

## CHAPTER II: THEORETICAL PERSPECTIVES

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The second chapter entitled '**Theoretical Perspectives**' attempts to explain in simple terms, what is a missile, the types and classification of missiles, the underlying principles in the building and launching of missiles like propulsion, guidance and control, the latest advances in the areas of missile technology, and missilery under development. Further this chapter also focuses on the conceptual aspects relating to missile race, missile rivalry and their associated relevant theories, dynamics of missile proliferation, the core issues connected with problems of national security and its analysis.

## CHAPTER II

### THEORETICAL PERSPECTIVES

**“In the coming years, the threat of missile proliferation will only grow — so must our thinking on this critical issue.”<sup>1</sup>**

**Harry Kazianis**

Missile proliferation is not a new problem. Since the days of World War II, countries have looked for ways to mitigate the awesome power of such technology. Combined with the prospect that such arms could be equipped with weapons of mass destruction (WMD), looking for ways to diminish such threats has only intensified as the technology has advanced and spread over the years. Many of the world's leading missile proliferators are arrayed in an arc, stretching from Libya to South Asia. The search for strategic weight, regional prestige, and the ability to counter overwhelming conventional military capabilities provide strong motives for proliferation. The spread of missiles of increasing range, lethality and accuracy is slowly but steadily growing in South Asia.<sup>2</sup>

Technology as a force multiplier provides the competitive and cutting edge. The technology of missiles encompasses multiple streams of engineering, technology and applied sciences, and today a number of factors are responsible for the successful launching of missiles. These involve coordination of a variety of subsystems. This chapter therefore attempts to focus on the conceptual aspects relating to missile race, missile rivalry and their associated relevant theories, the dynamics of missile proliferation, the major issues connected with the problems of national security and analysis. In addition this chapter briefly traces the historical evolution of missiles, and the significant advances in guidance and control technologies that have dramatically improved the lethality, reliability and accuracy of all types of missiles in the contemporary period at their respective backyards to understand the resultant implications arising out of the missile race.<sup>3</sup>

## What is a Missile?

Basically any object thrown at a target with the aim of hitting it is a missile. Thus, a stone thrown at a bird is a missile. The bird, by using its power of reasoning may evade the missile (the stone) by moving either to the left, right, top or bottom with respect to the flight path (trajectory) of the missile. Thus, the missile in this case has been ineffective in its objective of hitting the bird (the target). Now, if the stone too is imparted with some intelligence and quick response to move with respect to the bird, to overcome aiming errors and the bird's evasive actions, and hit it accurately, the stone becomes a guided missile.

The incorporation of energy source in a missile to provide the required force for its movement (propulsion), intelligence to go in the correct direction (guidance) and effective manoeuvring (control) are the main technologies of guided missiles. They help in making a missile specific to a target, that is, they determine the size, range and state of motion of a missile. The word **missile** comes from the Latin verb **mittere**, meaning "to send". In military usage, munitions projected towards a target are broadly categorized as missiles and rockets.

A powered, guided missile that travels through the air or space is known as a missile (or guided missile). A powered, unguided missile is known as a rocket. Rocket is a general term used broadly to describe a variety of jet-propelled missiles in which forward motion results from reaction to the rearward ejection of matter (usually hot gases) at high velocity. The propulsive jet of gases usually consists of the combustion products of solid or liquid propellants. In a more restrictive sense, rocket propulsion is a unique member of the family of jet-propulsion engines that includes turbojet, pulse-jet, and ramjet systems. The rocket engine is different from these in that the elements of its propulsive jet (that is, the fuel and oxidizer) are self-contained within the vehicle. Therefore, the thrust produced is independent of the medium through which the vehicle travels, making the rocket engine capable of flight beyond the atmosphere or of propulsion underwater. The turbojet, pulse-jet and ramjet engines, on the other hand, carry only their fuel, and depend on the oxygen content of the air for burning. For this reason, these varieties of jet engines are called air-breathing, and are limited to operation within the Earth's atmosphere.

A guided missile is broadly any military missile that is capable of being guided or directed to a target after having been launched. Tactical guided missiles are shorter-ranged weapons designed for use in the immediate combat area. Long-range, or strategic, guided missiles are of two types, cruise and ballistic. Cruise missiles are powered by air-breathing engines that provide almost continuous propulsion along a low, level flight path. A ballistic missile is propelled by a rocket engine for only the first part of its flight; for the rest of the flight the unpowered missile follows an arcing trajectory, small adjustments being made by its guidance mechanism. Strategic missiles usually carry nuclear warheads, while tactical missiles usually carry high explosives.<sup>4</sup>

### **History of Missiles**

Looking back into the history of rockets and guided missiles, we find that rockets were used in China and India around 1000 AD for fireworks as well as for war purposes. During the 18th century, unguided rocket propelled missiles were used by Hyder Ali and his son Tipu Sultan against the British. There is a reference that two rockets belonging to Tipu's forces were captured during the fourth Mysore war in the siege of Seringapatnam in 1799 by companies of the Bengal and Bombay Artillery of the East India Company. The current phase in the history of missiles began during World War II with the use of V1 and V2 missiles by Germany.<sup>5</sup> Since then there has been a tremendous and rapid global advancement in this field. It spawned growth and pushed the frontiers of many new technologies in the areas of materials science, aeronautics, communications, radar and computers. Huge amounts of prime resources have been channelized into this field resulting in the development of sophisticated missiles.<sup>6</sup>

Guided missiles were a product of post-World War II developments in electronics, computers, sensors, avionics, and, to only a slightly lesser degree, rocket and turbojet propulsion and aerodynamics. Although tactical, or battlefield, guided missiles were designed to perform many different roles, they were bound together as a class of weapons by similarities in sensor, guidance and control systems. Control over a missile's direction was most commonly achieved by the deflection of aerodynamic surfaces such as tail fins; reaction jets or rockets and thrust-vectoring were also employed. But it was in their guidance systems that these missiles gained their

distinction, since the ability to make down-course corrections in order to seek or “home” onto a target separated guided missiles from purely ballistic weapons such as free-flight rockets and artillery shells.

A guided missile is a rocket-propelled missile whose path can be controlled during flight either by radio signals or by internal homing devices. **Guided Missiles**, usually containing conventional or nuclear explosives, are guided in flight towards a target either by remote control or by internal mechanisms. Guided missiles vary widely in size and type, ranging from large strategic ballistic missiles with nuclear warheads to small, portable rockets carried by foot soldiers.

### **General Classification of Missiles**

Missiles are generally classified on the basis of their Type, Launch Mode, Range, Propulsion, Warhead and Guidance Systems. On the basis of **type**, they are classified as Cruise Missile and Ballistic Missile. On the basis of **launch mode**, the missiles are divided into Surface-to-Surface Missile, Surface-to-Air Missile, Surface (Coast)-to-Sea Missile, Air-to-Air Missile, Air-to-Surface Missile, Sea-to-Sea Missile, Sea-to-Surface (Coast) Missile, and Anti-Tank Missile. On the basis of **range**, the missiles are classified as Short Range Missile, Medium Range Missile, Intermediate Range Ballistic Missile and Intercontinental Ballistic Missile. The **propulsion** based classifications are Solid Propulsion, Liquid Propulsion, Hybrid Propulsion, Ramjet, Scramjet and Cryogenic. The **warhead bases** are Conventional and Strategic. On the basis of **guidance systems**, missiles are classified as Wire Guidance, Command Guidance, Terrain Comparison Guidance, Terrestrial Guidance, Inertial Guidance, Beam Rider Guidance, Laser Guidance, and RF and GPS Reference. Depending upon the **speed**, missiles are classified as Subsonic, Supersonic and Hypersonic.

#### **On the basis of Type:**

One more classification based on the type of trajectory decides whether a missile is called a **ballistic missile or a cruise missile**. By definition a ballistic missile is one which covers a major part of its range outside the atmosphere where the only external force acting on the missile is the gravitational force of Earth, while a cruise missile is one which travels its entire range in the atmosphere at a nearly constant

height and speed. However, a missile could have a combination of the two also where a missile could cover part of the flight in ballistic mode and later a terminal portion in cruise mode.

(i) **Cruise Missile:**

A cruise missile is basically a small, pilotless airplane. Cruise missiles have an 8.5 foot (2.61 meter) wingspan, are powered by turbofan engines and can fly 500 to 1,000 miles (805 to 1,610 km) depending on the configuration. A cruise missile's job in life is to deliver a 1,000 pound (450 kg) high-explosive bomb to a precise location -- the target. A cruise missile sustains flight through aerodynamic lift for most of its flight path and its primary mission is to place an ordnance or special payload on a target. It flies within the earth's atmosphere and uses jet engine technology. These vehicles vary greatly in their speed and ability to penetrate defences. ICBM Cruise missiles can be categorised by size, speed (subsonic or supersonic), range and whether launched from land, air, surface ship or submarine.

A cruise missile is a guided missile that carries an explosive payload and is propelled, usually by a jet engine, towards a land-based or sea-based target. Cruise missiles are designed to deliver a large warhead over long distances with high accuracy. Modern cruise missiles can travel at supersonic or high subsonic speeds, are self-navigating, and can fly on a non-ballistic, extremely low altitude trajectory. They are distinct from unmanned aerial vehicles (UAV) in that they are used only as weapons and not for reconnaissance. In a cruise missile, the warhead is integrated into the vehicle and the vehicle is always sacrificed in the mission. Cruise missile designs fundamentally derive from the German V-I of World War II. Advances in transistor and computer technology allowed self-correcting avionic and aeronautical designs that allowed missiles to be guided in flight, as opposed to only at launch. These advances developed into guided missiles and guided bombs, and later into the modern cruise missile.

**General Design**

Cruise missiles generally consist of a guidance system, payload and propulsion system, housed in an airframe with small wings and empennage for flight control.

Payloads include the warhead. Cruise missiles tend to be propelled by a jet engine, turbofan engines being preferred due to their greater efficiency at low altitude and subsonic speed.

### **Guidance Systems**

Guidance systems also vary greatly. Low-cost systems use radar altimeter, barometric altimeter and clock to navigate a digital strip map. More advanced systems use inertial guidance, satellite navigation and terrain contour matching (TERCOM). The use of an automatic target recognition (ATR) algorithm/device guidance system increases the accuracy of the missile.

### **Categories**

Cruise missiles can be categorized by size, speed (subsonic or supersonic), and range, and whether launched from land, air, surface ship, or submarine. Often versions of the same missile are produced for different launch platforms; sometimes air- and submarine-launched versions are a little lighter and smaller than land- and ship-launched version.

**Based on speed, cruise missiles are further classified as:** 1) Subsonic cruise missile; 2) Supersonic cruise missile; and 3) Hypersonic cruise missile.

- a) **Subsonic cruise missile** flies at a speed lesser than that of sound. It travels at a speed of around 0.8 Mach. A well-known subsonic missile is the American Tomahawk cruise missile. Some other examples are Harpoon of USA and Exact of France.
- b) **Supersonic cruise missile** travels at a speed of around 2-3 Mach i.e. it travels a kilometre approximately in a second. The modular design of the missile and its capability of being launched at different orientations enable it to be integrated with a wide spectrum of platforms like warships, submarines, different types of aircraft, mobile autonomous launchers and silos. The combination of supersonic speed and warhead mass provides high kinetic energy ensuring tremendous lethal effect. BRAHMOS is the only known versatile supersonic cruise missile system which is in service.
- c) **Hypersonic cruise missile** travels at a speed of more than 5 Mach. Many countries are working to develop hypersonic cruise missiles. BrahMos Aerospace is also in the process of developing a hypersonic cruise missile, BRAHMOS-II, which would fly at a speed greater than 5 Mach.

### **Advantages of Cruise Missiles**

- The big advantage of the cruise missile is its smallness and cost.
- These increase the security of the nation.
- Its small size also improved the weapon's chances of penetration.
- The map matching system (TERCOM) is combined with an inertial navigational system to form the TAINS. This not only gets the cruise to its target but also gets it with accuracy.

### **Disadvantages of Cruise Missiles**

- The lack of a human pilot means, you cannot re-use the thing.
- The missiles are not always accurate, they are expensive, and are becoming scarce.
- While they are cheaper than ballistic missiles, they are more expensive than the gravity bombs dropped from a manned aircraft.
- Their low and slow flight means they can be engaged by a much wider variety of systems, including MANPADS and SAMs.

For some countries, cruise missile technology offers the means for developing a precision strike capability much more cheaply than would be required to procure a modern air force. Once built, cruise missiles require little maintenance and fewer trained personnel to operate and deploy than does a fleet of jet aircraft. Moreover, unlike strikes from manned aircraft, cruise missile use does not carry the political risk of captured pilots. They are also suitable against both land- and sea-based targets. Furthermore, cruise missiles are better suited for the delivery of chemical or biological munitions than are ballistic missiles. The most common mission for cruise missiles is to attack relatively high-value targets such as ships, command bunkers, bridges and dams. Modern guidance systems permit precise attacks.

### **(ii) Ballistic Missile:**

A ballistic missile is a missile that has a ballistic trajectory over most of its flight path, regardless of whether or not it is a weapon-delivery vehicle. Ballistic missiles are categorised according to their range, with maximum distance measured along the surface of Earth's ellipsoid from the point of launch to the point of impact of the last element of their payload. The missile carries a huge payload. The carriage of a deadly warhead is justified by the distance the missile travels. Ballistic missiles can be

launched from ships and land based facilities. Prithvi-I, Prithvi-II, Agni-I, Agni-II and Dhanush ballistic missiles are currently operational in the Indian defence forces.

Ballistic missiles are powered during their initial phase of flight (usually called “boost phase”), before leaving the atmosphere and following an unpowered, inverted-U shape trajectory toward a predetermined target. Ballistic missile ranges can vary from 100 or so kilometres (km) to more than 10,000 km. Ballistic missiles are classified by range as indicated in the following Table 2.1.

<b>Type</b>	<b>Range</b>
Short Range Ballistic Missile (SRBMs)	150-799
Medium Range Ballistic Missile (MRBMs)	800-2399
Intermediate Ballistic Missiles (IRBMs)	2400-5499
Intercontinental Ballistic Missiles (ICBMs)	5000+

**Table 2.1: Classification of Ballistic Missiles**

### **Ballistic Missile Fundamentals**

A ballistic missile is one whose payload reaches its target by means of an initial powered boost phase followed by free flight along a high arcing trajectory. Part of the flight may occur outside the atmosphere. Guidance occurs during the boost phase and, in more advanced systems, during the final phase of the trajectory. Ballistic missiles fly at supersonic speeds and carry their own fuel oxidizer, unlike air-breathing cruise missiles. Missile accuracy is normally described as “circular error probable” (CEP) – a statistical measure of the distance from the aim point within which 50% of the missiles fired will impact. The measure reflects the operational variability between individual missiles caused by variation in engine performance, calibration or system control. Most of a missile’s deviation from its intended trajectory occurs during the boost phase, and a smooth propulsion system is needed to achieve high accuracy. A CEP can only be estimated with confidence by firing a substantial number of missiles (at least 15) at predetermined aim points. Overall system error is a statistical combination of the CEP

and the uncertainty associated with the location of the launch point and the target. The political and psychological reaction to ballistic missile use can be out of proportion to their actual military effect. Missiles consequently have a potential role as terror weapons. In order to understand the design principles of the missiles, it is imperative to know the basic principles of rocketry and Sir Isaac Newton's laws.

## **Isaac Newton's Laws and Principles of Rocketry**

### **Newton's First Law**

A body "continues in its state of rest or in uniform motion in a straight line unless acted upon by an unbalanced force". This law of motion is just an obvious statement of fact, but to know what it means, it is necessary to understand the terms rest, motion and unbalanced force. Rest and motion can be thought of as being opposite to each other. Rest is the state of an object when it is not changing position in relation to its surroundings. If a person is sitting still in a chair, he can be said to be at rest. This term however, is relative. The chair may actually be one of many seats on a speeding airplane. The important thing to remember here is that the man is not moving in relation to his immediate surroundings. If rest were defined as a total absence of motion, it would not exist in nature. Even if the man were to be sitting in his chair at home, he would still be moving, because his chair is actually sitting on the surface of a spinning planet that is orbiting a star. The star is moving through a rotating galaxy that is, itself, moving through the universe. While sitting "still," a person is, in fact, travelling at a speed of hundreds of kilometres per second.

Motion is also a relative term. All matter in the universe is moving all the time, but in the first law, motion refers to changing position in relation to surroundings. A ball is at rest if it is sitting on the ground. The ball is in motion if it is rolling. A rolling ball changes its position in relation to its surroundings. When a man is sitting on a chair in an airplane, he is at rest, but if he gets up and walks down the aisle, he is in motion. A rocket blasting off the launch pad changes from a state of rest to a state of motion.<sup>7</sup>

The third term important to understanding this law is unbalanced force. If one holds a ball in one's hand and keeps it still, the ball is at rest. All the time the ball is

held there though, it is being acted upon by forces. The force of gravity is trying to pull the ball downward, while at the same time the person's hand is pushing against the ball to hold it up. The forces acting on the ball are balanced. Let the ball go, or let the hand move upward, and the forces become unbalanced. The ball then changes from a state of rest to a state of motion.

In rocket flight, forces become balanced and unbalanced all the time. A rocket on the launch pad is balanced. The surface of the pad pushes the rocket up while gravity tries to pull it down. As the engines are ignited, the thrust from the rocket unbalances the forces, and the rocket travels upward. Later, when the rocket runs out of fuel, it slows down, stops at the highest point of its flight, then falls back to Earth. Objects in space also react to forces. A spacecraft moving through the solar system is in constant motion. The spacecraft will travel in a straight line if the forces on it are in balance. This happens only when the spacecraft is very far from any large gravity source such as Earth or the other planets and their moons. If the spacecraft comes near a large body in space, the gravity of that body will unbalance the forces and curve the path of the spacecraft. This happens, in particular, when a satellite is sent by a rocket on a path that is parallel to Earth's surface. If the rocket shoots the spacecraft fast enough, the spacecraft will orbit Earth. As long as another unbalanced force, such as friction with gas molecules in orbit or the firing of a rocket engine in the opposite direction from its movement, does not slow the spacecraft, it will orbit Earth forever.<sup>8</sup> Thus we find an unbalanced force is required to change the state of rest or of uniform motion.

### **Newton's Third Law**

Action and reaction are equal and opposite. That is, if a body exerts a force on another body, the other body too exerts a force on the first body, of the same magnitude but in the opposite direction. The propulsion of a missile is achieved with the help of a rocket engine. It produces thrust by ejecting very hot gaseous matter, called propellant. The hot gases are produced in the combustion chamber of the rocket engine by chemical reactions. The propellant is exhausted through a nozzle at a high speed. This exhaust causes the rocket to move in the opposite direction (Newton's third law).

For the purpose of explanation here, Newton's third law is being discussed before the second one. This law states that every action has an equal and opposite reaction, a law that can be practically understood when one steps off a small boat that has not been properly tied to a pier. A rocket can lift off from a launch pad only when it expels gas out of its engine. The rocket pushes on the gas, and the gas in turn pushes on the rocket. The whole process is very similar to riding a skateboard. Imagine that a skateboard and rider are in a state of rest (not moving). The rider jumps off the skateboard. In the third law, the jumping is called an action. The skateboard responds to that action by travelling some distance in the opposite direction. The skateboard's opposite motion is called a reaction. When the distance travelled by the rider and the skateboard are compared, it would appear that the skateboard has had a much greater reaction than the action of the rider. This is not the case. The reason the skateboard has travelled farther is that it has less mass than the rider. This concept will be better explained in a discussion of the second law. With rockets, the action is the expelling of gas out of the engine. The reaction is the movement of the rocket in the opposite direction. To enable a rocket to lift off from the launch pad, the action, or thrust, from the engine must be greater than the mass of the rocket. In space, however, even tiny thrusts will cause the rocket to change direction.<sup>9</sup>

One of the most commonly asked questions about rockets is how they can work in space where there is no air for them to push against. The answer to this question comes from the third law. Imagine the skateboard again. On the ground, the only part air plays in the motions of the rider and the skateboard is to slow them down. Moving through the air causes friction, or as scientists call it, a drag. The surrounding air impedes the action-reaction. As a result rockets actually work better in space than they do in air. As the exhaust gas leaves the rocket engine it must push away the surrounding air; this uses up some of the energy of the rocket. In space, the exhaust gases can escape freely.

### **Newton's Second Law**

The rate of change of momentum is proportional to the impressed force and takes place in the direction of the force. As per the second law, also called the law of momentum, the rate of change of momentum causes a force to be developed. The

change in momentum of the missile body including the rocket motor casing, the nozzle and other systems due to the ejected matter creates a force leading to the propulsive action on the missile body. The missile, propelled into air, would continue to move if there were no other forces acting on it.

This law of motion is essentially a statement of a mathematical equation. The three parts of the equation are mass (m), acceleration (a), and force (f). Using letters to symbolize each part, the equation can be written as follows:

$$\mathbf{f = ma}$$

By using simple algebra, we can also write the equation in two other ways:

$$\mathbf{a = f/m}$$

Newton's second law reads: force equals mass times acceleration. To explain this law, the old style cannon is used as an example.

When the cannon is fired, an explosion propels a cannon ball out the open end of the barrel. It flies a kilometre or two to its target. At the same time the cannon itself is pushed backward a meter or two. This is action and reaction at work (third law). The force acting on the cannon and the ball is the same. What happens to the cannon and the ball is determined by the second law. In the following two equations,

$$\mathbf{f = m (cannon) * a (cannon)}$$

$$\mathbf{f = m (ball) * a (ball)}$$

the first equation refers to the cannon and the second to the cannon ball. In the first equation, the mass is the cannon itself and the acceleration is the movement of the cannon. In the second equation the mass is the cannon ball and the acceleration is its movement. Because the force (exploding gun powder) is the same for the two equations, the equations may be combined and rewritten as:

$$\mathbf{m (cannon) * a (cannon) = m(ball) * a (ball)}$$

In order to keep the two sides of the equations equal, the accelerations vary with mass. In other words, the cannon has a large mass and a small acceleration. The cannon ball has a small mass and a large acceleration. However, resistance to its forward

movement due to air (commonly called the aerodynamic drag) and the force of gravity acting downwards towards the centre of the earth are to be taken into account. By using Newton's first law, also called the law of inertia, compensative forces are imparted to the missile to overcome these negative forces.

Newton's second law of motion is especially useful when designing efficient rockets and missiles. To enable a rocket to climb into low Earth orbit, it is necessary to achieve a speed in excess of 28,000 km per hour. A speed of over 40,250 km per hour, called escape velocity, enables a rocket to leave Earth and travel out into deep space. Attaining space flight speeds requires the rocket engine to achieve the greatest action force possible in the shortest time. In other words, the engine must burn a large mass of fuel and push the resulting gas out of the engine as rapidly as possible. Ways of doing this is described in the next chapter, Practical Rocketry. Newton's second law of motion can be restated in the following way: the greater the mass of rocket fuel burned, and the faster the gas produced can escape the engine, the greater the thrust of the rocket.

### **Putting Newton's Laws of Motion Together**

An unbalanced force must be exerted for a rocket to lift off from a launch pad or for a craft in space to change speed or direction (first law). The amount of thrust (force) produced by a rocket engine will be determined by the mass of rocket fuel that is burned and how fast the gas escapes the rocket (second law). The reaction, or motion, of the rocket is equal to and in the opposite direction of the action, or thrust, from the engine (third law).<sup>10</sup>

### **Parts of Propulsion System**

All types of rocket propulsion engines contain a chamber, a nozzle and an igniter. The chemical reaction of propellant chemicals (usually a fuel and an oxidiser) takes place in the chamber and produces gases. The energy due to this high pressure reaction permits the heating of the product gases to a very high temperature (2000-3500°C). These gases subsequently are expanded in the nozzle and accelerated to high velocities. The nozzle design, i.e., its shape and size are critical for the efficient function of the propulsion system. Terms like thrust, specific impulse, exhaust

velocity, specific propellant consumption, mass ratio and factor of safety are some of the parameters that decide the performance of propulsion.

### **Design Principles of Ballistic Missiles**

Strategic ballistic missiles can be divided into two general categories according to their basing mode: those that are launched from land and those launched at sea (from submarines beneath the surface). They also can be divided according to their range into intermediate-range ballistic missiles (IRBMs) and intercontinental ballistic missiles (ICBMs). IRBMs have ranges of about 600 to 3,500 miles, while ICBMs have ranges exceeding 3,500 miles. Modern land-based strategic missiles are almost all of ICBM range, whereas all but the most modern submarine-launched ballistic missiles (SLBMs) have been of intermediate range.

Prelaunch survivability (that is, the ability to survive an enemy attack) has been a long-standing problem with land-based ICBMs. (SLBMs achieve survivability by being based on relatively undetectable submarines.) At first, they were considered safe from attack because neither US nor Soviet missiles were sufficiently accurate to strike the other's launch sites. Hence, early systems were launched from above ground.

However, as missile accuracies improved, above-ground missiles became vulnerable, and in the 1960s both countries began to base their ICBMs below ground in concrete tubes called silos, some of which were hardened against nuclear blast. Later, even greater improvements in accuracy brought ICBM basing strategy back to above-ground systems. This time, prelaunch survivability was to be achieved by mobile ICBMs that would confound an attacker with multiple moving targets. In order to increase their range and throw weight, ballistic missiles are usually multi-staged. By shedding weight as the flight progresses (that is, by burning the fuel and then discarding the pumps, flight controls, and associated equipment of the previous stage), each successive stage has less mass to accelerate. This permits a missile to fly farther and carry a larger payload.

The flight path of a ballistic missile has three successive phases. During the boost phase, the rocket engine (or engines, if the missile contains two or three stages) provides the precise amount of propulsion required to place the missile on a specific

ballistic trajectory. Then the engine quits, and the final stage of the missile (called the payload) coasts in the midcourse phase, usually beyond the Earth's atmosphere. The payload contains the warhead (or warheads), the guidance system, and penetration aids such as decoys, electronic jammers and chaff to help elude enemy defences. The weight of this payload constitutes the missile's throw weight—that is, the total weight that the missile is capable of placing on a ballistic trajectory toward a target. By midcourse the warheads have detached from the remainder of the payload, and all elements are on a ballistic path. The terminal phase of flight occurs when gravity pulls the warheads (now referred to as the re-entry vehicles, or RVs) back into the atmosphere and down to the target area. Most ballistic missiles use inertial guidance to arrive at the vicinity of their targets. This technology, based on Newtonian physics, involves measuring disturbances to the missile in three axes.

The device used to measure these disturbances is usually composed of three gyroscopically stabilized accelerometers mounted at right angles to one another. By calculating the acceleration imparted by external forces (including the rocket engine's thrust), and by comparing these forces to the launch position, the guidance system can determine the missile's position, velocity and heading. Then the guidance computer, predicting the gravitational forces that will act on the re-entry vehicle, can calculate the velocity and heading required to reach a predetermined point on the ground. Given these calculations, the guidance system can issue a command to the missile thrust system during boost phase to place the payload at a specific point in space, on a specific heading, and at a specific velocity - at which point thrust is shut off and a purely ballistic flight path begins.

Ballistic missile guidance is complicated by two factors. During the latter stages of the powered boost phase, the atmosphere is so thin that aerodynamic flight controls such as fins cannot work and the only corrections that can be made to the flight path must come from the rocket engines themselves. But, because the engines only provide a force vector roughly parallel to the missile's fuselage, they cannot be used to provide major course corrections; making major corrections would create large gravitational forces perpendicular to the fuselage that could destroy the missile. Nevertheless, small corrections can be made by slightly gambolling the main engines so that they swivel, by placing deflective surfaces called vanes within the rocket

exhaust, or, in some instances, by fitting small rocket engines known as thrust-vector motors or thrusters. This technique of introducing small corrections into a missile's flight path by slightly altering the force vector of its engines is known as thrust-vector control.

Another complication occurs during re-entry to the atmosphere, when the unpowered RV is subject to relatively unpredictable forces such as wind. Guidance systems have had to be designed to accommodate these difficulties. Errors in accuracy for ballistic missiles (and for cruise missiles as well) are generally expressed as launch-point errors, guidance/en-route errors or aim-point errors. Both launch- and aim-point errors can be corrected by surveying the launch and target areas more accurately. Guidance/en-route errors, on the other hand, must be corrected by improving the missile's design—particularly its guidance. Guidance/en-route errors are usually measured by a missile's circular error of probability (CEP) and bias. CEP uses the mean point of impact of missile test firings, usually taken at maximum range, to calculate the radius of a circle that would take in 50 percent of the impact points. Bias measures the deviation of the mean impact point from the actual aim point. An accurate missile has both a low CEP and low bias.<sup>11</sup>

The single most important difference between ballistic missiles and cruise missiles is that the latter operate within the atmosphere. This presents both advantages and disadvantages. One advantage of atmospheric flight is that traditional methods of flight control (e.g., air foil wings for aerodynamic lift, rudder and elevator flaps for directional and vertical control) are readily available from the technologies of manned aircraft. Also, while strategic early-warning systems can immediately detect the launch of ballistic missiles, low-flying cruise missiles presenting small radar and infrared cross sections offer a means of slipping past these air-defence screens.

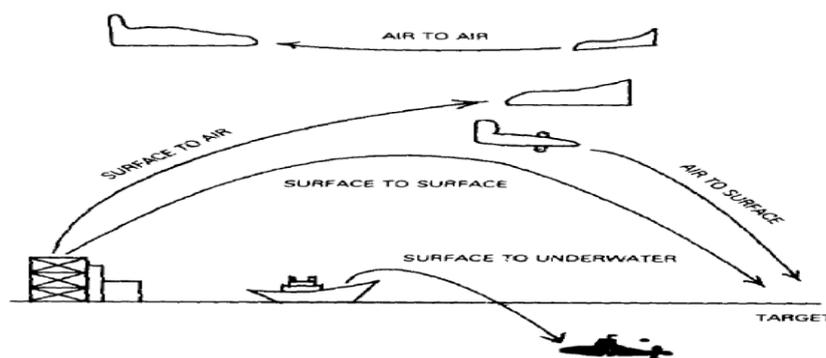
The principal disadvantage of atmospheric flight centres on the fuel requirements of a missile that must be powered continuously for strategic distances. Some tactical-range anti-ship cruise missiles such as the US Harpoon have been powered by turbojet engines, and even some non-cruise missiles, such as the Soviet SA-6 gainful surface-to-air missile, employed ramjets to reach supersonic speed, but at ranges of 1,000 miles or more these engines would require enormous

amounts of fuel. This in turn would necessitate a larger missile, which would approach a manned jet aircraft in size and would thereby lose the unique ability to evade enemy defences. This problem of maintaining balance between range, size, and fuel consumption was not solved until reliable, fuel-efficient turbofan engines were made small enough to propel a missile of radar-evading size.

As with ballistic missiles, guidance has been a long-standing problem in cruise missile development. Tactical cruise missiles generally use radio or inertial guidance to reach the general vicinity of their targets and then home onto the targets with various radar or infrared mechanisms. Radio guidance, however, is subject to line-of-sight range limitations, and inaccuracies tend to arise in inertial systems over the long flight times required of strategic cruise missiles. Radar and infrared homing devices, moreover, can be jammed or spoofed. Adequate long-range guidance for cruise missiles was not available until inertial systems were designed that could be updated periodically by self-contained electronic map-matching devices.<sup>12</sup>

#### **On the Basis of Launch Mode:**

Another classification of missiles which is very popular is based on the method of launching surface-to-surface-missiles (SSM) surface-to-air missiles (SAM), air-to-air missiles (AAM), and air-to-surface missiles (ASM). The same is reflected in **Figure 2.1**.



**Figure 2.1: Missile Classification by the method of Launching<sup>13</sup>**

(i) **Surface-to-Surface Missile:** A surface-to-surface missile is a guided projectile launched from a hand-held, vehicle mounted, trailer mounted or fixed, installation. It is

often powered by a rocket motor or sometimes fired by an explosive charge since the launch platform is stationary.

(ii) **Surface-to-Air Missile:** A surface-to-air missile is designed for launch from the ground to destroy aerial targets like aircrafts, helicopters and even ballistic missiles. These missiles are generally called air defence systems as they defend any aerial attacks by the enemy.

(iii) **Surface (Coast)-to-Sea Missile:** A surface (coast)-to-sea missile is designed to be launched from land to ship in the sea as targets.

(iv) **Air-to-Air Missile:** An air-to-air missile is launched from an aircraft to destroy the enemy aircraft. The missile flies at a speed of 4 Mach.

(v) **Air-to-Surface Missile:** An air-to-surface missile is designed for launch from military aircraft and strikes ground targets on land, at sea or both. The missiles are basically guided via laser guidance, infrared guidance and optical guidance or via GPS signals. The type of guidance depends on the type of target.

(vi) **Sea-to-Sea Missile:** A sea-to-sea missile is designed for launch from one ship to another ship.

(vii) **Sea-to-Surface (Coast) Missile:** A sea-to-surface missile is designed for launch from ship to land based targets.

(viii) **Anti-Tank Missile:** An anti-tank missile is a guided missile primarily designed to hit and destroy heavily-armoured tanks and other armoured fighting vehicles. Anti-tank missiles could be launched from aircraft, helicopters and tanks, and also from shoulder mounted launchers.

### **On the Basis of Range**

This type of classification is based on maximum range achieved by the missiles such as short range, medium range, intermediate range and intercontinental. This classification is mainly used in the context of SSMS. Missiles which travel a distance of about 50 to 100 km are designated as short-range missiles. Those with a range of 100 to 1500 km are called medium-range missiles and missiles having a range of up to

5000 km are said to be intermediate-range missiles. ICBMs belong to the class of long-range missiles which can travel a distance of 12000 km. The Indian technology demonstrator Agni is in IRBM class.

### **Missile Propulsion**

Propulsion is the means of providing power to accelerate the missile body and sustain, if necessary, to reach the required target. The basis for the working of missile propulsion systems are the well-known Newton's laws of motion. In order to aid a quick retrospect, these are stated here again.

#### **On the Basis of Propulsion and Engines**

(i) **Solid Propulsion:** Solid fuel is used in solid propulsion. Generally, the fuel is aluminium powder. Solid propulsion has the advantage of being easily stored and can be handled in fuelled condition. It can reach very high speeds quickly. Its simplicity also makes it a good choice whenever a large amount of thrust is needed.

(ii) **Liquid Propulsion:** The liquid propulsion technology uses liquids as fuels. The fuels are hydrocarbons. The storage of missile with liquid fuel is difficult and complex. In addition, preparation of missile takes considerable time. In liquid propulsion, propulsion can be controlled easily by restricting the fuel flow by using valves, and it can be controlled even under emergency conditions. Basically, liquid fuel gives high specific impulse as compared to solid fuel.

(iii) **Hybrid Propulsion:** There are two stages in hybrid propulsion - solid propulsion and liquid propulsion. This kind of propulsion compensates the disadvantages of both propulsion systems and has the combined advantages of the two propulsion systems.

(iv) **Ramjet:** A ramjet engine does not have any turbine unlike turbojet engines. It achieves compression of intake air just by the forward speed of the air vehicle. The fuel is injected and ignited. The expansion of hot gases after fuel injection and combustion accelerates the exhaust air to a velocity higher than that at the inlet and creates positive push. However, the air entering the engine should be at supersonic speeds. So, the aerial vehicle must be moving in supersonic speeds. Ramjet engines cannot propel an aerial vehicle from zero to supersonic speeds.

(v) **Scramjet:** Scramjet is an acronym for Supersonic Combustion Ramjet. The difference between scramjet and ramjet is that the combustion takes place at supersonic air velocities through the engine. It is mechanically simple, but vastly more complex aerodynamically than a jet engine. Hydrogen is normally the fuel used.

(vi) **Cryogenic:** Cryogenic propellants are liquefied gases stored at very low temperatures – most frequently liquid hydrogen as the fuel and liquid oxygen as the oxidizer. Cryogenic propellants require special insulated containers and vents which allow gas to escape from the evaporating liquids. The liquid fuel and oxidizer are pumped from the storage tanks to an expansion chamber and injected into the combustion chamber where they are mixed and ignited by a flame or spark. The fuel expands as it burns and the hot exhaust gases are directed out of the nozzle to provide thrust. Currently, other types of propulsion like ionic, nuclear, plasma, etc. are under research and development, but no known missile uses these.

#### **On the Basis of Warhead:**

(i) **Conventional Warhead:** A conventional warhead contains high energy explosives. It is filled with a chemical explosive and relies on the detonation of the explosive and the resulting metal casing fragmentation as kill mechanisms.

(ii) **Strategic Warhead:** In a strategic warhead, radioactive materials are present and when triggered they exhibit huge radioactivity that can wipe out even cities. They are generally designed for mass annihilation.

#### **On the basis of Guidance Systems:**

(i) **Wire Guidance:** This system is broadly similar to radio command, but is less susceptible to electronic counter measures. The command signals are passed along a wire (or wires) dispensed from the missile after launch.

(ii) **Command Guidance:** Command guidance involves tracking the projectile from the launch site or platform and transmitting commands by radio, radar or laser impulses or along thin wires or optical fibres. Tracking might be accomplished by radar or optical instruments from the launch site or by radar or television imagery relayed from the missile.

(iii) **Terrain Comparison Guidance:** Terrain Comparison (TERCOM) is used invariably by cruise missiles. The system uses sensitive altimeters to measure the profile of the ground directly below and checks the result against stored information.

(iv) **Terrestrial Guidance:** This system constantly measures star angles and compares them with the pre-programmed angles expected on the missile's intended trajectory. The guidance system directs the control system whenever an alteration to trajectory is required.

(v) **Inertial Guidance:** This system is totally contained within the missile and is programmed prior to launch. Three accelerometers, mounted on a platform space-stabilised by gyros, measure accelerations along three mutually perpendicular axes. These accelerations are then integrated twice, the first integration giving velocity and the second giving position. The system then directs the control system to preserve the pre-programmed trajectory. These systems are used in the surface-to-surface missiles and in cruise missiles.

(vi) **Beam Rider Guidance:** The beam rider concept relies on an external ground or ship-based radar station that transmits a beam of radar energy towards the target. The surface radar tracks the target and also transmits a guidance beam that adjusts its angle as the target moves across the sky.

(vii) **Laser Guidance:** In laser guidance, a laser beam is focused on the target, and the laser beam reflects off the target and gets scattered. The missile has a laser seeker that can detect even miniscule amounts of radiation. The seeker provides the direction of the laser scatters to the guidance system. The missile is launched towards the target, the seeker looks out for the laser reflections and the guidance system steers the missile towards the source of laser reflections that is ultimately the target.

(viii) **RF and GPS Reference:** RF (Radio Frequency) and GPS (Global Positioning System) are examples of technologies that are used in missile guidance systems. A missile uses GPS signal to determine the location of the target. Over the course of its flight, the weapon uses this information to send commands to control surfaces and adjusts its trajectory. In a RF reference, the missile uses RF waves to locate the target. Thus the guidance systems are indicated in the following **Figure 2.2**

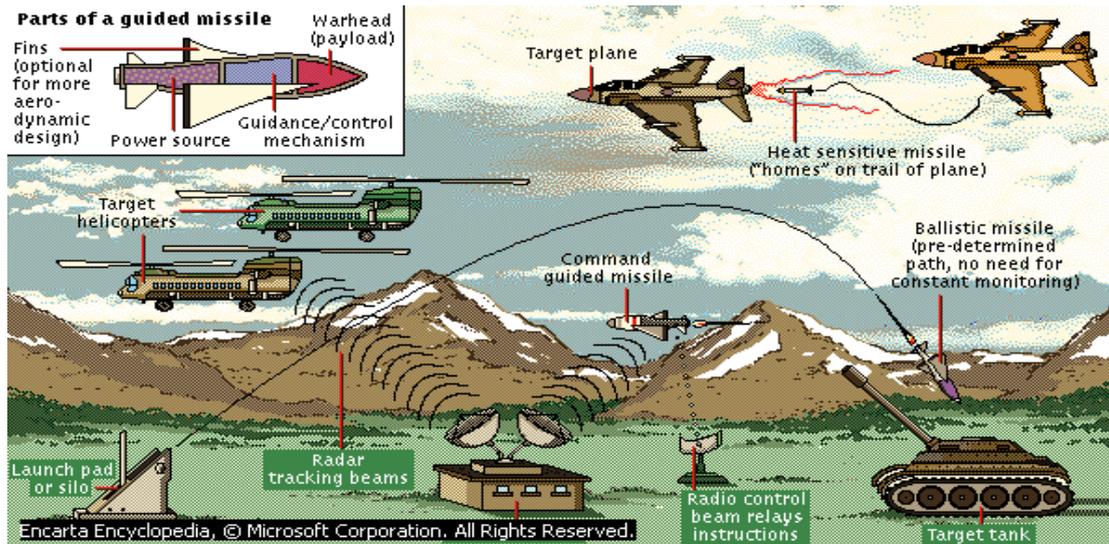


Figure 2.2: Popular Guidance Systems<sup>14</sup>

Thus, missiles are generally classified on the basis of type, launch mode, range, propulsion and the guidance systems. In a nutshell the entire classification of missiles are given in the following **Figure 2.3**

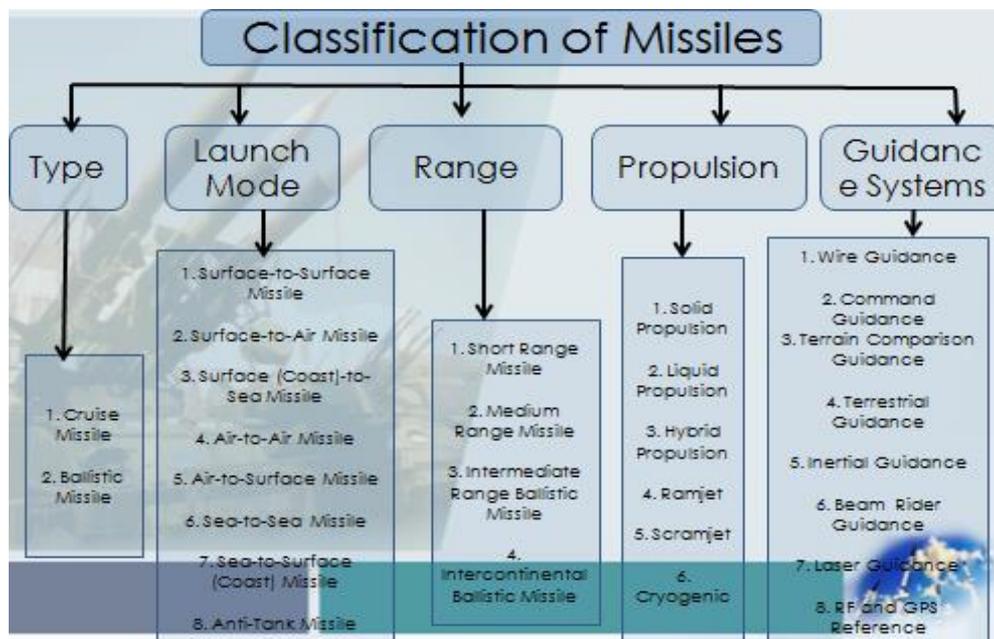


Figure 2.3 Classifications of Missiles<sup>15</sup>

### Types of Guided Missiles

Presently, there are many types of guided missiles. They can be broadly classified on the basis of their features such as type of target, range, mode of launching,

system adopted for control/ propulsion/ guidance, aerodynamics, etc. They are also termed in a broad sense as strategic or tactical, defensive or offensive. **On the basis of target they could be called as** anti-tank/anti-armour, anti-personnel, anti-aircraft/helicopter, anti-ship/anti-submarine, anti-satellite or anti-missile. The missile Milan manufactured in India is an anti-tank missile. Roland, Rapier, Crotale, etc., are examples of anti-aircraft missiles and the much talked-about Patriot missile belongs to the anti-missile class. **On the basis of launch platform, missiles can be termed as** shoulder fired-tripod launched, land mobile (wheeled vehicle or tracked vehicle) and aircraft/helicopter-borne.

### **Missile Control**

A missile gets propelled and guided towards its target destination by the systems explained earlier. In missiles the control function is to ensure stability of the missile and implement the guidance signals received from external sources or generated onboard. The control, after processing the guidance signals, actuates the aerodynamic surfaces on thrust vector to generate turn of the missile speed and direction as required.

The guidance system is to detect whether the missile is flying above or below, or to the left or right, of the required path. It obtains these deviations or errors and sends signals to the control system to reduce these errors to zero. The task of the control system therefore is to manoeuvre the missile quickly and efficiently, making use of these signals. In order to appreciate controls we shall briefly describe the motion of the missile as a free body. The missile has a total of six degrees of freedom of movement. Out of this, three degrees are translational or linear about the three axes viz., x, y and z, while the other degrees are rotational movement about three axes termed as pitch, yaw and roll.

Pitch is the turn of the missile when it climbs up or down. Yaw refers to its turn to left or right. The roll is when the missile rotates about its longitudinal axis, which is also called roll axis. The longitudinal axis is the one running from nose to tail. If a missile is resting horizontally then, the pitch axis is the one which is normal to longitudinal axis and parallel to the horizontal axis and pitch axis. Missiles can roll when in motion due to various reasons.

## **Missile Aerodynamics**

The study of the movement of a body in the presence of air is called aerodynamics, and this study is vitally important for the design of aircraft, missiles and rockets. The atmosphere as we know is densest close to earth's surface at sea level. As we go higher it becomes thinner (i.e. the pressure and density are lower). The actual atmosphere is up to a height of about 80 kilometres. The temperature also varies with height. The layer of atmosphere nearest to earth is called troposphere. Above that is stratosphere which is further subdivided into lower stratosphere and upper stratosphere. Beyond that, is ionosphere or ozonosphere and the last is exosphere. The very high speed fighter aircrafts fly up to altitudes of about 30 km, while transport jets fly up to about 10-11 km.<sup>16</sup>

The aircraft and missiles are bodies that are heavier than air and so can support their weights only if they produce a force to counter it. This force can be either lift force, generated by the flow of air over the wings and body, or generated by means of an engine in the form of thrust. This is done by helicopters or by aircraft with swing-engines (vertical take-off type) where main engines can be swivelled. In missiles (most are launched vertically or with an inclination), a part of the weight is countered by the rocket engine thrust. When a body, with wings or without wings, is moving through air, there are forces generated which act on the body to oppose its motion (drag force). In other words, these forces must also be countered by the engine's thrust. The drag force depends upon the fineness or bluntness, and size of the body. To minimise the drag force one has to choose an aerodynamic shape such that functional requirements are also met. In the missiles, aerodynamic surfaces called wings, fins and control surfaces, and body called fuselage (with suitable nose, shaped conical or ogival followed by cylindrical) are designed to provide the necessary lateral manoeuvrability. This is achieved by deflecting control surfaces through actuation mechanism and thereby altering the balance of forces, and generating turning moments. This happens at a very rapid rate. In cruise missiles, wings are provided to generate lift force while the missile flies in a horizontal level mode. Most of aerodynamics is studied by mathematical analysis of flow and then further validated by tests on scaled-down models in wind tunnel, where forces are measured and correlations generated. An experimental data bank is generated for subsequent designers.

Aerodynamic considerations and structural design factors are intimately related to propulsion and guidance aspects. Hence the external aerodynamic configuration of the missile is also of primary emphasis. Many aeronautical engineers who were earlier airplane designers transformed themselves from 'airplane to missile' aerodynamicists due to the similarity in principles involved and the rapid growth in varieties and classes of missiles used in modern warfare. The external missile shape and design is finalised keeping in view the needs of other subsystems and performance criteria. Thus mechanical and electrical missile system engineers play equally important roles in the overall missile design. This necessitates a good insight and appreciation on the part of these personnel for the overall missile design.

Aerodynamic characteristics of various external components and their configuration aid their selection towards an optimum missile performance with respect to its lift and drag characteristics, aerodynamic stability and manoeuvrability. Comprehensive and accurate data to enable a missile technologist to zero-in on a particular configuration is not readily available since much of the essential data is classified. Moreover, the requirement of stupendous quality of data desirable and sufficient for a fairly efficient design is a deterring factor too.<sup>17</sup>

### **Test Ranges**

Extensive testing of missiles precedes with their deployment. This testing is in two phases, i.e., development testing and user evaluation testing. These tests are done at test ranges which are suitably located keeping in view the safety requirements. The ranges have instrumentation facilities to collect data for evaluation of the missile flight. The safety zones of these regions are very much dependent on the size and range of the missile and the flight path. Some of the ranges are located close to sea while some others are located in desert areas. In India the major range facility is located in Orissa at Balasore.

There are two other test ranges equipped with instrumentation for testing launch vehicles, Thumba near Trivandrum and Sriharikota near Chennai. These ranges are mainly for the use of the Space Department. The instrumentation facilities provide for tracking radars, electro-optic instruments and telemetry receiving stations, and meteorological facilities. In the range, flight tests are carried out from the Block House.

Real-time data processing facilities and other facilities exist to ensure the range safety for carrying out flight vehicles in case of using telemetry command system.<sup>18</sup>

Strategic missiles represent a logical step in the attempt to attack enemy forces at a distance. As such, they can be seen as extensions of either artillery (in the case of ballistic missiles) or manned aircraft (in the case of cruise missiles). Given the extremely long ranges required of strategic weapons, even the most modern guidance systems cannot deliver a missile's warhead to the target with consistent, pinpoint accuracy. For this reason, strategic missiles have almost exclusively carried nuclear warheads, which need not strike a target directly in order to destroy it. By contrast, missiles of shorter range (often called tactical- or battlefield-range) have been fitted with both nuclear and conventional warheads.

Most other countries pursuing missile technology have not developed strategic weapons to the extent of the United States and the former Soviet Union. Although a few other nations have produced them, however, their emphasis has been on ballistic rather than cruise missiles because of the extremely sophisticated guidance systems required of cruise missiles. Also, as with any technology, there has occurred a transfer of ballistic missile technology to less-developed countries. Combined with the widespread capacity to produce chemical warheads, such weapons represent a potent addition to the arsenals of emerging powers of the Third World.<sup>19</sup>

### **Nuclear versus Conventional Missiles**

Conventionally armed ballistic missiles are used to engage targets beyond the range of artillery. Some analysts argue that ballistic missiles are either too expensive or not sufficiently accurate to use for conventional military operations.<sup>20</sup>

### **Cost-effectiveness**

Battlefield and short-range ballistic missiles, the types most likely to be used for conventional operations, are cheaper than aircraft. In addition, SRBMs require much less infrastructure and training. Strike aircraft need airfields, trainer aircraft, maintenance hangars, flight controllers, etc. in addition to regular (and expensive) training for all personnel involved.

## **Operational effectiveness**

The second argument against a conventional role for missiles is that unless accuracy is high, the small effect radius of conventional explosives renders impossible a high probability of target damage or destruction. Warheads that use sub-munitions have a larger effect radius than unitary high explosive warheads.<sup>21</sup> For large area targets such as airfields and industrial facilities, it may well be cost-effective to launch multiple missiles<sup>22</sup> at one target in order to achieve an acceptable probability of success.

## **Missile Guidance**

Many questioners often seem "concerned" about how missiles are able to seek out and accurately navigate their way to the correct target without assistance from a human operator. Missile guidance refers to a variety of methods of guiding a missile or a guided bomb to its intended target. The missile's target accuracy is a critical factor for its effectiveness.

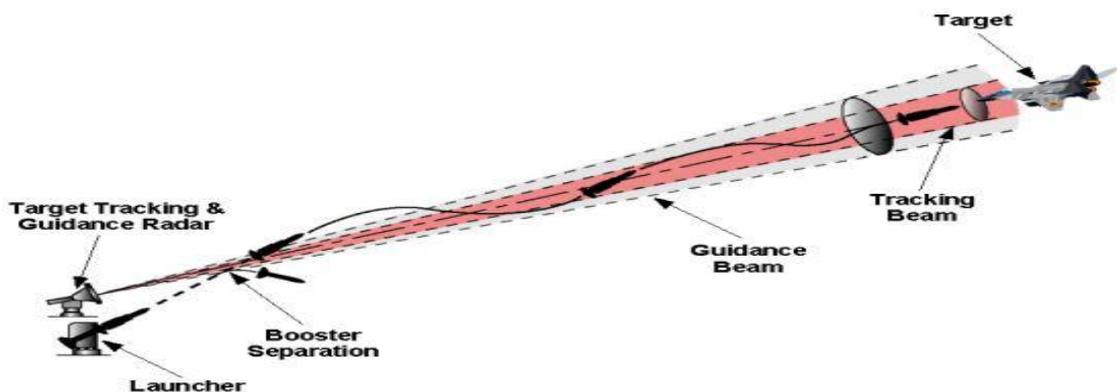
## **Guidance Methods**

The earliest guided missiles used simple command guidance, but within 20 years of World War II virtually all guidance systems contained autopilots or auto-stabilization systems, frequently in combination with memory circuits and sophisticated navigation sensors and computers. Missile guidance has evolved at a tremendous rate over the past five decades, and recent break-through in technology ensures that smart warheads will have an increasing role in maintaining military superiority. Missile guidance is a method by which a missile receives its command to move along a specific path to reach a target. In some missiles, these commands are generated internally by the missile computer auto pilot. In others, commands are transmitted to the missile by some external source. The missile sensor receives it and reacts. This data is processed by the computer and used to generate guidance command. Five basic guidance methods came to be used, either alone or in combination: command, inertial, active, semi-active, and passive.<sup>23</sup> However for a specific mission, particular guidance technique is used. The different types of guidance techniques are: beamer rider guidance, command guidance, homing guidance,

semi-active guidance, active homing guidance, passive homing guidance and ranging navigation guidance.

### Beam Rider Guidance

The beam rider concept relies on an external ground- or ship-based radar station that transmits a beam of radar energy towards the target. The surface radar tracks the target and also transmits a guidance beam that adjusts its angle as the target moves across the sky. The missile is launched into this guidance beam and uses it for direction. Scanning systems on board the missile detect the presence of the beam and determines how close the missile is to the edges of the beam. This information is used to send command signals to control surfaces to keep the missile within the beam. In this way, the missile "rides" the external radar beam to the target as shown in **Figure 2.4**.



**Figure 2.4: Beam Rider Guidance**<sup>24</sup>

### Command Guidance

The target and the missile are separately tracked by two different radars and the information is fed to a ground based computer that calculates the paths of the two vehicles. This computer also determines what commands need to be sent to the missile control surfaces to steer the missile on an intercept course with the target. These commands are transmitted to a receiver on the missile allowing the missile to adjust its course as shown in **Figure 2.5**.

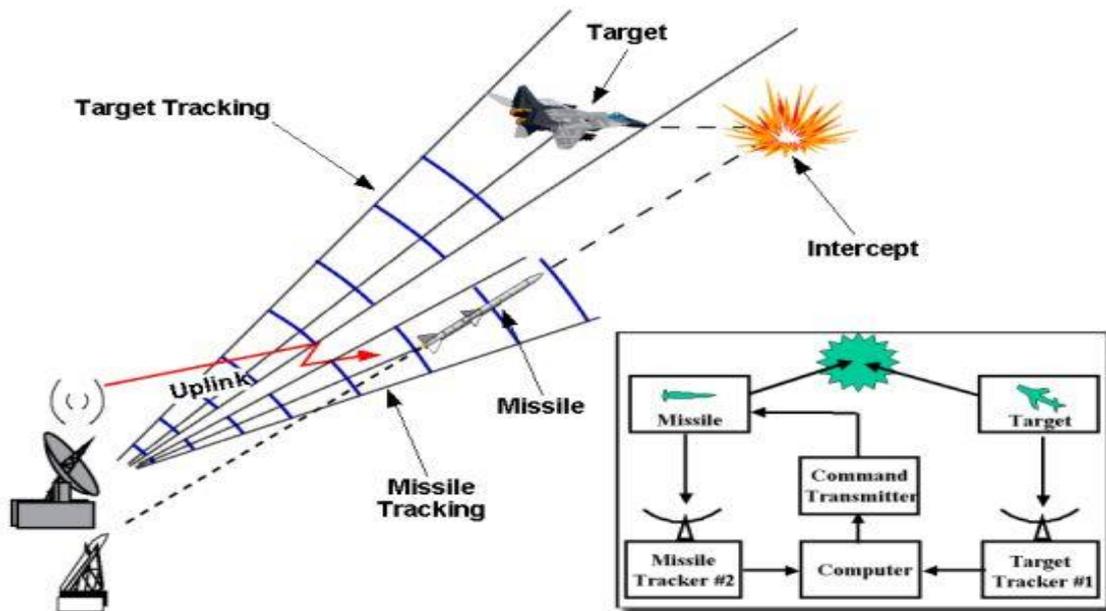


Figure 2.5: Command Guidance<sup>25</sup>

## Homing Guidance

Homing guidance is the most common form of guidance used in anti-air missiles today. Three primary forms, namely semi active, active and passive guidance, fall under the homing guidance umbrella.

### Semi-Active Homing Guidance

A semi-active system is similar to command guidance since the missile relies on an external source to illuminate the target. The energy reflected by this target is intercepted by a receiver on the missile. The difference between command guidance and semi-active homing guidance is that the missile has an on-board computer in this case. The computer uses the energy collected by its radar receiver to determine the target's relative trajectory and send correcting commands to control surfaces so that the missile will intercept the target as given below in the **Figure2.6**.

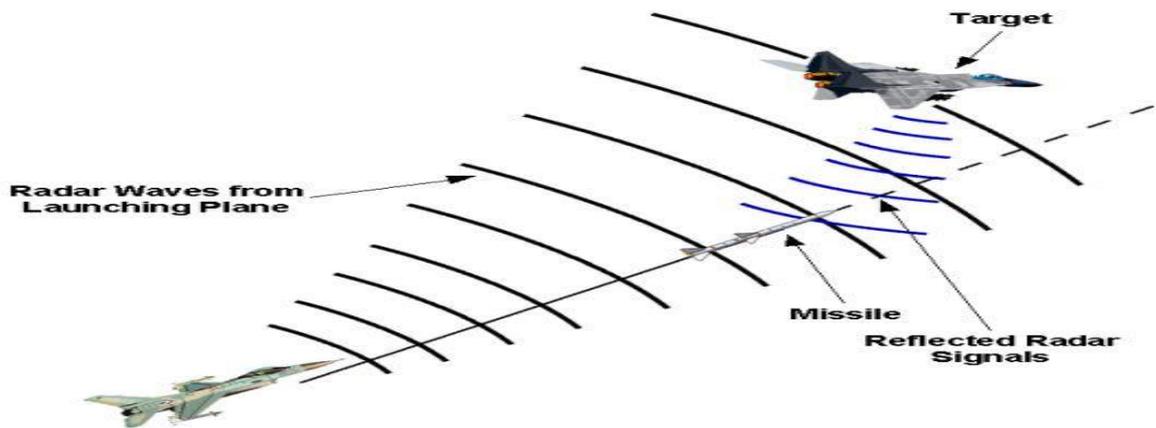


Figure 2.6 : Semi-Active Homing Guidance<sup>26</sup>

### Active Homing Guidance

Active homing works just like semi-active except that the tracking energy is now both transmitted by, and received by the missile itself. No external source is needed. It is for this reason that active homing missiles are often called "fire-and-forget" because the launch aircraft does not need to continue illuminating the target after the missile is launched, as given in the **Figure 2.7**.

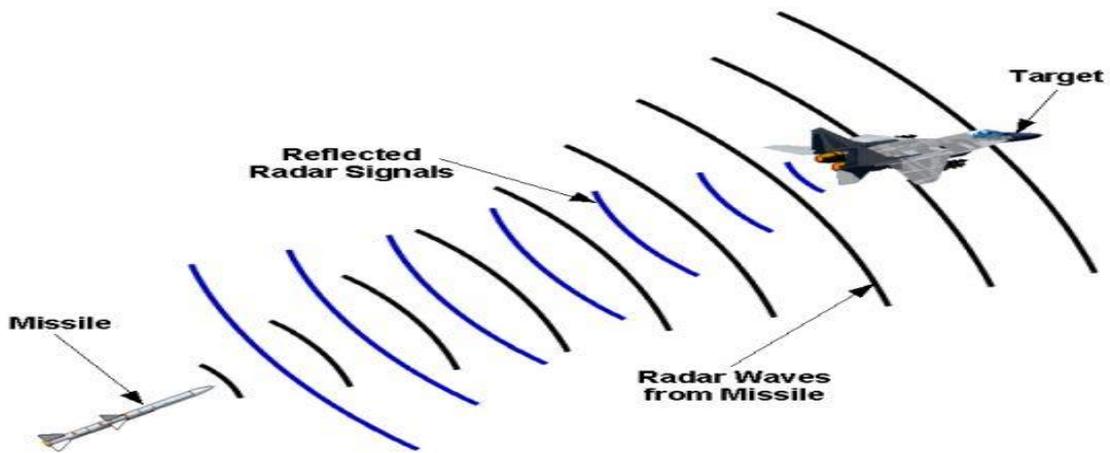
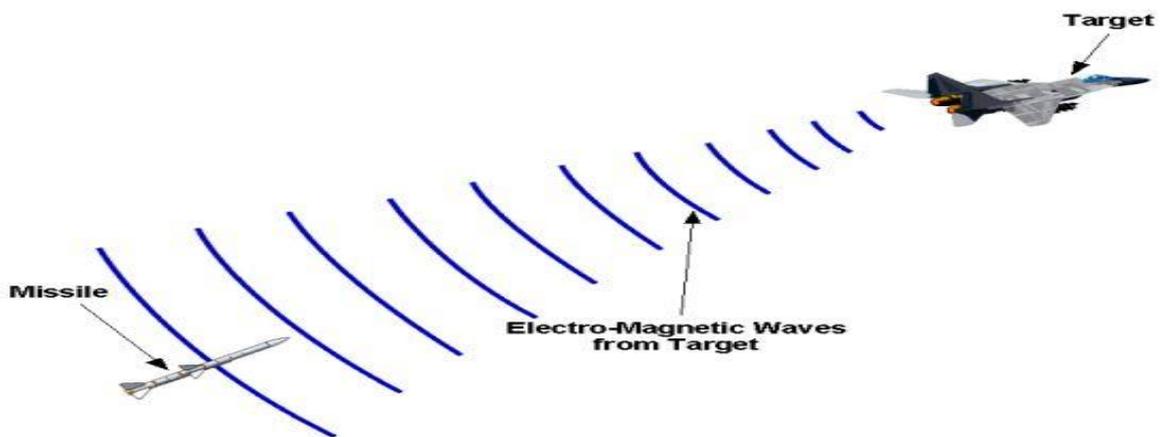


Figure 2.7: Homing Guidance<sup>27</sup>

## Passive Homing Guidance

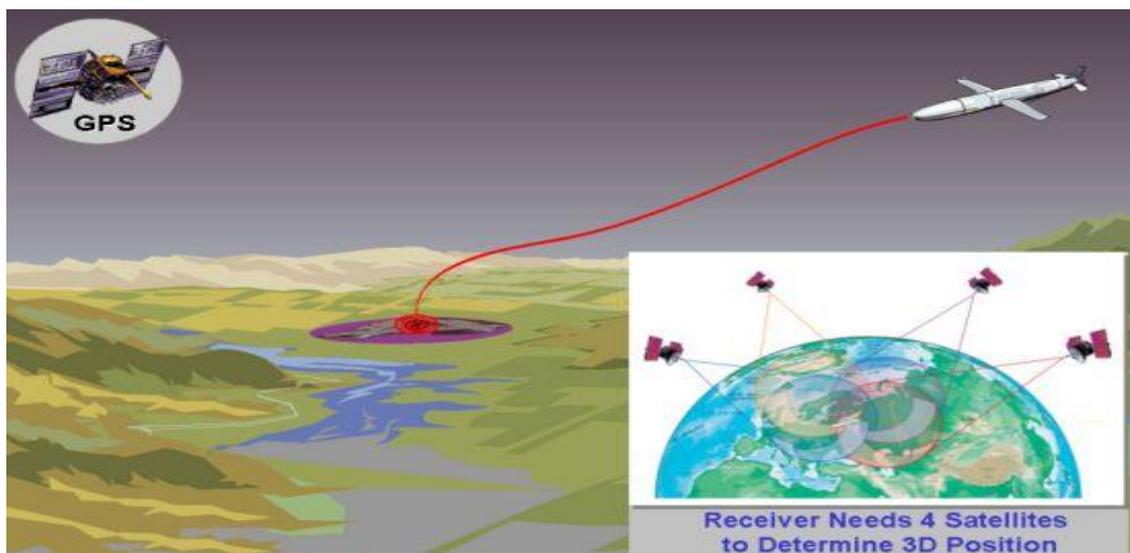
A passive homing system is like active in that the missile is independent of any external guidance system, and like semi-active in that it only receives signals and cannot transmit. Passive missiles instead rely on some form of energy that is transmitted by the target and can be tracked by the missile seeker as indicated in the **Figure 2.8** given below.



**Figure 2.8: Passive Homing Guidance**<sup>28</sup>

## Ranging Navigation Guidance

It uses GPS for the location. GPS consists of a constellation of 24 satellites in geo synchronous orbit around the Earth. If a GPS receiver on the surface of the Earth



**Figure 2.9: Ranging Navigation Guidance**<sup>29</sup>

can receive signals from at least four of these satellites, it can calculate an exact three-dimensional position with great accuracy which is shown in the **Figure 2.9**.

## **Guidance Systems**

Guidance systems vary greatly; however the purpose of a guidance system is to direct the missile to its target accurately. The use of an automatic target recognition (ATR) algorithm/device in the guidance system increases accuracy of the missile. The types of guidance systems are inertial navigation system, terrain contour matching (TERCOM), digital scene mapping area correlator (DSMAC) and satellite navigation.

### **Inertial Navigation System:**

An inertial navigation system includes at the least a computer and a platform containing accelerometers, gyroscopes, or other motion-sensing devices. Accelerometers measure the vertical, lateral, and longitudinal accelerations of the controlled missile while gyroscopes measure the angular velocity of the system.

### **TERCOM (terrain contour matching):**

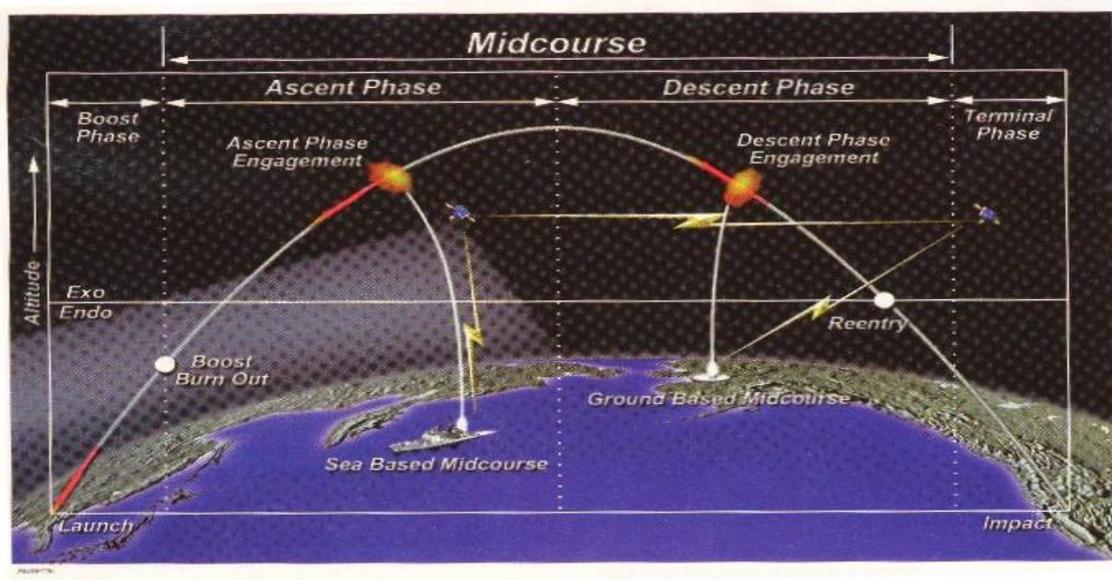
Terrain contour matching uses a pre-recorded contour map of the terrain that is compared to measurements made during flight by an on-board radar altimeter. The missile's radar altimeter feeds measurements into a smaller buffer, and averages them out to produce a single measurement. The two measurements are compared to overlay the strip on the known map, and the positioning of the strip within the map produces a location and direction. The guidance system then uses this information to correct the flight path of the missile.

### **DSMAC (Digital scene-mapping area Correlator):**

A series of photographs are taken from surveillance aircraft and are put into a carousel in the missile. Another camera takes pictures out of the bottom of the missile. A computer compares the two images and attempts to line up areas of high contrast. This system is very slow and its role is being taken over by TERCOM.

## Satellite Navigation:

Another way to navigate a cruise missile is by using a satellite positioning system, such as Global Positioning System (GPS). Satellite navigation systems are precise and cheap. And if the satellites are interfered with (e.g. destroyed) or if the satellite signal is interfered with (e.g. jammed), the satellite navigation system becomes inoperable. On the whole, the GPS-based navigation is useful in a conflict with a technologically unsophisticated adversary. The satellite navigation pattern is shown in **Figure 2.10**.



**Figure 2.10 Satellite Navigation**<sup>31</sup>

## Significance of Missile Development in South Asia

Missiles are attractive to many nations because they can be used effectively with a formidable air defence system, where an attack with manned aircraft would be impractical or too costly. In addition, missiles can be used as a deterrent or as an instrument of coercion. Missiles also have the advantage of lesser maintenance, training and logistic requirements than manned aircraft. Even limited use of these weapons could be devastating, because missiles can be armed with chemical, biological or nuclear warheads.<sup>32</sup>

Currently cruise missiles are among the most expensive of single-use weapons, up to several million dollars apiece. However, they are cheaper than human pilots

when total training and infrastructure costs are taken into account. Thus the guidance system used in a cruise missile is a complex system which involves several systems working in tandem, and therefore it is essential that the guidance system is properly designed for accurate interception of targets. The main worry is that if they get into wrong hands, they will cause huge destruction of area, money and men. Similarly ballistic missiles play an increasing role in the political and security dynamics of Southern Asia. India and Pakistan frequently match missile tests on a tit-for-tat basis. The presence of significant numbers of ballistic missiles concurrent with a crisis creates a security dilemma where the protagonists might opt for pre-emptive military action.<sup>33</sup>

Regional stability is derived from strategic stability, crisis stability, and arms race stability. Strategic stability (in the nuclear context) is a situation where neither side has incentives to use its nuclear weapons first. An alternative definition requires each side to have a secure second-strike capability. Crisis stability is when neither side fears a pre-emptive strike. Arms race stability is when neither side fears that its potential adversary is developing weapons that might undermine strategic stability or crisis stability.<sup>34</sup> The current security problem in Southern Asia stems from asymmetry. Threat perceptions need to be managed and reduced. Strategic stability with respect to ballistic missiles and nuclear weapons is best achieved within an arms control framework aimed at achieving a mutually agreed set of objectives. It seems likely that, in the absence of arms control agreements, the growth of ballistic missile forces in the region will continue.

### **Arms Race**

The phrase **arms race**, in its original usage, is a competition between two or more parties to have the best armed forces. Each party competes to produce larger numbers of weapons, greater armies, or superior military technology in a technological escalation. International conflict specialist Theresa Clair Smith defines the term as "the participation of two or more nation-states in apparently competitive or interactive increases in quantity or quality of war material and/or persons under arms."<sup>35</sup> Nowadays, the term is mostly used to describe any competition where there is no

absolute goal, only the relative goal of staying ahead of the other competitors, essentially the goal of proving to be "better".

**Arms race**, by definition, is the competitive, resource-constrained, dynamic process of interaction between two states or coalitions of states in their acquisition of weapons (Brito and Intriligator, 1995<sup>36</sup>). After the Cold War, the United States and the Soviet Union's arms race no longer dominate global politics, and regional antagonisms have become the focus. For example, arms races exist between Greece and Turkey, Iran and Iraq, North and South Korean, and India and Pakistan.

In the case of the arms race between India and Pakistan, it is well known that India and Pakistan's rivalry relationship began at the same time as their creation as separate states in August 1947. Now more than 60 years after their independence, India and Pakistan have made significant economic, social and political developments. But they have been in conflict with each other constantly and have had at least four major wars and many small scale armed conflicts. The conflicts arose mainly due to internal religious differences and the ongoing external political hostility leading to arms race which was denied by both the governments. What is still important and worrying is the question of existence of arms race which in turn hinders the economic development of both the countries.

More generically, the term "**arms race**" is used to describe any competition where there is no absolute goal, only the relative goal of staying ahead of the other competitors in rank or knowledge. An arms race may also imply futility as the competitors spend a great deal of time and money, yet end up in the same situation as if they had never entered the arms race. Various models and estimate methods have been used to study the arms race phenomenon in different countries<sup>37</sup>. In short, an arms race is an interstate competition that motivates states to innovate, design and deploy the most lethal war technology in order to gain the upper hand against their rival states. However, arms races also create the looming danger of mutual destruction as an unintended by-product of both states striving to gain the upper hand in the battlefield.

Primarily, in older economic and political theories, arms races are viewed as an action–reaction process triggered, fuelled and shaped by real or perceived external threat. One state, fearing a second state as a threat, embarks on a military build-up. The

rival state, observing the action of the first state, reacts by augmenting its military power, which in turn motivates the first state to increase its military power, and thus the arms race starts. This action–reaction framework is consistent with several prominent international relations model such as the security dilemma, the spiral model, and structural neo-realist theory. It is well-documented in the existing literature that military spending can pose a security dilemma, when a state chooses to retaliate to the military build-up of another state because it is unaware of the rival’s true intentions. The reciprocated increases in arming potentially engender a spiral of hostilities, increasing the chances for the outbreak of armed conflict.

In the latest work on arms races it is usually assumed that a sequence of states, or leaders of these states, choose in turn one of two options, A (to arm) or B (not to arm), with each state observing all of its predecessors’ choices. They have common preferences among the two choices but do not know which is better. Each state knows the costs and benefits of its own military build-up, but it is unsure of the costs and benefits of its rivals in the arms race. In other words, the costs and benefits of arming often depend on the social, moral, political and psychological considerations of the leaders of states, which are often idiosyncratic and country- or leader-specific. In this scenario, leaders have an incentive to learn from social interactions about their rival’s true preferences, actions and intentions.

The latest vintage of game-theoretic models of arms race has provided a complete formalization of the critical role of information revelation, transmission and pre-play communications to offer new insights into the dynamics of arms race. In a similar vein, the latest cohorts of international relations models, highlight the role of social learning, information problems and information acquisition to explain the onset of arms race. From these valuable new works we now learn that there is nothing automatic, instantaneous and sacrosanct about arms race as there is positive probability that the détente equilibrium will prevail to stem costly and self-destructive arms races from occurring. Arms races will not go astray as the desire to arm will be bound by the leash of this détente equilibrium. In other words, apparently there is no ‘economic’ justification for arms races to race to the bottom.<sup>38</sup>

## **Game Theory, Motivation and the Power of Actors in International Relations**

One of the basic assumptions of the realist approach to international relations is that nation-states are motivated only by their own interests. This school of thought emphasizes that nation-states consider the needs and interests of other nation-states only when the other nation-states have the capability to enforce their demands by threatening or performing damaging actions. This means that nation-states are not guided by ethical or humanitarian considerations, and that international law and even treaties and similar formalized agreements do not really restrict the international activities of nation-states. Missile proliferation is a potential risk in South Asia. The possession, employment and deployment of missiles can be seen as a means to enhance a nation's ability to fight a war. And therefore, zero missile regimes in South Asia is a distant dream since the region can never be declared free from all theatre, tactical, intermediate and intercontinental missiles. However, game theory in international relations is still restricted to the analysis of the interactions among nation-states based on security and defence issues.

### **Deterrence and Arms Races**

Analyses of deterrence and arms races are probably among the most studied topics in international relations in general, and are also among those most frequently analysed using game theoretic instruments. Most of the analyses of deterrence refer to threats of using force, and only these cases are considered below. Under these circumstances, arms races are simply the sequences of events that take place when the nation-states in a confrontation want to increase the believability of their threats. The objective of the two nation-states in a direct confrontation is to protect themselves against the possibility of destruction or domination by the other. Either of the nation-states involved is likely to feel more secure if it acquires weapons, even if this is done purely from defensive reasons. On the other hand, since weapons can be used as much for defence as for attack, the other nation-state can never be sure of the intentions of the first. For this reason, it feels obliged to produce or purchase weapons to prepare itself to defend its interests.<sup>39</sup>

## **Understanding the Arms Race Factor in South Asia**

The apparently rapid pace of nuclear developments in India and Pakistan has led many analysts to warn of an impending arms race between the two countries. India and Pakistan are indeed entangled in a long-standing security competition. However, they are not two closely matched opponents engaged in a competitive tit-for-tat cycle of nuclear weapons development in which one state makes advancements to its nuclear capability and the other reacts in kind. An analysis of aggregated missile test data since 1998 reveals that the armament dynamics is far more complex. The Indian and Pakistani nuclear programs are largely decoupled. The data show little correlation between the adversaries' testing behaviour contrary to what would be expected in a classic arms race. In fact, the types and ranges of missiles under development provide concrete evidence of the divergence in their nuclear objectives and security strategies.<sup>40</sup>

India and Pakistan are indeed racing towards their respective national security objectives, but they are running on different tracks and chasing vastly different goals. Pakistan is building weapons systems to deter India from conventional military operations below the nuclear threshold. India is developing systems primarily to strengthen its strategic deterrent against China, meaning this dynamic is not confined to the subcontinent. Government policies that aim to change the trajectory of the South Asian security competition need to take these complexities into account.

“India and Pakistan are edging dangerously close to a spiral in the growth of their nuclear weapons arsenals. This could become a mindless race, driven by mutual suspicion, rather than the actual needs of deterrence and stability.”<sup>41</sup> Missile testing provides an interesting alternative window into the current security dynamics between India and Pakistan. Through analysing aggregated missile test data since 1998, it becomes apparent that the Indo-Pakistani relationship is explained less by classic conventional or nuclear arms race models than by the asymmetries in their security strategies as reflected in the types of nuclear delivery capabilities they are developing. These asymmetries are widely recognized, but the missile data add concrete evidence of the extent to which Indian and Pakistani nuclear capabilities are disjunctive.

## **Nuclear-capable Missile Tests as a Measure of Arms Racing**

Indian and Pakistani nuclear developments are the main cause of arms race concerns. Ideally, the best measure of whether the two are in fact in a classic, reciprocal nuclear arms competition would be the rate at which both sides are deploying nuclear-armed missiles or bombs (or, perhaps, “deployable” missiles, given the going assumption that both countries keep their nuclear weapons in a recessed posture, with warheads and delivery vehicles stored separately).<sup>42</sup>

Nuclear-capable ballistic and cruise missiles also shed considerable light on how states operationalize their nuclear arsenals. Technical details such as payload, range, launch platform and fuel type are strongly linked to nuclear doctrine, posture, and the trajectory on which these are evolving—even in the absence of formal declaratory policy. Nuclear-capable missile tests also arguably reflect, at least to some degree, the rate of development of a country’s nuclear weapons program. Few flight tests might suggest that a state in an adversarial relationship assesses that it is reasonably secure with its existing capabilities and therefore need not respond to developments by its competitor. A higher number of test launches and testing of new missile capabilities could suggest the opposite that a state might be in the action-reaction throws of an arms race, particularly if there were observable relationships in the types and capabilities of missiles being tested.

Nuclear missile tests are an imperfect measure of arms racing. For one, there may not be a strong relationship between missile testing and missile deployment (or, in a recessed deterrence posture, induction into strategic forces). And in terms of racing behaviour, since missile tests can be planned years in advance, a test conducted in a specific year most likely reflects the decision-making of prior years. It is also tempting to assess that tightly coupled periods of missile testing by adversaries reflect an action-reaction cycle, or perhaps nuclear signalling. Thus analysing the operational ranges of different types of missiles and their intended platform indicate the strategic objectives of a state’s nuclear posture.

## **Deterrence Theory in Southern Asia**

There is a clear linkage between nuclear deterrence and ballistic missile capability.<sup>43</sup> George Fernandes, the Indian Defence Minister, made the following statement on April 23, 1999: “The acquisition of a missile system capable of delivering conventional or nuclear warhead bridges a key gap in the nuclear deterrent profile of the country. The double distinction of being nuclear-capable and a possessor of the means of delivery means that India can hold its head high without fear of being bullied in a hostile security environment. China with its vast nuclear arsenal, Pakistan with its nuclear weapons and delivery system capability, America perching in Diego Garcia and eight other Asian countries possessing missiles is quite a grim security scenario.”<sup>44</sup>

In the formative stages of the US-Soviet nuclear competition, deterrence theorists identified a *stability-instability* paradox associated with the acquisition of offsetting nuclear weapon capabilities. The essence of this paradox was that nuclear weapons were supposed to stabilize relations between adversaries, and to foreclose a major war between them. At the same time, offsetting nuclear capabilities might well increase instability by encouraging provocations and conflict at lower levels, precisely because nuclear weapons would presumably provide protection against escalation.<sup>45</sup>

The India-Pakistan dynamic is different and in some ways more volatile than the historic United States-Soviet Union rivalry. Sagan<sup>46</sup> notes that India and Pakistan have more in common than the Americans and the Soviets, who were on opposite sides of the globe and viewed each other as mysterious, often unpredictable adversaries. In contrast to the subcontinent, the US and Soviet rivalry was ideological without disputed territory and a history of armed conflict.

### **Rivalry**

The American Dictionary of the English Language defines rivalry as “The act of competing or emulating or the state or condition of being a rival.”<sup>47</sup> The Collins English dictionary defines rivalry as “the act of rivalling: competition or the state of being a rivals or rivals or rivalrous”.<sup>48</sup>

## **The Meaning of Rivalry**

This research begins by examining the meaning and importance of the "rivalry" concept. At the most basic level, the concept of "rivalry" denotes a longstanding, competitive relationship between two or more actors. More precise conceptualizations offered by scholars who have studied rivalry or related concepts such as "enmity" or "protracted conflict" highlight three central elements in rivalry: competition between the same set of adversaries, the perception of threat and hostility by each side, and a temporal dimension reflecting the impact of past interactions and the expectation of future interactions.

Most political science applications of "rivalry" and related concepts have focused on what might be termed "enduring, militarized, interstate rivalries," or rivalries between two nation-states that involve frequent militarized confrontations and that last for long periods of time. Yet the rivalry concept has a much broader range of potential applications than this one very specific usage. The new menace of arms rivalry was brought to the South Asian continent by nuclear weapons tests of both countries in 1998. The Kargil war of 1999 was also seen as a factor driving up the two rivals' military spending. In the 2000s, military expenditures in both countries had shown continuing rises which were fuelled by rapid economic growth, especially in India. This brief conflict in the history of India and Pakistan and their military expenditure dynamics indicates that, although other actors (China, Russia and the United States) have been present in the interaction between India and Pakistan's arms acquisition process, in many ways they have been driven by the arms race with each other which could be characterized by an action-reaction model.

Research on rivalry emphasizes the differences between contexts of enduring rivalry, proto-rivalry and isolated conflict. Research on the evolution of rivalry further emphasizes the changing context of relations between rivals, highlighting the differences in relations between rivals in the earlier and later phases of their rivalry relationship. In each case, the study of rivalry and evolution has identified contexts or settings in which we would expect to observe different patterns of interstate behaviour or conflict. By leading us to expect different patterns or outcomes in different contexts, the study of rivalry and evolution allows us to generate and test more refined theories,

and offers the possibility of more meaningful results than general studies that do not distinguish between different types of contexts.

The term “enduring rivalry” is borrowed from T. V. Paul (2006).<sup>49</sup> He defines “enduring rivalry” as conflicts between two or more states, lasting more than 2 decades, with several militarized interstate disputes punctuating the relationship in-between and characterized by a persistent, fundamental and long-term incompatibility of goals between the states. Having discussed the conceptual meaning of "rivalry" this study now considers the theoretical and empirical contributions of this concept to the study of the India-Pakistan missile race. **Thus the concept of a rivalry is implicit in the concept of an arms race.**

### **Empirical Studies of Arms Race between India and Pakistan**

Various models and estimate methods have been used to study the arms race phenomenon in different countries: for example, the arms races between Greece and Turkey, and between South and North Korea. In this section, we focus on empirical studies of an arms race between India and Pakistan (see **Table 2.2**). The empirical

	<b>Authors</b>	<b>Models</b>
1	Richardson (1960) <sup>50</sup>	Classical Richardson Model
2	McGuire (1965) <sup>51</sup>	Social Welfare Maximization Model
3	Wolfson (1968) <sup>52</sup>	Emulative Model
4	Wolfson (1968, 1990) <sup>53</sup>	Rivalry Model
5	Rattinger (1975) <sup>54</sup>	Bureaucratic Model
6	Intriligator and Brito (1976, 1984) <sup>55</sup>	Strategic Deterrence-Attack Model
7	Isard and Anderton (1988) <sup>56</sup>	Submissiveness Model
8	Hartley and Russett (1992) <sup>57</sup>	Public Opinion Model

**Table 2.2: The Richardson Arms Race Model and its Variants**

results are not conclusive. Hollist (1977) provides empirical analysis of a competitive arms process in India and Pakistan for the period 1949-1973. Different variants of Richardson-type arms race models are employed and assessed, which consider the effects of submissiveness, explicit cost constraints and technology factors. However, the results show that the estimated coefficients of reaction factor are less than clear for India and Pakistan. Furthermore, the estimated sign of reaction factor is negative in most models and inconsistent with the hypothesis of the Richardson-type model.

### **Intriligator and Brito Strategic Deterrence-Attack Model<sup>66</sup>**

The Strategic Deterrence-Attack Model which is developed by Intriligator and Brito (1976, 1984) is different from the Richardson-type arms race model. The Strategic Deterrence-Attack Model focuses on the potential of arms use and its effect on arms production. Thus, this model considers the strategic factors in the arms race. The use of arms has two purposes: attack (war) or deterrence (peace), and these strategic considerations which are perceived by defence planners are connected to the arms race in the Intriligator and Brito model. In their basic model, there are two Super Powers that confront each other with their missile stockpiles.

The security considerations are the two countries' potential for deterrence or attack. Intriligator and Brito set up a hypothetical missile war which could be used to calculate this potential in a computer simulation. The time path for missiles and casualties in the two countries can be used to describe the simulation of a missile war. If the objectives of the defence planners in both Country 1 and Country 2 are to be fulfilled to deter, each must possess sufficient missile stocks to absorb an all-out first-strike and still respond with a second strike which inflicts unacceptable casualties. Intriligator (1975) solved the deterrence conditions for countries.

According to Intriligator and Brito (1986), large missile stockpiles could have a deterring effect. Thus, heavily armed countries in an arms race would not tend to initiate war since the casualties and damages would be huge and unacceptable. However, when two countries have low levels of armaments and at the beginning of an arms race, the risk of war will be high.

The Intriligator and Brito model involves the deterrence-attack strategy, effectiveness coefficients, rates of fire, and time intervals for firing. These factors are important in influencing the cone of deterrence and provide policy implications for arms control. The model also presents possible peace equilibrium and the possible outbreak of war under different conditions. However, the Intriligator and Brito model has a similar reaction framework to the Richardson model and also has some limitations. For example, one country starts an attack which is counterforce, and its rival will then have a retaliatory strike which is counter value, but there is no theoretical evidence to support this predetermined counterforce and counter value attacks. Furthermore, the impact of the quality of armaments on the modern arms race becomes more and more important rather than the quantity of weapons in the Intriligator and Brito model.

### **The Concept of Rivalry Factor**

Before examining the contributions of rivalry to the study of interstate conflict, we must consider the meaning of rivalry. A number of scholars have discussed rivalry and related concepts in international relations, including "enmity" (Finlay, et al., 1967<sup>67</sup>, Feste, 1982<sup>68</sup>), "protracted conflict" (Azar et al., 1978; Brecher, 1984<sup>69</sup>), and "enduring rivalry" (Wayman, 1989; Goertz and Diehl, 1992b<sup>70</sup>, 1993<sup>71</sup>, Vasquez, 1993<sup>72</sup>, Bennett, 1993<sup>73</sup>). Each of these concepts refers in the general sense to a longstanding, competitive relationship between two or more adversaries. Drawing from the above scholars' works, enduring rivals can be described as two or more "actors whose relations are characterized by disagreement or competition over some stakes that are viewed as important, where each perceives that the other poses a significant security threat, and where this competition and threat perception last for substantial periods of time" (Hensel, 1994<sup>74</sup>).

The studies reveal that enduring rivals are often characterized as being involved in repeated confrontations or crises, which helps to highlight the rivals' disagreement over important stakes and which contributes to each rival's perception of a security threat from the other. Thus "enduring rivalry" in empirical research has become synonymous with "enduring militarized rivalry" (Wayman, 1989<sup>75</sup>; Goertz and Diehl, 1993<sup>76</sup>; Hensel, 1996<sup>77</sup>). Examples of states that are commonly described as enduring

rivals include France and Germany through much of the nineteenth and twentieth centuries, the United States and Soviet Union during the Cold War, India and Pakistan since 1947, and Israel and Syria since 1948.

Rivalry can also be considered in a broader and more continuous fashion. Many adversaries do not engage in enough confrontations to build up the history of disagreement or the level of threat perception that characterize full-fledged enduring rivalry. Even if such adversaries never become full enduring rivals, some scholars (e.g., Wayman and Jones, 1991) consider the possibility of "lesser" forms of rivalry between non-militarized interstate relations and full enduring rivalry. The concept of rivalry is best viewed as a continuum, with enduring rivalry at one extreme end of the continuum, non-militarized relations at the other extreme, and these other forms of conflict (or lesser forms of rivalry) in the middle. Although some scholars treat "interstate rivalry" as synonymous with "enduring interstate rivalry," the present chapter employs the term "rivalry" in a more continuous sense, allowing for different types or levels of rivalry. "Enduring rivalry" represents the high end of this continuum and hereafter will specifically be called enduring rivalry.

Thus the existing literature about rivalry and the evolution of rivalry has made a number of scholarly contributions. Perhaps most important has been a renewed focus on the context in which interstate interactions take place. As Goertz and Diehl (1996)<sup>78</sup> point out, the notion of rivalry has led to the development of the "rivalry approach" to war and peace, which focuses scholarly attention on contextual issues that are typically overlooked in traditional research on interstate conflict.

Confrontations between rivals like India and Pakistan also appear to be more severe and escalatory than other, non rivalry confrontations, and enduring rivalries are much more likely than non-rival adversaries to experience war at some point. On the basis of these observations, enduring rivalry is an important topic to study if we are to understand interstate conflict. If we can understand the processes and dynamics of rivalry, then we should be able to account for most militarized conflict in the modern era, including much of the most dangerous or escalatory conflict. Managing or ending rivalry is undoubtedly an important topic, but it would also be desirable to understand how to prevent rivalry before it begins. Given the high costs - military, economic,

political and social – of interstate rivalries, successfully managing or ending the rivalry should be seen as a second-best solution, behind avoidance or prevention of rivalry in the first place. Studying the origins of rivalry thus offers the hope that policy-makers would be able to learn from the lessons of previous rivalries -- as well as the lessons of previous disagreements that did not lead to outright rivalry -- in managing their own disagreements short of rivalry, thereby avoiding the tremendous costs and risks involved in rivalrous interstate relationships. Thus the concept of a rivalry is implicit in the concept of an arms race.

### **The Optimism-Pessimism Debate and Nuclear Missile Proliferation**

The optimism-pessimism debate and nuclear proliferation focus on the current debate in international relations literature over the risks associated with the proliferation of nuclear weapons. Scholars are divided into roughly two schools: proliferation "optimists," who argue that proliferation can be beneficial and that its associated hazards are at least surmountable, and proliferation "pessimists," who believe the opposite. This debate centers upon a theoretical disagreement about how best to explain and predict the behaviour of states. Optimists generally ground their arguments on rational deterrence theory and maintain that nuclear weapons can actually increase stability among states, while pessimists often ground their arguments on "organization theory," which contends that organizational, bureaucratic, and other factors prevent states from acting rationally.

A major difficulty with the proliferation debate, however, is that both sides tend to advance their respective theoretical positions without adequately supporting them with solid empirical evidence. The question is whether the nuclear programs in India and Pakistan have adequate controls over their nuclear arsenals and fissile material stockpiles (such as highly enriched uranium and plutonium). The strengths and weaknesses of different systems of nuclear control help predict what types of controls the proliferating states are likely to employ. Further the spread of nuclear weapons would tend to have seriously negative effects on regional stability by increasing risks of accidental, unauthorized, or inadvertent use of nuclear weapons, and risks of thefts of fissile materials for use in nuclear or radiological devices by aspiring nuclear states or terrorist groups. Conflict in the present era is likely to occur between

states possessing radically asymmetric weapons of mass destruction (WMD) capabilities. Currently, the scholarly community is split into two opposed and mutually exclusive groups. One group believes in the efficacy of deterrence and thus tends to favour proliferation, while another grouping of research efforts questions the viability of deterrence in both the First and Third World. Historically, the presence of competing ideological perceptions in rivalries has led to fears of nuclear blackmail, attempts to achieve escalation dominance in force deployments, and anxieties about conventional and nuclear force imbalances that could undermine stability.

Deductively, in the confines of the game model, nuclear blackmail is still possible if threat credibility at the nuclear level favours one side, or if conventional force imbalances exist. Nuclear weapons generally fail to bridge the gap left by incapable conventional forces, and stability is always tied to particular variations of threat credibility and capability, rather than resting solely on the mutual possession of nuclear weapons by both rivals. Deterrence between developing countries is neither simple nor preordained. Although nuclear weapons might in some cases bestow status-quo stability between rivals that are under the constant threat of major attacks, they should be viewed as temporary military expedients at best, rather than long-term policy solutions.

### **Nuclear Missile Proliferation and New Nuclear Powers**

The spread of nuclear missile technology and weapons is a special case of the general issue of weapons proliferation. It is affected by the same factors; however, the dangers of the proliferation of a weapon of such power have led to a much more substantial political commitment on the part of the international community to attempt to prevent its spread. The primary concern over nuclear proliferation is the danger of the use of nuclear weapons in internal, local or regional crises that could, out of confusion, uncertainty of motives or willful action, escalate to involve major powers and threaten the entire globe. In addition, the possibility that nuclear weapons could be coupled with long-range ballistic delivery systems, increasingly available to those countries that want them, raises to a new level concerns over the spread of potentially devastating conflict. The further spread of nuclear capability, however, must be judged as likely to occur sooner or later at its own pace. The potential use of the weapon for

blackmail by renegade states or non-state groups is also a natural source of deep disquiet.

### **India-Pakistan Nuclear Rivalry: Perceptions, Misperceptions, and Mutual Deterrence<sup>79</sup>**

The history of India-Pakistan rivalry constitutes a chronology of struggle to establish “hegemony” by the former on the latter; “action-reaction”<sup>80</sup> type of security paradigm; misperceptions;<sup>81</sup> underestimation and overestimation, and mutual “fear.” The study of hegemonic war comprises a pivotal aspect of international relations theory,<sup>82</sup> and it would be appropriate to conceptualise these theoretical facets before explaining both countries’ conflict-ridden history.

Since human beings are driven by three fundamental passions – interest, pride, and, above all else, fear – they always seek to increase their wealth and power until other humans, driven by like passions, try to stop them. Even advances in knowledge, technology or economic development would not change the fundamental nature of human behaviour or of international relations. On the contrary, increases in human power, wealth and technology would serve only to intensify conflict among social groups and enhance the magnitude of war.<sup>83</sup> But, in the South Asian context, India, by virtue of its size, considers the entire region as a single cultural, geographical and strategic entity in spite of the existence of different countries in South Asia. Pakistan is the only South Asian country, which has so far challenged India’s desire to dominate the subcontinent. Therefore, India considers Pakistan a “regional de-stabilizer” that has challenged New Delhi’s desire to control the entire subcontinent as a single unit.<sup>84</sup>

It is generally accepted that nuclear weapons play a credible role in preventing wars. According to Kenneth Waltz, a leading theoretician of deterrence, “nuclear weapons have helped to preserve the peace where it has been most endangered, and prevented war” from spreading further to the other volatile regions, as it did “between the United States and the Soviet Union, between India and Pakistan” and the Middle East. In theory, if any one country endeavours to assemble nuclear weapons, then, the other threatened state would also do the same. Thus, it would be self-defeating on the part of any country to involve in a nuclear arms race, or to attempt to use the nuclear strength as a weapon of war.<sup>85</sup> India and Pakistan are still in the early stages of nuclear

development, and their C<sup>4</sup>I<sup>2</sup> (Command, Control, Communications, Computers, and Intelligence and Information) systems are also still in nascent stages. In spite of this, Pakistan's earlier ambiguous nuclear status, and its ability to strike back, had restrained India in the 1980s from a preventive strike. The mere fear of Islamabad returning a nuclear attack had kept the Indian war-machine at bay.<sup>86</sup> As Waltz points out, so much comes in such small packages that it could effectively thwart any design to use the nuclear weapons now, or in the future, as a weapon of war.<sup>87</sup>

### **Theoretical Debate**

Now, it would not be out of context to elaborate the different realist schools of thought associated with the study of international relations. It was Hans Morgenthau, who had introduced "realism" as a methodology to examine international relations. But, in the 1970s, Kenneth Waltz's "neo-realism" made a distinct divergence from Morgenthau's realism that thenceforth was classified as "classical realism."<sup>88</sup> Since the 1970s, international political theory has developed around two types of realism: "structural realism,"<sup>89</sup> and "offensive realism."<sup>90</sup> There is also the theory of "defensive realism"<sup>91</sup> in addition to other "neoclassical," "contingent," "specific," and "generalist" realism theories.<sup>92</sup> Some theorists assert that the great powers tend to "maximize their relative power"<sup>93</sup> with continuous endeavours to issue diktats to other states.

"For defensive realists, the international structure provides states with little incentive to seek additional increments of power," writes Mearsheimer, which instead "pushes them to maintain the existing balance of power. Preserving power, rather than increasing it, is the main goal of states." On the other hand, the "Offensive realists believe that status quo powers are rarely found in world politics, because the international system creates powerful incentives for states to look for opportunities to gain power at the expense of rivals. A state's ultimate goal is to be the hegemon in the system."<sup>94</sup> Interestingly, Kenneth Waltz, who considers that in anarchic conditions in international politics, security is the highest end for the states to maintain their positions in the system, rebuts this theory.<sup>95</sup> But, in the nuclear age, regional or global hegemony is only feasible to establish with an explicit nuclear superiority, which Mearsheimer defines as "a capability to devastate its rivals without fear of retaliation."<sup>96</sup> As argued earlier, the entire paradigm of security of South Asia is

premised on “security,” “fear,” and “hegemony” principles; hence, India and Pakistan have entangled themselves in a perpetual cobweb of “offensive” and “defensive” type situations respectively. Consequently, India sought to prevent the emergence of “peer”<sup>97</sup> competitor on the subcontinent and Pakistan, to challenge its hegemony. This “peer” rivalry between the two states took a turning point in 1974, when India conducted its first nuclear test, which ushered in a new era of nuclear arms race on the subcontinent.<sup>98</sup>

In contemporary international politics, distrust, uncertainty and insecurity have compelled states to indulge in an arms race in which modern technology has added lethality to weapons as never before.<sup>99</sup> There are growing concerns over the possibility of accidental war. Thucydides also expressed similar apprehensions concerning the role of accidental war while writing the history of the *Great War* between the Spartans and the Athenians. The war once begun, writes Thucydides, lets loose forces that are completely unforeseen by the protagonists. This de-stabilises the very concept of mutual deterrence that has been built on the foundations of nuclear weapons, and may set-up risky dynamics of nuclear deterrence – upon which both Pakistan and India have premised their strategies – the “stability-instability paradox,” as some analysts have described the prevailing scenario.<sup>100</sup>

### **Uncertainty, Fear and the Nuclear Problem<sup>101</sup>**

According to most security dilemma theorists, permanent insecurity between nations and states is the inescapable lot of living in a condition of anarchy.<sup>102</sup> A root cause of the security problems of India and Pakistan lies in the condition of uncertainty about the others’ intentions – a ‘dilemma of interpretation’<sup>103</sup>, arising out of anarchy in international politics. As Kenneth Waltz<sup>104</sup> described almost half a century ago, the system of international politics is marked by an anarchical character due to the absence of a political authority above sovereign states which could enforce law, resolve disputes and especially, offer transparency.<sup>105</sup>

Anarchy fuels the dilemma of interpretation and therefore, the security problems between Pakistan and India.<sup>106</sup> The condition of uncertainty, together with the ambiguous symbolism of weapons – the problem of how to ‘distinguish between offensive and defensive weapons’<sup>107</sup> – creates mutual fear. Following the nuclearization

of the Indo-Pakistani relationship, the fear has been exacerbated extensively due to the possible impact of a pre-emptive nuclear attack: “The nightmare scenario here is that if Pakistani or Indian decision-makers ever came to believe that the other was about to launch a nuclear attack, would it become rational to pre-empt in the belief that this was the only means of limiting damage from the other side’s nuclear arsenal?” Anarchy’s feature of uncertainty, mutual fear and the nuclear sword of Damocles in South Asia exacerbates the dilemma of interpretation between both states, and therefore, security paradox is defined as a situation in which two or more actors, seeking only to improve their own security, provoke through their words or actions an increase in mutual tension, resulting in less security all round.”<sup>108</sup> In this connection, one needs to understand the South Asian Security Paradox.

### **The South Asian Security Paradox**

As described above, uncertainty and, in fact, the anarchic structure of the international system has led to a ‘dilemma of interpretation’ between India and Pakistan. Even if one side tries to send defensive/mitigating signals to the other, the fear of cheating will dominate the other side’s approach as long as there do not exist any solid mechanisms of reassurance. In combination with mutual fear resulting out of the Indo-Pakistani shadow of the past, ‘misplaced suspicion regarding the motives and intentions’ of the counterpart fuels the second level of the South Asian security dilemma, which is generally referred to as ‘dilemma of response’.

When the interpretation-dilemma is somehow settled, ‘the decision-makers on both sides need to determine how to react’, which comprises a significant field of tension. If the response is based on misplaced suspicion, generally the decision-makers react in a militarily confrontational manner, then they risk creating a significant level of mutual hostility when none was originally intended by either party; if the response is based on misplaced trust, there is a risk they will be exposed to coercion by those with hostile intentions. When decision-makers decide to resolve the spiral of mutual hostility between two arch rivals (although neither wanted it), the situation might lead to a ‘security paradox’. The core argument of the security dilemma is that, in the absence of a supra-national authority that can enforce binding agreements, many of the steps pursued by states to bolster their security have the effect – often unintended and

unforeseen – of making other states less secure.” And, at least since the nuclearization of Indo-Pakistani relations in 1998, both states seem to be trapped in exactly such a security paradox. With the Indian nuclear test in 1998, alarm bells in Pakistan started to ring, and its leaders felt pressured to demonstrate its nuclear capability too. Both sides followed a defensive ‘deterrence’ security-paradigm, which, in the end, decreased the security between both substantially. Since 1998, India and Pakistan are trapped in a security paradox arising out of mutual fear, suspicion and arms race. Therefore, the key for getting out of this South Asian security dilemma lies in the hands of India and Pakistan.<sup>109</sup>

### **Offence-Defence Theory**

Offence-defence theory is a term for several theories that link the severity of the security dilemma, and therefore the likelihood of war, to the types of military technology available to actors and the ease of conquest. In his classic article, "Cooperation under the Security Dilemma," Robert Jervis argued that the security dilemma is most severe and the international system is less stable when offensive weapons systems enjoy an advantage over defensive weapons systems. By contrast, when the defense is more potent, status quo actors find it easier to adopt compatible security policies, and the pernicious effects of the security dilemma are greatly diminished.

The relative advantage of offensive or defensive weapons systems is called the "offense-defense balance." The extent to which actors can differentiate between offensive weapons and defensive weapons is called "offense-defense differentiation." Although different theorists offer competing definitions and measurements of the offense-defense balance, Jervis<sup>110</sup> referred to the modalities of battlefield conquest: military tactics, strategy, technology, and a state's geography. Thomas Christensen and Jack Snyder, Sean Lynn-Jones, Stephen Van Evera, Charles Glaser and Chaim Kaufmann<sup>111</sup>, among others have refined and expanded Jervis's original conception of the offense-defense balance. All versions of offense-defense theory see nuclear weapons (and particularly secure, second-strike nuclear arsenals) as the ultimate defense-dominant weapons system. Offense-defense theory is one variant of defensive realism. Nonetheless, offense-defense theory is controversial even among self-

described realists, because of the difficulty in defining and objectively measuring the theory's explanatory variable — the offense-defense balance.

### **The Level of Missile Proliferation Analysis**

Nuclear proliferation is manifold in attributes which can be analysed. The dominant tradition in Western literature speaks of anti-proliferation or proliferation-control or 'slowing proliferation'. This tradition is relevant for policies of Western governments and for academicians and other analysts. Its cultural base deserves a full length study (which is beyond the scope of this work). The other tradition is the weaker one in contemporary international studies and in strategic studies. This refers to assessment of the dynamics of nuclear proliferation in several scholarly works that has shifted academic attention to the need to explain and to predict the nuclear proliferation process, and to explore its motivations and dynamics by looking for common patterns of nuclear development by various nations, as revealed in empirical case histories. The first, the dominant Western tradition is prescriptive and policy-relevant. The second tradition has emerged in writings which have appeared in the West. As of mid-1980s this tradition is still weak in its impact on Western policies.<sup>112</sup>

Given this distinction between the two traditions, three different levels of proliferation analysis may be noted. Responding to the first and dominant Western academic and policy tradition, the first level is concerned with the utility of establishing international technological, political and legal controls aimed at slowing or preventing nuclear proliferation. The second level is concerned with the acquisition of nuclear arms by hostile pairs of regional powers in the Indian sub-continent, the Middle-East and South America (i.e. India-Pakistan; Israel-Iraq; Argentina-Brazil). Here the stress is on the dynamics of regional nuclear competition in the context of regional conflicts. The underlying assumptions of these two levels of thinking are that (a) these regional rivals are, or may be, less stable or responsible than the Great Powers in the northern hemisphere; (b) their irresponsibility could lead to regional nuclear conflicts; and (c) such conflict might in some way lead to global nuclear conflict. Therefore, the implication here is that the further spread of the ability to make nuclear weapons into unstable, conflict-prone regions should be stopped or at least delayed. In this sense the study of regional nuclear proliferation, with the set of assumptions noted

above, responds to the prescriptive and policy demands of the first (the dominant) Western academic and policy tradition.

The third level of proliferation analysis relates to the processes of national decision-making about nuclear matters: nuclear energy, nuclear proliferation, nuclear posture, and arms control and disarmament. In this level the emphasis is on incentives and disincentives underlying nuclear proliferation. By and large in Western literature this level is the least researched of the three levels of analysis. The strengths and weaknesses of each level may be briefly noted. The first level of proliferation studies is prescriptive and Western policy relevant. Its principal deficiency is that it does not assess the motivations, the decisions, the processes and the inhibitors of nuclear proliferation. It is not empirical. The second level has two variations: one which argues that regional proliferation is destabilizing; and the other (Waltz)<sup>113</sup> the contrary.

The Waltz argument is a healthy corrective to the (self-righteous) Western assumption that further nuclear spread is necessarily destabilizing for regional and international politics. He discusses the consequences of nuclear proliferation in Third World regions in general terms but he does not assess the national nuclear decision-making processes in South Asia, the Middle East and other regions. Moreover, he does not assess significant developments which shape a country's nuclear posture, its motivations, its nuclear capability, and its external strategy at levels below that of possession of nuclear arms. Walt's argument is politically appealing but its relevance for Pakistan-India strategic relations is very doubtful. Hence this present study attempts to examine the missile development programmes of both India and Pakistan and their impact. In view of this, the next chapter entitled "**India's Missile Development Programme**" attempts to examine the development of different types of missiles and its resultant implications.

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