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**GLOBAL POSITIONING SYSTEM: FUTURE  
DIRECTION FOR THE ADF'S PRECISION GUIDED  
BOMB CAPABILITY?**

**By**

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## **About the Author**

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## INTRODUCTION

Arguably, the 1991 Gulf War saw the most effective campaign in the history of air warfare. A key factor in the air campaign was the employment of precision guided munitions (PGMs), mostly laser guided bombs (LGBs). The success of PGMs demonstrated that, in general, targets that can be located may be accurately destroyed or neutralised by day and night, in almost any weather. More recently, the utility of PGMs has been reinforced by Nato operations in the Balkans. Despite the effectiveness of PGMs they can be an expensive capability to acquire in the numbers required to sustain an operational tempo; in this respect the LGB has proven to be a relatively cost-effective precision weapon.<sup>1</sup>

The force multiplier value of PGMs in the precision strike role has long been recognised by Australian strategic guidance. This has resulted in the RAAF having established a credible precision strike capability using the Texas Instruments (TI) Paveway series of LGBs. Despite the utility of this weapon, which accounts for the majority of the ADF's PGM inventory, there are operational constraints related to technical characteristics of laser guidance. Weapon delivery is dependent on constant target designation, a requirement that is compounded by the need for the designating aircraft to perform evasive manoeuvres in a hostile battlespace. Additionally, laser designators can only illuminate targets individually, eliminating the ability for concurrent multiple target engagements. Adverse atmospheric conditions, especially high moisture levels in north Australia, also impinge on the ability to adequately identify and illuminate a target, degrading the weapon delivery envelope.

Extant LGB operational limitations, especially in the context of the growing capabilities of modern air defence systems, have spawned the development of new generations of autonomous, all-weather air delivered precision bombs. The forefront of such technology is GPS guidance. GPS guided bombs are currently being introduced by the United States military to complement existing LGBs, although they will eventually dominate their precision guided bomb stockpiles. While GPS bomb guidance overcomes many of the LGB's shortcomings, they are not without their own operational constraints. In particular, concerns have been expressed regarding the susceptibility of the low-powered satellite-generated GPS carrier signal to jamming, spoofing and interference. The next generation of GPS receivers will incorporate a variety of anti-jam/anti-interference technologies and techniques to minimise vulnerability.

## THE LGB AS A FORCE MULTIPLIER: AN OPERATIONAL OVERVIEW

Precision has always been recognised as an important attribute of weapon development. While the genesis of modern PGMs is found in the Second World War, it was not until the Vietnam conflict that PGMs achieved sufficient systems maturity and reliability to enable wider operational employment. The conflict marked the introduction of a variety of powered and unpowered air-to-surface precision weapons

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<sup>1</sup> Typically, the acquisition cost of LGBs is 5-10 per cent of that of powered PGMs. Kopp, C., 'F-111 Upgrade Options', *Australian Aviation*, October 1998, p 37.

utilising command radio, electro-optic (EO), and infra-red (IR) guidance systems, but it was the low-cost and simple LGB which had the greatest impact<sup>2</sup>. A description of laser guidance technology is at Annex A.

The debut of the LGB demonstrated the weapon's potential as a cost-effective force multiplier.<sup>3</sup> With a Circular Error Probable (CEP) accuracy of approximately nine metres from a stand-off range of three to five kilometres the need to operate mass flights of aircraft directly against a single aim point disappeared.<sup>4</sup> Additionally, an aircraft dropping an LGB could release its payload from outside an enemy's defensive envelope, improving survivability. Since this time, LGBs have entered the arsenals of an increasing number of modern military forces - including Australia and its neighbours - while weapon system effectiveness has been progressively enhanced.

The 1991 Gulf War clearly demonstrated how radically precision attack has transformed the traditional notion of military campaign planning and execution. While LGBs accounted for only 4.3 per cent of the tonnage dropped by allied airmen in the Gulf War the weapons were credited with approximately 75 per cent of the critical damage achieved.<sup>5</sup> The effect of the allied precision strike campaign devastated Iraq's warfighting ability from the outset. Postwar analysis indicated that the 38 day air campaign had reduced Iraq's logistic ability to support the Kuwaiti theatre of operations by 91 per cent without creating wide-area destruction.<sup>6</sup>

The Gulf War has not been an isolated example of the leveraging effect of LGBs. Nato operations in the Balkans in recent years have relied heavily upon precise point strike, LGBs accounting for approximately 65 per cent of the weapons expended.<sup>7</sup> The Balkans experience has highlighted the political value of the synergy between PGMs and air power where collateral damage must be minimised, friendly force casualties avoided and conflicts responded to with expeditious precision.

## **CURRENT RAAF PRECISION GUIDED BOMB CAPABILITY**

The ADF's current precision guided bomb capability is based on the Paveway II LGB, although these are being supplemented with the more capable Paveway III weapon.<sup>8</sup> The LGBs are delivered by the RAAF's RF/F-111C and F/A-18A aircraft

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<sup>2</sup> In 1972, the Paveway I guidance kit cost approximately USD\$2,700 compared to over USD\$20,000 for the GBU-8 electro-optic guidance kit. T. Clancy, *Fighter Wing: A Guided Tour of an Air Force Combat Wing*, Berkley Books, New York, 1995, p 149.

<sup>3</sup> In all, 25,000 LGBs were dropped in the Vietnam conflict by the United States, the first use being in 1968, of which 18,700 scored direct hits. *Asian Defence Journal*, 8/95, p 45.

<sup>4</sup> CEP is a measure of weapon accuracy. It is the radius of the circle in which there is a 50 per cent probability that the weapon will impact.

<sup>5</sup> Hallion, R.P., 'Precision Guided Munitions and the New Era of Warfare', *Air Power History*, Fall 1996, p 11.

<sup>6</sup> *ibid.*, p 12.

<sup>7</sup> Of note, 91 per cent of the munitions dropped by the US Air Force were LGBs. *Ibid.*, p 13.

<sup>8</sup> The RAAF first acquired an LGB capability in 1984 with the introduction of the Paveway II guidance kit for the Mk.82, 83 and 84 general purpose (GP) free fall bombs.

utilising the AN/AVQ-26 Pave Tack and AN/AAS-38 podded laser designators respectively; ground designation is also employed.<sup>9</sup>

### **LGB Operational Limitations**

While the RAAF have established a credible precision strike capability using the LGB, specific characteristics of laser guidance technology have resulted in significant operational limitations. The effective employment of the RAAF's Paveway LGBs is affected by three factors which shape the risk profile for designating and attacking aircraft, and overall mission success.

**Single Target Engagement.** Existing laser designator pods cannot concurrently and continuously illuminate multiple targets. This limitation means that concurrent multiple target engagement is not feasible, reducing operational flexibility. The concurrent engagement of multiple targets requires parallel aircraft missions to be generated, increasing the risk of aircraft attrition.

**Dependent Weapon Delivery.** LGB homing is a semi-active weapon guidance system, which is dependent on constant target illumination. Effective weapon delivery is dependent upon the designating aircraft maintaining line-of-sight laser illumination up to weapon impact; this may necessitate performing evasive manoeuvres around the target while operating in hostile battlespace. While automatic target tracking during evasive manoeuvres facilitates aircraft survivability, the designating aircraft must still maintain the target in the Forward-Looking Infra Red/Target Designator's (FLIR/TD) field of view; this can be a significant workload factor in a single crew aircraft. If an adversary can force a designating aircraft to break target tracking, this will negate weapon accuracy.

**Atmospheric Degradation.** Problems of target designation are compounded by adverse atmospheric conditions degrading target identification and illumination. In particular, operations in north Australia are affected by high levels of humidity and precipitation; dust and smoke particles further degrade weapon performance. Moisture and particulates in the atmosphere scatter the infrared signal, while laser wavelength energy is attenuated by cloud, fog or smoke. Cumulatively, these factors may have a significant effect on degrading the weapon employment envelope.<sup>10</sup>

Additionally, laser designators are deployed on only a limited number of RAAF aircraft. The result is that the number of platforms that can deliver LGBs is much larger than the number that have independent target designation capabilities, restricting weapons engagement options.

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<sup>9</sup> At present the RAAF's 15 Ex-USAF F-111G aircraft while having a very accurate digital offensive avionics suite cannot integrate with guided weapons or the Pave Tack designator pod. This limitation is to be addressed under programme AIR 5404 Phase 2 (Precision Weapons Modification).

<sup>10</sup> Of note, operational experience in the Gulf War indicated that weather-related aborts of missions carrying LGBs were too frequent; almost 30 per cent of F-117 sorties in the Baghdad area of operations resulted in 'no-drops' due primarily to cloud obscuring the line-of-sight to the target. Kopp, C., 'The Paradigm Shift in Strike Warfare', *Air Power International*, Volume 3, Number 2, 1998, p 38.

## **LGB Supportability**

Supportability of the ADF's existing LGB capability does not present a problem in the short to medium term. With the withdrawal of the F-111 aircraft from US Air Force (USAF) service, the RAAF has acquired the full holding of Pave Tack pods and spares from the United States. The AN/AAS-38 pod will remain in service with the United States Navy (USN) and Marine Corps (USMC) and will continue to be supported for the foreseeable future. The production of the Paveway series of munitions will continue, although this will increasingly be to meet export market requirements. Australia's allies and in particular the United States will continue to retain stocks of LGBs, although these will diminish as newer weapons such as GPS guided munitions are introduced.<sup>11</sup>

## **FUTURE REQUIREMENT FOR ADF PRECISION GUIDED BOMB CAPABILITY**

### **Strategic Guidance**

Australian strategic guidance has long identified precision strike to be an ADF force structure development priority; contemporary guidance has reinforced this view.<sup>12</sup> The ADF precision strike role encompasses the capacity to undertake operations against the interests of an adversary, including against ships, land-based forces and infrastructure. Guidance states that specific targets would be struck from the air with precision munitions, by day or night and in all weather conditions. These concepts are reflected in the RAAF core air power capability of precision strike.<sup>13</sup>

The evolving lethality of modern air defence weapon systems has progressively impinged upon the effectiveness of the RAAF's extant precision strike capability. In Australia's strategic context major players in the broader region have invested in advanced area and point defence systems. This has included modern fighter aircraft, such as the MiG-29 and Su-27/30, advanced C4I technology including AEW&C aircraft, and next generation air-to-air and surface-to-air missile (AAM/SAM) systems. These developments in the regional air defence environment degrade the survivability of RAAF strike assets forced to penetrate a hostile battlespace.

### **Requirement for Autonomous Stand-off PGMs**

The future credibility of the RAAF's precision strike capability will be increasingly reliant on autonomous stand-off PGMs. This requirement has been recognised under program AIR 5398 which aims to provide the F-111C/G with a broad suite of modern guided munitions for use in reactive defence suppression and precision stand-off

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<sup>11</sup> The USAF is planning to acquire 800 more before priority is shifted to the acquisition of JDAM. Tirpak, J.A., 'Brilliant Weapons', *Air Force Magazine*, February 1998, p 53.

<sup>12</sup> *Defending Australia: Defence White Paper 1994*, Australian Government Publishing Service, Canberra, 1994, p 52; *Australia's Strategic Policy*, Directorate of Publishing and Visual Communications, Department of Defence, Canberra, 1997, pp 61-63.

<sup>13</sup> AAP1000, *The Air Power Manual*, 3rd Edition, Air Power Studies Centre, Canberra, 1998, pp 29, 38.

attack against area and hardened point targets.<sup>14</sup> The first step in this process has been the RAAF's acquisition of the AGM-142E Popeye stand-off missile; these will provide the capability to accurately engage heavily defended point targets beyond the range of current area defence SAM systems.<sup>15</sup> This weapon is in the initial phases of aircraft integration.

While the RAAF has an established requirement to acquire sophisticated powered stand-off weapons, the inherent cost of these systems will ensure that there remains an important role for the more cost-effective precision guided bomb. Although precision guided bombs do not have the kinetic energy of a missile at impact and have less range, they still provide a valuable and accurate stand-off strike capability for significantly less cost than a missile. As such, the precision guided bomb will remain the most cost-effective 'level of effort' weapon for the ADF where precision is required in a low to medium threat environment, or following suppression of defences in a high threat environment.

Despite the demonstrated leveraging effect of LGBs, the RAAF acknowledges that the lack of an autonomous, all-weather capability is an operational limitation. Although later generations of laser guidance systems have improved designation performance and targeting accuracy under adverse weather conditions and evasive manoeuvring, all LGBs suffer from the same fundamental operating limitations due to the characteristics of laser guidance technology. In this respect, GPS guidance is being promoted as a cost-effective alternative to LGBs.

## **GPS GUIDANCE: A PARADIGM SHIFT IN PRECISION BOMBING?**

GPS guided bombs evolved out of the US military's Inertially Aided Munition (IAM) programme of the early 1990s. Based on experience of the Gulf War, the program was intended to improve the accuracy of GP bombs that had no laser or optical guidance capability. The IAM concept indicated that a GP bomb fitted with an inertially-guided tail kit could provide accuracy and all-weather capability, however, the concept relied upon a highly accurate and expensive inertial package. The critical enabling technology to make the IAM concept cost-effective was the introduction of the NavStar GPS guidance system. A description of GPS guidance technology is at Annex B.

GPS guided bombs are seen as the next step in revolutionising the nature of precision bombing. For an aircraft to support such munitions, it requires a GPS receiver and interfaces on the pylons to download target and launch point coordinates to the weapon's guidance package containing a GPS receiver and inertial unit. Following weapon release, the bomb's GPS receiver is used to correct the accumulated drift error in an inertial reference platform which directs the weapon's autopilot. Once released, the weapon is fully autonomous with no capability for aimpoint correction.

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<sup>14</sup> C. Kopp, 'F-111 Upgrade Options', *Australian Aviation*, Aerospace Publications Pty Ltd, Canberra, October 1998, p 35.

<sup>15</sup> The AGM-142E has a stand-off range of approximately 50 nautical miles.

Weapons trials in the United States have demonstrated that GPS/inertial guided bombs will produce an accuracy comparable to second generation laser guided weapons such as Paveway II. The employment of Differential GPS (DGPS) techniques can produce a dramatic improvement in CEP.<sup>16</sup> Weapon accuracy, however, is reliant upon the ability to receive the satellite derived GPS carrier signal. This signal is relatively weak and may be affected by electrical interference, jamming, spoofing and naturally occurring atmospheric disruptions. This is explained more fully at Annex B.

### **GPS Guided Bomb Development**

The first GPS-guided bomb was the Northrop GPS Aided Munition (GAM). GAM was devised as a means of providing the B-2 bomber with a precision conventional attack capability; the weapon guidance system employs a DGPS technique referenced to the B-2 delivery aircraft's GPS Aided Targeting System (GATS) to provide a 6 metre CEP.<sup>17</sup> Other development projects have included Rockwell's Mk.82GT tail kit for the Mk.82 500lb GP bomb, Northrop-Grumman's very low cost GPS Guided Munition (GGM) bomb tail kit, and British Aerospace Australia's GPS-guided glidebomb which has a design range 'in excess of 80 nautical miles'.

Potentially, the most successful GPS guided bomb development to date is the Boeing-McDonnell Douglas Corporation Joint Direct Attack Munition (JDAM). JDAM is an INS/GPS guidance upgrade to the existing inventory of Mk.83 1000 lb (GBU-31) and Mk.84 2000 lb (GBU-32) GP unitary bombs and the 2000 lb hard target penetrator bomb. The US Department of Defence has committed itself to the acquisition of 87,000 JDAM kits for use by the US Air Force, US Navy and Marine Corps; this figure is more than double the current US military holding of 36,000 LGBs. Export licences for JDAM have received US Congressional approval.

## **GPS VERSUS LASER: A TECHNICAL WEAPON DESCRIPTION OF JDAM AND PAVEWAY II/III**

### **JDAM**

JDAM, which was introduced into initial US military service in 1997, is representative of the state-of-the-art GPS-guided bomb technology. The JDAM kit consists of a new tail section which contains the INS/GPS guidance package and body strakes for body lift and manoeuvrability (Figure 1); later upgrades may add a terminal seeker to improve accuracy.<sup>18</sup> JDAM can be delivered from very low level and up to 50,000 feet at speeds up to 1.3 Mach. Delivery modes include level, dive or

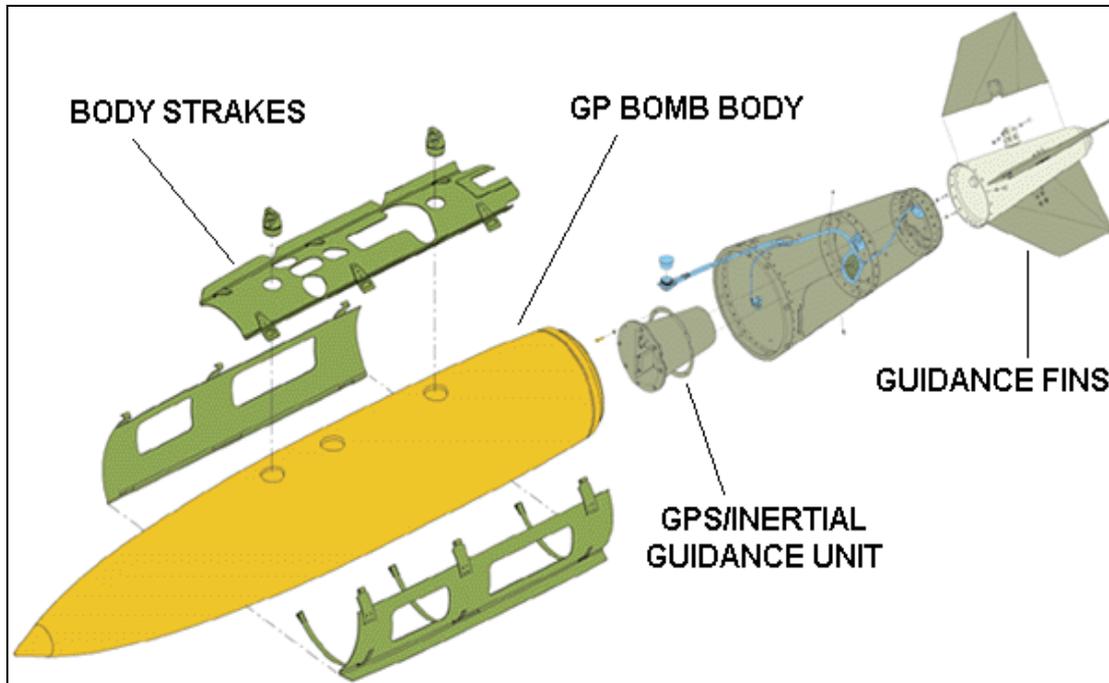
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<sup>16</sup> In US Air Force weapons trials a GBU-15 glide bomb modified with an INS/GPS/DGPS guidance package was released from 25,000 feet and 11 nautical miles down range; weapon impact produced a CEP of two metres. Four DGPS base stations used for weapon guidance corrections were located approximately 1,000 nautical miles from the test range.

<sup>17</sup> GATS is built around the B-2's Hughes APQ-181 J band phased array Low Probability of Intercept (LPI) attack radar. This system is capable of providing high resolution Synthetic Aperture Radar (SAR) target imagery which in conjunction with GPS provides highly accurate in-flight targeting data.

<sup>18</sup> The employment of millimetric radar terminal homing is estimated to improve accuracy to a CEP of three metres or less.

toss with an on-axis or off-axis delivery and can be programmed for steep or shallow dive trajectories to attack horizontal and vertical targets. The weapon has a CEP of nine metres and a stated range of greater than five nautical miles, although in toss mode JDAM's range will be comparable with Paveway III. The JDAM guidance kit has an acquisition cost of approximately USD\$18,000.



**Figure 1 - JDAM (Courtesy of the Boeing Company)**

The JDAM is continuously updated by aircraft mission systems prior to release using a MilStd-1760 interface. The aircraft transfers GPS timing, navigation messaging, GPS constellation data, GPS crypto key and target coordinates and impact parameters. Once the weapon's GPS is initialised and the inertial unit aligned it is then ready for release. Once released, the bomb's INS/GPS takes over and autonomously guides the bomb to its target. The Guidance Control Unit provides accurate guidance in both GPS-aided INS modes of operation and INS-only modes of operation. This inherent JDAM capability is intended to counter the threat from near-term technological advances in GPS jamming, although INS-only mode has a degraded level of accuracy, with an estimated maximum CEP of 30 metres.

### **Paveway LGB**

The Paveway family of LGBs is representative of laser guided bomb technology. The Paveway II LGB was introduced into US service in 1976 as a development of the Paveway I LGB. The Paveway II is designed for medium to high altitude delivery with a range of approximately six nautical miles and a CEP of seven metres. The weapon can be delivered in level, dive or toss modes. The main components are the gimballed seeker unit with canard control surfaces and deployable stabilisation fins (Figure 2). The Paveway II guidance kit has an acquisition cost of approximately USD\$25,000.

The Paveway II employs a simple four quadrant optical seeker to control flight. An error signal from the guidance unit's gimballed seeker head produces a simple non-proportional control (bang-bang) loop which recognises only full or zero deflection of the canard control surfaces. This results in a jerky weapon trajectory and sub-optimal use of the weapon's kinetic energy.



**Figure 2 - Paveway II**

An important limitation of the Paveway II is the restricted delivery envelope. The simple bang-bang guidance system, which attempts to align the velocity vector with the instantaneous line of sight, will attempt to fly the bomb directly to the target. During lower altitude deliveries this may result in the bomb falling short due to command guidance flying an inappropriate trajectory for the weapon's kinetic energy and glide ratio.

The Paveway III Low Level LGB (LLLGB) is a significantly enhanced development of the Paveway II weapon (Figure 3). The Paveway III is especially designed for low altitude toss delivery and has a stand-off capability of greater than ten nautical miles with a CEP of approximately two metres. The increased weapon manoeuvrability and increased seeker sensitivity improve performance envelopes for all modes of delivery. The Paveway III guidance kit has an acquisition cost of approximately USD\$59,000.

The seeker assembly of the Paveway III is substantially better than that of its predecessor. The optical subsystem is far more sophisticated, with greater sensitivity, a range of scanning modes to acquire the target and a much larger instantaneous field-of-view (FOV). Coupled with a digital autopilot, this provides the weapon with the capability to fly an optimal glidepath during midcourse phase, then transition to a shaped terminal homing algorithm to achieve its CEP. The seeker will automatically sense the delivery trajectory after release (dive, level or toss) and select the appropriate midcourse trajectory algorithm. This better matches weapon kinetic energy with designated target impact point overcoming the problems of the Paveway II.

Unlike the Paveway II, the LLLGB can correct for relatively large deviations from planned release parameters in the primary delivery mode (low-altitude, level

delivery). It also has a larger delivery envelope for the dive, glide and toss modes than does the Paveway II (Figure 4). The wide FOV and mid-course guidance modes programmed in the LLLGB allow for a 'point-shoot' delivery capability. This capability allows the attacking aircraft to point at the target and release the weapon after obtaining appropriate sight conditions. The primary advantage of this capability is that accurate dive/tracking is not required to solve wind drift problems.



Figure 3 - Paveway III

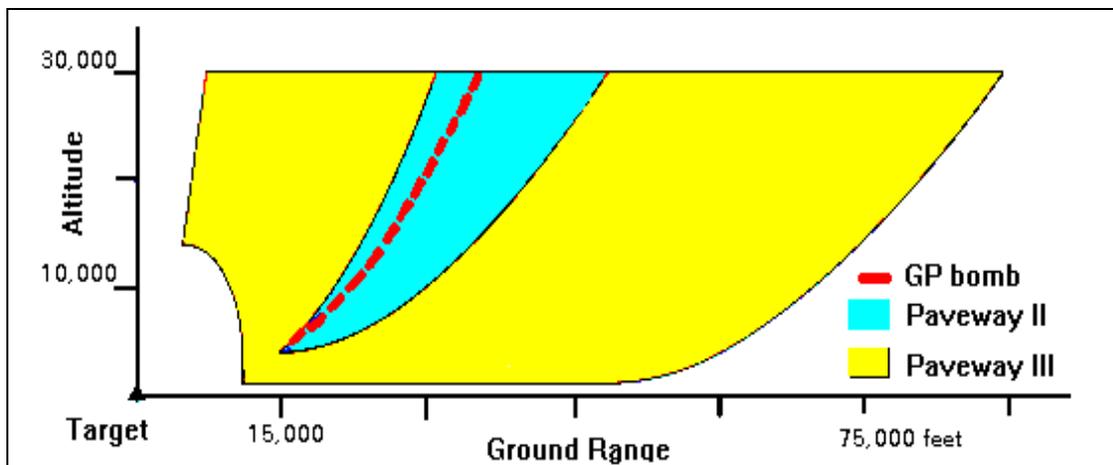


Figure 4 - LGB Delivery Envelope<sup>19</sup>

<sup>19</sup> Paveway III, Military Analysis Network, <http://fas.org/man/dod-101/sys/smart/gbu-24.htm>.

## GPS VERSUS LASER: AN OPERATIONAL COMPARISON OF JDAM AND PAVEWAY II/III

### Weapon Supportability

The support infrastructure for Paveway II/III is already well established within the RAAF; JDAM can utilise the same infrastructure without modification or addition. JDAM kits are individually stored in hermetically-sealed polythene bags inside a foam lined fibreglass shipping container. The shelf life of the sealed package is 20 years and maintenance is not required while in storage. In comparison, the hermetically-sealed Paveway II/III kits have a shelf life of approximately 15 years, with a five-yearly maintenance requirement for the guidance head. JDAM and Paveway II/III are compatible with the standard US AERO-51, MHU-141, MHU-191 and MJ-40 bomb trailers/ hoists; the RAAF presently utilises the MHU-141 and MJU-4.

*Assessment.* JDAM presents no logistical integration problems while having better storage characteristics compared to Paveway II/III.

### Aircraft-Weapon Carriage and Release

The RAAF's RF/F-111C and F/A-18A/B aircraft are fully stores compliant for the carriage and release of Paveway II/III; modification and certification would be required for JDAM. While the US military have cleared JDAM for carriage and release by the F/A-18C/D, no trials have been conducted on the F/A-18A/B or the F-111. The RAAF now being the sole F-111 operator would have to undertake carriage and stores release certification for this aircraft.

The JDAM requires a MilStd-1760 weapon pylon interface to enable the download of pre-launch data from the delivery aircraft; the RF/F-111 is compliant but not the F/A-18A/B. A result of the F-111's recent Avionics Update Programme (AUP) is that the avionics suite provides a de facto MilStd-1760 interface to the four wing swivel pylons. The AUP design however, has mounted the wing pylon decoder boxes on the sides of the internal weapon bay negating the internal carriage of JDAM; modification for internal weapon carriage is technically feasible.<sup>20</sup> The F/A-18A/B weapon pylons would need to be modified to provide MilStd-1760 interface compliance for JDAM carriage and release; this is technically feasible.

Additionally, JDAM requires the delivery aircraft to have a GPS receiver to initialise the weapon. While the RF/F-111C/G has received a MAG-R GPS unit as part of the AUP, the F/A-18A does not have GPS receiver unit. The F/A-18A is due to receive a GPS capability in the aircraft's forthcoming sensor upgrade.

*Assessment.* JDAM requires RF/F-111C/G and F/A-18A modification and certification before being accepted into RAAF service; Paveway II/III does not present this complication.

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<sup>20</sup> To carry the JDAM internally the decoder boxes would need to be relocated either into the wing pylons or along the roof of the bay; the latter is technically the simpler process but would need to ensure clearance for a stowed Pave Tack, should this be retained, and bomb rear assembly. The aircraft's original MAU-12 weapon ejectors would also have to be refitted into the weapon bay.

## Targeting

While the deployment of both LGBs and GPS guided bombs is reliant upon targeting intelligence, the GPS weapon system is more reliant upon exact target coordinates. This is a significant difference given that LGBs have an operator in the guidance loop to refine the aimpoint and minimise collateral damage. GPS guided weapons are wholly autonomous and their impact precision is determined primarily by the accuracy of targeting data prior to weapon release, hence, once released, GPS guided bombs are committed with no in-flight aimpoint corrections being possible.

In this respect, the use of GPS/inertial guided bombs will place a premium on the quality of targeting intelligence. Whilst contemporary satellite, aerial and radar reconnaissance can tolerate some inaccuracy in the knowledge that the delivery aircraft will usually acquire the target visually and correct weapon aimpoint, GPS guided bombs must be accurately targeted from the outset. Any inaccuracies in establishing or loading target coordinates will produce weapon impact offset and risk increased collateral damage.

The semi-active nature of laser guidance provides a valuable means of weapon aimpoint correction following weapon release, a feature GPS guided bombs do not possess. For GPS guided bombs, the most reliable method to accurately ensure that target positioning or pre-loaded target coordinates are correct prior to weapon release is to use high resolution imaging SAR. Radars such as the APG-76 have resolutions of approximately one metre at stand-off ranges in the order of 50 nautical miles. These radars could be used to confirm weapon aimpoints previously loaded into the nav-attack system prior to weapon release. The RAAF does not presently have such a capability.

*Assessment.* JDAM places a greater intelligence requirement on exact target location; LGBs benefit from man-in-the-loop aimpoint correction.

## Delivery and Guidance Considerations

GPS weapon guidance provides autonomous, multiple target, all-weather engagement; LGB's semi-active laser guidance does not provide this ability. The ability to concurrently attack multiple targets in a single pass unrestricted by the requirement to identify a target and maintain target designation up to weapon impact confers an important attack capability overcoming laser's inherent shortcomings as well as providing greater delivery aircraft survivability. Additionally, JDAM imposes a reduced crew workload for weapon delivery; this is a significant advantage when operating in a hostile battlespace, especially in a single-crew aircraft.

GPS guidance provides a more efficient and flexible usage of available aircraft. Any aircraft which can carry JDAM becomes an independent weapons platform; this overcomes the RAAF's LGB limitation that potential delivery platforms exceed the number that can self-designate.

The autonomous nature of GPS guided bombs however, also carries an important operational limitation which is overcome by laser's semi-active guidance. The reliance of GPS guided bombs upon accurate pre-launch target coordinates largely

limits the employment of these weapons to static targets, such as an adversary's buildings and infrastructure. The requirement for LGBs to be positively guided to their targets enables aimpoint adjustment during the weapon's trajectory and allows the accurate engagement of mobile targets such as vehicles and ships.

*Assessment.* JDAM's autonomous all-weather attack capability confers significant operational advantages over LGBs, especially for concurrent multiple target engagement; LGBs have an important operational advantage in being better able to attack mobile targets.

### **Weapon Counter-Counter Measures**

Laser weapon guidance is presently more robust to adversary counter-measures than is GPS weapon guidance, although technical developments are addressing this discrepancy. While laser designation cannot be jammed, LGBs can be spoofed. To overcome this, the laser illumination is pulsed and the pulse trains coded. This ensures that there is discrimination between multiple target/weapon pairs while providing effective Electronic Counter-Counter Measures (ECCM) against seduction by optical beacons.

While current GPS receivers have some anti-jam/interference immunity built into the signal structure, this is presently insufficient to protect them from a determined attack. Techniques such as beam steering and adaptive nulling can overcome these problems, but they are often difficult to implement and can be prohibitively expensive. Boeing's Anti-Jam GPS Technology Flight Test (AGTFT) programme is developing an inexpensive solution to the jamming vulnerability of GPS-aided inertially guided weapons. AGTFT combines a Harris anti-jam electronics module with a Boeing-developed guidance unit incorporating a Collins GPS receiver coupled with a Honeywell inertial navigation unit and a four-element anti-jam GPS antenna. Modified JDAMs carrying this equipment, replacing the weapon's standard single-element antenna, have repeatedly demonstrated the ability to rapidly acquire and maintain the GPS carrier signal in a high-power jamming environment.<sup>21</sup>

The next generation of GPS receivers, incorporating a variety of cost-effective anti-jam/interference technologies and techniques, will largely overcome existing concerns regarding the vulnerability of the low-power GPS carrier signal to jamming, interference or spoofing. With this ability the LGB and GPS guided weapon will be equally robust in terms of guidance integrity.

*Assessment.* LGBs have an inherently better ECCM capability; whilst JDAM's weakness is presently the vulnerability of the weak GPS carrier signal, this is, however, currently being corrected through technical means.

### **Cost-effectiveness**

JDAM's cost is comparable to the Paveway II kit while offering similar or better accuracies; the incorporation of a terminal seeker on JDAM will offer Paveway III

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<sup>21</sup> In the first trial, following weapon release at 44,000 feet, it acquired the carrier signal within 12 seconds in a high-power jamming environment, descended through winds of up to 170 km/h, continuously tracking the signal and impacted within three metres of the target.

accuracies at a comparable cost. Notably, JDAM does not require the acquisition of FLIR/TD pods or the infrastructure for their support.

*Assessment.* JDAM provides a cost-effective precision strike capability.

## CONCLUSION

Australian strategic guidance identifies the requirement for the ADF to maintain a precision strike capability; the RAAF has primary responsibility for effecting this capability. The effectiveness of the RAAF's present capability is being diluted by relative advances in modern air defence systems which provide greater point and area defensive coverage. To maintain credibility in the precision strike role the RAAF will need a flexible and integrated mix of modern stand-off PGMs, both powered and unpowered. The cost-effectiveness of the precision guided bomb will ensure that this weapon has continued relevance in the future and will continue to form the core of the ADF's PGM arsenal.

The RAAF currently relies primarily upon LGBs to meet the precision guided bomb requirement. Specific characteristics of laser guidance technology however, impose operational limitations on the munition's effective employment. In particular, laser's semi-active guidance system precludes concurrent multiple target engagements while necessitating the designating aircraft maintain line-of-sight contact with the target. Both these factors impinge upon aircraft survivability and mission effectiveness, while adverse weather factors further influences mission viability. Logistic supportability is not a limiting factor for the RAAF's LGB capability.

LGB operational limitations, which are not unique to the RAAF, have spawned the development of GPS-guided bombs. The American JDAM is the first of these weapons to enter operational service. JDAM provides a number of features which make it attractive in meeting the RAAF's future precision guided bomb capability. Most significant amongst these is the weapon's autonomous all-weather precision strike capability and the ability to conduct concurrent multiple target engagements. Additional benefits include a more flexible employment of available strike assets while providing reduced crew workload for weapon delivery in a hostile battlespace. These advantages are provided at a cost commensurate with that of the Paveway II LGB.

While JDAM offers significant advantages in overcoming operational limitations with laser guidance, it does also have limitations. Notably, the inability to perform aimpoint correction following weapon release means that JDAM is dependent on highly accurate target coordinates which must be based upon accurate and timely intelligence; the lack of post-launch weapon updating also means that JDAM is not well-suited to the attack of mobile targets. Additionally, the integration of JDAM on the RAAF's RF/F-111C/G and F/A-18A will require aircraft modification and weapon carriage/release certification.

On balance, however, JDAM's advantages outweigh the limitations in meeting the RAAF's future precision guided bomb requirement. Adoption of JDAM would also ensure continued RAAF interoperability with Australia's allies, especially the US

military. Nevertheless, LGBs will retain an important capability for highly precise strike and for the attack of mobile targets. In this capacity, the RAAF will probably need to retain an interim LGB capability, using Paveway III, in the transition to JDAM and pending the development of improved weapon accuracy.

**Annexes:**

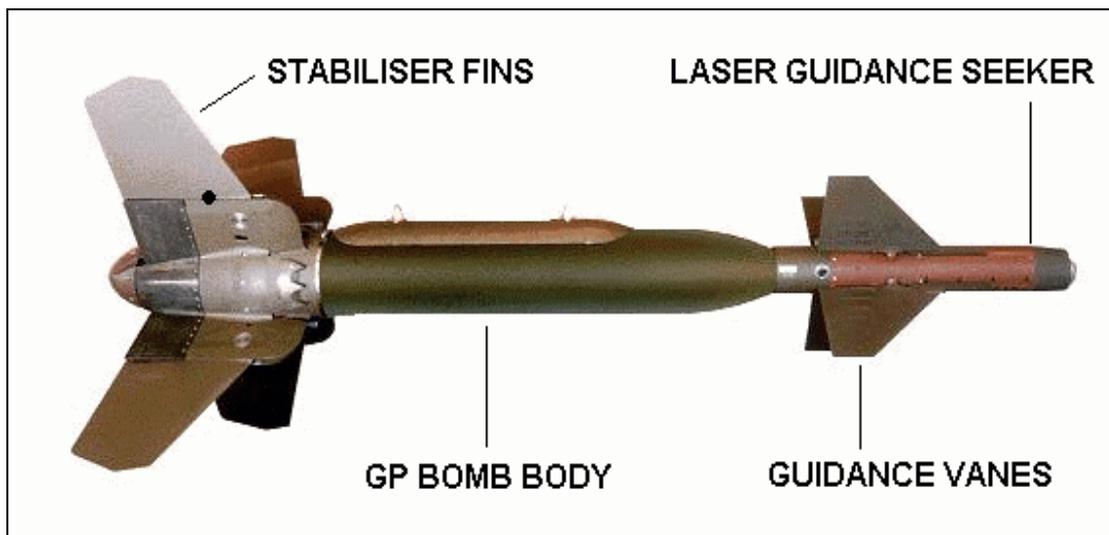
A. Laser Guidance Technology

B. GPS Guidance Technology

## ANNEX A

**LASER GUIDANCE TECHNOLOGY**

Laser homing is a semi-active, line-of-sight weapon guidance system which is dependent on constant target illumination. The main components of the LGB guidance system are a nose package containing a laser guidance seeker and guidance vanes (Figure A1). Western-designed laser guidance packages are designed to mount on to the widely acquired Mk.80 series of free fall GP bombs without weapon modification.



**Figure A1 - LGB Components**

The guidance package homes onto the reflected laser signal from an airborne or ground based target designator; target illumination must be maintained up to LGB impact. Laser light, because it is coherent and tends to stay in a tight beam, has the ability to illuminate a very small target from long distances. A laser beam impinging on an object from a distance will create a spot of very bright light, the laser spot, which is then detected by spot trackers or guidance seeker. While the LGB guidance seeker is able to guide the bomb to a precise aimpoint, the weapon must be dropped within a narrow 'basket' for it to have sufficient kinetic energy to reach the target.

Once the laser spot is detected, the Computer Control Group (CCG) provides steering commands to the Airfoil Group Assembly (AGA). The CCG is mounted in a gimbaled aerodynamically aligned assembly. Laser light reflected off a target passes through a protective nose window and an infra-red filter and is focussed by an aspheric lens on to a four-quadrant silicon photoelectric sensor. The sensor is slightly shifted along the longitudinal axis of the assembly so that it lies in front of the focal plane of the lens and the image of the laser spot is slightly defocused. If the spot is perfectly aligned with the weapon's velocity vector, all quadrants are equally illuminated. If the spot lies off-centre it will illuminate each quadrant differently. Each quadrant generates electric current proportional to its illumination. Voltages proportional to these currents are then amplified and fed into a mixer network which

compares the signals and generates left/right-up/down commands. These are then fed to the guidance computer and the AGA.

The aimpoint accuracy of the LGB is reliant upon the effectiveness of the laser target designator (TD). Laser designators, which may be airborne or ground based, provide a single coherent beam for target illumination. Airborne designators usually combine the designator with a Forward Looking Infra-Red (FLIR) capability for target identification and operator tracking. Typically the FLIR/TD are gimballed and stabilised to provide precise spot-beam pointing and automatic target tracking; this is particularly important where the designating aircraft may need to undertake evasive manoeuvres in a hostile battlespace.

## ANNEX B

### GPS GUIDANCE TECHNOLOGY

#### NavStar GPS Guidance System

The NavStar GPS satellite navigation system uses a constellation of satellites and earth-bound master clock to allow GPS receivers to fix their position in time and space. The Operational GPS Constellation uses 24 satellites orbiting in precise 12 hour orbits to provide global microwave signal coverage. GPS navigation is based upon the precise calculation of range to several satellites, the positions of which are known, by measuring time of signal propagation. A GPS receiver will use four or more pseudo-range measurements to compute a position in Earth-Centered, Earth-Fixed (ECEF) coordinates. These are converted into geodetic latitude, longitude and height above the surface of an ellipsoid typically using the WGS-84 Earth Model. Differential GPS (DGPS) improves GPS accuracy by the remote broadcast of an error signal which tells a receiver the difference between calculated and actual position.

For guided munitions, the bomb's GPS receiver is used to correct the accumulated drift error in an inertial reference platform which directs a weapon's autopilot. Because the GPS package is highly accurate an inexpensive inertial package may be used. For an aircraft to support such munitions, it requires a GPS receiver and interfaces on the pylons to download target and launch point coordinates to the weapons. Trials in the United States have demonstrated that a GPS/inertial guided bomb will offer accuracies comparable to a second generation laser guided weapon such as Paveway II. Trials have indicated that the employment of DGPS updates produces a dramatic improvement in CEP.<sup>22</sup>

The introduction of GPS-aided precision guidance will have an operational impact not unlike the introduction of laser guided weapons, but with distinct advantages. Unlike a laser guided weapon, a GPS/inertial weapon does not require the launch aircraft to remain in the target vicinity to illuminate it for guidance. Additionally an attacking aircraft can program its weapon load for individual targets, release these from stand-off range almost concurrently and then immediately egress the target area enabling autonomous multiple target engagement. Weather is no longer an operational constraint.

While the deployment of DGPS/GPS/inertial guided weapons promises a significant improvement in air power capability, the low power level of the satellite radiated GPS signal may be a significant vulnerability. In particular GPS weapon guidance may be affected by electrical interference, jamming, or spoofing; naturally occurring disruptions in the ionosphere may also affect GPS reception

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<sup>22</sup> In US Air Force weapons trials a GBU-15 glide bomb modified with an INS/GPS/DGPS guidance package was released from 25,000 feet and 11 nautical miles down range; weapon impact produced a CEP of two metres. Four DGPS base stations used for weapon guidance corrections were located approximately 1,000 nautical miles from the test range.

## **Interference**

There are many potential sources of electrical interference which can degrade signal quality, especially as the electromagnetic spectrum becomes more heavily utilised. These include harmonics from television transmitters, mobile telephone networks, electromagnetic interference from other electronic equipment and 'signal fratricide' resulting from attempts to deny GPS access to a potential adversary. Typically, a 100 Watt transmitter (comparable to a mobile phone) at a distance of 20 kilometres may be sufficient to prevent a MilStd GPS receiver from acquiring a GPS signal.

## **Jamming**

Jamming is the deliberate attempt to block out the GPS carrier signal. The jamming task is simplified by the GPS signals being transmitted by satellites operating on well-known frequencies, using well-defined modulation characteristics, at low signal-to-noise ratios. Small battery-powered jammers can be sufficiently powerful to be militarily useful. The Russian organisation Aviaconversia is presently marketing a 4 Watt jammer for use against GPS and its Russian equivalent, GLONASS. The device, which is claimed to be effective over ranges of up to 200 kilometres, costs less than USD\$4,000.

## **Spoofing**

Spoofing is the deliberate transmission of an inaccurate GPS carrier signal to provide erroneous spatial referencing. Typically, spoofing endeavours to override the weak Carrier/Acquisition (C/A) signal in one channel with a false time signal input. This task is simplified given that the C/A signal is transmitted on the widely publicised frequency of 1.023 MHz and can be over-ridden by relatively low-powered interference.

## **Ionospheric Disruption**

Naturally occurring disruptions in the ionosphere can also affect GPS reception resulting in rapid fluctuation (scintillation) of satellite signals at or near the earth's surface. This phenomenon is most intense at night and within 20° of the magnetic equator. Signal scintillation can produce severe fading or result in rapid phase gradients that exceed the ability of the receivers to maintain satellite lock. Research is presently being conducted to better understand how scintillation structures develop and to enable practical means for maintaining reliable satellite communication linkages.