Military technology

Modern satellite navigation aided weapons

Dr Carlo Kopp

Satellite navigation (SATNAV) systems – exemplified by the US Navstar GPS system, the Russian Glonass system, and the emerging EU Galileo system – are becoming a ubiquitous technology across many applications. The most mature and widely used of these systems is GPS, which has found a wide number of civilian applications, rivaling its sibling, the Internet, and is the case study of civil community benefit from military basic research. Less visible is the extent to which SATNAV technology has invaded the domain of weapons guidance. Two decades ago SATNAV was used only as supplementary guidance system in the most expensive category of long range cruise missiles – now it is pervasive.

F-22A Raptor dropping a GBU-39/B Small Diameter Bomb.

When the GPS system was conceived, the primary agenda was to provide an all-weather and all-altitude capable affordable replacement for stellar tracking navigation systems, for use by military platforms and long range strategic weapons such as ICBMs, SLBMs, ALCMs and SLCMs. Long range navigation during that period was shifting to inertial systems, which accumulate position errors over time. GPS provided the capability to continuously correct the inertial errors, so that the positioning accuracy of the vehicle did not degrade with time of flight.

The first platforms to be fitted with GPS receivers were US strategic bombers, warships and submarines. The first weapons to be fitted were the AGM-86 series and RGM-109 series cruise missiles. Early receivers were bulky, heavy, power hungry, slow to acquire and track satellites, and had limited accuracy. A typical period receiver was a single-channel design, progressively stepping its way through all visible satellites until enough measurements were made to perform a position calculation. Common problems in early receivers included frequent losses of signal, slow synchronization, and slow revisit rates. For most period applications this did not matter.

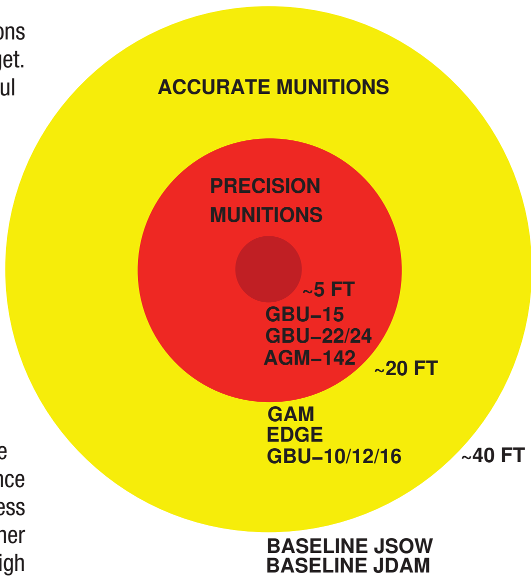
The situation changed dramatically during the early 1990s as the size, weight and power consumption of GPS receivers declined. Receivers became small enough to install in guided bomb tail-kits.

Until then the primary guidance techniques used in smart bombs and tactical missile rounds were television homing guidance, and laser homing guidance, also used in artillery rounds. Both relied on having clear line of sight to a target, which resulted in basic operational limitations due to the local environment – low cloud and atmospheric haze could reduce signal levels to the point where lock was broken and the weapon went ballistic. Another less obvious problem with these passive and semi-active optical techniques was that the seeker provided accurate measurement only of the relative angles between the weapon and the target, which put hard limits on the particular guidance control laws which could be used, and thus the shape of the weapon flight trajectory. While techniques such as proportional navigation can work very nicely, more than often the kinetic and potential energy of the weapon, determined by its initial speed and height, were not efficiently used to maximize weapon range or optimize its impact angle during the terminal or "endgame" phase of flight.

The US Air Force sought to overcome these problems with the Inertially Aided Munitions (IAM) program during the 1980s, the intent being to produce an all weather smart bomb which could

F-15E releasing five GBU-31 JDAMs.

autonomously fly through all weather conditions along an energy optimal trajectory to the target. The inertially aided bomb proved to be successful in its technical objectives, but the cost of the inertial units with sufficiently low drift to meet precision requirements was much too high for an affordable mass production weapon.
The advent of GPS changed this completely, as the combination of a low cost GPS receiver and low cost inertial unit provided viable accuracy at a fraction of the cost of a top end pure inertial system with equal accuracy.
A less obvious advantage of the GPS aided inertially guided bomb was its autonomy after launch, as an aircraft could preprogram multiple weapons for multiple proximate targets, and once the bombs were released could immediately egress the target area as there was no need to further support the outbound weapons. This was of high value tactically, as it minimized aircraft exposure.
The first attempts to develop a GPS guided bomb were performed by DSTO in Australia, but the program did not progress due to great skepticism in Russell Offices during that period. The RAAF had to wait almost two decades for its first GPS aided bombs, sourced from the US.
The first GPS aided inertially guided bomb to enter service was the Northrop GBU-36 GAM (GPS Aided Munition), unique to the B-2A Spirit, and based on the Mk.84 2,000 lb bomb. It was soon followed by the 5,000 lb GBU-37 GAM, which used the bunker buster warhead from the GBU-28. The GAM weapon system introduced an important innovation, which was a form of platform referenced differential GPS. Before the GAM was dropped, the launch aircraft weapon system would program it with a list of exactly which satellites the GPS receiver on the launch aircraft was tracking. In this fashion the GPS errors seen by the bomb and the launch aircraft were identical, and automatically compensated each other, resulting in much improved accuracy



GUIDED MUNITION ACCURACY (CEP) [ft]

compared to a more basic use of GPS.
The success of the GAM spurred the development of the Joint Direct Attack Munition (JDAM) family of weapons, based on much the same concept, but intended for use across the full spectrum of combat aircraft. Initial objectives for the JDAM were modest – accuracy of the order of 12 metres, which was inferior to laser and TV guidance, but vastly better than dumb bombs.
In parallel with the Air Force JDAM, the US Navy developed the GPS aided inertially guided AGM-154 JSOW (Joint Stand Off Weapon), a gliding airframe which could be fitted with submunition or penetrator payloads.
The JDAM was first used en masse during the 1999 bombing of Serbia, carried by the B-2A Spirit fleet for all weather attacks on strategic targets. The success of the initial JDAMs rapidly led to accelerated production. Initial variants were the 2,000 lb GBU-31 and 1,000 lb GBU-32, soon followed by the 1,000 lb navy GBU-35. The most recent variant of the family is the 500 lb GBU-38, widely used for counter-insurgency operations.
In this campaign the USAF innovated operationally, by distributing to squadrons computer generated charts of local GDOP errors versus time of day and date, allowing strikes to be planned into time periods where the GDOP error was minimal for that geographical location. Anectodal claims of errors as low as two metres exist.
The success of the JDAM produced immediate effects. One was that integration across other combat aircraft was accelerated, to the extent that the JDAM is now almost ubiquitous. An important aspect was that platforms not equipped with laser targeting pods could be cheaply provided with all weather accuracy. The B-52H and B-1B Lancer fleets were rapidly equipped for JDAM – a decision which proved critical two years later as the USAF annihilated Taliban and Al Qaeda troops in Afghanistan. For the first time ever, heavy bombers gained the high accuracy of tactical fighters.
Another effect was that funding was provided to develop highly accurate wide area differential guidance, resulting in the US WAGE and EDGE systems, which provide precision capability.
The third effect, arising from the mass production of low cost GPS inertial packages for the JDAM and JSOW, was the retrofit of these across a wide range of existing munitions. Boeing retrofitted JDAM derived hardware into variants of the AGM-84 Harpoon/SLAM family of short range cruise missiles, the AGM-86C CALCM cruise missile, and rebuilt existing television/IIR weapons into the EGBU-15 glide weapon and AGM-130 standoff weapon. Raytheon/TI retrofitted their JSOW derived systems into the EGBU-24/28 Paveway III laser

guided bomb, and developed the new EGBU-10/12/16 Paveway IV series.

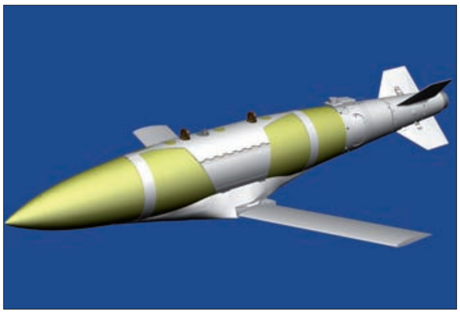
The advent of GPS guidance across so many legacy and new weapon types created a market for GPS jammers, quickly occupied by Russian industry. In turn this produced a surge of US funding to enhance the jam resistance of receivers, and to develop highly jam resistant phased array technology antennas.

The two latest US air delivered smart munitions to enter production, the GBU-39/B Small Diameter Bomb, and the AGM-158 JASSM, are both designed around GPS aided inertial guidance. GPS has also found its way into large caliber guided artillery shells.

The AGM-88E AARGM (Advanced Anti-Radiation Guided Missile), the latest in the HARM family, is also equipped with a GPS inertial package, as is the latest AIM-120D AMRAAM Air to Air Missile.

The revolutionary impact of GPS across the full spectrum of guided munitions has also been reflected in Russian and Chinese guided weapons. The Russians recently introduced the KTRV-GNPP KAB-500S/S-E, which is a satnav inertial guided 500 kg bomb, with a Kompas PSN-2001 (Pribor Sputnikovoy Navigatsii) satellite receiver, which is claimed to use 24 channels and be capable of using secure Glonass and GPS C/A signals. KTRV this year also announced the new Kh-25MSE satnav inertially guided missile, derived from the existing AS-10 Karen airframe, an analogue of the US AGM-65 Maverick series. This highly accurate battlefield weapon uses a separate radio uplink for differential corrections transmitted by a local ground beacon.

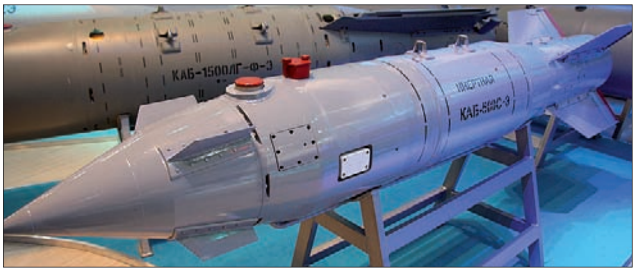
The Chinese have been much more active in this area, developing the Luoyang / CASC FT-1 through FT-5 and LS-6 series of satnav inertial guided bombs and glide bombs. These weapons are direct equivalents to the US JDAM series, and its winged glidebomb derivatives, such as the Australian developed JDAM-ER series. No less importantly, the new LT-3 laser guided bomb combines a P-nav precision laser seeker with an LS-6 tailkit, to produce a weapon directly equivalent to the Boeing GBU-54/B Laser JDAM.



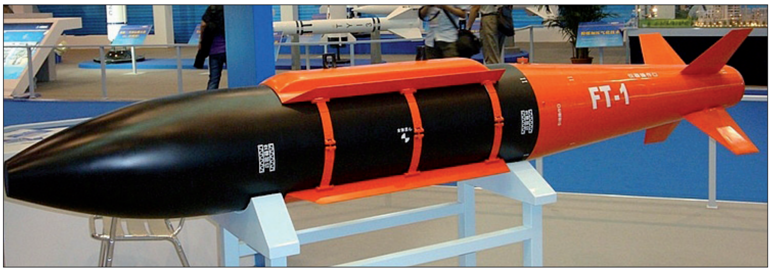
Australia's JDAM-ER combines the JDAM tailkit with the HdH/DSTO glide wing kit.

We can expect both the Russians and Chinese to follow the US lead, and retrofit satnav inertial technology across a wide range of legacy munitions, likely to also include long and medium range Surface to Air and Air to Air Missiles – the 3M54/14 / SS-N27 Sizzler cruise missile is already so equipped, making it a "dual role" weapon like late model US Harpoons.

In conclusion, satellite aided inertial guidance is now becoming ubiquitous across all guided munition categories, globally, either as the sole guidance system, or the basic guidance system, where it is supplemented by a homing seeker. Future developments will be centred in reducing costs, improving antenna jam resistance and multipath rejection, and integrating existing and future differential systems to improve accuracy. Satellite inertial guidance is now the dominant technology and this will continue for the foreseeable future.



KTRV/GNPP KAB-500S-E.



The Luoyang FT-1/FT-2 "Sino-JDAM" are equivalents to the GBU-32 JDAM, the latter including a glide wing kit.