Technology Electronics External 2.7 –

Demonstrate understanding of redundancy and reliability in technological systems

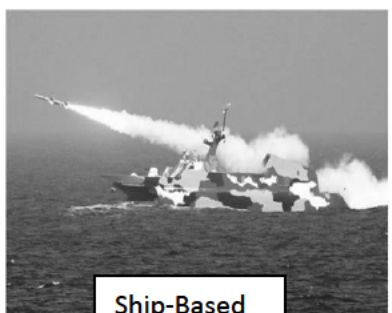
System - Cruise Missile

Purpose of a Cruise Missile:

A Cruise Missile (Guided Missile) is an advanced, guided, self-propelling weapon system which enables land, air, sea and undersea based military craft to accurately and reliably target and destroy selected enemy assets and/or positions across a large distance without running the risk of losing personnel or coming under enemy fire.

Onboard ships, submarines and aircraft, Cruise Missiles are often considered to be a weapon subsystem due to the presence of other weapon alternatives, such as guns. While on land-based missile batteries, which are entirely focussed on the deployment Cruise Missiles, they are considered to be a single system.


Land-Based


Ship-Based


Submarine-Based

Aircraft-Based

Reliability – Definition and Examples:

Reliability is the extent of a system (or subsystem)'s ability to perform its function(s) correctly in both expected AND unexpected circumstances.

Reliability in all technological systems (be it a vehicle or a Cruise Missile) is largely determined by the levels of fault-tolerance, reparability, maintainability and validity in a design.

The extremely high cost of a Cruise Missile (US Tomahawk = US$1.45 Million) (BrahMos = US$2.37 Million) coupled with the fact that it is a 'one-time-use' system rather than a lasting system, there is a lot of reliability present in a Cruise Missile in the form of fault-tolerance, as opposed to repairability and maintainability (Since a Cruise Missile is not designed to survive after its purpose is fulfilled), in order to ensure that it performs its function correctly even if it means at a diminished level, which is a much better alternative to a total failure.

Fault Tolerance

Fault-tolerance is the ability of a system, if hardware or software is compromised, in order for the system to continue to perform its function albeit at a reduced level of effectiveness. Fault-tolerance essentially offers an alternative action for a system in order to avert total failure and loss. This is important in any technological system as it will enable a system to either continue on to fulfil its purpose albeit at a reduced level of effectiveness (In the event of a missile or any one-shot system) or survive until it can be repaired (In the event of a vehicle).

An example of fault-tolerance is the solid rubber cores used in certain tyres of cars. If a tyre sustains damage such as a puncture, the solid rubber core in the tyre can keep the car functional albeit at a reduced speed and for a limited distance until a repair shop can be reached.

Repairability

Repairability is the level of difficulty for a system, if hardware or software is compromised, to be restored to a sound condition. Repairability is important for long-lasting systems such as planes and cars to ensure that such a system can return a sound and functional state after a fault occurs. It is important for a system to be easy to repair as it would enable said system to be restored quickly to working order so that it can return to performing its functions once more without causing any long disruptions/delays to users, thus making it reliable.

An example of a good reparability is also found in the car. If any portion of a car is compromised, the car is relatively easy to repair as there are many people (mechanics and non-mechanics alike) and spare parts for cars are also readily available, thus making the car easy to restore to a sound condition.

Maintainability

Maintainability is the level of difficulty for a system to be kept in working order over time. Maintainability is also focussed on long-lasting systems. It is important for a system to be easily maintained as it would allow any faults in a system and their causes to be isolated and corrected accordingly. It also enables worn/damaged components to be replaced with new parts or repaired without need of a replacement. It also enables future systems of a similar make to be improved on. Maintainability is important in a lasting system in order to make sure that it can continue to reliably function over a long period of time without breaking down.

An example of good maintainability is, once again, found in a car. A car is capable of being easily maintained, worn parts such as tyres and pipes can be easily replaced in order to enable a car to remain functional for long periods of time.

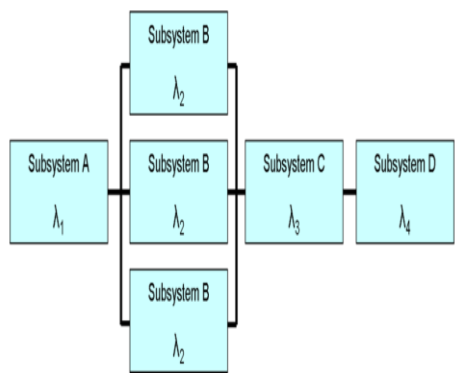
Validity

Validity is the logic behind the actions of a system. Validity is generally found in the programming of any technological system and is important in reliability as a reliable system is one that performs the most logical, and thus safest, actions to fulfil a purpose rather than a system which performs the fastest, but most dangerous actions to fulfil a purpose. Validity ensures that a system is able to perform its function in the best possible way AND/OR ensure that system survives the actions it takes in the event of non-hostile/routine conditions.

Redundancy – Definition and Examples:

Redundancy is the duplication of (or addition to) critical components within a system or a subsystem with the intention of increasing the level of reliability within said system through the introduction of a back-up or fail-safe function.

Redundancy is designed to duplicate and thus 'back-up' critical subsystems in order to ensure their function should the original subsystem fail. Most examples of redundancy in technological systems exist in the form of a back-up power supply/back-up power generator designed for usage in the event that the primary power supply fails.



The aforementioned qualities (price and type of system) of a Cruise Missile also mean that there is a lot of redundancy alongside fault-tolerance present in a Cruise Missile to ensure that it performs its function. Redundancy is used to duplicate and thus 'back-up' critical subsystems in order to ensure their function should any of the original subsystems fail.

Due to the fact that cruise missiles are expected to come under fire and ultimately be destroyed, they generally do not have much in the way of hardware redundancy as any redundant components set into the Cruise Missile itself cannot guarantee that the missile will actually hit its target.

While hardware redundancy improves the reliability of a system by providing a 'back-up alternative' should critical systems fail to operate, it makes the design of any system extremely rigid as the design must also include back-up components to provide redundancy and thus improve reliability.

In a Cruise Missile, most redundancy comes in the form of software redundancy through extra programming that exactly needed by individual Cruise Missiles but rather needed by the system (or subsystem when onboard an aircraft, submarine or ship) to ensure the destruction a selected target.

The benefit of software redundancy is that it improves the reliability of a system and does not take up any physical space the design. Therefore it allows a system to be upgraded physically without compromising any of redundancies, and thus leaving the level of reliability within said system uncompromised.

However, the disadvantage concerning the type of software redundancy within a Cruise Missile is the fact they concern the function of a Cruise Missile weapons system/subsystem as a whole rather than the function of individual Cruise Missiles, therefore the redundancy involved in a Cruise Missile will not improve the ability for any single missile to reach its target, but rather only ensures that A missile will reach its target, or a target, during a strike where multiple missiles are concerned.

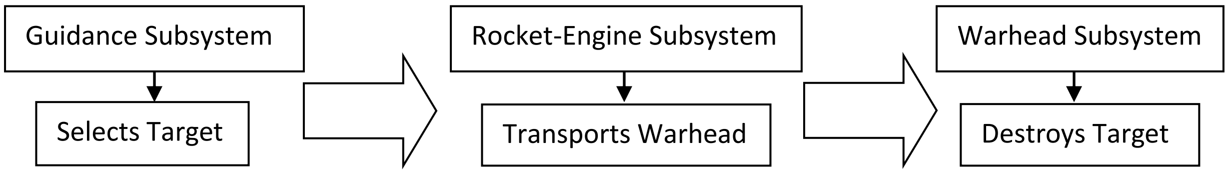
<u>The Cruise Missile System:</u>

A cruise missile (like most other missiles) consist of three main component subsystems held within a large, aerodynamically streamlined (typically bullet-shaped) protective steel casing, though the composition of the frame's metal largely depends on its function. For example, armour-piercing Cruise Missiles possesses high-density depleted uranium or tungsten-carbide casings to enable the missile to penetrate the dense materials commonly used to protect high-value military assets such as bases and/or aircraft carriers.

The component subsystems in a Cruise Missile are as follows:

(1) Missile Guidance Subsystem
(2) Rocket Engine Subsystem
(3) Warhead Subsystem

These interdependent subsystems function together to make the entire Cruise Missile system. The rocket-engine subsystem requires the guidance subsystem to designate a target, the warhead subsystem relies on the rocket-engine subsystem to transport it to the target and finally, the rocket-engine and guidance subsystems all rely on the warhead to fulfil the purpose of the Cruise Missile and destroy the designated target.



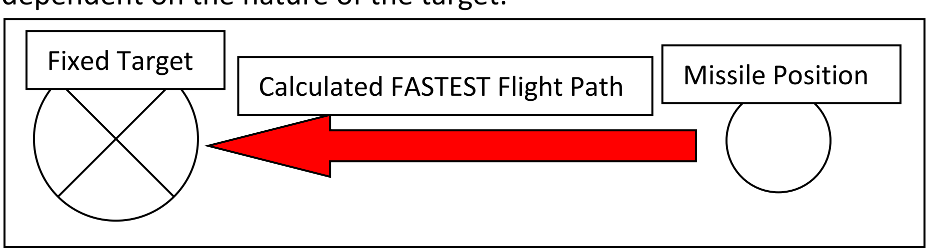
Reliability & Redundancy - Guidance Subsystem:

The Guidance Subsystem of a Cruise Missile covers both the weapon's targeting and in-flight guidance functions. The guidance systems are designed in order to provide a logical method for the Cruise Missile to target and destroy designated enemy assets AND to ensure that missile is capable of reaching its target, ensuring the reliability to the system through validity.

A Cruise Missile is capable of accurately targeting an enemy asset that is far beyond both visual and radar lines-of-light, meaning that enemies cannot immediately detect it upon launch and take measures against it. Also it possesses a flight-path that can be easily manipulated and controlled at launch and also in-flight through the use of internal navigation systems such as gyroscopes etc.

Other munitions such as air-dropped bombs (As shown in the image to the right) require a target to be within sight, physical aim and can only be controlled during launch, making such weapons unreliable due to the fact that they are very susceptible to human-error (Timing and aim), weather conditions (Primarily wind-related) or essentially being wasted if the plane or vehicle carrying the weaponry is destroyed en route to its target.

To ensure the reliability of a Cruise Missile, most, if not all of Cruise Missiles, are designed with two types of guidance methods: Preset Guidance and Homing Guidance. The type of guidance used, is dependent on the nature of the target.

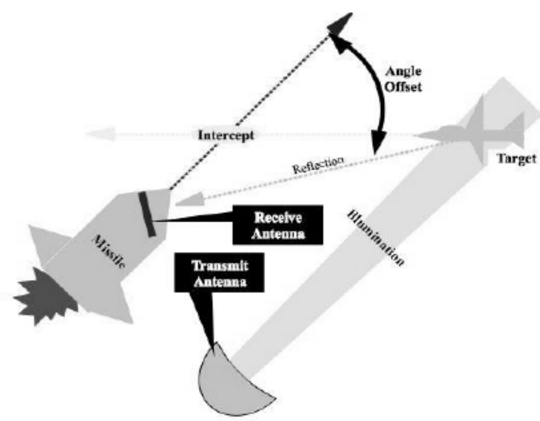


Preset Guidance (Exemplified in the diagram above) works as follows and is designed to allow a Cruise Missile to reliably engage stationary targets: A target is selected through usage of GPS and co-ordinates provided from satellites.

Simple co-ordinates are provided by the satellite and relayed to the guidance subsystem's computer AI which then generates a path which is the fastest and most logical pathway for the missile to take in order to destroy its target. In flight, internal components such as gyroscopes, fins and side-rockets act to keep the rocket itself on-course towards the target.

Issues presented by obstacles such as high mountains and city sky-scrapers are usually negated by the fact that Cruise Missiles is almost always designed to travel towards an altitude of 14,000m at the early stages of flight before dropping in altitude when nearing its target.

Preset Guidance is extremely unreliable when dealing with moving targets due to their tendency to move out of the missile's effective blast-radius since only a single co-ordinate is used. Therefore Cruise Missiles are designed to also function with Homing Guidance, which allows them reliably engage moving targets such as aircraft, naval vessels and land-based vehicles.

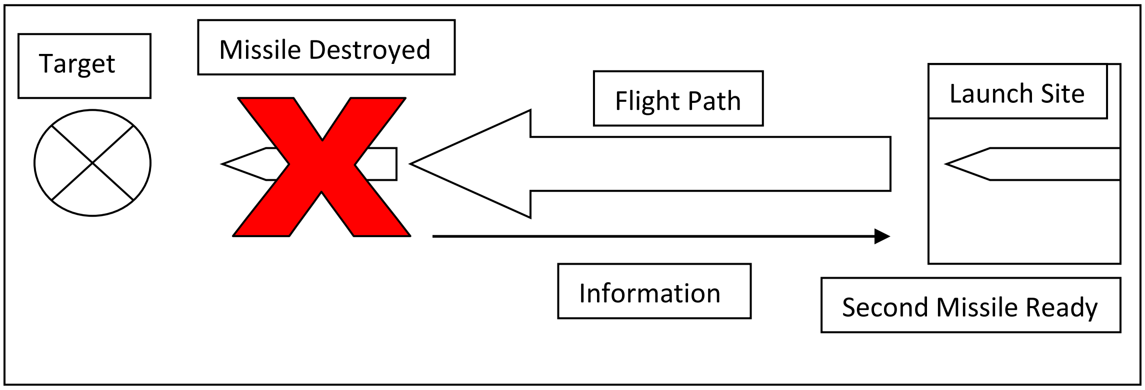


The diagram demonstrates the usage of homing guidance.

Active homing works (Shown in the diagram) using a land-based radar (Generally set on the air-craft, ship, submarine or missile battery which the Cruise Missile was initially fired from) to lock onto a moving target (Regardless of where it is located, be it land, sea or air) and relay information regarding the position of its target through means of transmitting and receiving antennas. The Cruise Missile's guidance AI will adjust the missile's flight path to always fly towards the target's position through the use of internal guidance mechanisms (E.g. Fins and Gyroscopes) set inside the missile, enabling it to continuously change directions and follow the target. Most Cruise Missiles are capable of achieving Mach 3 speed enabling it to easily reach and destroy any sea and land-based target (by means of superior speed) and also allows it to match the speed of the SR-71 Blackbird (Which has a top speed of roughly Mach 3 as well), the fastest manned aircraft deployed so far.

The only disadvantage to active homing is that once a target leaves the radar's range, the missile will no longer have a target to follow. This is why reliable Cruise Missiles have a very heavy emphasis on speed; a faster speed gives a target less time to escape the range of the tracking radar used.

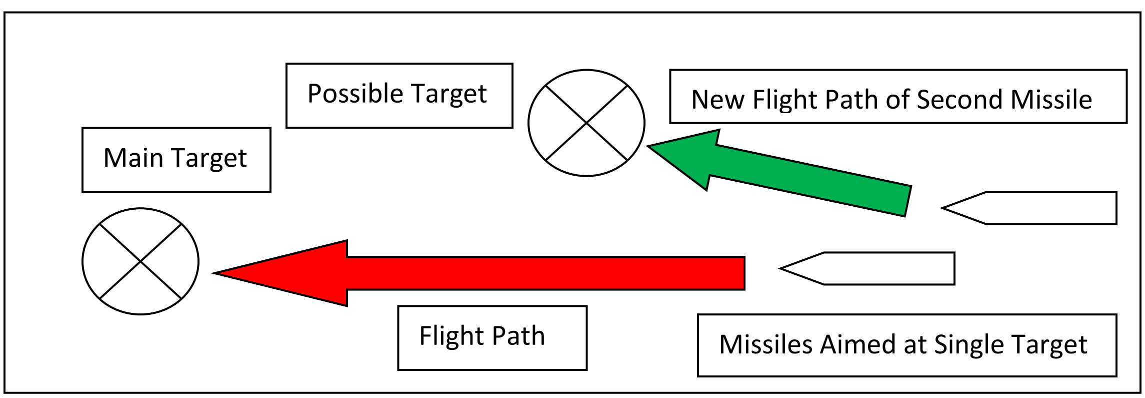
Timing Redundancy:



As shown above, timing redundancy is used during strikes (Involving multiple Cruise Missiles) on strategically-important and thus well-defended targets such as a carrier, static air defences, bases or even cities in which missiles, no matter how reliable they are, are expected to be intercepted and destroyed.

Timing redundancy helps to ensure the destruction of a selected target, which is the purpose of the entire system/subsystem. Timing redundancy works by relaying information concerning launched missiles back to the launch site itself. If the information relayed stops suddenly before a target location is reached, then it is stated in programming (and assumed in reality) that the missile was destroyed. Therefore after a few seconds or so, a second missile is launched at the exact same target until one is registered to have hit the target or detonated in a very close proximity, reliably ensuring that a target has been eliminated or rendered ineffective.

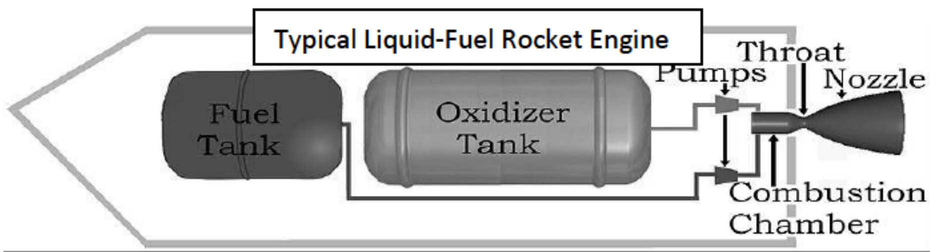
Data Redundancy:



Data redundancy is used in the way that, missiles are also capable of relaying and carrying extra information back to their launch site in mid-flight as opposed to only during launch. At times, multiple missiles are launched (Generally at short intervals after each other rather than all at once) targeting a single target (This is generally used in the event of attacking a large strategic city or large territory). Should one missile register that it has hit its target, and then the information is relayed onto the control site (Generally situated in the launch site) that the missile has struck. As a result, all other Cruise Missiles nearby in flight will have their target re-routed by the control site, to target a preset 'secondary target' that was designated prior to the flight, thus ensuring that the missiles can reliably deal effective damage to a large target area rather than hit the same target area and effectively 'waste' themselves and the resources used in their construction.

<u>Reliability & Redundancy- Rocket Engine Subsystem:</u>

The Engine Subsystem of a Cruise Missile is what enables the entire system to travel towards its designated target. Cruise Missiles (And most military missiles in general) use liquid-fuel such, as hydrogen tetroxide or kerosene, in order to fuel their flight. Due to the nature of Cruise Missiles and their function of destroying military assets, they are required to be extremely fast in order to lessen the chance that they will be intercepted by an enemy. As a result of that, most (If not all) Cruise Missiles are capable of achieving Mach 3 (1000m/s).



Typical Liquid-Fuel Rocket Engine

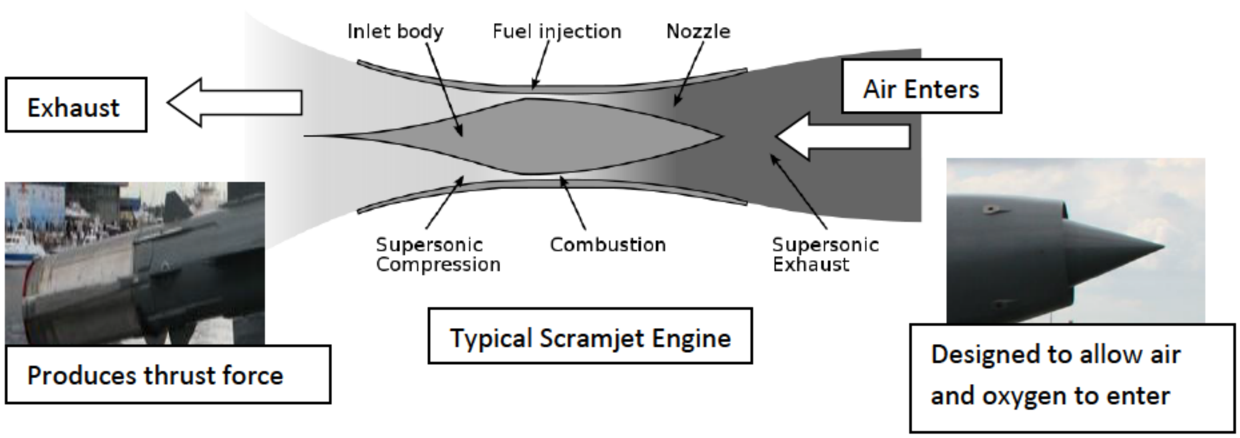
The principal of a liquid-fuelled rocket engine is the Newtonian Law: "For every reaction, there is an equal or opposite reaction." The engine (as shown above) is composed out of 3 main sections which lead onto one another in function, the fuel tanks (Fuel and Oxygen/Oxidizing Agent), the combustion chamber and the rocket nozzle.

Fuel (Such as Kerosene or Hydrogen Tetroxide) and an oxidizing agent (such as oxygen) are pumped from their individual tanks into a combustion chamber where the two fuels are burned together to create enough thrust force (which is the stated "...opposite reaction..." in Newton's Law) to allow the entire missile to travel.

Due to the fact that Cruise Missiles are used to engage over long distances (300km for a BrahMos Cruise Missile) WHILE maintaining speeds up to Mach 3, typical liquid-fuel rocket engines alone will not be sufficient to reliably act as the missile's main mode of transportation, as they would require immense amounts of fuel to maintain their flights and the implications of entirely using normal rocket engines for Cruise Missiles would make them very impractical. E.g. More fuel = Bigger fuel tanks = Bigger missile = More resources needed.

Therefore many modern Cruise Missile rocket engine designs are complimented with an 'Air-Breathing Scramjet Engine' as well. 'Scramjet Engines' work in a similar principal to the original rocket engine in the sense that it requires oxygen and fuel, but instead of storing vast amounts of oxygen inside the missile's casing the engine burns oxygen in its surrounding atmosphere instead. Due to the absence of any large fuel tanks inside the missile, it can travel quickly and thus reliably while retaining a practical size AND be open for any possible upgrade or improvement.

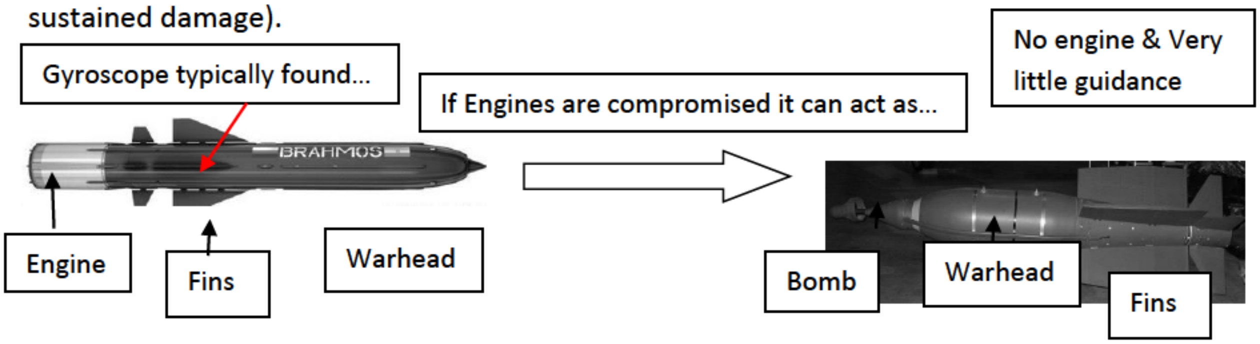
The only disadvantage to the usage of 'Air-Breathing Scramjet' is that it will only function at extremely high speeds such as Mach 1 and beyond. Thus, the Cruise Missile still requires a small rocket engine fuel to bring it up to the 'ideal' velocity before the 'Scramjet' can function and take over as the primary driving force of the missile.



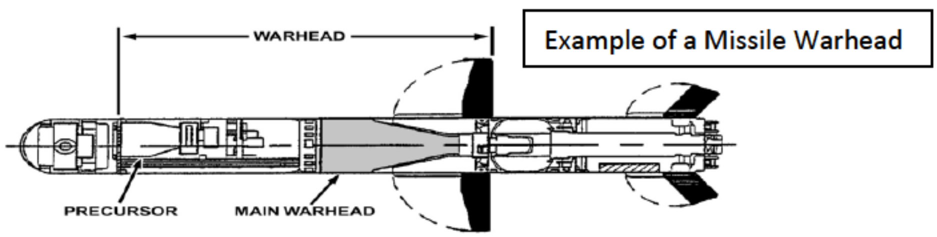
However, due to the equivalent speeds of Cruise Missiles versus other commonly deployed surface-to-air defence missiles such as the MIM-Patriot used by the US and NATO (Which is able capable of Mach 5 speeds, exceeding those of a Cruise Missile), there is an extremely high chance of a Cruise Missile being intercepting and sustaining heavily damage (If it is not out-right destroyed).

Many Cruise Missiles are designed with fins located higher up than the tail end of the missile where the exhaust of its engine is located, this designed so to improve the survivability of the missile's fins when sustaining damage since most damage is received either at the front (electronic navigation section) or back (engine section) of the missile, depending on whether a counter-missile was fired from defensive batteries ahead of the missile or an intercepting aircraft behind the missile.

While the engine or navigation subsystems are operational, these fins act as flight stabilisers to ensure reliability during flight. Should the any of the aforementioned subsystems be damaged beyond usage during the flight, the fins coupled with a gyroscope (Both which are designed to be placed in close proximity together near the missile's centre to improve their survivability) enable a Cruise Missile to act as a bomb and continue on a limited, gravity-influenced path of motion downwards from its current altitude towards the target thus enabling it to ,in the very least, cause damage and disruption (Should the target have been a fixed position within a base or city) and at best actually reach the target (If the target was close-by when the missile sustained damage).



Reliability & Redundancy - Warhead Subsystem:



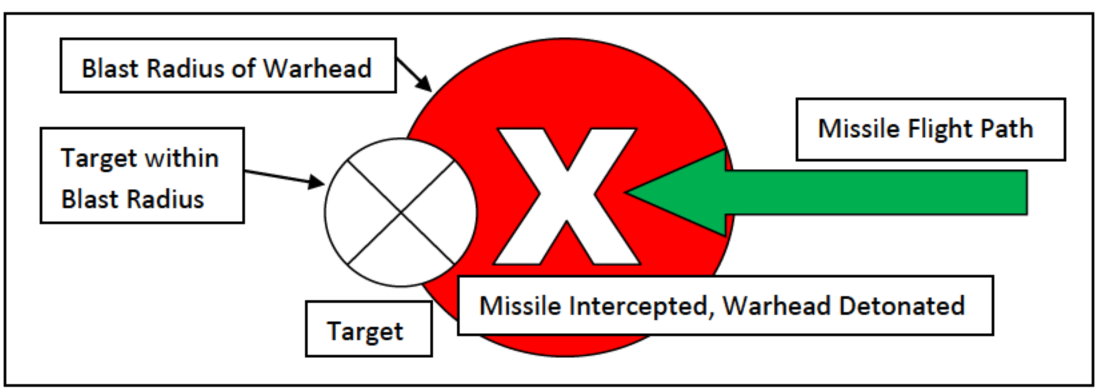
The warhead of a Cruise Missile (Regardless of the make) carries the explosive/toxic, and thus main weapon (Damaging) component of the entire system and are thus carried within a secure steel casing inside the Cruise Missile (As shown in the diagram above). Cruise Missile warheads are capable of carrying chemical, biological, nuclear and conventional (explosive or incendiary/fire-spreading) material inside it depending on the purpose (Though the first three are banned under Modern International Law).

A warhead can be detonated through various means, most of which are automatic and thus controlled by the warhead subsystem. The means of detonation are also largely dependent on the purpose and contents of the Cruise Missile itself. Most warheads are detonated through physical contact with the target location or the target itself. Incendiary (In use), biological and chemical warheads (In theory and design), at times, are detonated through a 'proximity detonator', using a laser inside the Cruise Missile (Typically the front) to measure distance and detonating only when the warhead is at a set distance from its target. This method is generally used to take advantage of weather conditions which may spread incendiary, chemical or biological agents. Altitude detonation uses barometers and altimeters to measure the altitude of a Cruise Missile and detonate it once it reaches a set altitude. This is widely designed for nuclear warheads, as the result of a nuclear blast in high altitudes is an electro-magnetic pulse capable of disrupting electronic devices over wide areas.

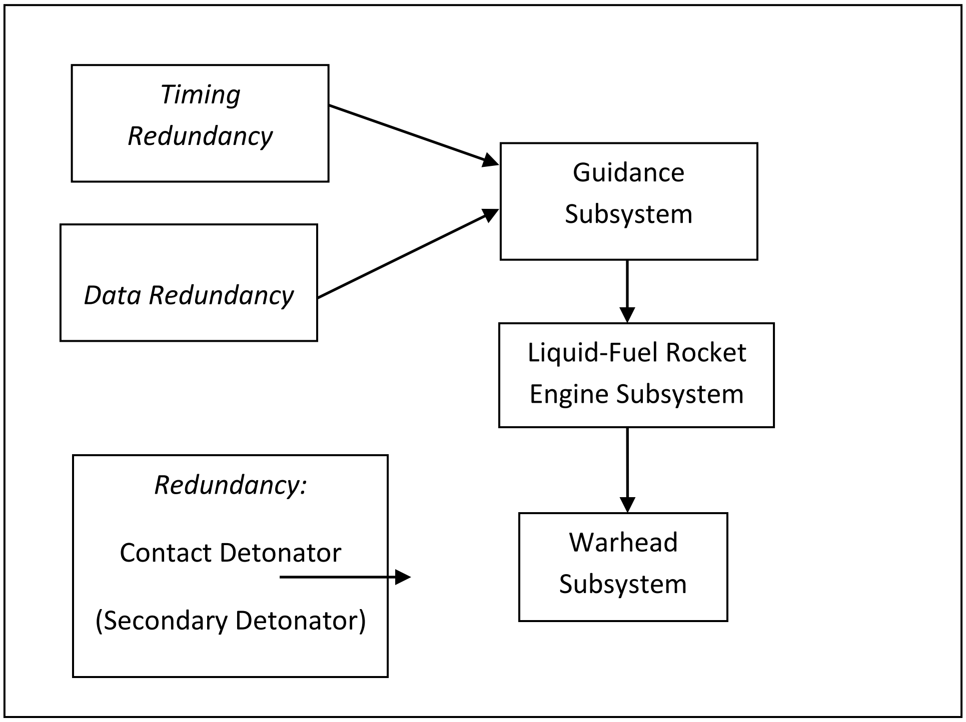
Along with those three methods of detonation, Cruise Missiles are capable of being detonated manually by human remote control. This method, however, is less favoured over the other three automatic methods and is generally used as a last resort should the warhead's other systems fail.

As aforementioned, MIM-Patriot Counter-Missiles is capable of intercepting the BrahMos Cruise Missile, the fastest supersonic Cruise Missile currently in service. Therefore, there is a very high chance that the damage from an intercepting projectile will damage the Cruise Missile enough to exposed or damage the warhead and/or destroy the other subsystems in the Cruise Missile such as in-flight guidance (gyroscopes etc.) and the rocket-engine.

As result, altitude/proximity/remote-detonation warheads are designed to carry a redundant contact detonator (as opposed to a remote-detonator which may not be reliable due to the factor of human error) not only as back-up but also as fault-tolerance. When any damage to the warhead itself is sustained, it regarded as 'physical contact' by the Cruise Missile and thus the warhead is detonated. This helps enable a Cruise Missile to perform its function of destroying or limiting the function to severely damaging a target (Thus either delaying its deployment or rendering it entirely useless) even when intercepted, as there is a chance that the Cruise Missile was intercepted at a relatively close range to a target, given the missile's high speed and depending on the efficiency of enemy defence-systems, thus making the target susceptible to damage should the missile detonate at the point where it was intercepted (As shown in the diagram below).



Cruise Missile Block Diagram (Redundancy within a Cruise Missile):



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Ship Based Cruise Missile	http://www.andrewerickson.com/wp-content/uploads/2010/07/East-China-Sea-Exercise_Type-022-Firing-Missile_Xinhua.jpg
Submarine Based Cruise Missile	http://www.fas.org/man/dod-101/sys/smart/slcm-dvic470.jpg
Cruise Missile Image	http://www.ausairpower.net/USN/BGM-109D-Cutaway-S.jpg
Definition of Reliability	http://en.wikipedia.org/wiki/Reliability
Definition of Redundancy	http://en.wikipedia.org/wiki/Redundancy_(engineering)
Air Based Cruise Missile	http://2.bp.blogspot.com/-6PDWeuamRDg/S7GWbDMAS4I/AAAAAAAARAQ/3KO3coy4WWc/s1600/brahmos_airlaunch.jpg
BrahMos Image 1	http://thumbnails.visually.netdna-cdn.com/the-russianindian-brahmos-supersonic-cruise-missile_502916006c89b.jpg
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