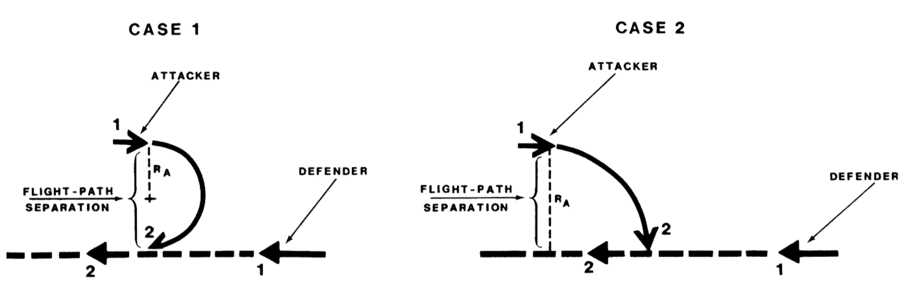

Figure 2-9. Effects of Flight-Path Separation

approach situations. Such flight-path separation may be vertical, lateral, or a combination of both (oblique). This principle is particularly important when one fighter is diving toward a forward-quarter pass with a climbing adversary. The initial portion of the climbing fighter's lead turn will have a gravity assist, giving it a reduced turn radius when compared with the diving fighter, which must oppose gravity in its pull-up. In such situations the pilot of the diving fighter normally should attempt to pass as closely as is feasible above his opponent to preclude an in-plane gravity-assisted lead turn. Unless he is purely vertical, the climbing opponent met with this tactic is forced to turn out-of-plane to receive a gravity assist, to perform a blind lead turn downward, or to complete a purely vertical lead turn, opposing gravity until he is in a vertical attitude.

Although of great benefit, flight-path separation is not essential for a lead turn. A fighter can early-turn its opponent even when the two fighters are meeting head-on on a collision course. In doing so, however, the lead-turning fighter is actually giving its opponent flight-path separation. If the attacker performs a lead turn at too great a range (based on relative speeds and turn performance) the defender may use this separation to gain advantage. Therefore, such a maneuver must be delayed, reducing separation so that the defender will overshoot if he attempts to turn on the attacker. A further consideration of this tactic is the possibility that the attacker may lose sight of the defender, since this is essentially a blind lead turn. Figure 2-10 shows the possible results of this early turn performed properly (case 1) and started too early (case 2). Because of the risks involved, fighters with inferior turn performance (larger radius) or greater speed generally should not attempt this maneuver, since the advantage to be gained seldom justifies the possible consequences. In this case the lead turn should be delayed until the opponent's reaction time does not allow him to counter before the pass has occurred.

Nose-to-Nose and Nose-to-Tail Turns

Nose-to-nose and nose-to-tail turns are two options of fighters meeting in forward-quarter passes. Figure 2-11 graphically defines these maneuvers.

As can be seen from this illustration, the names are fairly descriptive. In the first case, one fighter turns left, across the tail of its opponent, while

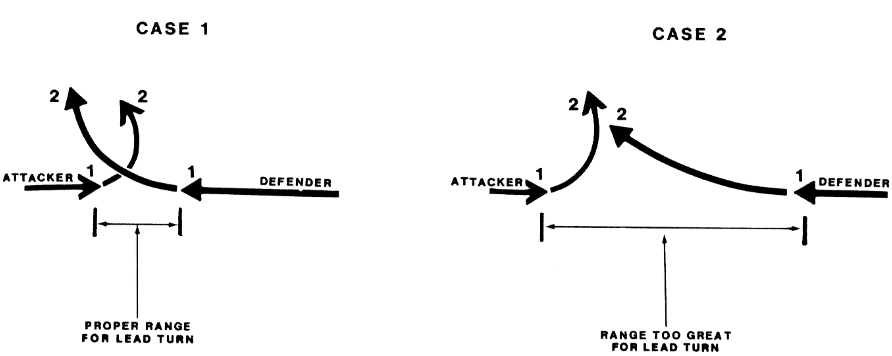

Figure 2-10. Lead Turns without Flight-Path Separation

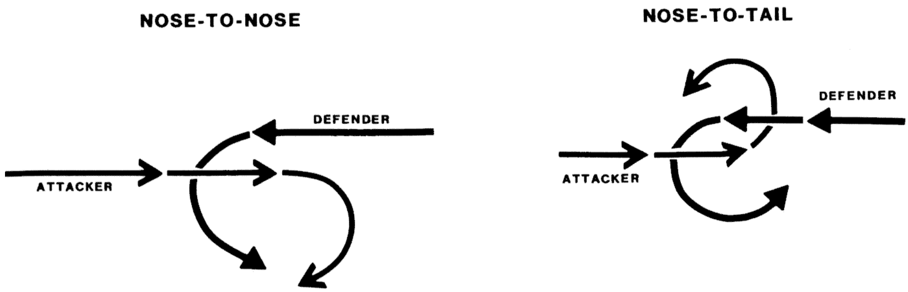

Figure 2-11. Turn Options

the other turns right, away from its adversary, so that the two fighters again approach in a nose-to-nose fashion. In the second, each pilot chooses to cross the other's tail, resulting in a nose-to-tail relationship.

In choosing the nose-to-nose turn, one pilot turns away from his opponent at the pass. In nearly parallel approach situations with considerable flight-path separation, such as that shown in Figure 2-11, this choice may result in a short blind period when the adversary is out of sight behind and beneath the attacker's aircraft. Such a situation could lead to loss of sight if the bogey does something unexpected during this time, but with a fairly close pass this is unlikely. The nose-to-nose option also tends to keep the opponents relatively close together throughout the maneuver, so that maintaining sight is easier. This is to the advantage of the pilot of a larger, easier-to-see fighter, since reduced separation makes it less likely that he will lose sight of an opponent in a smaller aircraft.

The pilot choosing to turn nose-to-nose is giving up any flight-path separation in the plane of his intended maneuver. For this reason, as well as to decrease the blind period in the initial phase of the turn, the attacker should attempt to minimize in-plane flight-path separation at the pass, but some out-of-plane separation may be beneficial. For instance, if he is planning a level nose-to-nose turn, the attacker may make a fairly close pass directly beneath or above the bogey. This tactic eliminates all horizontal flight-path separation (useful to the opponent) and also reduces the blind period.

Figure 2-12 shows the effects of turn-performance variation on nose-to-nose turns. In case 1 the two fighters have the same turn rates, but the attacker has a tighter radius and slower speed. This smaller radius allows the attacker to stay inside the defender's turn, generating flight-path separation that the defender is unable to take away by pointing his aircraft at the attacker. The attacker then uses this separation by reversing at point "3" (lead turn) to arrive at point "4" with good position advantage. Case 2 depicts the same situation, except in this case the fighter with the larger radius also has a much faster turn rate. This turn-rate advantage, however, does the defender very little good. The attacker generates nearly the same flight-path separation, which results in almost the same angular advantage after the lead turn. In practice, relative turn radius largely determines

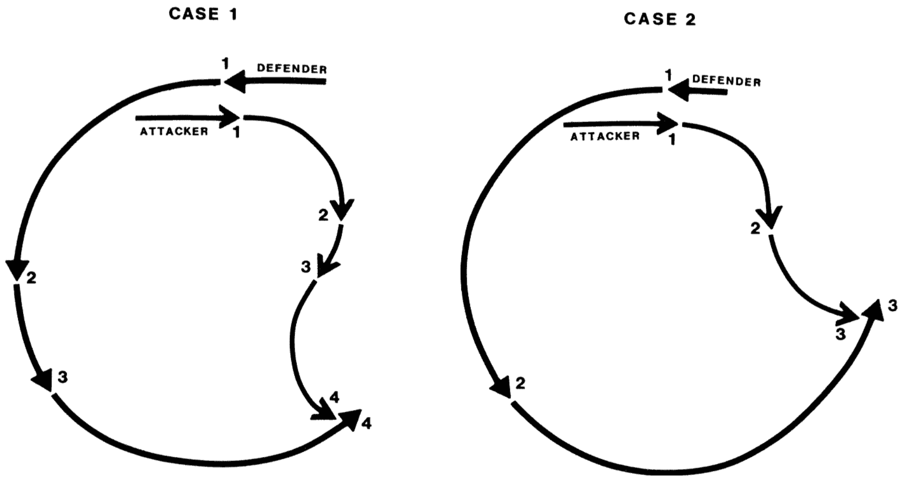

Figure 2-12. Turn-Performance Effects on Nose-to-Nose Turns

potential angular advantage, and turn-rate capability has only a minor effect in nose-to-nose turn situations.

Actually, both turn radius and speed play significant roles in generating advantage in nose-to-nose turns; their relative importance is a function of maximum separation between opponents. This maximum separation occurs as the two fighters reach parallel headings in the maneuver, which in Figure 2-12 (case 1) happens at time "1." Figure 2-13 illustrates the significance of this factor in nose-to-nose geometry.

In each case the attacker (in the fighter nearer the bottom of the figure at time "I") is slower and therefore has a tighter turn radius than the bogey fighter, but about the same turn rate. In case 1 the engagement begins with the fighters side by side and separated by a distance less than the turn radius of either aircraft. Note that very little turning is required by the attacker for him to gain a very good angular advantage at time "3," as the faster bogey essentially just flies out in front of its opponent. When maximum separation (time "1") is less than the larger of the two turn radii, relative speed is the primary factor in determining advantage.

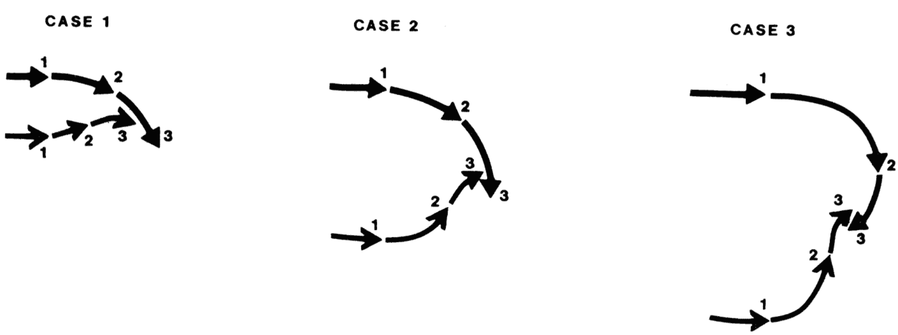

Figure 2-13. Effects of Flight-Path Separation on Nose-to-Nose Turns

In case 2 the fighters again start abeam, but initial separation in this instance is considerably greater than the larger of the two turn radii, and less than the larger turn diameter. (This is also the situation in Figure 2-12.) Here more turning is required, but still the tighter-turning attacker gains a nice bite by time "3." In this situation both radius and relative speeds play a role, but radius is the dominant factor.

Case 3 begins with even greater initial separation, this time exceeding the larger turn diameter. Here the tighter-turning fighter is unable to generate significant flight-path separation and can gain only a very small angular advantage at time "3." Relative speeds contribute essentially nothing in this situation, and a fighter must have a tighter radius to gain any advantage at all.

Figure 2-14 illustrates the effects of turn performance on nose-to-tail maneuvers. In case 1 the two aircraft have identical turn rates, but the attacker has a much smaller radius of turn. From a neutral start at time "1," the fighters maintain their neutrality throughout the maneuver to time "3," and if their paths were continued, the opponents would meet again at their original positions. In this situation a turn-radius advantage did not benefit the attacker, as it did in the nose-to-nose case. The attacker could have gained an advantage, however, if he had chosen to employ a lead turn prior to meeting at time "1," as discussed earlier.

In case 2 the two fighters have the same turn radii, but the attacker has a considerable turn-rate advantage. Note that this situation results in an offensive position advantage by time "3." It is, therefore, primarily turn rate that produces advantage in nose-to-tail maneuvers; however, a radius advantage is also of some benefit as flight-path separation at the pass increases. With greater flight-path separation at the pass, a reduced radius can result in a larger advantage because of lead-turn possibilities.

When planning to use a nose-to-tail turn, the pilot of the better-turning fighter should try to gain some flight-path separation with the bogey, in the

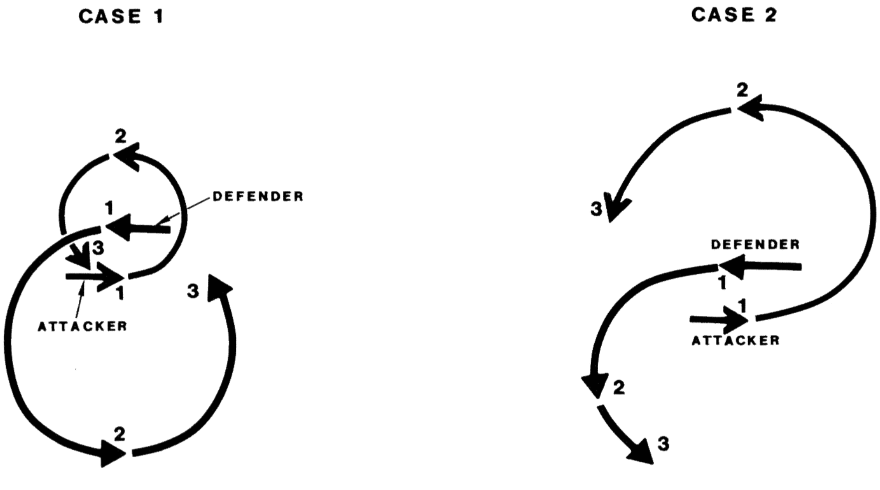

Figure 2-14. Turn-Performance Effects on Nose-to-Tail Turns

plane of the intended turn, before the pass. Generally, this may be achieved by making a small turn away from the bogey before meeting it in forward-quarter approach situations. This separation has considerable impact on the success potential of an early turn, as shown, and it also may reduce or eliminate the blind period occurring at the pass. A very close pass can result in a considerable blind period for the attacker if the bogey crosses the attacker's tail and flies toward his belly-side during the nose-to-tail maneuver. Passing slightly above or below the opponent is not as effective in reducing this blind period as it is with nose-to-nose turns.

Nose-to-tail turns, in general, result in greater separation between opponents during the maneuver, increasing the possibility of losing sight of an opponent in a smaller aircraft, and offering the opponent a better opportunity to escape if he desires. The greater resulting separation may, however, facilitate satisfying weapons minimum-range constraints.

So far this discussion has been limited to nose-to-nose and nose-to-tail turns in the near-horizontal plane. Obviously these maneuvers may occur in any plane, and the near-vertical case is interesting, particularly for nose-to-nose situations. Figure 2-15 illustrates this case. Here the fighters meet essentially head-on and both immediately pull straight up vertically, creating a nose-to-nose condition. Both fighters have similar turn rates, but one has a considerably smaller radius because of less airspeed. From the previous discussion it would be expected that the tighter-turning fighter would gain an advantage from this maneuver, and indeed it does at time "3," where it has generated some flight-path separation.

If the tighter-turning fighter is equipped with a weapon that can be fired effectively from position "3," this may be the end of the story. This generally is not a good gun snapshot opportunity, however, unless the high fighter is very slow and separation is minimal. Likewise, the rather close range and high aspect involved would cause minimum-range problems for most missiles.

If he is unable to fire, the attacker must reverse for a lead turn to

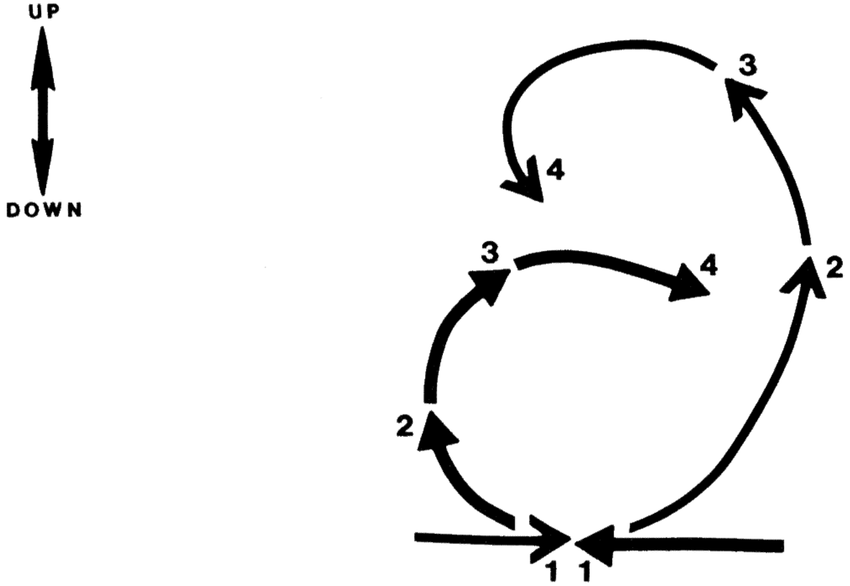

Figure 2-15. Nose-to-Nose in the Vertical Plane

capitalize on his flight-path separation. In this case, however, the aircraft does not have sufficient energy performance to execute a second vertical maneuver at the top of the first. Unable to press his advantage, the pilot of the lower fighter is forced to level off or to dive to regain airspeed. This may allow the high-energy fighter to employ its gravity assist, taking full advantage of the resulting separation to convert to an effective offensive position at time "4." The moral of this story is: Flight-path separation is of little value if it can't be used.

Flat Scissors

The flat scissors is actually a series of nose-to-nose turns and overshoots performed by two fighters essentially in the same maneuver plane, each pilot attempting to get behind the other. Figure 2-16 illustrates a flat-scissors series. In this scenario both fighters have about the same turn-rate capability, but the fighter near the bottom of the figure at time "1" is slower and therefore has a tighter radius of turn. At time "1" the fighters begin side by side, neither having an advantage, and each pilot turns toward the other in an attempt to get behind his opponent. The shorter turn radius of the slower fighter allows it to remain inside its opponent's turn approaching time "2." In this way lateral separation that can be used for a lead turn is created between the two flight paths. This flight-path separation cannot be used by the faster fighter, since it is already turning as hard as possible to the right and would have to turn even harder to perform a lead turn. The slower fighter, however, can reverse its turn direction prior to passing its opponent and gain an angular advantage at the first pass. Although the lead-turning fighter overshoots its opponent's flight path at about time "1," there is little danger because of the opponent's faster speed. Noting this overshoot, the pilot of the faster fighter reverses at time "2" in order to maintain sight of his adversary. This reinitiates a nose-to-nose situation, and by time "3" the slower fighter has a significant angular advantage. At this time another reversal allows the slower fighter to maintain its angular advantage while closing to gun-firing parameters at time "4." The segment of the attacker's turn from time "3" to time "4" is said to be "in phase" with his opponent (i.e., both are turning in the same

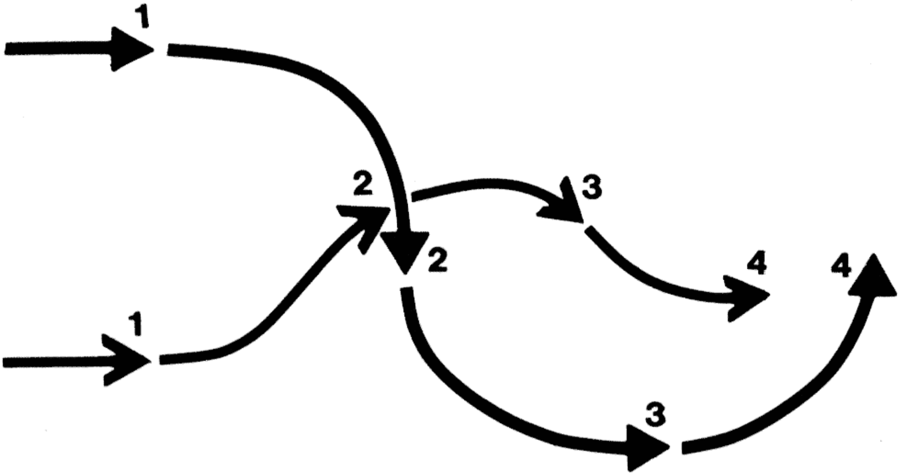

Figure 2-16. Flat Scissors

direction). Although the engagement was determined rather quickly here because of the large disparity in speed, in more evenly matched situations the crisscrossing of the flat scissors may continue for several cycles before one fighter gains a significant advantage.

This maneuver is best analyzed in phases: the nose-to-nose turn, the reversal, and the lead turn. Each of these phases normally is repeated in order during each cycle of the flat scissors.

During the nose-to-nose phase each pilot attempts to get the nose of his aircraft pointed at the opponent first to produce flight-path separation inside the other's turn which cannot be taken away. In general, the slower or tighter-turning fighter will win this phase, as illustrated in Figure 2-13. The flat scissors tends to draw fighters closer and closer together, so speed usually remains the determining factor in the nose-to-nose phase as long as the scissors maneuver continues. To gain advantage during this phase, a fighter should decelerate as quickly as possible.

After one fighter has generated some separation, it must reverse and lead-turn its opponent in order to gain further advantage. Reversal technique and timing are critical to success in the scissors. First, the rolling reversal should be as rapid as possible. This usually involves unloading the aircraft and applying full roll controls, as described in the Appendix. Each fraction of a second during the reversal the aircraft is traveling essentially in a straight line, wasting valuable turning time and decreasing hard-won separation. A significant roll-performance advantage can negate a substantial speed differential.

The timing of the reversal determines the TCA at the overshoot, with an early reversal resulting in lower TCA and subsequently greater angular advantage (lower AOT) later in the maneuver. The reversal point also controls the nose-tail separation at the overshoot, however. The longer the reversal is delayed, the greater the separation will be when the overshoot occurs. Assuming the opponent reverses at the overshoot, setting up another nose-to-nose situation and continuation of the scissors, the nose-tail separation at overshoot is directly related to the range and AOT the next time the attacker's nose is pointed toward the target. Figure 2-17 illustrates this relationship.

In case 1 the two fighters are in the initial nose-to-nose phase of a flat scissors at time "1" Both fighters here have about the same turn rate, but

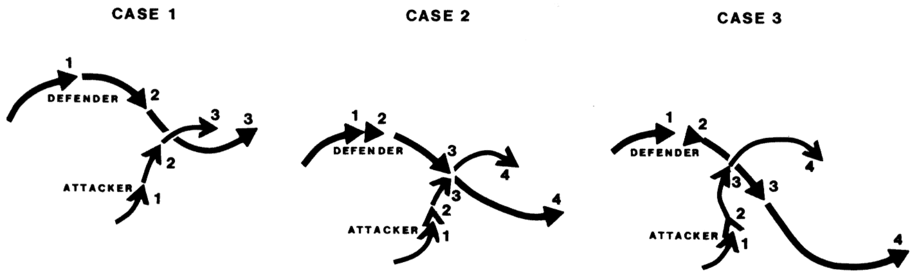

Figure 2-17. Effects of Reversal Timing

one (the attacker) is slower, with a tighter radius, and has gained some advantage. Recognizing this advantage (i.e., recognizing that he can point at his opponent first), the attacker reverses immediately, while his nose is still pointed well ahead of the defender. Turning away from the opponent at this point actually gives away the flight-path separation the attacker has developed, by allowing the defender to point his aircraft at the attacker first. In effect, the attacker has traded this separation for an early lead turn. Realizing the attacker is going to fly across his nose, the defender also reverses at time "1." If the defender is gun equipped he may have a snapshot opportunity here, but in this case his higher speed causes him to overshoot with little nose-tail separation and low TCA, flying out in front of the attacker. At time "3," the attacker has his nose on the defender at very close range and small AOT. Against an opponent with a gun, or a missile with a short min-range, this tactic (passing ahead of the target) is not recommended. Otherwise, as long as the attacker is slower, the early lead turn can result in a very lethal position advantage for him. Up to a point, the earlier the lead turn, the greater the final advantage. The "point," of course, is when the final nose-tail separation is reduced to zero. Any earlier lead turn than this may result in at least a temporary bogey position advantage. The slower the attacker's speed relative to the defender, the earlier he can reverse, and, in general, the greater advantage he can achieve without taking this risk.

In case 2 the same fighters are at the same starting conditions at time "1" This time the attacker delays his reversal until time "2," causing him to pass directly above or below the defender at point "3." At this time the defender reverses, again setting up a nose-to-nose condition, and the attacker brings his nose to bear on the bogey at time "4." The attacker's resulting position is at longer range and greater AOT than that in case 1. Such a position may be preferable if the attacker is not gun equipped, as the greater separation may satisfy missile min-range requirements.

In case 3 the setup, once again, is the same, but the attacker delays his reversal even longer, in this instance until he is pointed at the defender at time "2." This causes the attacker to cross some distance behind the defender at time "3," as the bogey reverses, and results in further increases in range and AOT at time "4."

This sequence of examples serves to highlight the importance of reversal timing in execution of the flat scissors. In general, an early reversal reduces final separation and AOT. The optimum timing depends largely on the range and AOT constraints of the attacker's firing envelope. Relative speeds, turn-radius capabilities, and defender's weapons also play a role. In general, however, the earliest possible reversals lead to the earliest advantage for a gun-equipped fighter.

In such a highly dynamic situation, reversal timing is very subjective. Practice, experience, and an ability to judge relative motion are the determining factors in the outcome of this maneuver, particularly when the aircraft are equally matched.

The lead-turn phase of the flat scissors begins at the attacker's reversal and ends when the defender reverses. The dynamics of this phase are essentially the same as for any lead turn, as previously detailed, and so are not discussed further here. In general, as one fighter begins to gain an advantage in the flat scissors the nose-to-nose phase will become shorter and the lead-turn portion will last longer. In this way the winning fighter begins to get "in phase" with the defender's maneuvers, and eventually the attacker will not overshoot during the lead turn. This event will terminate the scissors.

For obvious reasons, the flat scissors is a very desirable maneuver for fighters that enjoy a low-speed turn-performance advantage (i.e., fighters with lower wing loading, as explained in the Appendix). Less maneuverable, high-speed fighters should avoid this situation like the plague. The scissors is avoided by maintaining sufficient speed for vertical maneuvering and by simply refusing to engage in a co-planar nose-to-nose turn with a slower, better-turning opponent. If a pilot is trapped in such a situation, the sooner he recognizes his disadvantage, the better his chances are for escape. If the defender has an energy advantage, he may be able to pull up at the overshoot and gain separation in the vertical. Figure 2-18 illustrates a means of disengaging in slow-speed situations.

The initial conditions of this setup are the same as those in case 2 of Figure 2-17. This time when the attacker reverses and overshoots at point "2," the defender does not reverse, but continues his hard right nose-to-tail turn until he regains sight of the attacker deep in the rear quarter at time "3." At this point the defender begins an extension maneuver to gain speed and separation, continuing to turn only enough to maintain sight. By time "4" the attacker is beginning to bring his nose around to point at the defender. If the attacker is equipped with only guns or short-range missiles, the extension may already have created enough separation to exceed the attacker's maximum firing range. In this case the defender may continue

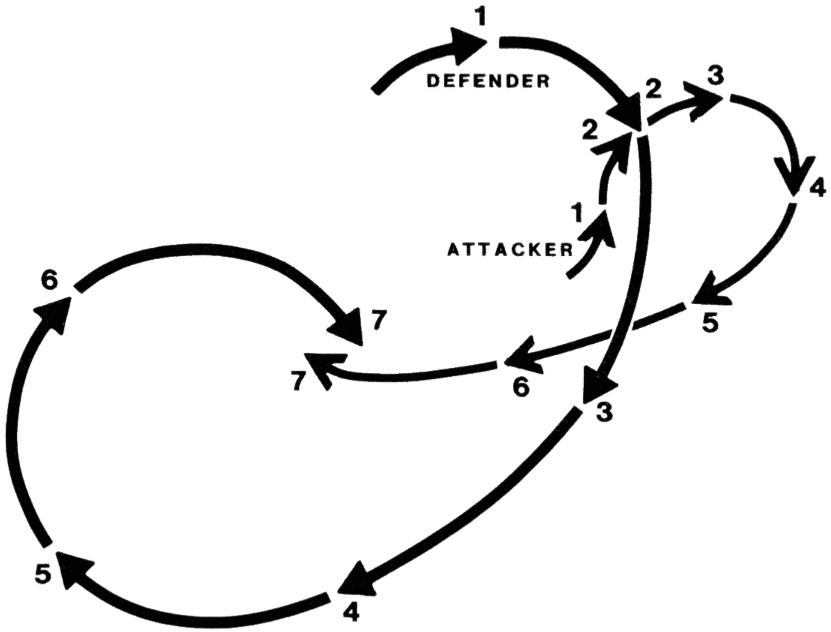

Figure 2-18. Disengaging from a Flat Scissors

his extension to escape, provided he can maintain a speed advantage. If the separation is not sufficient (time "4"), the defender can begin a hard turn back toward the attacker to defend against a possible weapons firing. If he is placed out of firing parameters by this turn, the attacker may be expected to use lead-, pure-, and lag-pursuit techniques to close the range and reattempt to get inside the defender's flight path. The defender's intent should be to get his nose back on the attacker to take out any flight-path separation and to maximize the TCA at the next pass. This he accomplishes at point "7," meeting the attacker with close to a 180° TCA. From this position the defender can engage from a neutral start, or he can repeat his extension maneuver, gain even more separation, and probably escape.

Still another option exists for fighters that have a climb-rate advantage at slow speeds. This involves continuing the flat scissors, but simultaneously climbing at a steeper and steeper angle. A lower-powered opponent will not be able to match this climb angle and must remain in a more horizontal maneuver plane. The defender's greater climb angle reduces the forward component of velocity relative to that of the attacker, possibly leading to a position advantage for the high fighter, assuming speed differential is small.

Vertical and Oblique Turns

The Appendix discusses gravity effects on turn performance. Gravity effects are investigated here to determine how they may be used to advantage in air combat.

Turn performance is dependent on radial acceleration (G_R), which is the vector sum of load factor and gravity. This vector sum is determined by the aircraft's roll and pitch attitude, as shown in the Appendix and in Figures A-18 and A-19. At a given speed, turn performance is directly proportional to G_R, resulting in improved performance when the lift vector is below the horizon, and vice versa. A further consideration is the orientation of the lift vector relative to the gravity (weight) vector. When these two vectors remain in the same plane (i.e., during purely vertical maneuvering) the gravity effect is maximized, both positively and negatively, and the entire lift vector contributes to G_R. From a purely geometrical viewpoint, these relationships mean that for a 360° turn, the vertical plane maximizes turn performance, while a horizontal turn produces the poorest average performance. Performance in oblique turns will vary between these two extremes according to the steepness of the maneuver plane. In a purely vertical maneuver the adverse effects of gravity on turn performance through the bottom half of the loop are offset by the gravity assist over the top, while in a level turn the aircraft must fight gravity throughout.

As a practical matter, however, this phenomenon is of much less importance than average aircraft speed during the maneuver. Turn performance (both radius and rate) is optimized near corner speed; therefore, the maneuver plane that allows the fighter to remain closest to its corner speed for the duration of the maneuver generally will optimize turn performance. If an aircraft is at or below its corner speed, a nose-low vertical or oblique turn may allow a power-limited fighter to remain near optimum speed for maximum performance. Conversely, a nose-high maneuver tends to reduce excess speed.

Since many fighters are unable to maintain corner speed at maximum G (i.e., they are power limited under these conditions), nose-low spirals often maximize turn performance for them. The optimum descent angle depends on many factors, even for the same aircraft with the same power. These factors include weight, configuration, and altitude; greater weight, increased drag, and higher altitude usually require steeper descents.

The fighter pilot is concerned not only with optimizing absolute turn performance, however, but also with his performance relative to that of his opponent. Maximum performance is of little value if the aircraft is turning in the wrong direction. For instance, if a defender wishes only to maximize AOT for an attacker in the rear hemisphere, the defender generally should turn toward the attacker in the plane of the attack, assuming his aircraft is physically able to maneuver in this plane. This usually is accomplished in high-G situations by rolling to place the opponent near the vertical-longitudinal plane (i.e., perpendicular to the wings) so that all the radial acceleration is working in the right direction. If both fighters are using the same technique this results in co-planar maneuvering.

Placement of the radial-acceleration vector, which for simplicity can be called the lift vector, may be compared with placement of the velocity vector in performing lead, pure, or lag pursuit. Since these two vectors define the maneuver plane, the velocity vector will follow where the lift vector pulls it. Placing the lift vector ahead of or behind the target in out-of-plane maneuvers is essentially lead or lag pursuit, respectively, and is used for the same reasons lead or lag pursuit are used, as demonstrated by the lag displacement rolls and yo-yos.

It has been shown that turn radius is important in many maneuvers, such as nose-to-nose turns. The fighter pilot is concerned primarily with the projection of his radius in the maneuver plane of his opponent. Figure 2-19 illustrates this principle.

In this example the opposing fighters meet on opposite headings, and one (the defender) chooses to turn horizontally while the other (the attacker) pulls straight up vertically. At time "2" each has completed about 90° of turn in its respective plane, and neither has any great advantage. At this point the attacker is in a near-vertical attitude and rolls to point his lift vector ahead of his opponent's position in a lead-pursuit maneuver, predicting the bogey's future position across the circle. As the attacker peaks out at the top of his "pitch-back" maneuver, his nose is oriented toward a point almost directly above the defender at time "3." Looking at the top view of this maneuver (i.e., looking straight down from above) reveals that the change of vertical maneuver planes in the nose-high pitch-back has essentially had the effect of reducing the attacker's turn radius in the horizontal plane, which is the plane of the opponent's maneuver. As with other nose-to-nose maneuvers, this smaller radius has given the attacker flight-path separation, this time both vertically and horizontally. He also has an angular advantage, largely because of his tighter horizontal turn radius and the nose-to-nose geometry.

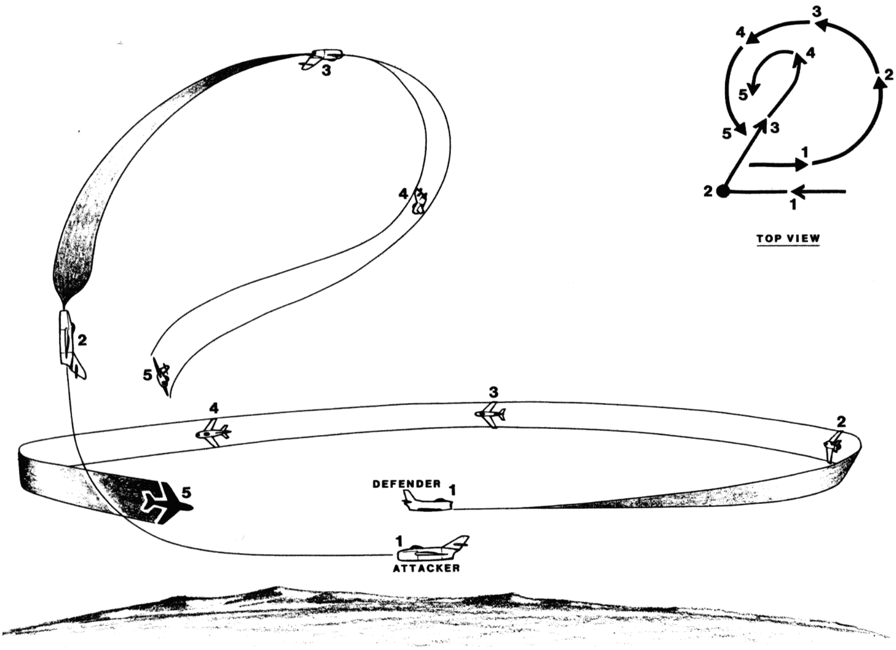

Figure 2-19. Vertical versus Horizontal Maneuvering

At time "3" the attacker could pull down inverted to point at the target for a boresight, forward-hemisphere missile shot, if he is so equipped; but, as was explained, the look-down involved may not be optimum for missile seeker performance. In this case the attacker chooses to fly essentially a straight path along the top of his maneuver, accelerating to improve his turn capability. During this period his nose drifts into a lag position as the defender passes underneath. At time "4" the attacker begins a pull-down, using the increased turn rate and decreased radius provided by the oblique-turn geometry and the gravity assist to gain a very advantageous offensive position in the defender's rear hemisphere at time "5."

A lead-pursuit roll at time "2" usually results in a steeper dive and somewhat greater potential angular advantage for the attacker than do the pure- or lag-pursuit options; but the cautions mentioned in the high yo-yo and barrel-roll attack discussions also apply here.

The effects of vertical and oblique maneuvers on an aircraft's energy state can also influence the outcome of an engagement. Possibly the best way to approach this concept is to determine the fighter's sustained-G capabilities (level, constant speed) at its given conditions of weight, power, configuration, and altitude. If a fighter is in a descending or climbing maneuver, this same load factor cannot be exceeded without loss of energy. For instance, in a nose-low oblique turn the rate of descent is equivalent to negative specific excess power (P_S). (See the energy-maneuverability discussion in the Appendix for an explanation of P_S.) If the pilot adjusts load factor to maintain constant speed, he is losing energy in proportion to his descent rate, but he is also increasing his turn rate. In order to maintain energy in such a maneuver he must reduce G and constantly accelerate, which would result in approximately the same turn rate in this oblique maneuver plane that he could achieve in a level, constant-speed turn at his altitude. However, if speed is allowed to increase to a value higher than that best for sustained maneuvering, allowable G for maintaining energy will decrease further. Likewise, even unloaded dives at speeds higher than maximum level airspeed may reduce total energy, even if the aircraft continues to accelerate.

Rolling Scissors

While a flat scissors often follows a slow-speed, horizontal overshoot, the rolling scissors more often results from a high-speed overshoot or an overshoot resulting from a high-to-low attack. In this situation, the defender pulls up to reduce both speed and the forward component of his velocity, further adding to the attacker's overshoot problems; then he rolls toward his opponent, continuing to pull the nose directly toward the attacker's constantly changing position. If the attacker continues to pull directly toward the defender, the fighters begin to develop twin spiraling flight paths as each performs barrel rolls around the other. Figure 2-20 depicts this scenario.

Here the attacking fighter (MiG-21) overshoots the defender (F-5E) with high TCA in a nose-down attitude at time "2." Recognizing the impending overshoot, the defender rolls 90° away from the direction of the initial attack (quarter rolls away) and begins to pull up into the vertical. As the overshoot occurs the defender rolls to keep his lift vector pointed toward

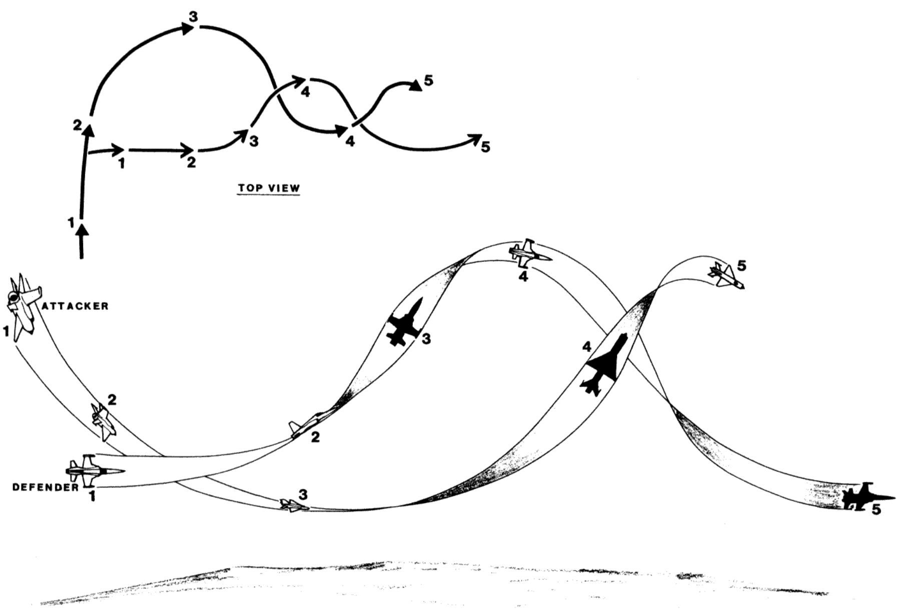

Figure 2-20. Rolling Scissors

the bogey and continues to pull to maximize the overshoot. Simultaneously the attacker is rolling to keep his lift vector on the defender in an attempt to point at his target. The defender's reduced airspeed and higher nose attitude approaching time "3" provide what appears to be a much-improved position at time "4," well above and slightly behind his opponent. The fighters continue to pull toward each other, with the MiG nose-high and the F-5E nose-low until point "5." At this time the advantage appears to have reversed. As long as the scissors is fairly neutral, the fighter at the top of its rolling maneuver will appear to have a position advantage but will lose it again on the bottom.

Success in this maneuver, as in most others, depends on both relative aircraft performance and pilot technique. Unlike the flat scissors, the rolling variety is not a contest determined by which fighter can fly slower. Although the forward component of velocity is still the deciding factor, the helix angle (i.e., the steepness of the climbs and dives) usually has more impact on this velocity component than does absolute speed, assuming speed differentials are not excessive. The rolling scissors is, therefore, a contest of energy management, a trade-off of airspeed and position in which slow-speed sustained turn performance is a critical factor, with slow-speed acceleration and controllability also very important. Figure 2-21 illustrates the techniques involved in winning the rolling scissors.

The initial setup in this scenario is the same as that in the last example. Both aircraft have about equal energy and performance, and the MiG (the

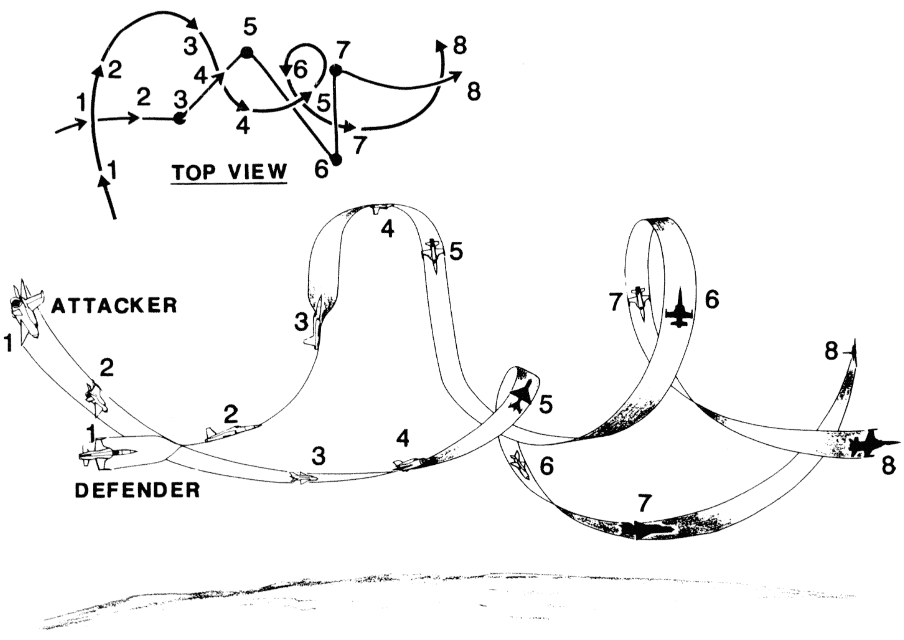

Figure 2-21. Rolling-Scissors Technique

attacker) will use the same tactics as before—that is, continuously pulling toward the defender. But this time, rather than rolling toward the attacker between times "2" and "3," the defender continues to pull straight up into the vertical. Once vertical, this fighter rolls quickly, placing its lift vector ahead of the attacker's position (lead pursuit), just as shown in Figure 2-19. Unlike the example in Figure 2-19, however, the opponent (i.e., the attacker) here is not restricted to horizontal maneuvering, and so he pulls up obliquely toward the high fighter, reducing the flight-path separation generated by the vertical maneuver of the defender.

The direction chosen by the defender to stop his roll at time "3" is calculated so that the inverted, wings-level pull-down will place him at point "4," the peak of the maneuver, with his nose aimed at a point almost directly above the bogey's predicted position at that time. Again returning to Figure 2-19, this situation is analogous to time "3" in that example. The horizontal depictions (i.e., top views) of both these examples show that each is essentially a nose-to-nose maneuver to this point. The high fighter's vertical move has created vertical separation, and pointing its nose directly at the opponent (as viewed from above) as quickly as possible has maximized its angular advantage. The next phase of the high fighter's maneuver will be designed to take advantage of its separation, by use of nose-to-tail geometry and a gravity assist, and to convert to the greatest position advantage.

In Figure 2-21, the F-5E passes directly over the MiG at time "4" and pulls down vertically into the MiG's rear hemisphere. This maneuver causes the MiG pilot to reverse his turn, rolling to the left in order to keep his lift vector on the high fighter and also to help maintain sight. These requirements deny him the opportunity to go purely vertical, and he is forced to keep his flight path in an oblique plane, which increases his forward speed across the ground relative to that of his opponent.

> The important thing in [tactics] is to suppress the enemy's useful actions but allow his useless actions. However, doing this alone is defensive.
>
> Miyamoto Musashi (1584-1645)
> Japanese *Samurai* and Philosopher
> More Than 60 Victories in Hand-to-Hand Combat

By selecting a lead roll at time "3" and maintaining a constant maneuver plane until time "5," the high fighter has in effect "averaged out" the opponent's position during that time. Lead pursuit is being employed during the first half of the inverted pull-down, and lag pursuit results during the last half, which has nearly the same effect as pure pursuit (i.e., keeping the lift vector on the bogey) throughout the pull-down. This technique maximizes the angular gain as well as the energy efficiency of the high fighter.

Approaching position "5," the F-5E pilot determines that insufficient separation has been generated to avoid an overshoot. Therefore, in a purely vertical dive, he performs another lead roll and pulls wings-level through the bottom of his maneuver, passing as closely as possible behind the bogey. This portion of the maneuver is analogous to the reversal and subsequent overshoot described in the flat scissors. The more aggressive the lead roll at time "5," the smaller the high fighter's nose-tail separation and TCA will be at the overshoot. If this lead is overdone, it is possible to squirt out in front of the bogey at the overshoot and lose the offensive. If insufficient lead is taken, the high fighter will pass well behind the MiG at the bottom of the maneuver, giving away valuable separation that the opponent can use to turn around and bring his nose to bear as the F-5E approaches the top of its next vertical move.

An extremely important further consideration in this phase is the high fighter's airspeed as he begins his pull-out. Since another vertical move is planned after the impending overshoot, the pilot must ensure adequate airspeed at the bottom of the loop to enable him to complete the maneuver with good control over the top. This airspeed should be gained as quickly as possible in an unloaded dive at about time "5." The pull-out can begin as the required airspeed is approached, using a load factor near sustained-G capability for that particular airspeed/altitude condition. With two fighters closely matched in energy performance this will usually result in the diving fighter bottoming out below the altitude of its opponent at the overshoot. This situation is acceptable as long as the altitude differential is not so great as to allow the bogey to pull down for a gun snapshot as the diving fighter passes underneath. On the other hand, it is not advantageous for the pilot of the diving fighter to delay the pull-out after reaching his desired speed, since it is preferable to pass above the bogey if possible.

After the overshoot the F-5E continues to pull to the pure vertical at time "6" and rolls as before to aim at a point calculated to be directly above his opponent's position when the F-5E reaches the top of the loop. Pulling over the top of each vertical maneuver it is important that the pilot of the high fighter not hesitate or "float" in an unloaded condition, but continue to apply G to get his nose back down expeditiously. Any delay coming over the top allows the bogey time to get its nose higher, slowing its forward velocity and also reducing flight-path separation. The proper amount of G to be used across the top of each loop is generally small (in the range of 1 to 2 Gs), since most fighters will be slow and unable to pull much more at this point. (If the fighter is not slow on top, excessive speed was probably attained in the preceding pull-out.) Added to the 1 G of gravity, however, this load factor can produce substantial turn performance at slow speeds. Maximum-attainable G should be used over the top of each loop, unlike in the bottom of the maneuver, when sustained-G levels are appropriate.

One further note about coming over the top of the loop: It is not necessary for the attacker to cross over the bogey's flight path at this point (as shown in Figure 2-21) for the rolling scissors to work. Depending on how hard the bogey turns, it may be necessary to delay the pull-down in order to ensure crossing its flight path. This is not advantageous, as any delay reduces subsequent advantage. In this situation it is better to pull down inside the opponent's horizontal flight path, as illustrated in Figure 2-19. Unless it is determined that an overshoot can be avoided at the bottom of the maneuver, however, care should be taken to ensure that the pull-down is continued to a vertical attitude.

At position "7" in this example the high fighter has the necessary separation to avoid another overshoot, so rather than the lead roll and wings-level pull-out as before, it performs a rolling pull-out to arrive at an offensive lag-pursuit position at time "8."

In case things do not work out quite as smoothly as he would wish, the defender (in the F-5E) may wish to disengage from the rolling scissors and exit the fight. The time to make this decision is during the pull-down to the vertical dives, positions "5" and "7" in this example. If things do not look rosy at such times, the pilot of the high fighter should modify his pull-out to minimize separation and maximize TCA at the next pass. Ideally he would like to pass directly over the bogey on an exactly opposite heading (180° TCA) and dive away in an extension as described in Figure 2-18.

> To get ability you need good training.
>
> Colonel Erich "Bubi" Hartmann, GAP

To recap, the most efficient technique in the rolling scissors limits all turning to vertical planes (i.e., wings-level pull-ups and pull-downs) until purely vertical attitudes are reached. All heading changes (horizontal turns) are performed by rolling in the vertical attitude. Lead rolls are normally employed in both the climbs and the dives. Max-G should be used over the top of each loop, and sustained-G levels are maintained along the bottom. Speed control is very important, particularly in the pull-out.

Returning to Figure 2-21 for a moment, consider that the condition that precipitated the rolling scissors, and the eventual loss of the offensive for the attacker, was the overshoot that occurred between times "1" and "1." If the attacker had recognized the situation earlier he could have rolled his wings level (performed a quarter roll) at time "1," pulled up vertically to minimize his overshoot (as with the high yo-yo), and probably retained the offensive even if a rolling scissors had resulted.

When both fighters are fairly evenly matched in performance and use the tactics outlined here, the rolling scissors often evolves into a co-planar tail-chase in the vertical plane. The same techniques still apply, except that no rolls are required. The successful pilot must control speed, modulate load factor with airspeed for best sustained performance, and pull lead (i.e., use max-G) across the top of the loop and lag (use sustained G) along the bottom.

> The most important thing for a fighter pilot is to get his first victory without too much shock.
>
> Colonel Werner Moelders, Luftwaffe
> 115 Victories, WW-II and Spanish Civil War

Defensive Spiral

The defensive spiral is essentially a very tight rolling scissors going straight down. It quite often results when one fighter has achieved a close-in, rear-hemisphere position against a slow-speed opponent. Figure 2-22 depicts an example of this maneuver.

In order to generate some AOT to spoil a guns-tracking solution, the

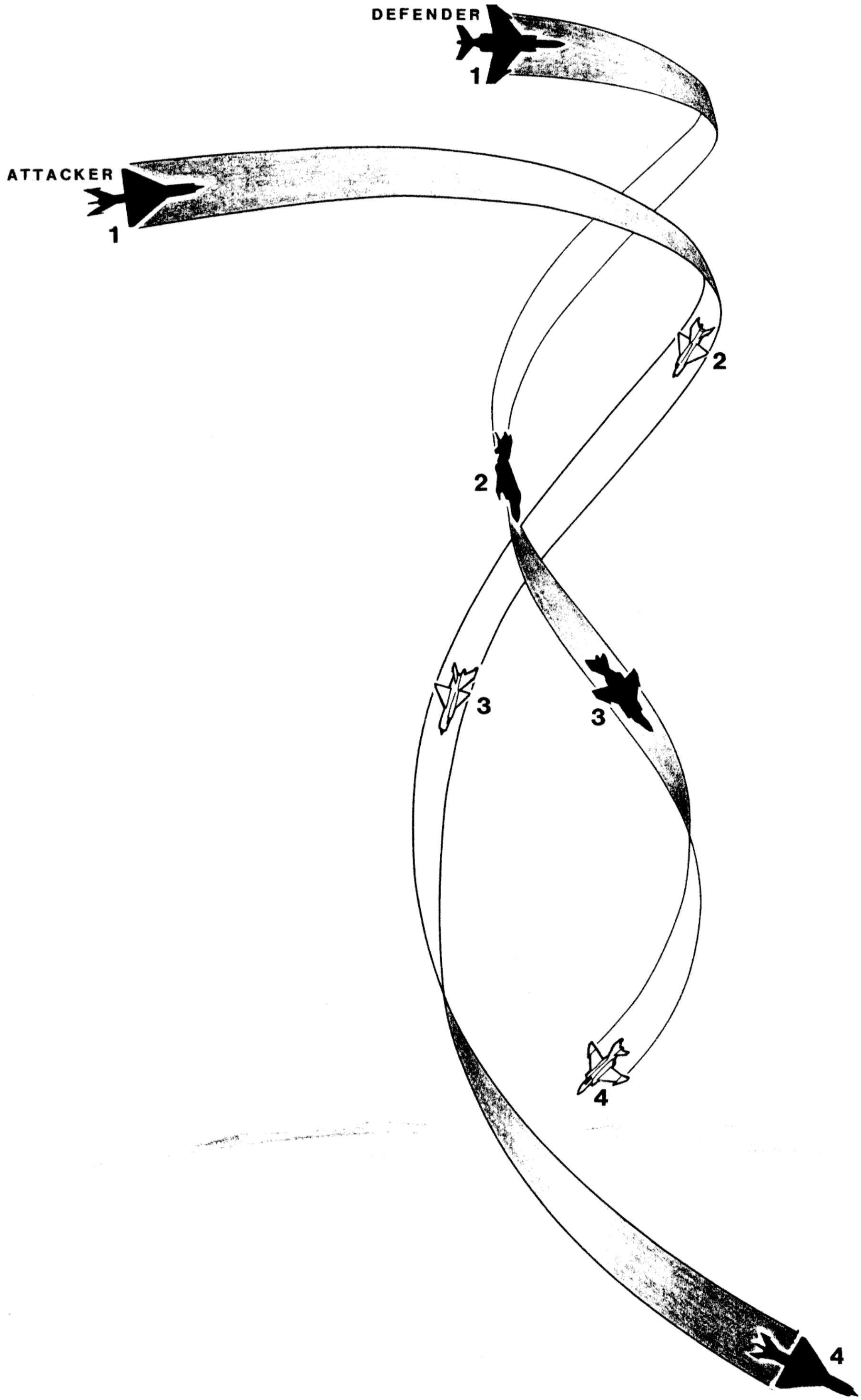

Figure 2-22. Defensive Spiral

slow-speed defender may roll nearly inverted and pull down sharply, using his gravity assist. To maintain his lead for a gun shot, the attacker follows the target into the nose-low spiral, as shown at time "2." At this time both fighters have rolled to place their lift vectors on the other, and they have entered a vertical, descending rolling scissors or defensive spiral. The rolling maneuver is quite effective for spoiling guns-tracking solutions, since the maneuver plane is constantly changing, but obviously there is a very real limit to the duration of this tactic—that is, terra firma.

As with the rolling scissors, success in the defensive spiral depends largely on forward, or in this case downward, velocity. The descent rate is the product of airspeed and steepness of the dive. The typically close range at which this maneuver is performed requires the fighters to roll rapidly to keep the opponent in sight, above the plane of the wings. This continuous roll tends to keep the lift vector horizontal, preventing a pull-out and prolonging the steep descent angle.

Most aircraft tend to accelerate rather rapidly when commencing a dive at a slow airspeed. With the two fighters approximately co-speed in the spiral, it is the relative acceleration that will change nose-tail separation. Minimum acceleration is the desirable factor, so idle power, speed brakes, reverse thrust, drag chutes, or almost any action that reduces forward thrust and increases drag is appropriate. At slow speeds, the largest component of maximum total drag is usually induced drag, which is generally maximized by maintaining the highest controllable angle of attack. (See the Appendix for a discussion of aerodynamic drag.) Normally any configuration that increases maximum lift at a given airspeed, such as extended flaps and slats, also increases induced drag. One exception to this rule may be fighters with swing-wing designs. Although maximum lift is usually attained with wings spread for the greatest wing span, this configuration also tends to make the wing more efficient from a lift-to-drag standpoint, and induced drag may be reduced under these conditions.

Returning to the example in Figure 2-22, the defender has reduced his acceleration to a minimum, allowing the attacker's increasingly greater speed to reduce altitude separation to zero (time "3"); he will be flushed out below by time "4." At this point the original defender is back in the driver's seat and can modulate his power and configuration as necessary to stabilize and maintain the desired nose-tail separation while holding his position in the spiral, waiting for the bogey to begin a pull-out. When this occurs the low fighter should present an excellent, stabilized guns-tracking target. Likewise, "4" would also be a good time for the high fighter to exit the fight if he desires. He can roll to place his lift vector on the bogey, initiate a pull-out, generate maximum TCA crossing over the bogey, and extend for separation.

This decelerating tactic (actually minimum acceleration) can be particularly effective for fighters that are able to generate a great amount of induced drag, as well as for those that are equipped for reverse thrust. One caution is required, however. If the decision is made to press the offensive gained by this technique, the high fighter had better not miss his firing opportunity as the bogey performs a pull-out, since the lower fighter usually will complete its level-off with superior energy, which then may be used to regain the advantage.

As the defensive spiral progresses, most fighters tend to accelerate to some degree. If maximum-controllable AOA is maintained, this increased speed will result in greater load factor and turn-rate capability (below corner speed). At steep dive angles, most of the heading change required to keep the opponent in sight above the plane of the wings is accomplished by roll rate. Greater speed allows more of this heading change to be achieved by turn rate and results in gradually reducing dive angles with increasing airspeed. Although further increases in airspeed would reduce the dive angle even more, at angles steeper than about 40° the added speed usually more than offsets the reduced dive angle attained, resulting in greater descent rate. If, as a result of aerodynamic design, one fighter can maintain an equal or slower speed than its opponent while still generating greater turn rate, it will have a shallower dive angle and a reduced descent rate. Should dive angle decrease to less than about 30°, it will become the dominant factor in descent rate. In this case, maximum power, minimum drag, and maximum-lift configuration should be used to improve turn rate, shallowing the dive angle and reducing descent rate. If speed ever increases to above corner velocity in the spiral, deceleration is in order regardless of descent angle.

Returning for a moment to the beginning of this maneuver, success in the defensive spiral rests largely in the ability to induce the opponent into following the initial nose-down move. This reaction is likely if the attacker is attempting to achieve a guns-tracking solution on the defender by matching his bank angle at position "1" in Figure 2-22. The defensive spiral can, therefore, be a very effective guns-defense tactic, but it may subject the defender to a close-range snapshot as the spiral begins. The defender should generally enter the spiral by rolling just fast enough to stay ahead of the attacker's bank angle. As the attacker attempts to match the target's attitude, he suddenly finds himself in the spiral at position "2," with the defender already having begun deceleration tactics. By easing into the maneuver in this manner, the defender may avoid "scaring off" the attacker. A snap roll into the spiral immediately informs the attacker of the defender's intentions, allowing the attacker to counter effectively by delaying his pull-down. Although this technique (i.e., a snap roll) would remove the target from immediate guns-tracking danger and temporarily increase nose-tail separation, it would leave the defender open to a rear-quarter missile shot, probably cause loss of visual with the attacker, and usually allow the attacker to maintain the offensive.

One of the most effective counters to the defensive spiral, when it is recognized early, is for the attacker to continue his level turn at time "1" to pass directly over the target's position and then begin the pull-down. This tactic makes it extremely difficult for the defender to maintain sight, and generates enough separation to preclude immediate loss of the offensive by a vertical overshoot.

> Success flourishes only in perserverance—ceaseless, restless perserverance.
>
> Baron Manfred von Richthofen

When it is performed properly, the defensive spiral may offer a hard-pressed defender an escape opportunity or even a temporary close-in gun shot. Unless the attacker loses sight or blunders badly, however, it is unlikely that this maneuver would produce a good missile-firing opportunity or result in a lasting offensive position for the defender.

If one of the fighters stops its rolling maneuver at any point and begins a wings-level pull-out, the defensive spiral has ended, and deceleration tactics are no longer appropriate. The first fighter to commence a pull-out offers his opponent the opportunity to continue the spiral to a rear-hemisphere or belly-side position and probably will lose sight temporarily. If the opponent has generated a vertical advantage at this point and is gun equipped, he may have a shot opportunity. Otherwise, it is probably prudent for the opponent to use this chance for escape. Escape may be executed by rolling for the bogey's blind spot, then pulling-out directly away from the bogey at full power and max-lift conditions. If the bogey is missile equipped, it probably will be necessary for the escaping opponent to turn slightly back toward the bogey after reaching an approximately level attitude in order to reacquire it visually and watch for a possible missile launch during the extension maneuver.

As long as the spiral is fairly even, exiting the maneuver usually can be accomplished by simply leveling the wings and pulling-out at max-power and max-lift AOA. The first fighter to attempt this exit from a neutral position should bottom-out above an opponent with similar performance and should have greater energy. Although the opponent will probably be in the rear hemisphere, it will take him some time to get his nose back up for a gun shot, if, indeed, he has sufficient energy to accomplish this at all. This delay is often enough for the higher fighter to extend beyond effective guns range or to position offensively above the lower-energy opponent. Extending from a missile-equipped bogey, however, may be hazardous.

You fight like you train.

Motto, U.S. Navy Fighter Weapons School (TOPGUN)

Notes

1. Cordon Nelson et al., eds., *Air War: Vietnam,* p. 245.
2. Robert S. fohnson, *Thunderbolt! p.* 191.