



Missile Technologies

Murali Mohan Gade
Scientist 'G',
Directorate Of Systems,
DRDL, DRDO
Dr. A.P.J. Abdul Kalam Missile Complex
Hyderabad.

“DRDO-Industry-Academia Conclave-2026 (DIAC-2026)”
SSPL, DRDO, New Delhi.
21st February 2026

Introduction to Missiles



- ❖ A **guided missile** is a **guided self-propelled flying weapon** usually propelled by a **rocket motor** or a **jet engine**. An **unguided self-propelled flying munition** is called as a **rocket**.
- ❖ **Guided missiles** form the cutting edge of all **weapons of war** today.
- ❖ While **guided missiles** have become more and more **sophisticated and smart**, the **fundamentals of missiles** remain unchanged.
- ❖ A host of **different disciplines of science and engineering** go into the making of a **guided weapon system**.
- ❖ A **rocket or missile** exploits **Newton's 3rd law**. A **force** pushes a **steady stream of gas** out behind the **rocket**, and a **force of equal magnitude** pushes the **rocket/ missile** itself in the **opposite direction, forward** as shown in Fig-1.

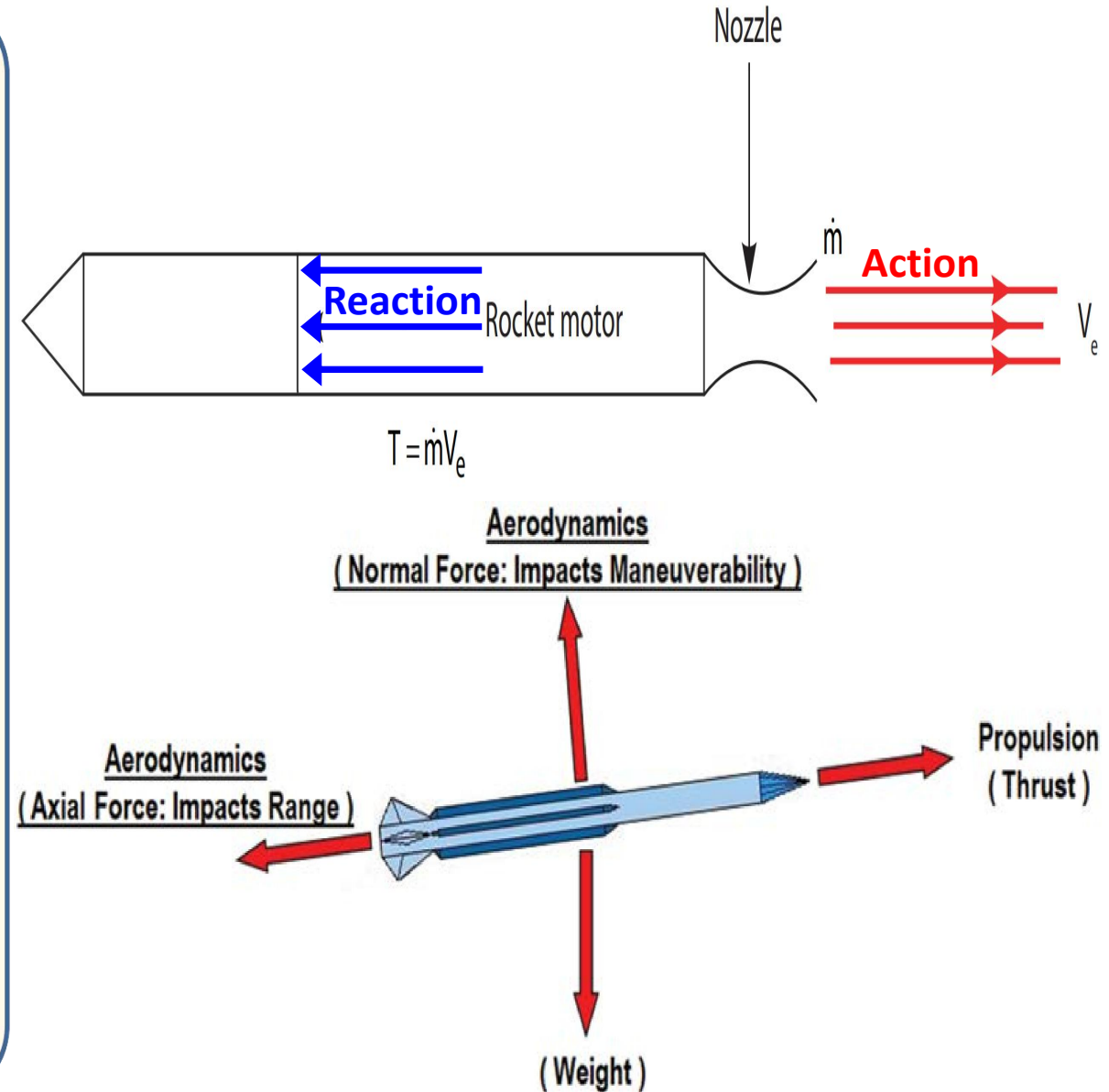


Fig-1: Forces acting on a missile

Classification of Missiles



- ❖ **Guided missiles** may also be classified as **strategic** or **tactical**, with further subdivisions depending on the role.
- ❖ **Strategic missiles** are **large missiles**, often with **nuclear warheads** and **very long ranges**, meant to **destroy the enemy's ability to wage war**.
- ❖ The target for **strategic missiles** will be a **fixed position on earth**, such as a **city, troop forming up position**, etc., whose **coordinates are known a priori** and the **missile has to be programmed to fly to this geographical position**.
- ❖ **Strategic missiles** follow either a **ballistic trajectory (Ballistic Missiles)** or a **low altitude aerodynamic trajectory (Cruise Missiles)** as shown in Fig-2.

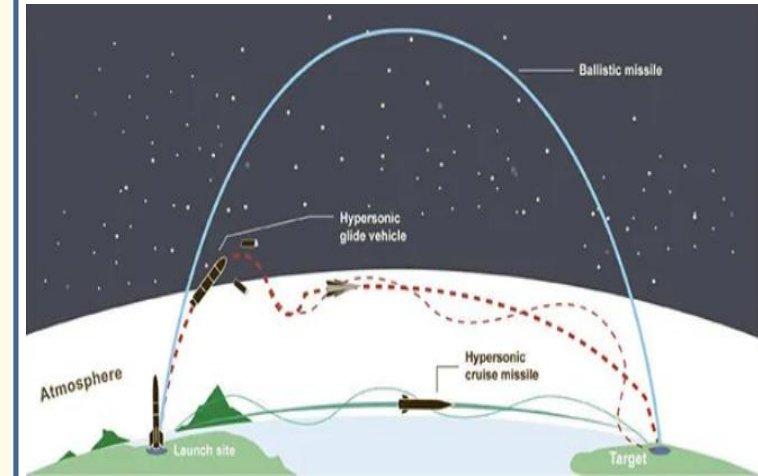


Fig-2: Trajectory of strategic missiles

Classification of Strategic Missiles: Ballistic Missiles



- ❖ **Ballistic missiles** are accelerated to reach **hypersonic velocities** at a **point P**, at which, the **thrust is terminated** (**cut-off velocity ≈ 7 km/sec**) and the **missile** subsequently flies, **subject only to gravity**.
- ❖ It invariably flies above the atmosphere, with the **apex** being at an **altitude of 300 km or more** and **re-enters the atmosphere to terminate on the target**. Consequently, it has to **overcome the problem of re-entry into the atmosphere**.
- ❖ When it enters the **atmosphere** again at **hypersonic velocities**, **extremely high temperatures** are produced due to **atmospheric friction**, which can **melt most of the metals**.
- ❖ **Carbon-carbon re-entry shields** are used to **withstand these temperatures**.

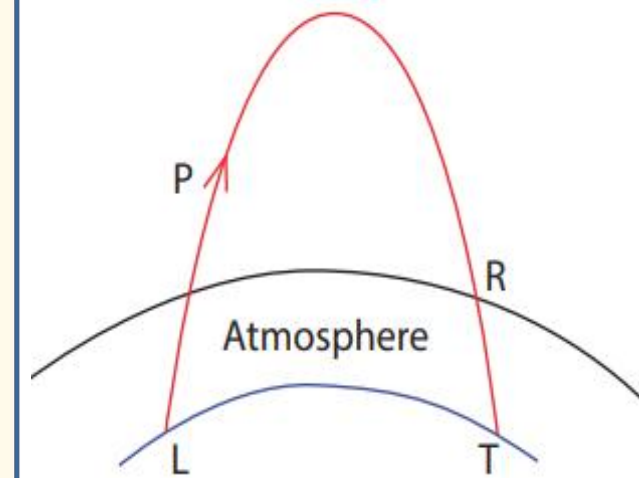


Fig-3: Ballistic Missile Trajectory

- ❖ The **surface/submarine** launched **ballistic missiles** are **classified** based on the **range of the missile**.
- ❖ They may be called '**Inter Continental Ballistic Missiles**' (**ICBM**) if the **range is over 5500 km**;
- ❖ '**Intermediate Range Ballistic Missiles**' (**IRBM**) if the **range is between 3000 km and 5500 km**;
- ❖ '**Medium Range Ballistic Missiles**' (**MRBM**) when the **range is between 1000 km and 3000 km**;
- ❖ '**Short Range Ballistic Missiles**' (**SRBM**) if the **range is > a few hundred kilometers, but < 1000 km**.
- ❖ '**Theatre Ballistic Missile**' (**TBM**) if any **ballistic missile** with a **range less than 3500 km**.
- ❖ The **long-range ballistic missiles** invariably carry **nuclear warheads**.
- ❖ Many **ICBMs** carry **multiple warheads** called '**Multiple Independently Targetable Re-entry Vehicle**' (**MIRV**), which can **attack different target locations**.

Classification of Strategic Missiles: Cruise Missiles



- ❖ **Cruise missiles** fly the **aerodynamic trajectory**. They are usually **subsonic** and fly at a **very low height** of a few meters above the ground/sea to avoid radar detection.
- ❖ **Tomahawk** is the well known missile of this type. These are usually **powered by turbojet engines** and are practically **unmanned aircraft**.
- ❖ They have **low radar and infrared signatures** to avoid detection. Their **range is extremely large**, varying from a few hundred kilometers to several thousand kilometers.
- ❖ There are also a few **cruise missiles**, often **air-to-surface**, with ranges of a few hundred kilometers, which fly at **supersonic speeds** at great heights, typically, well above 10 km.
- ❖ Those, which have a long range may be powered by **Ramjet engines (e.g. BrahMos)**, and those in the shorter range bracket may opt for **rocket engines**.

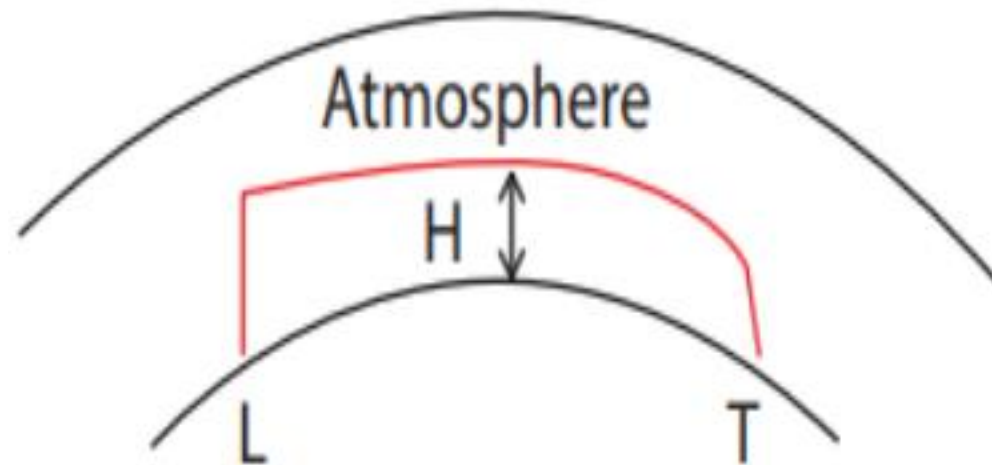


Fig-4: Cruise Missile Trajectory

Classification of Missiles: Tactical Missiles against Moving Targets



- ❖ **Tactical missiles**, on the other hand, are meant for battlefield use for the limited purpose of winning the battle or encounter and will be launched to engage moving targets.
- ❖ **Tactical missiles** have far smaller ranges, measurable in tens of kilometers instead of hundreds and thousands of kilometers of the **strategic missiles**.
- ❖ All the **SAMs, AAMs, ATGMs & ASHMs** come under **tactical missiles** category.

Classification of Missiles

- ❖ **Missile Classification based on *Missile Launch Platform & Type of Target to be Engaged*:**
 1. **Surface-to-Surface Missile (SSM)** (e.g. Prithvi, Agni, Scud)
 2. **Surface-to-Air Missile (SAM)** (e.g. AKASH, QRSAM, AKASH-NG, LRSAM, VSHORADS, S400, Patriot)
 3. **Air-to-Surface Missile (ASM)** (e.g. NGARM, RudraM-II, RudraM-III, SANT, AGM-65 Maverick)
 4. **Air-to-Air Missile (AAM)** (e.g. Astra, Meteor, AIM-120)
 5. **Anti Ship Missile (AshM)** (e.g. BRAHMOS, NASM-MR, HARPOON, EXOCET, NEPTUNE, YJ-18)
 6. **Anti Tank Guided Missiles (ATGMs)** (e.g. NAG, HELINA, MPATGM)
 7. **Underwater-to-Surface Missile (USM)** (e.g. B05, UGM-96 Trident)
 8. **Underwater-to-Underwater Missile (UUM or Torpedo)**

Classification of Missiles



❖ Missile Classification based on *Speed of the Missile*:

1. Subsonic Missiles: Missile Speed < 1 Mach (e.g. NAG, MPATGM, HELINA, NASM-SR)
 2. Supersonic Missiles: Missile Speed > 1.2 to 5 Mach (e.g. AKASH, QRSAM, AKASH-NG, S400, PATRIOT)
 3. Hypersonic Missiles: Missile Speed > 5 Mach (e.g. LRAShM, AVANGARD, KINZHAL, DF-17, YJ-21, HACM)
- ** 1 Mach = Sound Velocity in air (at 15°C) \approx 340 m/s.**

❖ Missile Classification based on *Type of Propulsion of the Missile*:

1. Solid Propulsion Missiles (e.g. QRSAM, VSHORADS, ASTRA, NAG, MPATGM, NGARM, NASM-SR, AGNI)
2. Liquid Propulsion Missiles (e.g. PRITHVI, RS-28 Sarmat, DF-5, Trident II DS)
3. Solid Fuel based RAMJET Air breathing Missiles (e.g. AKASH, SFDR, Meteor, KH-31)
4. Liquid Fuel based RAMJET Air breathing Missiles (e.g. BRAHMOS, STAR)
5. Turbojet Engine based Air breathing Cruise Missiles (e.g. EXOCET, Kalibr, Babur, CJ-10)
6. Turbo Fan Engine based Air breathing Cruise Missiles (e.g. NIRBHAY, SCALP EG, AGM-86 ALCM)
7. SCRAMJET based Air breathing Cruise Missiles (e.g. HSTDV, X-51A, HAWC, ZIRCON)

Various Sub Systems in a Tactical Missile



- ❖ **Guided Missile Subsystems:** Any missile system is made up of several subsystems. These are as follows:
 - **Propulsion**
 - **Airframe**
 - **Guidance**
 - **Control System (Autopilot)**
 - **Actuation System:** Electro Mechanical Actuator (EMA), Electro Pneumatic & Electro Hydraulic.
 - **Sensors:** Inertial Navigation System (INS) consisting Rate Gyros & Accelerometers, GPS, RF/ IIR Seeker.
 - **On-Board Computer** for executing **Control, Guidance & Mission Software**
 - **Avionics Systems (RF Data Link, Telemetry System)**
 - **Warhead, and Safety & Arming Mechanism (SAM)**
 - **Proximity Fuze (Radio / Laser Proximity Fuze)**
 - **Missile Power Supply (Thermal Battery or Alternator in Turbojet/ Turbo Fan Engine based Cruise Missiles)**

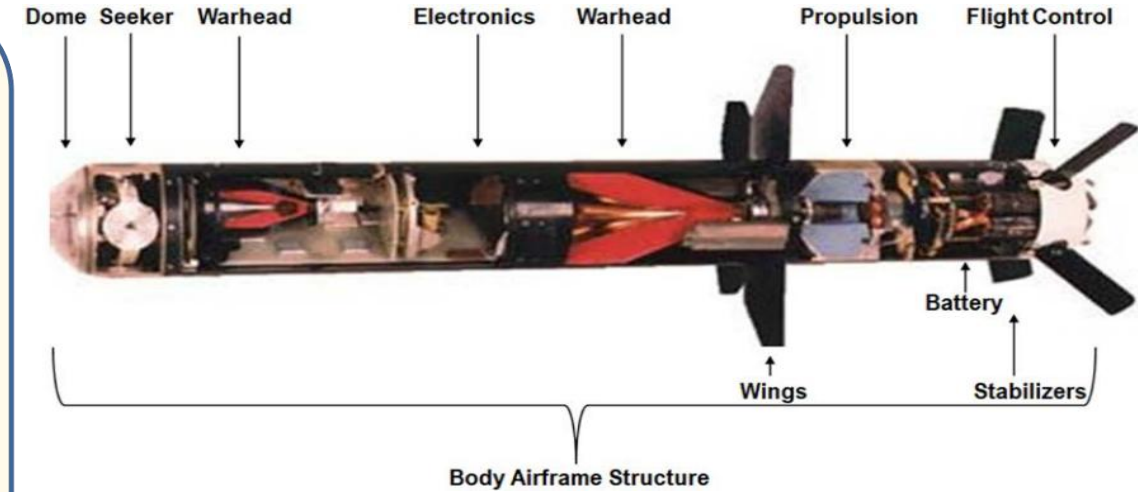


Fig-5: Various Sub Systems in a Tactical Missile

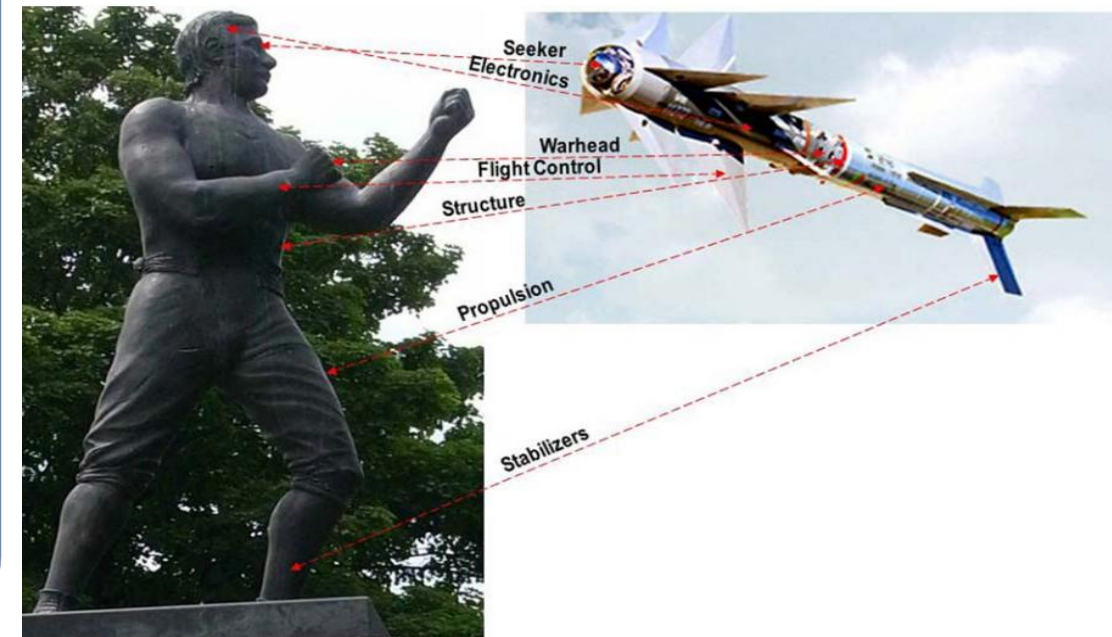


Fig-6: Missile Subsystems are Analogous to a Human Boxer

Missile System Conceptual Design & System Engineering



- Start from **mission requirements** and select an **existing baseline missile**.
- The baseline missile enables **balanced system engineering** using **validated test data**.
- Modify **aerodynamics, propulsion, subsystems, mass, and trajectory** to meet **new requirements**.
- Evaluate against **flight performance requirements** (**range, time-to-target, maneuver capability** etc.)
- If requirements are **not met, resize and iterate**.
- After meeting flight performance requirements, assess **other measures of merit and constraints**.
- These include **seeker performance, lethality, survivability, reliability, cost, and platform integration**.
- Once all the requirements are met, **finalize the conceptual design** and transition to **preliminary design**.

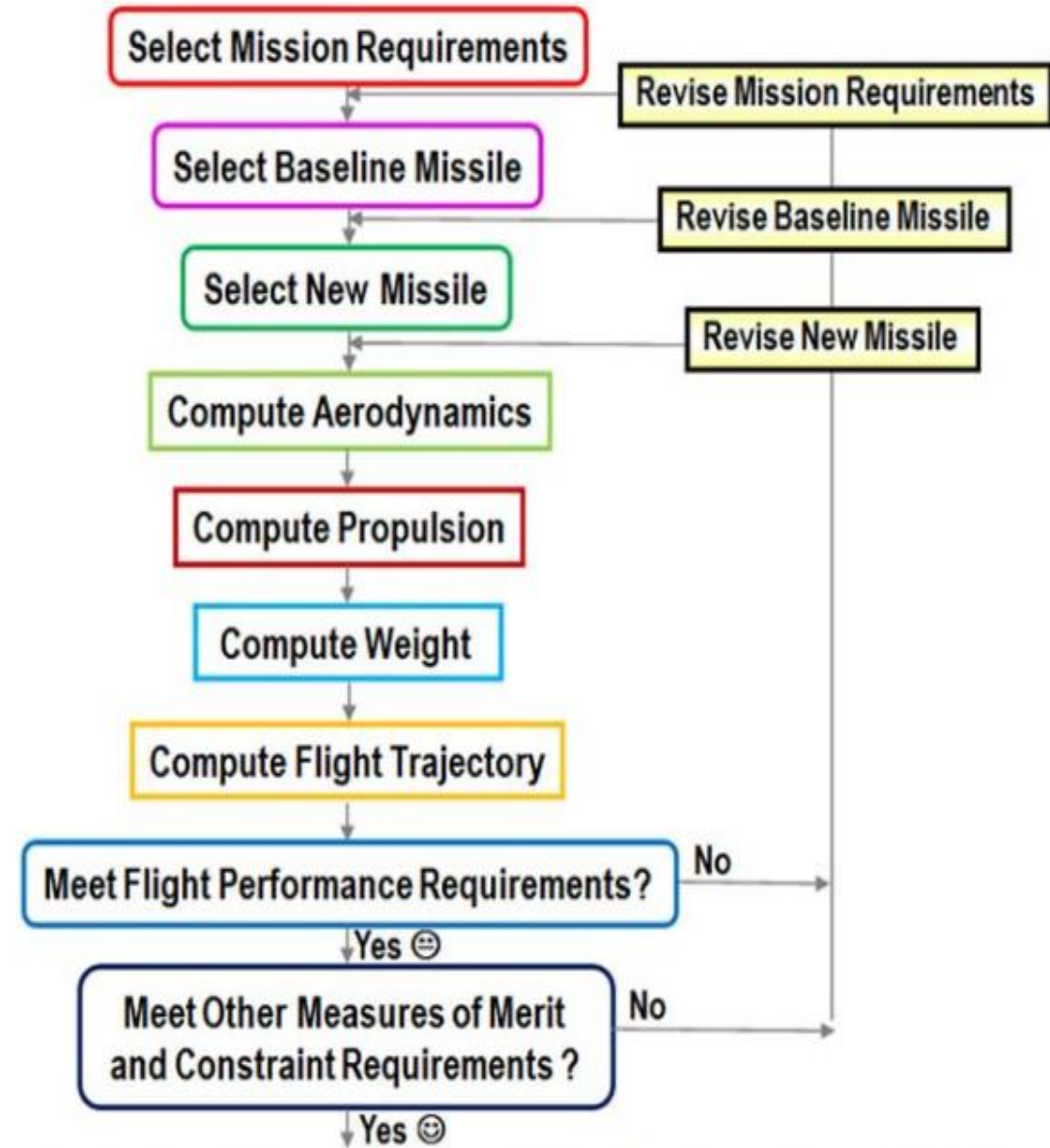
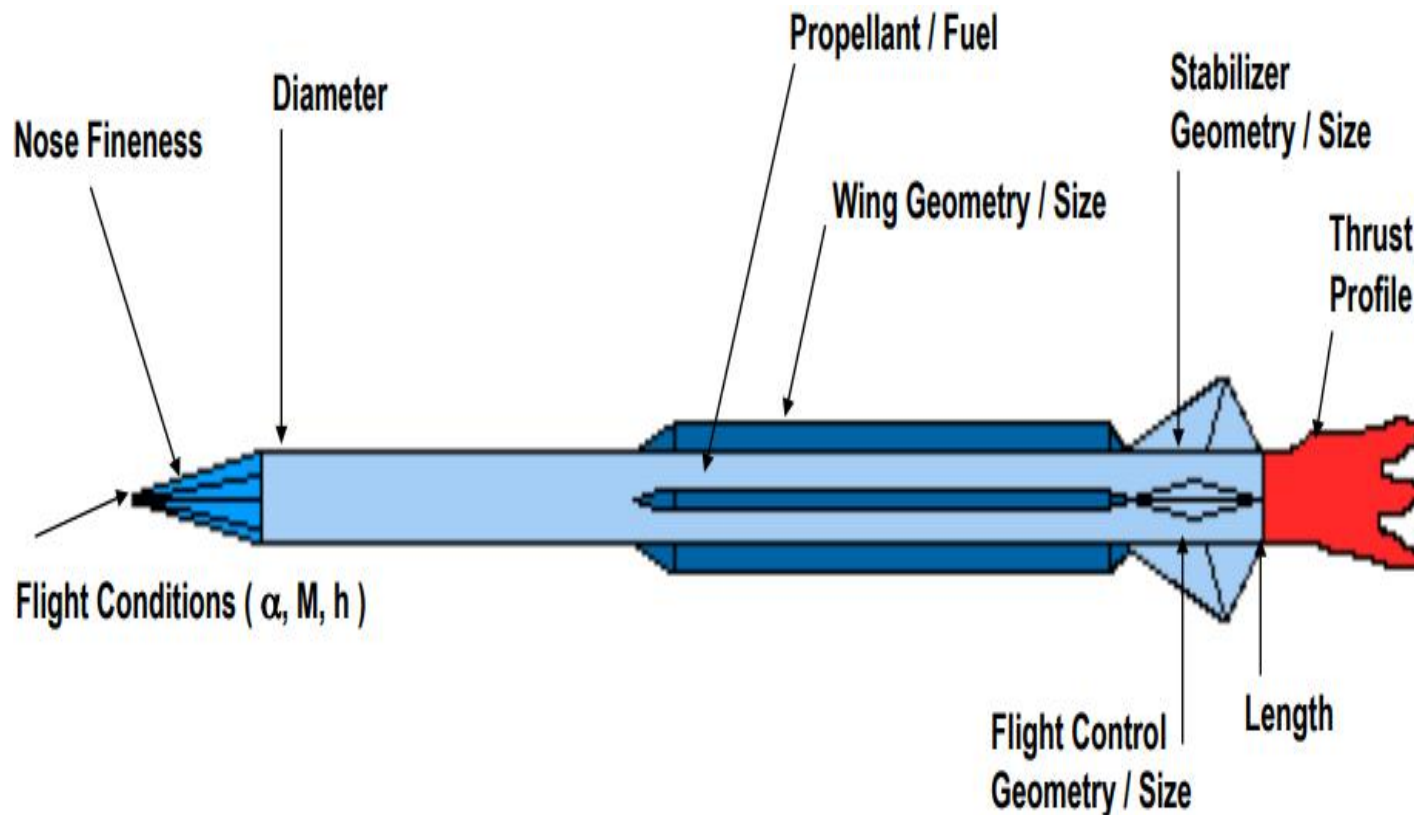


Fig-7: Missile Conceptual Design and System Engineering Process 9

Missile Technologies: Aerodynamics



- ❖ Aerodynamic configuration and system engineering synthesis requires consideration of alternative configurations, aerodynamic technology, and the process for resizing the missile.
- ❖ **Geometry Outputs:** Body size (diameter, length) & nose shape.
- ❖ **Surface Outputs:** Size/ Geometry of Wings, stabilizer & control surfaces.
- ❖ **Aerodynamic Outputs:** Aerodynamic coefficients and derivatives (C_L , C_D , C_m , Stability & Control).



❖ Key Outputs:

- ✓ Lift, Drag, Moment coefficients
- ✓ Static stability derivatives
- ✓ Control effectiveness
- ✓ Trim & maneuver limits

❖ Applicable across Regimes:


Subsonic–Transonic–Supersonic–Hypersonic

Fig-8: A typical Missile Aerodynamic Configuration

Missile Technologies: Aerodynamics



Impact of Aerodynamic Design Variables on Mission Measures of Merit:



Aero Configuration Sizing / System Engineering Parameter	Typical Impact on Missile Mission Requirements / Measures of Merit (MOM)									
	Flight Performance MOM			Other Typical Measures of Merit						Sys Engr Constraint
	Range	Maneuverability	Time to Target	Robustness	Lethality	Miss Distance	Observables	Survivability	Cost	Launch Platform
Nose Fineness (l_N / d)	○●	○	○●	○	○●	○●	●	●	○	○
Diameter (d)	●	○	○●	○	●	○●	○	○	○●	●
Length (l)	○●	○	○●	○	○●	○●	○	○	○●	●
Wing Geometry / Size (S_W)	●	●	○●	○	●	●	○●	○●	-	●
Tail Stab Geom / Size (S_T)	○●	●	○	○	○●	○●	○●	○●	-	●
Flight Control Geometry / Size ($S_{Control}$)	○●	●	○	○	●	●	○●	○●	○	●
Flight Conditions (Angle of Attack α , Mach Number M , Altitude h)	●	●	●	●	●	●	●	●	●	○

● Very Strong ○● Strong ○ Moderate - Relatively Low

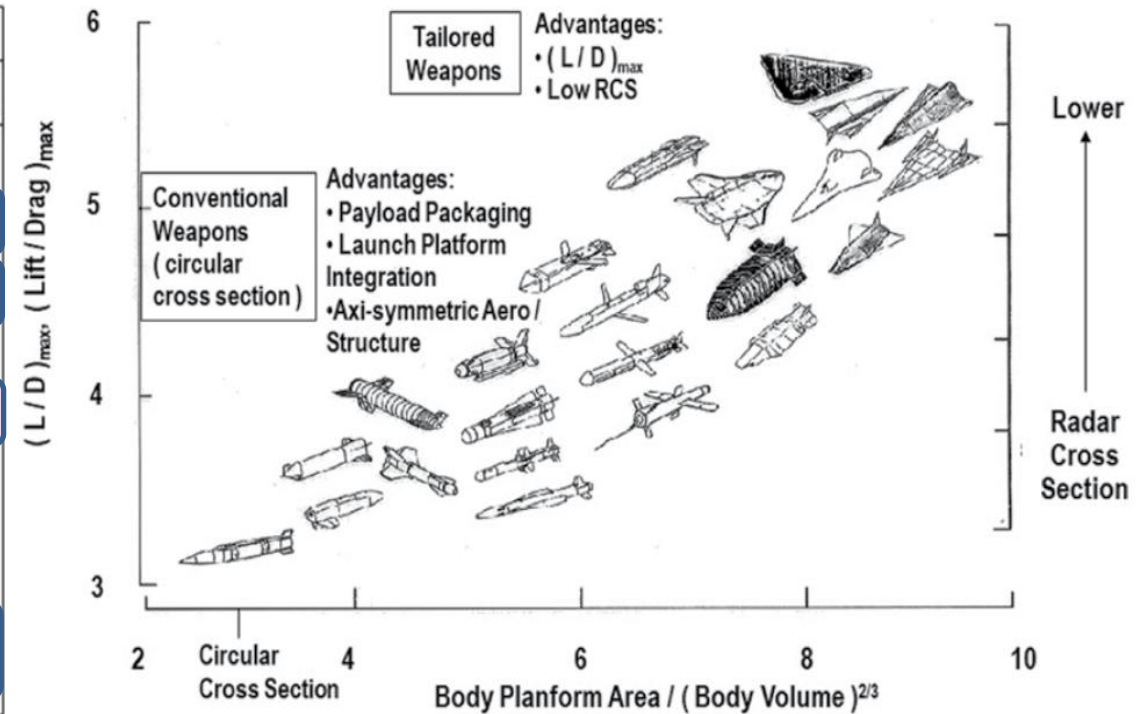
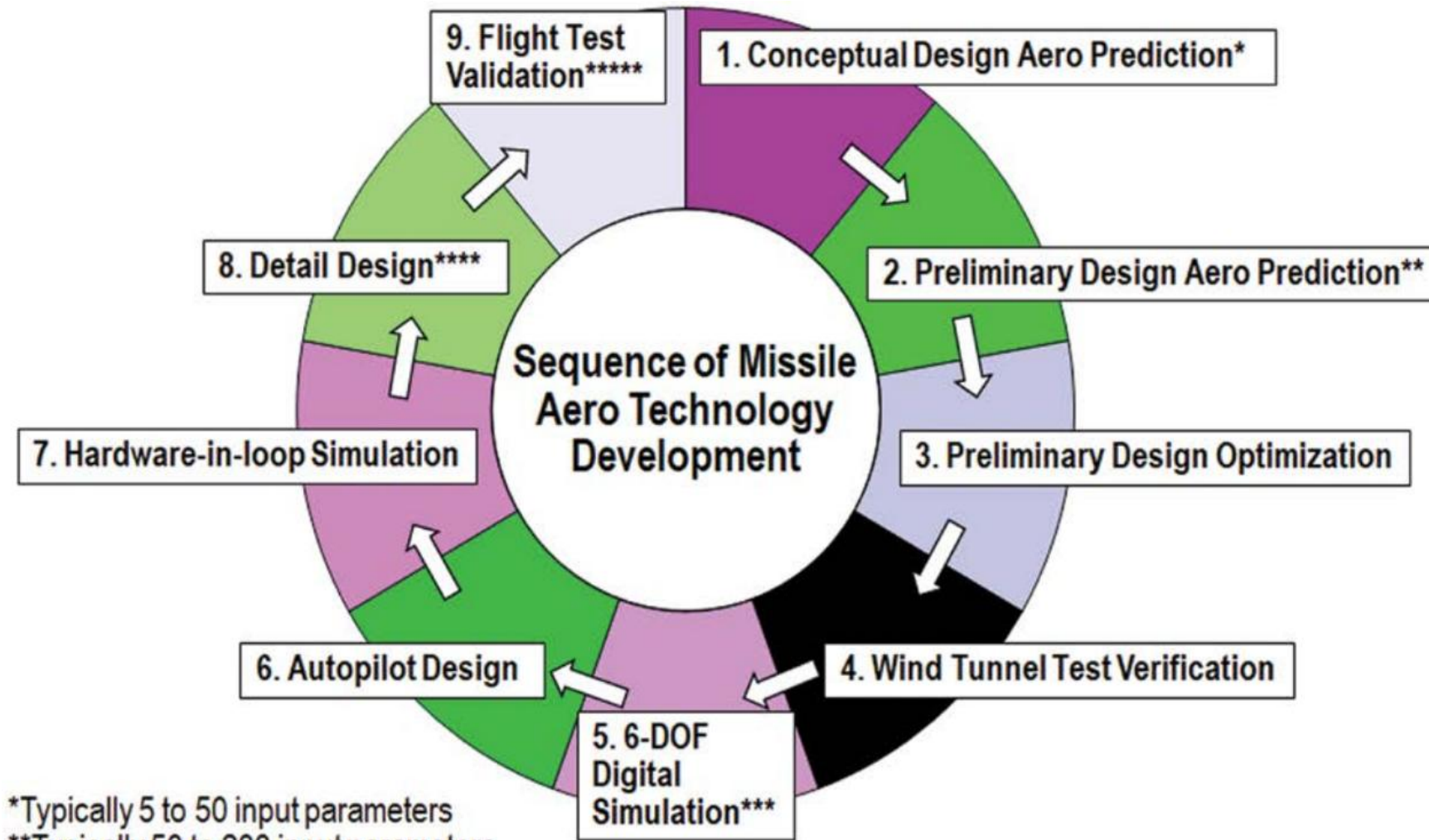


Fig-9: Key Trade-off: Aerodynamic efficiency vs Stealth

- ❖ **Key Trade-offs:**
- ✓ Drag vs Seeker Range
 - ✓ Drag vs Warhead Lethality
 - ✓ Maneuverability vs Stability
 - ✓ L/D vs Radar Cross Section (RCS)
 - ✓ Control authority vs Heating & Loads

Missile Technologies: Aerodynamics Technology Development Process



*Typically 5 to 50 input parameters

**Typically 50 to 200 input parameters

***Examples: CDAC++, MATLAB

****Typically over 200 input parameters

*****Typically about 50 channels for telemetry (TM) data (e.g., acceleration, angle of attack, Mach number, altitude, roll angle, flight control deflection, hinge moment, temperature)

Fig-10: Missile Aerodynamics Technology Development Process

Missile Technologies: Propulsion Technologies



- ❖ The propulsion system is essentially the engine, which enables the missile to start from rest, reach a high velocity, and keep flying at this velocity.
- ❖ Missile propulsion uses rockets or jet engines, both work based on Newton's third law. High-pressure gases from fuel combustion are accelerated through a nozzle and expelled rearward to produce thrust.
- ❖ Reaction produces a forward thrust on the vehicle: the key difference is that a jet engine carry only fuel and use atmospheric oxygen, while a rocket motor carries both fuel and oxidizer as chemicals, making them self-sufficient for burning.
- ❖ Hence, rockets can provide thrust, even if there is no atmosphere, whereas jet engines cannot.

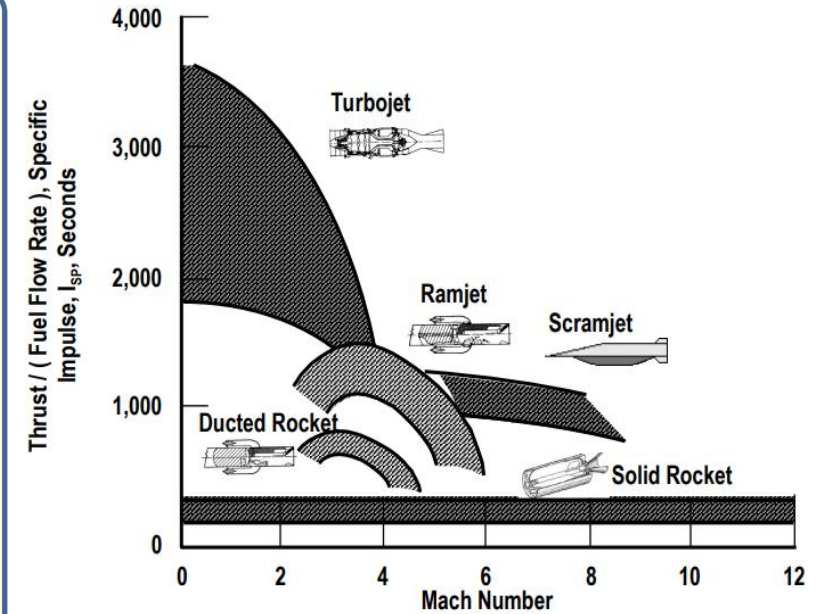


Fig-11: Specific Impulse (I_{sp}) of tactical missile propulsion alternatives

- ❖ If a rocket ejects propellants at the rate of \dot{m} kg/sec at a velocity of V_e m/sec, the forward Thrust produced on the missile will be $T = (\dot{m}V_e)$ Newtons.
- ❖ The Figure of Merit for rocket propellants is Specific Impulse (I_{sp}), defined as $I_{sp} = \left[\frac{T}{\dot{m}g} \right]$ seconds.
- ❖ The propulsion sizing output includes the thrust, Specific Impulse, and the propellant/ fuel weight.
- ❖ Fig-10 shows the Specific Impulse (I_{sp}) of tactical missile propulsion alternatives.

Missile Propulsion Technologies: Rocket Engines



Solid Rocket Motor:

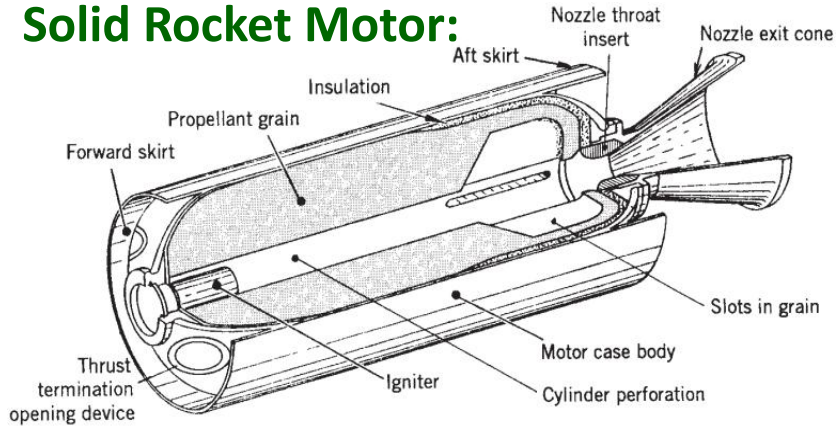


Fig-12: Schematic of Solid Rocket Motor

Liquid Rocket Engine:

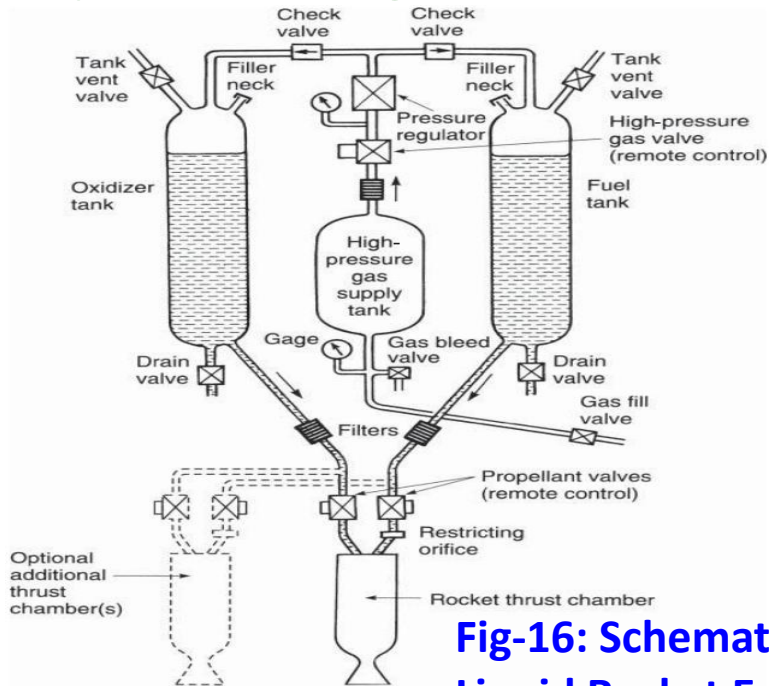


Fig-16: Schematic of Liquid Rocket Engine

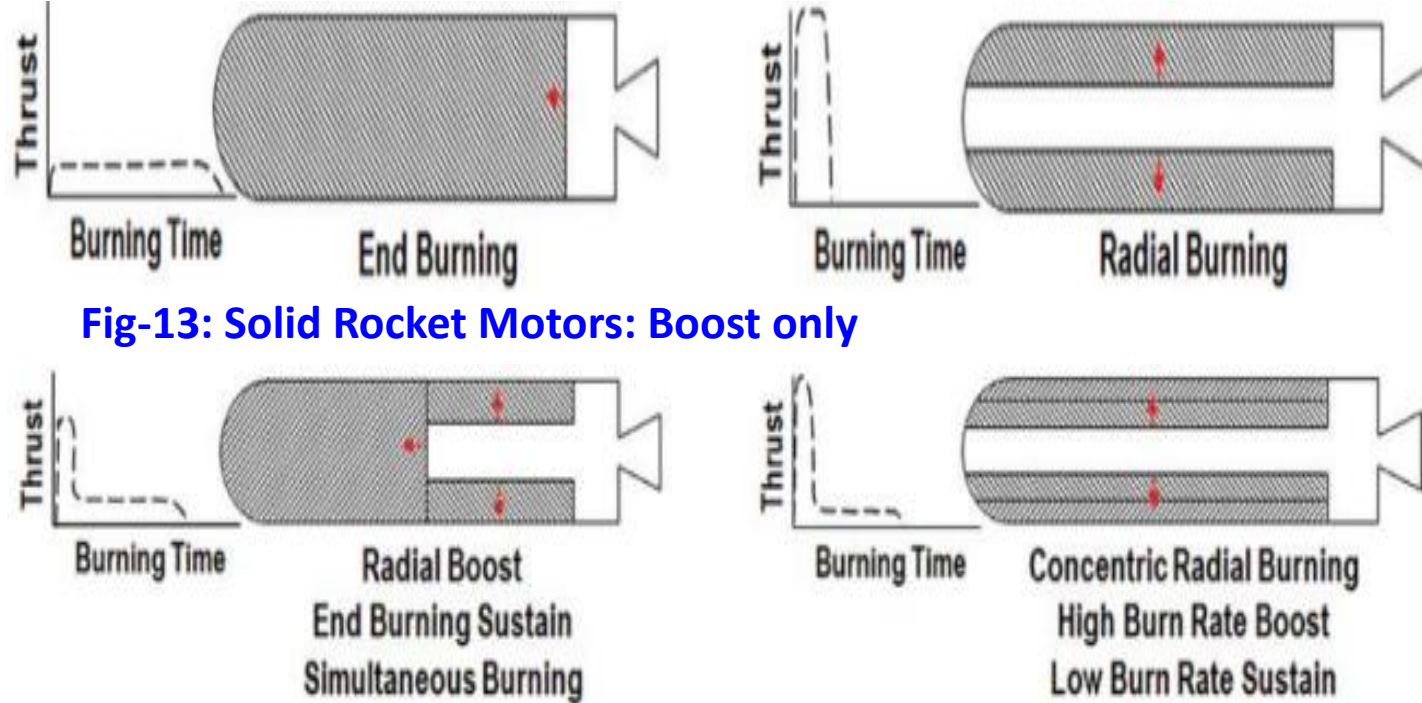


Fig-13: Solid Rocket Motors: Boost only

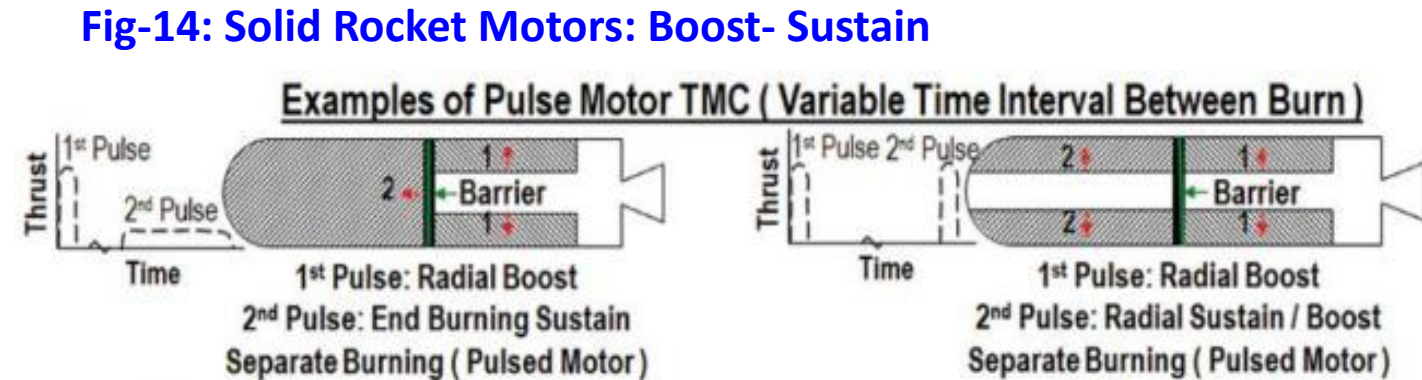


Fig-14: Solid Rocket Motors: Boost- Sustain

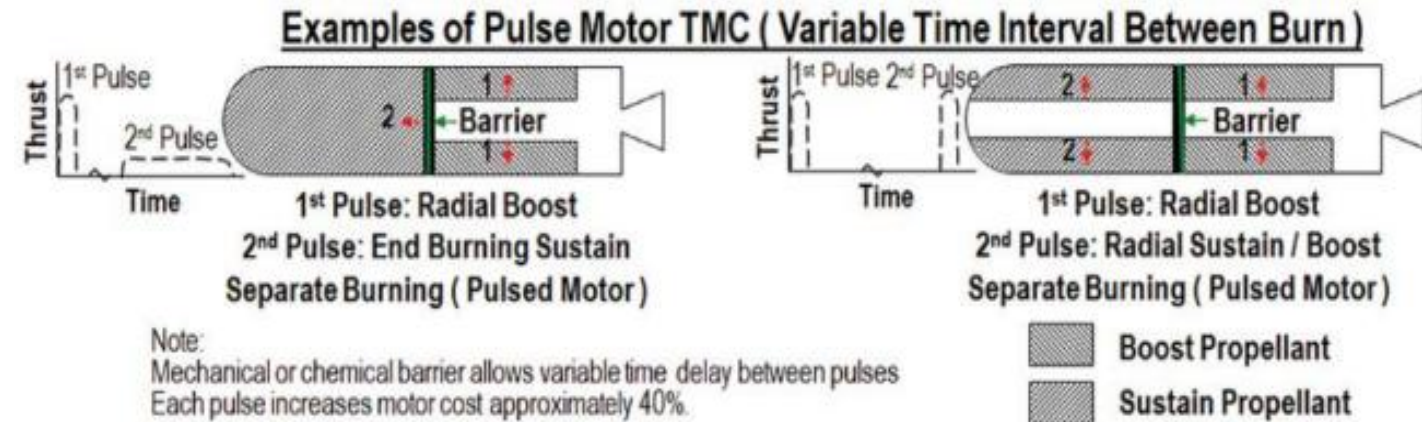
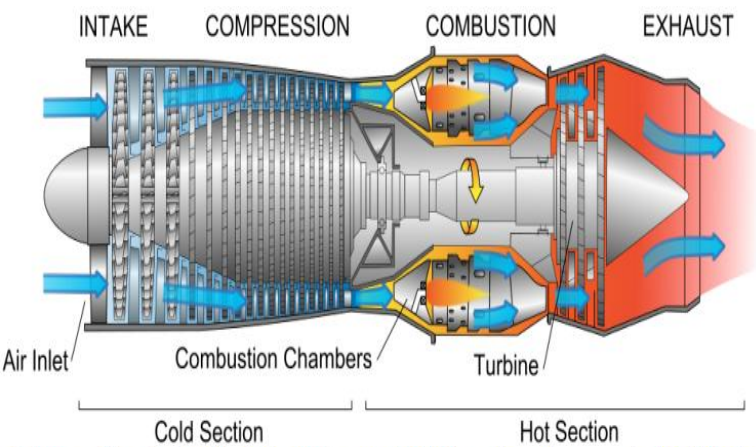


Fig-15: Solid Rocket Motors: Pulsed Motors

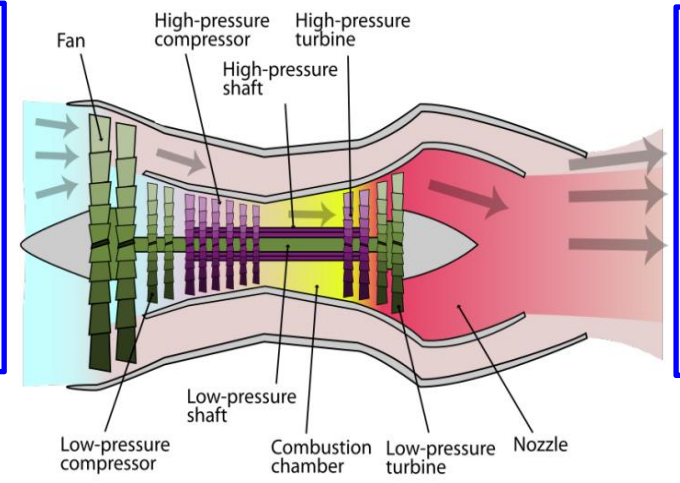
Missile Propulsion Technologies: Air breathing Engines



Oxidizer: Atmospheric
Operating Principle:
 Mechanical compression;
 thrust from high velocity
 exhaust.
**** Subsonic/ Supersonic**

Schematic of a turbojet engine, which has five stages: 1. Air inlet or intake stage; 2. Compressor stage; 3. Combustion stage; 4. Gas generator turbine stage; 5. Exhaust stage through a nozzle.

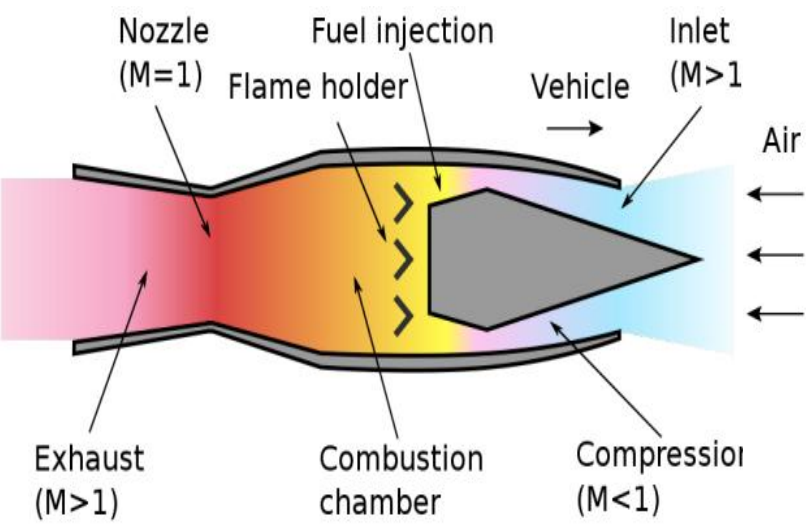
Fig-17: Schematic of Turbojet Engine



Oxidizer: Atmospheric
Operating Principle:
 Mechanical
 compression; thrust
 mainly from bypass flow
**** Efficient Cruise**

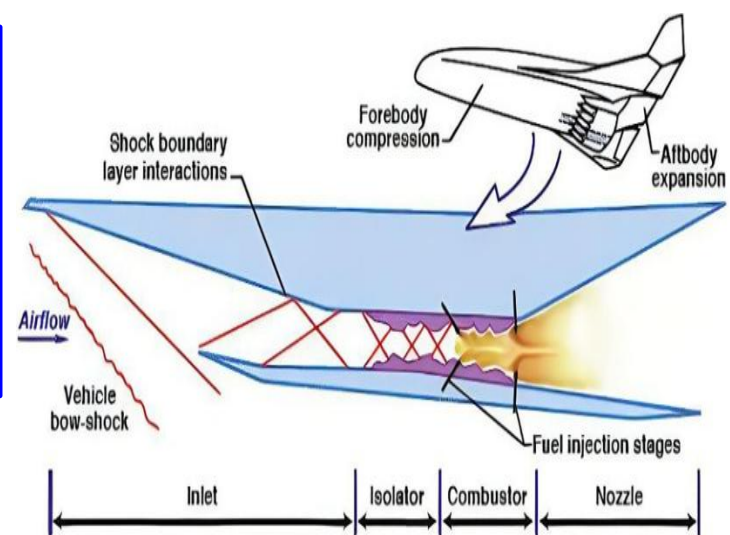
The flow in a turbofan engine is split into two paths, the bypass ratio being the ratio between the mass flow through the fan and the mass flow through the core.

Fig-18: Schematic of Turbofan Engine



Oxidizer: Atmospheric
Operating Principle:
 Aerodynamic (Ram)
 compression with
 subsonic combustion
**** Mach 2-5**

Fig-19: Schematic of Ramjet Engine



Oxidizer: Atmospheric
Operating Principle:
 Shock compression
 with **Supersonic
 combustion**
**** Mach 5 +**

Fig-20: Schematic of Scramjet Engine

Missile Technologies: Comparison of Propulsion Technologies



Parameter	Solid Rocket Motor	Liquid Rocket Engine	Turbojet Engine	Low-Bypass Turbofan Engine	Ramjet Engine	Scramjet Engine
Propulsive efficiency	Low	Low	Medium	High	Medium	Low
SFC	-N.A-	-N.A-	High	Low	Medium-High	Very High
Isp (sec)	180-300	300-460	2000-4000	4000-7000	1000-3000	1000-2000
Optimal Mach No.	0-Infinity	0-Infinity	M 0.8 – 1.5	M 0.6-0.9	2.0-4.5	5-10+
Diameter	Small	Medium	Small	Large	Small-Medium	Very Small
Range	Very Low	Low	Medium	Very High	Medium	Low-Medium
Thrust-to-Weight ratio	Extremely High	High	Medium	Medium	High	Very High
Technological maturity	Very High	Very High	High	High	Medium	Low/ experimental
Missile e.g.	QRAM, ASTRA	PRITHVI, DF-5	NASM-MR, Exocet	Nirbhay, Tomahawk	AKASH, BrahMos	HSTDV, ZIRCON

Missile Technologies: Navigation Technologies



- ❖ The Art and Science of maneuvering safely and efficiently from one point to another is called as Navigation.
- ❖ It is the process of finding position of an object w.r.t. the reference frame.

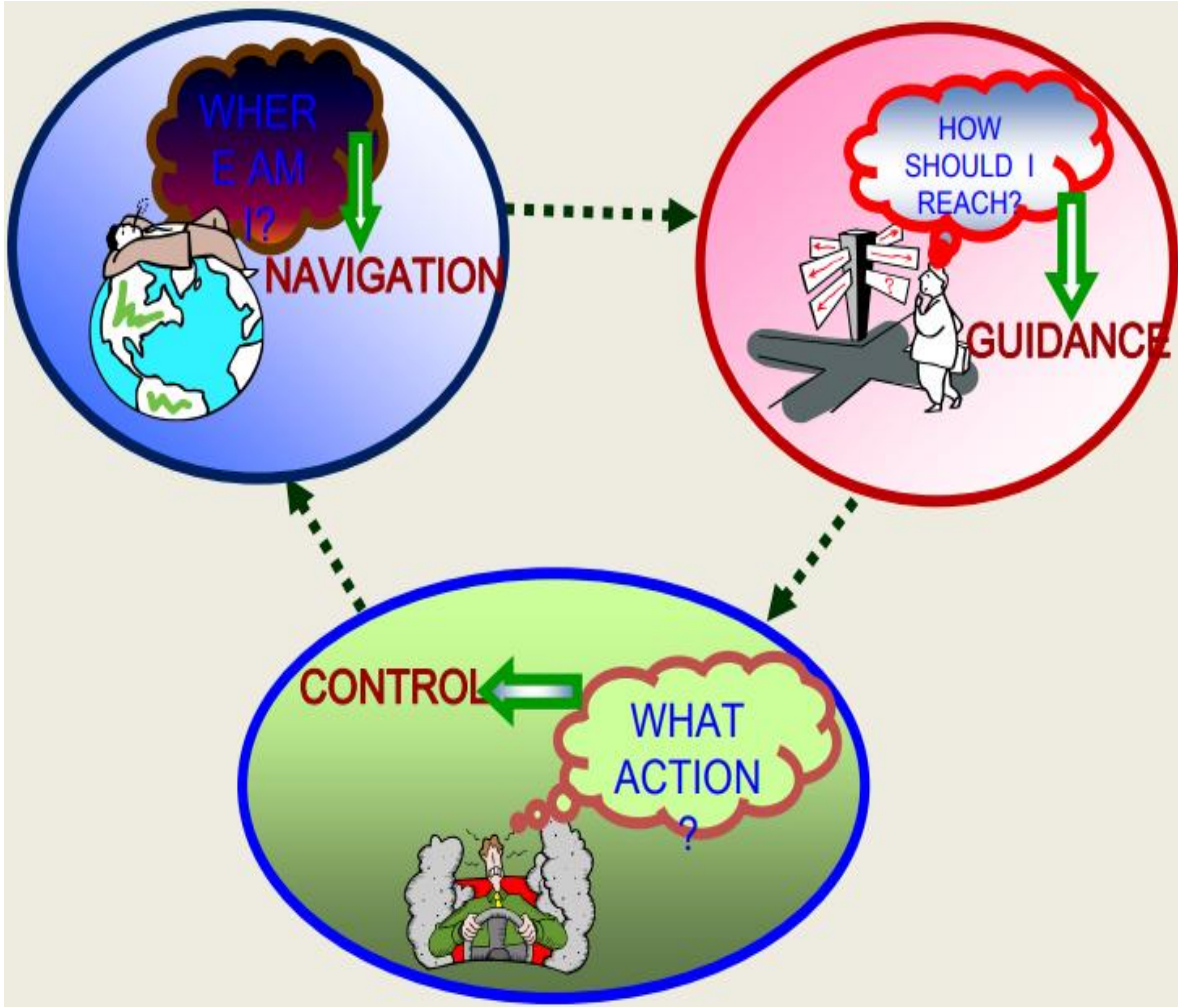


Fig-21: What is Navigation, Guidance & Control

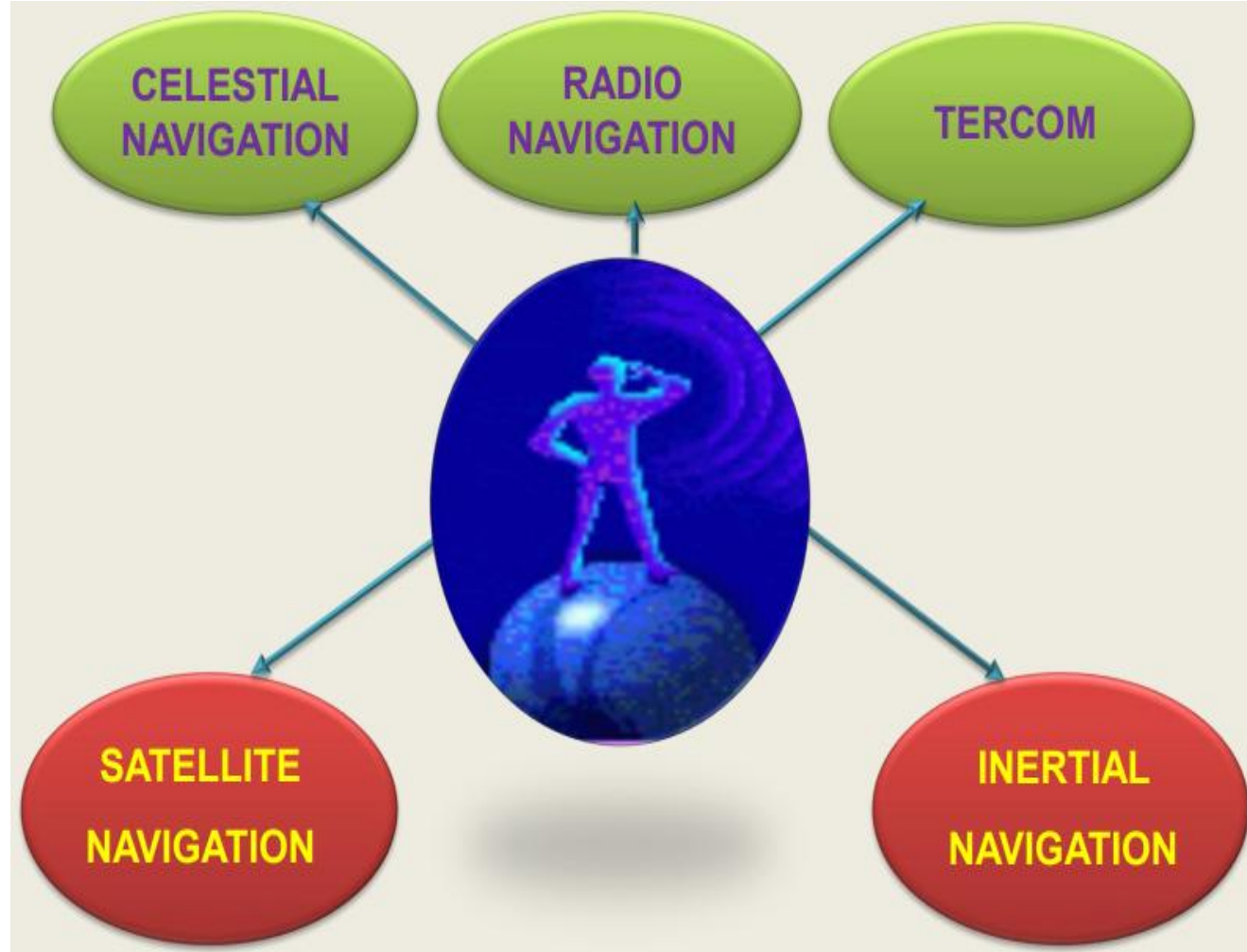
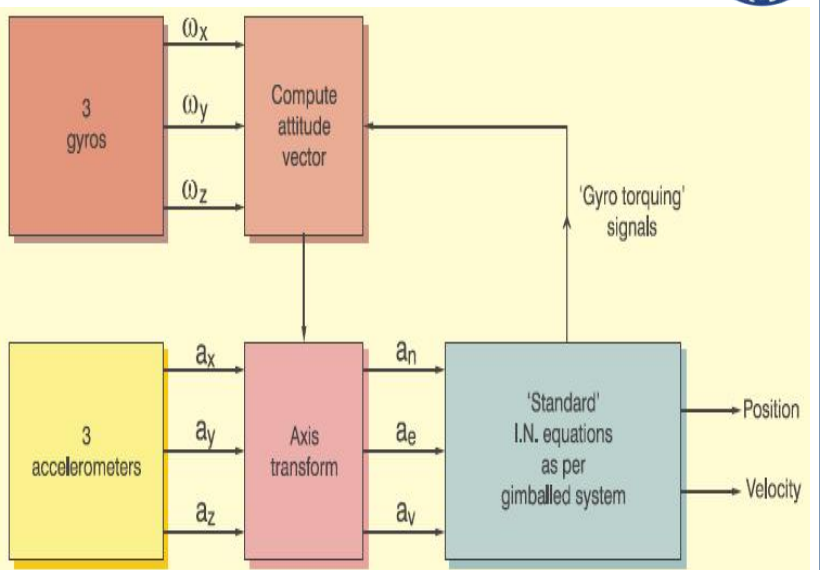
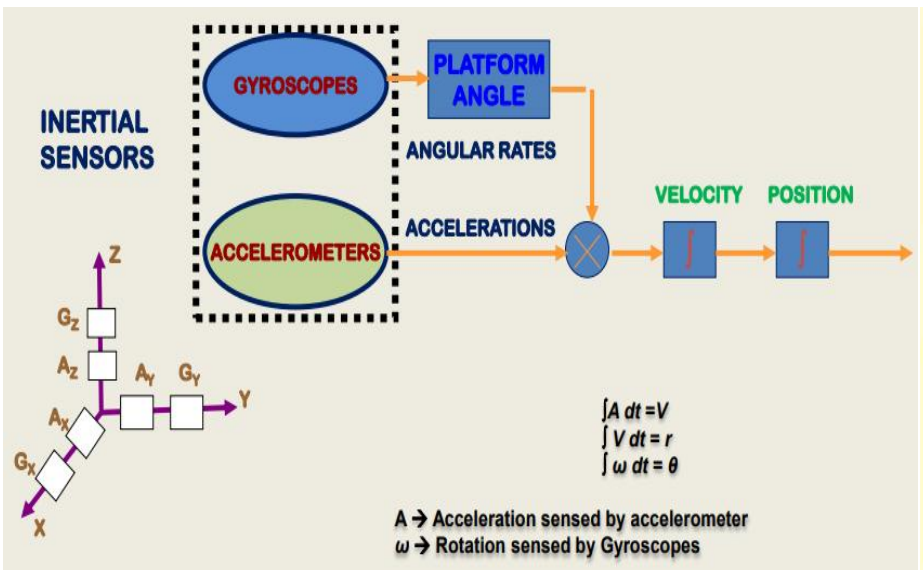
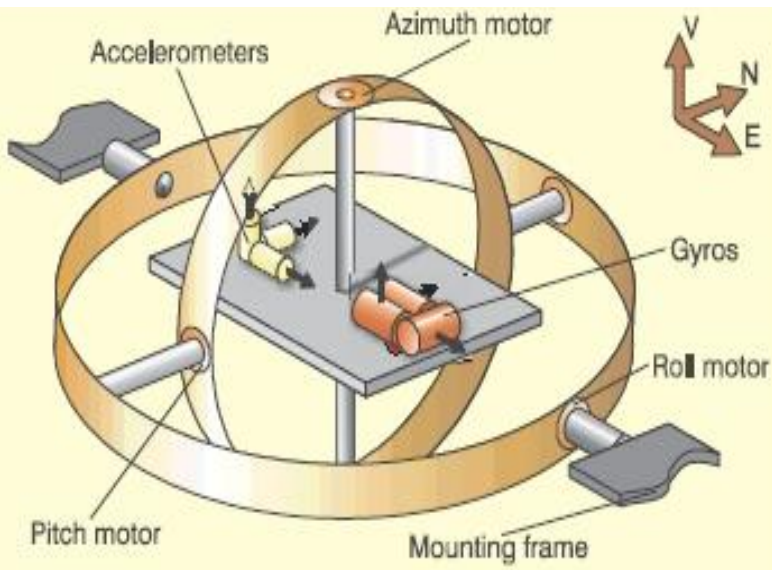


Fig-22: Types of Navigation

Missile Navigation Technologies: Inertial Navigation System (INS)



PLATFORM SYSTEM

- Mechanically Complex
- Less Computations
- Very popular up to 1970s

Ring Laser

Fiber Optic

Micro-Machined Electro-Mechanical Systems (MEMS)

STRAP-DOWN SYSTEM

- Mechanically Less Complex
- Computational Intensive
- Popular from 1980s

Fig-23: Gyro-Stabilized INS

Fig-24: Strap down INS

Missile Navigation Technologies: Inertial Navigation System (INS)









Note:

- Strategic Missile INS
 - INS Requires Large Kalman Filtering (e.g. > 100 States), Small Alignment Error, and Low Drift Rate - to Minimize INS Error in Long Duration Flight with Autonomy (No / Few Updates)
 - Requires INS and Update Insensitivity to Threat Countermeasures
 - Examples of Gimbaled INS: Trident (with Stellar Update), Minuteman, ALCM (with Terrain Contour Matching (TERCOM) Update, Tomahawk (with TERCOM, Digital Scene Matching Area Correlation (DSMAC) Update
- Tactical Missile INS
 - INS Driven by Low Cost and Small Size.
 - Small Size Strapdown INS Usually Has Relatively Large Alignment Error & Large Drift Rate. This May Be Corrected by Frequent Updates to INS (e.g., Satellite Global Positioning System (GPS) Updates)
 - Examples of Strapdown INS: Excalibur Micro-machined Electro-Mechanical Systems (MEMS) with GPS Updates, JDAM ring laser gyro (RLG) with GPS updates, SLAM-ER RLG with GPS updates, Polyphem fiber optic gyro (FOG) with GPS updates

Fig-25: Tactical Inertial Navigation System Drivers are Cost & Weight; Strategic INS Drivers are Accuracy & Autonomy.

Missile Navigation Technologies: Inertial Navigation System (INS)



<u>Strapdown Gyro</u>	<u>Example Global Positioning System (GPS) / Inertial Navigation System (INS) Application</u>	<u>Gyro Cost</u>	<u>Gyro Size / Weight</u>	<u>Accuracy if GPS not Jammed</u>	<u>Accuracy if no GPS or GPS Jammed</u>
Ring Laser 	JDAM 	○	○	●	◐
Fiber Optic 	Polyphem 	◐	◐	●	◐
Micro-Machined Electro-Mechanical Systems (MEMS) 	Excalibur 	●	●	●	◐ ○

● Superior ◐ Good ○ Average ◑ Poor
 Note: Relative accuracy compared to earth rate (○ 15 deg / h)

Fig-26: Comparison of various INS Sensors.

Missile Technologies: Tracking/ Estimation

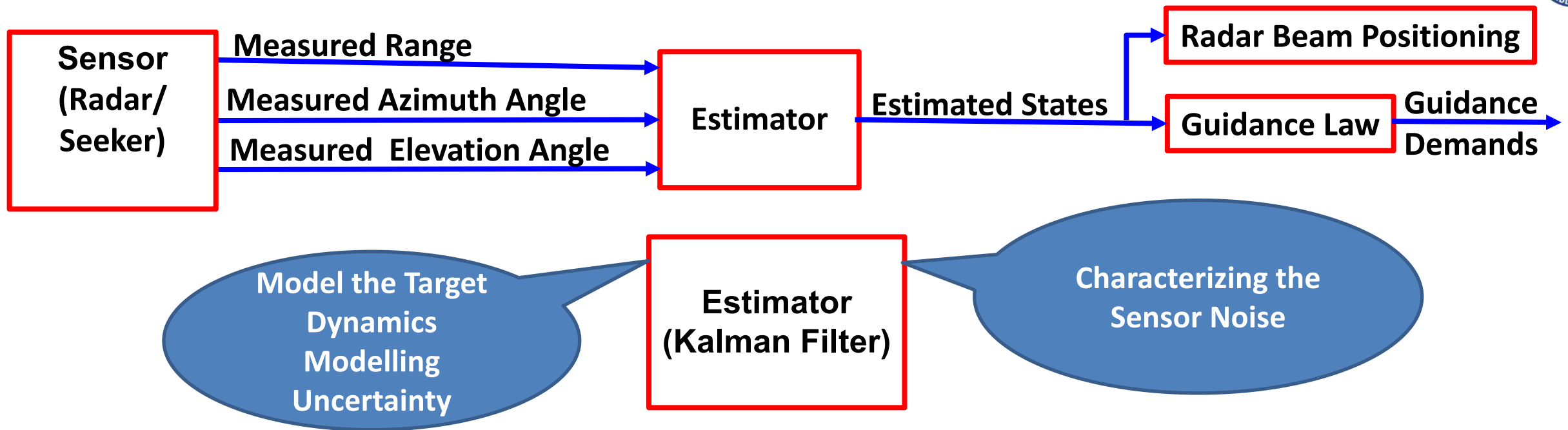


Fig-27: Radar/ Seeker Estimator for Target Tracking.

Requirement for the Estimator:

- Filtering the Noise with Low Tracking Lag
- Estimating Higher order States (Velocity, Acceleration etc)
- Ground Based Radar: Sensor Platform Fixed & Target is Moving (Moving Platform also exists in few cases)
- On-Board Seeker: Sensor Platform Moving and Target is also Moving

Different types of Estimator Algorithms existing in practice:

(1) Kalman Filter; (2) Extended Kalman Filter (EKF); (3) Unscented Kalman Filter (UKF); (4) Particle Filter etc.

Missile Technologies: Guidance Technologies

❖ The missile "Guidance" can be defined as the strategy of steering a missile toward a possible intercept with a target, while "control" can be defined as the tactics of using the missile control actuators to implement the strategy dictated by the guidance unit.

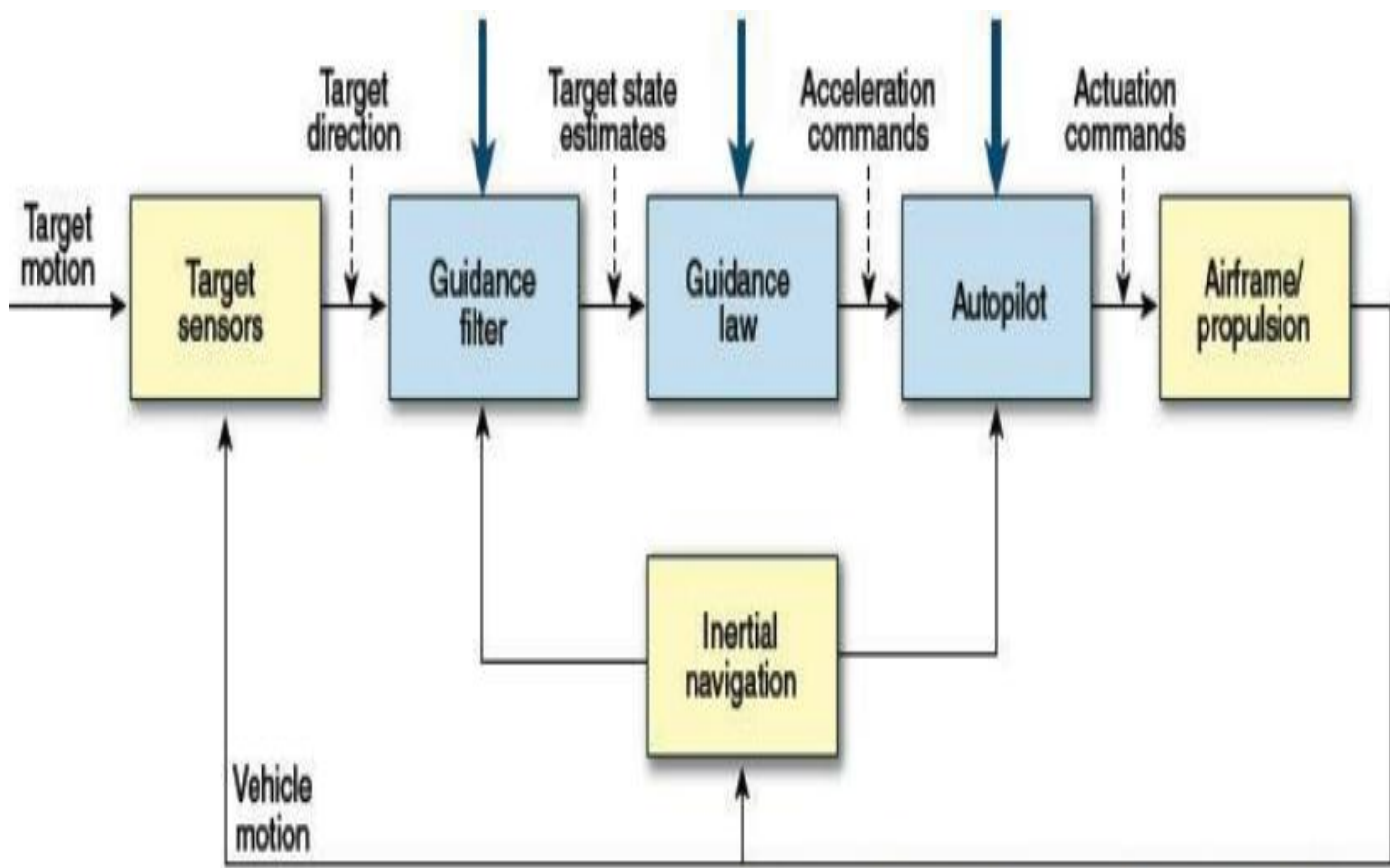


Fig-28: Navigation, Estimation, Guidance & Control Loops of a Tactical Missile

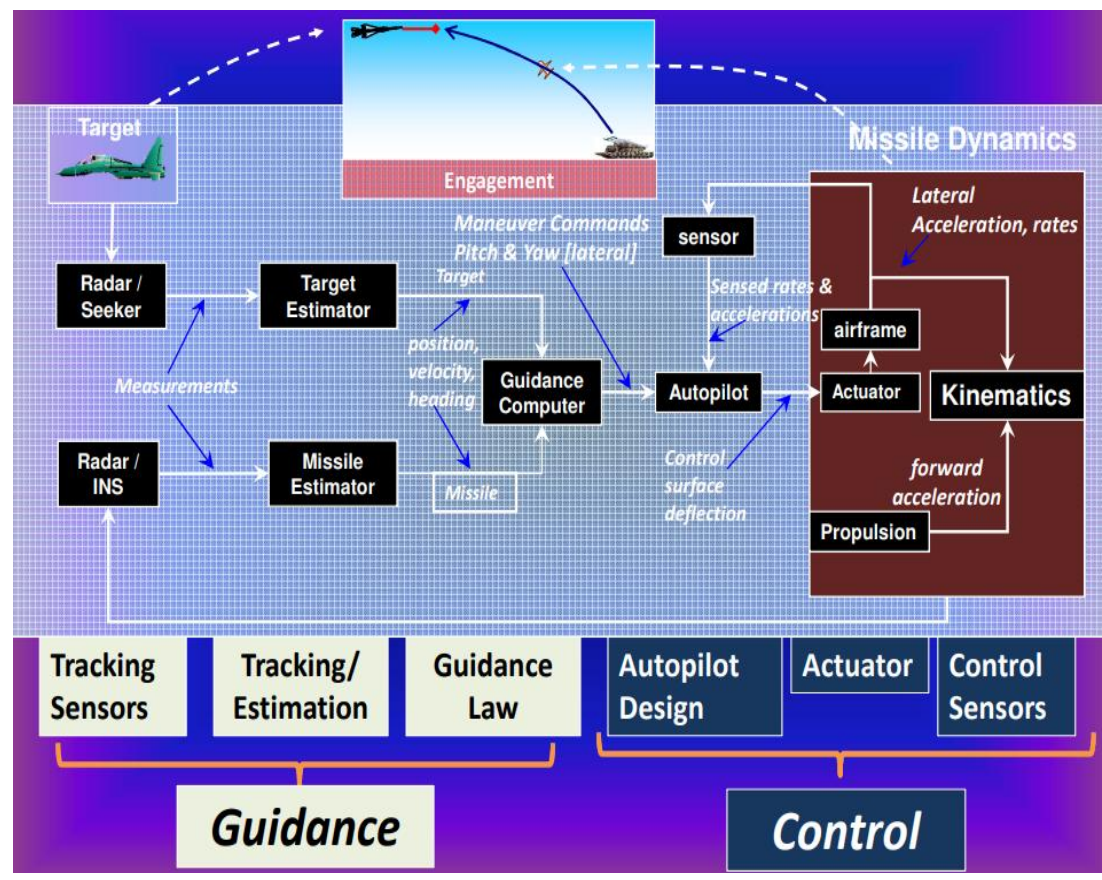


Fig-29: Detailed Block diagram of Estimation, Guidance & Control Loops of a Tactical Missile

Missile Technologies: Guidance Technologies

❖ The primary functions of the elements that make up the guidance system include sensing, information processing and correction. In the sense of guidance, the flight of a missile can be divided into three main phases: 1. Boost or Launch phase 2. Midcourse phase 3. Terminal phase

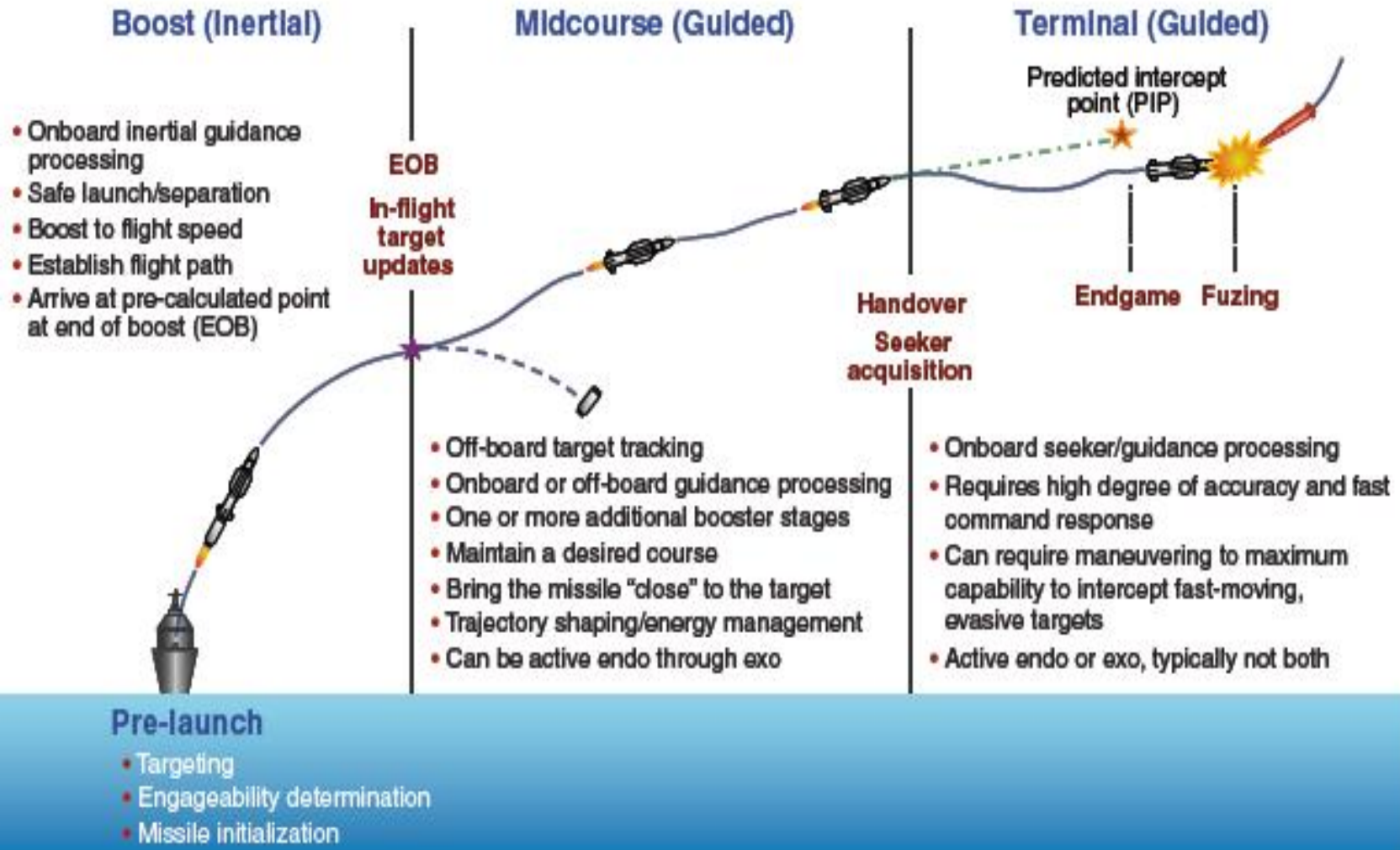


Fig-30: Various Phases of the Missile Guidance

Missile Technologies: Missile Guidance Technologies



- ❖ According to the 'profile' of the target, guidance systems can be classified into two types: (1) Go-Onto-Location-In-Space (GOLIS) and (2) Go-Onto-Target (GOT).
- ❖ While GOLIS systems are usually limited to stationary or near-stationary targets, GOT systems prove to be highly effective in taking down both stationary and moving targets.

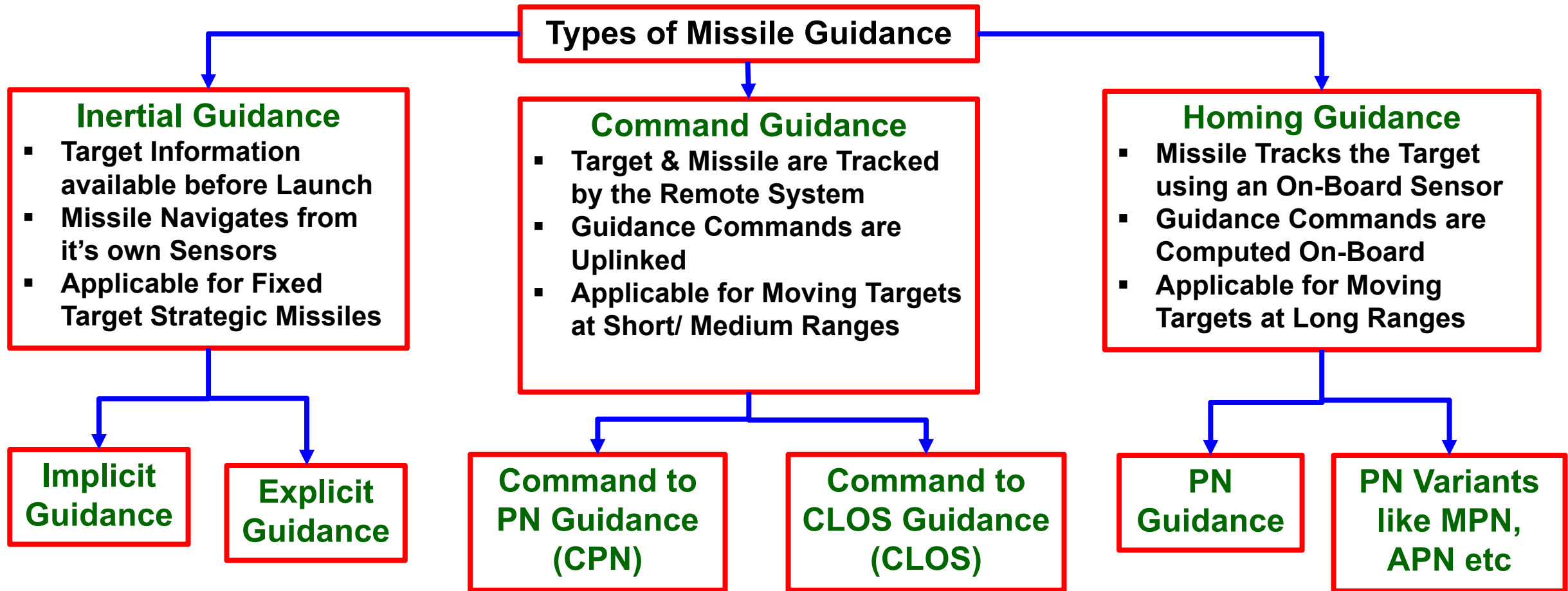


Fig-31: Types of Missile Guidance.

Missile Guidance Technologies: Command to PN & Homing Guidance

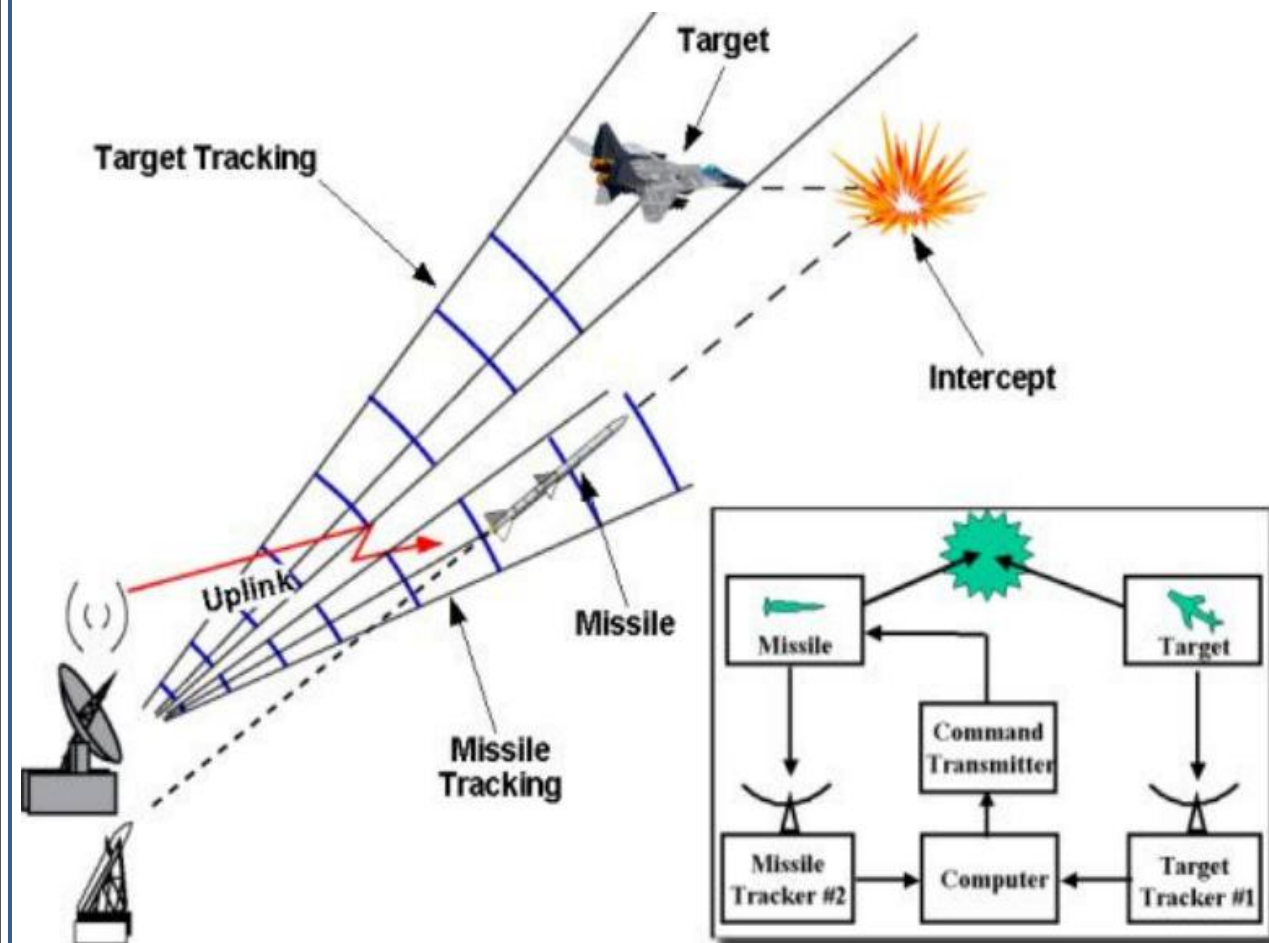


Fig-32: Command to PN (CPN) Guidance of a Surface to Air Missile (SAM) System

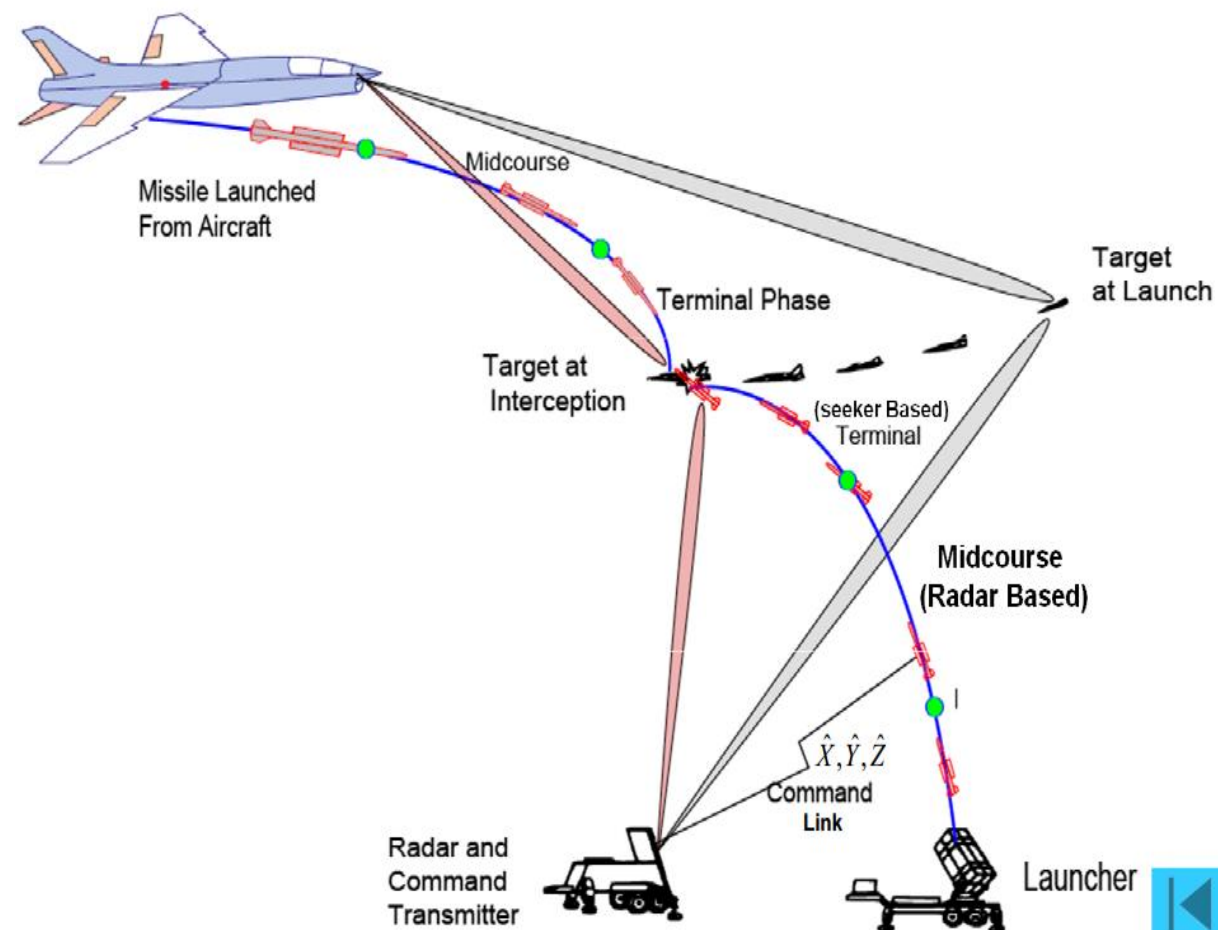


Fig-33: The Homing Guidance Scheme for SAM & AAM

Missile Guidance Technologies: Types of Homing Guidance



Types of Homing Guidance: (1) Active (2) Semi-Active & (3) Passive Homing Guidance

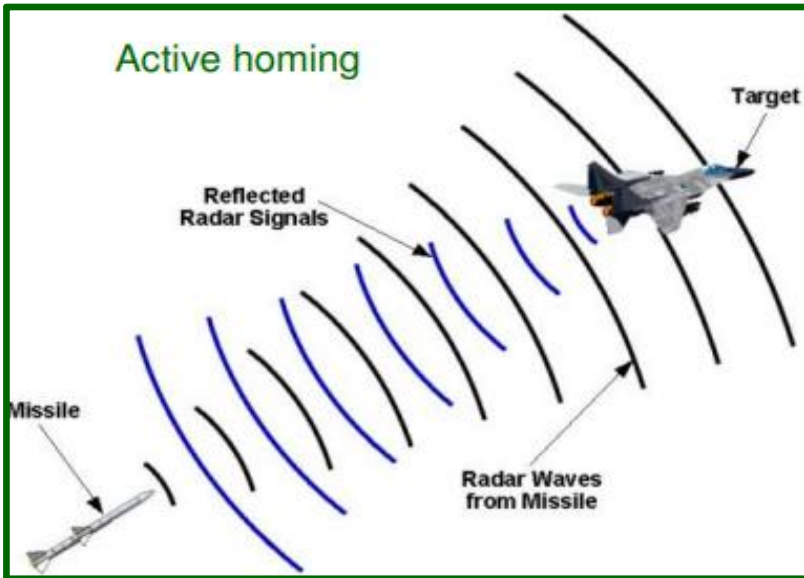


Fig-34: Active Homing Guidance

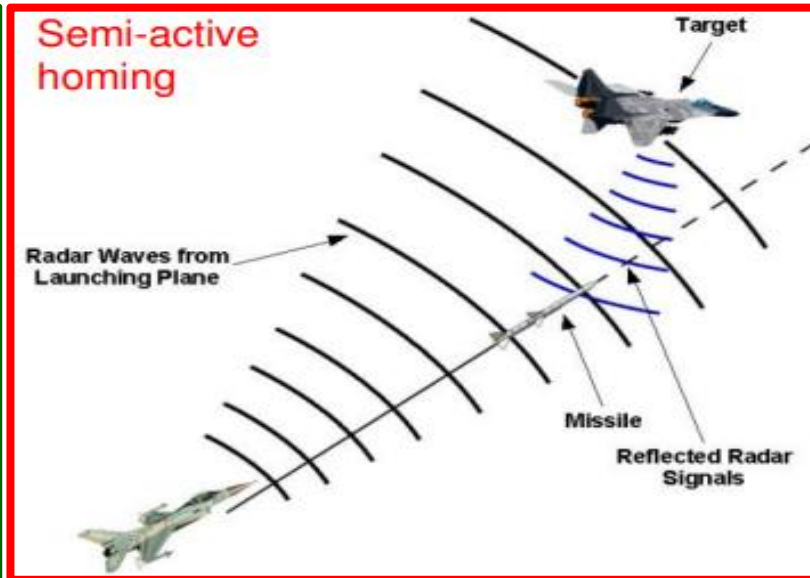


Fig-35: Semi-Active Homing Guidance

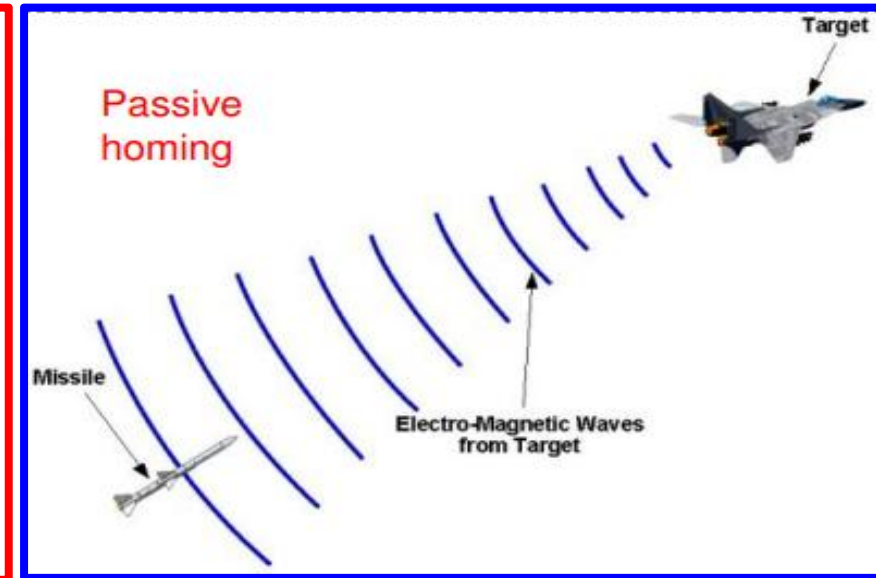


Fig-36: Passive Homing Guidance

Active Homing Guidance

- Both RF Transmitter, Receiver & a Signal Processor are carried on-Board the Missile
- It is Fully Autonomous.
- Ex: QRSAM, AKASH-NG, Astra

Semi-Active Homing Guidance

- Transmitter of the Energy is External to the Missile (Land) & Only the Receiver & Signal Processor are carried on-Board the Missile.
- It is Not Fully Autonomous.
- Ex: AIM-7 Sparrow, Patriot

Passive Homing Guidance

- Only Receiver is placed On-Board the Missile & Utilizes the IR Energy emanating from the Target.
- It does not require a Transmitter.
- Used by Heat Seeking (IR) Missiles
- It is Fire & Forget.
- Ex: NAG, MPATGM, VSHORADS

Missile Guidance Technologies: Constant Bearing or PN Guidance



- Proportional navigation is a guidance law that relies on the fact that two objects are bound to collide if their direct line of sight does not change as the range closes. To understand this, consider the example of two cars approaching the same point from two different directions.
- If the relative velocity of these two cars remains constant as they move towards the same point (in technical terms, the bearing angle between these two cars does not change over time as they close in), then they are on a collision course and therefore bound to collide.

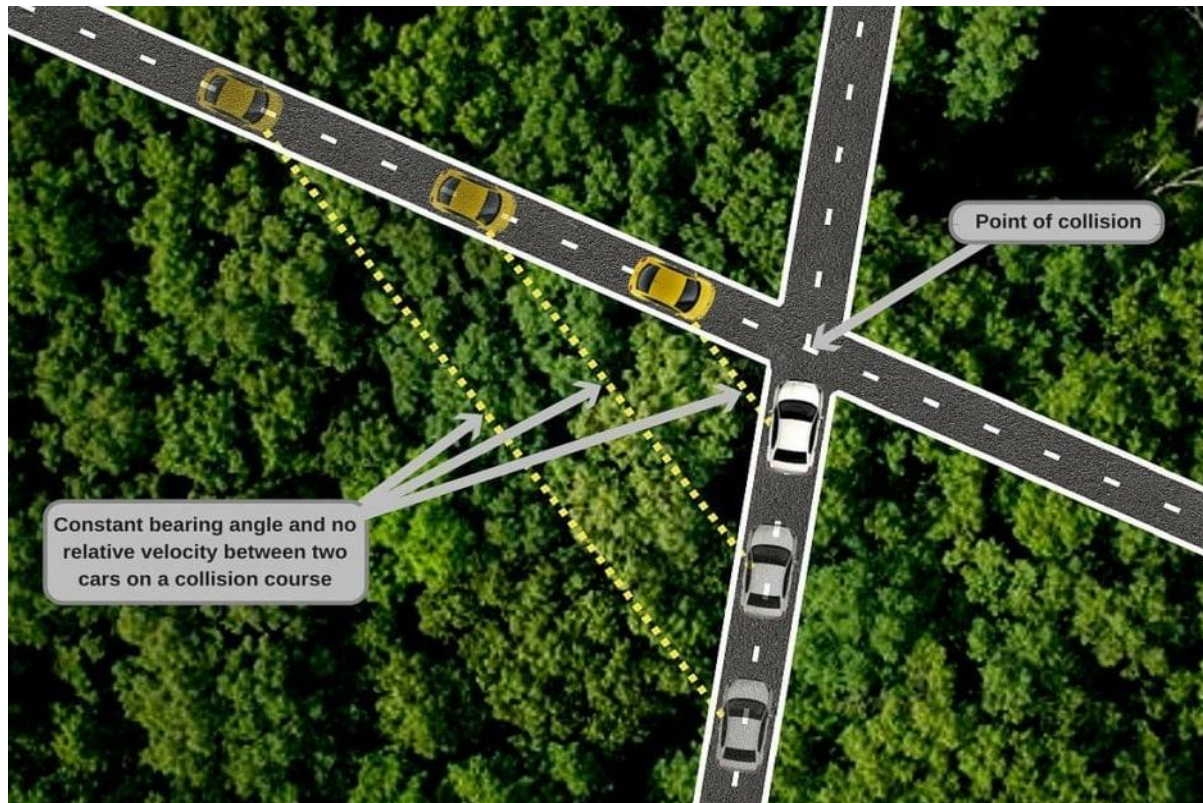
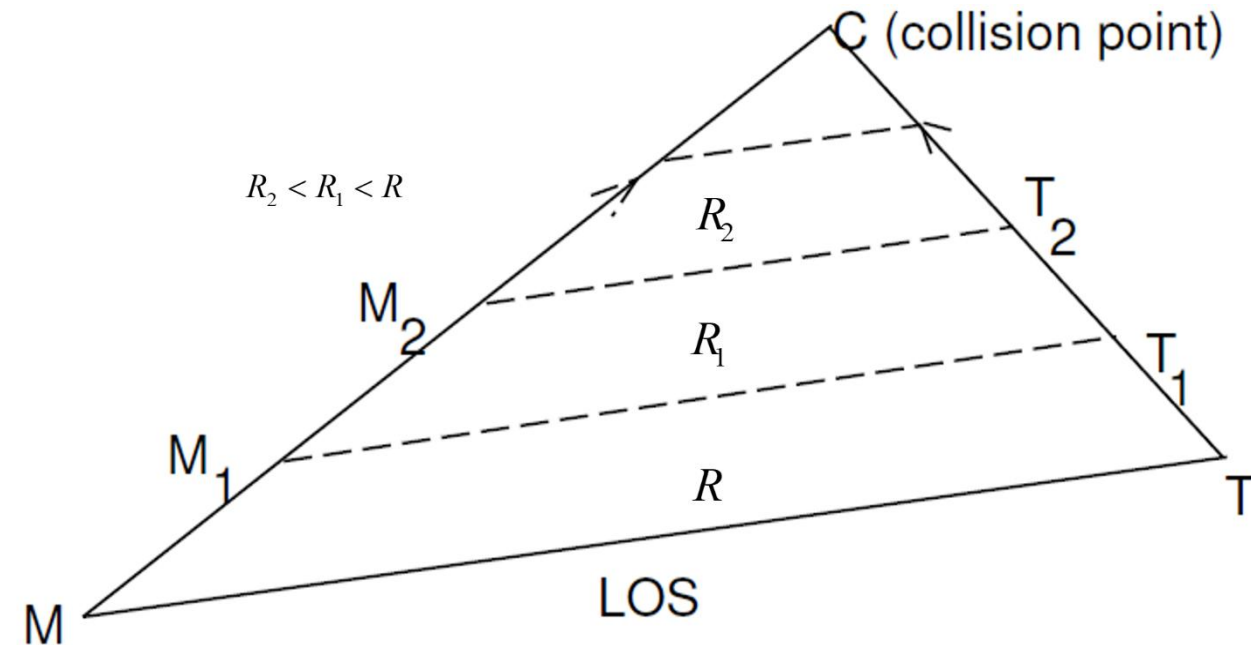


Fig-37: Two Cars on a Constant Bearing for Collision

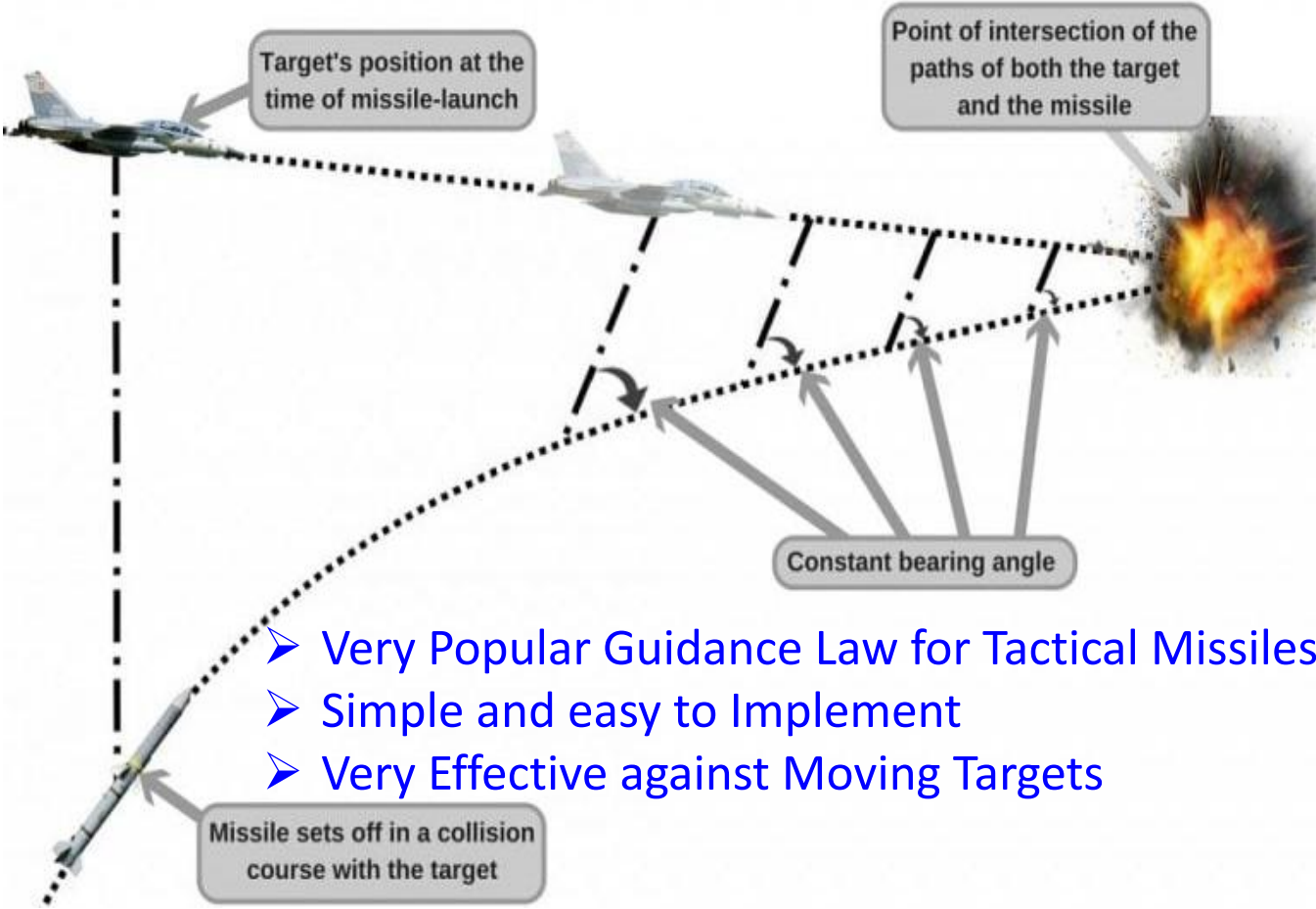


Line-of-sight separation decreases and line-of-sight angle does not rotate
i.e, $\dot{\theta}=0$ and $\dot{R} < 0 \Rightarrow$ Collision.

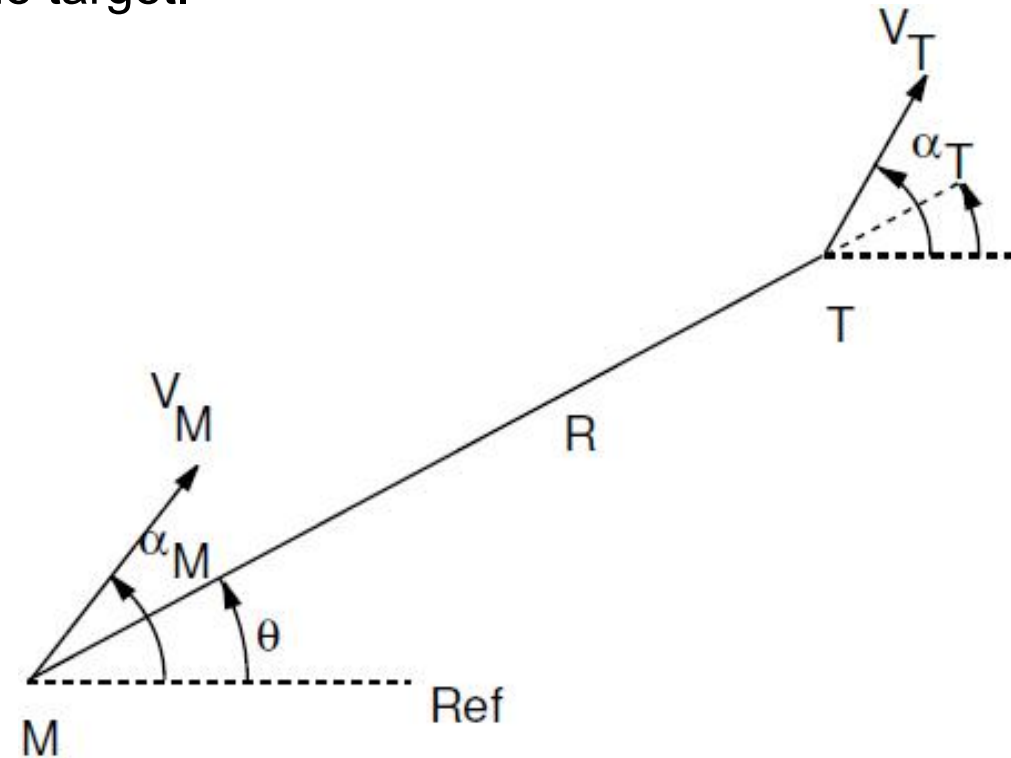
Fig-38: Collision Triangle in Constant Bearing Guidance

Missile Guidance Technologies: Constant Bearing or PN Guidance

➤ In a Proportional Navigation system, the missile stays on a trajectory with a constant bearing angle to the target. Unlike the pursuit guidance system, such missiles don't pursue the target; they just keep moving in a carefully calculated direction (keeping the angle between them and the moving target, say, an aircraft, unchanged) with a constant velocity to eventually smash into the target.



- Very Popular Guidance Law for Tactical Missiles
- Simple and easy to Implement
- Very Effective against Moving Targets



General form $\dot{\alpha}_M = N\dot{\theta}$
 $\alpha_c = N'V_c\dot{\theta} = N'V_c\dot{\lambda}; \lambda = \theta = \text{LOS Angle b/w Missile \& Target}$
 $N' = \text{Navigation Gain} = 3 \text{ to } 5 \text{ (4 is a Good choice)}$

Fig-39: Constant Bearing or PN Guidance in Tactical Missile

Fig-40: Vector Diagram of PN Guidance in Tactical Missile 28

Missile Technologies: Guidance Technologies



Type of Terminal Guidance	Launch Platform Survivability	Missile Sensor Cost / Weight	Accuracy	Counter-Countermeasures (CCM)	Fire Control Correction / Fuzing
Active Homing: Radar Frequency (RF), Laser	○	- ○	○ ●	○	-
Passive Homing: Infrared (IR), RF, Anti-Radiation Homing (ARH)	●	○ ○	○ ●	- ●	-
Semi-Active Homing: RF, Laser	- ○	○ ○	○ ○	○	●
Command: RF, Laser, Wire	-	●	- ○	●	●
Multi-Mode: Command Updates, Inertial, Active or Passive Homing	○	○	○ ●	○ ●	●

Note: ● Superior ○ Good ○ Average - Poor

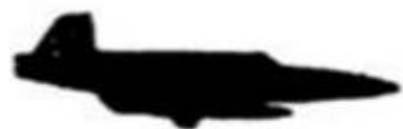
Fig-41: Missile Terminal Guidance Drivers include Launch Platform Survivability, Missile Sensor Cost, and Accuracy

Missile Technologies: Midcourse Guidance using GPS Aided INS



Global Positioning System (GPS)

- 24 Satellites in 6 Circular Orbit Planes
- 55 Deg Orbit Inclination
- 12 Hour Orbit Period
- Orbit Perturbations Due to
 - Lunar Gravity
 - Solar Gravity
 - Solar Radiation
- Popular Transmit Frequencies
 - L1 @ 1.57542 GHz
 - L2 @ 1.22760 GHz



Launch



INS or GPS / INS
Midcourse
Guidance

Search And
Acquisition

Terminal Guidance



Fig-42: In most of the Missiles, Midcourse Guidance is provided by either INS or GPS Aided INS

Missile Technologies: Cruise Missile Guidance Technologies

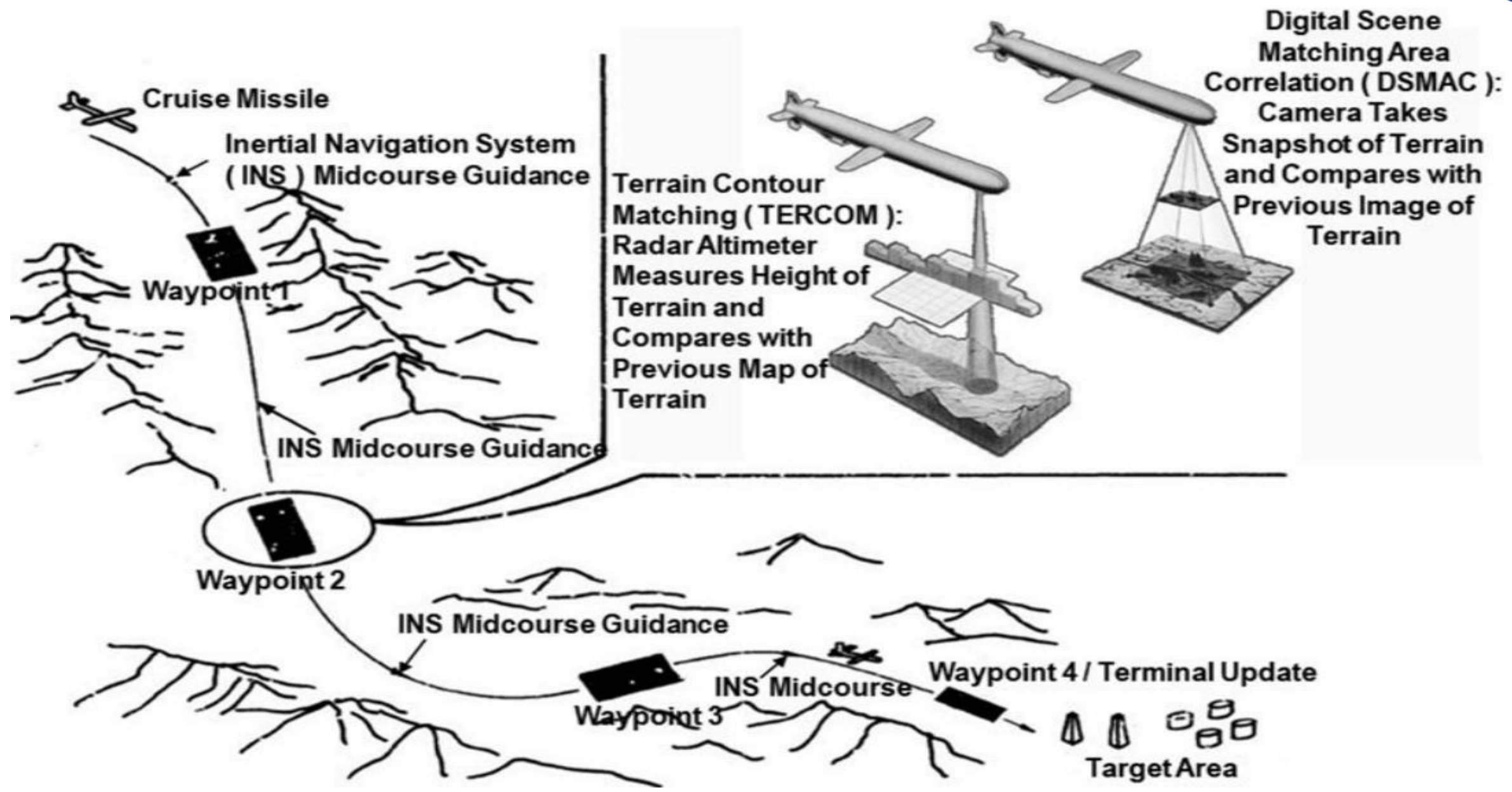


Fig-43: TERCOM & DSMAC Guidance Algorithms are very popularly used in Land Attack Cruise Missiles like Tomahawk

Missile Technologies: Missile Control System (Autopilot)



- ❖ Tactical missile autopilots (**Automatic + Pilot = Autopilot**) are part of the wider **Guidance, Navigation and Control (GNC) system** whose goal is to **achieve a successful intercept**. The missile flight control system or autopilot is the minor loop inside the main guidance loop.

- ❖ Following three tasks are the major functionalities of a flight control system:
 1. Ensuring the **Stability** of the missile for all the operating points under parameter uncertainties (**Robustness**).
 2. **Tracking** the input guidance commands with good transient response
 3. **Disturbance rejection** (Requirement of **high control loop stiffness**).

- ❖ The missile autopilot task is to turn guidance commands in to fin deflection commands and is generally divided into two lateral direction (Pitch and Yaw) controllers and the roll orientation or roll rate controller.

- ❖ These three “channel control” outputs are then mixed to produce fin deflection commands to four individual fins.

- ❖ The controllers are designed either using Gain Scheduling for large flight envelope applications or algorithmic autopilots.

Missile Technologies: Missile Control

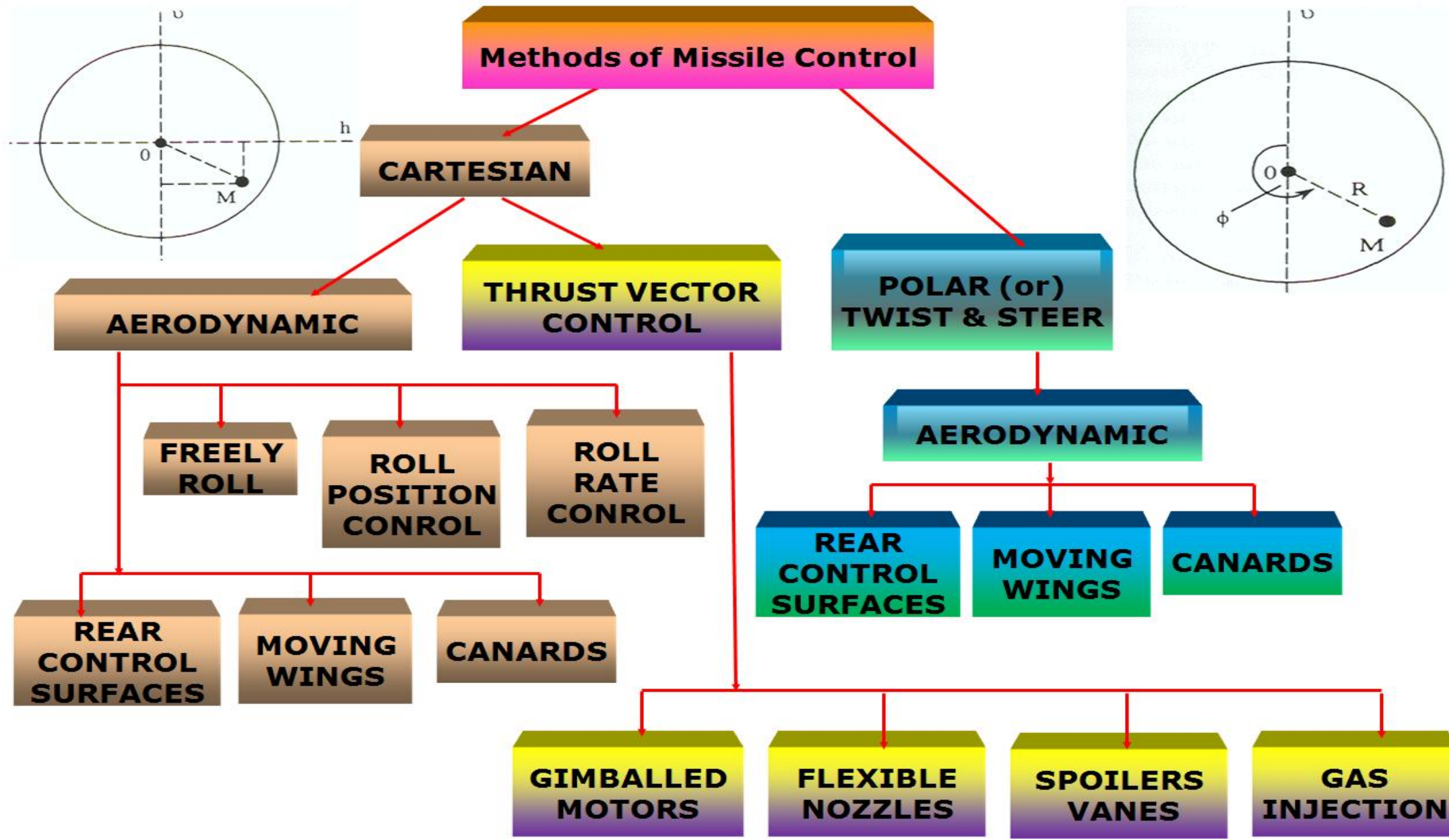


Fig-44: Methods of Missile Control

Missile Control Technologies: The Aerodynamic Cartesian Control (ADCCS)



The aerodynamic cartesian control can be categorized as:
 (1) Tail control surfaces (Rear fins) (2) Canards (Forward fins) (3) Moving wings

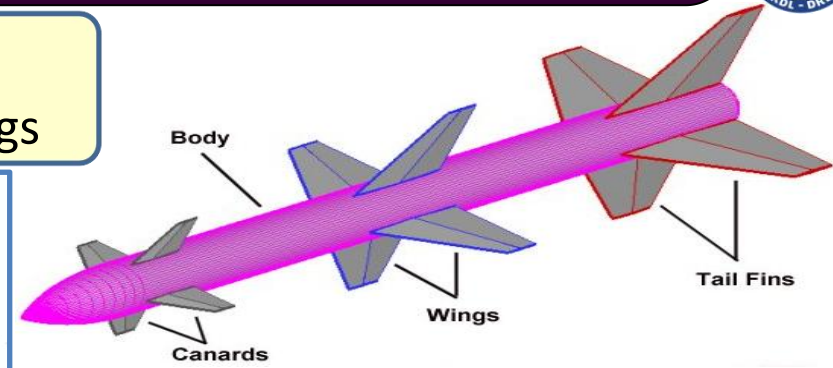


Fig-45: Aerodynamically Controlled Missile

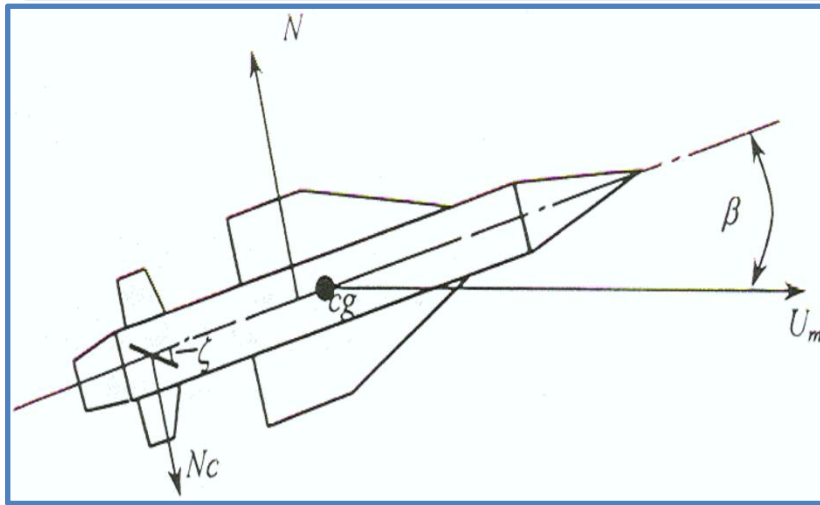


Fig-46: The Tail Controlled Missile

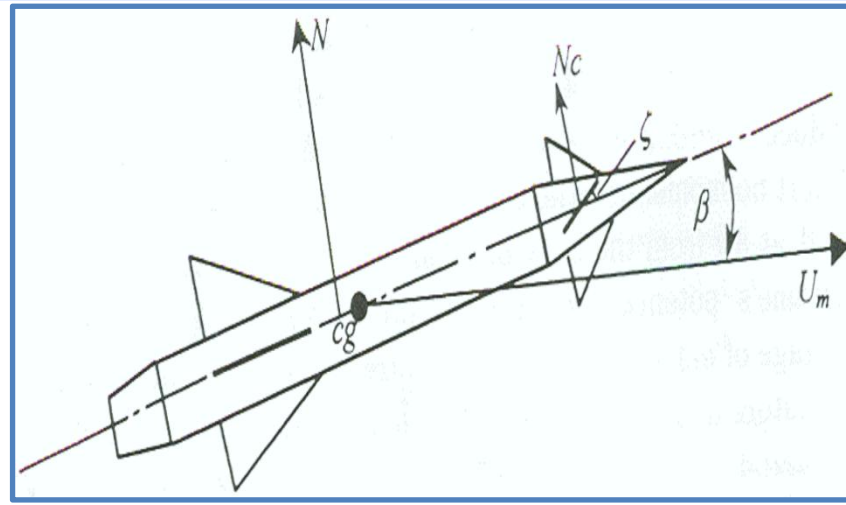


Fig-48: The Canard Controlled Missile

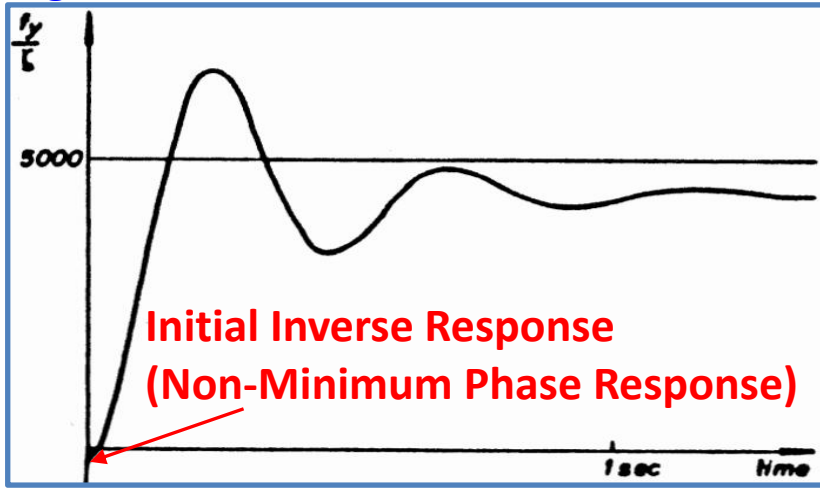


Fig-47: Step Response of a Tail Controlled Missile

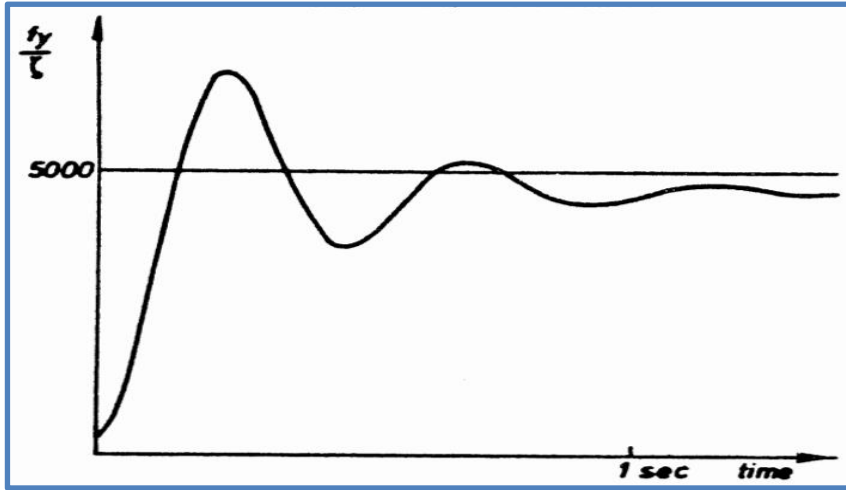


Fig-49: Step Response of a Canard Controlled Missile

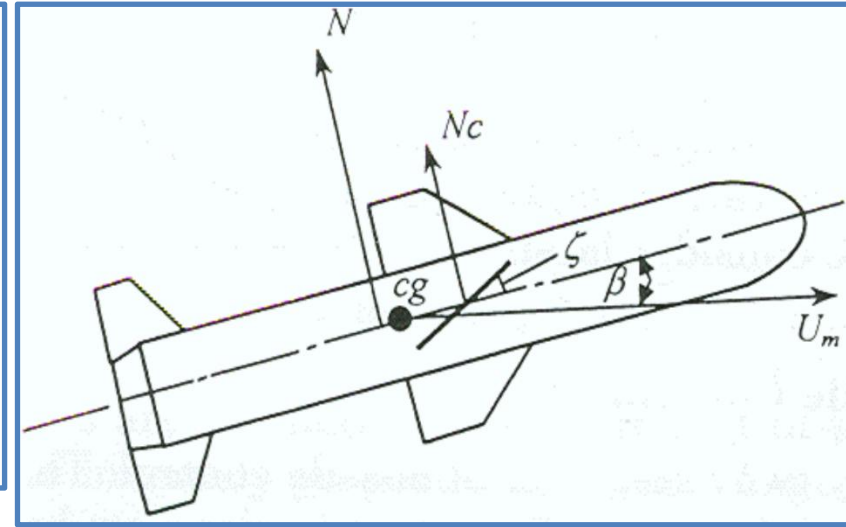


Fig-50: The Wing Controlled Missile

Missile Control Technologies: The Aerodynamic Polar Control (ADPCS)



- ❖ If there is only one set of control surfaces and wings, the steering commands have to be issued not in Cartesian form, but in Polar form.
- ❖ If the missile has to maneuver to the *Right*, and we call this command x , and Up , which we call y , then in Polar form the steering commands are R and ϕ such that: $R = \sqrt{x^2 + y^2}$; $\tan \phi = x/y$
- ❖ The usual method is to regard the ϕ signal is a command to roll through an angle ϕ measured from the vertical and then to maneuver outwards in this correct roll orientation as shown in below Fig.
- ❖ The Bloodhound missile uses the Twist and Steer Control strategy.

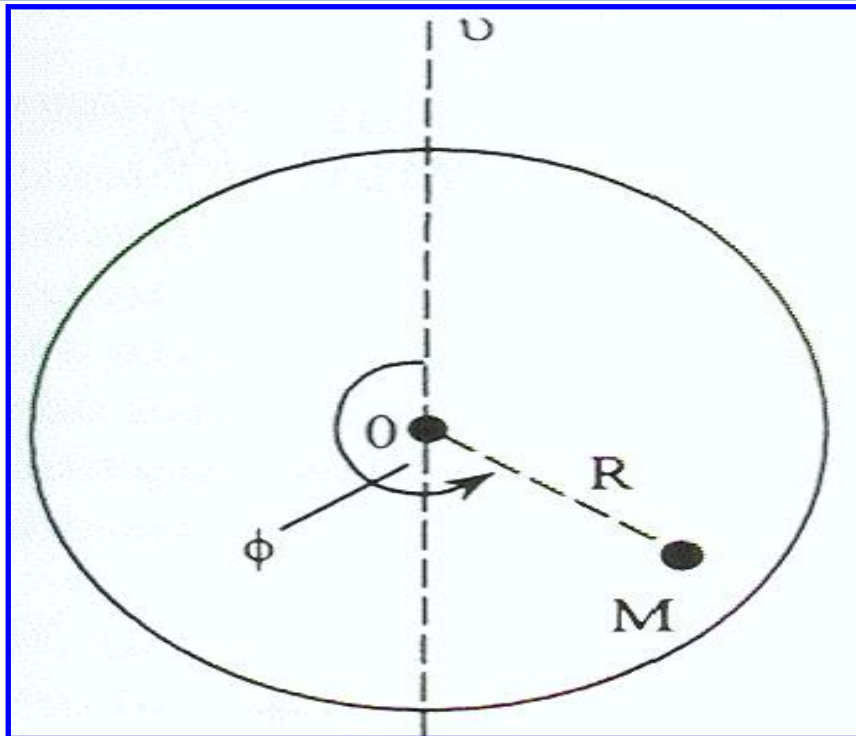


Fig-51: The Aerodynamic Polar Control



Fig-52: Bloodhound Missile (Polar Control)

Missile Control Technologies: The Thrust Vector Control (TVC)



- ❖ A different way to steer a missile is by redirecting the propulsion exhaust, known as **Thrust Vector Control (TVC)**. This method operates independently of atmospheric dynamic pressure.
- ❖ If the magnitude of the **Thrust** is **T** & it's direction is deflected by an angle ϕ , the **force \perp 'r to the body is $T \cdot \sin(\phi)$** , which applies a moment to the missile & **enables it to maneuver in the lateral direction**.
- ❖ It is essential to use TVC in the vertical launch phase of all strategic missiles.
- ❖ TVC is the best option for short-range tactical missiles with low flight times for engaging the fast moving crossing targets or lately detected targets.
- ❖ Vertical launch followed by a rapid turnover is an attractive concept for missiles carried & launched from a vehicle. This gives a full 360° arc of fire. It is cheaper & simpler and can eliminate heavier launchers.

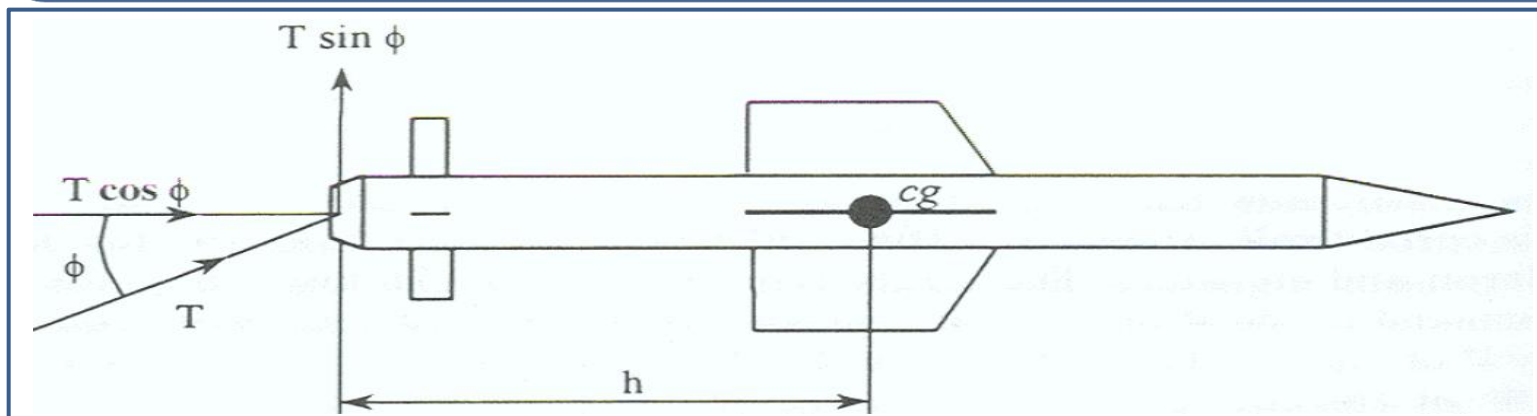


Fig-53: Thrust Vector Control of a Missile

Missile Control Technologies: The Thrust Vector Control (TVC)



❖ Methods of Thrust Vector Control:

1. Gimballed Motors
2. Flex Nozzle Control (FNC)
3. Jet Vane Control (JVC)
4. Secondary Fuel Injection
5. Reaction Control Systems (RCS)

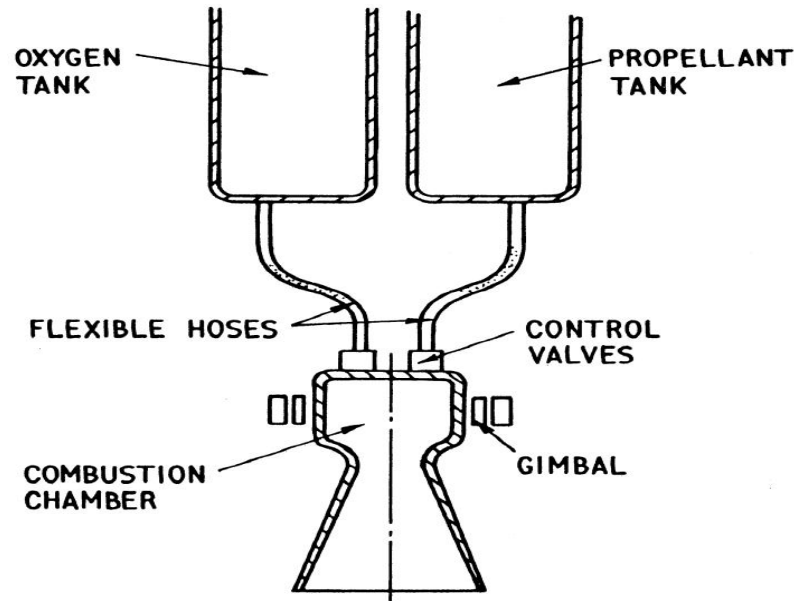


Fig-54: Gimballed Motors

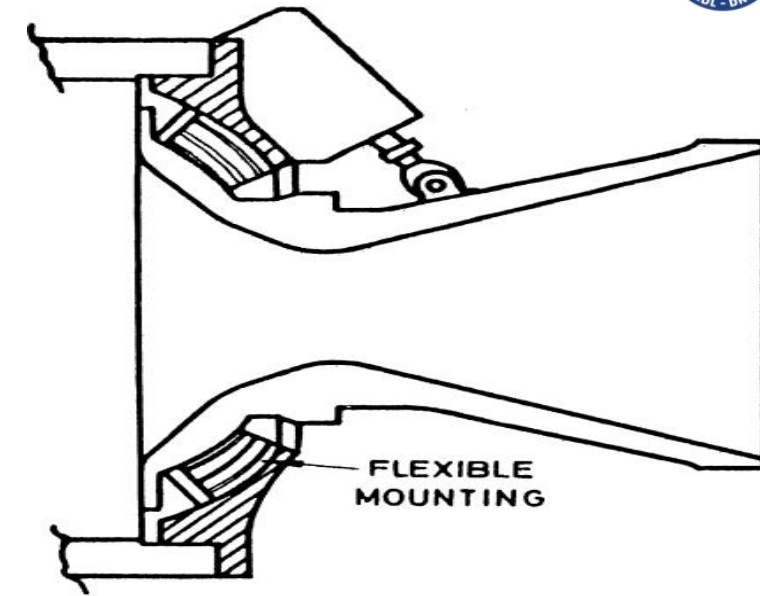


Fig-55: Flex Nozzle Control (FNC)

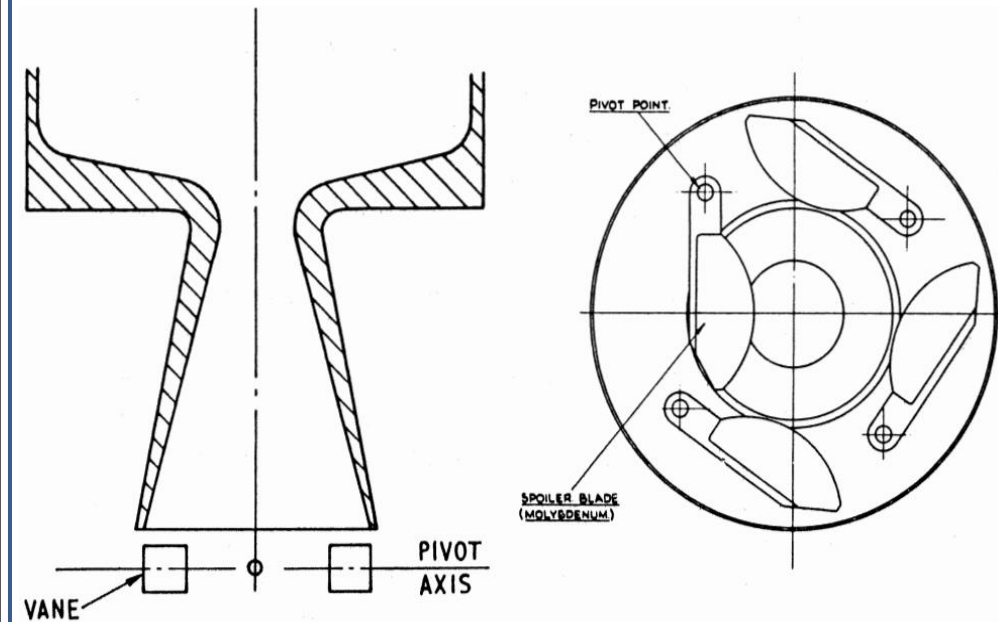


Fig-56: Jet Vane Control

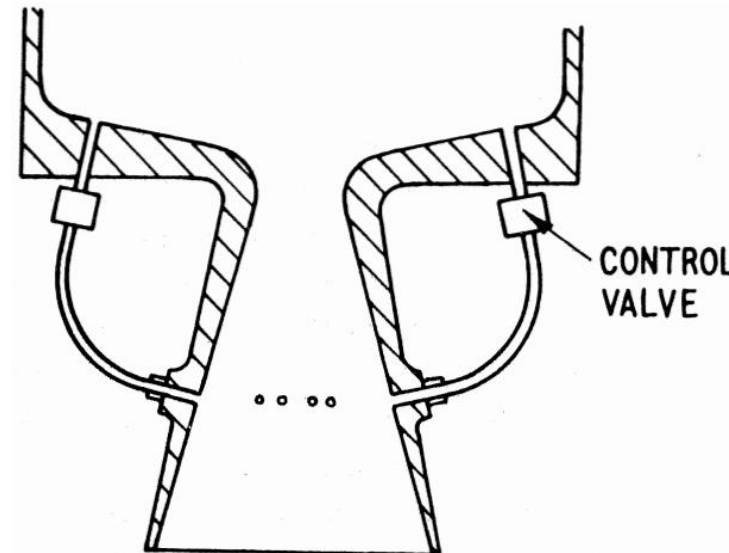


Fig-57: Secondary Fuel Injection

Missile Control Technologies: Classification of Missile Autopilots



- ❖ All autopilots are examples of closed loop, negative feedback or automatic control systems.
- ❖ The objective of a closed loop system is to make the response of the object being controlled to a command much more predictable in the presence of external disturbances, loads and biases, changes in the environment and variability in the object being controlled.

- ❖ Major functions of a lateral acceleration autopilot:
 - ✓ The maintenance of near- constant steady state aerodynamic gain.
 - ✓ To increase the effective weathercock (short-period) natural frequency of the airframe.
 - ✓ To increase the weathercock damping.
 - ✓ To reduce the cross-coupling between pitch & yaw motions.
 - ✓ To shape the closed-loop lateral acceleration response.
 - ✓ To improve the stability margins (Gain & Phase margins) and enhance the robustness.

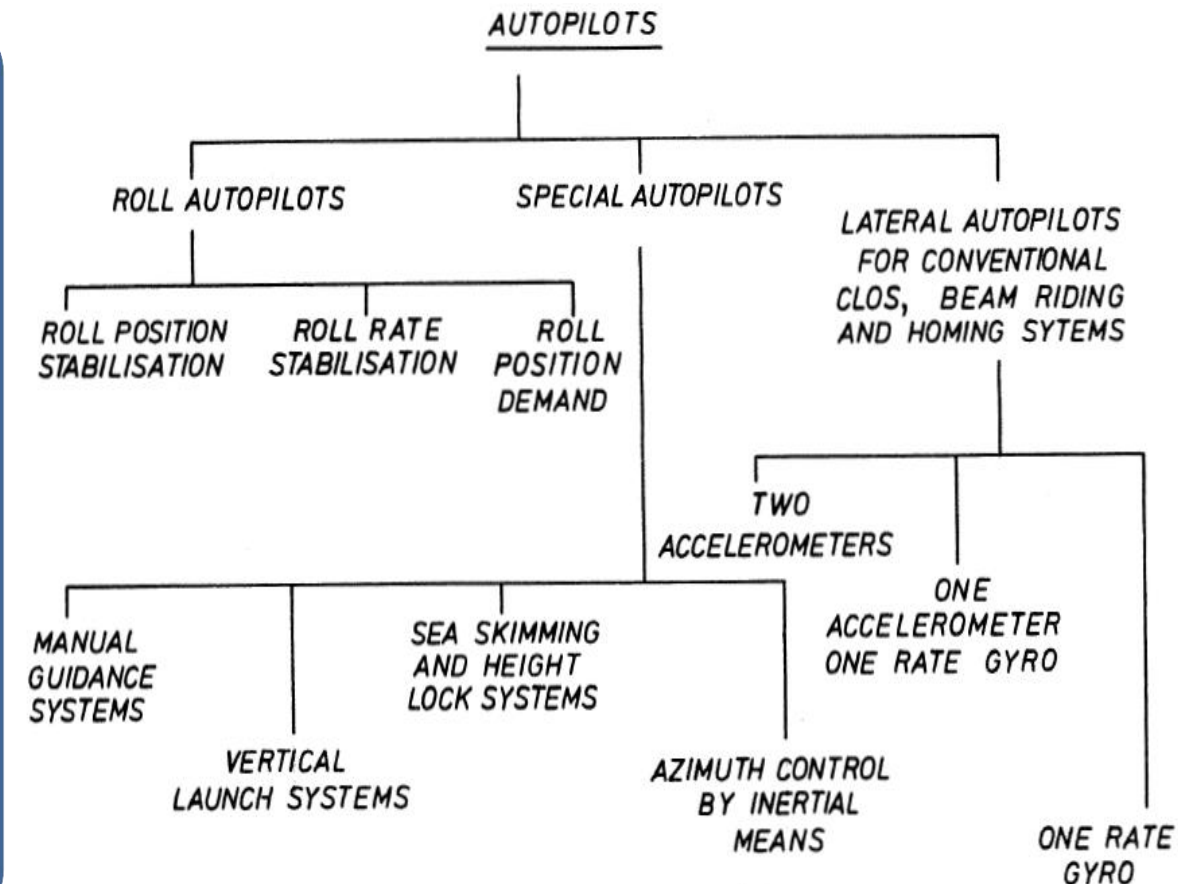


Fig-58: Classification of Missile Autopilots

Missile Control Technologies: Lateral Acceleration (Latax) Autopilot

❖ An arrangement whereby an accelerometer provides the main feedback and a rate gyro is used to act as a damper is common in many high performance command and homing missiles.

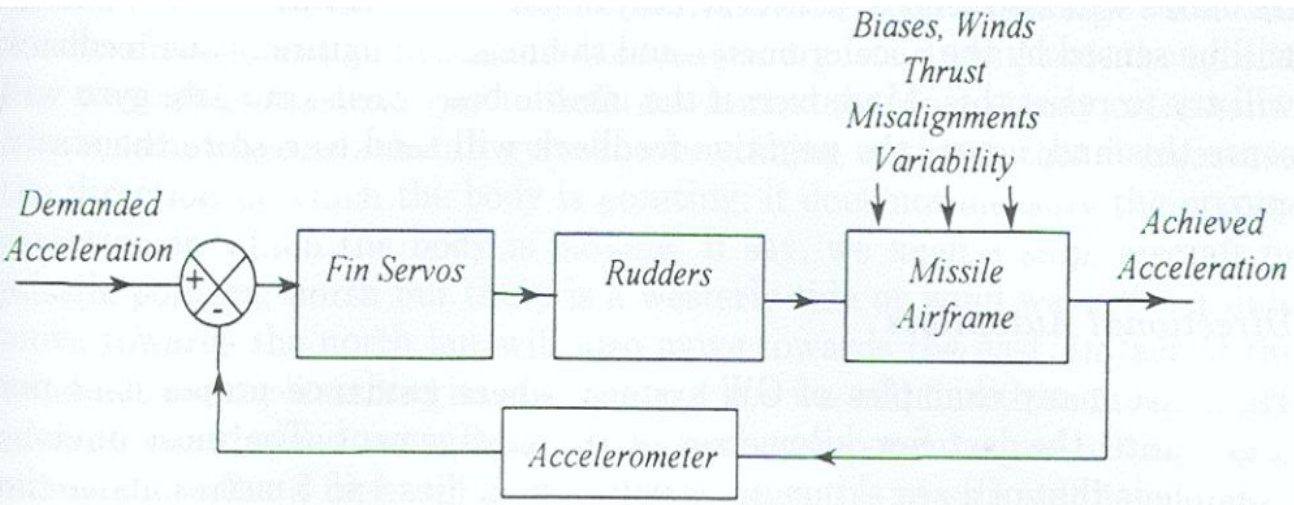


Fig-59: Lateral 'g' Autopilot of a Missile

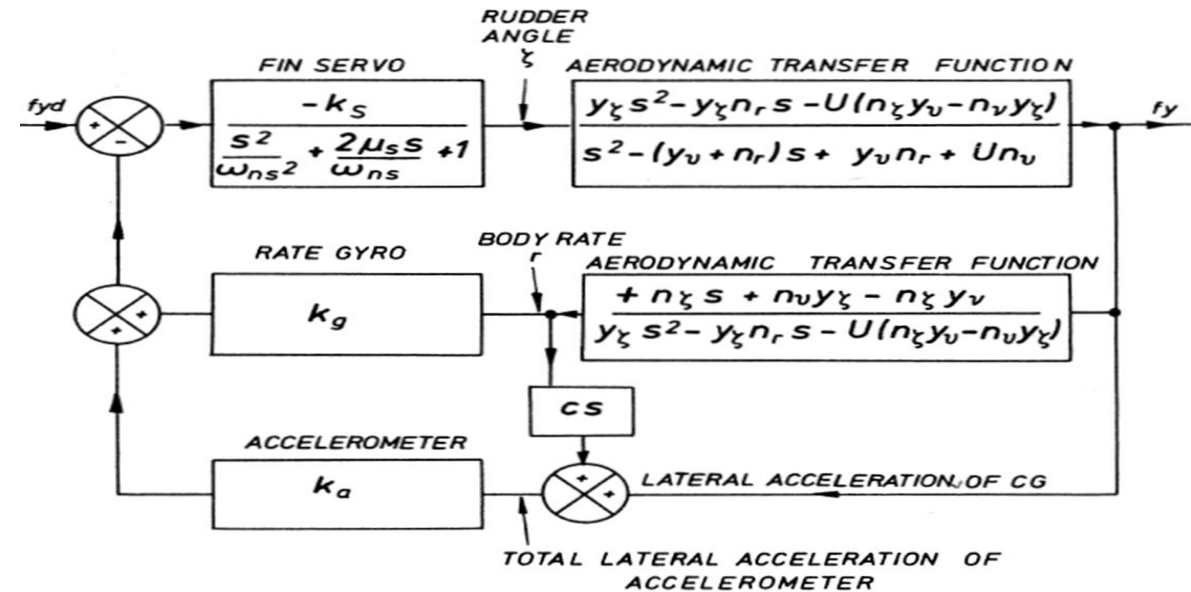


Fig-60: Two Loop Lateral Acceleration Autopilot

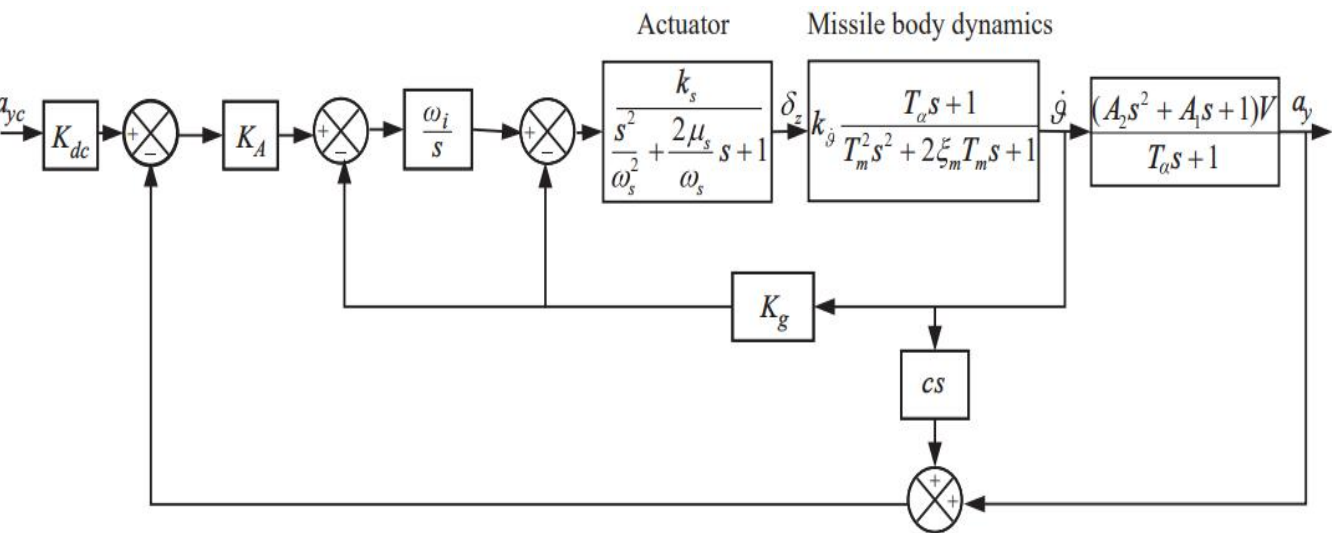


Fig-61: Three Loop Lateral Acceleration Autopilot

Missile Control Technologies: Lateral Acceleration (Latax) Autopilot



Time Vs Latax achieved by Linearized Missile Airframe : At an Altitude of :0 Km and at a Mach Number of :2.9386

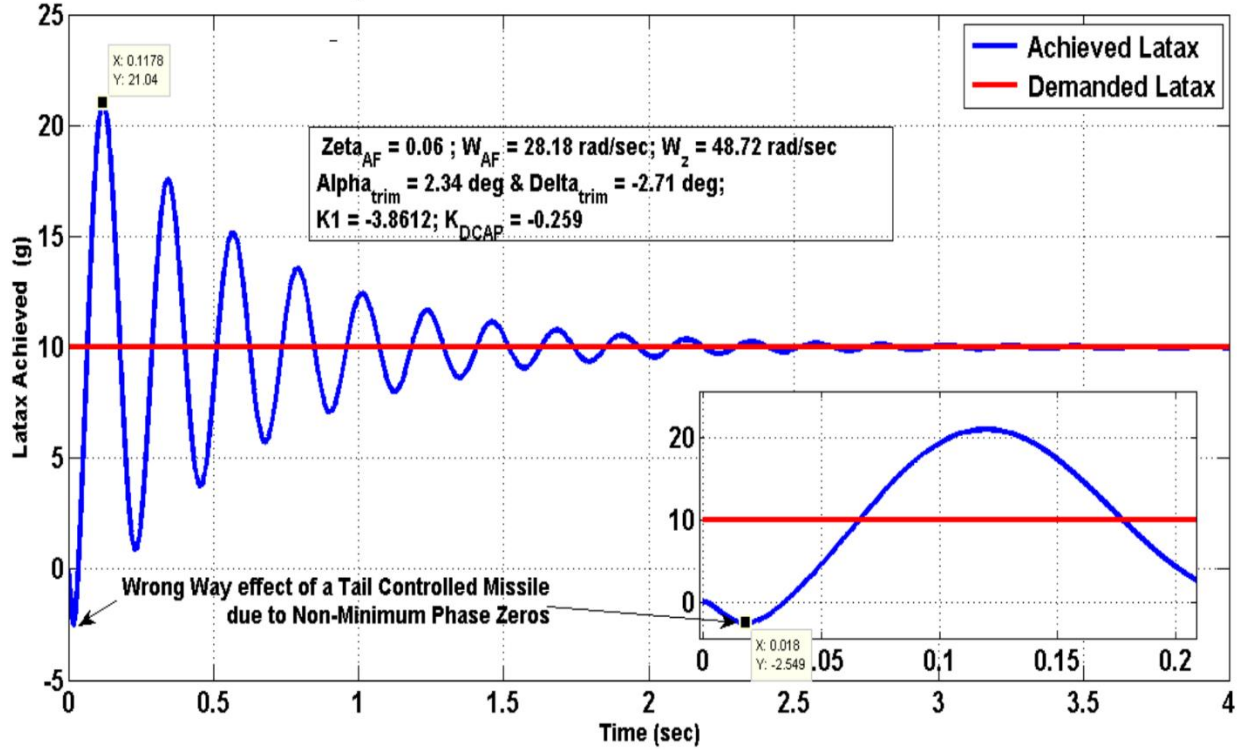


Fig-62: Step Response of Open Loop Lateral Acceleration Autopilot

Time Vs the Missile Airframe Achieved Latax with 3-Loop Latax Autopilot Design, @ Sea Level & @ Mach No :2.9386

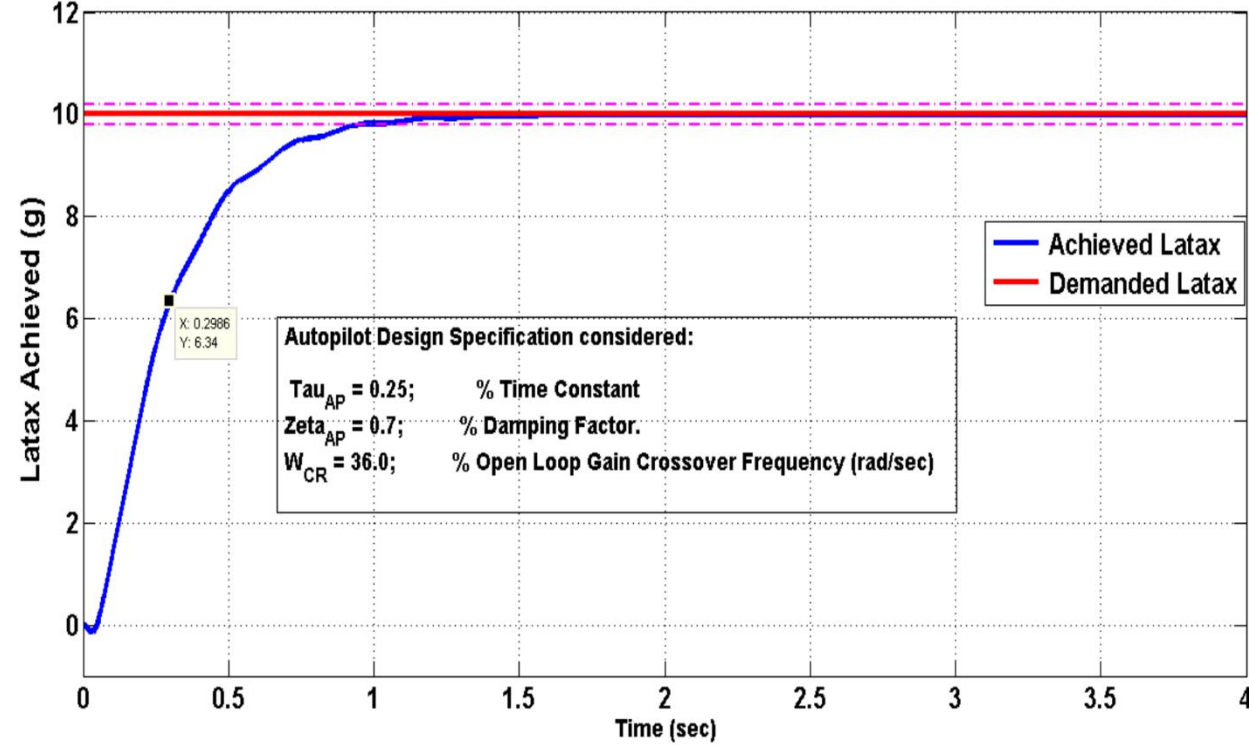


Fig-63: Step Response of Three Loop Lateral Acceleration Autopilot

Missile Technologies: Guidance & Control

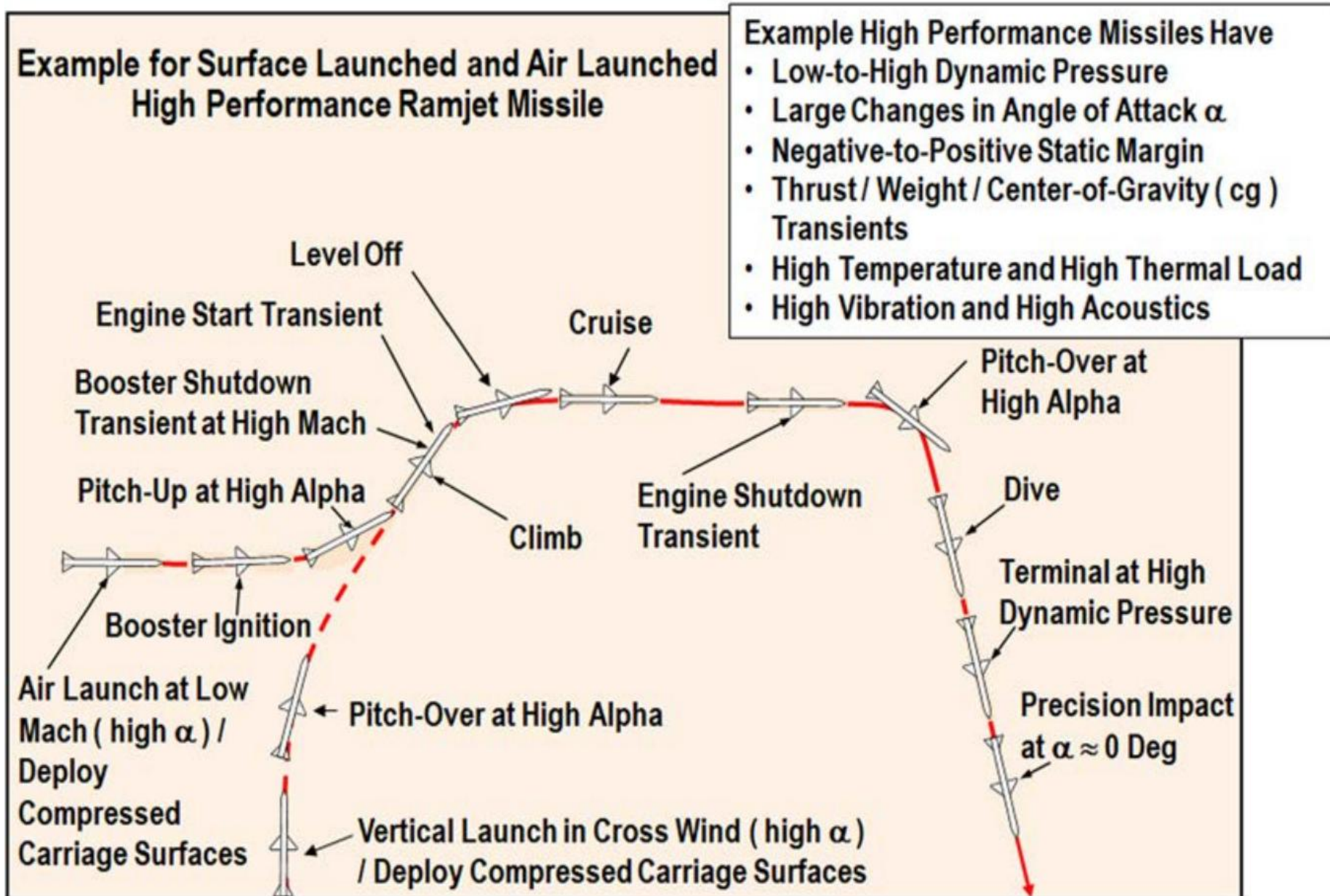


Fig-64: Missile Guidance & Control must be Robust for Changing Events, Environment, and Uncertainty

Missile Technologies: Actuation System Technologies



- ❖ Actuation Systems control fins, thrust vectoring, and control surfaces by converting electrical command signals into mechanical motion.
- ❖ These actuator command signals are generated by the missile autopilot based on guidance and control laws.

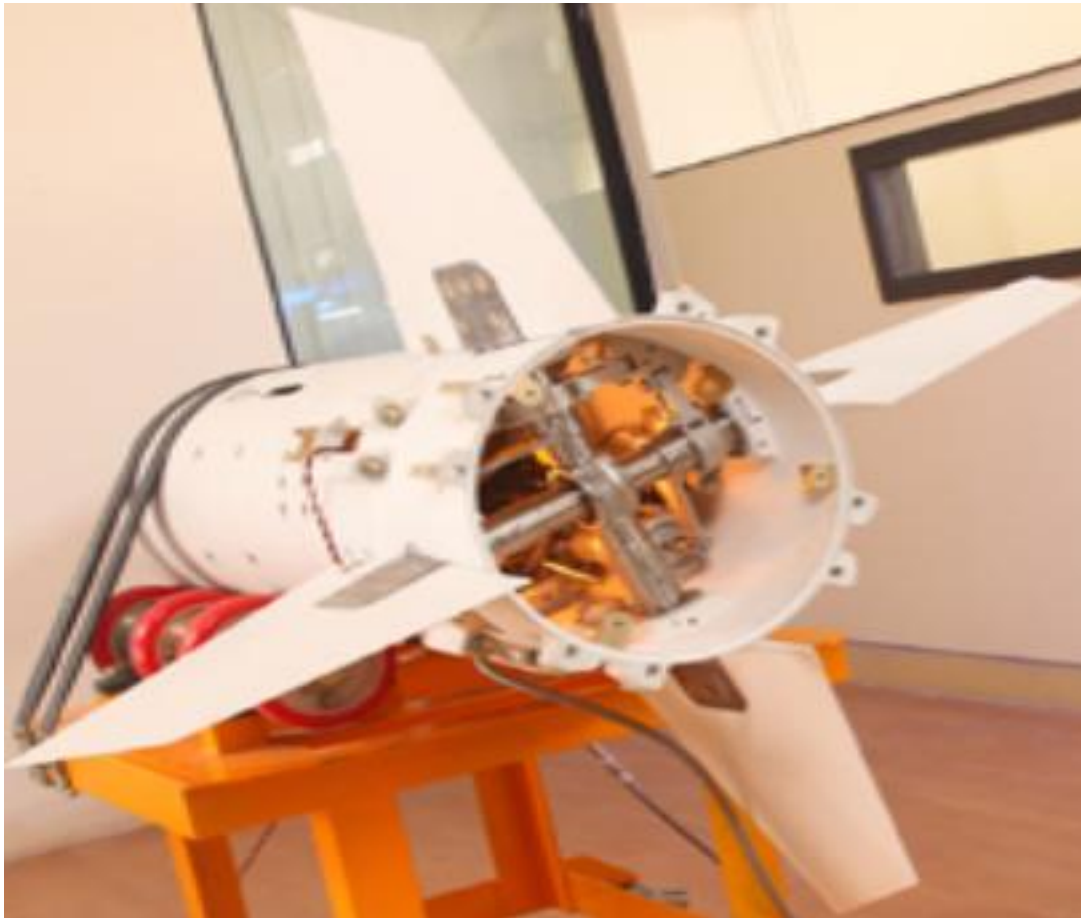


Fig-65: Missile Section with Actuators (EPA) connected to Control Surfaces

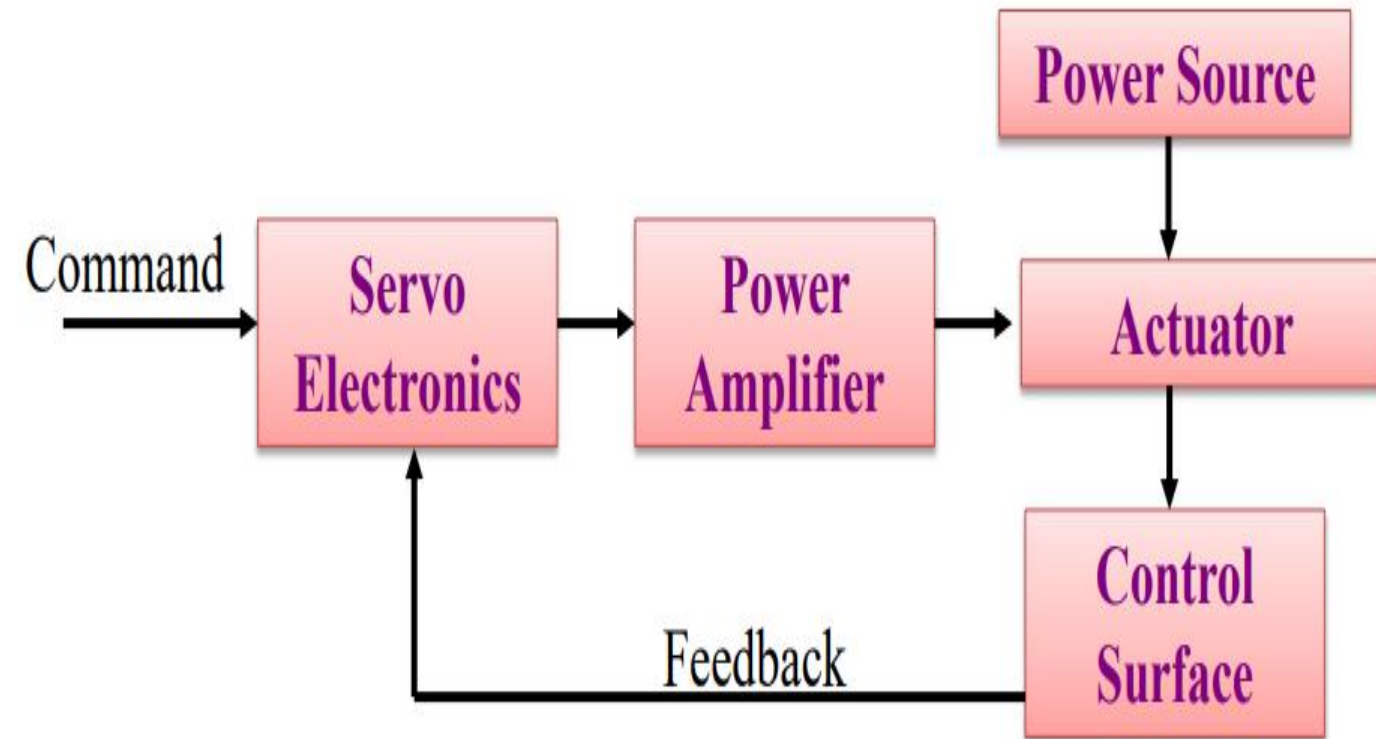


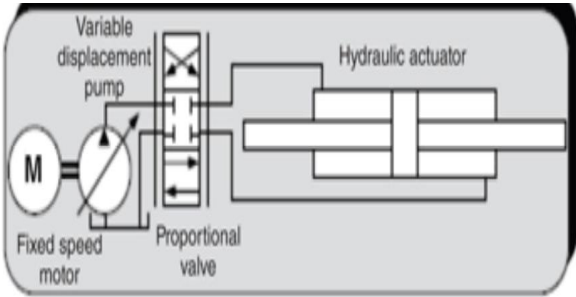
Fig-66: Elements of Actuation System

Missile Technologies: Actuation System Technologies



Classification of Actuation Systems

Electro-Hydraulic Actuation System (EHA)



Electro-Pneumatic Actuation System (EPA)



REMA

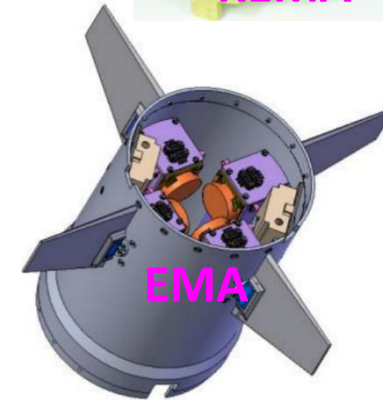
Electro-Mechanical Actuation System (EMA)

Linear EMA

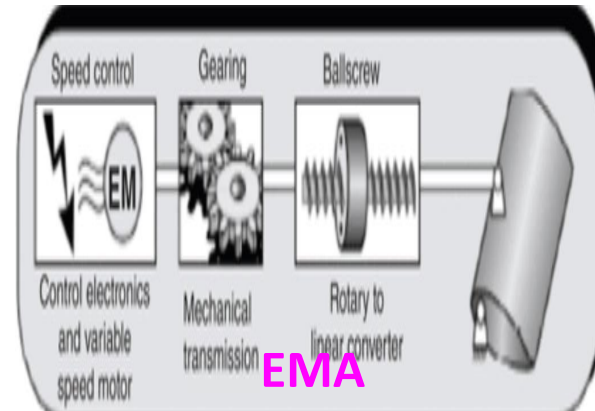
Rotary EMA

Brushed DC Motor

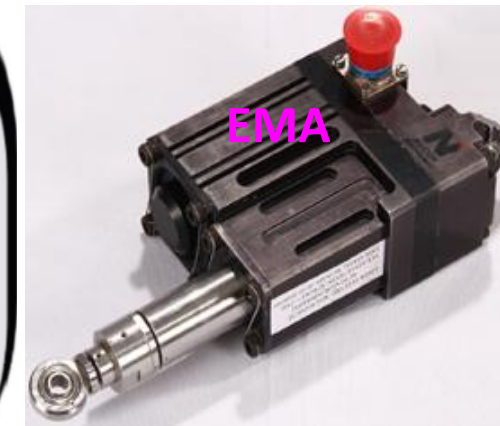
Brushless DC Motor (BLDC)



EMA



EMA



EMA

Fig-67: Classification of Actuation Systems

Missile Technologies: Actuation System Technologies



Parameter	Electro-Hydraulic Actuator	Electro-Pneumatic Actuator	Electro-Mechanical Actuator
Operating Principle	Use electrical signals to control hydraulic servo valves and pumps → high-pressure fluid drives actuators.	Use electrical signals to control pneumatic servo valves → high-pressure compressed air/gas drives actuators.	Use electric motors plus mechanical linkages (gears, lead screws) translate motion with feedback.
Force/ Power Density	High	Low to Medium	Medium
Precision & Control	Medium to High	Medium	High
Response Speed	High	Moderate to High	High
Weight & Footprint	Heavy	Light	Medium
Maintenance Needs	Moderate to High	Low	Low
Complexity	High	Medium	Medium
Typical Cost	High	Low	Medium

Missile Technologies: Seeker Technologies



- ❖ Currently, most missile guidance adopts proportional guidance or its improved guidance law. The main information required for this kind of guidance law is the inertial LOS angular velocity.
- ❖ A missile seeker is composed of a seeker head to collect and detect energy from the target, a tracking function to keep the seeker boresight axis pointed toward the target, and a processing function to extract useful information from the detection and tracking circuits.
- ❖ The seeker usually is mounted in the nose of the missile where it can have an unobstructed view ahead. The seeker antenna or optical system is usually mounted on gimbals to permit its central viewing direction (boresight axis) to be rotated in both azimuth and elevation relative to the missile centerline).
- ❖ The gimbaled portion of the seeker head usually is stabilized to keep it pointing in a fixed direction regardless of perturbing angular motions of the missile body.
- ❖ As the target is tracked by the seeker, the \dot{q} signal required for guidance can be obtained by measuring the seeker angular velocity in the inertial space.

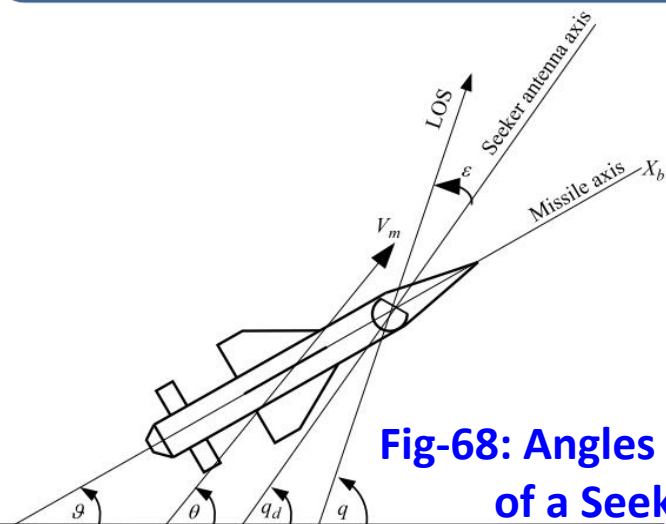


Fig-68: Angles diagram of a Seeker

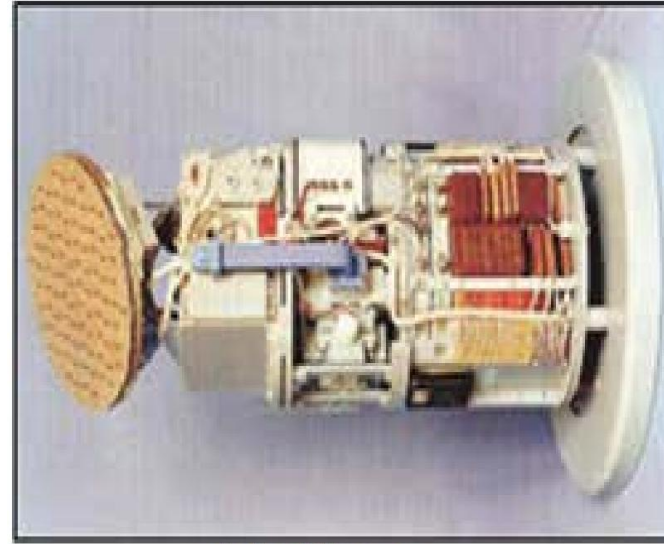
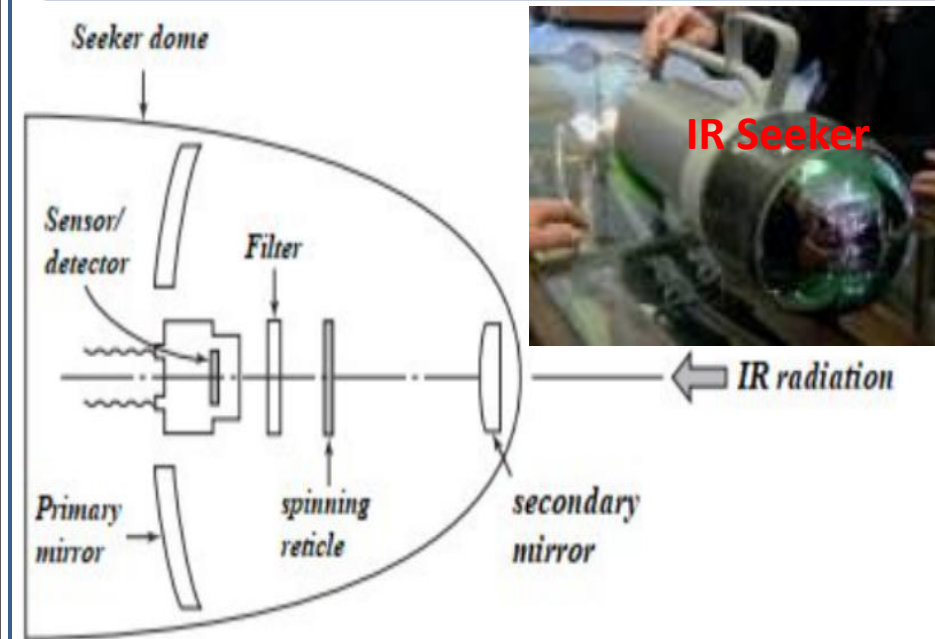
where,

- ϑ —Angle of the x -axis of the missile with respect to the inertial space;
- θ —Angle of the missile velocity vector with respect to the inertial space;
- q —LOS angle of the missile and the target relative to the inertial space;
- q_d —Angle of the seeker antenna axis with respect to the inertial space;
- ϵ —Angular error of the missile-target line with respect to the seeker axis measured by the seeker detector (optical, radio, laser, etc.).

Missile Technologies: Seeker Technologies



- ❖ The two common seeker types are **Optical and Radio Frequency (RF)**.
- ❖ The methods and equipment used to sense signals in the optical and RF bands are different so they lead to different implementations of the two types of seekers.
- ❖ **Optical Seekers:** seekers that sense radiation in the ultraviolet (UV), visual, and infrared (IR) portions of the electromagnetic spectrum are classed as optical seekers. The radiation is transmitted through the atmosphere from the target.
- ❖ **Radio Frequency Seekers:** are essentially a radar in which the antenna is employed to collect RF radiation reflected from the target. The RF power may be generated by systems onboard the target, by a target illuminator on the ground or by a transmitter onboard the missile.



AA-12

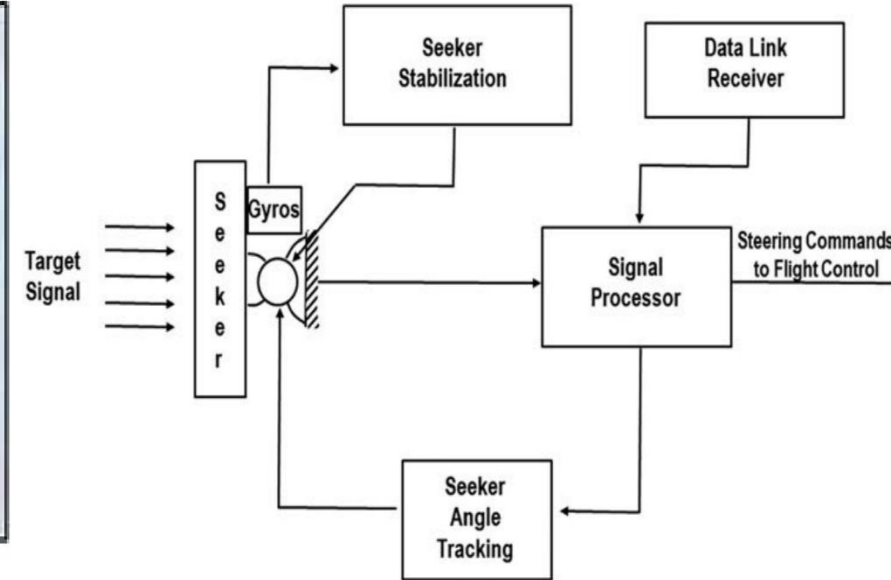


Fig-70: Simplified Block Diagram of a Gimballed Seeker

Fig-69: Optical (IR) Seeker

Fig-69: RF Seeker

Missile Technologies: Seeker Technologies

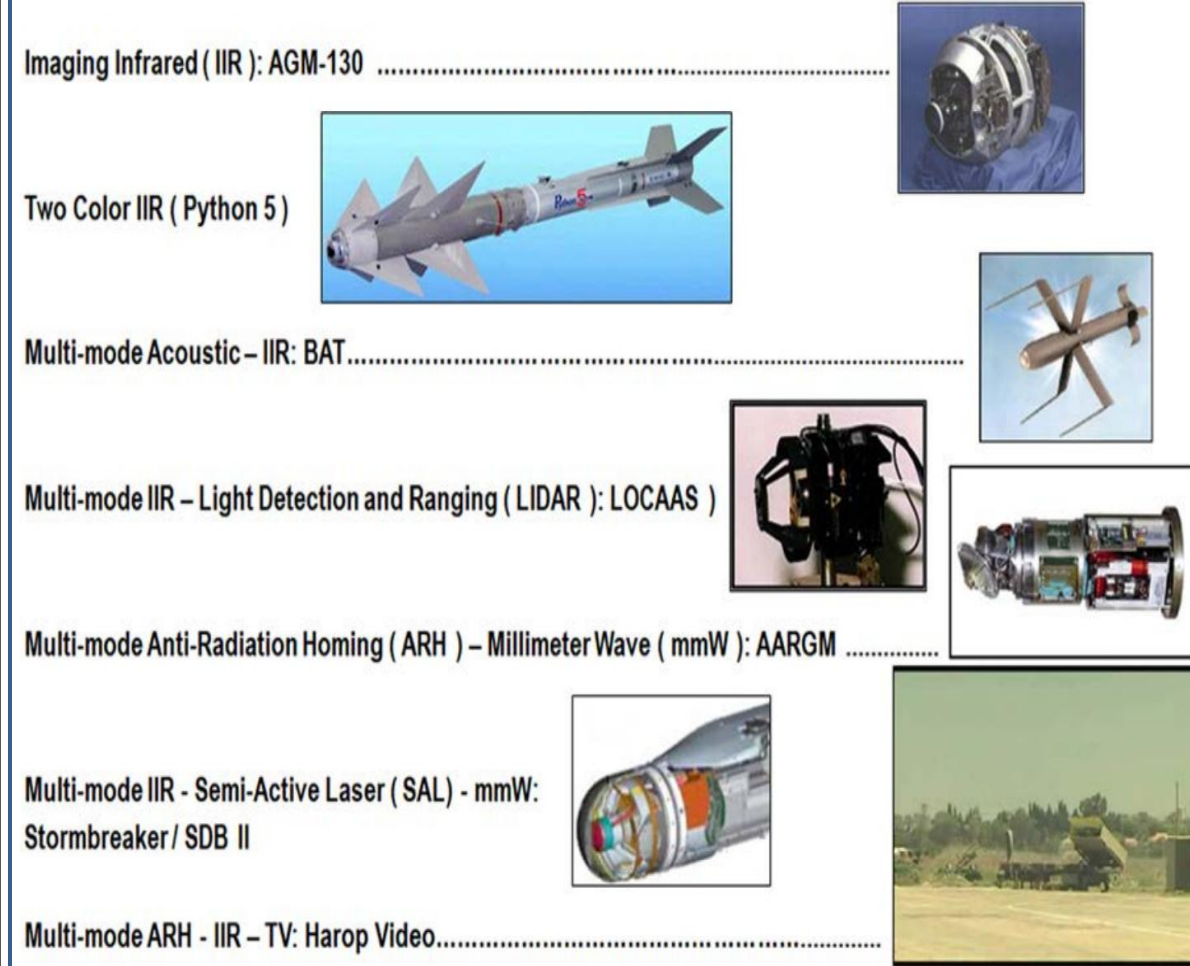


Fig-71: Examples of Countermeasure Resistant Seekers

Seeker / Sensor	Angular Resolution	Adverse Weather Impact	Automatic Target Recognition	Range	Moving Target	Volume Search Time	Hypersonic Dome Compat.	Diameter Required	Weight and Cost	Maturity
• Synthetic Aperture Radar (SAR)	● ◐	●	● ◐	●	○ -	◐	●	◐ -	-	-
• Active Imaging millimeter wave (mmW)	◐ ○	◐ ○	◐ ○	○ -	● ○	○	●	○	-	-
• Passive Imaging mmW	◐	◐ ○	●	-	◐ ◐	○	●	- ◐	◐ ○	-
• Active Imaging Infrared (LIDAR)	●	-	●	○	◐	-	◐ ○	●	◐	◐ ○
• Semi-active Laser / Active Non-image Infrared (LADAR)	●	-	○	○	◐ ○	◐	◐ ◐	◐	●	●
• Active / Semi-active Radar	◐	●	○ -	◐ ●	◐	●	●	○ ●	○ -	●
• Passive Imaging IR	● ◐	-	● ○	◐ ○	○	◐	-	●	○ ◐	◐ ○
• Passive Non-image Infrared	○	-	-	○	○	◐	-	●	●	●
• Acoustic	-	● ◐	◐	-	○ -	●	-	-	●	◐
• GPS / INS / Data Link	● ◐	●	●	●	◐ -	●	●	●	●	◐

Note: ● Superior ◐ Good ○ Average ◑ Below Average - Poor

Fig-72: Comparison of Performance of different Seekers (Performance of Seekers is Improved by GPS, INS & Data Link Sensors)

Missile Technologies: Warhead Technologies



- ❖ The function of any missile is to deliver a warhead to a designated target. Even the most accurate guidance and powerful propulsion systems are of limited value if the warhead cannot produce a sufficiently lethal effect at the right moment to disable or destroy the target.
- ❖ The warhead essentially consists of a **payload**, a **fuze** and **safety and arming mechanism (SAM)**.
- ❖ The initiator and booster are often integral parts of the fuze and/or SAM.

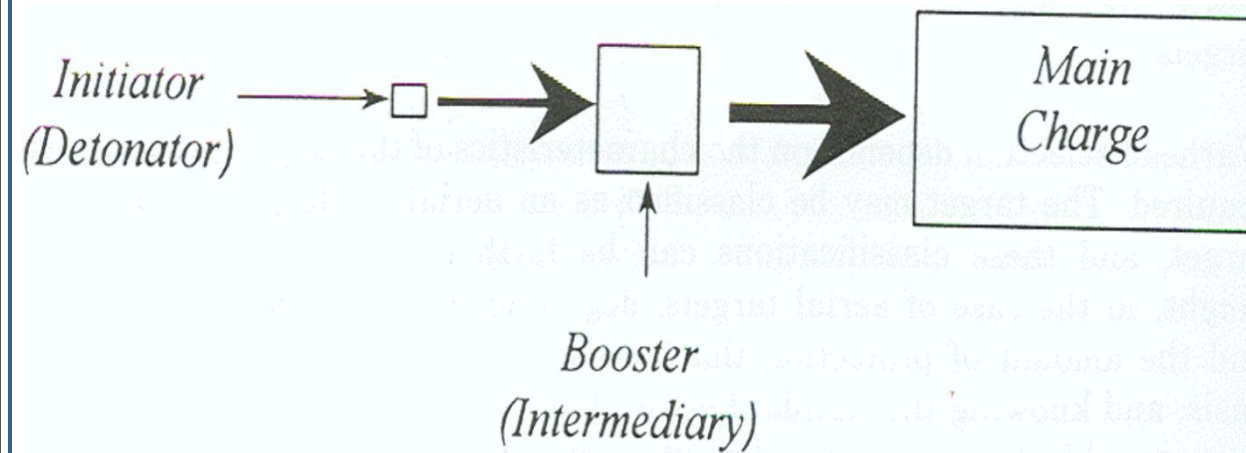


Fig-73: High Explosive Train in a Warhead

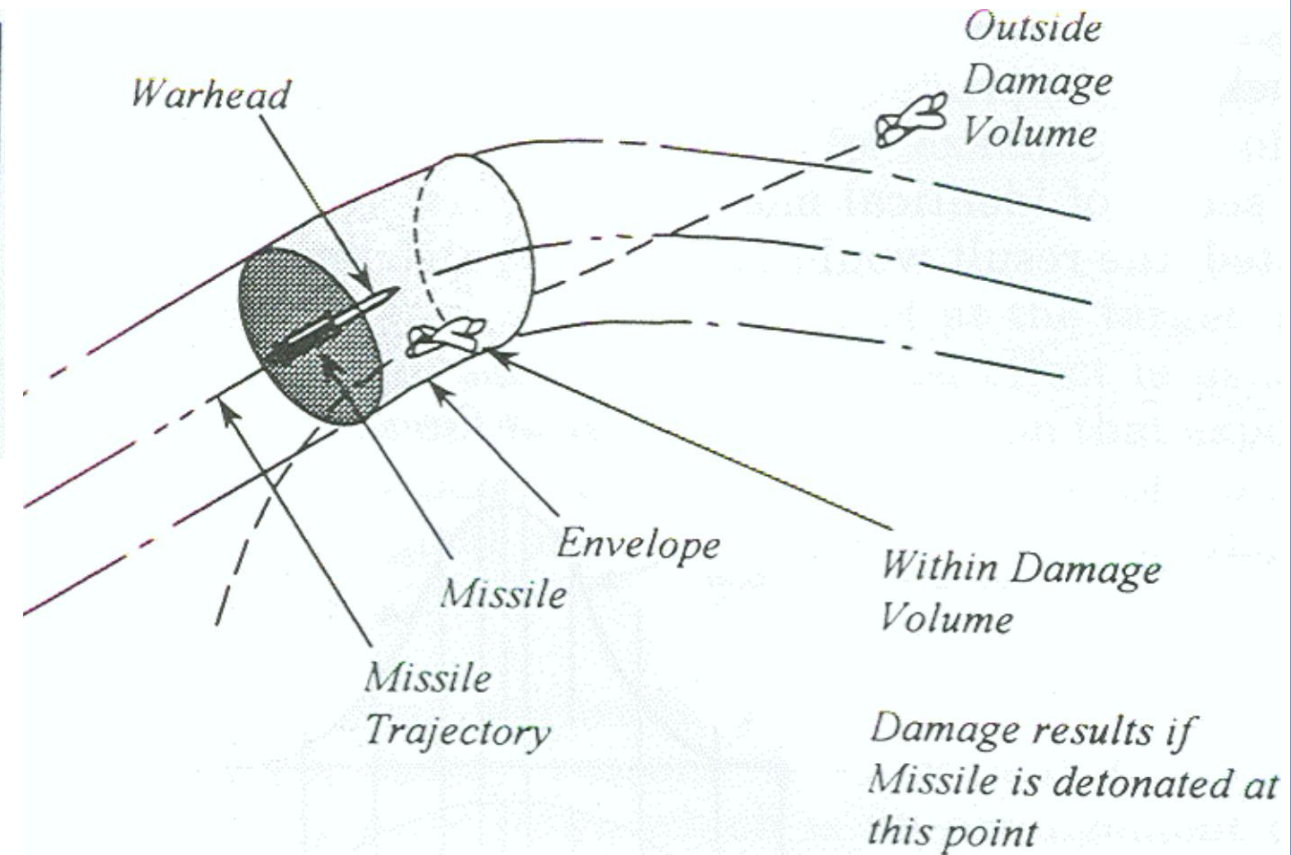


Fig-74: Damage Volume of a Warhead

Missile Technologies: Warhead Technologies



Depending on the released chemical energy from the HE filling, warheads can be classified into one or the other of five main groups as follows:

1. Blast warhead: It depends on the blast, or the high pressure pulse produced by the explosion of the HE filling on the air (or the water in underwater explosions) surrounding the warhead. This pressure wave, which is the blast, travels outwards from the point of explosion and can destroy structures, personnel, etc.

2. Fragmentation warhead: This warhead is widely used against targets such as aircraft, personnel, etc. The detonation of the HE in these warheads produces a large number of metal fragments from the shattered casing, which travel at high supersonic speed. When they hit a target, their capacity to cause damage depends on their remaining kinetic energy, which, in turn, depends on their mass and residual velocity.

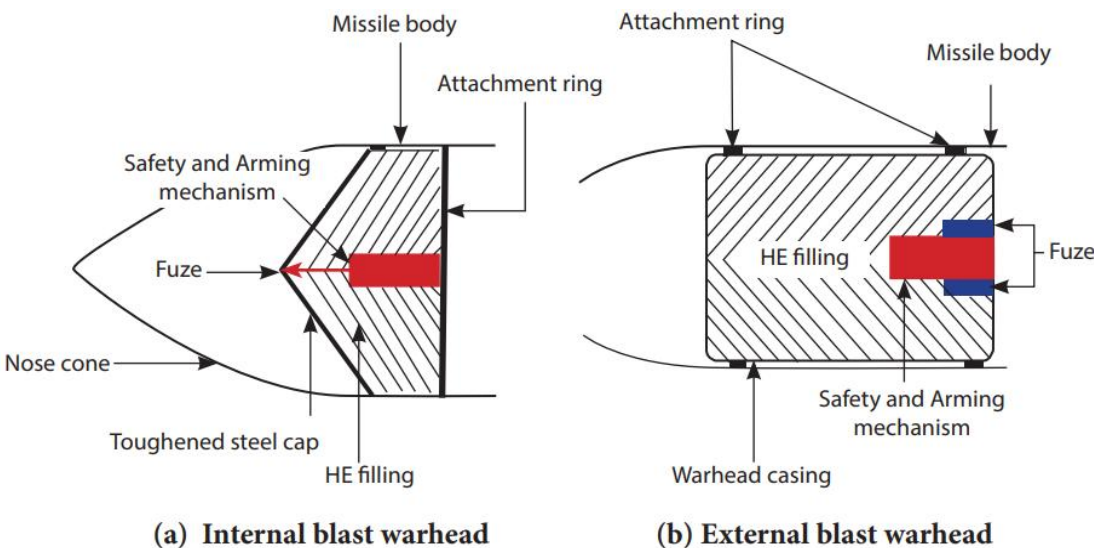


Fig-75: Blast Warhead

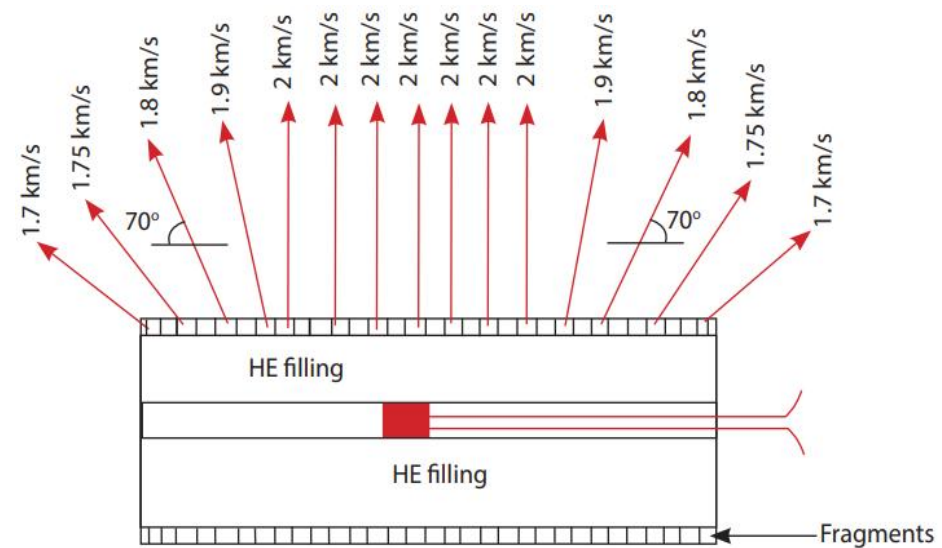


Fig-76: Fragmentation Warhead

Missile Technologies: Warhead Technologies



3. Continuous Rod warhead:

It contains several rods joined together, which are thrown out as a ring with a high velocity. The ring expands and can produce heavy damage to any aircraft, which it encounters.

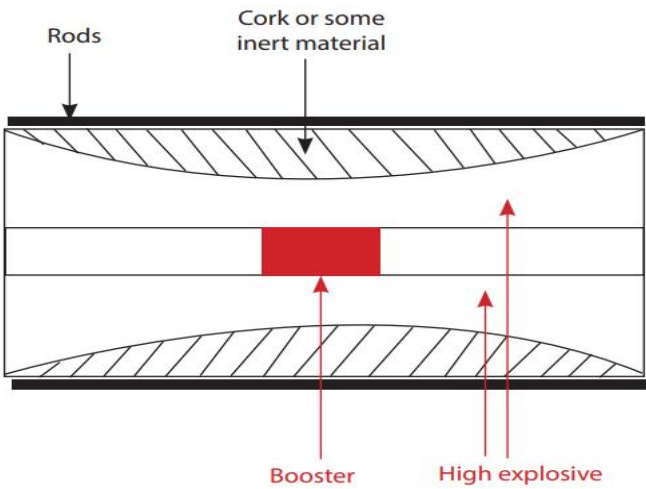


Fig-77: Continuous Rod Warhead

4. Shaped Charge warhead: This is widely used against armoured targets such as tanks. Any warhead has to physically hit this type of target, but even then most cannot penetrate the armour. The shaped-charge warhead, concentrates the energy of the explosion in an extremely narrow area, punches a hole through the armour, and causes damage inside the target.

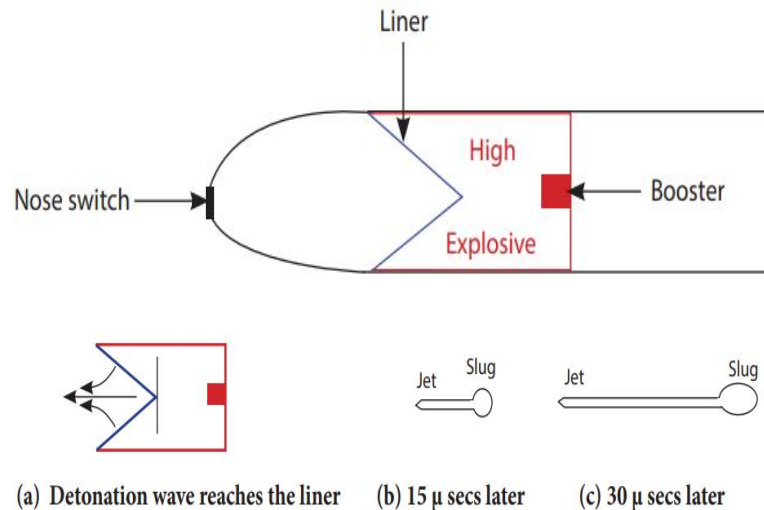


Fig-78: Shaped Charge Warhead

5. HESH warhead: This is another warhead, which can be used against armour. It contains a plastic explosive, which explodes in contact with the armour's external surface. It causes shock waves in the metal body, causing a 'scab' to detach itself from the inner surface, which travels with high velocity inside, killing the crew and damaging the equipment.

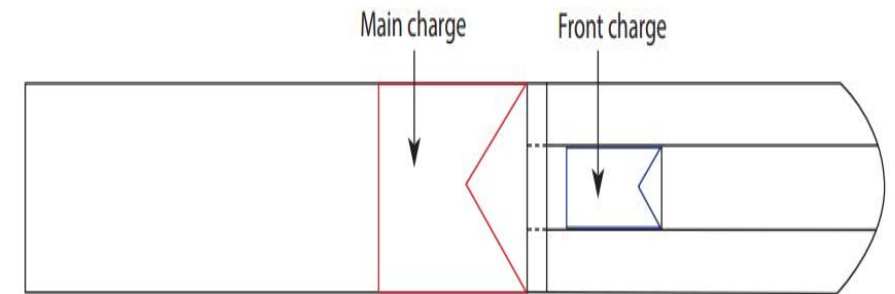


Fig-79: Tandem Charge Warhead

- ❖ Many of the subsystems onboard a missile require electrical power.
- ❖ The missile may have RF seeker, guidance electronics, IR detectors, electric motors, gyros and accelerometers, control electronics, proximity fuze, and onboard computer, all of which require electrical power.
- ❖ In addition, electrical power will also be required for devices such as chamber pressure transducers, squibs, and pyro cartridges.
- ❖ Different AC and DC voltages may be needed to operate these different devices. Most missiles produce one central type of power, either AC or DC and convert it to yield the other type of power required.
- ❖ Requirements of the Missile Power Supply:
 - (a) It must have the necessary power capability.
 - (b) The voltages must be correctly produced at the output.
 - (c) The power supply should have excellent voltage regulation.
 - (d) The power supply must have a very long shelf life, usually 10 years or more.
 - (e) It must have a very low activation time, usually a fraction of a second.
 - (f) It must have high reliability and maintainability.
 - (g) It should occupy as small a space as possible.
 - (h) It should have high energy density' (energy-to weight ratio).

Missile Technologies: Missile Power Supplies

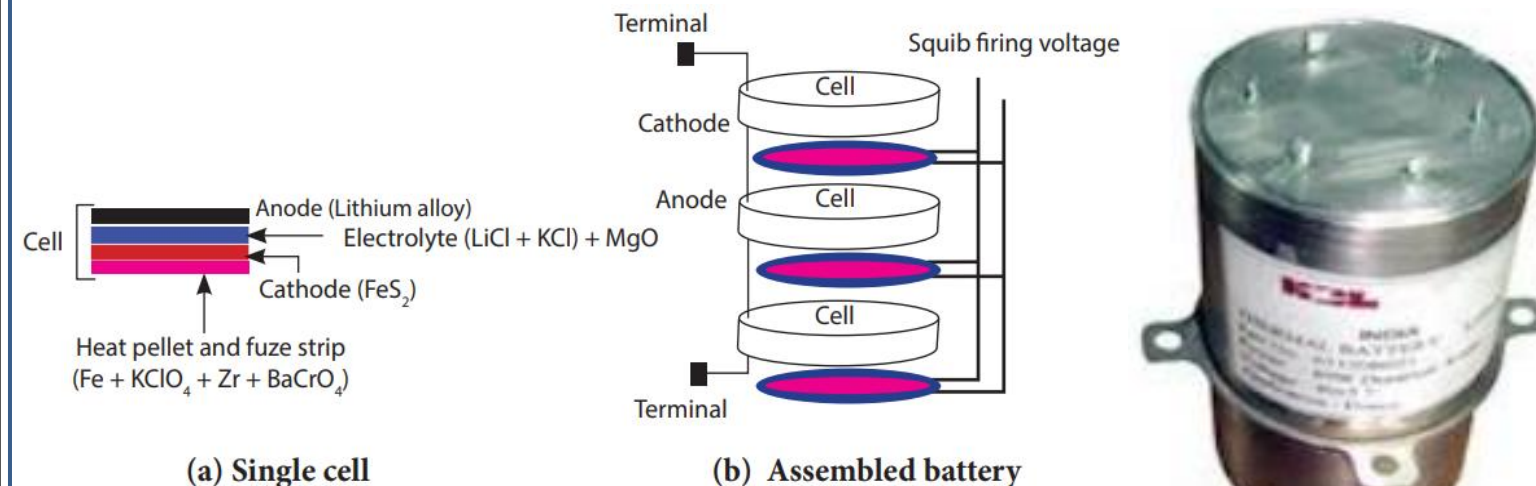


❖ Classification of missile power supplies:

1. Primary batteries
2. Reserve batteries:
 - (a) Liquid injection batteries
 - (b) Thermal batteries: (i) Calcium thermal battery & (ii) Lithium thermal battery
3. Rotary alternators: (a) Flux switch alternators (b) Rotating permanent magnet alternators.

❖ Lithium Thermal Battery (LTB):

- The lithium thermal battery (LTB) is far superior to the calcium battery in tolerance from open circuit to high discharge currents.
- It also has higher energy density, larger current capability, higher predictable performance, and a simple construction and therefore very popular in most missile applications.



(a) Single cell

(b) Assembled battery

Fig-80: Lithium Thermal Battery (LTB)



- ❖ **Airframe** is the main structural body of the missile, it **carries all the missile subsystems**.
- ❖ **During launch and flight**, it experiences:
 - **High longitudinal loads (acceleration)**
 - **High lateral loads (maneuvering)**
 - **Severe heating**, especially in **supersonic/ hypersonic flight**
- ❖ **Material strength decreases at high temperature** → airframe must **withstand loads without deformation** under high temperatures.
- ❖ **Weight is critical**:
 - Heavier airframe → **reduced range & maneuverability**
 - Design is always a **strength-weight compromise**
- ❖ **Aerodynamic forces acting on airframe**:
 - Drag: opposes motion
 - Lift (normal force): supports flight & enable maneuvering
- ❖ **External shape** must:
 - **Minimize drag**
 - **Provide required lift force**
 - **Maintain structural rigidity**

Missile Technologies: Airframe



❖ Materials used:

- **Rocket motor casing:** high-strength steel (often **maraging steel**)
- **Main airframe:** aluminum alloys (e.g., **Duralumin**)
- **Nose cone/ radome:** high-temperature **composites (FRP)**, transparent to radio waves.
- **Titanium alloys** → high strength-to-weight, good high-temperature performance
- **Nickel super alloys (Inconel)** → extreme temperature zones (near rocket motor, high-Mach flight)
- **Small missiles:** airframe often **entirely composite (FRP)**.

Type	Material	Tensile Stress (σ_{TU} / ρ)	Buckling Stability ($\sigma_{Buckling} / \rho$)	Max Short-Life Temp	Thermal Stress	Joining	Fatigue	Cost	Weight
Metallic ↓	Aluminum 2219	○	◐	- ○	-	◐	-	● ○	○
	Steel PH 15-7 Mo	◐	-	●	○	●	◐	● ○	-
	Titanium Ti-6Al-4V	◐	○	●	◐	○	◐	-	○
Composite ↓	S994 Glass / Epoxy and S994 Glass / Polyimide	◐	- ○	○	◐	○	●	●	◐
	Glass or Graphite Reinforce Molding	-	- ○	○	◐	○	●	○	◐
	Graphite / Epoxy and Graphite Polyimide	●	○	○ ◐	●	-	●	-	●

Note: ● Superior ◐ Good ○ Average - Poor

Airframe = Strength + Aerodynamics + Thermal resistance + Minimum Weight

Missile Technologies: Missile Airframe Structure Manufacturing Processes

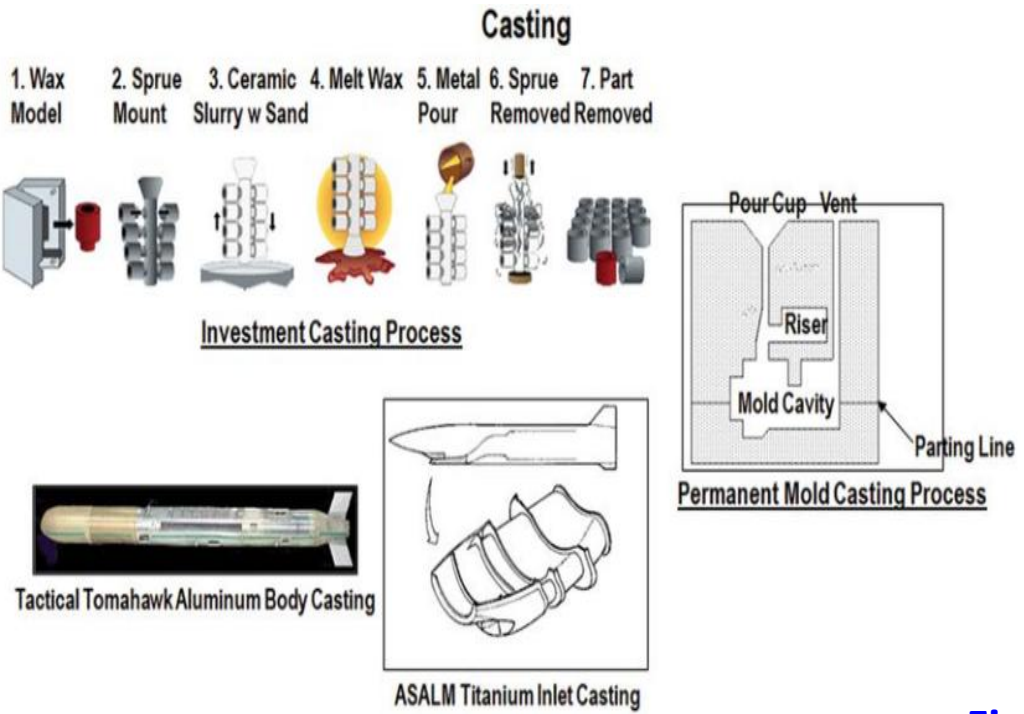


Fig- 81: Investment Casting

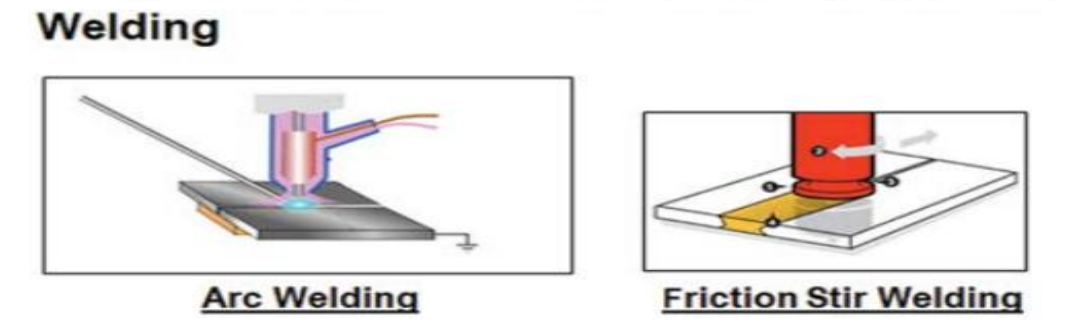
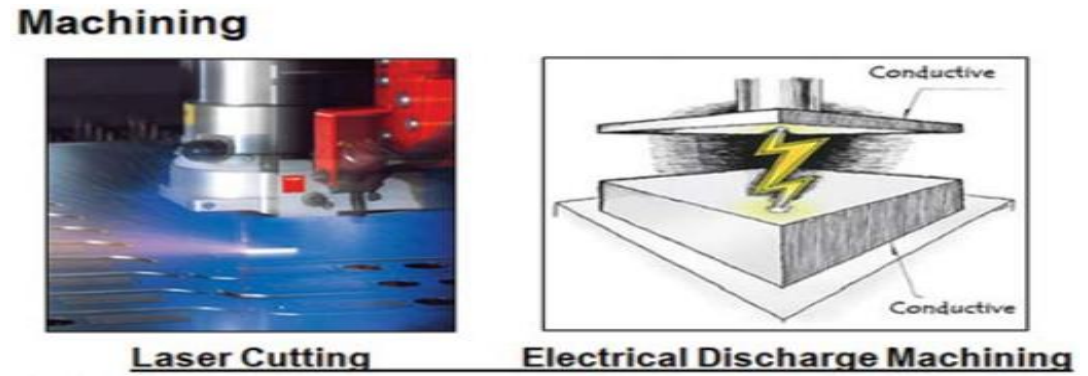


Fig- 82: Cutting, Milling, Drilling, EDM; Resistance/Arc, Laser, Friction Welding

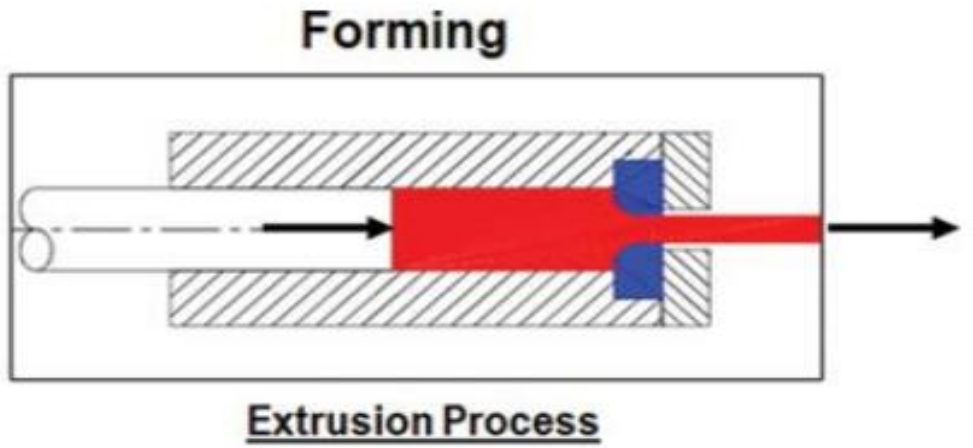


Fig- 83: Forging, Ring/Strip Rolling

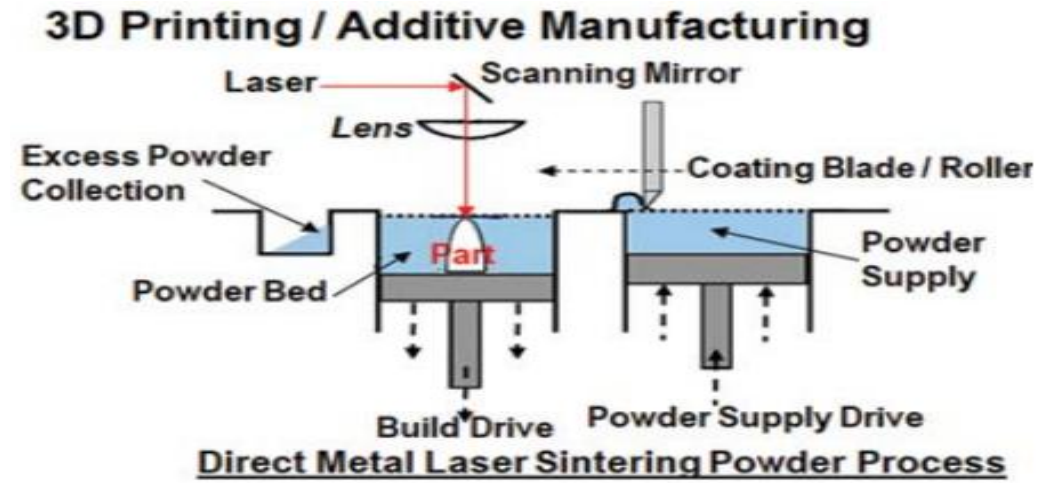
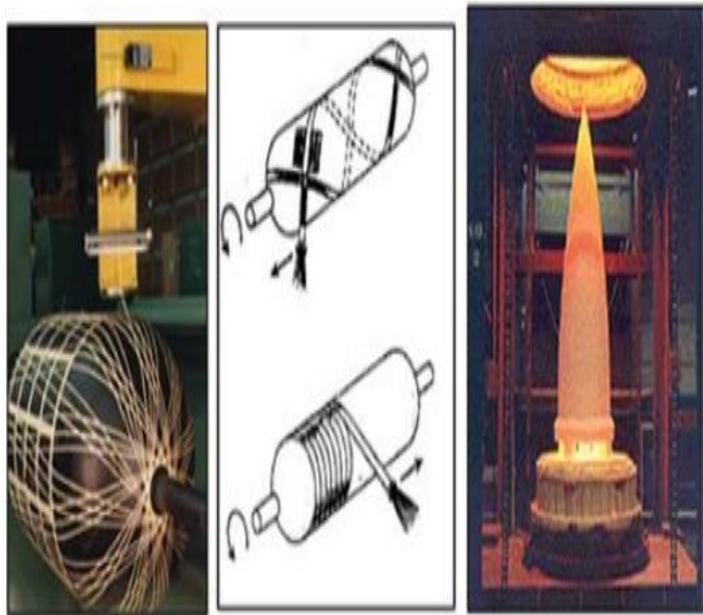


Fig- 84: 3D Printing/ Additive Manufacturing Using DMLS

Missile Technologies: Missile Airframe Structure Manufacturing Processes



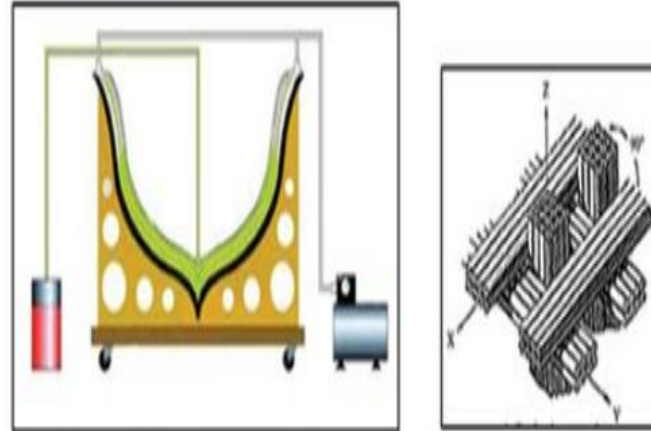
Composite Filament Winding



Filament Winding

PAC-3 Quartz Composite Radome

Resin Transfer Molding



Resin Transfer Molding Process

3D Fiber Orientation

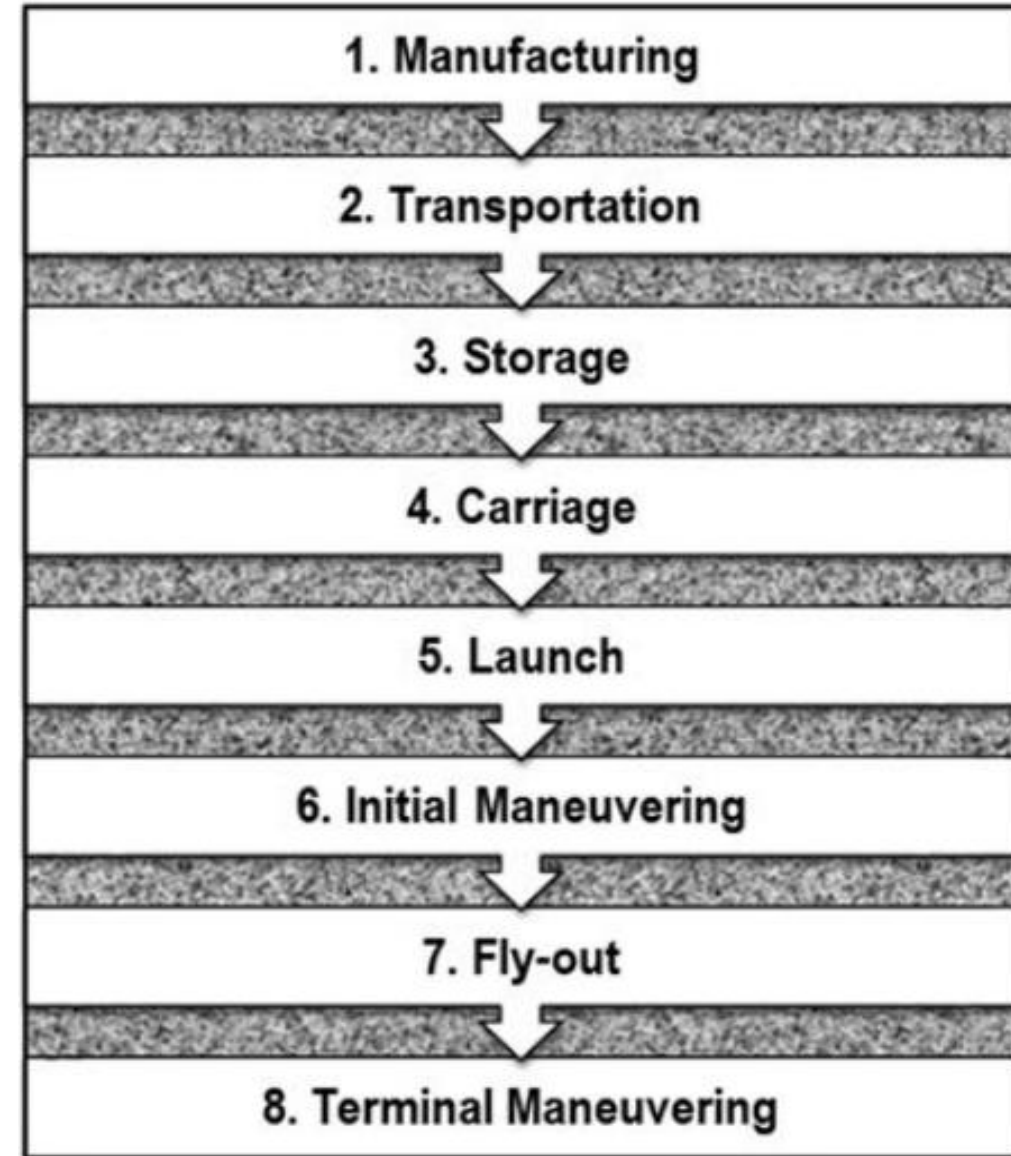


Fig- 85: Carbon Fiber Manufacturing; Composite Filament Winding, RTM, Vacuum Bagging

Fig-86: Missile Structure Is Based on Considering the Cradle-to-Grave Environment

Missile Technologies: Hardware-In-Loop Simulation



- ❖ **Hardware-In-Loop Simulation** is used for system design verification, validation of guidance, navigation & control systems, system integration, pre-flight and post flight performance evaluation.
- ❖ Evaluation of onboard mission software & integrated missile system performance from pre-launch till impact.
- ❖ Evaluation of flight subsystems (OBC, INS, Actuators, IR/RF/MMW Seeker, RPF, Radio Altimeter, Data Link)
- ❖ Independent validation of guidance, control & navigation systems.
- ❖ Validation of mission performance for various trajectories & disturbance conditions including subsystem failure modes in real-time.

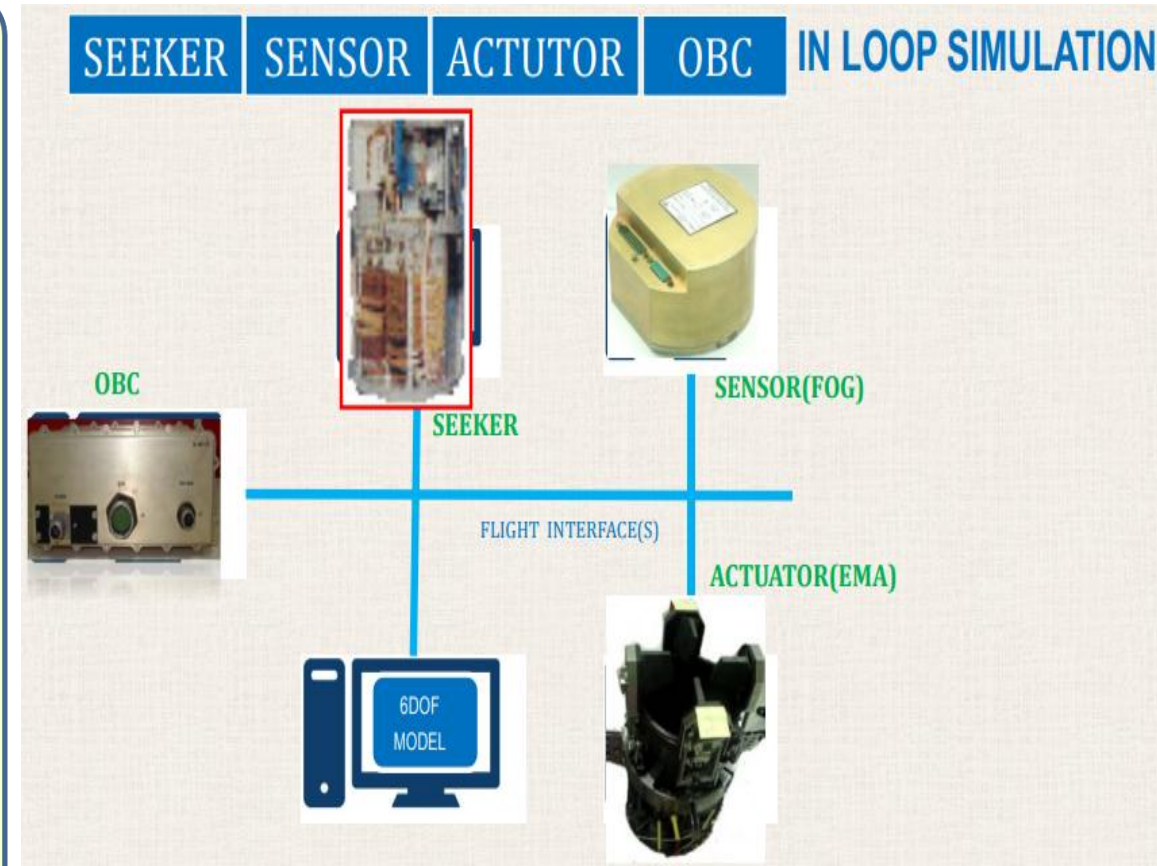
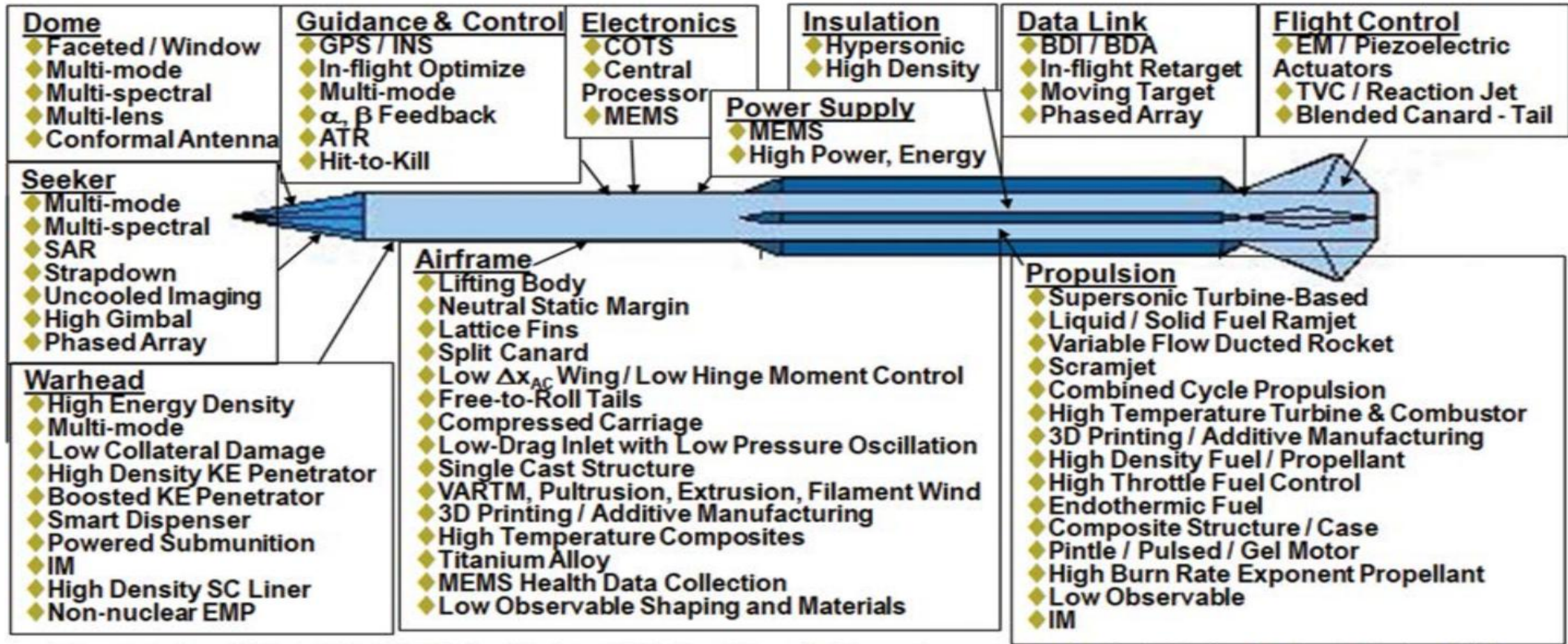


Fig-87: Block Diagram of a Missile Hardware-In-Loop Simulation (HILS) Test Setup

- ❖ **On-board Computer Systems, Two Way RF Data Link Systems, Radio Altimeters, Radio/ Laser Proximity Fuzes, Telemetry Systems, etc** are also very important sub systems used in the missiles.

Enabling Technologies that enhance Tactical Missile Performance



Nomenclature: GPS = Global Positioning System, INS = Inertial navigation system, α = Angle of attack, β = Angle of sideslip, ATR = Automatic target recognition, COTS = Commercial off-the-shelf, MEMS = Micro-machined electromechanical sensor, BDI = Battle damage indication, BDA = Battle damage assessment, EM = Electromechanical, TVC = Thrust vector control, SAR = Synthetic aperture radar, KE = Kinetic energy, IM = Insensitive munition, SC = Shaped charge, EMP = Electromagnetic pulse, Δx_{AC} = Change in aerodynamic center location, VARTM = Vacuum assisted resin transfer molding, 3D = 3 dimension

Fig-88: Enabling Technologies that enhance Tactical Missile Performance

Success Stories of Indian Missile Systems

Operation Sindoor was also a DRDO and Indian industry success story

The Akash air defence system showcases atmanirbharta in defence in its truest sense



By Major General Pawan Anand (Retd)

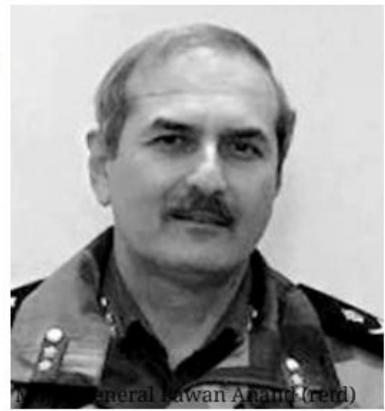
Issue Date: May 25, 2025

Updated: May 18, 2025 07:47 IST



Cruise control: BrahMos supersonic cruise missile being test fired; it can be launched from land, sea or air | PTI

India watched in awe as drones were shot out of the night skies over many of its cities and photographic evidence of precision strikes across the length and breadth of Pakistan emerged. Many never believed we were capable of this modern-age warfare. We not only defended our airspace but also penetrated Pakistan's much touted air defence network, striking at the heart



Major General Pawan Anand (Retd)

of its terror network and military installations with telling effect.



Operation Sindoor vindicates the need for and indeed the success of *atmanirbharta* in defence. It was one of the pillars of the Atmanirbhar Bharat initiative and naysayers have been firmly silenced. And BrahMos and Akash have become household terms.

BrahMos, developed and produced with Russian collaboration, has a range of 280km, within Missile Technology Control Regime limit of 300km. Its range could be extended to 400km, and to 800km, if required. BrahMos delivers a massive payload of up to 250kg of explosives with a circular error probability of 10 metres (if the BrahMos missile was fired multiple times, it would hit within 10 metre of the target in 80 per cent of the attempts). A precision strike would thus cause huge destruction. It travels at Mach 3 (thrice the speed of sound), can be launched from land, sea or air and follows random trajectories (sometimes 2 to 5 metres above the earth or water surface) making it difficult to detect, much less intercept. The destruction seen on the runway at the Rahim Yar Khan airfield and the radar near Lahore was most likely caused by BrahMos strikes.

The Akash air defence system showcases *atmanirbharta* in defence in its truest sense. Its development is fully indigenous and components almost so. It has a range of 25km to 45km and intercepts targets 20km high. Its 60kg warheads explode with proximity fuses, fragmenting to assure destruction on reaching even the vicinity of the intended targets in the air. The sophisticated, DRDO-developed Rajendra radar system detects and tracks 64 targets and guides eight missiles simultaneously. The high kill rate that was on display during the days of hostilities proves Akash's efficacy in battle against drones and aircraft.

“ The Akash air defence system showcases *atmanirbharta* in defence in its truest sense. Its development is fully indigenous and components almost so. ”

Success Stories of Indian Missile Systems



Op Sindoor Victory (Atmanirbharta Success Story – The Crowning Glory)

By capsnetdroff - May 13, 2025



Foreign Secy Vikram Misri with Wing Commander Vyomika Singh and Colonel Sofiya Qureshi briefing media on Op Sindoor

6 0

Author: Air Vice Marshal Ashish Vohra VSM (Retd.), Additional Director General, Centre for Air Power Studies

Keywords: Pahalgam attack, terrorist attack, Operation Sindoor, Integrated Air Defence System.

Atmanirbharta Success Story – the Crowning Glory

Though there are several reasons for this stupendous success of the Indian armed forces, the most significant contributor to the success of Op Sindoor has been the phenomenal performance of the indigenously developed Indian weapon platforms – the indigenously designed and developed Integrated Air Defence System, the indigenously designed and developed Akash Missile system, the Medium Range Surface to Air Missile system (MRSAM), jointly developed by Defence Research and Development Organisation (DRDO), and Israel Aerospace Industries (IAI), the integration by Hindustan Aeronautics Limited (HAL) of the Brahmos Air Launched Cruise Missile (ALCM) onto the Su-30 MKI, the locally manufactured loitering munition (Skystriker) and the DRDO developed C-UAS system [(D-4) Drone, Detect, Deter and Destroy] system, our Regional Navigation Satellite System (RNSS) – the Navigation by Indian Constellation (NAVIC) providing precise coordinates for our long range precision weapons, the re-engineering of life-expired R-73's as Surface to Air Missile for Assured Retaliation (SAMAR) weapons, the indigenously upgraded L-70 guns, the Zu-23 mm systems and the Schilka systems.

The other major contributors to the success of Op Sindoor, though not of Indian origin, were the Russian Long Range Surface to Air Missile (LRSAM) – the S-400, the French Rafale aircraft with its Meteor Beyond Visual Range (BVR) Air-to-Air Missile (AAM), SCALP and HAMMER long-range precision weapon systems, and the Israeli IAI designed Loitering Munition (Harop).

Success Stories of Indian Missile Systems



LRASHM Hypersonic Glide Missile



DRDO Successfully Conducted Salvo Launch of Pralay Missiles

DRDO Carries Out Successful Salvo Launch Trial of Pralay Missile

PRALAY Short Range QUASI - BALLISTIC Missile



DRDO Successfully Tests SFDR Technology

India joins the club of nations with advanced missile propulsion capability

SOLID FUEL DUCTED RAMJET (SFDR) TECHNOLOGY MISSILE



DRDO FLIGHT-TESTS

INDIGENOUS MPATGM

AGAINST MOVING TARGET

NIGHTMARE FOR PAK, CHINA? INDIA'S TANK KILLER IS READY!



NAG Mk-II & MPATGM MISSILES

Success Stories of Indian Missile Systems



रक्षा मंत्रालय
MINISTRY OF
DEFENCE



रक्षा उत्पादन विभाग
DEPARTMENT OF
DEFENCE PRODUCTION

India strengthens its skies!

DRDO has successfully conducted the maiden flight tests of the Integrated Air Defence Weapon System (IADWS)



Multi-layered air defence with QRSAM, VSHORADS & a high-power laser-based Directed Energy Weapon (DEW).



3 aerial targets destroyed simultaneously – UAVs & drones.



Integrated operation of all the weapon system components is controlled by a Centralised Command and Control Centre



Many More Powerful Missiles developed by DRDO:

1. Agni Series Ballistic Missiles
2. ASTRA
3. QRSAM
4. AKASH-NG
5. NAG Mk-II
6. MPATGM
7. ULPGM,
8. VSHORADS etc.

**DRDO, India achieved
Atmanirbharta
in
Missile Systems**

References



1. Eugene L. Fleeman, “Missile Design Guide”, AIAA Education Series, 2022.
2. Eugene L. Fleeman, “Missile Design and System Engineering”, AIAA Education Series, 2012.
3. Eugene L. Fleeman, “Maximizing Missile Flight Performance”, 2009, PDF available online at <https://kirill200281.narod.ru>
4. Eugene L. Fleeman, “Tactical Missile Design”, AIAA Education Series, 2001.
5. SR Mohan, “Fundamentals of Guided Missiles”, DRDO Monographs/ Special Publication Series, DESIDOC, New Delhi, 2016.
6. Paul Zarchan, “Tactical and Strategic Missile Guidance”, 6th Edition, AIAA, 2012
7. P. Garnell & D.J. East, “Guided Weapon Control System”, Pergamon Press, 1977.
8. Qi Zaikang and Lin Defu, “Design of Guidance and Control Systems for Tactical Missiles”, CRC Press Taylor & Francis Group, 2020.
9. J F Rouse, “Guided Weapons, 4th Edition, Brassey’s Series, London.
10. Gautam Choubey, Manvendra Tiwari, “Scramjet Combustion Fundamentals and Advances”, Butterworth-Heinemann, Elsevier, 2022.
11. G.P. Sutton and O. Biblarz, “Rocket Propulsion Elements”, 9th Ed., Wiley, 2017.
12. JG Leishman, “Introduction to Aerospace Flight Vehicles”, Embry-Riddle Aeronautical University, 2023, available online at <https://eaglepubs.erau.edu>.
13. “Israel-Iran conflict: How ballistic missiles work and where can they reach?”, [https:// www.aljazeera.com](https://www.aljazeera.com)
14. “Cruise Missile vs Ballistic Missile – What’s the Difference?”, <https://defensefeeds.com/analysis/weapons/cruise-missile-vs-ballistic-missile/>



**JAI
HIND**

Thank You