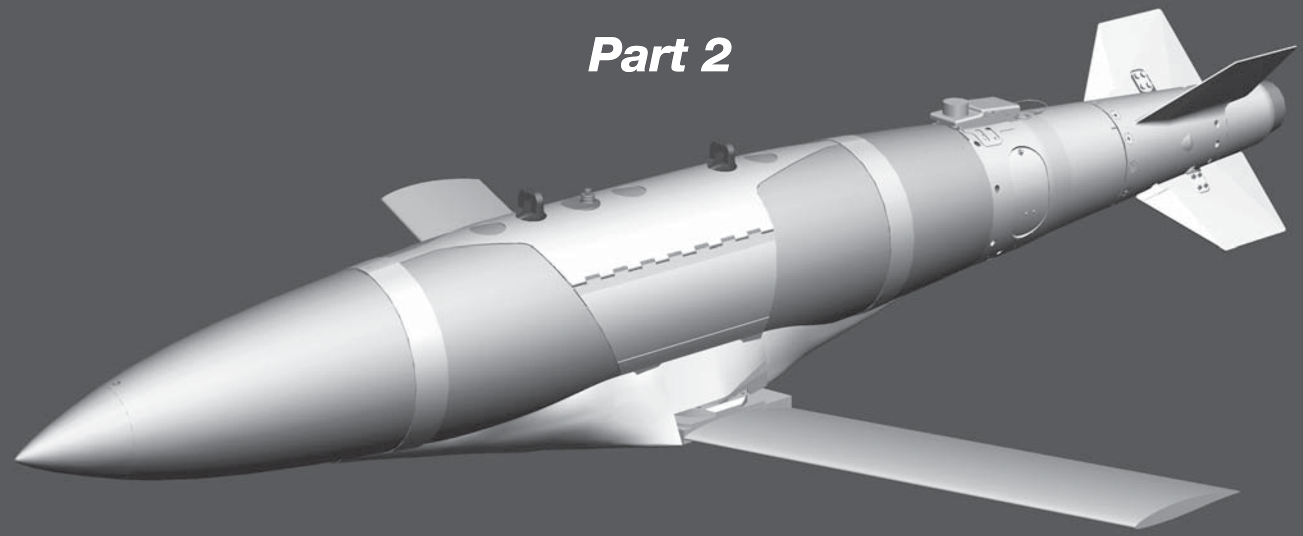
by Carlo Kopp

JDAM Matures

Part 2



The Joint Direct Attack Munition family of GPS aided inertially guided bombs represents perhaps the most important single development in bombing technique over the last two decades, and will in time supplant the established laser guided bomb as the most widely used low cost guided munition.

Providing aircraft with the ability to attack multiple aimpoints in a single pass, JDAM provides a force multiplying effect unseen in scale since the laser guided bomb displaced the dumb bomb during the latter part of the Vietnam conflict. In this month's final part, growth derivatives of the JDAM will be explored.

JDAM Precision Seekers

From the very outset of the JDAM program, the intention of the US Air Force was to equip the basic weapon with a range of precision terminal homing seekers. The basic idea was to provide an 'accurate' basic weapon, with the terminal seeker providing the remaining 'precision' capability.

To that effect, the JDAM Guidance Control Unit (GCU) was designed with additional growth capacity in empty slots for more cards, but also with unused spare interfaces to permit additional hardware to be integrated with minimal effort. In this fashion, specific software could be written for seeker equipped variants and loaded into the standard low cost mass production GCU. A unique seeker would then be plugged into the unused GCU interfaces via an umbilical routed from the nose of the bomb.

This highly flexible model was devised to accommodate as many different options in seeker technology as the user might ever want. By dividing the system into discrete modules, where the mass produced 'baseline' hardware is kept unchanged, it is possible to achieve the large economies of scale which are characteristic of very large, uniform and mature mass production builds.

Cost has traditionally been the greatest impediment to the large scale use of precision munitions. While a well guided GBU-10/12 Paveway II laser guided bomb can be very accurate, and is cheap due to its primitive seeker design, the weapon is also in many respects fragile since the seeker's simplicity denies redundancy to protect against hardware failures, and the guidance technique is vulnerable to the loss of laser illumination. Opting for more sophisticated proportional navigation style laser semiactive homing, with an inertial capability, as used in the later GBU-22/24 Paveway III bombs drives up the cost.

Television guided bombs have also proven expensive. The GBU-8 HOBOS, which evolved into the cruciform wing GBU-15 family of weapons, proved to be amongst the most expensive guided bomb kits ever mass produced. The requirement to provide a stabilised platform for the bomb's seeker, and robust radio datalinks, resulted in a cost structure which effectively compromised these capable weapons in large scale use. The key difficulty with the GBU-15 series was its uniqueness – the airframe components were unusable for other purposes and this drove up the unit cost.

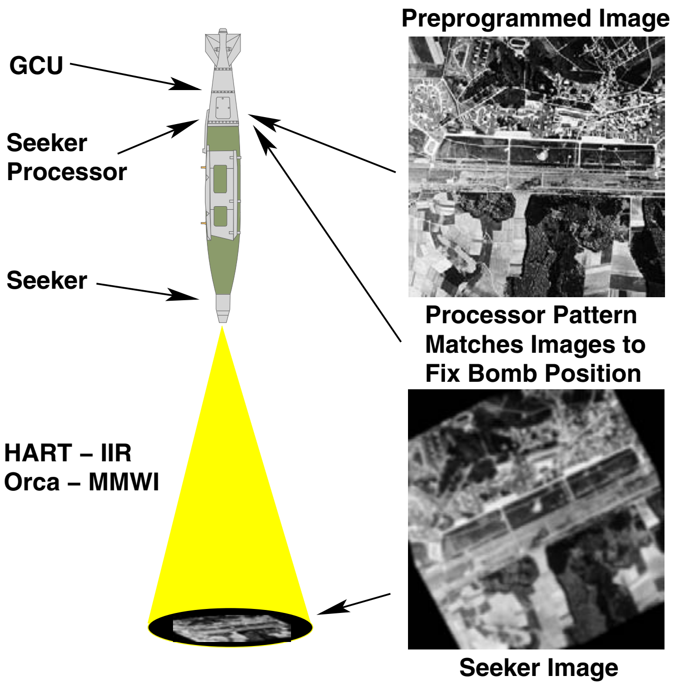
The advent of the JDAM as a 'platform' for range of precision seekers or guidance packages changes the basic economic equation. The unique portion of the precision weapons kit is the seeker hardware/software alone, with the remainder of the weapon being essentially standard low cost mass production hardware. Therefore nearly all of the investment in developing and producing the precision weapon is concentrated into the seeker alone.

To date no precision seekers have been deployed operationally, or at least not announced in the public domain. In part this is because the basic JDAM has proven generally more accurate than originally expected. Operational use of techniques such as strike planning in optimal GDOP windows, deployment of improved later generation GPS satellite vehicles have clearly driven accuracy close to the GBU-10 class, and with the eventual use of wide area differential GPS (eg WAGE) and B-2 derived platform referenced differential GPS, there will be little pressure for precision seekers. Why add US$10k to 20k to the cost of each bomb if you can get 80% of its accuracy via cheaper techniques?

However, this does not by any measure mean that seekers are dead. On the contrary, many situtations will demand seekers. Moving targets in a jamming environment will almost certainly require seeker technology to retain precision accuracy if the GPS channel is lost.

JDAM Radar Seekers

The US Air Force ran two technology demonstrations during the late 1990s. The classified Raytheon/Sandia Hammer-



Imaging seekers are one technique which will provide the JDAM with genuine precision capability. A typical design for such a seeker will see the JDAM seeker take a snapshot of the target surroundings, which is then compared with a preprogrammed image to fix the bomb's position. Once the error is found, the target aimpoint is corrected and the bomb dives into the target. MilliMetric Wave Imaging techniques were demonstrated in the Orca program, while DAMASK demonstrated an IIR seeker. Both techniques have growth potential for attacks on moving targets such as vehicles or shipping (Author/USAF).

head program demonstrated the use of Synthetic Aperture Radar (SAR) active seeker for the JDAM, with a 3 m CEP. While details have not been released as yet, it is reasonable to speculate that the design uses a scene matching area correlation technique to fit a SAR map against a preprogrammed target area map.

At that time the US Air Force also sponsored the classified Orca program, to demonstrate a millimetric wave (MMW) radar seeker with a 3 metre or better CEP. MMW seekers have been used for instance on radar guided anti-tank mortar rounds, and the technology is central to the latest variants of the Hellfire missile carried by the AH-64D Longbow Apache. No details have been released on Orca to date. Given the potential of the technology, an MMW seeker could be used for attacking moving targets like shipping or armour, and using scene matching area correlation techniques in the manner of the Pershing II IRBM, it could also be used for precision strikes on fixed targets.

Clearly there is considerable potential in radar seeker technology for the JDAM, and many possibilities exist.

JDAM Electro-Optical Seekers

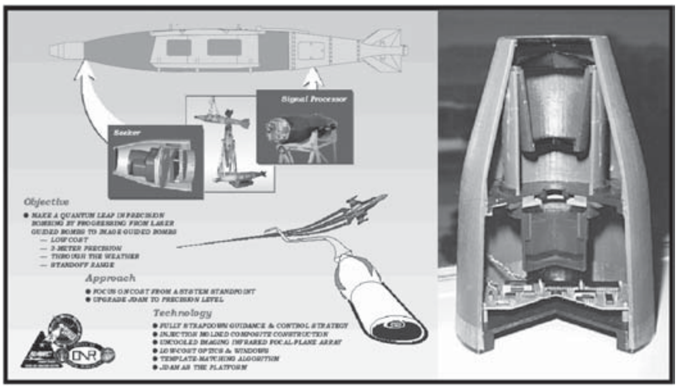
At this time there are very few electro-optically (EO) guided bombs in operational service. The US Air Force retains residual stocks of the GBU-15, which have been since upgraded to EGBU-15 configuration by the additional of a GPS receiver and IMU to provide JDAM-like midcourse guidance. The Israelis have a range of weapons, but stocks and configurations remain largely undisclosed.

A key obstacle to the use of autonomous and datalink supported EO guidance techniques has been cost. To achieve a respectable acquisition range of several miles, the seeker optics must be stabilised down to tens of microradians or better jitter performance. Typically multiple fields of view are required. The result was an expensive to produce gimballed optical package with the additional encumbrance of cryogenic cooling if infrared day/night capability was needed. If the weapon was to be remotely guided from a cockpit, then the weapon would also require an expensive jam resistant wideband video datalink to carry the seeker image to the launch aircraft. While autonomous target recognition techniques have matured in recent years, one to two decades ago they were both expensive and unreliable.

Much has changed since in basic technology. In daylight imaging, high resolution CCDs and CMOS imagers are now much cheaper and immeasurably better than the vidicon tubes of the 1970s. In infrared imaging, bolometric uncooled and cryogenically cooled Indium Antimonide, Mercury Cadmium Telluride, Platinum Silicide and Aluminium Gallium Arsenide Quantum Well Imaging Photodetector (QWIP) focal plane or 'staring' arrays are now available. Of particular interest is the QWIP technology since it permits high resolution imaging chips operating in the MWIR (midwave or 4-5 micron band) and LWIR (longwave or 8-12 micron band), but also allows a single imaging chip of the proper architecture to concurrently image in both the MWIR and LWIR bands – effectively two band specific thermal imagers in one slab of Aluminium Gallium Arsenide semiconductor producing two video signals at the same time. Not surprisingly, the leading wave of QWIP imagers is in the high volume commercial medical/industrial markets rather than low volume military market.

No less important is the uncooled bolometric thermal imaging technology, which is much less sensitive than cooled semiconductor imaging chips, but also much cheaper, and not requiring the dollar hit of a refrigeration package. It's principal market lies in automotive thermal imagers, popular in top tier US limousines.

Electro-Optical guidance, be it autonomous or datalink aided, is potentially valuable to the JDAM family of weapons. While it cannot penetrate cloud, it is compact and ex-



The DAMASK program demonstrated the viability of an uncooled autonomous thermal imaging seeker on the baseline GBU-31 JDAM. The DAMASK would take a snapshot of the target scene, and pattern match the image against a stored image of the target area to refine its position estimate. The result is accuracy of the order of several feet, and trials drops as good as 2 ft from the intended aimpoint. The HART program will see this technology incorporated into a production weapon (US Navy).

tremely precise. With the weather immune GPS/IMU guidance, an EO seeker equipped JDAM can fly under the cloudbase to acquire its target. Widely available EO targeting pods, especially on US aircraft, provide a source of good quality infrared imagery which can be downloaded to a seeker equipped JDAM before release. With satellite and UAV generated high resolution imagery, and datalinks to combat aircraft, there are few obstacles to target imagery being tranmsitted in seconds from a source to a bomber, and through the Mil-Std-1760 umbilical, to a seeker equipped JDAM before release.

The first EO seeker demonstrated on a JDAM was the DAMASK (Direct Attack Munitions Affordable Seeker), sponsored by the Office of Naval Research (ONR) under a USD 15M contract. The aim of the DAMASK project was to demonstrate a very cheap yet highly accurate low cost EO seeker, with no moving parts.

The DAMASK design was innovative in many respects. The low cost seeker was designed around an uncooled imaging-infrared focal plane array (UIIFPA) device, using low cost optics and a molded composite casing. The imaging array is based on the same technology used in the Cadillac Seville 2000 head up FLIR, to achieve exceptionally low unit costs. A commercial signal processing module was adapted to support the seeker, and installed in the unused tailkit volume. The US Navy estimated the unit cost of a DAMASK kit at US$12.7k in mass production.

The DAMASK employs scene matching techniques well proven in systems such as the Tomahawk. Before the bomb is released, the launch aircraft downloads an image of the target, produced by satellite, the aircraft's SAR or FLIR. When the bomb is released is flies over the target and then noses over to point down at a very steep angle. In this terminal flight phase it images the area surrounding the target, and then performs the correlation operation to determine the bomb's actual position against its intended position. The system was to calculate weapon alignment to 100 microradians accuracy, for a 2.6 metre error at impact.

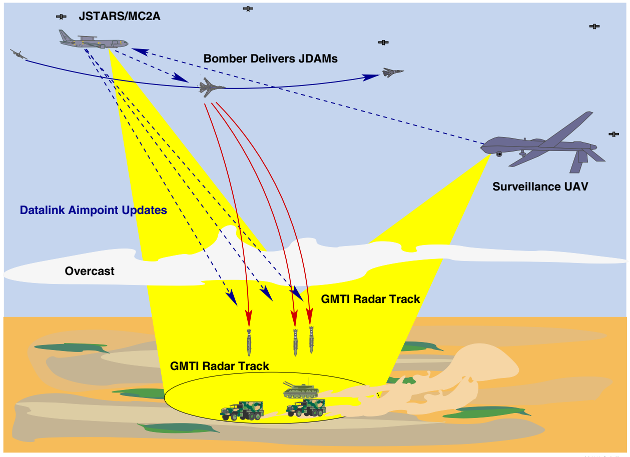
Once the JDAM's position is updated from the target scene, the weapon will correct its donwward trajectory, pulling multiple Gs if required as it is travelling down very quickly at several thousand feet of altitude at this point. Once the trajectory adjustment is completed, the weapon continues on inertial/GPS guidance to impact.

The DAMASK demonstration presented some interesting problems. The issue of seeker alignment was demanding, especially since the minute flexure in the bomb body was enough to introduce potentially problematic errors. Image roll alignment proved to be an issue, as did motion induced image blurring and image distortion resulting from lens behaviour. Image processing speed also presented challenges, since the time window for processing the acquired image was very short.

DAMASK proved to be a resounding success, with trial weapon drops including simulations of GPS jamming by disabling the bomb's GPS receiver. The first drop saw the weapon impact within 2 ft of the intended aimpoint.

The DAMASK program was essentially a technology demonstration to prove that the concept of a simple EO seeker worked effectively.

The current US Navy HART (Hornet Autonomous Real-Time Targeting for F/A-18C/D/E/F) program builds on the DAMASK effort. HART is aimed at providing a production EO seeker for the JDAM, which incorporates the capability to download the image from the aircraft's FLIR/EO targeting pod (AAS-38 or ASQ-228 ATFLIR/Terminator) providing the ability to precisely target 'pop-up and relocatable targets'. The formal FBO statement for the program specifies Boeing as the sole source. Whether the HART seeker package will incorporate the Autonomous Target Recognition (ATR) algorithms devised by Boeing for the AGM-84E SLAM family of missiles is unclear from published materials. HART will



JDAM Moving Target Engagement CONOPS (AMSTE)

The DARPA AMSTE program recently demonstrated a successful strike against a moving target using a JTIDS datalink aided JDAM. The target was tracked by two separate airborne GMTI radars, providing a continuous stream of target coordinates which were fused and then tranmitted over a JTIDS channel to the JDAM in flight. The weapon is reported to have impacted within the lethal radius of the target (Author)

run until 2007.

Whether the US Air Force adopt the HART seeker, or indeed it becomes available to export clients, remains to be seen. The nature of the design lends itself to integration on any FLIR/EO pod equipped Mil-Std-1760 capable aircraft, which both the RAAF's F-111C Block C-4/5 and F/A-18A HUG will become in the timelines of interest.

Datalink Guided JDAMs

The limitation of the 'baseline' JDAM guidance package is that it was designed to engage fixed targets, the original intent being to fit precision seekers for attacking moving targets. More recent developments in the US suggest that a radical change may be afoot in this area.

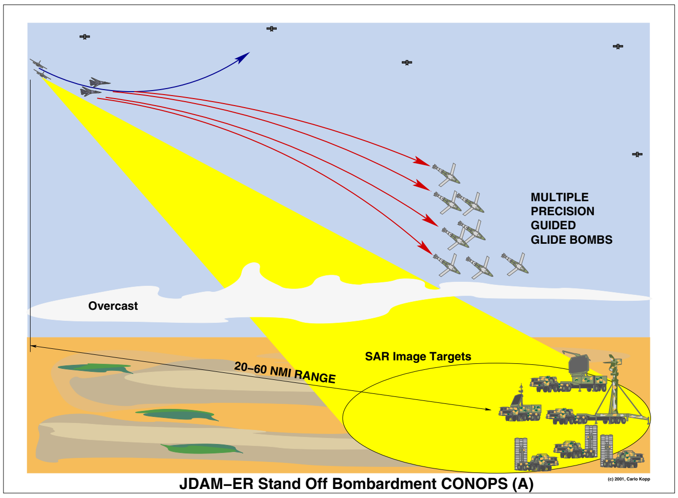
The Affordable Moving Surface Target Engagement (AMSTE) technology demonstration program is a complex effort which is intended to develop and prove techniques for the engagement of moving ground targets, using cheap munitions and standoff radar targeting techniques. In particular, AMSTE is exploring Ground Moving Target Indicator (GMTI) radar techniques, target position refinement using information from multiple radars on multiple aircraft, and the use of datalinks to guided weapons.

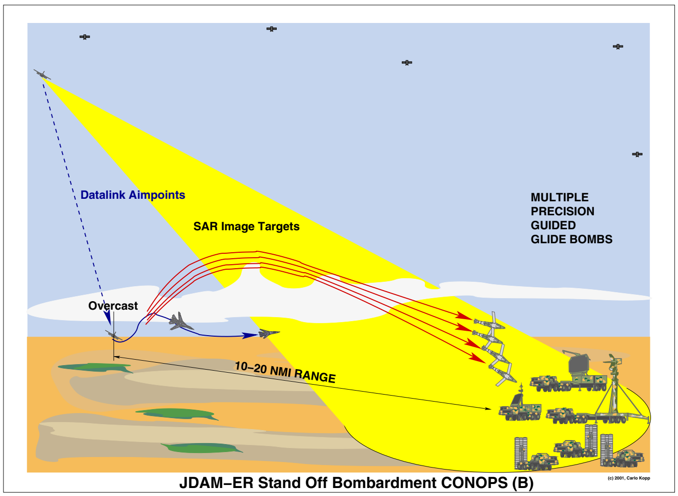
Perhaps the most dramatic outcome of the AMSTE effort was the August 22, 2002 demonstration, in which a JDAM modified with a JTIDS datalink receiver successfully engaged a moving vehicle in a column, using target coordinates produced by a distant E-8 JSTARS and a second radar on an airborne testbed.

The inert JDAM was dropped by an F-16C at 20,000 ft, the target was part of a vehicular column travelling at 30 km/h. Once released, the JDAM acquired the JTIDS signal and continuously updated its aimpoint position as it flew toward the target. DARPA have not disclosed the frequency of updates, but it is likely that a whole JTIDS net was reserved for this purpose.

The AMSTE demonstration is important since it proves the feasibility of continuosly datalinking a moving target's position to a JDAM in flight. The position information could be produced a GMTI radar on a distant aircraft, be it a fighter with a larger radar, an ISR platform or a UAV, or it could be produced by a FLIR/EO/laser targeting system on a fighter or an endurance UAV such as a Predator or a Global Hawk. Once the targeting sensor is measuring the location of the target vehicle, it takes little effort to pump this information out on a datalink radio channel to a bomb in flight.

Handling the target coordinates at the bomb end is per-





Pic.3 JDAM-ER-CONOPS-1B.eps JDAM-ER-CONOPS-1A.eps (both over one caption)
The HdH JDAM-ER effort builds on the DTSO GTV/Kerkanya glidebomb effort, using the standard JDAM tailkit with suitable software alterations. With a standoff range likely to be well in excess of 50 NMI, the JDAM-ER will revolutionise much of the bombing game. The weapon will be suitable for medium/high altitude drops, and low level toss deliveries, placing the bomber outside the range of most air defence weapons (Author).

haps the most challenging aspect of such systems. The guidance software will have to incorporate a Kalman filter which estimates the position of the target vehicle based upon a track history of continuously transmitted coordinates. A prediction of the target's position based on this data is then used to adjust the bomb's aimpoint. Since the JDAM is flying blind toward its target, the quality of the prediction algorithms is critical to success.

Another important aspect of 'seekerless' JDAM engagement of moving targets is the accuracy of the transmitted coordinates, since these are added to the JDAM's guidance error. While many radars support GMTI techniques, very few support the more accurate multi segment Differential Phase Centre Antenna (DPCA) techniques, as these require specific adaptations to the radar antenna design, and feed designs. As a result, the range and bearing accuracy of GMTI radars usually does not match that achieved in SARs. The AMSTE program works around this limitation by fusing GMTI tracks from multiple airborne radars, to yield a 'best estimate' of target position. The target bearing error can be modest, and triangulation of the target using bearings from two or more radars separated by several miles evidently makes the difference.

When the AMSTE derived technique does eventually become operational, it will permit the concurrent engagement of multiple ground vehicles in all weather day/night conditions. Whilst it may not match the accuracy of seeker equipped JDAMs, it makes up for that limitation in much lower weapon costs.

Combining a datalink midcourse system with a cheap autonomous short range seeker, such as a device derived from an anti-armour submunition, of course yields the best of both worlds.

What is clearly evident is that the sanctuary of motion will not last long for evaders of the JDAM.

Australia's Winged JDAM-ER

The notion of a GPS aided inertially guided glide bomb is nothing new, but fielding one has proven to be a time consuming task. Australia is in a unique position insofar as the DSTO GTV/Kerkanya demonstration put it in the forefront of glide bomb kit research – until recently this innovative DSTO effort sat in limbo.

The first attempts to convert the GTV/Kerkanya concept into viable production weapons never got off the ground, in both senses of the phrase. During the 1990s Hawker de Havilland pursued the Icarus I and II concepts, the former using a BAe ALARM anti-radiation seeker, the latter using a JDAM-like GPS/inertially guided tailkit. A lack of funding saw both efforts confined largely to paper studies. AWADI also pursued the idea of a production GTV/Kerkanya derivative, but aimed from the outset at a GPS/inertially guided tailkit solution under the Agile Gliding Weapon (AGW) designation. With the entry of the JDAM into full scale production, the idea of fusing the AGW wing kit with the JDAM tailkit was explored as a joint effort between AWADI and Boeing. The AWADI effort collapsed after the company was acquired by BAeA. Thus, it appeared, the effort to revive the GTV/Kerkanya as a production effort was doomed to failure.

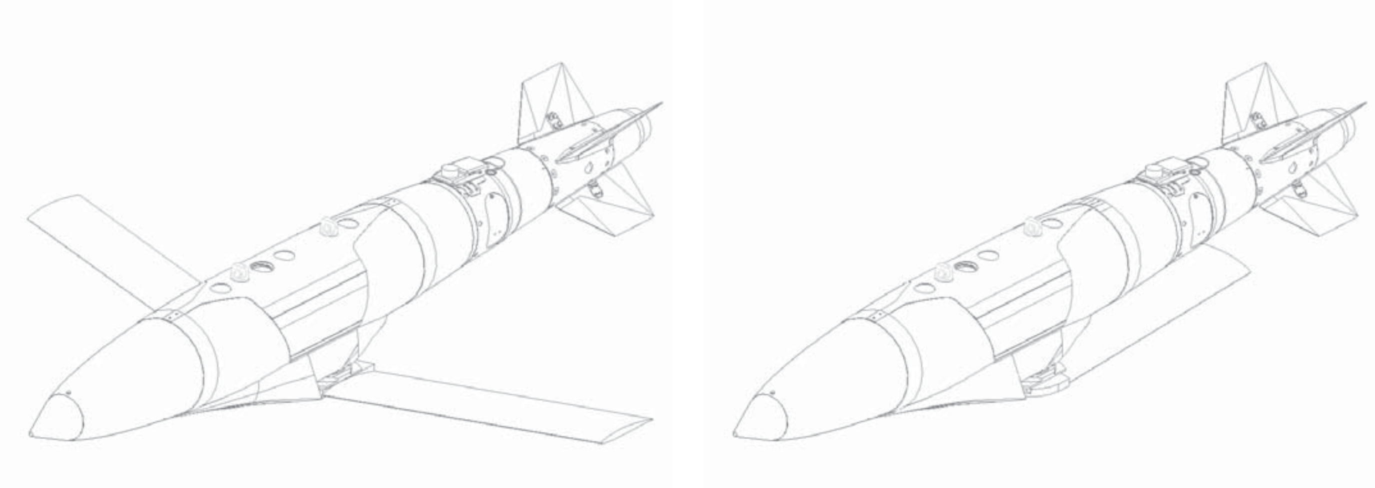
Last year Hawker de Havilland (now Boeing owned) at Fisherman's Bend were awarded RAAF funding to pursue a Concept Technology Demonstration of a GTV/Kerkanya derived wing kit for the GBU-38 500 lb JDAM. HdH licenced the DSTO intellectual property in the GTV/Kerkanya and acquired all archived DSTO design data, reports, and remaining demonstrator hardware components to support this effort. HdH have received 'great support' from DSTO, RAAF Capability Development, the DoD CTD program office and DMO.

Over the last 2 years, the HdH development team at Fisherman's Bend have been working in earnest to convert the GTV/Kerkanya research findings into a viable design for mass production. This effort has involved analysing the basic design issues for the wing from the ground up, and re-evaluating nearly all basic design assumptions.

The current intent is to perform a critical design review at the end of 2002, resulting in a qualified design by mid 2003 and flight trials in late 2003. Should no unforseen difficulties arise, the HdH 'Range Extension Kit' for the GBU-38 JDAM (JDAM-ER for 'Extended Range') could enter Low Rate Initial Production (LRIP) some time in 2004.

The basic JDAM tailkit is well suited to such an adaptation since the Guidance and Control Unit (GCU) has available internal growth capacity, and spare unused interfaces to permit the control of additional hardware. The wing kit would thus be connected to the GCU via an umbilical, and additional code added to the baseline JDAM to provide for release of the wing, and provide a unique autopilot for the winged variant. In the simplest of terms, the JDAM tailkit hardware would remain unchanged, but software would be added to adapt the tailkit to the glide wing.

The HdH design uses an untapered wing planform like the GTV demonstrator, but differing from the later tapered wing planform on the Kerkanya. This reversion loses a few percent in aerodynamic efficiency, but improves the radar scattering behaviour of the wing, and is much easier to mass produce at low cost. Unlike the DSTO demonstrators which



The HdH JDAM-ER is being designed for very low mass production unit cost, which is reflected in a number of design features. The most evident is the revival of the DSTO GTV untapered wing planform, which sacrifices a little range performance but is significantly easier to manufacture. The 'baseline' GBU-31/32/35/38 tailkit is used, with software alterations to support the changed aerodynamics and wing deployment functions (HdH).

used differential pressure sensing ports and a pitot tube to achieve optimal gliding performance, the baseline HdH design will derive its velocity from GPS/inertial outputs. While this does not extract the full glide range potential from the design, it does reduce cost and complexity considerably, and improves the reliability of the wing kit.

Key design objectives for the HdH product are lowest possible mass production cost, zero hardware changes to the existing GBU-31/32/35/38 tailkits, best possible performance, modularity, ease of maintenance and especially shortest possible assembly time in the field. The latter will be critical to user acceptance of the kit, the less time expended and the fewer errors in assembly when deployed in the middle of nowhere, the more popular the kit will be with its users. The design philosophy is centred on producing a flexible product which can further grow as customers request additions. Should a customer pursue a high wing configuration, improved glide range, or a different wing sweep angle, the basic design is aimed at accommodating such changes at the lowest incremental cost.

HdH intend to offer scaled variants of the kit for the Mk.82, Mk.83, Mk.84, BLU-109/B, BLU-110/B, BLU-118/B warheads, and any future warheads in this weight class.

At the time of writing the external design was frozen with detail design currently progressing to design review. Available illustrations reflect the current configuration, but are likely to change in detail areas to reflect future customer requirements.

The importance of the HdH effort cannot be understated. In strategic terms, a JDAM-ER with 30 to 50 NMI of standoff range for a high altitude release provides a very cheap mass production standoff weapon which defeats all but the largest and most capable area defence SAMs in service. As the range of the weapon is well matched to typical combat aircraft radar SAR modes, it provides a genuine standoff all weather capability. Should the JDAM in the future acquire a standard datalink, this capability would be expanded to encompass moving targets.

The JDAM-ER is not a substitute for the AGM-142 SOW, as the latter is a supersonic weapon with a pinpoint precision imaging seeker and remote datalink control. When dealing with well defended very high value targets, such as radar installations, mobile command posts, command bunkers or communications nodes, or targets of opportunity, the AGM-142 permits positive operator control of the weapon to impact with a fairly short flight time. This contrasts with the less precise, much slower but also much cheaper JDAM-ER. The low cost of the JDAM-ER permits its use against much lower value targets, even if these are well defended. In practice the RAAF would use the AGM-142 to engage air defence and command-control-communications targets, while concurrently using the JDAM-ER to engage the fixed targets being defended by those same assets.

Like all other variants of the JDAM, the JDAM-ER will permit massed attacks against prebriefed targets. A fighter could pickle off an arbitary number of these weapons, and turn tail while the bombs each autonomously fly to their targets. Even with a 50 NMI glide range, the footprint the fighter can hold at risk encompasses roughly a 100 NMI circle. A key issue for the RAAF will be achieving a mature Mil-Std-1760 capability on its F-111C/G and F/A-18A fleets before the weapon becomes available.

Exploiting the full potential of the JDAM-ER, especially the 500 lb GBU-38 varianant, will require 'smart bomb rack' technology, with a Mil-Std-1760 capability on each ejector. For the F/A-18A this would require a dual or triple rack, for the F-111C/G a modified BRU-3/A six hardpoint rack. The GBU-38/JDAM-ER would be especially well suited to the F-111C/G as with four 6 hardpoint smart racks it has to potential to engage 20-24 aimpoints on a single pass, subject to clearances. Autonomous targeting of the JDAM-ER will require either a good Synthetic Aperture Radar or a high resolution thermal imager with exceptional jitter performance. The latter makes a good case for some technology insertion into the Pave Tack, since no existing thermal imaging pods come near the required performance (doubters might consider looking up the jitter specifications of such if they choose not to believe this author).

Most observers consider the introduction of the JDAM into the RAAF inventory as a forgone conclusion, under the AIR 5409 Bomb Improvement Program, although the JDAM has had its fair share of doubters and critics in Russell over recent years. One hopes that repeated 6 o'clock news observation of BBC and CNN TV footage from Afghanistan will have dispelled their fears or indeed dislike of the weapon! Whether one likes the JDAM or not, it has proven its effectiveness very convincingly.

In conclusion the JDAM is the vanguard of a new generation of low cost, digital, autonomous weapons, designed for genuine all weather use. It is revolutionising air warfare in a manner analogous to the laser guided bomb three decades ago, and promises to develop into a diverse family of derivative weapons adapted to a range of demanding niche roles. Air forces without JDAM capability today will be as handicapped as air forces without laser guided bomb capability were two decades ago.