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Evolution of Smart Weapons

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International Strategic and Security Studies Programme
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Executive Summary

The concept of aerial bombing has evolved and undergone significant improvements in terms of technologies, systems and deployment. While the bombs dropped from balloons in the second half of nineteenth century had a Circular Error Probability (CEP) of a few kilometres, the most recent smart glide weapons can achieve sub-metre CEP. This report gives an overview of evolution of aerial bombing systems and technologies over the decades. The revolutionary developments in the field of Electronics, Sensors, Software and Mechanisms in the recent years, and their impact on improved performance of the systems are highlighted. The status of critical technologies required for developing smart weapons systems in India is mentioned along with their technological readiness level, thereby bringing out that India needs to progress further on Terminal Homing Systems in order to achieve global standards. The report also contains a non-exhaustive survey of glide weapons, Guided bomb units, and Laser guided bombs in order to capture the current trends across the world. A section on the future of smart weapons has also been added, which looks at plausible developments in the future.

Evolution of Bombs-Ancient, Medieval, 1850's and beyond

Human beings have always had conflict with other living beings and among themselves, right from the ancient times. The survival of human beings depended on their ability to fight the adversaries, be it humans or animals. So, conflict has always been inherent in nature for human beings ever since, and throughout their evolution they have looked at how to gain an advantage in any conflict.

The ancient period saw the evolution of conflicts from fist fights to engagement with different types of weapons like sticks, stones and spears. Each of these weapons either increased the "reach" of the attacker or his "stand-off distance" from the adversary. The sharp end of the spears caused increased damage to the targets and poisonous substances increased the lethality of the weapon. Over the years, the bows and arrows were used for hunting. Bows imparted higher initial momentum and hence the arrows could travel larger distances as compared to the spears thrown by human beings. Since the arrows were not stable in flight, fins made of feathers were used to increase their stability. The arrows were also shaped in such a way as to reduce the effect of air resistance. Pointed arrows improved the aerodynamic characteristics and also enhanced damage to the target.

With the invention of gun powder in the 12th century, the type of weapons used in conflicts changed considerably. The explosives were able to cause higher levels of damage on targets. Gun powder was packed in metal containers and attached to the arrows which were used as delivery platform for the explosive material. Gun powder was initially used as an incendiary material to damage the target through fire[1]. Later the technology of detonation enabled the capability to impart enhanced damage on targets through explosion.

All the above weapons had limitations in the accuracy of trajectory, and hence, they had to be deployed from relatively closer stand-off distances.

1850's and beyond saw the emergence of weapons being deployed from air. An Austrian artillery officer, Franz von Radetsky, hatched the idea of using balloons to carry the weapons and release from an altitude. These weapons came to be known as bombs and were able to engage against targets with increased momentum, thereby inflicting increased damage. Bombs are explosives packed in aerodynamically shaped containers, which are detonated on impact or based on pre-set exploding conditions.

[2]Bombs were carried in air balloons by the Austrians and used against Venetians as early as 1849, decades before the first powered aircraft came into existence. Though the Balloon bombs had little

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1 How gunpowder changed the world, Whipps, Heather. April 6, 2008. https://www.livescience.com/7476-gunpowder-changed-world.html (accessed September 12, 2018).

2 "On this day: Austria drops balloon bombs on Venice" FindingDucleniaStaff, Aug 11, 2011, http://www.findingdulcinea.com/news/on-this-day/July-August-08/On-this-Day--Austria-Rains-Balloon-Bombs-on-Venice.html

impact in its first usage due to their inaccuracy, the Austrians managed a victory over Venice in just over 2 days.

Drifting of balloons due to wind affected the accuracy of engagement of the bombs with intended targets. The adversaries were quick to respond with anti-balloon defence systems, thereby challenging the safety of the persons travelling in the balloon.

After the first flight of a heavier-than-air platform by Wright brothers in 1903, and further enhancements powered aircraft flights in subsequent years, the concept of aerial bombing evolved and matured through the experience gained from various conflicts. Lieutenant Giulio Gavotti dropped four grenades over Libya, though none of the Turks were injured or killed.[3] This marked the arrival of aerial bombing from a powered aircraft. The Zeppelin's were used by the Germans against the British to bomb British bases and cities during the World War One.[4] The challenge thrown up by aerial bombing resulted in the development of anti-aircraft weapon systems which posed a threat to the aircraft and its crew.

The enhanced operational envelopes of aircraft resulted in bombs being released from larger stand-off distances, thereby avoiding exposure of the aircraft to adversary's anti-aircraft weapons. But this affected the accuracy of engagement of the bombs with intended targets. The pilots had to conduct several missions and several passes to achieve desired levels of success in neutralising the targets. This led to a thorough analysis of the factors which finally affect the accuracy of engagement of the weapon with the target.

Factors affecting Trajectory and Miss distance of a Bomb

"An ideal bomb, carried on an ideal aircraft and released by an ideal pilot, at ideal initial flight conditions and travelling through ideal atmosphere, will always hit a target at the same location"

However, there are many factors which contribute to the accuracy of engagement of the bomb with the target. The factors can be categorised as the following.

a) The information available to the pilot on the coordinates of the target: The pilot works out the mission plan and point of bomb release, based on the coordinates of the target available to him prior to the mission. The source and format of this information can have certain levels

[3] "100 Years ago, World's first aerial bomb dropped over Libya" Eyder Peralt, Mar 21, 2011, https://www.npr.org/sections/thetwo-way/2011/03/21/134735395/100-years-ago-the-first-aerial-bomb-fell-over-libya

[4] "World War One: How the German Zeppelin wrought terror" BBC News Aug 4, 2014 http://www.bbc.com/news/uk-england-27517166

of inaccuracy, depending on how and when this information is generated. Added to this is the uncertainties imposed by time-critical moving targets.

b) The actual flight parameters of the aircraft, like altitude, speed and attitudes at the instant of bomb release can be different from that intended by the pilot, due to limitations in the process of sensing these physical parameters and displaying them in the cockpit. Moreover, if the stand-off distance is not safe enough, the pilot, in an operational environment, will also be under tremendous pressure to complete the bomb release and move away from the threat posed by adversary's air defence weapons and equipment.

c) Any time delay between the decision by the pilot to release the bomb and the actual process of its release from the aircraft contributes to the final miss distance. For example, the pilot arrives at his decision on the basis of information displayed on his display panel for several parameters and presses the button to release the bomb at the appropriate instant. Assuming that the aircraft is flying at a speed of about 250 m/sec (~0.75 M), and the delay is of the order of about 100 milliseconds, it will result in a miss distance of 25 m.

d) Deviations in dimension, mass, mass distribution, centre of gravity and surface finish of each bomb affects its trajectory and its dynamic characteristics.

e) The atmospheric conditions like wind, gust, rain, temperature, air density and other variables affect the bomb's trajectory.

The factors discussed above contribute significantly to the accuracy of a bombing mission and the resultant miss distance.

Wars are times when new concepts, innovations and inventions are thrown up for offence as well as defence. The conventional bombs had warhead and fuse, were aerodynamically shaped so that they can travel faster and farther through the air. With proliferation in weapon systems being deployed from air, countries invested in development of systems that enabled them to neutralise these threats. Radars could pick up incoming aircraft at longer distances and anti-aircraft guns posed threat to the aircraft during bombing missions. This called for development of enhanced stand-off capability while deploying air-launched weapons. With increased stand-off distance the challenge of controlling the drift in trajectory of the bomb and minimising its final miss distance with respect to the target also emerged. Over the years, various methods have been developed to enhance stand-off distance, and some of them are listed below.

Methods to improve Accuracy and decrease Miss distance

Advances in electronics technology resulted in the advent of airborne electronics systems, called Avionics systems. This led to significant improvements in flight performance of the aircraft. The sensors were more accurate and reliable, control systems became more robust and pilots were able to fly the aircraft more accurately, thus leading to better control on initial conditions of the aircraft at the instant of bomb release. Introduction of airborne sensors like Radars and Laser-based ranging systems helped in improving the Circular Error Probability (CEP) of bomb delivery. The effectiveness of bombing was improved progressively by adapting the following technical solutions.

a) **Accurate information of Target coordinates**: For fixed targets of strategic importance, it is easier to determine the coordinates based on intelligence obtained through multiple sources. However, for time critical and moving targets, the dynamic nature of their location implies that the validity and accuracy of intelligence information has a shelf-life. Satellites, Unmanned Aerial Vehicles (UAVs) and other surveillance sources are used to obtain the latest and more accurate information on targets of interest.

b) **Bomb Release from Ideal Slant Range**: Visual cues and sensors available in conventional aircraft have limitations in providing information to the pilot on Slant Range to Target. Moreover, some of these sensors are affected by local weather conditions. Modern aircraft are fitted with Laser based Ranging system which gives the Range-to-target with reasonable accuracy and precision. However, this calls for Line-of-Sight (LOS) between the aircraft and the target during the process of target acquisition and bomb release.

c) **Accurate Initial Conditions of Aircraft at the instance of Bomb Release:** When a bomb is loaded on the aircraft for a mission, its trajectory parameters are stored in the Mission Computer of the aircraft as a look up table. When the pilot selects the weapon release mode, the Mission computer continuously computes the trajectory of the bomb using the Weapon release Algorithm, the instantaneous aircraft flight parameters and the weapon system look up table. When the impact point as computed by the Mission computer and the target location overlap, the pilot is given a cue to release the bomb. In more advanced systems, the Laser Range Finder generates the Slant Range to Target, and this information is used in conjunction with the Mission computer algorithm to initiate automatic bomb release.

d) **Mid-course Navigation & Guidance System**: The availability of low cost GPS receivers with reasonable levels of accuracy has resulted in Navigation information being used for mid-course guidance system to correct trajectory deviations caused due to initial release errors, atmospheric disturbances and dynamic characteristics of bombs. Of late, Inertial Navigation systems based on MEMS sensors, with periodic updates of GPS data are being used to further improve the accuracy of bomb delivery.

e) **Terminal Homing System**: Active and passive terminal homing systems have also been incorporated on bombs to achieve single digit Circular Error Probability (CEP).

The most popular system consists of a Laser Seeker Unit (LSU)[5] mounted on an Aero Stabilised Unit (ASU) integrated to the front section of the bomb. The ASU aligns with the relative wind direction, which in effect is the trajectory of the bomb during its free fall. An observer or a UAV surveillance platform operating at a safe stand-off distance in the region near the target illuminates the target using a Laser designator in such a way that the laser energy reflected from the target is available in the direction from which the aircraft is approaching for the bombing mission. The pilot releases the bomb in the general direction of the target and flies away from the target area. During the free fall of the bomb, the reflected laser beam from the target is captured as a spot on the Laser detector of the Seeker. If the trajectory of the bomb is matching with the Line-Of-Sight (LOS) to the target, then the laser spot is captured at the centre of the detector. The deviation of the laser spot from the centre of the detector is used as the error parameter between the LOS to the target and trajectory of the bomb. The Terminal Homing guidance loop generates control commands for the bomb in order to minimise this error so that the bomb is forced to travel along the LOS and thus home on to the target.

The Laser Guided system has been integrated on several conventional bombs as an add-on kit to improve their deployment accuracy. The add-on kit consists of a front section which houses the LSU in the ASU and the Guidance & Control components, including canard control surfaces. The conventional fins of the bomb are replaced by an add-on tail section, which consists of a smaller main tail section and an additional tail section, which is kept folded inside the main tail section. The main tail provides stability required for safe carriage & separation, and the extended tail provides additional stability and damping required during the controlled phase of flight of the bomb.

During 1980's the utility and effectiveness of Laser Guided Bombs (LGB) was demonstrated in various conflicts across the globe. The concept of LGB was implemented in such a way that virtually no modifications were called for on the aircraft. The fin deployment mechanism and the Guidance & Control system were activated using lanyards and delay switches. By using matching pairs of Tail sections and Canard surfaces specific to different types of bombs, the same guidance & Control system hardware was used across several class of bombs.

To put things in perspective, in the late 1930s it was a very popular claim that the Air Corps Bombardier could drop a bomb into a pickle barrel from over 30,000 feet. However, the claims fall flat as the average score of an Air Corps Bombardier was 400 feet CEP from a modest 15,000 feet altitude. This shows the difficulties of aerial bombing while maintain the accuracy of the bomb. Added to this is the increase in stand-off distance which would affect the accuracy of the bomb.[6]

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5 FAS. February 12, 2000. https://fas.org/man/dod-101/sys/smart/lgb.htm (accessed June 17, 2018).

6 Air force Magazine. Correll. October 2008 http://www.airforcemag.com/MagazineArchive/Pages/2008/October%202008/1008daylight.aspx (accessed July 12, 2018)

Methods to increase stand-off Distance

There are various methods by which the stand-off distance for bomb delivery can be increased:

a) **Aircraft Flight conditions at the instant of Bomb release**

A higher release altitude results in increased forward travel of the bomb. Similarly, a higher release speed also results in increased forward throw. The altitude and speed of release, however, are limited by the operational envelope of the aircraft.

Bombs released from an aircraft in straight & level flight mode travel more than those released in a dive mode. Sometimes bombs are also released in a toss mode. Even though this may result in an incremental increase in forward throw, this mode is mainly used in low and medium altitude missions and executed from behind hills in mountainous regions where it is difficult for the adversary's air defence surveillance systems to detect the approaching aircraft.

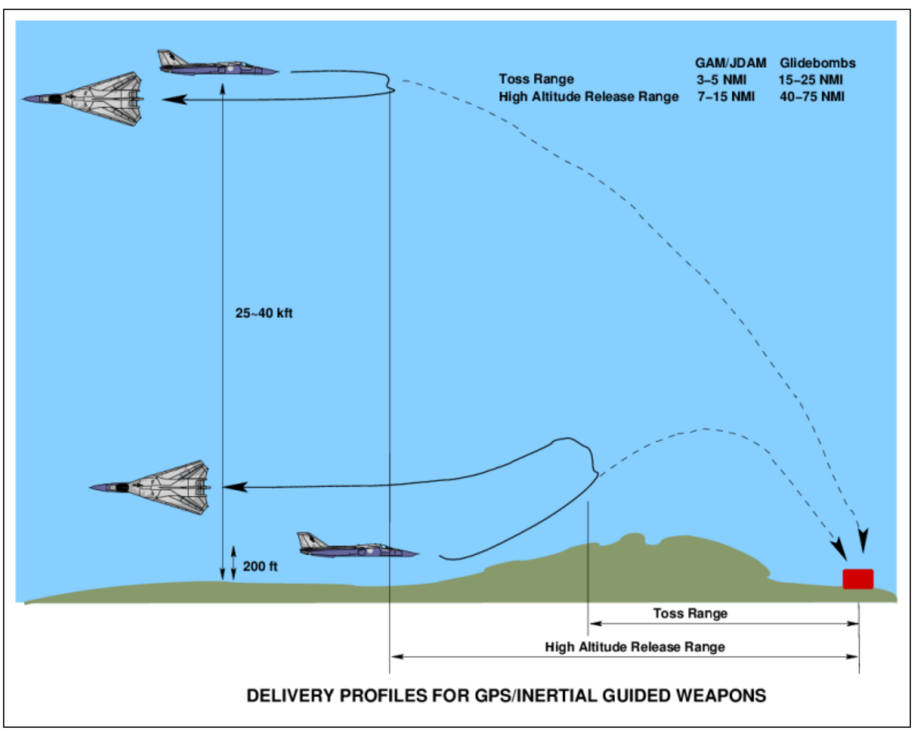


Figure 1. Bomb Delivery from Aircraft

(*Source*: Kopp. *Air Power Australia.* 1996. http://www.ausairpower.net/TE-GPS-Guided-Weps.html (accessed" August 12, 2018)

b) **Improved Aerodynamic efficiency of the bomb**

Proper aerodynamic design of the contour of the bomb and tight control on its surface finish results in incremental decrease in aerodynamic drag. This in turn increases forward throw.

During the Second World War the Germans came up with the concept of 'glide bombs.' These bombs had a conventional wing as a lifting surface which improved the aerodynamic efficiency of the bomb. The wing makes the bomb to glide during its free fall and results in significant increase in distance travelled before it hits the ground. However, the glide bombs could not achieve improved accuracy since the increased time of travel also resulted in drift in trajectory of the bomb due to wind, gust and other parameters, resulting in increased miss distances. The concept was also not pursued because of the challenges involved in ensuring safe separation of the winged configuration of the bomb from the parent aircraft under all release conditions.

In the recent past, advances in technologies related to mechanical systems, pyrotechnic devices and electronic systems and their miniaturisation has resulted in the development of reliable wing deployment mechanisms. This has led to the development of wings which are kept in a folded condition and deployed after the bomb separates safely from the parent aircraft.

Glide bombs incorporated with mid-course Navigation and Terminal Homing capabilities are the order of the day. Several options of new designs of glide bombs, as well as add-on kits for retro-fit on existing stock of conventional bombs are available in the international market.

c) **Adding a Rocket motor to produce thrust**

The addition of a rocket motor to the bomb to produce thrust and increase the range has been tried out even during the Second World War. Germans deployed the V-1 and V-2[7] systems in large numbers against Britain and France. The rocket motors also increased the speed of the weapon resulting in increased momentum at impact on the target.

The concept of rocket powered weapons, aided by mid-course navigation systems and terminal phase guidance system opened up the way for conceptualisation and development of an entirely different class of weapons called ballistic missiles.

d) **Adding a Gas Turbine Engine to provide Sustained Thrust**

When the gas turbine engine technology matured on combat aircraft and commercial jet liners, the same was used on weapon systems to develop a new class of missiles called Cruise Missiles. The fuel-efficient turbofan engines enable the weapon system to travel longer distances under efficient cruise conditions. Advances in mid-course navigation systems and Terminal Homing systems have been incorporated in the Cruise Missiles to travel very long distances under optimal cruise conditions, and thus achieve efficient missions.

[7] Defencyclopedia,NRP July 1, 2014. https://defencyclopedia.com/2014/07/01/the-worlds-first-guided-missiles-v1-and-v2/ (accessed May 27, 2018).

Modern Day Glide Bombs

a) **Ab-Initio Designs**

The ab-initio design of a glide bomb provides the designer adequate freedom to optimise the configuration and achieve the best performance. The only constraints would be those enforced by the parent aircraft in terms of dimensional limitations, structural integrity during carriage, and requirement for safe separation. The aerodynamic shape, layout of equipment within the bomb and the quantum of warhead to be carried can be optimised to achieve the best results

Figure 2. Ab-initio Israeli Glide bomb-Spice 250

(Source: Rafael Advanced Defense Systems ltd. http://www.rafael.co.il/4512-2680-EN/Marketing.aspx accessed: August 14, 2018)

b) **Add-on Kits**

The add-on kit concept was developed and demonstrated in the ‘80s for laser guided bombs. This resulted in conversion of thousands of conventional bombs of different weight class into ‘smart’[8] bombs. These bombs were extensively used in various conflicts and thus the efficacy of guided bombs was established beyond doubt.

[8] Roger A. Beaumont (1981) Rapiers Versus Clubs: The Fitful History of “Smart Bombs”, The RUSI Journal, 126:3, 45-50, DOI: 10.1080/03071848109441946

Figure 3. Add on Guided bomb Units

(Source: FAS. February 12, 2000. https://fas.org/man/dod-101/sys/smart/lgb.htm, accessed June 17, 2018)

In a similar manner, the existing stock of 'dumb' bombs can be converted to glide bombs by integrating an add-on kit. The following factors need to be covered while designing the add-on kit

(i) The kit should have mechanical and electrical compatibility and connectivity with the pylon on the aircraft[9].

(ii) The kit should have matching mechanical compatibility and connectivity with the basic dumb bomb

(iii) The structural integrity of the modified bomb should ensure safety of the aircraft throughout its flight envelope

(iv) After installation of the bomb with the add-on kit, there should be adequate clearances with respect to the aircraft and ground, as mandated for safe take-off and landing requirements

(v) The separation characteristics of the modified bomb from the parent aircraft, including under emergency flight conditions, should meet all the safety requirements applicable to the aircraft

Figure 4 shows add on kits for different bombs which converts them to glide bombs.

[9] Aircraft/Stores Compatibility, Integration and Separation Testing, NATO Science and Technology Organisation, Sep 2014, accessed 12 Nov 2018.

Figure 4. Add on kits for Glide bombs

Source:

a) Kopp. Air Power Australia. April, 2012 http://www.ausairpower.net/APA-PLA-GBU.html (accessed: September 23, 2018)
b) Szondy. New Atlas. February 27, 2015. https://newatlas.com/jdam-er-test-boeing-raaf/36250/ (accessed: September 20, 2018)
c) Indian Defence News. August 20, 2016.http://www.indiandefensenews.in/2016/08/drdo-successfully-tests-glide-bombs-in.html (accessed: October 1, 2018)

The following options of add-on kit can be developed to provide the desired level of weapon effectiveness.

(i) A deployable wing and matching tail surfaces, and Navigation and Control system for mid-course guidance would ensure reasonable levels of weapon effectiveness
(ii) If a terminal homing system with an active or passive seeker also is integrated it would ensure the best level of weapon effectiveness.

Issues involved in deployment of a Weapon system from an aircraft

a) **Integration**

Whenever a new combat aircraft is designed, adequate consideration is given to the weapon systems to be integrated on to it. Combat aircraft are designed to be in operation for 30 to 40 years. Hence any new design should be capable of integrating existing weapon systems as well as those which be developed in the future. This requirement is handled by providing standard mechanical and electronics interfaces on the aircraft. Hard points are provided on the fuselage and under the wings of aircraft where weapon systems can be integrated. Separate sections, called pylons, are provided at these hard points. The pylons are designed as per internationally accepted standards. One side of the pylon caters to the interface requirements of the aircraft and the other side caters to the interface requirement of weapon systems.

Electrical, Electronic and Data interface between the aircraft and the bomb is ensured by adapting standard protocols. This ensures that the interface requirements can be handled through custom software modifications on the aircraft and the bomb.

Weapon systems are also designed in such a way that they cater to the standard interface requirements of aircraft on which they are expected to be integrated. It is a golden rule that the integration of a weapon system shall not, by and large, affect the operational and performance envelope of an aircraft.

b) **Safe Carriage**

Weapons should have adequate clearances from the main body of the aircraft. There should be adequate clearance from the ground after integration of the weapon on the aircraft, even at the attitudes of the aircraft during take-off and landing and also in case of collapse of the landing gear.

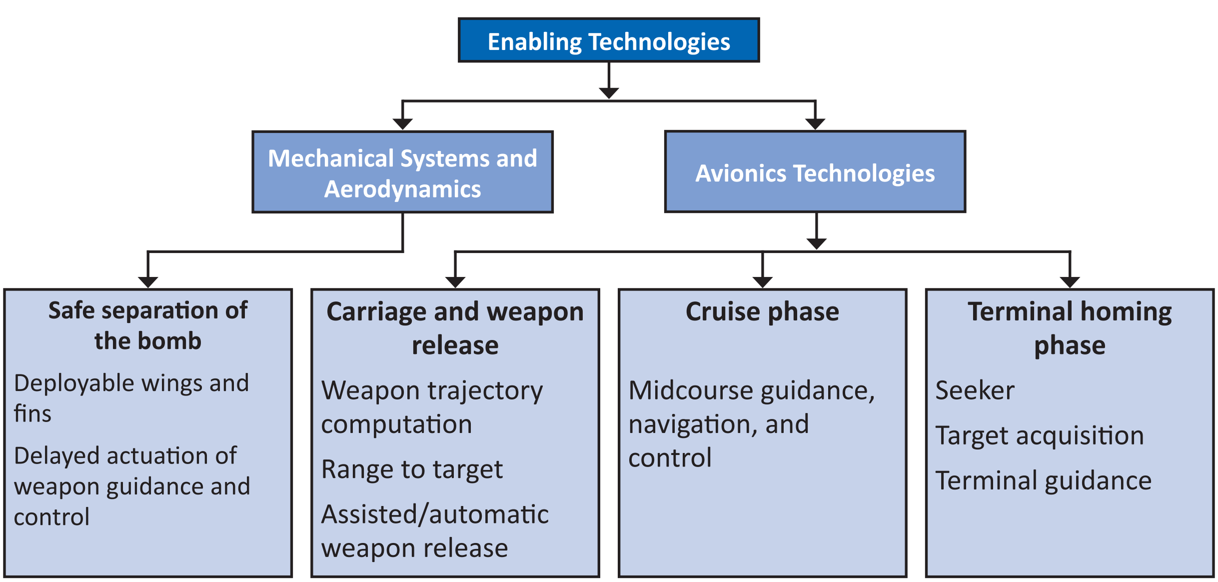
There should be no restrictions on the manoeuvres of the aircraft with the weapon loaded, especially any emergency manoeuvres required for the safety of the aircraft. The bomb and its interface with the pylon should have the structural integrity to withstand the loads experienced during carriage on the aircraft in flight.

c) **Safe Release & Separation**

The bombs should separate safely from the aircraft without causing any damage to it, under normal and emergency flight situations within the flight envelope for which it is cleared. Any change in the physical configuration of the bomb, like deployed wing or fins, is allowed only after its transient dynamic characteristics are stabilised and it travels a safe distance away from the aircraft. These time delays, which were achieved through a lanyard mechanism earlier, are nowadays done through highly reliable electro-mechanical devices.

Enabling Technologies

The enabling technologies for a smart weapon can be mainly categorised as shown in the flowchart.

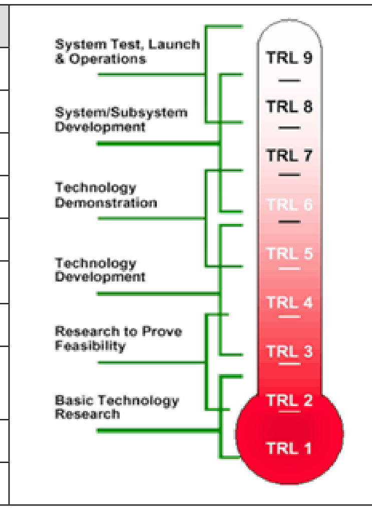


Technology Readiness Level (TRL)

The TRL for technologies in Indian smart glide bombs of are marked in Table 1.

Table 1. Technologies involved and TRL

Technology	Technology Status
Mechanical Systems	9
Wing & Fin deployment mechanisms	7
Safe separation	8
Pyro Devices	8
Avionics Interface	8
Mid-Course Guidance systems	7
Seekers-EO/IR (Lock-on before launch)	7
Terminal Guidance and homing (Lock-on before launch)	7
Seekers-EO/IR (Lock-on after launch)	3
Terminal Guidance and homing (Lock-on after launch)	3



(Source: *Airspace Systems.* https://web.archive.org/web/20051 206035043/http://as.nasa.gov/aboutus/trl-introduction.html, accessed: October 13, 2018)

The technology readiness level and the status of the technologies are explained in the Figure 5. TRL 1 denotes the lowest level of the technology, and TRL 9 denotes the highest level of technology status.

The initiatives by various research institutions in India have resulted in improved TRLs for most of the critical enabling technologies like deployment mechanisms, mid-course Guidance, Control and Navigation, Aerodynamic optimisation, integration with Avionics systems of existing aircraft and safe carriage and separation from these aircraft. However, the most critical enabling System and Technology, that of Terminal Homing Seekers, especially with Lock-On-After-Launch (LOAL) capability is yet to mature within the country. Designers have been able to demonstrate their capabilities in designing the computers and embedded algorithms required for using the Terminal Homing systems. But unrestricted access to critical components like Focal Plane Arrays, and even total seeker systems in the desired numbers is what is preventing them from achieving the desired progress.

The recent conflict on India's western border shows the importance of precision strike munitions required to achieve single-pass kill capability for air-launch weapons. SPICE 2000 glide bomb is said to have been deployed in the strike conducted by IAF to destroy terror training camps.[10]

[10] The Hindu, Dinakar Peri, 27 February 2019, https://www.thehindu.com/news/national/when-12-warplanes-locked-on-to-the-target/article26379607.ece (accessed 20 March 2019)

Survey of Smart Bombs

A survey of the present glide bombs has been done for eight countries. Some of the main parameters looked into are range, warhead, weight, length, diameter, guidance system, accuracy, and launching aircraft. They have been tabulated in Appendix 1.

A survey of Laser Guided Bombs (LGB) and Guided Bomb Units (GBU) has been made and the same has been tabulated in the Appendix 2. Weapon systems have progressed world over right from the dumb gravity bombs to the smart weapons. The development of avionics systems, GPS, led to the development of laser guided bombs, guided bomb units etc. It can be seen from the table that the dumb bombs which were made earlier, have been converted into smart weapon systems with guidance units. Retrofitting has been used, and standard guidance kits have been developed which has improved the CEP of the bombs. With GPS and other mid-course guidance kits, the CEP has improved to the order of few tens of metres. When both the GPS and the INS systems work in tandem the CEP is of the range between 10-20m. The weapon systems with terminal homing have CEP in single digits. The Israeli Spice bombs for example have a CEP of 3 m which is much lower than the systems with just the mid-course guidance systems. Accurate weapon systems are possible with the advancement in MEMS, Nano-electronic technologies, miniature INS systems which are reliable and accurate.

Future of Smart Weapons

The smart weapons have evolved and come a long way from the dumb bombs. While the CEP achieved with bombs deployed from balloons was of the order of kilometres, advanced systems and technologies resulted in CEP of tens of metres for the bombs with mid-course navigation, and single digit, and even sub-metre CEP for the weapons with Terminal Homing systems. As enabling technologies mature and systems and subsystems become affordable the smart weapons will further evolve into intelligent weapons through innovative concepts.

The smart weapons could either be based on add-on-kits which make dumb bombs smarter, or an ab-initio design. However, the end objective is to achieve better accuracy with lesser number of missions and passes over the target area. Some of the developments which are expected to come along in the near future include addition of rocket motors, air breathing engines etc. Adding a rocket motor to the bomb makes it a missile, enabling increase in range or increased momentum at impact. Adding an air breathing engine takes it closer to a cruise missile with a distinct advantage in range and endurance. A glide weapon which, at present, can glide through a distance of 70 km would have its range increased to a few hundred kilometres.

Several path-breaking concepts like Multiple Independent Warhead Systems (MIWS) and cooperative homing, swarms by the MIWS are expected to evolve through innovative application of Systems and technologies developed from Unmanned Aerial Vehicles and Drones.

APPENDIX 1: SURVEY OF GLIDE BOMB

COUNRTY	GLIDE BOMB	RANGE (km)	WARHEAD (kg)	WEIGHT (kg)	LENGTH (m)	DIAMETER (m)	GUIDANCE	ACCURACY (m)	LAUNCH PLATFORM
India	Garuthamma Garuda	100 30	HE, ICL 20 HE, ICL-20	1000 1000	Not Specified Not Specified	Not Specified Not Specified	Not Specified	Not Specified Not Specified	Su-30MKI (Testing)
Israel	Spice bomb Griffen LGB	60	Mk 83, Mk-84	11,34,53,907	Not Specified	Not Specified	CCD/IR Laser homing	3 5	F-15, F-16, Gripen, Panavia Tornado
USA	GBU-15 GBU-12 Paveway	14.8	907	1651 230	3.9 3.27	Not Specified 0.273	Laser guided	9.3-27.8 1.1	F-4 Phantom, B-452, F-111, F-15
Russia	Drill KAB-500KR	30+ 15-17	15*20=300 380	540 520	3.1 3.05	0.45	Low light television	Not Specified	Not Specified Not Specified
China	GB-6 Stealth Glide bomb FT-12	130 150	500	680 500 (or 700)	Not Specified Not Specified	Not Specified Not Specified	Satellite based and INS/GPS	Not Specified 20	Not Specified Not Specified
France	A-to-G modular weapon (AASM)	50-60	250	340	3.1	Not Specified	Hybrid INS	10	Mirage-20, Rafale
United Kingdom	Free Fall LMM (for UAV)	8	3	13	0.7	0.076	Multi-mode guidance	Not Specified	Tested from Schiebelcamcop- ter S-100
Pakistan	Takbir Bomb H-2 SOW H-4 SOW	80-100 60 120	200-250 Not Specified Not Specified	Not Specified Not Specified	Not Specified Not Specified	Not Specified Not Specified	Satellite Electro-optic guidance	Not Specified Not Specified	Not Specified Mirage III, V JF-17 (Speculated)

Appendix 2: Survey of LGB and GBU's (non-exhaustive list)

General Purpose bombs	LGB kits	LGBs	Guidance units	Comments
United States of America **Mark 80 series** Mark 81, 82,83,84 which are 250,500,1000,2000 lb respectively	Paveway I, II, III systems were developed as kits and added to the dumb bombs	Mk 80 series of weapons can be converted to smart bombs by adding Laser guidance, i.e. as LGB's	Mk 80 series can be converted to smart bombs by using GBU Paveway II, GBU JDAM, all of which have a guidance system (INS/GPS based) with it.	---
British 540lb. and 1000 lb. bombs	---	---	---	Wide range of pins, fuse and retarder options. Increasing usage of guided bombs
Russian 1954 series high drag bombs 550,1100,3300,6600 lb respectively	KAB 1500L, KAB 500Kr are guidance kits; similar to the Paveway systems	---	KAB 500 L is a laser guided bomb developed by the Soviet Union, fitted on FAB 500 bombs.	Max altitude 12000m, and 1000 km/hr
France SAMP BL EU 2, SAMP 25FE, SAMP T400, SAMP BL4 are 250,250,400,1000 kg bombs respectively	Bombe Guidée Laser (BGL) systems of MBDA developed on similar lines as the US Paveway guided bombs, BGL 250,400,1000 kg bombs; weapon system is called as ARCOLE	---	---	---
Israel	Addition of Laser guided kits called LIZARD; the weapon system was called as WIZARD; used on Mk series weapons	---	Griffin LGB kits used on Mk 80 series of bombs and other dumb bombs, converts them to guided smart bombs	Spice guidance kits, EO guided, expensive when compared to GBU's
India HSLD bombs of 250, and 450 kg	---	ADE developed	Sudarshan LGB kit developed, effective range 9 km Next generation LGB(NG-LGB) with range of 50 km under development	Two types of tail units, Retarder Tail Unit (RTU) for high-speed low-level bombing and Ballistic Tail Unit (BTU) for high-speed high-altitude bombing

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Abstract: The concept of aerial bombing has evolved and undergone significant improvements in terms of technologies, systems and deployment. While the bombs dropped from balloons in the second half of nineteenth century had a Circular Error Probability (CEP) of a few kilometres, the most recent smart glide weapons can achieve sub-metre CEP. The revolutionary developments in the field of Electronics, Sensors, Software and Mechanisms in the recent years, and their impact on improved performance of the systems are highlighted. This report gives an overview of evolution of aerial bombing systems and technologies over the decades, and also the future of smart weapons.

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