



Lesson Title

R-77 Air-to-Air Missile Evasion Training – Part 2

Aim

To teach pilots more about the active air-to-air missile threats in Allied Force, in particular the R-77 and how to evade them from inside the 'no-escape zone'.

Time Required

2hr (30 min ground school, 15 min setup, 1 hr flying, 15 minute de-brief)

Topics to be Covered

1. Brevity associated with the lesson.
2. The basics of the jammer.
3. The basics of chaff.
4. The basics of how a missile works.
5. The end game.
6. Training for R-77 missile evasion inside E-Pole ranges.

Brevity

In addition to the brevity covered in Part 1 of the R-77 evasion training all students should understand the following additional brevity terms which will be used during Part 2:

- a. **NOTCH** (Direction) - All-aspect missile defensive manoeuvre to place threat radar/missile near the beam.
- b. **BEAM/BEAMER** (Direction) – Bogey/Bandit manoeuvring to put you at his 3 or 9 o'clock, often given with cardinal directions: east, west, north, south.
- c. **OUT** (Direction) - Directive/Informative - Perform a defensive manoeuvre to place the threat radar/missile on the tail.
- d. **DRAG/Dragging** (Direction) - Bogey/Bandit manoeuvring to 60 degree less aspect.
- e. **BREAK** (Up/Down/Right/Left) - Directive to perform an immediate maximum performance turn in the indicated direction. Assumes a defensive situation.
- f. **MUSIC ON/OFF** - Electronic radar jamming on or off.

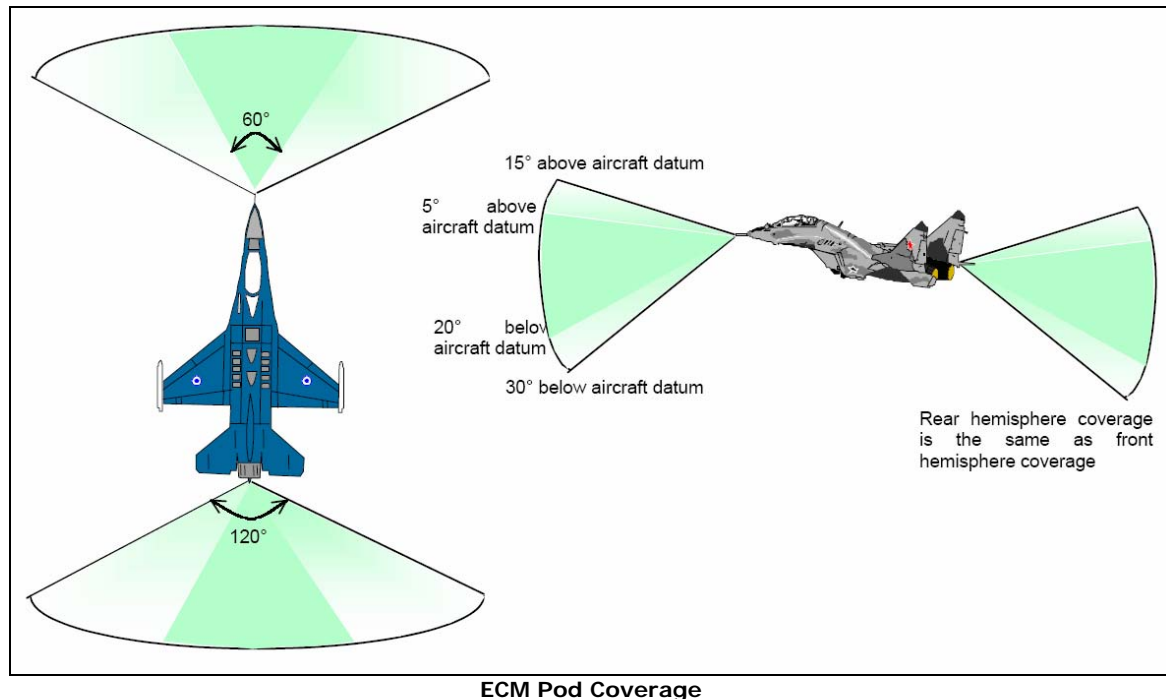
The Basics of the Jammer



In Allied Force you can only carry one type of jammer on the F-16, the AN/ALQ-131. The ALQ-131 ECM Pod is modular in design containing various electronic receivers, antennas, and powerful transmitters designed to alter the flight path of an incoming enemy missile. The pod is controlled from the cockpit by both automatic and manual means and is designed to operate in a

dense, hostile environment of radar directed (RF) threats that require pulse Doppler or continuous wave jamming techniques. An important function is the ability to "look through" which permits periodic surveillance of the threat environment while jamming is in progress.

As ECM systems have transmitting and receiving antennas, there are coverage zones. The ECM coverage zones, for podded systems such as the ALQ-131 and the Russian Sorbstiya, and internal jammer systems, are defined as shown below for both azimuth and elevation coverage.



The full effect of ECM jamming power is concentrated within 30° in azimuth on each side of the airplane. Jamming power reduces beyond this until it becomes totally ineffective at 60° and beyond.

For elevation coverage, the full jamming power is concentrated in an arc extending from 5° above the aircraft horizontal datum, to 20° below the aircraft datum. Jamming power decreases exponentially from 5° above the horizontal plane to 15° above the horizontal plane, and from 20° below the datum plane to 30° below the datum plane. At elevation above 15° and below 30° from the aircraft datum horizontal plane, the jammer is totally ineffective.

To obtain full ECM protection, the threat emitter must be within the pod coverage where the jamming power is concentrated. Once outside, jamming effectiveness decreases rapidly. If you decide to notch, the jammer will lose its effectiveness, as the emitter will exit the ECM coverage arcs and fall into the dead zones. You will need to decide if it is more effective to beam the threat or to employ ECM against it. This is where your pre-mission planning threat analysis will be useful.

The guidelines to remember about your ECM coverage are as follows:

- a. The HUD field of view is approximately 20 degrees in azimuth. From your vantage point in the seat, the main jamming energy will be concentrated from the left to the right edge of the cockpit brow. Any emitter that you see inside this arc will be jammed to full effect. The effect of jamming outside these arcs is hard to determine due to the exponential falloff.

b. From your HUD pitch ladder, the main jamming energy is concentrated between the HUD bore cross (which is at 5° above the datum horizontal plane), extending to 25° downwards. For example, if the bore cross is at the 5° pitch ladder mark, then the lower bound of the jamming energy is at the – 20° pitch ladder mark. Any target inside this coverage will receive the full effect of the jamming.

If the jammer has enough power, it will prevent a lock-on by the threat emitter. As the aircraft closes in on the emitter, there will come a point when the target's skin return is sufficiently strong for the threat emitter to lock onto despite the jamming. This is commonly termed as the threat emitter "burning through" the jammer.

You must also be aware of the home-on-jam (HOJ) capabilities of active radar guided air-to-air missiles such as the AIM-120, AIM-54 and AA-12. Activating your jammer in the presence of such missiles will of course degrade the acquisition performance of the radars onboard these missiles but these missiles will switch to the HOJ mode. Though HOJ does not provide a very good fire control solution for the missile end game, it is sufficient to allow the missile to home and get closer to within the burn-through range of its onboard radar. You are often better off not using your jammer against such active threats once they reach burn-through range.

The Basics of Chaff



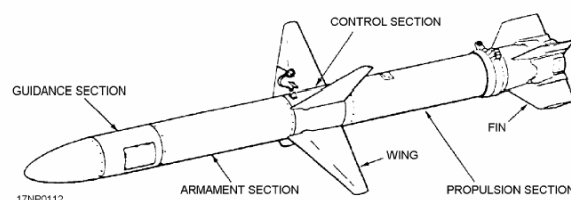
Chaff is a passive electronic countermeasure in the form of metal strips that are ejected from an aircraft. It creates a cloud of material that looks like a big radar target to a radar guided missile. The idea is for the missile to either go after the larger target, or the target can be obscured by the cloud of chaff long enough for the aircraft to move out of the missiles seeker view.

Unfortunately against modern ARH missile chaff is very ineffective. At longer ranges, the chaff bloom can be distinguished due to the rapidly decreasing velocity of the chaff cloud which allows the missile to reject it after tracking both the chaff cloud and target for a while as the target return is still inside the seeker FOV. At closer distances, the missile will switch lock to the chaff cloud as before, but being closer to the target, the target radar return has a higher chance of leaving the seeker FOV while the seeker is still tracking the chaff cloud, thus lowering the chances of missile reacquisition. At very close ranges, the line of sight rate of the chaff cloud versus the target is higher, and this allows the missile to determine immediately the presence of chaff and reject it.

The Basics of How a Missile Works

The basic layout of the missile consists of 4 sections:

- a. Guidance section.
- b. Warhead and fusing section.
- c. Control section.
- d. Propulsive section.



Rocket Motor Properties

Most missiles equipped with solid rocket motors do not have a long burn. There are two basic types of thrust profiles, a pure boost which will give a very short burn time but a very high thrust to accelerate the missile to the maximum velocity at burnout, and a boost-sustain profile, which consists of a short boost phase of high thrust (still lower boost thrust than a pure boost profile), where the missile is accelerated to its maximum velocity and a longer sustain phase with lower thrust to maintain this velocity while the motor is burning.

The disadvantage of a pure boost profile is that once the motor has burnt out, the missile will begin to decelerate rapidly even when not manoeuvring. If the missile manoeuvres, the higher drag will slow the missile down even more (and this is a weakness we can and should use to our benefit). Kinematic range is thus shorter for pure boost rockets. The upside of a pure boost rocket is that the missile can prosecute the target more rapidly than a missile with a boost-sustain rocket, while the rocket is still burning. The manoeuvring potential is also higher during rocket firing, though the disadvantages outweigh the benefits once the rocket has burnt out.

R-77 Guidance

Almost all modern missiles guide themselves to the target using proportional navigation. The target line of sight (LOS) is used as an input to the guidance system, to compute a collision course. This involves turning the missile until a heading is found which stops the target's apparent LOS drift rate. By maintaining this lead angle, the missile will theoretically fly a straight path to intercept a non-maneuvring target. The lead required to stop the drift rate is dependent on target speed and aspect, as well as missile speed, but *not* range. We can use tactics to maximise the missile's lead pursuit, which in turn will use more energy correcting to match our flight profile and improve the chance of defeating the missile during the end-game.

The R-77, like other ARH missiles uses a monopulse radar seeker. The distinct advantage of this radar is that the use of ECM will not seriously affect its tracking ability. The flip side of the coin is that monopulse radars are capable of tracking only single targets.

Conventional self protection jammers have little ability to defeat a monopulse radar. The normal deception and noise tactics do not work well, as even if it denies the monopulse tracker certain information such as velocity or range, the radar can still track in angular position, and this is sufficient to plot a path towards the target and close in for the onboard monopulse radar to burn through and re-acquire the target. Short bursts of ECM may however prove effective in make the missile use more energy due to the lack of data available when plotting the intercept.

ARH seekers are also equipped with Home-On-Jam (HOJ) capabilities. HOJ allows the radar to obtain information about the jamming source and since the jamming transmission is one-way, this in effect acts as a beacon for the missile to home onto. Once inside burn through range, the missile will transit to full active homing for terminal guidance.

This type of radar has a high resistance to chaff as it decelerates rapidly after being dispensed, and this is easily detected. The chaff bloom is also fairly ineffective in the initial acquisition mode due to the range but may have some effect when the missile just turns autonomous and has yet to lock onto the target. Once locked on, the chaff bloom is easily distinguished from the target return and is very ineffective at close range.

As a rule of thumb, against the R-77 chaff is most effective between about 4nm and 8nm. Above and below these ranges effect drops off quickly. It is almost totally ineffective within about 2nm.

At the first sign the missile is going autonomous (usually an audible chirp) you should dispense chaff at a rapid rate before the missile has a lock on you. Once locked on, the missile is exceedingly difficult to decoy with chaff but rapid dispensation of 3 – 4 bundles of chaff can sometimes break a lock, although this is heavily dependent on the missile range and intercept geometry.

While all radars are less effective in look-down due to ground clutter, the R-77 is slightly less susceptible due to the inertial mode and datalink capabilities, enabling the seeker to look at the last known good position of the target and attempt to acquire the target.

You may also be able to take advantage of the Doppler-notch as these radars rely on a Doppler filter which screens out returns below a set threshold called the doppler-notch (sometimes known as the Moving Target Reject, or MTR). This confers the radar the ability to look-down and search for targets without being confused by slowing moving vehicles and other ground clutter, though the performance is much poorer compared to look-up performance (often about 2/3).

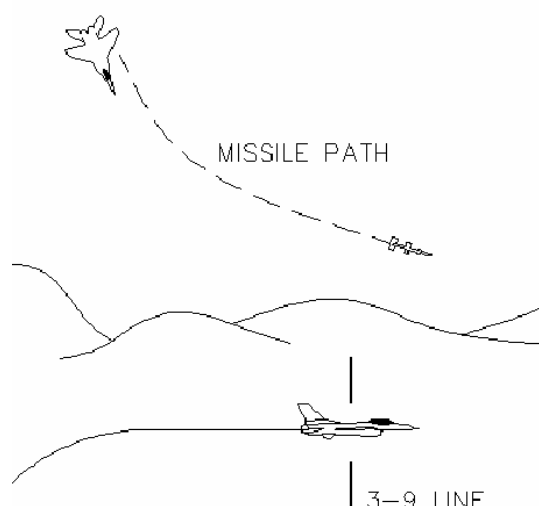
In summary:

- a. The R-77 missile uses the monopulse radar. This makes them very resistant to ECM but bursts may prove effective in making the missile use more energy due to the lack of data available when plotting the intercept.**
- b. Apart from the bursts described above, you should turn your jammer off inside of the threats radar burn through range due to the R-77s HOJ capability.**
- c. Chaff is very ineffective, but it should be tried. Rapid use of chaff just as the missile goes autonomous may be enough to prevent the lock.**
- d. Notching and gaining airspeed will reduce the missiles radar effectiveness due to the Doppler notch effect. It will also reduce the amount of energy the missile has and maximize lead pursuit to increase our chances of getting outside the missiles LOS.**
- e. Ground clutter degrades the missiles effectiveness and combined with chaff, ECM bursts and notch it may prove effective. The by-product of diving towards the ground is also to force the missile to fly into the denser air at lower altitudes, where the drag will be higher, thus increasing its energy bleed rate.**

The End Game

The best way to defeat an ARH missile is to commence evasion early enough that you can defeat it using the Out as demonstrated in Part 1 of the R-77 evasion lesson. This will not always be possible however and on occasion you will find yourself inside the 'no-escape zone'. In this case the tactics covered above such as the Doppler-notch, ECM burst, manoeuvring to make the missile lose energy and maximizing lead pursuit may be enough to defeat the missile but more likely is that the R-77 will keep tracking you. As the missile gets within about 4nm we enter the end-game where we have one final trick up our sleeve, albeit one with several variations on the theme. If this fails then it's time to reach for the ejection handle.

Generating LOS Problems



All missiles have LOS tracking rate limits. The LOS rate is at its highest in a front quarter close range engagement, or in the beam, and reduces towards the rear quarter due to the lower closure rates. As the missile gets to its end-game you want to try a maximum g break to try and generate sufficiently high LOS rates to exceed the missile's tracking ability.

We can also take advantage of the missile's lead pursuit when doing a break-turn during the end-game. The greater the lead, the greater the LOS problems we can create during the break. You should execute your manoeuvre when the missile is within 1 – 2nm of you, and a hard turn into it at high speed will often generate a lot of LOS rate.

During the break you may lose the missile from the RWR for a short period due to sensor shadow so don't stop too early. Additionally you may still see the R-77 on your RWR for several seconds even once it has been defeated. The best way to check if you are outside of the seeker LOS is to acquire the missile visually after the break and determine if you are still being tracked. If the missile appears to be stationary in relation to your canopy then it is probably still tracking so continue the break.

All the techniques demonstrated in the practical phase of the lesson rely on the LOS technique as this is the most effective method for defeating the ARH inside the 'no-escape zone'.

Training For R-77M Missile Evasion at Inside E-Pole Ranges

Falcon Version		Patch Status	Theatre of Operations (Check one)					
Allied Force		V1.12	Balkans		Balkans 2005		Balkans 2010	
			Korea		Korea 2005		Korea 2010	X
Package Information								
Takeoff time	Callsign	Task	Target	Time on Target	Package #	AC # & Type		
Dogfight setup – Load the file R-77 Evasion Part 2. The lesson is designed for a maximum of 4 students and 1 instructor.								
Air to Air Weapon Loadout (Free or Fixed)			Fixed					
Air to Ground Weapon Loadout (Free or Fixed)			N/A					
Mission Flight plan (Free or Fixed)			As instructed					

1. This practical lesson covers R-77M evasion techniques designed for use when you are inside of the E-Pole range. Part 1 of the R-77 Evasion covered what to do when you find yourself outside the 'No-Escape Zone'.

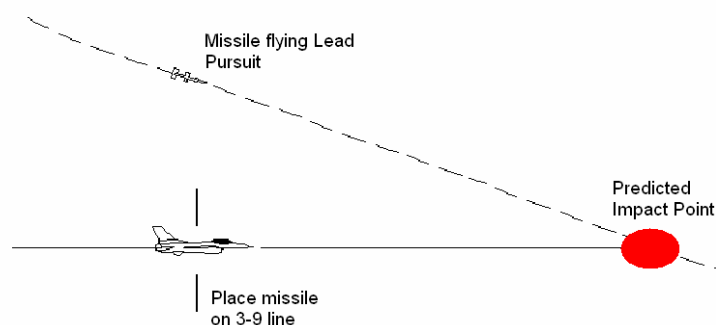
2. Make sure everyone enables invulnerability, unlimited fuel, external views and labels as they join the dogfight.

3. Once everyone is in dogfight module, the instructor should switch teams and get into a MiG-29S. The 4 students should be in the same team and flying the F-16C-52. Move the practice area out over the sea.
4. Commit. Once in the cockpit the students should ensure they are in Cat I mode and turn labels and the ACMI on. They should also split into elements with the second element heading away from the engagement while the first element proceeds in 10 mile trail toward the MiG-29. ECM should not be used during these engagements until the student has been fired at.
5. Remember to maintain your airspeed above corner speed. This maximizes your manoeuvre potential and the ability to turn quickly to generate LOS problems for the missile.
6. The instructor will lock up the element lead F-16 and let him know when he enters Rmax1. He will fire at 18-20nm and crank to gimbal limits. He will inform the student when the missile goes pitbull and what the A-Pole range is. It may also be useful for those watching if the student evading a missile switches smoke on. Those watching from an external view may also want to use the action view to watch the missile and check its energy state.
7. Except where the techniques described below differ, after detecting a launch, the student needs to react immediately by:
 - a. Fly an arcing path that will bring you around the missile, keeping it in at your 3 or 9 o'clock for as long as possible. You should note that it is important to fly so as to beam the radar in the missile not the radar in the launching aircraft once the missile radar goes active.
 - b. Use notch-Doppler, chaff, ECM bursts and the ground clutter effect to try and defeat the missile. If this is unsuccessful be prepared to carry out one of the techniques shown below:
8. Once the first element has completed the first technique, repeat it again with the second element.
9. Exit the dogfight and play back the ACMI. The instructor should comment on each student's technique and note any areas for improvement. You should also focus on the missile's energy state at various points in the engagement.
10. Get back into the dogfight module (same settings as before) and fly the second technique using the same setup. Review the ACMI then repeat for the final technique. You can also practice firing from closer to the students once they are proficient in the techniques.

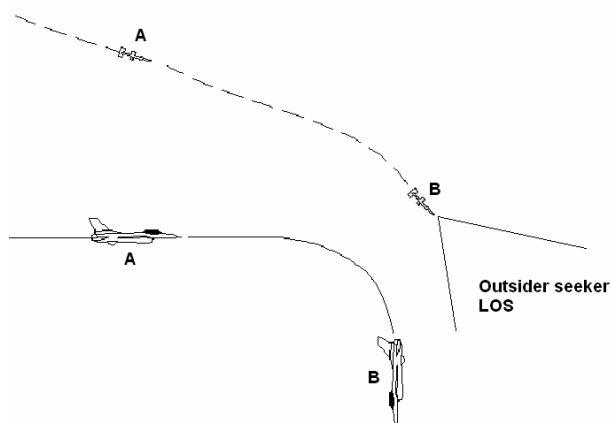
Technique 1 – High G Break Away from the Missile

11. This technique put the threat at your 2-3 or 9-10 o'clock thus forcing the missile into the largest possible lead pursuit course to create turning room and LOS problems. At the last moment the plan is to break hard away from the missile's flight path taking advantage of its larger turn circle and lead pursuit to move you outside of the seeker LOS so it cannot track you.
12. While this makes it almost impossible to maintain an offensive position that will allow you to fire an AIM-120 at the threat, it is significantly easier to successfully achieve than Technique 2 as the timing of when you begin the break turn is less critical.

13. When the R-77 goes autonomous, notch away from the missile to place it on your 2-3 or 9-10 o'clock position. This forces the missile into a lead pursuit course i.e. forcing it to turn a greater distance away from the eventual course it will need to take to score a hit on you. This is essential for the eventual break turn. Don't forget to chaff and make sure your jammer is off as you may be able to defeat the missile in the Doppler-notch.



14. As the R-77 enters the inner ring of the RWR break away from the direction of the missile e.g. if the missile is at your 9 o'clock then break right, if the missile is at your 3 o'clock then break left. If you need to break further than approximately 90° - 120° then, you have likely misjudged the break timing (too early) and the missile may be able to slip in behind you, just keep the break going and you may get away with it. Remember to chaff, and continue watching the RWR for missile position and additional threats.



15. You can view a short video and ACMI of this technique, created by Seeker, here:

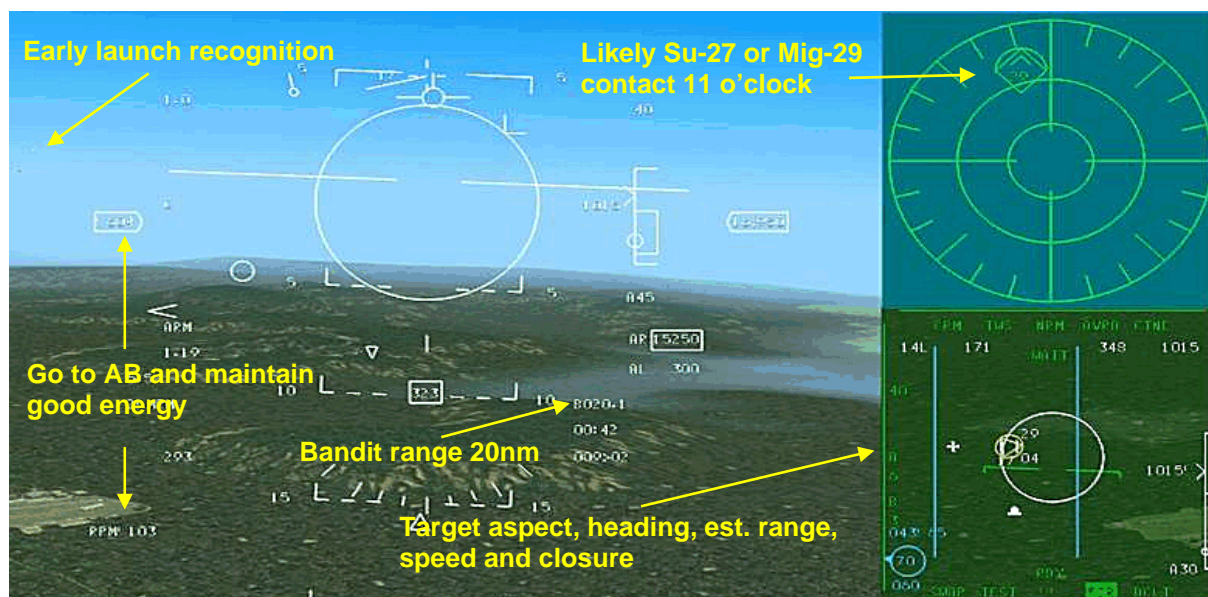
http://185th.co.uk/files/Training/Operational/A2A/R-77_Evasion/Part_2/R77M-technique1.zip

Technique 2 – High G Break into the Missile



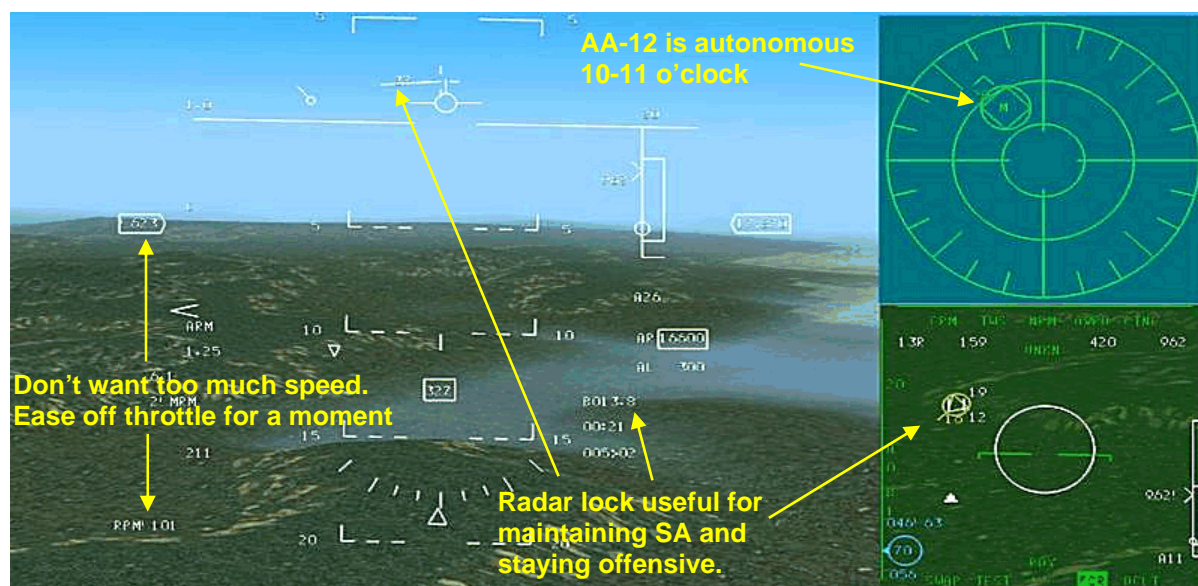
16. Technique 2 is more difficult than Technique 1 as it requires more precise timing of when to begin the break for it to be achieved successfully. It does however offer the major advantage of allowing you to maintain an offensive position on the bandit throughout.

17. The plan is to take a slight offset from the missile to force it into a slightly more exaggerated lead pursuit course to create turning room. At the last moment you break hard into and across it's flight path taking advantage of its larger turn circle and its need to turn further and harder to intercept when you break. The geometry of the flight and relative headings between defender and missile will take the defender out of 'effective' lethal range if the break was judged correctly.



18. In the picture above, an initial offset was taken to reduce closure with the target and prepare for a defensive manoeuvre while maintaining lock, and watching for visual confirmation of a missile launch.

19. When the R-77 goes autonomous notch away from the missile to place it on your 10-11 o'clock or 1-2 o'clock position, and keep a lock on your opponent. This allows you to maintain a firing solution, helps good SA, gives you information on the bandit, and forces the missile into a lead pursuit course i.e. forcing it to turn a greater distance away from the eventual course it will need to take to score a hit on you. This is essential for the eventual break turn. Don't forget to chaff and make sure your jammer is off.



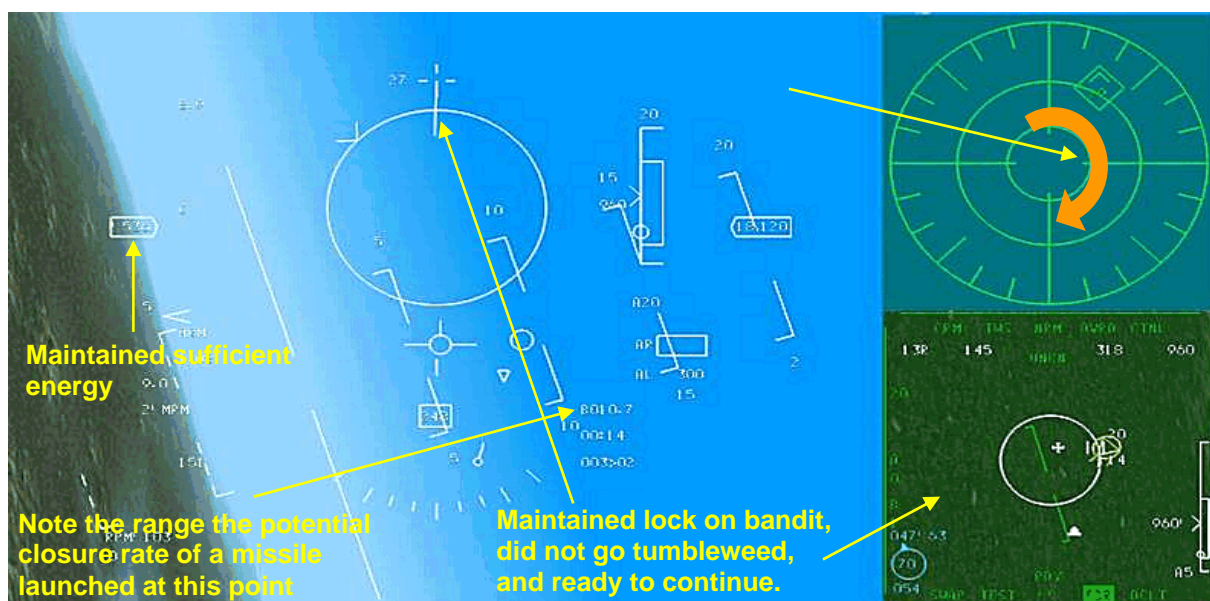
20. In the picture above, we have notched to put the missile at 10-11 o'clock, have good energy (500 to 600 knots is adequate), the radar lock is providing data on the bandit, and at 13.8nm we have a good probability of kill with an AIM-120 launch. Due to the proximity of the R-77 our defensive options are now limited and we are committed.

M symbol has entered inner circle and we are ready to break.

Maintain lock

Go back to AB during the break

23. During the break, dispense chaff (it can't hurt to try even if it is almost completely ineffective at this close range), maintain good G, and watch your energy, the RWR, and the bandit. In this particular engagement, the missile was lofted and approaching from higher trajectory, so the pilot chose to break upward 5 ° and only required an 80 ° break to defeat the missile. The 'M' symbol travelled around the inner circle of the RWR, disappeared briefly around 3 o'clock, then re-appeared around 4 o'clock and travelled very rapidly to 6 o'clock where it exploded harmlessly behind.



24. Note that we are now offset to the left and still have a radar lock on the bandit and maintained good launch solution through-out the whole manoeuvre. We are now set-up with good geometry and sufficient energy (go nose down to stabilize speed) to meet and defeat a second missile if necessary. Defeating a launch at 10nm uses the same principles but will require faster reactions and the break turn will need an adjustment in timing.

25. You can view a short video and ACMI of this technique, created by Seeker, here:

http://185th.co.uk/files/Training/Operational/A2A/R-77_Evasion/Part_2/R77M-technique2.zip

Technique 3 – The Notch and Short Loop

26. Technique 3 is designed to be used against ARH shots from very short range. These would often be fired at about 10nm and, in a typical BVR engagement, may well be the second missile, where the first was fired from 20nm to force you defensive and keep you busy while the bandit manoeuvred in for the 10nm 'kill shot'. In these instances the missile will normally go pitbull straight off the rails and if you do nothing the motor will still be burning until it gets very close. It therefore arrives at the end-game with a large amount of energy that makes it very difficult to defeat with a standard break-turn.

27. What we are trying to achieve with the notch and short loop technique is to manoeuvre our aircraft to the notch and increase our speed to make the missile pull as much lead pursuit as possible, thereby increasing the manoeuvring and distance the missile has to achieve in order to reach us. We then reverse our direction, again forcing the missile to turn even further due to it's lead pursuit path and lose yet more energy. We then execute a short loop away from the missile to get out of the seeker LOS and defeat it. Even if the missile is still tracking at the end of the manoeuvre, it should have lost enough energy for a conventional break-turn to defeat it.

28. The student should be flying at 400-450 KCAS before being shot at and the instructor will fire the R-77 at 10nm range and you will hear and see the missile go active almost immediately on the RWR.

29. Once you have the missile on the RWR, do a 3-4g turn to put the missile on your 3 or 9 o'clock position. You should do this with about 5 degrees pitch down to build up the airspeed to 500-550 KCAS. It is very important to keep the turns smooth and keep up your speed because if you pull too hard and scrub your speed then the missile will close on you much sooner and you won't have enough energy for the loop.

30. Fly straight for 3-4 sec while deploying 5 packages of chaff every 2 sec then continue your 3-4g turn to put the missile on the other side of you ie if it was at your 3 o'clock it should now be at your 9 o'clock and vice versa. Don't forget chaff and also to turn with the nose down to build up more airspeed. Note: it is very important that this second turn is away from the missile (ie the M symbol passes through your 6 o'clock and not your 12 o'clock). Remember, if you start with the missile on your 3 o'clock turn left, if it starts on your 9 o'clock turn right. This keep more distance between you and the missile and makes it use more energy to get to you.

31. By now you should be travelling at about 600 KCAS and the missile will be very close and entering the inner circle of the RWR and you may even have the missile visual. Start a 6-7 g climb (with a 10-20 degrees of bank away from the missile) to smoothly bring the missile on your 5 or 7 o'clock and it should be defeated but if it is still tracking then a break turn into the missile at this point will get the job done.

32. Remember not to lose too much altitude during the loop because you may need to turn offensive or give yourself room to manoeuvre if another missile is inbound. During the loop you may also find yourself high aspect to the bandit and have a brief opportunity to fire. While this won't be practiced during the training, during a real engagement you should use this chance to get a Fox-3 in the air and force the bandit defensive, giving you some much needed breathing space. It may even kill the bandit if it continues in high aspect.

33. You can view a short video and ACMI of this technique, created by Seeker, here:

http://185th.co.uk/files/Training/Operational/A2A/R-77_Evasion/Part_2/R77M-technique3.zip

Acknowledgements

In putting this document together several references were used, in particular thanks go to:

Authors of RP5 manual for providing many of the technical details especially on the operation of the jammer, chaff and R-77 guidance system within Falcon.

Helldiver for providing information about Technique 1.

FreeBirds VFW for the CWT Lesson 6 Presentation that was used for Technique 2 text and pictures.

Dragoon for providing the information about Technique 3.

Seeker for providing the ACMI and video for all 3 Techniques.