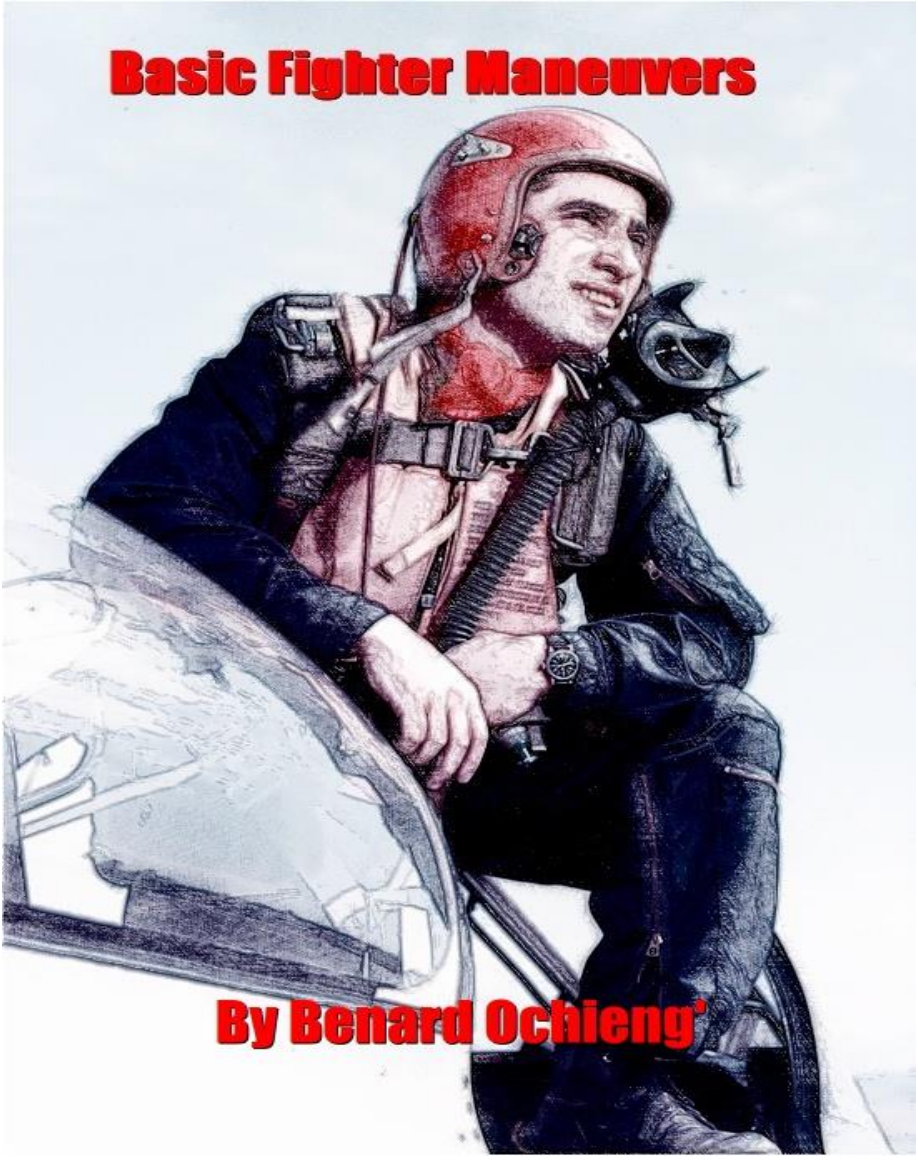
# Basic Fighter Maneuvers



By Benard Ochieng'

This book is meant for Air Combat students in College or University and all enthusiasts in the field. This book simplifies and summarizes the key concepts in Basic Fighter Maneuvers (BFMs) also known as Air Combat Maneuvers or dogfighting, and also dives into the history of air combat, exploring briefly how it began to what is today, and how it might look like tomorrow. The focus is on 1 versus 1 air combat maneuvering.

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I have been a passionate enthusiast of air combat and military aviation since childhood, and with 10 years of experience (2014-2024) in flying computer air combat simulators at the time of publishing this print book in 2024. I have experience with Novalogic's F-16 Multirole Fighter simulator and Digital Illusions Design's (DID'S) F-22 Total Air War (TAW) simulator, which I use more frequently.

I love Tom Cruise's Top Gun movie series and I have contemplated joining the Air Force severally in my life but turned down those ambitions to pursue other interests and passions.

I authored this book to express my passion for air combat and military aviation and this book is dedicated to honor my father **Joseph Omondi Muchura.**

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## 1) Introduction

**Basic Fighter Maneuvers (BFMs)** or **Air Combat Maneuvers (ACMs)** also referred to as **dogfighting**, are defined as tactical maneuvers done in a fighter aircraft by a pilot with the aim of gaining positional advantage over an opponent in air combat. It entails the fundamentals of aerodynamic flight, pursuit geometry, and the physics of managing an aircraft's **specific energy** also known as its thrust-to-weight ratio.

BFMs can be offensive in order to shoot down an enemy aircraft or defensive in order to evade the enemy's air-to-air weapons systems or neutral where the attacker and defender struggle to gain position to shoot down the other or they can be evasive, in order to allow the defender to disengage from a fight and escape.

BFMs involve **energy management**, and therefore, managing the aircraft's **potentia**l and **kinetic energies**. The pilot needs to climb higher (gain altitude) to gain more potential energy, which can be converted to kinetic energy in a high-speed dive. Situations arise in air combat when potential energy(altitude) is key, at times kinetic energy(speed) is key in maneuvering efficiently.

## 2) History of BFMs

BFMs can be traced way back to **World War I** (1914-1918). Air combat itself began with handguns aboard reconnaissance aircraft when two pilots or reconnaissance officers shot one another in close range with handguns in a scenario where one party was caught conducting reconnaissance in the other's territory.

With time machine guns replaced handguns in dogfighting and later they were installed at the nose of the aircraft. BFMs then began to develop in the course of encounters between armed aircraft during the First World War.

The inter-war period between World War I and II saw rapid development in the fields of aircraft design and new and much better aircraft for civilian and military use. These were aircraft fitted with piston engines but as time approached the **Second World War**, British Royal Air Force officer **Frank Whittle**, invented the jet engine, and later in the war Nazi Germany invents the first jet fighter **the Me-262**. This marked a significant technological leap in dogfighting history as jet fighter aircraft were much faster than piston and propeller-powered aircraft.

Jet fighter aircraft were used for dogfighting extensively since the **Korean War** than in World War II and dogfighting incorporated rockets for air-to-air engagements and later the USA invented the first **air-to-air missile**, the **AIM 9 Sidewinder** for use in dogfighting, marking another technological leap in the history of dogfighting, actually shaping it into what it is today.

The first dogfights involving missiles took place during the Cold War, between the Air Force of the **Republic of China (Taiwan)** and the Air Force of the **Communist People's Republic of China** during the **Taiwan Strait Crisis** in the 1950s. It is during a dogfight that a Taiwanese AIM-9 Sidewinder missile supplied from the USA failed to explode when it hit a Communist Chinese jet fighter, remaining stuck and it was transported to the USSR for examination and reverse engineering. This is how the communist world obtained missile technology for dogfighting. Missiles since then have been used in air combat.

Dogfighting also has always involved the use of energy beams to jam sensors and electronics of other aircraft or ground vehicles/radar stations or navy ships from an aircraft since the Second World War.

In the future, 6$^{th}$ generation fighter jet aircraft will be introduced and developers promise to incorporate high-energy laser beams for use in dogfighting against enemy aircraft. These lasers should be powerful enough to cut an aircraft into halves.

Lastly, different individual BFMs have developed since World War I and others emerged in the course of time through other wars. We shall discuss a few of each of these maneuvers later but now I want to mention one called the **Lufbery** developed in Word War I. It involves many defender aircraft flying in a circle to lure an enemy attacker aircraft to fly in front of the aircraft behind a single defender.

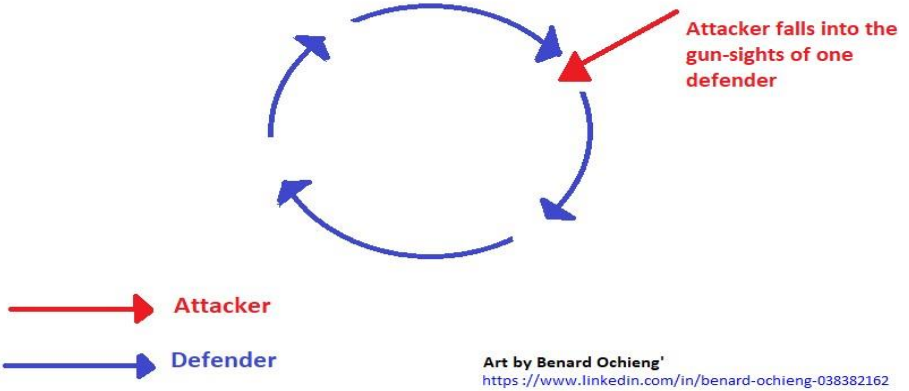



**Image above: The Lufbery**

**3) <u>BFMs in Military Training</u>**

During military training or actual air combat, a pilot needs:

1) Knowledge of his/her own aircraft
2) Knowledge of the opponent's aircraft
3) To know his strengths
4) To exploit the opponent's weaknesses/mistakes
5) Good eyesight and situational awareness
6) Good 3D space to maneuver against an opponent

BFMs in training will be classified into **primary** and **relative** BFMs. Primary BFMs are the general and simple maneuvers performed with no respect to the opponent's position and include climbs, turns, and rolls. Relative BFMs are performed with respect to the motion of another aircraft and are generally complex. They include high and low yo-yos.

During military training, BFMs are practiced with similar aircraft, for example, an F-16 vs another F-16, or with dissimilar aircraft, for example, an F-16 vs an F/A-18 aircraft. The latter is referred to as **Dissimilar Air Combat Training (DACT)** and is more realistic to actual air combat scenarios.

**Above: A cockpit view of an F-15 Eagle pilot in a flight training exercise with other F-15 pilots.**

## 4) Principles of BFMs

### 4.1) Specific Energy and Energy Management

Energy is key in maintaining control of and maneuvering an aircraft. When an attacker has too much energy, it is easier to get in range of the defender for a shot but too difficult to prevent an overshoot. When the attacker has less energy, it is difficult to get in range of the defender but it is easier to be in control to prevent an overshoot. The defender can escape from the attacker if he or she has more energy, but with too little energy, the defender loses maneuverability.

Think of energy as the fighter's mass at any given moment in time and it is the result of thrust/power. With reference to BFM, energy will be categorized into two:

-Kinetic energy
-Potential energy

Kinetic energy of the fighter jet aircraft becomes a function of its mass and speed, with mass remaining constant. This is shown in the mathematical expression below:

$$K \alpha ms$$

**K** is **kinetic energy**, **m** is **mass** and **s** is **speed**

Potential energy of the fighter jet aircraft becomes a function of its mass, gravity and altitude. This is shown in the mathematical expression below:

$$P \alpha mga$$

**P** is **Potential energy**, **m** is **mass**, **g** is **gravity** and **a** is **altitude**

When we sum the potential and kinetic energies of the aircraft, we get its **total energy**.

**Total Energy (Et) = K + P**

This differs from an aircraft's **specific energy**, which is the aircraft's **thrust to weight ratio.** Lighter aircraft tend to have higher specific energy and the reverse is true. This can be shown in the mathematical expression below:

**Specific Energy (Esp) = thrust/weight**

Specific energy is used more conveniently for measurement than the aircraft's total energy. Why? Take a scenario of a heavier and lighter aircraft flying at the same speed altitude. In this case, mass is the only differentiating factor and the heavier aircraft has more total energy.

Managing an aircraft's energy during air combat is key to survival. Situations arise when you need more kinetic energy(speed) to maneuver well, at times you need more potential energy. These two energy states are interconvertible. To gain more potential energy, a pilot needs to climb higher (gain altitude), this also reduces speed to prevent an overshoot. This potential energy can be converted to speed when needed, in a high-speed dive.

4.2) Pursuit geometry

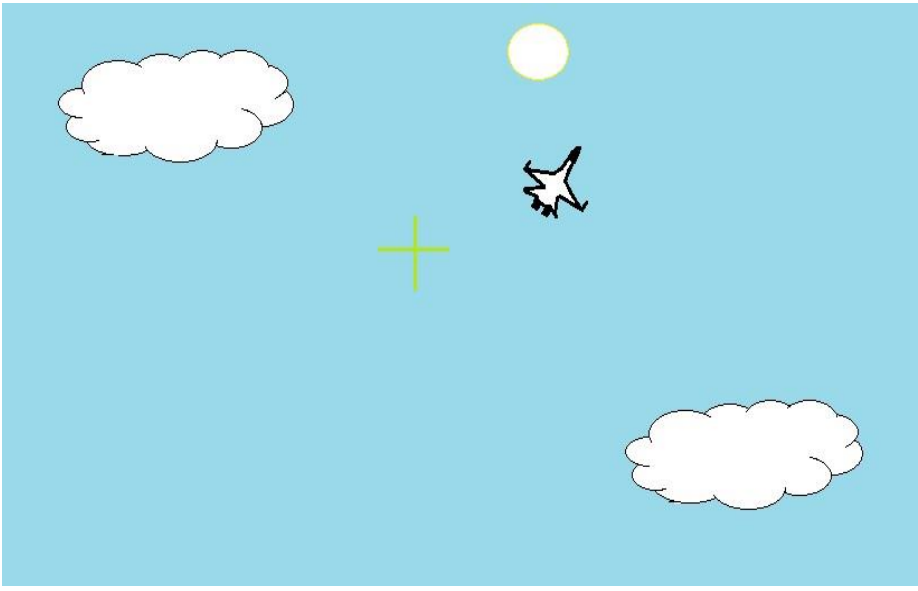
The pursuit (attack)geometry comes into three forms as per the angle of attack of the attacking aircraft's nose in relation to the defender. They are:

1) Lag pursuit
2) Pure pursuit
3) Lead pursuit

4.21) Lag Pursuit

A lag pursuit is when attacker flies into behind of the defender(opponent). The gun cross or aircraft's nose aims behind the defender aircraft.
A lag pursuit finds use in stopping or reversing closure rate and decreasing **angle-off tail (AOT)**. It allows the attacker to maintain or increase **forward separation** (nose-to-tail separation). Lag pursuit comes in two forms, **hot-side** and **cold-side lag pursuit**. A hot-side lag pursuit occurs when the forward separation between the two aircraft in air combat is large, exposing the defender's top-side view to the attacker and also putting the attacker in the defender's rear view. Tighter turns are used as a defense against a hot-side lag pursuit.

A cold-side lag pursuit occurs when the forward separation between aircraft in air combat is small, exposing the defender's belly side to the attacker's view. It puts the attacker in the defender's blind spot. Reversing turns are used as a defense against cold-side lag pursuit.



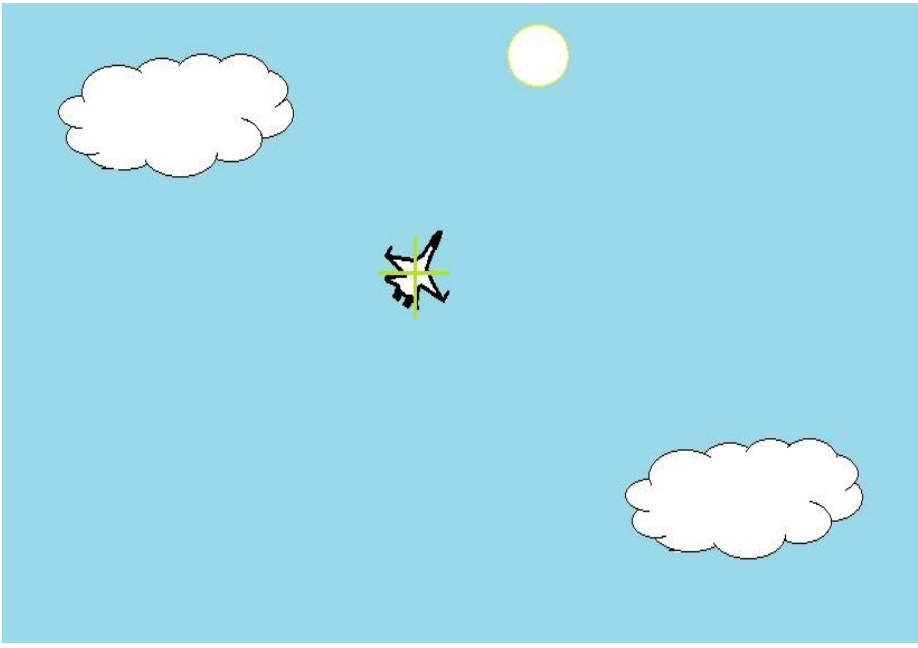
**In a lag pursuit, the gun cross on the Heads-Up Display (HUD) remains behind the defender aircraft.**

4.22) Pure Pursuit

A pure pursuit occurs when an attacker flies straight onto the defender's position in the sky during air combat. The gun cross/aircraft nose of the attacker points straight at the defender's aircraft.

Like lead pursuit, pure pursuit provides an increased closure rate and AOT though not as fast as in lead pursuit. The attacker needs to accelerate to maintain a pure pursuit since it is not as effective against a

faster-moving air target. Pure pursuit is often used when acquiring a missile lock on an air target/opponent.



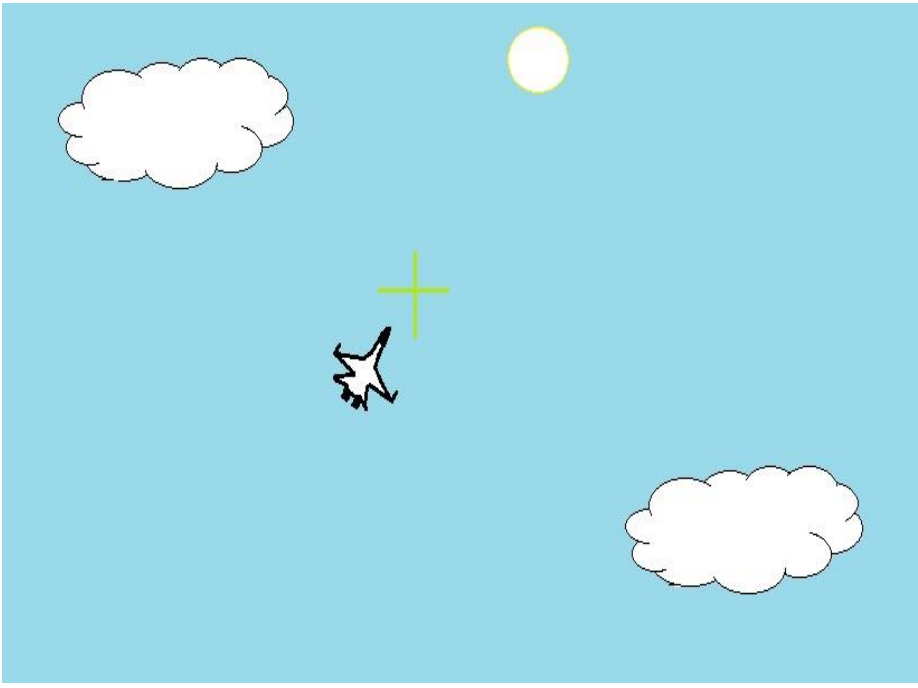
**In a pure pursuit, the gun cross on the Heads-Up Display (HUD) remains right on the defender aircraft.**

4.23) Lead Pursuit

A lead pursuit occurs when the attacker's aircraft nose/gun cross aims ahead or in front of the defender's position in space during air combat. Lead pursuit primarily provides increased closure rate even when in pursuit of a faster opponent. It increases AOT and decreases distance between the attacker and defender by providing a shorter path of travel.

Lead pursuit is useful during gun attacks, because the fast motion experienced during air combat demands that the aircraft cannons be aimed at a point in space ahead of the defender(opponent), where the defender will be when the bullets arrive. This is called **"leading the target"**.

Lead pursuit causes an obstruction of the attacker's view to the defender because of the aircraft's nose aiming ahead of the defender's position in space.



**In a lead pursuit, the gun cross on the Heads-Up Display (HUD) remains in front the defender aircraft where the bullets will be when the defender arrives, this act is called "leading the target".**

4.3) Positioning

A fighter aircraft can find itself in three different kinds of positions during air combat:

1) Neutral position
2) Offensive position
3) Defensive position

4.31) Neutral Position

This is when both opponents spot each other at the same time and each struggle for an offensive position and to throw the other into a defensive position.
None of the fighter aircraft can put the gun cross on the other or point the aircraft nose at the other.

4.32) Offensive Position

This is when one fighter pilot spots the other first, hence one becomes the attacker and the other the defender.
Only one aircraft has the ability to put the gun cross on the other or point the aircraft nose at the other for a kill shot.

4.33) Defensive Position

This is when one pilot spots the other late and is thrown into the defensive by the attacking pilot.
The defender is primarily concerned with denying a shot to the attacker and converting to a neutral position.
The defender's secondary objective is to dominate the attacker or escape the fight. If the attacker has less

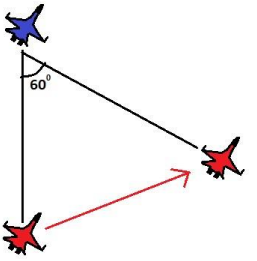
speed/energy, the defender is in a position to use energy/speed to disengage from the fight and escape. If the attacker has more speed/energy, the defender will try to maneuver to force **a dangerous overshoot**. A dangerous overshoot is when the faster attacker flies out in front of the defender causing a reverse in roles, the attacker becomes the new defender and vice versa.

## 5) Concepts of BFM

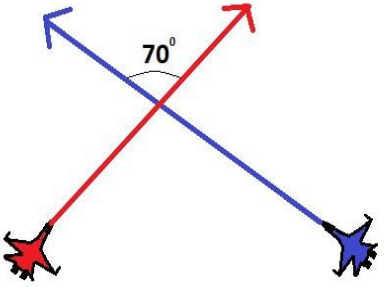
### 5.1) Positional Geometry

BFM involves maneuvers between two aircraft and five main factors do change during air combat. They are:

1) **Range-** This is the distance between two aircraft.
2) **Aspect**- This is the position of an attacker off the defender's nose or tail. It is measured in angles from behind your opponent, that add up to a maximum of 180 degrees. The lower your aspect angle, the more you get into an offensive position behind your opponent. Look at the diagram on the next page for a better understanding.




3) **Heading Crossing Angle (HCA/Angle Off)** – This is the angular difference in heading between an attacker and defender. It equals aspect angle when the attacker points at the defender. It measures how aligned the aircraft fuselages are. Look at the diagram at the top of next page for a better understanding.




4) **Closure (Velocity Closure) Rate** – This is the change in range over time. +Closure-rate means a decrease in range while -closure-rate means an increase in range.

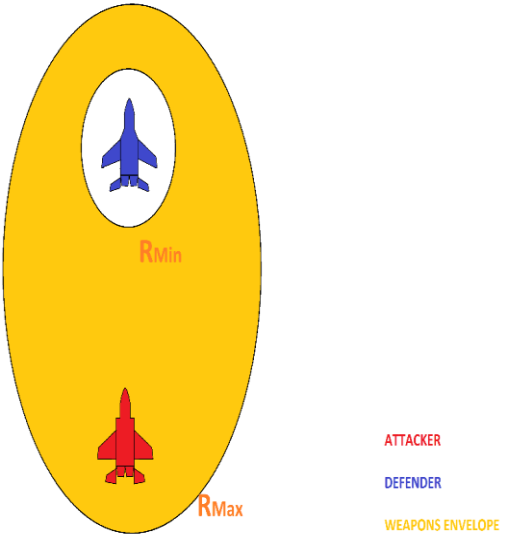
5) **Weapons envelope** – This is the area within which you can shoot at your opponent. It enlarges as you get in the firing range of the target but shrinks when you get too close to the target or when you are out of the firing range of the target.

   If a fighter aircraft is getting closer to its opponent aircraft from the front of the opponent aircraft, then the weapons envelope enlarges from the opponent's front and shrinks at the opponent's back. The reverse is also true, if a fighter aircraft is closing in range to its target aircraft from behind the target aircraft, the

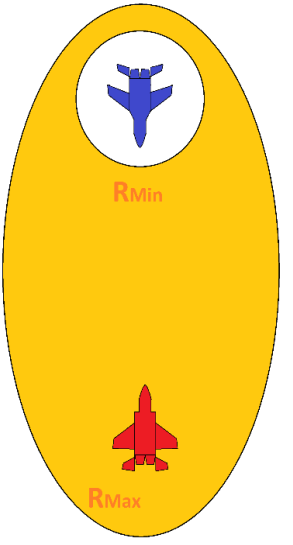
weapon's envelope enlarges at the target's back and shrinks at the target's front.

Within a weapons envelope, the minimum range within which an attacker aircraft can't shoot its target is called the **RMin,** and the maximum range within which an attacker aircraft can shoot its target is called the **RMax.**

The size of the area between the **RMin** and **RMax (which is the weapons envelope)** is dictated by the type of weapon employed during air combat and what the target is doing. For example, if a pilot employs a radar-guided missile like the AIM-120 AMRAAM, then the area between the **RMin** and **RMax** grows, and if the pilot employs a heat-seeking missile like the AIM-9 Sidewinder, then it becomes smaller. It becomes smallest if the pilot employs a gun. This is because different weapons systems have different firing ranges. Look at the illustrations on the next page for a better understanding.




**Attacker is in pursuit of Defender and is in weapons firing range and the Attacker's Weapons Envelope shrinks on the Defender's front and grows on the Defender's back.**




ATTACKER

DEFENDER

WEAPONS ENVELOPE

**Attacker and Defender are closing range on one another and the Attacker's Weapons Envelope is shrinking on the Defender's back but growing on the Defender's front.**

5.2) The Turn Circle

When an attacker gets behind the defender(opponent), he/she has 3 problems to solve to achieve the kill shot on the defender: First, to get into the same geometric plane as the defender. Secondly, to get in range of the defender with no overshooting and thirdly, to pull enough lead on the target (defender/opponent).

The defender to avoid being shot down has to counter the attacker's solution to these problems by maneuvering aggressively. This brings us to the **Turn Circle**.

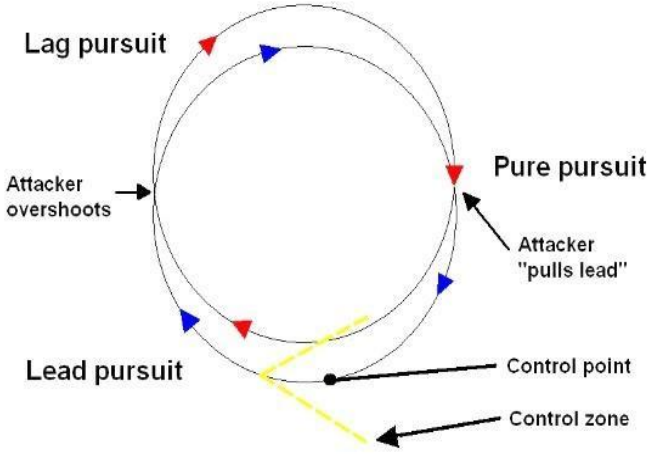
An aircraft usually turns around a circular path on a given length of radius. The circumference of the path is called the **"bubble"** or **a turn circle** and is sometimes interchangeable with the term **turn radius**, while the centre of the circle is called the **"post".**

A change in g(gravity)-force load on the aircraft causes a change in the size of the bubble/turn radius and changing in the position of the post in relation to the fighter aircraft depending on how tight the aircraft is turning. An aircraft turning tightest at its maximum g-force load, cannot turn any tighter, and it creates a "safe zone area" between itself and the post. It is in this safe zone area where an attacking aircraft will try to position itself for a kill shot. This is the same as **leading the target**, and the attacker needs to pull his/her control stick harder for a tighter turn and a smaller turn radius to avoid **overshooting** (flying past the defender to his/her front).

Once the attacker gets inside the defender's bubble, the attacker is in lead pursuit and may be in a good position to shoot the defender. When the attacker flies onto the defender's path of flight before an overshoot, he/she is able to stop or reverse closure rate. This point termed the **"control point"**, because the attacker can maintain control of flight.

The control point lies in an area, that's cone-shaped, called the **"control zone"** that provides the attacker enough time and range to be able to react to the defender's countermeasure maneuvers.

## Turn circle geometry



5.3) The 3-9 Line and Overshoots

What is the 3-9 line? What do you mean by an overshoot? Let us start with the 3-9 line. Imagine a fighter aircraft is superimposed onto the centre of a clock with its nose pointing at 12 o'clock and draw a line between 3 and 9 o'clock. This line is the aircraft's 3-9 line.

To be successful an attacker aircraft needs to keep the defender/opponent ahead of its 3-9 line, in short, to keep the opponent ahead of its nose for a kill shot. If the defender slips past this line to the attacker's rear/tail, the attacker is likely to become the new defender and get shot down, this is referred to as **reversing roles**, the attacker becomes the new defender and vice-versa.

An overshoot occurs when the attacker has too much speed and overtakes the defender, and the slower defender/opponent slips behind past the attacker's 3-9 line to the attacker's tail for a kill shot, in short, the faster attacker slips ahead of the defender's 3-9 line. An overshoot may result in **a role reversal** as mentioned above.

An overshoot, as we mentioned earlier, can also occur when the attacker is turning with the defender and is not pulling hard enough on his/her control stick for tighter turns against the defender, hence, the attacker's turn radius/turn circle/bubble becomes larger than that of the defender.

This means that in a turning fight, **whoever is pulling the control stick harder is going to turn tighter and have a smaller turn circle/radius/bubble and is more on the advantage**, for the attacker it means he/she will be in lead pursuit and more able to deliver a kill shot while for the defender it means that the attacker will be thrown into a lag pursuit and unable to deliver the kill shot and the attacker

may be forced to overshoot, forcing a role reversal. And **whoever is not pulling the control stick harder is going to turn less tight and have a bigger turn radius/circle/bubble and is going to be thrown into the disadvantage**, for the attacker it means he/she will be thrown into a lag pursuit and unable to deliver the kill shot and he/she may be forced to overshoot forcing a role reversal while for the defender it means that the attacker is going to be in lead pursuit and will be able to deliver the kill shot.

And so, to avoid overshooting and role reversals, the attacker needs to fly against the defender with optimal speed, not too fast, not too slow. The attacker also needs to pull his control stick harder than the defender to maintain a smaller turn radius/circle/bubble allowing him/her to maintain lead pursuit and shoot his/her target.

5.4) Circle-Flows (Circle-Fights)

In BFM, there are two forms of circle fights or circle flows, a **one-circle** and **two-circle flows/fights.**

A **one-circle fight** occurs when **both aircraft turn in different directions on the same horizontal plane** at the merge during air combat. For example, one turns left and the other turns right.

Because of the **shorter distance between the two aircrafts in a one-circle fight**, **a one-circle fight becomes useful when you need a quick gun-kill or to jam/defend against the enemy's missile**.

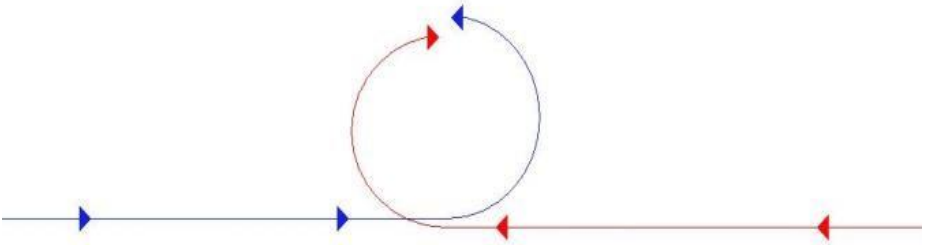
A **two-circle fight** happens when **both aircraft turn in the same direction on the same horizontal pane** at the merge during a dogfight. For example, they both turn left or right.

Because of the **longer distance between the two aircrafts in a two-circle fight, a two -circle fight becomes useful when you need a missile-shot at the enemy aircraft**.

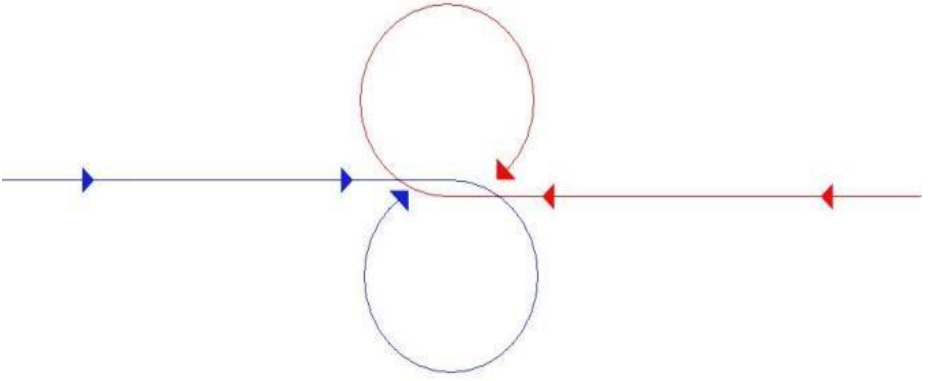
**The situation is different when it comes to up and down (the vertical plane)** because **we all have the same sense of which side is up and which is down because of gravity**. My down cannot be your up and your down cannot be my up, unlike the sense of right and left which are gravity-independent, my left is your right and your left is my right when we face each other in opposite directions.

So, if **both aircraft turn up or down** at the merge, they both end up in **a one-circle fight** but if **one aircraft turns up and the other aircraft turns down**, then they both end up in **a two-circle fight**. And so be careful to notice the differences in outcomes when aircraft turn on the **same vertical plane** (up and down) and also when they turn on the **same horizontal plane** (right and left). Look at the illustration in the next page for a better understanding.

# One circle flow



# Two circle flow



**6) <u>Types of Maneuvers</u>**

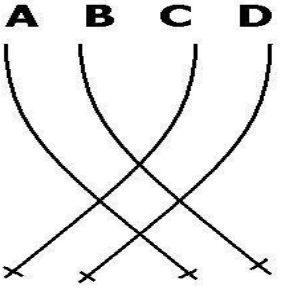
BFMs come in many different forms and I will only take you through a few of the many that exist. They include the following:

<u>Defensive Split</u>

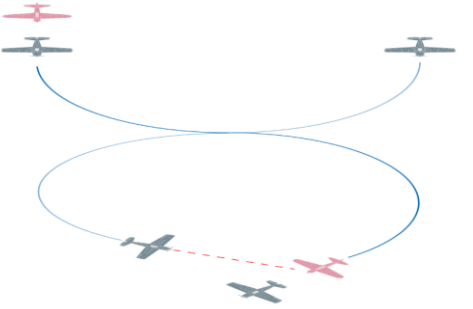
This is a defensive maneuver for a pair of aircraft. The defenders turn in opposite directions to compel the attackers to follow just one aircraft, then the other defender pounces on them for an attack. This is more similar to the thatch weave and weave plain maneuvers.

<u>Thatch Weave</u>

This was developed by **John S Thatch** and named by **James H Flatley** of the US Navy. It involves two defender aircraft turning in opposite directions, intersecting flight paths to lure the attacker aircraft into focusing the attack on one defender aircraft. One of the defenders(wingman) would then come into position to attack the attacking enemy aircraft.



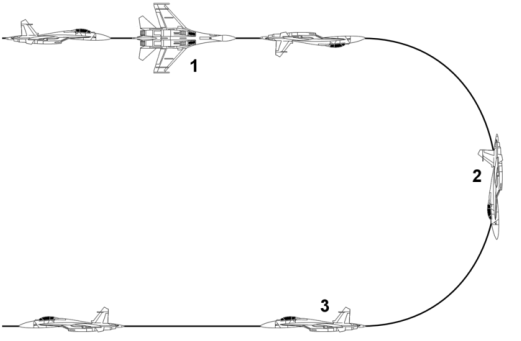
Weave plain



Split-S

This is the opposite of an Immelmann turn we shall discuss next. To perform this move, a pilot flying at high speeds rolls the aircraft into an inverted position and pulls the stick back on him/her, the aircraft performs a half-loop and the direction of flight changes by 180 degrees.

It is useful for disengaging from air combat and exchanging altitude for airspeed.

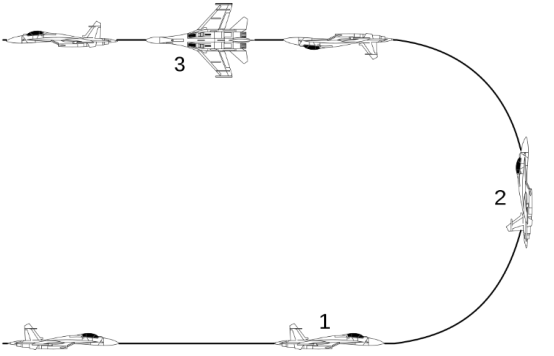



**Left: A split-S**

Immelmann-turn

This involves a 180-degree change in direction of flight during a climb. The pilot flying at high speeds, pulls the stick back on him/her performing a half-loop thus inverting the aircraft. The pilot then rolls back to the upright position.

This move trades off airspeed for altitude.




**Above: An Immelmann turn**

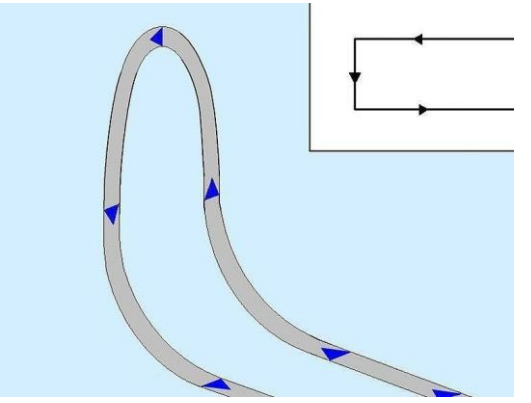
Combat Spread

This is commonly used before an air-to-air engagement. A pair of attacking fighter aircraft will separate about by 1 mile horizontally and 1500 feet vertically.

The fighter at lower altitudes becomes the defender to lure enemy fighters into a fight with the wingman flying at higher altitudes in a "perch" position.

Wing-over

With this maneuver, a pilot can make a 180-degree turn with just a small turn radius. The pilot makes a quarter loop in a vertical climb, then a flat turn over the top, diving to complete the quarter loop at the original altitude, but moving in the opposite direction.



## 7) Defending Against Enemy Aircraft's Attack

In air combat, there's nothing that feels as good as being in control of a fight with the enemy aircraft on your gun-cross at the mercy of your guns or missiles.

What if the opposite happens and you find yourself in a defensive position against an attacking enemy aircraft?

How do you defend against the enemy aircraft's guns or missiles?

### 7.1) Defending Against Enemy Guns Attack

When an enemy aircraft is on your six o'clock (behind you) closing in quickly from a lag pursuit to a pure pursuit and eventually on a lead pursuit, and then you begin to notice bullet tracers flying fast past your cockpit, what should you do?

The best thing to do is to deny the enemy aircraft the same flying plane of motion, which means you dive to the ground with a split-S in an instant.

If you are very close to the ground with no room to dive, then you have no choice but to pull the control stick harder on you for tighter turns until the enemy aircraft gets out of your turn circle (bubble) and overshoots, and from this point, you can reverse roles by going on the offensive against the enemy aircraft.

Alternatively, you could fly into the bright sun during the day, so that the enemy is frustrated by the sheer brightness of the sun in an attempt to visually identify and track your aircraft. If the enemy can't keep up and stalls to lower altitudes, you get the chance of reversing roles and you can go on the offensive.

This option is not good enough especially if the enemy is on your six o'clock (behind you) because he/she has enough turning room to counter any move you make on the same flying plane of motion as his/hers and he/she can easily go on a lead pursuit on you and fire weapons on you as you climb into the sun. Turning and flying up into the sun also slows down your aircraft thus making you an easy target.

7.2) Defending Against Enemy Missiles

How do you defend against enemy missiles fired on you by the enemy, whether from a SAM (Surface-to-Air Missile) Launcher on the ground or from an enemy aircraft in the air?

Defense against enemy missiles typically relies on certain aircraft maneuvers and your aircraft's countermeasures systems. The countermeasures fool the missile's sensors and seeker with false information so as to lure the missile from its intended target. The countermeasures systems and the evasive maneuvers must always be used simultaneously to increase the chances of evading an incoming enemy missile. The maneuvers naturally deplete the missile's kinetic energy (slow down the missile) forcing the missile to maximize its fuel consumption to generate more kinetic energy, thus the missile quickly runs out of fuel and is left to rely on accumulated kinetic energy or inertia (which also runs out quickly) to keep flying to its target. Once the missile is left with no source of propulsion, it falls to the ground and some are designed to automatically self-detonate once they have failed to hit their target or have realized that they can't hit their target. The countermeasures systems involved in missile defense include:

7.21) Flares {Infrared (IR) countermeasures}

These are hot burning chemical substances like phosphorus or magnesium released into the air to confuse the sensors and seeker systems of a heat-seeking missile (Infrared-guided missile), making the missile to home (guide itself) onto the hot flares instead of homing onto your aircraft's hot engine(s) or hot airframe (airframe heated by friction in the air).

Beware, that advancement in technology has enabled the production of heat-seeking missiles that can distinguish between the hot flares and an aircraft's hot engine(s) or hot airframe and thus are countermeasures-resistant (counter-countermeasures).

Technologies have also been developed to counter these countermeasures-resistant missiles and the technological tussle continues to develop systems that

can counter whatever offensive or defensive systems that the enemy puts on the battlefield.

**Above: Russian-made Mig-29 Fulcrum releasing flares**

**Above: An American F-15 Eagle releasing flares**

7.22) Chaff (Radar Countermeasures)

These are small strips of aluminum metal released into the air to create clouds of metal strips that give off false radar returns so as to confuse the sensors and seeker systems of radar-guided missiles.

The missiles are then fooled into homing onto these clouds of metal strips instead of the actual aircraft. Technological advances also have allowed the creation of chaff-resistant radar-guided missiles (counter-countermeasures) and their counter-counter-countermeasures.

7.23) Decoys

Decoys are devices that lure enemy missiles from your aircraft by generating false heat (IR) signatures or radar returns that are more or equal to your aircraft's heat (IR) or radar signature (radar turns).

Decoys can be launched from your aircraft into highly contested airspace with radar coverage so as to lure out enemy missiles fired from the ground (SAMs) or from enemy aircraft in the air.

Some decoys are towed behind your aircraft at some distance and are known as towed decoys.

7.24) Jamming Pods

What is jamming in air combat? And what are jamming pods?

Jamming (not just in air combat) is a practice in electronic warfare that involves saturating/overwhelming the enemy's search, detection and tracking systems with high energy electromagnetic radiation so that it becomes difficult for the enemy to process the incoming data/signals and also to filter out noise/interference and to make out a final picture of what is going on around them.

Jamming also involves the feeding in of the enemy's search, detection and tracking systems with false information so that they miscalculate their response and allow you to carry out what you want in an area of operation or to escape from the enemy. This is specifically called **deception** and it involves use of missile countermeasures like chaff and flares and also decoy drones.

Jamming pods are devices attached to the body/airframe of an aircraft that carries the jamming equipment operated by the pilot in a single-seat aircraft or an **Electronic Warfare Officer (E.W.O)** in the backseat of a two-man fighter jet. The back seater in a twin-seat fighter aircraft with little or no electronic warfare capabilities is sometimes just referred to as a **Weapons System Officer (W.S.O)**, pronounced popularly as **"Weezo"** in the US military. W.S.O is therefore a more general term than E.W.O which is more specific for a dedicated electronic warfare fighter like the **EA-18G Growler** which is an electronic warfare variant of the F/A-18 F Super Hornet. See the image in the next page for more.

**Image above: A twin-seat F-15E fighter/bomber aircraft with the Pilot in the front seat and the W.S.O at the back**

Both aircraft and their fired missiles can be jammed either by overwhelming/saturating them with sensory information (large amounts of electromagnetic radiation) or by fooling them with false information.

Both heat-seeking missiles and radar guided-missiles can be jammed when their sensors/seekers are over-illuminated with excess electromagnetic radiation in the form of infrared radiation and radio waves respectively. Infrared lasers can be useful in the case of jamming infrared-guided missiles.

An aircraft's radar and Infrared Search and Track Systems can also be jammed in similar or more ways making it difficult to search, detect, track and destroy enemy targets.

If you still don't understand what jamming is, then allow me to use simple analogies to explain. Imagine you are late from work at night and you are walking home carrying a torch(flashlight) and a self-defense weapon like a knife or a hand gun, and then a thug comes out of nowhere and tells you to empty your wallet. You then make it look like you are about to surrender and then you shine the full power of the flash light in his eyes, allowing you to escape or go on the attack. This is could be termed as jamming because you overwhelmed the attacker's photo-sensory organs (the eyes) with high intensity light, making it difficult for him to filter and process all the visual information flowing to the brain and thus is temporary left blind. This is how aircraft and missile radars; and also, their infrared sensors/seekers are jammed.

Or imagine you are with a friend to discuss sensitive matters in the house and you don't want your roommate or parents or relatives to hear what you are saying, and so you both go to your room and play loud music to dull out your conversation in the name of entertainment and fun.

This can also be termed as jamming, because the loud music dulls the sound from your voices thus the people slightly away or outside the room find it difficult to filter and process all the auditory information flowing to their brains through the ears. This is an example of **communications jamming** and is analogous to **radio communications jamming**.

7.25) Missile Defense Maneuvers

As we said before, to defend against enemy missiles, you may need to perform some maneuvers in the air as you employ the use of countermeasures systems relevant to the situation you are in to maximize your chances of defeating the missiles.

Before we get to the evasive maneuvers against homing enemy missiles, we need to understand the 3 main stages of a missile's flight, and they are:

a) The Boost Phase
b) The Midcourse Phase
c) The Terminal Phase

The **Boost Phase** is the first stage of flight and it occurs almost immediately after launch. At this stage the missile is low on kinetic energy and begins to burn out its fuel in order to accelerate and gain momentum to the target. The missile is most heavy at this stage because it carries more fuel and oxygen onboard (for non-air-breathing missiles) but this changes as it flies to the target. The missile is therefore less maneuverable due to low speed and also due to more weight and is less likely to counter the evasive maneuvers by the target and hit even a target that was nearby.

The **Midcourse Phase** is the second stage of flight and this stage represents most of the flight to the target. At the end of this stage the missile will have picked up maximum amounts of speed, acceleration and momentum as it flies to the target. The missile gets lighter throughout this stage and is less heavy at the end of this stage in comparison with the boost phase since it will have burned out a lot of fuel and used up lots of any stored onboard oxygen. The missile's maneuverability therefore increases throughout this stage because of reducing weight and increasing speed and acceleration. Improved maneuverability means the missile at this stage has higher chances of countering the evasive maneuvers by the target and possibly has higher chances of hitting the target.

The **Terminal Phase** is the last stage of flight to the target. At this stage, the missile will have fully consumed all of its fuel and onboard oxygen (if any was present), but not necessarily true as the amount of fuel and oxygen consumed would depend on the range at which the missile was fired to its target. If it was

fired from very far, then it is more likely that all the fuel and onboard oxygen will have been consumed, but if it was fired much closer to the target, it would be less likely that all the fuel and onboard oxygen will have been consumed. If a missile is fired much closer to its target, it is also more likely that if it hits its target, it would do so at its boost phase or midcourse phase.

The missile therefore should be lightest, fastest and most maneuverable at the terminal phase, meaning, the missile should possess maximum maneuverability and maximum chances of countering the evasive maneuvers from the target and eventually hitting it. These physical attributes die down as the missile expends the only kinetic energy left that it obtains from inertia because all or most of its fuel is used up.

So, putting into consideration the physical realities of these 3 stages of a missile's flight, at what stage do you think it is best to start evading the missile? For me, I would recommend starting evasive maneuvers when the missile is still at its boost phase rather than to wait for the terminal phase where it has a maximum **probability of kill (Pk).** All the same, it may not really matter at what stage you should start evading the missile as evading the missile would require you to make good use of the missile's own flight physics against it whether it is at the slow boost phase, or accelerating midcourse phase or fastest terminal phase.

How would you use the missile's flight physics against it? Well, that will depend on the **physics (speed/kinetic energy, weight and maneuverability)** of the missile at whatever stage you decide to start evasive action. We shall see more and in graphics on how flying out of the same plane of motion, line of sight (LOS) and field of view (FOV) of the incoming missile, are effective in missile evasion as we look into the various techniques of evading a homing missile. So let us see some of the evasive maneuvers that can be employed in evading missiles in the next page onwards.

7.251) Flying Perpendicular to the Missile's Flight Path as You Turn with the Missile (High G-Turns)

This method involves aligning the missile flight path perpendicular to your aircraft's flight path and maintaining the 90$^{o}$ angle with the missile **(put the missile at your 3 O'clock or 9 O'clock**) in a turn as you deploy countermeasures (chaff/flares) until the missile loses lock and overshoots behind you.

The underlying science behind this is that as you maintain this 90$^{o}$(perpendicular) angle with the missile in a turn, the missile is forced to maximize its energy (fuel) use which quickly runs out and the missile loses propulsion and eventually loses lock on your aircraft as it falls to the ground.

I think this 90$^{o}$ angle also makes the missile turn tightest (maximum turn rate) forcing it to maximize its fuel/energy use and the missile's seeker and guidance system are overworked and eventually the missile loses lock on your aircraft and overshoots as its turn radius/circle becomes larger than your aircraft's turn radius, this means that you have to pull very hard on the control stick towards you for a maximum turn rate (a smaller turn radius/circle/bubble) against the missile.

As the missile turns on you at its maximum turn rate, it struggles to continuously correct its trajectory to a calculated rendezvous point (where the missile should meet your aircraft in space and detonate) because of the **maximum G-force load** generated by the maximum turn rate.

This maximum turn rate puts both your aircraft and the missile on their maximum G-force load, beyond which could compromise the physical integrity of the aircraft's and the missile's body/airframe (meaning both could disintegrate/tear apart in mid-flight if they take in an extra G-force load).

And what are these G-force loads? The term **G-force** is the short form of **gravitational force**. When an object moves or turns in space, it creates certain forces on itself that are measured in relation to the strength of Earth's gravity. Earth's gravity is measured at a unit of 1G. If an aircraft or missile is turning at 2Gs, it means that the forces generated by the turn are equal to 2 times the force of Earth's gravity. Zero Gs creates weightlessness that is typically observed when

astronauts float in outer space. Zero Gs can also be artificially created in a Zero Gs aircraft.

Therefore, an aircraft's or a missile's **G-force load** is how much forces or weight it creates on itself as it moves or turns and an aircraft's or missile's maximum G-force load is the maximum amount of G-forces it can endure. These G-forces can be either positive (+) or negative (-).

***Positive G-forces (and inertia's negative G-forces) are generated as the aircraft or missile falls to the ground (the Earth) towards the source of Earth's gravity.***

***Negative G-forces (and inertia's positive G-forces) are generated as the aircraft or missile flies up away from the ground (the Earth), away from the source of Earth's gravity.***

7.252) Using the Geographical Landscape to Your Advantage

The geographic terrain/landscape can be very useful in evading detection, tracking, interception and being fired upon by the enemy anti- aircraft defense systems or by enemy aircraft in the sky.

A mountainous and rocky terrain, can be useful in evading an incoming missile (whether radar or IR- guided), as the rocks and mountains have huge radar signatures (radar returns/reflections) that can distract the missile from homing onto your aircraft's radar returns, just like chaff countermeasures. These radar returns/reflections from the ground or mountains are called **ground clutter**. The ground itself is a good source of infrared radiation (heat) during the day because it absorbs and reflects heat from the sun and therefore diving for the ground as you turn against a heat-seeking missile during a hot day could help in defeating the missile, though this is not a 100% guarantee that you will defeat the missile.

The mountains also provide an opaque cover that keeps (reflects) away enemy radar emissions and masks both your aircraft's radar signature from the enemy's radar, seekers/sensors of radar-guided missiles; and aircraft's heat {infrared (IR)} signature from the enemy's Infrared Search and Track Systems (IRST) and also from the enemy missile's infrared sensors/seeker.

And therefore, hiding behind a huge mountain breaks the missile lock on your aircraft and makes you disappear from the enemy's search, detection and tracking systems across multiple spectra of the electromagnetic spectrum, from the radio to infrared and visible spectra.

In the 2011 US Navy SEAL operation in Pakistan that killed **Osama bin Laden**, the US special forces operators used special stealth helicopters (have much lower acoustic, radar and infrared signatures) for the mission and the mission planners drew a flight path to the target area that took the team through a mountainous terrain to help them evade Pakistani radar as they flew in and out of the country.

7.253) Using the Sun and Clouds to Defend Against Infrared-guided Missiles (Heat-seeking Missiles)

During the day, the sun lights up our skies and gives most of the warmth for the day. The sun also warms up the clouds to some extent giving them a substantial infrared (heat) signature that could be enough to confuse a missile's infrared sensors/seeker.

You can fly into the clouds or the sun(preferably) to confuse the heat-seeking missile's infrared sensors/seeker thus breaking the lock on your aircraft, though this is not a 100% guarantee that you will defeat the missile.

Releasing flares as you fly into the sun or clouds increases your chances of confusing and defeating the heat-seeking missile because of the extra thermal radiation that may confuse the missile's infrared sensors/seeker.

7.254) Turning/Flying out of the Missile's Plane of Motion, Line of Sight (LOS) and Field of View (FOV)

As we mentioned earlier, it is possible to use an enemy missile's own flight physics against it regardless of whatever stage/phase of flight that it is in. So let us look at how we can use the enemy missile's own flight physics against it in order to evade it at each phase of the missile's flight.

a) Starting Evasive Maneuvers at The Missile's Boost Phase

If you start evasive action when the missile is still at its boost phase, you could easily weaken or break the **lock(focus**) that the missile has on you because it is much slower, much heavier and less maneuverable to counter any evasive maneuvers in its initial stage of flight and thus you could easily fly out of the missile's **line of sight (LOS)** and **conical field of view (FOV)** to break the missile's lock on you. If the missile turns back and manages to restore you on its LOS and FOV and the lock does not break, you should continue employing evasive actions by turning from the missile's LOS and FOV again in order to slow down the missile as it accelerates into the midcourse phase. And remember according to physics, every time an object in motion turns/changes direction it runs out speed (kinetic energy) and requires more energy(fuel and oxygen) to change the direction of motion and therefore, by the time the missile gets closer to you in visual range, it will significantly have lost its fuel and any onboard oxygen which translates to loss of speed/kinetic energy and maneuverability and thus much easier to evade, and that is why I recommend starting evasive maneuvers at the boost phase rather than at the terminal phase.

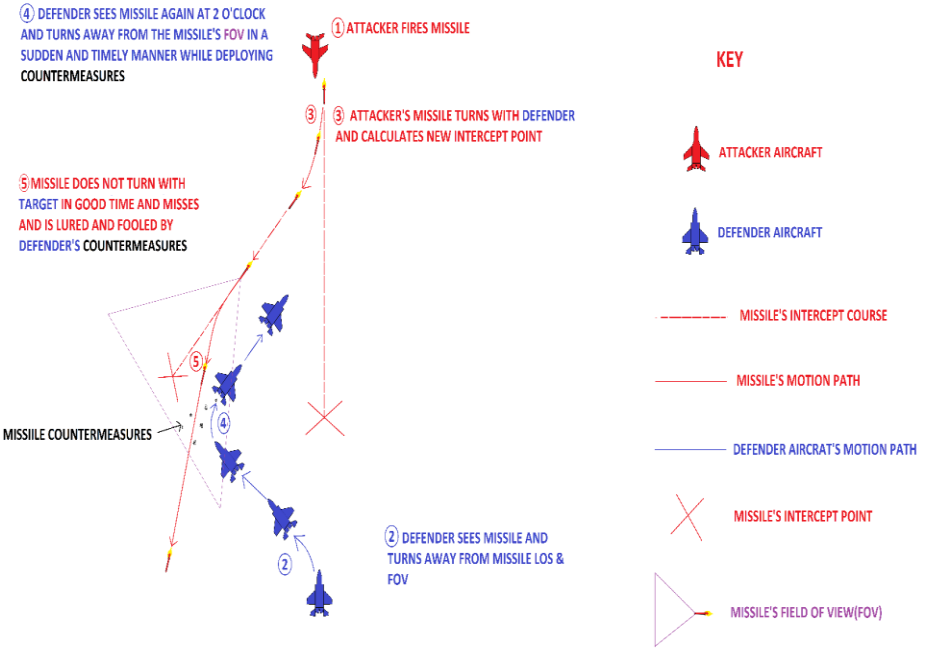
b) Starting Evasive Maneuvers at The Missile's Midcourse Phase

If you start evasive maneuvers at the midcourse phase when the missile is accelerating or just has achieved its maximum acceleration, you could use this acceleration against it by suddenly flying out of its LOS and FOV and deploying the relevant countermeasures-chaff or flares. Because the missile presumably has accelerated along a straight path towards you, a sudden move to the outside of its LOS and FOV would make it difficult for the missile to turn in good time in order correct its trajectory to its new calculated rendezvous/intercept point because to do so requires it to slow down in order to change direction, and slowing down becomes difficult due to its heightening/heightened state of acceleration. By the time the missile manages to correct its trajectory, you will have completely disappeared from its LOS and FOV and all that will be left in its LOS and FOV are the chaff/fares countermeasures that you released which will fool its sensors and seeker with false information thus luring it from its intended target which is your aircraft.

c) Starting Evasive Maneuvers at The Missile's Terminal Phase

If all the fuel and onboard oxygen is used up at the terminal phase, then the missile will be solely relying on its accumulated kinetic energy or inertia to keep flying to its target as it can no longer generate propulsion due to lack of fuel and or onboard oxygen. This means that if evasive maneuvers are initiated and used by the target in a timely manner, the missile as it turns with its target, will quickly run out of speed and all the kinetic energy it needs to counter those evasive maneuvers and would less likely hit the target. And the missile's own high acceleration from its inertia would betray it if the target suddenly disappeared from its LOS and FOV and there is insufficient time and kinetic energy to maneuver to restore the target to the missile's LOS and FOV.

See the diagram below for how turning away from the enemy missile's LOS and FOV is helpful in evading the missile. It can also apply for turning away from the missile's plane of motion:




**Above: Missile evasion maneuver by a defending aircraft against an attacking aircraft.**

For more or relevant information on evading enemy attacks in air combat, you can check on the information in the URL links below:

# How to evade missiles in air combat

http://www.ausairpower.net/TE-Evading-Missiles.html

https://ops.group/blog/intercept-avoidance-and-missile-evasion/

# Understanding Air to Air Missiles

https://en.m.wikipedia.org/wiki/Air-to-air_missile

You can try watching these videos on You Tube to learn more about Air Combat Maneuvers:

# All the basics of air combat (1 vs 1 engagements), missile evasion skills included

https://youtu.be/OCFMX5z-ed4

More:

https://youtu.be/KQI8fbYpl7o

## 8) Understanding the Heads-Up Display and Head (HUD)/Helmet-Mounted Display (HMD)

A HUD also called a **Heads-Up Guidance System (HGS**) is a transparent display which presents information without requiring the user to look away into other instruments for information. The name comes from a pilot being able to view the HUD's information with the head positioned "up" and looking forward, rather than angled down looking at lower instruments.

A HUD is also advantageous in that the pilot's eyes don't need to refocus to view the outside after looking at the optically nearer instruments. Another similar technology is the Head-mounted Display (HMD) which includes Helmet-mounted displays (HMDs). These are variations of HUDs which feature a display element that moves with the orientation of the user's head.

In the HUD, the information that a pilot needs is projected onto a glass called the **combiner** located directly in front of the viewer. HUDs when used in combat, require that the aircraft's nose be pointed directly at the target.

On the other hand, HMDs feed information the pilot needs straight into the pilot's eye or eyes and when used during combat, the aircraft's nose does not need to be pointed at the target, because the HMD allows targeting to be done by the pilot by simply moving his head and looking straight at the target. This allows HMDs to be used to **cue**(guide) weapons systems of various types to a target by simply turning the pilot's head to look at the target.

These HMDS that allow for the cuing of weapons systems are referred to as **Helmet-Mounted Sight and Display Systems (HMSDSs)** or just **Helmet-mounted Sights (HMSs**). For example, the gun turret of an **AH-64 Apache helicopter** is cued by the pilot's HMD. The HMD used by Apache pilots is known as the **Integrated Helmet and Display Sight System (IHADSS)**. The Apache is originally flown by US Army pilots but is also flown by other military forces around the world.

**US Army pilots in an AH-64 Apache attack helicopter. Take note of their HMDs.**

The US Navy uses the **Joint Helmet-mounted Cueing System (JHMCS)** on their **F/A-18 Super Hornet E** and **F** fighter aircrafts. It is also used by the US Air Force (USAF) on its **F-15 Eagle C** and **E** and also **F-16 C fighter aircrafts**. The **US Marine Corps** aviators also use the JHMCS on their **F/A-18 Hornet A, C** and **D aircrafts.**

**Above: A US Marine Corps aviator poses with the Joint Helmet-Mounted Cueing System (JHMCS).**

The USAF and some other air forces also use the **Scorpion Helmet-mounted Integrated Targeting (HMIT)** display system. The USAF uses it on **AC-130W** and the **F-22 Raptor**. The French Air Force uses it on the **Rafale F-4 fighter aircraft**.

To see more details on HUDs and HMDs, you may navigate through the links below and on the next page:

https://en.wikipedia.org/wiki/Helmet-mounted_display

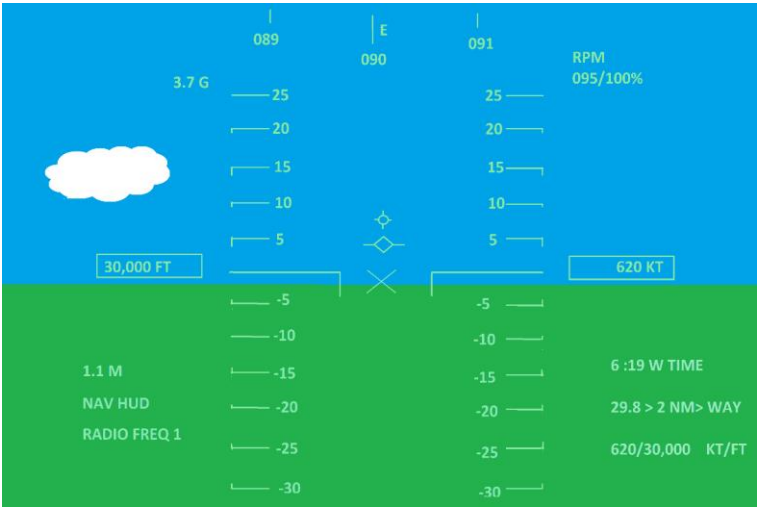
https://en.wikipedia.org/wiki/Head-mounted_display

https://en.wikipedia.org/wiki/Head-up_display

https ://m.youtube.com/watch?v=jwv0ibUG4Io

**Above: A US Navy F/A-18 Super Hornet getting refueled airborne.**

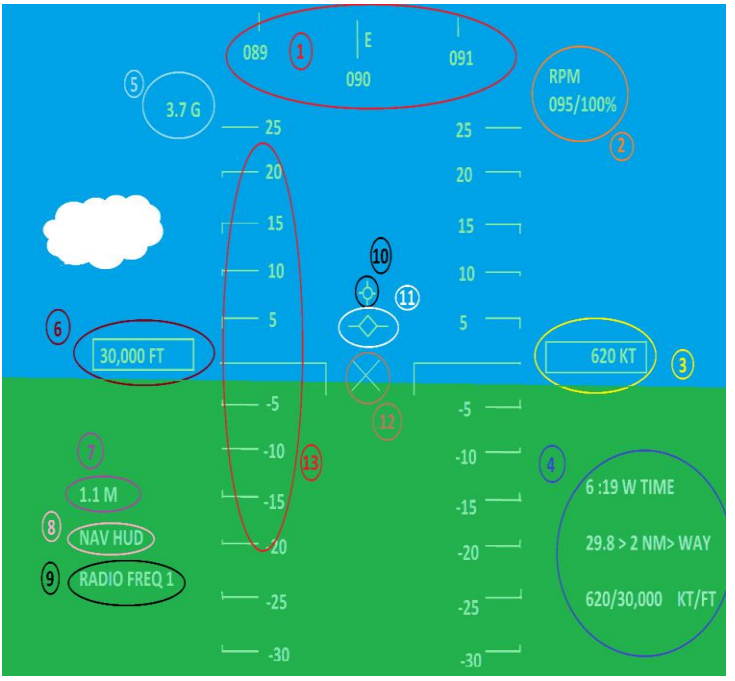
If you wonder what a HUD typically looks like, then take a look at the illustration below:




**A graphic representation of a typical Heads-Up Display (HUD) System**

Now, you must be wondering what all those letters, numbers, and symbols mean. We shall look at them one by one and be notified that the HUD illustrations given in this publication show nothing but just the most common information and symbols displayed on a HUD and not necessarily in their conventional forms or forms adapted by various military air forces around the world. Some HUD symbols and details may have been left out which you can go and find out by yourself from various sources of information.

So, what are some of the information displayed on the HUD? Let us use the illustration on the next page to go through them one by one.




**1) Heading indicator**

This is just but a compass direction/bearing display that helps you know where you are heading to, whether north, east, west or south or wherever.

**2) Thrust power indicator**

This shows the engine's number of revolutions per minute, which translates to how much thrust power/force is being produced by the engine(s). The more the RPM, the more the thrust force/power.

### 3) Air speed indicator

Air speed in aviation is measured by an air speed indicator in units called **knots**, shortened as **Kn** or **Kt** or **Kts**.

**1 Knot = 1 nautical mile (NM/nmi/M) per hour**
**1 NM = 1.151 miles(mi) = 1.852kilometers(km)**

### 4) Waypoint information

An aircraft typically flies to its destination on a planned/programmed path called a **flight path**. The flight path consists of a number points in space that an aircraft must fly through which are called **waypoints**.

In the illustration of the HUD:

- The **"6:19"** is the waypoint time shortened as **"W TIME"** which is the time left to reach the next waypoint.
- The **"29.8"** is the distance in nautical miles to the next way point. The **"2"** is the 2nd waypoint in the flightpath.
- **"620"** is the speed of the aircraft in knots which the aircraft should be at as is passes through that waypoint
- "**30,000"** is the altitude of the way point above sea level.

### 5) G-Force Indicator

This indicates how much G-forces is generated by and is acting on the aircraft as a result of the aircraft's acceleration and maneuvers. These G-forces are measured in units called **Gs** and in relation to the magnitude of Earth's gravity.

**1G = the magnitude of Earth's gravity**

The G-force indicated in the illustration is **3.7Gs**. This means the aircraft is generating forces acting on it that are **3.7 times the force of Earth's gravity**.

**Zero Gs** create **weightlessness** that is observed in astronauts in space. **Negative G-forces** cause what is called **red-outs** in pilots, which results from blood being too light and is pushed upwards in the body to the head thus rupturing blood vessels in the head including the eyes, thus creating a red vision called a red-out.

Too much **positive G-forces** are dangerous and they cause what is called **black-outs** or **grey-outs**, which result from the blood being too heavy and is pushed downwards in the body away from the head(brain) and thus the brain does not receive sufficient oxygen(**hypoxia**), water and vital food nutrients thus the pilot's vision dims out in **black** or **grey** (**loss of peripheral vision)**.

Above a given number of Gs, the pilot may lose consciousness and the number of Gs depends on the training, age, and physical fitness of the individual pilot. Pilots are taught **anti-G straining maneuvers** to avoid turning with too much positive G-forces that cause black/grey-outs and loss of consciousness. If a pilot turns with too much positive G-forces without correcting the situation with anti-G straining maneuvers, the pilot ends up **completely losing consciousness** and this is called **gravity-induced loss of consciousness** also called **G-LOC** which typically lasts for about 12 seconds but can also be as long as 45 seconds. And more dangerous than the G-lock is the **A-LOC** or **almost loss of consciousness (Acceleration-induced near loss of consciousness) or syncope** that renders the pilot completely confused and disoriented, and what makes the A-LOC more dangerous is that it lasts longer than G-LOC.

Pilots are taught **certain breathing techniques** to be able to deal with the effects of high positive G-forces. They are also equipped with special suits called **G-suits** which are worn over the **flight suit** and are useful in pushing back blood to the upper parts of the body during high G-turns.

You may find out more about G-forces, G-LOC, and A-LOC at the links below:

https://en.wikipedia.org/wiki/G-force

https://en.wikipedia.org/wiki/G-LOC

https://en.wikipedia.org/wiki/Syncope_(medicine)

We shall look at equipment for fighter pilots including the G-suit, on a separate topic on its own.

### 6) Altitude Indicator

This indicates the altitude at which the aircraft is flying. That is how far up from sea level the aircraft is flying. This is measured in units called **feet**, abbreviated as ft or FT as in the HUD.

### 7) Mach Number Indicator

It indicates the **Mach** (pronounced the same way as "mark") **speed** of the aircraft, which is the ratio between the aircraft's speed and the speed of sound in the air.

A speed of **Mach 1 equals the speed of sound in air**. A speed of Mach 1.1 as shown in the HUD illustration means that the aircraft is flying 1.1 times the speed of sound in air.

### 8) HUD Mode

This shows which mode the HUD and aircraft are in. The aircraft can be in different modes i.e., **Navigation (NAV) Mode** (as shown in the HUD illustration), **Air-to-Air (AA) Combat Mode,** or **Air-to-Ground (AG) Combat Mode** or **Landing/Inertial Landing System (ILS) Mode.**

In navigation (NAV) mode, the HUD's information is optimized to allow the pilot to fly through the waypoints along the flight path, and the NAV Mode is typically used when there are no aerial nor ground threats to the aircraft.

In combat mode, the HUD displays information in such a way that allows the pilot and aircraft to detect, track, and engage (fight and destroy) threats whether those threats are in the air or the ground.

In landing mode, the HUD displays information in a way that allows the pilot to land his aircraft on an airfield or an aircraft carrier. We shall see more of these modes through illustrations later on.

**9) <u>Radio Frequency/Channel Number</u>**

This shows the frequency/channel number that the pilot has switched to. There are different channels/frequencies of communication that a pilot uses for various purposes and for safety reasons because the enemy may be tuning in to listen to his or her communications with other military assets in the area.

There are channels/frequencies for communications with a wingman(wingmen), or a home(friendly)airfield or Airborne Early Warning Aircraft (i.e., AWACs) or a refuel air tanker or a broadcasting frequency/channel which is open to reach out to any military asset around whether friendly or enemy or neutral.

**10) <u>Gun Cross (Boresight Cross)</u>**

This shows exactly where the gun is pointing and exactly where the bullets will fly through or hit in close range if you fire the gun at that moment. It also shows where the nose of the aircraft is pointing.

## 11) The Flight Path Vector (FPV)

This is also known as the **velocity vector** and shows exactly **where the aircraft is flying to (the flight trajectory) if there's sufficient thrust force/power**.

When the FPV is above the artificial horizon, it means that the aircraft is climbing. If it is below the horizon, then the aircraft is descending, even if the nose of the aircraft is pointing above the horizon. The FPV is always accurate and is refreshed in real-time.

Beware that the difference in angles between the gun cross and the FPV is the aircraft's **Angle of Attack (AOA)**.

## 12) Waypoint (Next Waypoint) Indicator

This marks the position of a waypoint along an aircraft's flight path that is planned and programmed into the aircraft's **Global Positioning System (GPS)**.

The symbol for this indicator may vary i.e., a **small diamond box** or an **X** or any other symbol depending on the suitability or tastes of the HUD manufacturers and their client air forces.

## 13) Pitch Ladder

This is also called the **pitch attitude bars**. These indicate your angle of inclination from the horizon line. The **angles increase by $+5^0$ if you're climbing** and **decrease by $-5^0$ if you're descending**. The horizon line is at $0^0$ of the pitch ladder and in most cases the zero is never indicated.

Now let us look into those 3 modes that the aircraft and the HUD can be switched to. They are:

1) Navigation (NAV) Mode which we have looked into.
2) Air-to-Air (AA) Combat Mode
3) Air-to-Ground (AG) Combat Mode
4) Landing (ILS)Mode

As we said before, when a pilot is encountered with threats from the air or is tasked with destroying a target(s) in the air, he or she has to switch the aircraft to AA Mode to destroy the target(s) or threat(s) in the air with either guns (if the target is very close for example, below 1 nautical mile) or with missiles if the target is not in gun range.

When in AA Mode, the HUD displays information in such a way that it makes it easier for the pilot to search, detect, track, and destroy targets in the air. The pilot searches for the targets with two alternative search systems, the:

- **aircraft's radar systems** for both short and long-range targets. The radar uses **electromagnetic waves in the radio frequencies** of the **electromagnetic spectrum** to search, detect and track targets. The waves come from the radar's emitters and when they hit an object in the air or the ground, they bounce back to the radar and are picked up the radar's receiver. The radar waves bouncing back are called **radar returns**. Each aircraft has its own **unique radar return signature** which is known as the **aircraft's radar cross-section** and the aircraft's computers use this to identify and designate the target aircraft. To able to tell whether the target aircraft is friendly or an enemy, an aircraft has to be equipped with an **Identification Friend-or-Foe (IFF)Transponder**. This IFF transponder produces radio waves of a unique frequency that is received by the transponder of the target aircraft. The transponder of the target aircraft also produces its own radio waves and if the frequencies are the same, then the target

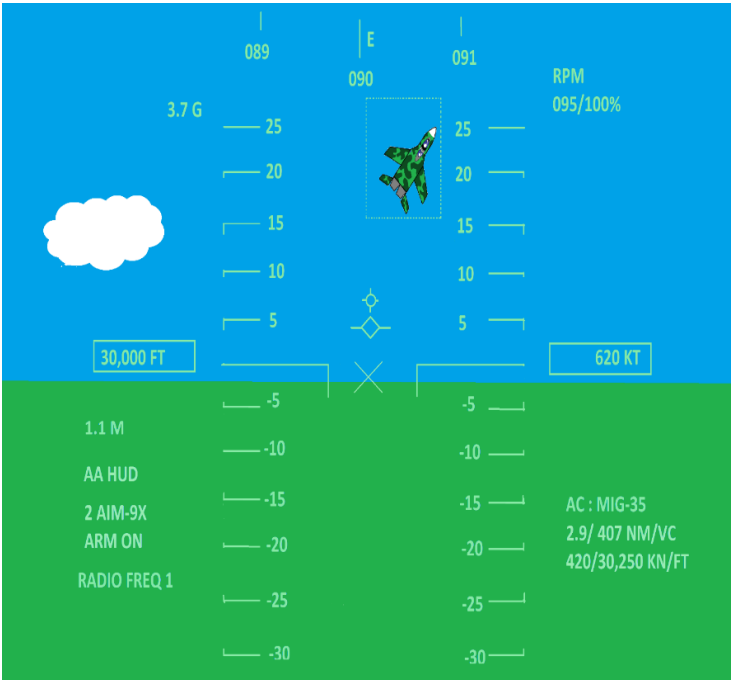
aircraft is a friendly and if not, then the target aircraft is a foe(enemy.)

- **aircraft's infrared search and track system (IRST)** for short range targets only due to the limited range of infrared-guided missiles that work in conjunction with the IRST. The IRST searches for targets within the infrared part of the electromagnetic spectrum. It works by searching for
  heat (infrared radiation)-producing objects in the sky and focuses(locks) on them. Aircraft generate heat from the engines and on their airframe (body frame) due to friction with the air. They are thus visible in the infrared spectrum to the IRST.

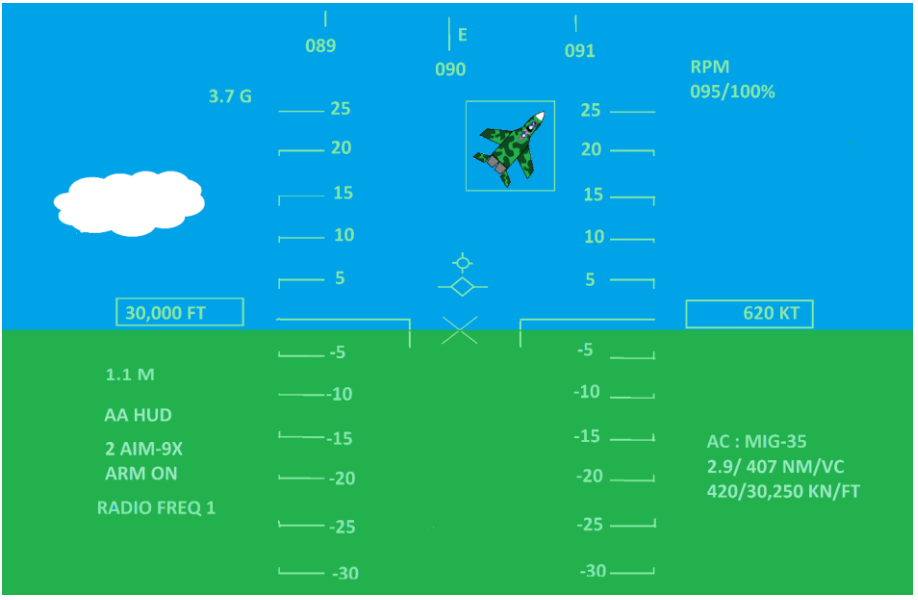
Sometimes the radar and the IRST can be used together to improve on the quality of searching, detecting and tracking targets especially if there is heavy rain and/or cloudy weather that make it harder for the IRST to detect targets because some of the infrared radiation(heat) from the target(s) is absorbed by the clouds and rain drops.

The target is always marked(designated) with a symbol in a HUD and the symbols may vary depending on the HUD manufacturers or suitability of air forces around the world, for example, squares, triangles, diamonds or any other can be used etc. The symbol used to mark targets in the air and on the ground can be similar or different for both air and ground targets. But for this publication we shall use the same symbol for both air and ground targets and I will use a square.

When a target has been detected by the aircraft's search systems (radar or IRST), it will be displayed on the HUD and for this publication as I have said, it will be shown in the HUD marked with a square surrounding it. The square can be called **a target designation box.** The square is first discontinuous(dotted) to mean that the target has been detected and is being tracked in the background. If the square is continuous (not dotted), it means that your aircraft is fully and actively tracking the target.



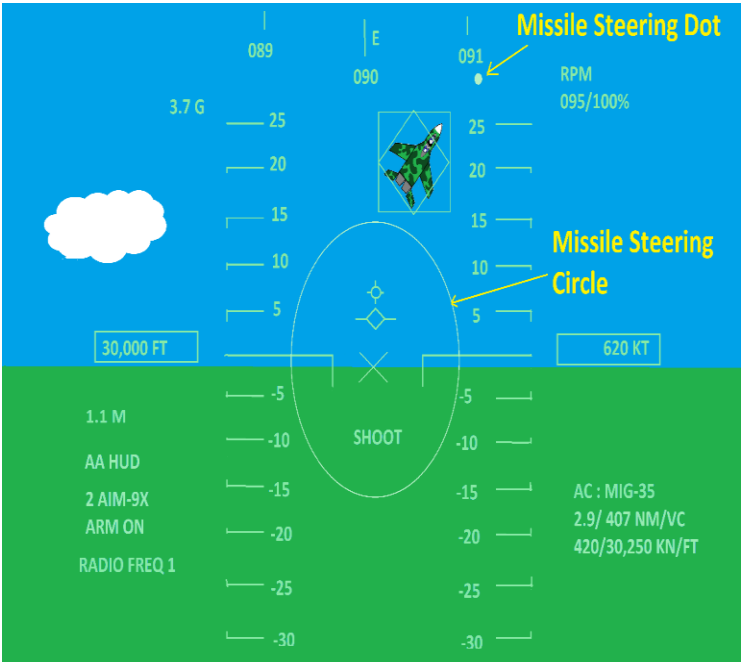

**Above: The target aircraft has been detected and marked by a discontinuous square hence it is being tracked in the background.**



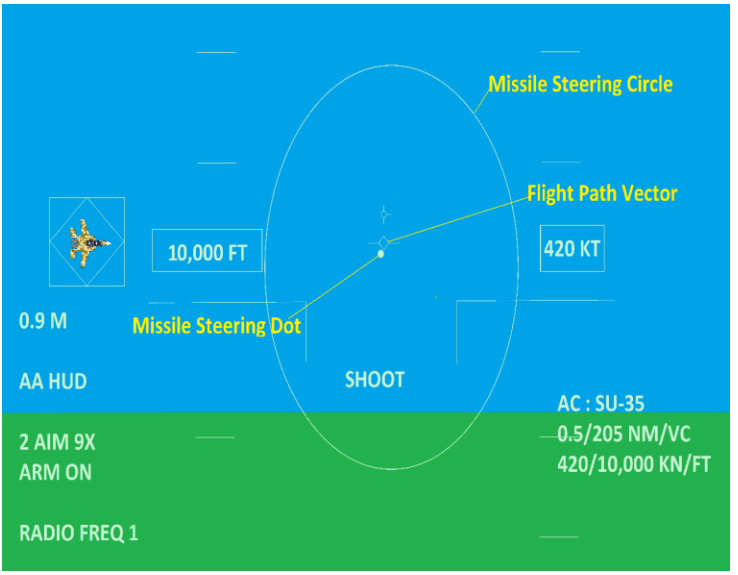

**Above: The target designation box is continuous square, meaning the target aircraft is being actively tracked**.

If a diamond box appears inside the square, then it means that your missile has locked onto the target and is in firing range of the target. Once you get in missile firing range of the target, you will see the HUD displaying the word **"SHOOT"** accompanied by a system generated voice saying the word "SHOOT". You can then get your aircraft in a good firing position by aiming at the front of the target to ensure that when you shoot your target, the missile has lesser chances of missing its target. This is done using the **missile steering circle** and **missile steering dot** information displayed on the HUD. The missile steering dot usually is displayed ahead of the target in the direction in which it is flying. The missile steering circle indicates the probability of kill, (also expressed on the HUD as a 00% pk value), i.e., the bigger the circle is portrayed, the greater the chances of

killing the target if the missile is fired at the target at that moment. The missile steering dot indicates where you ought to be aiming your nose in order to close the target. That means that you have to put your flight path marker (velocity vector indicator) on the missile steering dot so that both your aircraft and your fired missile can lead the target/go on lead pursuit at the target efficiently and get to the target faster with higher chances of hitting its target, thus also providing the shortest route to the target. Take a look at the illustration in the next page to see the symbology for the missile steering circle and steering dot.



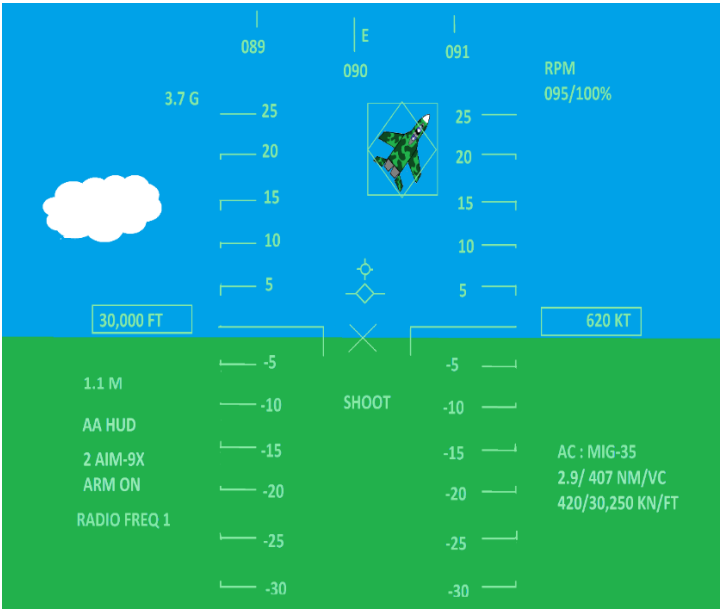

**Above: Take good notice of the missile steering dot and circle.**




**Above: The missile steering dot and flight path vector should be aligned for a maximum probability of kill(pK)**

The HUD also displays what weapon system has been selected, how much ammunition is available and whether the warhead(explosive) in a missile or air-to-ground bomb is armed (indicated on HUD as ARM-ON), meaning it has been switched on and is ready to explode on target. For example, in the illustration on the next page (look at lower left corner of HUD), the weapon selected is the heat-seeking (IR/Infrared-guided) **AIM-9X Sidewinder** missile and 2 of them are available, the missile is armed (ARM-ON) and the HUD mode is AA.

The HUD also shows details about the target. For example, its name, in this case as shown in the illustration below, the target is a **Mig-35 fighter aircraft,** how far the target is from your aircraft, how fast it is approaching your aircraft, its speed and altitude above sea-level. From the illustration below, the target is **2.9 nautical miles away**, approaching at a velocity closure (VC) of **407 feet per second** and flying above sea level at a height of **30,250 feet** at a speed of **420 knots (KN)**.




**Above: A diamond box sin the square means your missile has locked on target and you can shoot.**

Before we look at how the HUD is used in landing an aircraft, let us look at how it is used in a guns-only dogfight. In this kind of dogfight, the HUD displays **a gun funnel** and **gun cross**, both of which are useful in making successful shootdown of enemy aircraft. In some HUDs, the funnel is replaced by a line that moves like a snake depending on how the aircraft is maneuvering and is sometimes called the **gun(cannon)snake**. At the end of the gun snake is a circle.

To ensure a successful shootdown:

1) **always put the gun cross a head of the target's flight vector to help you lead the target (go on lead pursuit on the target). This helps you get closer to the target as fast as possible.**

2) **always ensure that your target is at the bottom end of the gun funnel/target is on the circular end of the gun snake as you fire your gun. This also helps you lead the target as bullets take time to arrive at the target and thus aiming ahead of the target is necessary.**

The gun in the aircraft never points straight forward but instead is always elevated at an angle, for example, $2^0$ to $4^0$. This means that if you fire your gun, the bullets will not take a straight path but instead they will take an elevated and curved path.

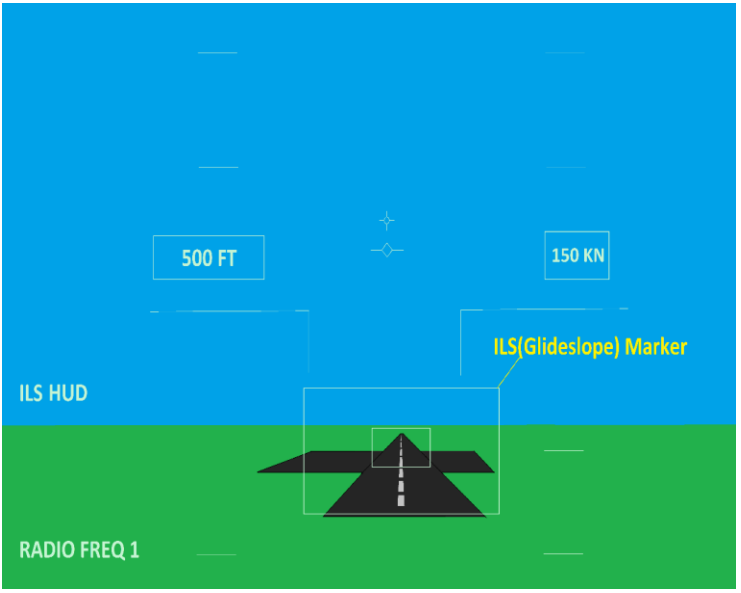
The curvature results from the fact that the bullets run out of kinetic energy as they climb into the air at an elevated angle and fall to the ground because of gravity. It is good to keep this in mind if you are engaging an aerial target that is within visual range but a little far off in the distance. Take a look at the illustration on the next page to see how to properly use the gun cross and gun funnel for an effective kill against enemy aircraft.

**The gun cross must always be put ahead of the target and the target must be at the bottom of the gun funnel for a successful shootdown of enemy aircraft.**

When a pilot needs to land his or her aircraft, then he or she has to switch the HUD to landing mode so that the HUD is optimized to display information that will guide the pilot into making a proper and safe landing. Aircraft as they attempt to land, often rely on the **Instrument Landing System (ILS)** to approach a runway at night or in bad weather or even during the day regardless of the weather. The ILS is a precision radio navigation system that provides short term range guidance to allow an aircraft to approach a runway.

The HUD potentially can be used in connection with the ILS to help a pilot approach a runway and land an aircraft while following a given **glideslope** (correct path to be followed for a successful landing). The HUD can be switched

to **ILS mode** and displays **ILS markers** (**glideslope markers**) to help the pilot find a proper glideslope for a successful landing. Take a look at the illustration below:




**ILS markers (glideslope markers) help the pilot find a proper glideslope for a successful landing.**

To see more on HUD symbology, you may navigate through the links below:

http://www.simscape.fr/F16HUD_Doc.html

https://www.f-16.net/forum/viewtpoic.php?t=863&p=21552

https://duotechservices.com/10-types-of-data=displayed-on-the-f-16-hud

https://web.deu.edu.tr/atiksu/ana44/hud.html

https://falcon4.wikidot.com/avionics:hud

## 9) Understanding the Hands-On-Stick and Throttle (HOTAS) System

HOTAS is an acronym of Hands-on Throttle and Stick. HOTAS is not actually a single system but a placement of vital buttons and switches of a fighter aircraft on the aircraft's flight control stick and throttle lever, to enable the pilot to keep his or her hands on the throttle and stick at all times without having to worry about performing certain vital actions and flying the aircraft with their hands removed from the throttle and stick to look for buttons, switches or controls in the cockpit.

HOTAS is jointly used in conjunction with other aircraft systems for a smoother and easier pilot experience, for example: direct voice input, the HUD and or the HMD. The goal of HOTAS is to create a smoother, easier, more convenient pilot experience and it does this by improving the pilot's situational awareness, improving the ability to manipulate switch and button controls in turbulence, under stress or during high G-force turns. It also improves on reaction time to a given threat in the air or ground and reduces the amount of time a pilot

needs to remove his or her hands from the stick and throttle in order to use other aircraft systems.

So, in detail, what does the HOTAS do, what functionality buttons or switches do we commonly have on the HOTAS? HOTAS has the following functionality button/switches:

- Radio communications switch
- Chaff/flare activation
- Speed brake controls
- Nose wheel steering
- Aerial re-fuel disconnect
- Many more

## 10) Combat Pilot Flight Gear

Now let us take a look at what equipment combat pilots wear or carry for a flight in a fighter aircraft and see the usefulness of each equipment. Before that, you may see some of the equipment in the image below and familiarize yourself with them.

**Above: US combat pilots in their flight gear**

10.1) **G-suit**

This is a suit that is worn over the flight suit and acts to help counter the effects of G-forces the pilot experiences during high G-force maneuvers. During high G-force maneuvers, the **G-suit fills up with air and pushes hard on the blood vessels in the legs and abdomen to prevent blood from accumulating in these areas** of the human body because **blood weighs more during high G-force experiences**. The **G-suit thus forces blood back towards the upper parts of the body including the brain**, thus helping the pilot avoid or minimize **black**/**grey**-outs or loss of consciousness.

10.2) **Helmet**

The helmet serves various purposes and is custom-fitted for every pilot. It protects the pilot from noise especially those coming from aircraft engines or cannon fire and explosions during air combat.
The helmet cushions the pilot's head from the high pressure resulting from the extreme acceleration of the fighter aircraft. This high pressure can cause headaches and swelling of the sinuses in the pilot's head.

The helmet also helps in identifying the pilot, whose call sign is stenciled across it. The helmet has a visor that is typically tinted in black to protect the eyes of the pilot from the glare of the bright sun.

The helmet also has communications equipment to allow for communication with other pilots or ground crews.

10.3) **Hand Gloves**

These are typically fire-resistant **Nomex** gloves designed to protect the pilot's hands from extreme heat in the event of fire breakouts in the cockpit.

10.4) **Flight Suit**

This is a full-body garment worn by pilots, especially military pilots and are designed to keep the wearer warm, carry a variety of equipment since they have many pockets and are also fire resistant to protect the pilot from severe burns in case of a fire outbreak in the cockpit. **Nomex** flight suits and other **Nomex** wearables are an example, known to be fire-resistant. **Nomex** is a fire-resistant meta-aramid material first developed in the early 1960s that is used to make certain garments and also finds other uses.

10.5) **Survival Vest**

This has pockets for keeping various equipment that can be used in the cockpit but more so after an ejection and landing on land or in the sea. We shall look at these equipment one by one from the most sophisticated to the simplest in section 10.9.

10.6) **Harness**

This is used to anchor the pilot to his seat and therefore functions in the same way as a car seatbelt.

10.7) **LPU-Life Preserver Unit**

This is filled with air to keep the pilot afloat if he or she ejects and lands on a large waterbody like a lake, river, sea, or ocean.

10.8) **Oxygen Hose and Mask**

These deliver oxygen gas to the pilot when the pilot is flying at higher altitudes where the oxygen partial pressure(concentration) is too low to facilitate the breathing process.

10.9 **Post Ejection Survival Equipment**

These are equipment that are useful to the pilot once he has ejected from his or her aircraft and is awaiting rescue and or evading enemy forces on the ground trying to capture him or her. They include:

a) Night Vision Googles (NVGs)

These allow the pilot to see in the darkness of the night by amplifying the slightest low-intensity visible lights in the cockpit and outside the cockpit. The NVGs can be attached directly to the pilot's helmet and can be used throughout a night flight even during take-off and landing.

Some NVGs work in the infrared (IR) spectrum and are designed to detect electromagnetic radiation in the near-infrared part of the electromagnetic spectrum and then convert the IR radiation to visible light for the pilot.

b) Maps

These are typically waterproof and usually kept in the leg pockets of the pilot's flight suit or pockets of the survival vest.

Maps help the pilot approximate their geographical positions or where they are headed to, whether during a flight or after an ejection.

c) Radio and Beacon

The radio helps the pilot communicate with a rescue team trying to find him after an ejection. The beacon releases sonar or radio signals when switched on, thus helping a rescue team pinpoint the exact location of a pilot after an ejection.

d) Flare

This is made of a substance that gives off light and heat (infrared radiation) in high intensities when ignited, like magnesium for example, thus helping a rescue team find a pilot easily after an

ejection at night or during the day, as flares are designed to be hot and visible in both daylight and at night in both the infrared and visible spectra. Flares can be carried by hand or fired from a flare gun to heights of about 1,250 feet in the air.

e) Finger Lights

These are small lighting systems worn over the pilot's fingers allowing the pilot to read maps and flight plans at night in the cockpit when flying.

f) Camouflage Paint
This is a special type of paint smeared on the face and uncovered body parts to reduce detection by blending with the natural environment.

g) Global Positioning System (GPS)
This is a device that links up with satellites orbiting the Earth in outer space to allow a user, in this case- a pilot, to pinpoint his or her exact geographical position. A pilot after ejecting from his or her aircraft can know exactly where he or she is, using this device.

h) Matches
These are typically waterproof, strike-anywhere matches that can be used by a downed pilot to light a fire for keeping warm or boiling water.

i) Tourniquet
This can be tied around injured parts of the body to stop or minimize bleeding.

j) Compass
This helps a downed pilot find his bearing if the GPS device fails.

k) Fire Starter
This is typically made of magnesium. It can be used to ignite a fire by scrapping against it using a knife or a rock.

l) Infrared Tape
This can be tied around the flight suit to help a rescue team locate a downed pilot quick enough because it is made of a material with a high reflectivity for infrared radiation(heat).

m) Strobe Light
This is a device that emits a high intensity light allowing the pilot to see at night and send a distress signal for help.

n) Relief Bag
This is useful in collecting drinking water after one has ejected and landed. They are also used by pilots to dump their urine safely instead of urinating on themselves during long flights.

o) Whistle
This is used to send an acoustic(sound) signal to rescuers or other allies on the ground so that they easily locate and find a downed pilot.

To see more on a combat pilot's flight gear and equipment, you may click on the links below:

https://en.wikipedia.org/wiki/G-suit

https://www.pbs.org/wgbh/nova/warplanes/pilo-nf.html

**11) BFMs In Filmography and The General Media**

BFMs have been featured in film forming part of a movie or television series based on air combat or video games (air combat simulators). Some of the popular films touching on air combat include **Tom Cruise's Top Gun 1 and 2, Top Gunner, JAG (TV series), Pearl Harbor,** and **Red Tails.**

Related computer air combat simulators include **Novalogic's F-16 Multirole Fighter, DID's F22 Total Air War, and Eagle Dynamic's Digital Combat Simulator (DCS) World** among others.

BFM in my opinion is the best thing that ever happened in the world, I love it, and I enjoy it very much, especially through these computer air combat simulators and film, maybe you should too if this is the first time you are coming across BFM.

Many thanks to you for taking the time to read this publication.

**Attributions**

1) Many thanks to the writers and artists on **Wikipedia.org** for availing content that was used to author this publication. The illustrations for Split-S, Combat-Spread, Thatch-Weave (Defensive Split), Weave Plain, Wingover and Immelmann-Turn maneuvers were obtained directly from Wikipedia under the free -to-use license and are in the public domains.
2) The illustrations for the Pursuit Geometry (Lag, Pure, and Lead Pursuit), the Lufbery maneuvers, missile evasion maneuvers, and the Heads Up Displays (HUDs) are my artistic creations as the author of this publication.
3) The cover art for this publication depicting the late American pilot **James Jabara** is my artistic creation as the author of this publication. The cover art was created drawing inspiration from a photograph of James Jabara while on active duty in Korea, standing on his F-86 Saber fighter jet.
4) Many thanks to all the artists on **pixabay.com** for availing their works of photography under the free-to-use license and in the public domain for use on this publication. The photographs are:
    - **A cockpit view of an F-15 Eagle pilot in a flight training exercise with other F-15 pilots by Military_Material@Pixabay.com (Page 9)**
    - **Russian-made Mig-29 Fulcrum releasing flares by ho7dog@pixabay.com (Page 36)**
    - **An American F-15 Eagle releasing flares by WikiImages@Pixabay.com (Page 37)**
    - **A twin-seat F-15E with pilot and WSO by WikiImages@Pixabay.com (Page 39)**

- **US Army pilots in an AH-64 Apache attack helicopter by Military_Material@Pixabay.com. (Page 51)**
- **A US Marine Corps aviator poses with the Joint Helmet-Mounted Cueing System (JHMCS) by Military_Material@Pixabay.com. (Page 52)**
- **A US Navy F/A-18 Super Hornet getting refueled airborne by Military_Material@Pixabay.com. (Page 53)**
- **US Combat pilots in their flight gear by clarencealford@pixabay.com (Page 73)**

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