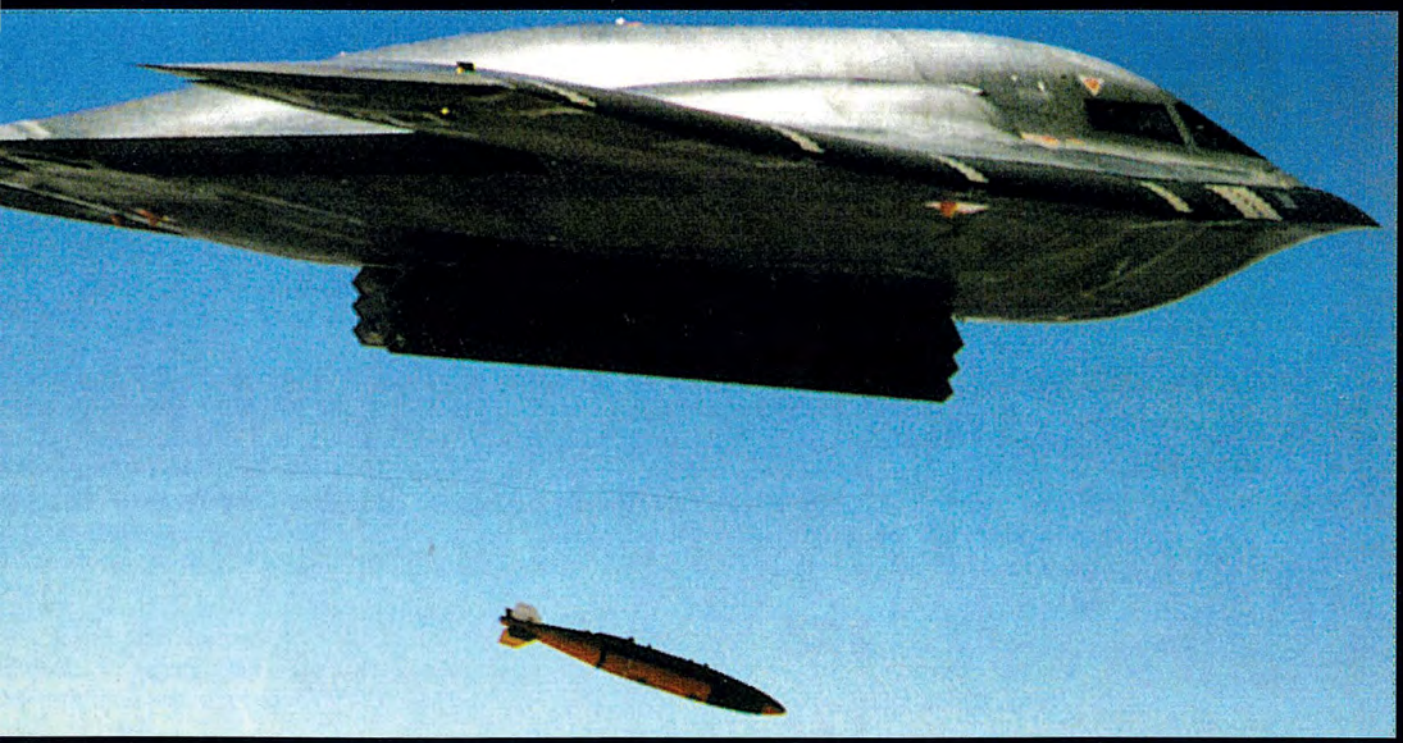
Precision Weapons -



By Wing Commander Greg Bagwell, MSc RAF

Considerations for their employment (or what the weapons manual doesn't tell you!)

AIR POWER DELIVERS?

Air power has come a long way in its short history; but perhaps the most amazing fact is that it has delivered on so many of its early promises in such a short timeframe. This is all the more remarkable when you consider that early air power theorists were making such grand predictions as the end of conventional warfare.[1] They described scenes of aircraft flying over an enemy's capital city, raining death and destruction from the skies, forcing him to capitulate. All this at a time when people were still a little nervous to even travel by motor car! Whilst some early writers even had the audacity to predict the demise of armies and navies, the Smuts Memorandum of August 1917, the paper that led directly to the creation of the Royal Air Force, discussed air warfare in these slightly less evocative terms:

> *"As far as can at present be foreseen there is absolutely no limit to its future independent war use. And the day may not be far off when aerial operations with their devastation of enemy lands and destruction of industrial and populous centres on a vast scale may become the principal operations of war, to which the older forms of military and naval operations may become secondary and subordinate".*

In 1917 this prediction may have looked a little suspect, as it probably did to many in 1944. However, in the last 10 years, air power has come very close to proving Smuts correct. Few could argue that today's force of choice in many scenarios, rightly or wrongly, is air power. The 1991 Gulf War, Bosnia, Kosovo, Iraq and more recently Operation DESERT FOX all stand testament to the fact that in crisis situations, air power is often considered as the first option. So what has brought air power to the fore in recent times?

In the Strategic Bombing of Germany during the Second World War, raids of hundreds of aircraft were tasked against single targets

AIR POWER DELIVERS – BUT PRECISION GETS IT IN THE RIGHT PLACE

The biggest setback for air power theorists over the first 60 years of manned-flight was that air power, although effective to differing degrees, required a massive weight of effort to achieve its aims. In the Strategic Bombing of Germany during the Second World War, raids of hundreds of aircraft were tasked against single targets. The weapon effort calculations of the day showed that, on average, a force of 4,500 heavy bombers, carrying a total of 9,000 tons of bombs, was required to destroy a target the size of a small house.[2] The German oil refinery at Leuna provides a more practical case study, where only 2.2 per cent of all bombs dropped on Leuna impacted in the refinery's production area. It was attacked no fewer than 22 times by large formations in the last year of the war in order to put it out of commission.[3]

US air power was to fare little better in the early part of the Vietnam War. The Cold War strategy prevalent at the time was heavily dependent on Nuclear weapons and, when necessary, interdiction against large armoured formations – neither activity requiring a great deal of precision. One of the major tasks given to air forces during the conflict in South east Asia was the interdiction of enemy supply lines. In the event the Ho Chi Min trail remained an elusive target; moreover, attacks against the major North Vietnam Bridges, which were much easier to target, proved just as hard to hit. It was not until the introduction of the recently developed Walleye and Paveway series of PGMs (Precision Guided Munitions) in the 1972 Linebacker campaigns that sortie effectiveness increased exponentially. Whereas that small house had taken some 4,500 aircraft and 9,000 tons to destroy it in 1945, in Vietnam, thanks to a combination of better weapon aiming and guided bombs, it required only 95 aircraft and 190 tons.[4] However, although precision weapons had been a success story they were too few in numbers to have a significant effect. Much of the credit for the change in fortunes was due to a change in targeting policy and the use of massed raids by B-52s, dropping "dumb" bombs, which brought the North's war-making capability to its knees.

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Actually, precision weapons had been in existence since the Second World War, starting with the German *Fritz X*, a radio-guided bomb, which was used in 1943 against the Italian battleship *Roma* to good effect! Radio continued to be the guidance method of choice until the 1960s and saw service in various weapon types by both the RAF and US air forces. However, the Nuclear age reduced the priority for precision weapon research and although the Korean War saw some limited successes, it was the particular problems posed in Vietnam which drove the development of the more capable laser-guided Paveway series of bombs.

If Vietnam had hinted at air power's potential, the 1991 Gulf War eliminated any lingering doubts. Approximately 9% of the total tonnage of air delivered weapons expended by the coalition during the Gulf War were precision munitions – of which nearly half were Paveway series bombs. Yet, these weapons were assessed to have caused approximately 75% of the damage on Iraqi strategic and operational level targets.[5] Not only could a single bomb destroy that proverbial house, but also you could choose which room! The biggest issue raised by this conflict, however, was the value of strategic bombing – for which the majority of PGMs was earmarked. The

differences between denial and coercion and the effects of strategic and tactical air missions in relation to the overall campaign have become major discussion points since the end of the Gulf War[6]. For the purpose of this article it is not necessary to add to this debate; however, what is important is that the employment of PGMs in a future conflict will require a full understanding of what strategic bombardment is and, more importantly, what it may or may not achieve.

Although there are still some sceptics, and there have undoubtedly been many failures of the new high-tech weapons and systems, the Gulf conflict pushed air power to the forefront of military thinking. Although precision played only one part in this new dawn of air power – stealth, C4I, electronic warfare, imaging, space based assets all played a vital part – it was the TV images of bombs striking small, discriminate targets that captured the imagination. However, although precision weapons offered a qualitative increase in performance it was the promise they gave of a whole new way of waging war which proved the most tantalising.

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THE GOLDEN BULLET?

Colonel Philip Meilinger listed as one of his "10 Propositions Regarding Air Power" that: "*Precision air weapons have redefined the meaning of mass*." By this he meant that concentration of force (a fundamental Principle of War) was now possible by targeting accurately rather than massing overwhelming force to guarantee a target's destruction. Judged by the changes in weight of effort required for a single target between the Second World War and the 1991 Gulf War, few could argue against this assumption. However, we can take Meilinger's thesis even further by looking at the effect that precision weapons have had on other principles of war. Surprise, offensive action, economy of effort and flexibility have all been enhanced immeasurably since the advent of precision weapons. But precision air power offered more than just a better way of waging conventional war, it offered a possible short cut to victory, something the early theorists had believed all along. Maybe air power could do it all?

Consider what might have happened if Saddam Hussein had been in one of those first targets hit on the night of 16/17th January 1991?

Centres of Gravity (C of G) have been around since the Big Bang; however, Clausewitz applied this physical quality to the conduct of warfare by calling it the "hub of all power and movement"[7]. Colonel John Warden developed the concept further, in his book "The Air Campaign", by discussing methods of sequencing a campaign around an enemy's C of G in order to bring victory. He even went as far as to create a strategic targeting model known as his "Five Rings"[8]. The model envisaged the enemy as a system with Military/Civil leadership at the centre of five concentric circles, followed by key production facilities, transportation infrastructure, civilian morale/popular support and with deployed military forces in the outermost circle. With his model Warden was able to take Clausewitz's thesis further, thanks, primarily, to the reach of air power and the lethality of precision weapons, which made a C of G vulnerable. Theoretically, if the C of G was easily definable, and, more importantly, finite, it could be destroyed in a single attack. No longer would you require large bomber raids, whose prime objective was to demoralise the enemy's will to fight, you could now go for the jugular and end the fight quickly and cleanly. Consider what might have happened if Saddam Hussein had been in one of those first targets hit on the night of 16/17th January 1991?

Precision weapons had come close to offering the 'Holy Grail' of air power theorists – the potential ability to end a conflict without the need for any sea or land operations. In practice of course a single target is unlikely to bring about an enemy's defeat. However, based on Warden's theory, the destruction of an enemy's key component(s) could feasibly be achieved with a small, finite number of precision weapons, thus making his defeat all the more likely.

SO WHAT'S THE PROBLEM?

Having painted such a favourable picture of precision air warfare you might expect me to round off by calling for the abolition of the Army and the Navy and a statement to the effect that air power can now do it all. But you would be wrong: even John Warden was careful to explain that an air campaign was ordinarily part of an overall joint theatre campaign. Instead I am going to offer a few words of warning. We should not forget that the Gulf conflict might actually have heralded the end of all-out conventional warfare, although I personally doubt it. But even if this was the case, limited, precision air strikes have recently been used in such diverse situations as peace enforcement and anti-terrorist operations, or to contain Saddam Hussein, and will undoubtedly be used again. In many scenarios precision weapons offer a compelling case for their use – limited duration and commitment, small relative cost, limited exposure of own forces, prolonged threat from a distance, and, moreover, a high chance of success if a target can be easily identified and located. However, the employment of precision weapons is not without its problems or limitations. The aim of this final section is to highlight some of the considerations, in no particular order of priority, which might need to be taken into account at all levels when planning precision weapon attacks. For the purpose of this article I have concentrated on precision weapons delivered from air vehicles, or those that are air vehicles themselves. However, many of the factors will be equally applicable to other types of precision weapons – including those used for non-lethal or information operations:

Expectations. The Gulf Conflict, and more recent air operations in Bosnia in Iraq, clearly demonstrated the awesome capability of precision weapons; however, we rarely make our failures public. Imagery of weapons entering buildings through doorways and ventilation shafts has raised high expectations of success from precision strikes. The CEP of most precision weapons is quoted in tens of feet; however, CEP tells literally only half the story[9]. Most weapons that require guidance do not perform well without that guidance, and, in the event of a system or weapon failure, some of the newer precision weapons could miss by miles rather than feet, with the release aircraft having no further influence over the weapon's trajectory. Therefore, it is important that senior decision-makers are aware of any risks, no matter how small. Weapon effort calculations are designed to tell you the chances of targeting success, not what happens when the bomb misses. We can normally guarantee the desired result but we cannot guarantee perfection.

Intelligence. Just as a weapon can fail to hit its target, so can it accurately hit the wrong one. If precision weapons are to be targeted against an enemy's C of G, then obviously we must know what it is. However, although the C of G should ideally be singular, it is unlikely that it will be a single target. For example the enemy's leadership could be a singular C of G, but it would be made up from a whole network of personalities, organisations, command cells, communications nodes etc. The key to eliminating such a target set is finding the key vulnerable point(s). Essentially, the level of intelligence required for precision strikes must be as precise as the weapon used. Whilst this would be the role of strategic intelligence cells, precise intelligence is just as vital at the tactical level. The destruction of the Al Firdos bunker (assessed as a communication node but unknowingly being used as a civilian air raid shelter), in Baghdad in 1991 was a classic example of an incomplete intelligence picture, and a prime example of a tactical event having strategic impact. As we design weapons that are able to penetrate many metres of concrete/earth it is becoming increasingly difficult, if not impossible, to gain a complete intelligence picture. Imagery will rarely provide all the information required and all available means will need to be fused into a comprehensive intelligence picture.

Targeting. Just as intelligence identifies the key elements of an enemy system/C of G and therefore the target, so the targeting cell should provide the key/vulnerable points of the target and therefore the desired impact point(s). However, the old tasking terms of destroy or disrupt are not precise enough aims for a precision strike. Target analysis must provide detailed weak/critical points of a target in order that an attack can achieve the desired effect. A good example of this is an attack against a power station, where the aim is to achieve disruption of power for a limited period. In this example, detailed target analysis might identify the dropping of the transmission lines as the most efficient method of achieving the desired result without causing excessive long-term damage, whereas longer-term destruction would probably require attacking a more critical component of the plant itself. Such considerations will be important when planning for the desired strategic end state of the conflict[10]. Therefore, it is crucial that any limitations on weapon impact are well understood by those carrying out the strike.

Discrimination. At the tactical level some newer, sophisticated weapons are beginning to employ target recognition techniques for autonomous attacks against military hardware (particularly ground vehicles). Thermal, acoustic or radar "blueprints" of equipment can be programmed into the weapons memory and recalled in flight in order to help the weapon locate a target. However, we are increasingly being employed in operations where it is difficult to discriminate between fielded military forces and the civilian population. Moreover, as coalition operations increase so do the chances of either side operating the same military hardware. A few algorithms will not always solve the discrimination problem, and employment of such weapons will have to be carefully controlled.

Collateral Damage. A popular phrase for precision bombing is "surgical strikes". Whilst the accuracy of a precision weapon, delivered to within 30 feet by an aircraft travelling at 700 feet a second, could be relatively termed as "surgical", the explosive force of a 500-lb warhead does not constitute keyhole surgery! Whilst every attempt can and should be made to limit collateral damage, the use of large warheads is always going to make this task difficult, particularly if the enemy uses the civilian population/infrastructure as cover. Although non-lethal weapons may offer a solution in some cases, they will probably be designed for specific target types, and will almost certainly not have much utility against hardened targets. There is, I believe, a strong case for smaller warheads in-service, preferably based on an existing series already in service, thus requiring minimal integration/clearances. Unfortunately, we have a lot of sledgehammers when there are a lot of nuts out there to crack (pun intended!)

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ROE (Rules of Engagement). As we attempt to minimise collateral damage in future operations the imposition of strict ROE is designed to make the employment of any weapon as closely controlled an event as reasonably possible. Precision weapons lend themselves to a higher degree of control because they can be controlled. In addition, the increasing proliferation of data-link systems in aircraft means that commanders could potentially monitor a crew's every action; indeed, most airborne command aircraft incorporate this as a design feature. There will be a fine balance on the degree of freedom

given to the bombing crew; however, the strategic effect of a single mission may be so important that the highest level of control will be imposed/warranted. Taken to its ridiculous (or is it?) conclusion the Prime Minister himself could have real-time imagery relayed to his office and have a weapon release button on his desk! Of course fire and forget systems such as Tomahawk will have the decision made at the highest level as a matter of course, since the operational/tactical input to their mission will merely be the entry of the target data. However, for air delivered weapons that require some human interaction in the committal phase of the attack the drafting of ROE will require careful consideration. For example, some targets could require such guaranteed accuracy that the aircraft/platform might be placed at increased risk to enemy defences. In this case the ROE will need to make the desired identification criteria extremely clear so that crews, who are effectively judge and jury, will be able to take the right course of action.

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Autonomy vs Man-in-the-loop. Many now feel that autonomous[11] weapons offer the ultimate solution for precision attacks. They don't put our own people in danger and they don't have to interpret ROE (the programmer does that for them – the last chance for human error). All this with an accuracy to equal or even beat man-in-the-loop systems. However, such weapons do not react to changes in circumstances, and an inability to make on the spot decisions on ROE issues may be a shortcoming. There may be many circumstances where the removal of any late human input to the targeting process would be unacceptable – peace support operations or other complex operations subject to strict ROE are two such examples. A pre-programmed attack against an enemy installation, launched from beyond line of sight, would not be able to assess the target's status close to impact; a civilian bus that happened to drive across the target area would probably be ignored with disastrous consequences! The same limitation holds true for attacks against fielded forces in close proximity to friendly units, where the situation would be changing by the minute. Whatever the scenario, the decision to employ one system or the other will rely on a pragmatic risk assessment between the endangerment of aircrew and the chances of fratricide or unacceptable, accidental collateral damage. But never forget that autonomous systems are designed, built and programmed by humans and they don't always work as advertised[12]. The man-in-the-loop of a designated attack is the last chance check that a Tomahawk never has.

Control of the Air. Although most precision weapons are designed to perform from a tactical release profile (i.e. minimum exposure time), the desire for optimum performance, and the limitations of the extant ROE, may require aircraft to fly line of sight to the target for a considerable period of time. Such a profile would require a high degree of control of the air. Even relatively slow moving cruise missiles are vulnerable to short range air defence systems. Unfortunately, precision strikes may often be an integral part of the plan to achieve that degree of air control. In the Gulf War these early missions were primarily conducted by stealth aircraft or expendable unmanned systems – a costly, unavailable option for most countries' armed forces. If such assets are not available then a suitable degree of air control may have to be provided for a particular strike by the use of extensive support packages of both Air Defence and Electronic Warfare/Suppression of Enemy (ground based) Air Defence aircraft. Even in the Gulf War, where the coalition forces had an extremely high degree of control of the air (some call it supremacy despite losses taking place late in the conflict), strike aircraft were heavily outnumbered by support aircraft – so much for one target – one aircraft!

Flexibility. Most precision weapons require detailed planning for their employment and, therefore, are best suited to unique, static targets. Although most potential targets could be attacked using precision weapons, mobile, fleeting targets will require special techniques and careful contingency planning. Paradoxically the cheaper (older), more basic precision weapons such as the Paveway series actually offer the most flexibility. This is particularly true once the delivery aircraft is airborne. Current autonomous weapons have little or no reprogramming capability once airborne or released, whereas an aircraft carrying laser or optical guided bombs could be re-tasked in the air, assuming the crews have sufficient target information. In addition, in exceptional cases, these bombs' impact points could even be changed after weapon release, assuming that it is within the dynamic range of the weapon, the seeker head and the capability of the crews involved.

Co-operative Techniques. Many precision attacks that require airborne designation utilise a combination of bombing and designating aircraft working in tandem – this is often due to payload restrictions or differing aircraft modification states. This requirement increases the degree of planning and airborne co-ordination between aircraft and could potentially increase the chance of failure or aborted attacks. Crews that perform such attacks will need to have trained together and, most probably, be co-located for best results. Fortunately, many western precision weapons are compatible with systems operated by different air forces, and potentially this means that an RAF aircraft could designate for a USAF bomber. Whether any government is going to sanction another country controlling the impact point of one of its own bombs is another matter! In coalition operations, particularly where one country cannot be seen to be carrying out operations alone, this might mean a duplication of assets in theatre, and negate the reduction in platform numbers which precision weapons were designed to achieve.

Combat Assessment. As Wg Cdr Moose Poole reminds us in his article in this volume, the ability of precision weapons to achieve the desired effect with minimal damage has actually made the task of Combat Assessment more difficult. This is particularly true for attacks against hardened/sub-ground installations, where the only evidence is a hole in a roof or wall. Combat Assessment techniques are becoming more sophisticated but it is likely that the physical evidence of a weapon strike will be insufficient to measure a mission's success. A classic example from the Gulf War was the destruction of Iraqi hardened aircraft shelters that may or may not have been occupied by aircraft. Even after the attack it was almost impossible to tell if aircraft had been destroyed inside or not. However, General Horner, the Joint Force Air Component Commander (JFACC) for the coalition, preferred a more pragmatic alternative to the dreaded tally in order to measure success. He suggested that observing the desired effect of attacks (i.e. the reduction of Iraqi sortie rates) was far more meaningful that the often inexact science of head counting[13], thus making BDA more of a qualitative process.

Increased Asymmetry. As potential foes assess our capabilities they will appreciate that asymmetric warfare will probably be their best course of action should we engage in hostilities. The use of the civilian/industrial infrastructure as cover, smaller concentrations of units and increased dispersal will be exploited to counter our strengths, thus making the use of any military force increasingly difficult. Whilst we would not wish to "dumb down" our capability to keep warfare symmetrical we must be aware of the enemy's likely response to our attacks and plan accordingly.

Effect on the Enemy's Morale. Interviews with Iraqi POWs from the Gulf War revealed that precision attacks against static armoured formations were actually countered by crews leaving their vehicles and taking shelter some distance away[14] – not, I believe, current practice in the British Army! In Baghdad normal civilian life carried on as best as could be expected. Amazingly the Iraqi military and civilian population alike probably had as much, if not more, faith in precision weapons than the coalition did. Precision attacks will, therefore, affect a nation's will in a different way to that of older, more traditional strategic campaigns of the past. An enemy may be frustrated and inconvenienced by the loss of key components; however, the knowledge that one's life is probably not at risk would probably make this easier to bear. Significantly, Col Warden suggests that the capabilities of air power and accurate weapons mean that we can, and should, attack the physical component of the enemy rather than his morale[15] – or more simply: his ability to fight, not his will to fight.

Recorded/Data linked Imagery. Precision munitions have introduced the added benefit of providing high quality imagery of an attack up to impact, either from the designator platform or the weapon itself. Such imagery has made good media copy, designed to maintain home support. But the added benefits are immediate, albeit crude, BDA and, perhaps more importantly, a counter to an enemy's false claims of missed or indiscriminate attacks. The value of such imagery should not be underestimated. However, most weapons with an autonomous capability or increased stand off range do not provide imagery; the inability to tell our side of the story will be sorely missed.

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Stand off vs Accuracy. Obviously the further you are from your target at weapon release, or more importantly its defences, the safer you will be. Whilst most manufacturers quote a weapon's maximum kinetic range as the key performance criterion, systems which require some form of target recognition prior to release will be limited by the range at which the target can be discriminated. This could be a simple factor of tracker head capability or even the pixel resolution of the in-cockpit display. For certain attacks designator aircraft will have to encroach inside the maximum release point, especially for small or well-camouflaged targets. In addition, aircraft will have to stay within "designation range" throughout the weapon's time of flight. The alternative would be to potentially trade off accuracy for increased aircraft safety.

Weather. Contrary to popular belief very few precision weapons are all-weather capable. Those that require optical sight of the target, in particular, have degraded or no effectiveness in bad weather, although most systems can perform at night in good visibility. Moreover, rain or smoke can affect laser energy, whilst thermal crossover[16] will have a dramatic effect on heat contrast or infrared systems. Weapons that use some form of independent guidance (inertial, GPS or terrain matching) do have an all-weather capability; however, ROE or targeting restrictions, particularly in limited operations, will probably necessitate at least some form of independent verification of target status prior to release. This could be by satellite or surveillance aircraft, which can themselves be degraded by poor weather conditions.

Cost. Obviously precision does not come cheap, although prices and complexity vary dramatically (e.g. $9,000 for a simple GPS guided bomb, $500,000 for a Block III Tomahawk missile). However, cost effectiveness is what really matters and the case for a particular weapon's use should be predicated on this factor alone. If the use of a single cruise missile can avoid the exposure of a number of manned aircraft over a heavily defended target then it will have justified its cost. Increasingly today the relatively small financial losses (especially when they are already paid for) are far outweighed by the political imperatives to minimise friendly losses.

Training. Since precision weapons don't come cheap, it should come as no surprise that the number of training releases is limited. In addition, the safety requirements, particularly for the longer-range weapons, also place huge restrictions on training opportunities. In future, weapon simulation may provide viable, realistic alternatives to real weapon drops. A precision weapon attack is not only a complex, skilled act, it will usually be against a high priority target with possible strategic implications – even for a tactical target. Therefore, it is vital that we continue to provide the best training possible for nominated crews, to ensure that they are given the best chance of success should the need arise.

Logistic Support. Precision technology has dramatically reduced the numbers of weapons normally required for a particular offensive air operation, thereby reducing pressure on strategic lift. However, whilst this will ease the bulk loading effort, technical support for the more complex weapons, designation systems and aircraft sensors will carry its own heavy logistic burden. The real problem arises when you try to provide a conventional (dumb weapon) and precision capability. Both will need different priorities and the deployment sequencing will be a delicate balancing act. Whatever the case, it will be vital that targeting issues are considered at the earliest opportunity of a deployment/operation. On the same note, in-theatre support for modern, complex test-beds and storage facilities will need careful planning. As ever this will be a combination of sufficient investment in a credible deployment capability and human ingenuity!

THE BOTTOM LINE

"...we must beware exaggerating our expectations. We have to understand not only the potential benefits of technology but also its limitations because the future of air power will stand or fall, not by promise or abstract theory, but by its relevance to political objectives and its ability to secure them at a cost affordable to the government of the day."

This excerpt from CAS' foreword to the first edition of this journal places this article in perspective. Nowhere is this statement more true than when discussing the employment of precision weapons. I hope I haven't left the reader with the impression that precision is a bad thing – it is **not**. But what I have tried to do is highlight some of its failings and limitations, for if you know what they are (and I am sure there are people out there with long lists of others) then you can eliminate them from your plan or at least minimise their effects.

However, I hope I have explained that the concept of precision goes beyond that of just pure weaponeering. Missing the proverbial barn door at the **right** farm is preferable to dropping a bomb down the ventilation shaft of the **wrong** factory. Precise intelligence and information is an integral part of the targeting process; without it your 10 foot CEP doesn't mean a thing.

In the final section you may have noticed an increasing division between autonomous and man-in-the-loop systems. You also may have detected my personal preference towards the latter (hardly surprising for aircrew you might say) at a time when most effort is going into increasing autonomy. Although both systems have their merits I believe the argument hinges on the balance between immunity and accountability. If you prefer immunity whilst carrying out attacks then you should buy as many cruise missiles as you can afford, whilst investing heavily in your country's anti-terrorist measures! If, on the other hand you are more concerned with accountability, then you keep a man (or woman!)-in-the-loop as long as you can. As in all things, there will be a compromise, and a sensible mix of capabilities will be the best course of action. However, although precision weapons are often referred to as "Smart" bombs, they are not, it is the human input that makes them that!

NOTES

1 See "Makers of Modern Strategy", edited by Peter Paret – Chap 21 "Voices from the Central Blue – The Air Power Theorists", Davis MacIsaac, p.628, Princeton University Press, 1986.

2 Gen Michael Dugan "The Air War" US News & World Report, 11 Feb 1991.

3 US Strategic Bombing Survey, "Oil Division Leuna", Report No. 115, Washington 1946.

4 Dugan, op cit.

5 Richard P Hallion, "Storm over Iraq", p.188.

6 See "Perspectives on Air Power", edited by Stuart Peach, TSO 1998, in particular Chapters 10 (A Lambert) & 11 (M Buckman) which discuss these issues at length.

7 Clausewitz "On War" translated and edited by Michael Howard & Peter Parte (Princeton Univ Press 1976) p.595.

8 See "The Enemy as a System" Col John Warden, Air Power supplement to Air Clues 1997, p.50.

9 CEP or Circular Error Probable is the radius of a circle centred on the target within which 50% of all bombs dropped will land.

10 Some power stations in Iraq were almost completely destroyed in the Gulf War, when a temporary disruption would have sufficed. There were long term implications of this to the civilian population in the aftermath of the war.

11 For the purpose of this article autonomous weapons are those weapons that need no human input during the final phase of flight. These could use a variety of aiming methods that include Imaging infrared, Synthetic Aperture Radar, INS and GPS.

12 "One of our cruise missiles is missing" Sunday Telegraph 30 August 1998. A Tomahawk Cruise Missile aimed at Afghanistan landed in Pakistan, some 400 miles off target!

13 Gen Horner interviewed by T Clancy for "Fighter Wing", Harper Collins, 1996.

14 BBC Documentary "The Gulf War" 1992.

15 Col Warden, op cit p.47.

16 A phenomenon which is due to the different ability of objects to retain heat – radiation from the sun after sunrise or convection after sunset will blur the contrasts between various objects, making them harder to distinguish from one another.