**INTRODUCTION**

GPS retransmission systems Global Positioning System (GPS) technology is increasingly being applied in many different military applications beyond navigation. Soldiers use GPS to enhance situational awareness on the battle field with systems such as Land Warrior. GPS applications are utilized for precision aerial resupply via the Joint Precision Airdrop System (JPADS) to guide ammunition, medical supplies, or food to units operating on the ground. GPS enabled asset tracking may provide current position and status of high value assets, such as VIPs, nuclear weapons, etc. In training applications, GPS technology may be used to track the participating assets, scoring the exercise and enabling a far more instructive de-brief.

GPS provides accurate target position information to smart weapons deployed from aircraft or ground based platforms, improving accuracy and lethality of these weapons systems. Have successfully been utilized in combat since 2004 to provide live wireless signals to commercial and military GPS receivers inside volumes where a clear view of the sky is unavailable. Successful examples include military free fall (MFF), precision aerial resupply (JPADS), air and ground assault, and ground vehicle patrols (DAGR, Land Warrior). GPS retransmission systems have been successfully employed on a range of platforms, including C-130, C-17, CH-47, MH-60, HMMWV, Stryker, Bradley, and more.

This white paper will discuss how GPS Retransmission can be a very cost effective solution to the problem of GPS denied environments for delivery of GPS guided munitions from aircraft weapons bays, under-wing munitions pylons, or artillery & mortar tubes.

GPS - a Technical Perspective

The GPS system traces its origins to the sixties. In 1960, Aerospace Corporation was founded for the purpose of applying then advanced technology to space and ballistic missile problems. In 1963, the company started work on Project 621, the Global Positioning System, a scheme for replacing strategic aircraft astro-navigation systems with satellite navigation. Whereas astro-navigation systems needed clear sky to track stars, the satellite navigation scheme would use microwaves and a satellite distributed master clock, thereby providing all weather operation and superior accuracy

The Operational GPS Constellation uses 24 satellites, of which 3 are spares, orbiting in precise 12 hour orbits. The orbit geometry is adjusted so that these orbits repeat the same ground track once perday, and at any point on the Earth's surface at any given time the same configuration of satellites should be seen.

The satellites are grouped, nominally in sets of four, into six orbital planes, each of which is inclined at approximately 55 degrees to the polar plane. A user at any point should be able to see between five and eight satellites at any time.

The GPS system provides two navigational services, the military Precise Positioning Service (PPS), and the civilian Standard Positioning Service (SPS). PPS provides nominally 17.8 m horizontal accuracy, 27.7 m vertical accuracy and time accurate to 100 nanoseconds. SPS provides nominally 100 m horizontal accuracy, 156 m vertical accuracy and time accurate to 167 nanoseconds, and is available to civilian users. The degraded accuracy results from the use of Selective Availability. In practice, achieved accuracy can significantly better the nominal figures.

**GPS Retransmission System Architectures**

GPS retransmission systems, in their simplest form, include at a minimum the following elements:

• Active Antenna (Active meaning the antenna includes an integrated Low Noise Amplifier)

• Interconnecting Coaxial Cable(s)

• Retransmission Amplifier/Signal Conditioner

• Passive Retransmission Antenna (or repeat antenna)

Obstruction

Retransmission

Antenna

LNA

Coaxial

J4 Cable

Retransmission Amplifier/Signal Conditioner

GPS

Active GPS Antenna

Rx.

**Figure 1. Simple GPS Retransmission System**

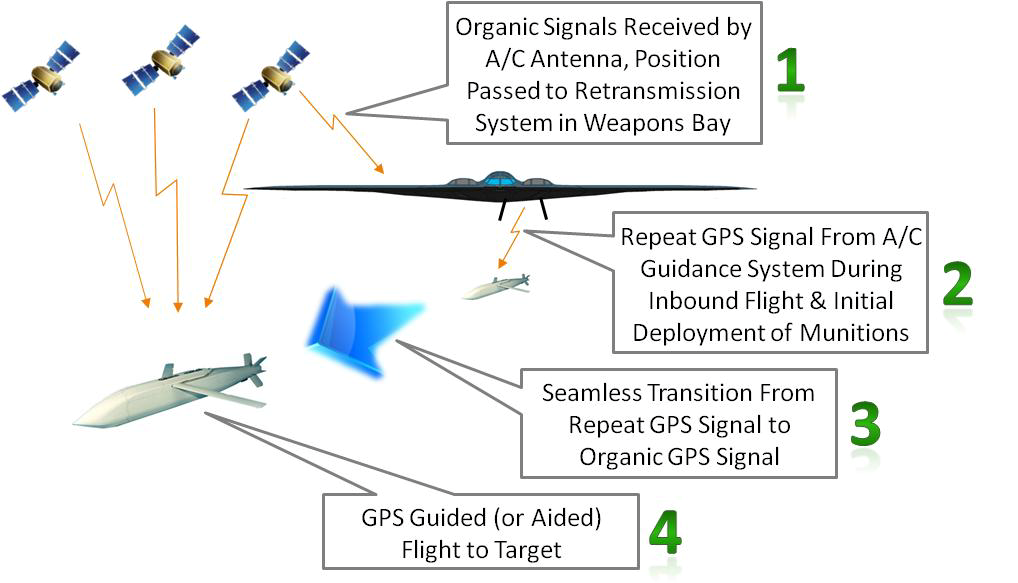
In this system, the GPS satellite signals are received by the active (receive) antenna, amplified and conditioned by the retransmission amplifier, and re-broadcast on the GPS frequency(s) by the retransmission antenna. Because the signal delay through the GPS retransmission system is common for each satellite once the signals are received by the exterior antenna,

GPS receivers operating in the retransmitted signal environment will generate a location, not at their actual position inside of the hangar, vehicle, or aircraft, but rather they will calculate the position for the system’s receive antenna that is located outside in view of the LOS signals. This limitation, however, is not critical for the applications described above, as the derived location is close enough to accomplish the intended function.

In the application of a GPS retransmission system repeating a wireless GPS signal to munitions stored in an aircraft’s enclosed weapons bay, the system utilizes the aircraft’s existing active GPS antenna to receive a signal from the satellites. The signal is transferred through an RF splitter to the passive, or repeat antenna, and received by the munitions’ active antenna, thereby providing a live GPS signal to the weapon.

This process creates an efficient manner for installation of munitions onto the aircraft by the weapons technician. Similarly, this system provides a more robust and efficient manner of transferring GPS data to munitions prior to separation. The guided munitions utilize their active antenna to receive a “hot” position signal and do not require a separate MIL-STD-1760 compliant GPS umbilical to provide this positional information then switch over to the antenna post-separation. Most importantly, during separation the weapon seamlessly transitions from repeat GPS signal to organic signals by keeping the ephemeris, within the weapon’s GPS receiver, active.

A transition from the umbilical signal to the munitions antenna is unnecessary, removing the burden from firmware or electromechanical switch within the weapon.



**Figure 2. GPS Retransmission System Function in Aircraft Deployed Munitions**

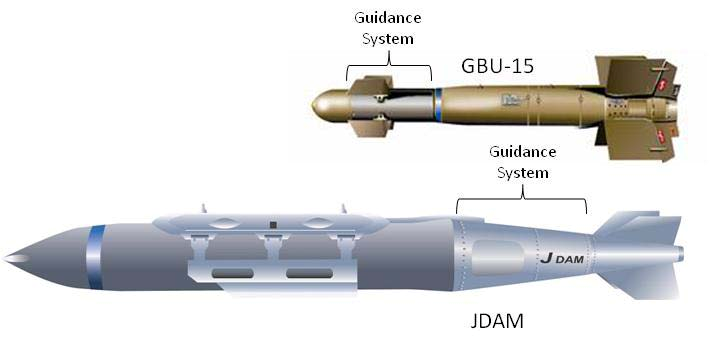
Figure 2 graphically depicts the concept of GPS retransmission systems for use with GPS guided munitions deployment

Within the aircraft weapons bay, the repeated GPS signal can be tailored to meet the requirements of different aircraft or weapons configurations. The signal power can be tailored to ranges of a few inches to ranges of 12 ft, depending on the application and requirements. Similarly, one or multiple repeat antennas, or near field antenna couplers, may be utilized in the system design to provide maximum GPS signal coverage for the weapons bay while eliminating the potential for the signal to propagate beyond the intended area of coverage. For example, a GBU-15

Air-to-Surface GPS guided weapon houses the guidance system and GPS antennas in the forward portion of the weapon. Alternatively, the JDAM GPS guided weapon houses the guidance system and GPS antennas at the rear of the system, with one of the GPS antennas facing rearward mounted to the tail section of the weapon, shown in Figure 3.

When loaded aboard an F-35 weapons bay, for example, the GPS retransmission system must be designed in a manner to provide GPS signal coverage for both types of munitions and may require two repeat antennas if both weapons were to be loaded onto the aircraft, simultaneously, for a mission.

This configuration requirement would also hold true with munitions systems loaded onto an aircraft’s wing pylon or underbelly where a clear view of the sky may not always be available. A repeated GPS signal extending 12 to 24 inches from the passive antenna or near field antenna coupler will provide a GPS signal to the munitions to ensure immediate organic positional information upon separation.



**Figure 3. GPS Guided Weapons Utilized by US Military Branches**

Figure 3. When loaded aboard an F-35 weapons bay, for example, the GPS retransmission system must be designed in a manner to provide GPS signal coverage for both types of munitions and may require two repeat antennas if both weapons were to be loaded onto the aircraft, simultaneously, for a mission

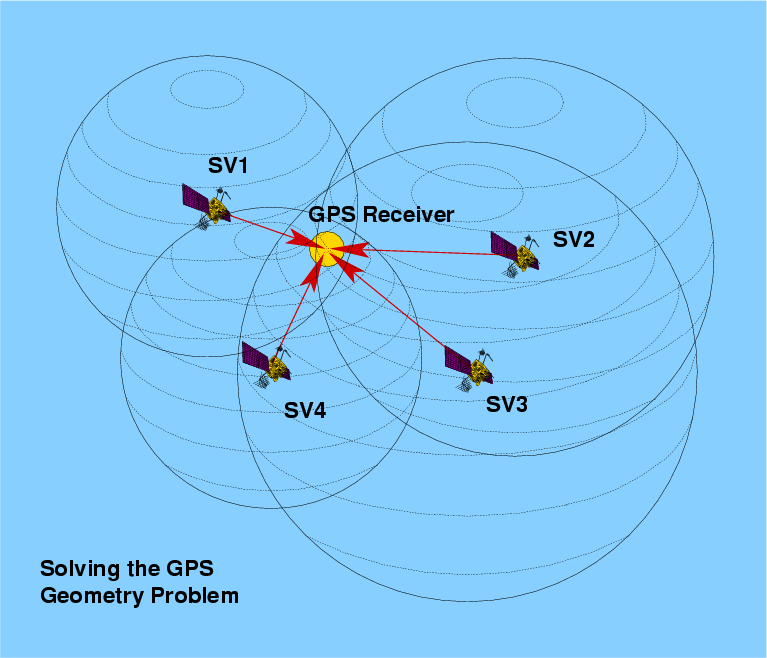


**Figure 4. F-35 Loaded With Different Types of Munitions**

Figure 4 demonstrates a typical weapons installation aboard the F-35 during qualification testing, emphasizing the requirement for consideration of the diversity of weapons systems and their antenna locations relative to the weapons bay.

**GPS Signals, Messages and Error Sources**

The basic idea behind GPS is straightforward, implementation becomes somewhat more complex. Both carriers are modulated in phase (conceptually similar to FM radio) with Pseudo-Random Noise (PRN) codes



GPS receivers can measure platform velocity by differencing consecutive position measurements, or by measuring the Doppler of satellite carrier signals and using this with computed direction to each satellite, to calculate velocity in three axes (like aircraft Doppler Nav inside out). Some receivers may use both methods to improve accuracy.

There are a number of error sources in GPS navigation. Electrical noise in the receiver, a well as phase noise in the PRN code modulation will degrade accuracy by about 2 meters. Each satellite uses four atomic clocks (two cesium and two rubidium) which are highly accurate, but drift in time nevertheless. If satellite clock errors are not corrected by the ground station, this will degrade accuracy by about one meter. Errors in orbital position estimation will also lose about one meter. As well unmodelled signal propagation delays in the troposphere, due changes in humidity, temperature and pressure changing the refractive index, will lose about one meter. Multipath, the effect of satellite signals bouncing off obstacles and arriving from several directions each with different time delays, will degrade accuracy by about 0.5 meter.

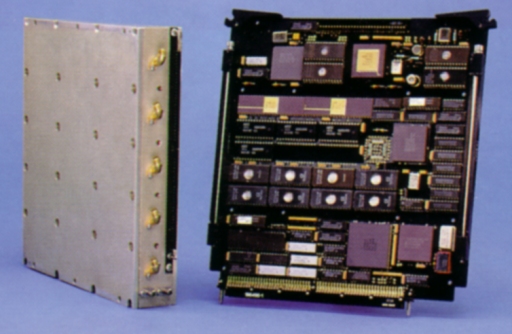
Non-military users will also experience an artificially produced error, resulting from Selective Availability. The SA mechanism introduces a time varying bias in the C/A signal, which is designed such that it is virtually impossible to remove. The potential C/A code accuracy of at least 30 meters is thus reduced to the nominal 100 meters.

**GPS Receivers**

With a system as complex as GPS there are a multiplicity of ways in which a receiver can be built, and this results in a wide range of achieved accuracies and costs across receiver types. The simplest receivers are single channel receivers, which time share a single channel of receiver hardware across the satellites in view. Whilst this saves in hardware costs, it is slow and as a result such receivers do not usually deliver spectacular performance, and are usually ill suited to fast moving platforms such as aircraft. Most high performance receivers today are five channel receivers, which dedicate a channel of receiver path and correlate hardware to each of the five or more satellites they are tracking. Such receivers can also accommodate platform motion more readily, indeed most airborne military receivers use at least five channels.



*Rockwell 5-channel commercial GPS receiver fits on a 4 x 2.5 in. printed circuit board*



*The Magnavox MX-8000 Anti-jam GPS Receiver (AGR)*

**What is GPS Retransmission?**

GPS Retransmission, or GPS Repeating, is the art of making the live GPS signals available to handheld or mobile GPS applications at locations where the signals are otherwise not available or experience limited, unreliable availability. Proven applications include the following:

• In the crew compartment of a military vehicle,

• In the cargo or weapons compartment of a military aircraft,

• In the garage or hangar bay of a military maintenance facility,

• In the final assembly stage of a military equipment manufacturer,

• In the wet-well or maintenance deck of a naval ship.

**Differential GPS Systems**  
  
Systematic GPS errors as well as the unavailability of GPS P-code to civilian users was seen as a challenge by many in the civilian technical community, and given the potential commercial payoff in using GPS to its full potential, it did not take very long for techniques to be developed to defeat the Selective Availability of the GPS system.

  The central idea behind all Differential GPS schemes is that of broadcasting an error signal which tells a GPS receiver what the difference is between the receiver's calculated position and actual position. The GPS error signal can be most easily produced by siting a GPS receiver at a known surveyed location, and by comparing the received GPS position with the known actual position. The difference in positions will be very close to the actual error seen by a receiver in the geographical vicinity of the beacon broadcasting the error signal.

Differential GPS schemes thus require a beacon to broadcast the local GPS error signal, as well as an airborne GPS receiver which can decode the broadcast, extract the error signal, and apply it to the position estimate which it has derived from the GPS constellation. Accuracies achieved by civilian C/A based DGPS have been as good as 1-3 meters, which has led to their application to areas such as Cat III Instrument condition approaches and landings. This level of accuracy is also more than adequate for the precision guidance of munitions, and DGPS schemes have thus become an area of major military interest.  
  
What is even more important, is that GPS guided weapons can be fed DGPS derived positions prior to release from an aircraft, and should their flight time be relatively short, very little positional error will be accumulated enroute to the target. Many existing munitions, e.g. the BGM-109 Block III Tomahawk and the AGM-130/GBU-15 already exploit P-code GPS to improve the accuracy of the inertial midcourse guidance. Adding DGPS corrections will significantly improve the positioning accuracy of the weapon prior to transitioning to terminal guidance. 

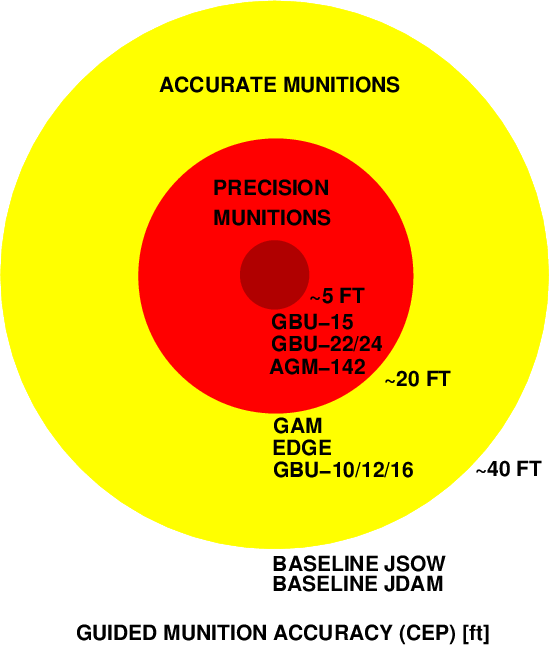
*RAAF's AUP Program will see the F/RF-111C fitted with a highly accurate 5 channel Rockwell MAGR GPS receiver, to provide precision velocity and position updates for the aircraft's dual RLG INS equipment*

To extend this model further, an aircraft could transmit via data link both DGPS corrections as well as the updated position of a moving target to a weapon in flight, which would use these to adjust its aim point on the way to the target.

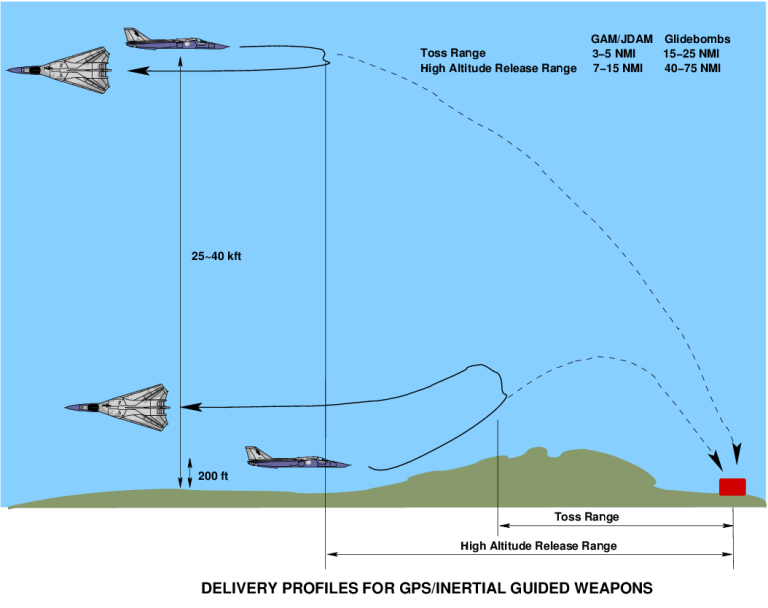
**GPS Guided Munitions**

The availability of GPS and highly accurate Differential GPS navigational aids has created a revolution in aircraft navigation. What is less commonly known is that GPS and DGPS are about to transform what we understand to be the nature of precision bombing. Indeed, the introduction of GPS and DGPS guided munitions will have an impact not unlike the introduction of laser guided bombs, with the resulting force multiplication effects significantly improving the potency of Western air forces as a strategic power projection tool.

For an aircraft to support such munitions, it will require a DGPS receiver, a GPS receiver and interfaces on its multiple ejector racks or pylons to download target and launch point coordinates to the weapons.  
  
The development of purely GPS/inertial guided munitions will produce substantial changes in how air warfare is conducted. A GPS/inertial guided weapon which is updated with DGPS corrected position will, if properly designed, offer accuracy only slightly lesser than a proportionally guided laser guided weapon or TV guided weapon. Unlike a laser guided weapon, a GPS/inertial weapon does not require that the launch aircraft remain in the vicinity of the target to illuminate it for guidance - GPS/inertial weapons are true fire-and-forget weapons which once released, are wholly autonomous and all weather capable with no degradation in accuracy. Existing precision weapons require an unobscured line of sight between the weapon and the target for the optical guidance to work. GPS/inertial weapons are oblivious to the effects of weather, allowing a target to be engaged at the time of the attacker's choosing.



*The impending deployment of GPS guided bombs and glide bombs will revolutionize air warfare as we know it. Affordable, all weather attack on multiple targets by single aircraft will become the norm. This diagram depicts the relative accuracies of established laser and imaging optical weapons, against the published performance figures for the first generation of GPS and DGPS guided weapons.*



*The GPS guided glide bomb allows the single bomber to reclaim the upper portion of the penetration envelope. As these weapons can be released from above 30,000 ft at transonic speeds, and glide for up to 75 NMI, they allow a bomber to engage its target from ranges where SAMs are wholly ineffective, and fighter CAPs are hard pressed to perform without AEW and tanker support. This provides a significant advantage to the attacker, who can saturate defenses with multiple weapons.*

The model postulated here assumes the air defense system is functional, however should it become subjected to intense radar and communications jamming and direct attack, and should fighters be available to threaten the defending interceptors, this profile becomes both highly survivable and very dollar efficient, particularly in a low air defense density environment such as the Asia-Pacific. In any event, this approach defeats all AAA and point defense SAM systems, which are a plague during low level operations.

**Targeting GPS Guided Weapons**  
  
the deployment of DGPS/GPS/inertial weapons will create some interesting problems in the area of targeting. Whereas existing laser and TV guided weapons have an operator in the loop to refine the aim point and minimize collateral damage, generic GPS guided weapons are wholly autonomous and their accuracy is determined primarily by the accuracy of the target coordinates loaded before launch. Once released, they are committed and no corrections are possible. Only should the weapons be equipped with a data link receiver, capable of feeding target position updates into the autopilot during flight, are aim point corrections or attacks on moving targets feasible.

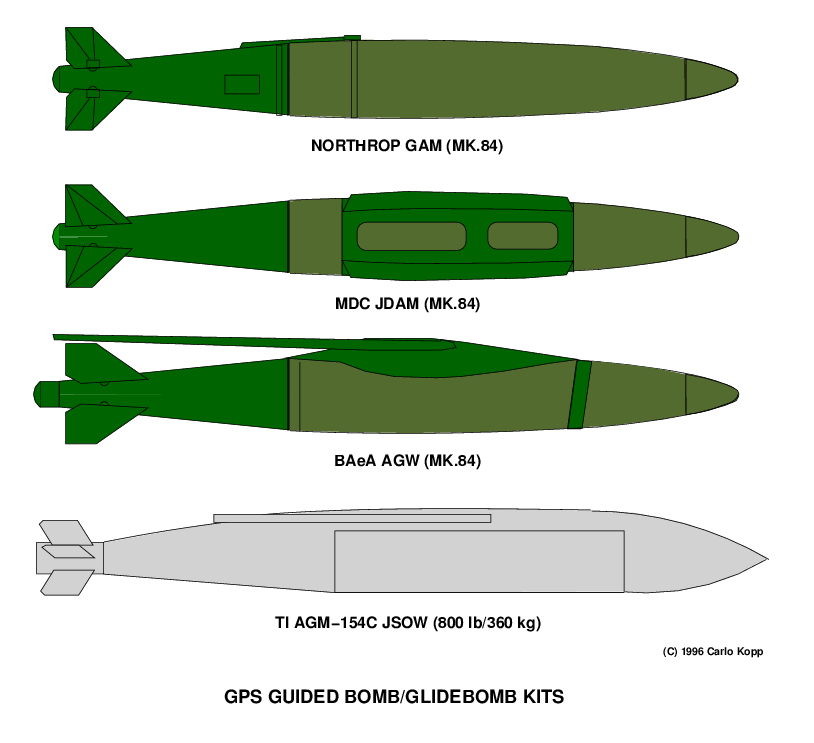
It is worth noting that a one way data link of this variety is a technically much simpler proposition than the wideband video data links used by TV guided weapons, and hence such a data link receiver will be much cheaper to build.

The use of any GPS/inertial guided weapons will place a premium on the quality of targeting information. Whereas contemporary satellite, aerial and radar reconnaissance can tolerate some inaccuracy as the delivering aircraft can visually acquire the target and correct the aim point if required, generic GPS guided weapons must be targeted accurately from the outset.

If the reconnaissance picture used for target selection is poorly registered against the maps used, or the maps are inaccurate, this error could not only compromise the attack on the target, but also produce politically problematic collateral damage.

A commander who unloads 8,000 lb of GPS guided bombs on infrastructure targets, only to find that a 0.5 mile error in his maps has placed the payload on a baby milk factory or religious or cultural artifact, is likely to be politically crucified if not by his own chain of command, then certainly by the lay media whose appetite for controversial death and destruction footage is insatiable

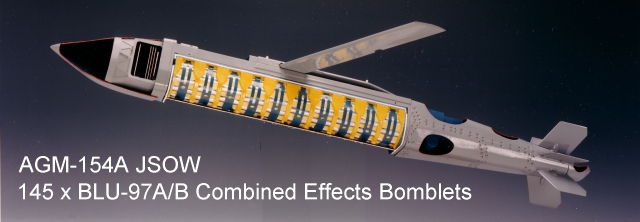
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**Hostile Exploitation of GPS Weapon Guidance**  
  
The more worrisome problem is that of GPS exploitation. Even during the Gulf War it was reported that the Iraqis used commercial GPS equipment to assist in calibrating Scud launch sites. The real problem will come about when Third World countries start dusting off their fifties and sixties technology cruise missiles and fitting them with commercial DGPS/GPS autopilots.  
  
Most of these weapons used combinations of inertial autopilot, radio command link and anti-ship radar homing guidance to attack either shipping or area land targets. In the latter instance, they were never taken seriously due their poor accuracy. With DGPS accuracies they become very effective standoff weapons.  
  
  
  
There are some very good examples. The Russians exported large numbers of AS-5 Kelt missiles, as well as ship launched P-21/SS-N-2 Styx missiles. The Chinese reverse engineered the Styx into the air and surface launched HY-2 Silkworm, and its derivatives, the larger HY-4 and C-601. These weapons typically carry 1,000 to 2,000 lb warheads, to ranges between 50 and 100 nautical miles. What is important is that the PRC is still manufacturing the Silkworm family of missiles and these have been very widely exported throughout the Third World.

**The Rockwell Mk.82 GPS guided Tailkit**

The USAF has nearly 100 B-1B aircraft in service, and these are now assigned to perform both conventional and nuclear missions. In the conventional strategic strike role, the aircraft can at this time only deliver Mk.82 or Mk.84 dumb bombs, the former off bomb racks and the latter off a rotary launcher. USAF ACC was unhappy with this limitation and contracted Rockwell to design a new bomb rack to support ten 1,000 lb cluster bombs rather than 28 Mk.82. A further contract has been let to provide support for the Wind Correct Munitions Dispenser (WCMD), an initially guided cluster bomb.

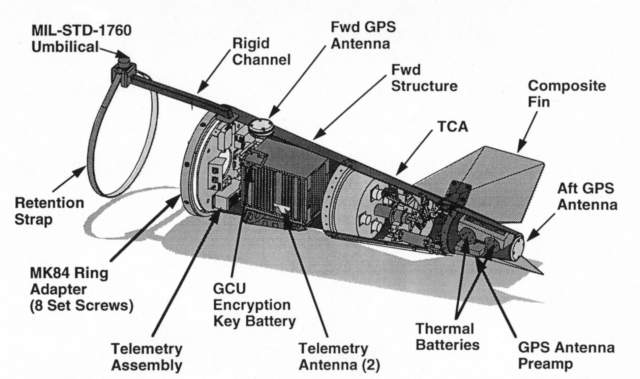



*AGM-154A/B/C Variants (Texas Instruments images)*

The EDGE Program  
  
Last year Technology Explained provided a comprehensive four part discussion of the new generation of GPS guided munitions, and their implications for air warfare in the next two decades. In this follow-up article, we will take a look at a very important technology demonstration program, which was sponsored by the USAF's JDAM program office.

The baseline GBU-15, used by the USAF and RAAF, is a glide bomb equipped with a TV or thermal imaging seeker and two-way radio data link. It was well suited for such a demonstration because it has both the volume to accommodate a GPS guidance package, once the existing seeker was removed, a highly reliable flight control section which simplified integration, and sufficient standoff glide range to guarantee a zero probability of hit should the DGPS system not perform and guidance default to inertial alone. Inertial errors increase with flight time, but GPS/DGPS errors do not. Six rounds were custom modified for the EDGE trials.  
  
  
Before weapon release the Kalman filtering software running on the bomb IFMU was fed with position and velocity data from the launch aircraft via the 1553B bus, in effect slaving the bomb to the position of the aircraft, with an allowance for the moment arm between the aircraft INS and weapon IFMU. Once the bomb was released, the GPS receiver would acquire five satellites within 10 seconds and the Kalman filter mode adjusted to support no less than 17 states. The filter was designed to progressively blend in GPS receiver measurements with increasing weight, after release (technical readers will note that the channel noise or error was initially assumed high, and then progressively reduced to match the expected error of the differentially corrected solution). This was to ensure that the data provided by the receiver was stable and "trustworthy", as receivers often take several seconds to settle in once activated. Differential corrections downloaded before launch was then fed into the Kalman filter. The software was implemented in DoD ADA high level language.



**Applications, Benefits, and Added Value**

When GPS receivers, or specifically the receiver’s antennas, are inside of vehicles (aircraft, land vehicles, boats, etc.) or buildings without a Line Of Sight (LOS) view of the GPS satellites, the receivers will not reliably provide position, navigation, or timing (PNT) information. This limitation can impact many military GPS applications, even if location data inside of the denied environment is not a requirement. For example, the receiver’s or system’s performance may be impacted in the following ways:

• When the receiver deploys from the vehicle or aircraft, the “time to first fix” (TTFF) can vary significantly based on various conditions (TTFF can be over 5 minutes worst case)

• GPS receiver battery life while operating inside of the vehicle is significantly reduced due to the computationally intensive signal acquisition process

• Lack of signal availability may preclude verification of system operation prior to deployment

• Targeting or landing zone updates are not immediately recognized by the GPS application due to ongoing satellite acquisition process.

With a GPS retransmission system installed and providing availability of the GPS signals in the otherwise denied environment, the applications may benefit in the following ways:

• In the weapons bay of a military aircraft, the GPS retransmission system:

 Enables acquisition and verification of weapons guidance payload prior to release

 Ensures confirmation of weapon systems guidance system status prior to release

 Simplified installation of weapons to aircraft eliminating GPS umbilical connection

 Increased reliability of aircraft weapons pylons due to elimination of umbilical connection

• In the cargo compartment of a military aircraft, the GPS retransmission system:

 Enables acquisition and verification of cargo payload receivers prior to air drop (JPADS)

 Eliminates TTFF, enabling payload guidance receivers to generate steering commands immediately upon exiting A/C

 Enables verification of position, velocity, and elevation of airborne soldier GPS prior to the jump

• In the crew compartment of a typical military vehicle, the GPS retransmission system:

 Maintains SA with valid location reporting even when inside of the vehicle, rather than reporting of “last known good” location, which would be the location just prior to entering the vehicle

 Eliminates costly delay in Time to first position Fix (TTFF) when exiting the vehicle

 Reduces GPS receiver battery consumption due to computationally intensive reacquisition process

• In the garage or hangar bay of a military maintenance facility and in the final assembly stage of a military equipment manufacturer, the GPS retransmission system:

 Eliminates requirement to perform maintenance outside of protective shelter, potentially exposing the asset and personnel to hostile fire

 Allows 100% system functional test, including the application’s receive antenna system

 Maintains “Hot” GPS Ephemeris enabling immediate taxi for A/C on alert status

**Performance Requirements & Expectations**

The state-of-the-art for GPS retransmission systems is such that certain levels of performance and quality are to be expected for any application. The following are the minimum performance criteria that absolutely should apply for a permanently installed solution where the system is optimized for installation on the particular aircraft.

• **Optimized Signal Coverage** – Optimized GPS signal coverage of the weapons bay can be accomplished given the proper antenna system design and installation.

• **100% Compatibility** – 100% compatibility is an absolutely reasonable requirement for GPS retransmission systems. If designed correctly, and appropriate methods are employed to address other system deficiencies – such as excessively high ERP or antenna system techniques to address multipath, GPS retransmission systems should be 100% compatible with any military or civilian GPS receiver utilized by any weapons systems, eliminating the requirement for non-recurring engineering of the stores management software to support GPS data transfer which may be specific to each weapon type.

• **Appropriate Signal Level** – GPS retransmission systems should be design to provide and maintain, regardless of variations within the GPS signal source, a precise GPS signal level within the coverage area that ensures GPS signal availability within the normal operating range of GPS Receivers.

• **Continuous GPS Lock During Separation** – Prolonged loss of GPS signal availability by the application receiver should not be observed, the GPS retransmission system should enable a seamless transition to the organic GPS satellite signals.

• **High Signal Quality** – The GPS retransmission system should be designed so as to maintain the GPS retransmitted signal quality. The Signal-to-Noise ratio of the retransmitted signal should not be degraded more than 3dB with respect to the LOS signal quality available outside of the aircraft.

• **Design & Manufacturing Quality** – With any aircraft system, a GPS retransmission system should demonstrate compliance to the military standards:

|  |  |  |  |
| --- | --- | --- | --- |
|  | Electrical Power Service Conditions | | |
|  | EMI/EMC | | |
|  | Environmental Conditions | | |
|  | Human Factors & Personnel Safety | | |
|  | General Safety | | |
|  | Software Development Process Quality | | |
|  | Construction | | |
|  |  | Materials, Processes, Parts |
|  |  | Finish & Color |
|  |  | Soldering |
|  |  | PWB |
|  |  | Interconnecting Wiring |

**Summary**

The proliferation of GPS and DGPS guidance is a double edged sword. On the one hand, this technology promises a revolution in air warfare not seen since the laser guided bomb, with single bombers being capable of doing the task of multiple aircraft packages. On the other hand, GPS and DGPS may be exploited by relatively unsophisticated industrial nations to provide them with a capability which until now has been the almost exclusive domain of the Western Alliance. The ease with which basic GPS signals can be jammed will result in another major cycle of ECM and ECCM development, as defenders and attackers build jammers and jam proof GPS receivers to counter jammers. To complete the analysis of this paradigm in air warfare, Parts 3 and 4 of this feature will review current US GPS and DGPS weapons development programs.

India should not fall behind in the GPS weapons game, the payoff in exploiting GPS is simply too lucrative to ignore. By the same token, Australia should look very hard at how it exploits the technology, and ensure that any GPS based weapons acquired are sufficiently resilient to Electronic Countermeasures’ to prevent jamming from compromising what has been gained. As the JDAM is expected to wholly displace the Pave way in US service during the first decade of the next century, the RAAF will have to look very carefully at what direct attack bread and butter munitions it plans to use on the F-111 and F/A-18 in this period. The JDAM may well find itself in service by default.

A follow on TE will address the USAF EDGE wide area differential GPS demonstration program, which has yielded some very impressive results, including positioning errors over wide areas of well below 1 meter.

**Conclusions**

The EDGE program demonstrated some very significant points. The first is that sub-meter positioning accuracies can be achieved using WADGPS schemes which exploit the full capabilities of military GPS receivers. The second was that substantial accuracy improvements can be achieved by using WADGPS schemes to augment the navigation solutions produced in GPS guided weapons. Because such WADGPS schemes allow for widely spaced ground stations, they are a viable proposition for operational deployment in any theatre where friendly territory can be accessed within 1000 NM of the intended area for weapon delivery.  
  
Analysis of test results and telemetry from the EDGE tests suggests that the principal source of error were GPS receiver multipath effects, and limitations in the update rate of the Kalman filters used. Experience with the ground stations initially was that multipath corruption was a serious source of error in the navigational solutions produced . As funding for the EDGE project terminated after the final drop, the USAF has yet to perform a more comprehensive analysis on the gathered test data and validate the conclusions of the tests. Given that Pave way II class accuracy was achieved during the tests, the USAF was not under any great pressure to do so.

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GPS Source Contact Information

Website: [www.gpssource.com](http://www.gpssource.com/)