An image of an aircraft taken at night, using the TIRRS system

*The technology, newly available to the RAF in the form of the Tornado Infra-Red Reconnaissance System (TIRRS) on the Tornado GR1a, meant that night imaging missions could be flown*

The paper begins with an analysis of recent conflict from the ISR perspective, taking the last decade as a recent and relevant time period, examining the Gulf War (1991), Bosnia (1995) and Kosovo (1999) as convenient episodes at approximately five-year intervals. The analysis will attempt to show the changes and improvements in ISR capability and draw out what is feasible and what is not, leading to the position we are today. It will also show what the ISR challenges are for conflict today, how conflict is changing and the consequences for the role and employment of ISR capability.

Having identified what remains challenging, the major discussion will propose potential solutions for maximising the employment of our ISR assets in order to bring significant additional benefit to bear on the battlefield. The editorial constraints and the classification restrictions for this paper preclude in-depth or technical analysis. The discussion will focus on the principal considerations. The paper is constrained in its focus on 'air ISR' capability as it cannot hope to cover all three Services' ISR capabilities, although there is certainly applicability across the joint and combined arena. Any broader examination would require more detailed research: work is already being undertaken, particularly in the Applied Research Program (ARP). It is hoped that this paper will complement, rather than duplicate, such work.

**The Gulf War**

This was the first major conflict after the end of the Cold War and inevitably attracted close scrutiny. Many lessons emerged from this unexpected and largely unenvisaged conflict, certainly unlike any expected NATO / Warsaw pact confrontation in Central Europe. Gen Adams, the USAF Deputy Chief of Staff for Plans and Operations at the time, said: "Reconnaissance needs attention. It's a continuing effort to assess how well we're doing every day. Many of our systems are configured for a Soviet-type scenario, and they are not as capable as they might be".[1] Analysis in the Australian Defence Forces Journal added comment on a number of weaknesses including the lack of timely Battle Damage Assessment (BDA).[2] Such detailed target imagery analysis is essential to ensuring that effort is not wasted on unnecessary re-attacks, and that any re-attacks which do prove necessary are targeted appropriately.[3] Lack of trained BDA analysts was a problem but the operational training of existing analysts also needed improving.[4] Despite such criticism, intelligence and BDA functions did work quite well, but the unexpected pace of the conflict demanded better capabilities. Most aircraft were not fitted with sensor video so that immediate reporting of impact results could provide an element of additional post-strike BDA without recourse to scarce ISR assets.[5]

Reconnaissance System (TIRRS) on the Tornado GR1a, meant that night imaging missions could be flown, albeit at low level only. However, only a few of these aircraft were available to the coalition. As cloud increased, reconnaissance assets were forced to operate at increasingly lower altitudes throughout the war as sensors were not capable of imaging through weather. Furthermore, no tactical assets were available to carry out reconnaissance at night at medium level.[9]

*"The ability to maintain the initiative was tied to the ability to undertake reconnaissance and surveillance" . . . The French Mirage F1CR was the only tactical platform with even a limited capability*

Reconnaissance assets were scarce. Even more importantly, the ability to manage all of the information collected by them was inadequate.[6] Intelligence gathering assets needed to be better managed to avoid expensive and unnecessary duplication of effort to achieve the right and timely coverage of the appropriate targets.[7]

To match the rapid pace of the war, real time transmission of reconnaissance information was required. So too was high-quality imagery which was capable of being provided at night and in poor weather.[8] The technology, newly available to the RAF in the form of the Tornado Infra-Red

Coalition warfare demands trust, yet intelligence sharing across the Coalition was lacking at tactical, operational and strategic levels. Sharing intelligence demands effective dissemination but this was poor due to an inadequate communications structure. Where sharing did occur, the lack of effective output was exacerbated by an inability to fuse intelligence from cockpit video, tactical reconnaissance aircraft and satellites.[10] Improved abilities to be able to process information quickly, together with improved dissemination capabilities were deemed essential.[11] The employment of smart weapons was seen as highly desirable but such weapons relied on

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accurate and timely target intelligence, especially of mobile targets, such as the infamous Scuds.[12]

This issue is continued by Gen Norman Schwarzkopf: "The lack of timely reconnaissance imagery is one of the shortfalls of Op Desert Storm".[13] The ability to control air assets and re-target in real-time in order to keep abreast of the fluid battlefield, proved essential: "The ability to maintain the initiative was tied to the ability to undertake reconnaissance and surveillance".[14] J-STARS (deployed as a prototype) did provide some capability to detect critical Iraqi war fighting capability in real or near real time.[15] Another report also adds comment on almost a total lack of data link systems for real time reporting. The French Mirage F1CR was the only tactical platform with even a limited capability.

The lack of intelligence system interoperability, across both strategic and tactical systems was a problem, as it prevented information from being collated more efficiently and then disseminated to commanders.[16] Col Mann relates the lack of timely intelligence to flaws in the "observe, orient, decide, act" (OODA) loop cycle.[17] He relates various C4ISR activities and processes to each component of the OODA loop and makes the noteworthy point that the OODA cycle is exactly that, a cycle, and therefore only as strong as the weakest link in the cycle. In Desert Storm's case, poor levels of observation lead to weak orientation and, while the Allied OODA loop was quicker and superior to the Iraqi's, it was not nearly as short and quick as Allied commanders would have wished.[18]

The presence of the media also posed problems, in particular the need to balance the release of potentially revealing intelligence with the desire to keep popular support strong through timely and accurate reporting. Management of the media and managing the media's requirements for imagery was also a lesson learned.[19]

Most Gulf War material is consistent in its key themes: the scarcity of assets; the importance of real-time information; an unexpected emphasis on night, all-weather activity; precision-guided munitions and their requirement for precise target locations; the criticality of command, control and decision-making (DM); intelligence dissemination, including to the media and interoperability.In

Bosnia, nearly five years later, had the Gulf lessons been learned, had progress been made, or did the nature of war change, bringing with it new requirements?

**Bosnia**

The Bosnian theatre of operations was very different to that of the Gulf War. From the relatively flat, Arabian desert environment with relatively clear skies, to the hilly, forested terrain of Bosnia under often low-lying European cloud cover. Bosnian terrain was much less conducive to ISTAR operations and the poorer weather had an equally degrading effect. The ground situation was significantly more challenging given the lack of a clear 'front line' to delineate friendly and enemy forces on the ground and where belligerents were mixed with non-combatants. This made it difficult to discriminate between forces.[20] The Allied forces found themselves having to cope with a shift from traditional targeting and offensive work to a peacekeeping and crisis management role that was more difficult and complex.[21] The target sets could not have been more different to the Gulf as Saddam's large, unconcealed armoured formations had given way to elusive, mobile Serb artillery and infantry units.

Bosnia did provide a testing ground for some new ISR capabilities. The US Predator UAV flew its first operational missions, and it was J-STARS first operational use with the USAF and its first use in the peacekeeping role.[22] The Predator deployed with a high-resolution (1 ft) Synthetic Aperture radar (SAR) sensor allowing it to conduct area imaging from above the weather. It could then fly to lower altitudes to gather more detail from its usual electro-optical/IR sensor.[23] An important factor was that the Predator offered the ability to conduct ISTAR operations in real time. It was equipped with UHF and Ku-band SATCOM data links so its operators could conduct a degree of immediate analysis and provide near real-time intelligence to the commander. The data links also allowed timely BDA to be undertaken, thus enabling and enhancing re-strike decision-making.

However, despite such advances as Predator and SAR, conventional NATO aircraft largely flew the 20,000-plus reconnaissance sorties accomplished during the conflict and there was much that still could not be achieved. Weather was still a significant problem. In one critical 10-day period, low clouds virtually wiped out all chances of imagery mission success and it was this weather factor that instigated the initial requirement to deploy the J-STARS.[24] With the advent of better weather, sensors were still hampered by the hilly terrain profile, and the thick vegetation that masked military targets.[25] The safety of friendly forces was jeopardised, as vital road and rail routes could not be kept under observation to ensure safety of movement.[26] Fast-jet ISR capability limitations could not be overcome by the use of UAVs either, as bad weather and high winds hampered Predator operations.[27]

The challenge of timely dissemination of imagery had still not been resolved since the Gulf War. Thousands of images were being processed daily, largely still from wet film, as most systems had not yet been upgraded to digital technology. The problem then, was how to get it to the decision makers and end-users. Generally, verbal reports were first transmitted through the intelligence system to the NATO CAOC at Vicenza and Southern Command HQ in Naples. This might then be followed by a video feed of the still image and finally, hard copy image transmission of specific targets.[28] RAF personnel describe how the transmission of a 4 x 3 in image on an A4 sheet took up to one hour via the NATO LOCE system and also how imagery hard-copy prints were hand-couriered to the user from the UK. The task-to-imagery-available cycle was taking in excess of 48 hrs.[29] Training was also still deficient. Imagery analysts were simply 'picture reporting' and unable to offer much in the way of an actual intelligence assessment or, for BDA, a re-attack recommendation based on damage assessed.[30]

Prior to post-strike BDA imaging however, pre-attack reconnaissance had to be conducted, either to search for and find targets or indeed to confirm known targets just prior to a strike. In his RUSI address, Sweetman describes many of the problems, commenting that the risks of hurting or killing civilians, the very people NATO was there to protect, had a huge importance and meant that stringent Rule of Engagement (RoE) were put in place. This drove an attendant to accurately locate and positively identify the target prior to attack.[31]

*The reconnaissance of chosen areas to provide the location of previously known and unknown targets is the biggest and highest priority task for ISTAR assets now and in the future*

On one occasion, Swedish troops came under mortar attack near Tuzla and requested air support. However, when the RN Sea Harriers dispatched to assist the troops under fire arrived, they could not locate the mortar threat and therefore could not drop any ordnance.[32]

Precision-guided munitions (PGM) were used in significantly greater numbers than in the Gulf War. Some reports suggest over 600 were used during Op Deliberate Force.[33] Their use had a significant knock-on effect for intelligence requirements, as USAF General Ken Israel remarked: “You cannot have precision-guided munitions unless you have precision guided reconnaissance”.[34] Many believe that the reconnaissance of chosen areas to provide the location of previously known and unknown targets is the biggest and highest priority task for ISTAR assets now and in the future.[35]

*Saratoga’s F-14 Sqn was processing as many as 3,500 images daily and more during surge operations*

Linked closely to the pre-attack reconnaissance requirement, is the growing political imperative of proving what has actually been attacked. Accurate and timely BDA imagery offers to analysts not only essential imagery of the mission results, but also to commanders at all levels the means to show exactly what was attacked and the damage caused. With media deployment now inevitable in any likely conflict zone, images of damage, which may or may not be as a result of Allied weapons, can be seen on TV screens worldwide in almost real time. Media deployed on the enemy’s ground are open to influence by the opponent’s regime and Allied forces must be able to quash any disingenuous claims.[36] Demands to provide such imagery for public consumption can come from all levels of command and from many and varied locations. The ability to provide the required imagery will therefore be dependent both on the communication links for dissemination and an appropriate imagery format to facilitate ease of viewing. Own force BDA needs will be subject to the same two requirements in order to provide rapid weapon effectiveness assessment and to inform re-tasking decisions. BDA and media requirements reinforce the need for responsive reconnaissance assets at the tactical / operational level that are able to gather and provide timely imagery.

The importance of BDA also drives an attendant ISR requirement at the very beginning of the targeting process. Prior to hostilities, aircrew consequently flew intensive reconnaissance missions over an area of interest, both to familiarise themselves with pre-planned targets and so that

the very latest imagery was available in order to assess whether targets were in accordance with the NATO targeting mandates, in particular to assess the risk of collateral damage.[37] The demand to provide imagery throughout the targeting cycle is driving even greater use of ISR assets. For example, with just four TARPS systems, *Saratoga's* F-14 Sqn was processing as many as 3,500 images daily and more during surge operations!

Since the Gulf War, modern, digital reconnaissance systems, fully integrated with the host aircraft avionics system have emerged. They offer accurate target positional data that can be rapidly downloaded into intelligence systems and is thus almost immediately available to the front line users and the C2 chain.[38] However, when such a digital reconnaissance system can store somewhere in the region of 12,000 images per mission, it is also clear that disseminating such a mass of imagery quickly is going to be extremely challenging! Bandwidth availability, particularly for imagery, which is so much more 'data hungry' than text and many other data types, is crucial to the successful flow of imagery to the end user. Imagery transmission certainly seems likely to be the largest single restriction in the reconnaissance cycle.

**Kosovo**

Nearly another five years later, the Kosovo conflict showed a further number of key differences, underlining the way in which the conduct of conflict is changing. The British experience emphasised "the extent to which our operations are joint".[39] The air operation involved assets from all three Services, aircraft and missiles from the RN, aerial surveillance assets from the Army and of course RAF air assets. Kosovo was significant in other new approaches with key differences to the Bosnia conflict just a few years before. One author wrote: "Commanders and warfighters found new capabilities that allowed them to take full advantage of precision-guided munitions, flexible surveillance and reconnaissance assets, and real-time situational awareness".[40] Kosovo marked the first real employment of UAVs in strength, although not in such great numbers with British forces. The US forces deployed Predator and Hunter UAVs (the latter with the CIA) providing a significantly enhanced ISR capability; their ability to loiter over hostile terrain providing 'stop and stare' and real time surveillance imagery. Perhaps the greatest change though was the high level of political interest and involvement in both air and (later) ground operations.[41] Such was this political interest that targeting was both more closely scrutinised and more tightly controlled than ever before. The North Atlantic Council set out targeting guidelines, then NATO Military Authorities selected target sets and then individual Allies finally cleared those targets assigned to them.[42] Such complex targeting processes demands

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**Hunter UAV**

*Political and legal oversight was exercised to an unprecedented degree during the Kosovo campaign*

significant, timely transmission of targeting data throughout the levels of command, flowing both nationally and internationally.

Many of the lessons learned from the Kosovo conflict are reported in the MOD's *Kosovo: Lessons* document. The first lesson is that: "an improved Intelligence, Surveillance and Reconnaissance capability is of great importance to all three Services . . . an improved capability would be of benefit across the board".[43] Imagery intelligence (IMINT) from a variety of sources played an important role in informing decision-makers (and the public) of key developments and in the selection and clearance of targets. This last point is crucial given the view that: "Accuracy in attack, and taking all feasible precautions with a view to avoiding, and in any case minimising, collateral damage, are important both politically and legally".[44] Such political and legal oversight was exercised to an unprecedented degree during the Kosovo campaign.

Politicians were also concerned about the need to ensure that the civil populace was kept up to date, to: "Cut through Milosevic's propaganda . . . to let people know the truth, and to let an informed public decide what was right".[45] Satisfying the media appetite for timely information and news stories was a major challenge: "In many ways, getting our messages across in the broadcast and written media was as crucial as the military campaign".[46] With such an importance attached to the media war, the ability to provide the right news, at the right time must be increasingly important to the military.

Winning such an information war is not easy. As digitisation of the battle space continues, systems increasingly provide data in a digital format. The proliferation of data formats also increases, so interoperability typically decreases. The requirement to win the information war places a great dependence on passing the data around the battlespace efficiently, so a huge premium is placed on bandwidth and connectivity.[47] The MOD clearly experienced such problems and consequently carried out a comprehensive intelligence review: "improving secure Information and Communication Technology (ICT) at both strategic and operational levels to enable the passage of intelligence and targeting information across and between these levels, is a major concern".[48] Whether it is to win the media campaign or to reap the benefits of digitisation, passing data efficiently and in a usable manner is of the utmost importance; this demands interoperability.

The political and legal implications of targeting, particularly to reduce collateral damage and minimise civilian casualties, are significant. It is this, and the drive to 'find and strike' rapidly, before a fleeting target disappears, that are the key issues. "Attacks against tactical targets in Kosovo proved to be a significant challenge to the Alliance, given the difficulties in locating and positively identifying targets".[49] The Yugoslav's ability to conceal forces and employ deception techniques caused such difficulties. Should such a target present itself, it seems highly likely that it would be under cover of darkness or poor weather and probably only fleetingly.[50] The ability to find and engage a target in such difficult conditions is vitally important and the MOD has identified the need to do it much better, from the entire sensor, C2 and weapon engagement points of view.[51]

BDA during the Kosovo campaign was certainly as essential as during the Bosnian campaign. The importance attached to the political imperative to keep the public and the media well informed, to be able to nullify Milosevic's information campaign, dictated the growing requirement for post-strike imagery. The images that commanders need for media publication are also the images required for BDA, so such post-strike imagery has become 'dual-use' in nature. After the campaign, Allies conducted comprehensive reviews of their BDA processes. The MOD noted that "sufficient background information should be compiled to enable the accurate assessment of the impact of operations and of an adversary's remaining capability".[52] A significant amount of the 'background information' referred to will come from reconnaissance missions flown before an offensive starts i.e. pre-strike imagery. This places greater demands on in-theatre ISR missions in the build-up phase and also requires more effective and widespread dissemination of *strategic* level imagery to the targeting and BDA cells at all levels. Co-ordinating weapon strikes on targets with

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imaging TOTs will offer timely BDA and maximise use of assets. Such timely BDA ensures rapid dissemination of imagery to cater for political and media requirements can be carried out.

The growing importance of ISR, has led to increased demand, placing severe stress on bandwidth availability that actually limited the deployment of some of the alliance's most useful assets'.[53] During Kosovo, the US bought significant commercial satellite bandwidth and still needed more. Gen Clark (then SACEUR) commented: ". . . the information environment was characterised by multiple imagery . . . "This imagery, however, 'eats up' megabits of information with each use. Often it must be routed simultaneously to several headquarters for study and review".[54] Clark added that, trying to operate a high-precision campaign needs robust information to plan effectively, control the strikes and then decide where to go back into. Clark notes that UAVs were limited in their employment (numbers) simply because the bandwidth required for their operation was not available. However, bandwidth is not only the key to effective employment of assets, it is also vital in ensuring that the product is flowed down to those who really need it, particularly in the lower echelons. It seems increasingly that, while we are certainly not asset rich, we are already in the position of not being able to disseminate what we are collecting to those who really need it. Improving dissemination emphasises the criticality of interoperability because: "Command, control, communications, computers and intelligence are the backbone of the alliance, and they have to be the first elements of interoperability".[55] If dissemination was already poor, then the added dimension of a ground offensive would only have emphasised the Kosovo campaign's interoperability and connectivity problems.

Summary of ISR effectiveness to date
Analysis of the past decade has analysed ISR capability in three major conflicts, showing both what was and was not possible and the progress that has been made. It illustrates the changing manner in which the ISR capability battle is being fought, how the ISR product is being used and shows the key issues, the challenges that remain. CDS recently summed up the UK's present capability ". . . we are constrained by ISTAR assets and availability and by the bandwidth available . . . Quite simply, we cannot be all-seeing all the time — we simply do not have the resources".[56]

As more ISR data become available (with ever more capable sensor systems), more end-users demand that product. Such end-users will inevitably have differing degrees of connectivity, variable bandwidth capacity or availability and deficiencies in data format reading and exploiting capabilities. The very same connectivity also impacts the command and control aspects of ISR and our ability to use such capability effectively. Increasingly, air power is demanded to deliver rapid effect in the battle space, yet the very connectivity we have seen to be so lacking in ISR product dissemination is likely to be the same connectivity bearing the C2 aspects needed to employ offensive air power to maximum effect. If these rapid effect operations are demanded, then how can we ensure that timely, efficient command, control and DM, whether carried out on or off the battle-field, is in place to deliver the desired effect in a highly time sensitive manner?

Time taken to either procure more systems or develop new technologies will neither bring immediate benefit nor maximise use of current systems. The shortfalls in overall ISR capability seen in recent conflicts and placed in the context of the changing way in which we are using the ISR product, show two key areas on which we can focus: firstly, ISR product dissemination, and secondly, employment of the sensor system on the battle-field so that the desired *offensive* effect can be brought to bear.

**Product dissemination**

*"Traditionally, the UK MoD has bought stand-alone, stovepiped systems, especially when it comes to intelligence-gathering equipment. The sensor reports back to a specific ground station and even though the information may be useful to another user, there's usually no way of ensuring it gets to him".*[57]

Product dissemination can be viewed as a comprised of two components: the product itself and its ease of use once it has been distributed; and the means of distribution. In the latter case, the means of distributing an ISR product is dependent upon point-to-point or networked connectivity and



A Tornado GR4A carrying the RAPTOR ISR system (AHB/RAF)

*Two principal Allies are not interoperable at the primary imagery level*

the data rate or capacity available. The reported deficiencies in dissemination capability will not be solved either quickly or easily. Only significant investment will provide an efficient and capable system architecture. The ISR product and its ease of use might be considered much more easily however, in that it should be relatively easy to ensure data can be used much more readily once it has been distributed. Ensuring the data also places the least burden on the distribution system should be an important consideration too. The key is data formatting. IMINT can be formatted so that data is distributed in a bandwidth efficient manner and to ensure that the data is in a format that can easily be opened and used by every user. Joint warfare is increasingly likely, so improving interoperability brings greater benefits. Anything that can be done to improve product usability and ease of distribution will have significant dividends.[58]

Examination of one key UK ISR system will demonstrate this issue. The RAF's new RAPTOR ISR system, fitted to the Tornado GR4 and recently operational in the Gulf, formats data coming off the sensor into a 'primary imagery format', PIF. RAPTOR's PIF is *not* bespoke, and conforms to NATO's ratified PIF standard, called STANAG 7023. RAPTOR's 7023 sensor data is taken into the Data Link Ground Station (DLGS), via digital tape from the recce pod or off the high-bandwidth Common Data Link (CDL), to be viewed and exploited. After an image analyst has analysed the *information* and turned it into *intelligence*, this imagery product becomes a 'secondary' image file and is saved in the NATO standard format for secondary imagery called STANAG 4545 (NATO Secondary Imagery Format, NSIF). NSIF is aligned with the US National Imagery Transfer Format, NITF 2.1, which is mandated for use on US military systems.[59]

Although such data standards exist and therefore interoperability should be assured, in practice the first interoperability hurdle has already arisen. Coalition partners are using the secondary imagery standard as their primary imagery format, so their ground stations cannot take RAPTOR's imagery data until after the primary imagery has been exploited and processed into secondary imagery. In this example, Allies at the theatre level are not interoperable at the primary imagery level. Another hurdle must also be overcome. While STANAG 4545 has been widely incorporated into commercially available but quite specialised imagery exploitation software, neither format has become available on standard home/office user COTS software. Even if the data file could be sent to an end-user, is unlikely that the information could be opened and viewed. To do so, the RAPTOR NSIF image file would need to be converted, re-saved and then disseminated in a more commonly used format, for example a JPEG file. Alternatively, all prospective end-users would need to have an imagery exploitation software package pre-loaded on their IT systems.

The former solution — conversion of the image into a more common standard prior to

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dissemination — will undoubtedly incur a time and workload penalty. However, if the imagery was converted and saved in the commonly used JPEG format, then this format offers an additional advantage by offering variable data compression. If the data is compressed to 1/4 of its original size for example, then the bandwidth or transmission time required for dissemination would be greatly reduced. In the bandwidth 'starved' operational environment, it seems likely that the time and workload penalty of saving exploited images in a compressed JPEG file format is more than compensated for by being able to distribute the image files more efficiently and readily open, and view them once at the end-user point.

While we have only been able to look at one case here, the importance that imagery formats have in influencing interoperability, distribution requirements and the usability of an ISR product should be clear. Unless commanders and equipment capability managers alike drive the need to procure ISR systems that produce data in a usable, interoperable and easily distributed format suited exactly to all end-user requirements for that imagery, then increasingly capable ISR collection systems such as RAPTOR will be creating nothing more than a data stockpile and little in the way of *intelligence* that is of real use to commanders, politicians and decision makers. There must be a clearer understanding of the benefits that interoperable format standards can bring to operations and therefore increased emphasis on the need to ensure system and data interoperability between Allies by military and political commanders at the highest levels.

**Delivering effect**

*"In broad terms, the principal purposes of our forces . . . are to find and strike the enemy. The focusing of intelligence collection and targeting effort, particularly against fleeting targets, demands the full panoply of an integrated capability to reduce the links between sensors and effectors, to shorten and reduce decision loops".* (Maj Gen R Fulton, CM (IS), MoD)

The second challenge is delivering effect on the battlefield, especially against difficult targets. To find and strike the enemy effectively, the key issues outlined by Maj Gen Fulton must be overcome: reducing links between sensors and shooters and shortening and reducing DM loops. The find and strike process begins with a sensor system finding the target, then the application of C2 to exercise the DM process and, having decided to engage the target, the strike is carried out with a platform and weapon of choice. This process has been called C4KISR, or, put in an element process order, ISR (find and fix the target), C4 (C2 and decision-making) and 'K' for kill. Examination of the process elements may reveal where ISR improvements may improve the whole 'find-and-strike' process.

The first element — ISR — is dedicated to finding the target. In the 'difficult target' situation, fixed, static, relatively easy targets are not the issue but the mobile and semi-mobile targets which offer limited time and space for the whole find and strike process. The start of the process may be cueing from another ISR asset, a SIGINT platform for example, or soon, ASTOR with its Ground Moving Target Indicator (GMTI) radar. Whether cued, or simply tasked to reconnoitre a given area or location, an ISR asset e.g. RAPTOR will image the area attempting to find a target. Once imaging is complete, the RAPTOR operator now has three options: to review the imagery in-cockpit, to data link it to the DLGS for an imagery analyst to review, or to do nothing and return to the operating location with the imagery recorded on tape.

The latter option, because of the transit time required, is unlikely to meet the timeliness being sought within sensor to shooter operations. The first two options may. If the Tornado navigator reviews the imaged target area, finding and identifying a target, then a target image and its geographical co-ordinates will be available. The target image/location must then be acted upon and to do so it must enter the next step in the process, the C2 element. The target image must be dispatched to the next man in the loop, the DM. In the simplest of cases however, the DM might be the same aircrew who has just found the target. In this case, the ISR and DM actors are one, and the target data need not be sent anywhere. However, this can only be the case if the sensor actor has been *enabled* as the decision-maker. To be enabled, sufficient authority needs to be delegated down to him/her in order to enable a positive engagement decision to be made. In this simple case of sensor-to-shooter (S2S), not only has the need to distribute the target

*It is no longer acceptable to bomb the wrong target, to kill innocent civilians or to damage non-military propert*

party or other actors in the process, i.e. the shooter who will carry out the kill element of the ISRC4K process. The principle that emerges is that the lower down the command chain the DM authority can be pushed, the simpler the necessary C4 connectivity can be. Fewer links are required and the dependency on the C2 connectivity in the S2S loop can be significantly reduced. In addition, if the DM is being taken on-board the sensing platform, then there is also likely to be a considerable reduction in the time taken from initial 'sensing' to final 'delivery of effect'. It is exactly this timeliness that is so vital for effective engagement of a so-called 'difficult' target. The driver thus appears to be managing the delegated engagement authority and, as a command issue, rests firmly in the DM or C4I element of the process.

*"Legality is topical today . . . I would simply note that it is a key issue and will remain so. It will become increasingly important . . ."*[60]

The increasing need to conduct conflict in a legal manner is being driven from the highest political levels. Commanders and politicians alike are concerned about the risks of collateral damage and injury to non-combatants. It is no longer acceptable to bomb the wrong target, to kill innocent civilians or to damage non-military property. Such concerns dictate the very careful management of the RoE and at what level of command the authority to engage a target can be given.

Collateral damage assessment (CDA) is broken down into Tier levels of risk. It is highly unlikely that any commander would be satisfied that the target meets his delegated RoE unless he has seen a current image of the target and can carry out a CDA and CCA assessment. This issue will drive a requirement to get the target image off-board the ISR platform and to the DM. So, as the RoE that permit target engagement either become more restrictive or are not delegated down to the 'shooter', the complexity of the S2S loop grows. This requires more sensor to effector links.

In the previous example, with RAPTOR acting as the ISR collector, the target image would need to be data-linked to the DLGS so that the target image could be processed, exploited and then re-packaged and transmitted to the commander empowered to make an engagement decision. The DM may well be the JTFC as he "is responsible for every single bomb that hits the deck".[62] The decision may rest with him, but there are also occasions when the decision may need to be made even higher up the command chain perhaps by CJO at PJHQ, or at the very highest, political, level. With each step up the chain of command, the complexity of the S2S loop increases, the time-cycle also inevitably increases, and with both, an increasing likelihood that the target will no longer be present to allow engagement, if and when the approval to do so is finally given. Furthermore, if the target is approved, then the approved-target image must flow back down the C2 chain to a shooter of choice. Additional S2S loop complexity is the result as the image/decision must get to the platform chosen to deliver the effect on the target. *Which* data format and *what* connectivity will ensure that will happen are additional considerations.

What can be derived from this is that the S2S loop complexity is largely driven by the level of command to which the target engagement authority is delegated. The higher the level of command at which the decision is taken, the longer and more complex the DM chain becomes: a greater number of 'actors' with attendant considerations of data format, bandwidth and connectivity all come into play. Above all, timeliness — so critical in engaging a 'fleeting' target — will decrease with growing complexity, causing an overall reduction in the likelihood of the S2S operation being successful. Nonetheless, once the target is approved the 'effect' element can then be carried out.

**Strike! But with what and how?**
Minimising collateral damage and reducing the risk of civilian casualties are of the highest political and legal concern, yet this may clash with the military need to destroy targets and enemy military force. Weapons that can be delivered so that the required effect can be ensured but also, in delivering it precisely, that the risk of collateral damage and civilian casualties is minimised are necessary. The PGM is therefore increasingly the weapon of choice on the battlefield.

In the UK's inventory, the standard PGM is the Paveway II laser-guided bomb (LGB). This is a standard 1000 lb bomb fitted with a laser guidance package and a weapon which can be carried by all of the RAF's offensive attack aircraft. During the Kosovo campaign, poor weather often constrained the employment of such weapons because the laser required to guide the bomb to the target could not see through weather. As a result, the MoD upgraded LGBs with GPS guidance kits so that these weapons can now be employed in all weather (GPS LGBs are called Enhanced Paveways).

The employment of the weapon in either the GPS or laser-guided mode has a dependency on the target data required by the person / platform delivering it, which will be a significant consideration within the ISRC4K loop. The delivery of the bomb in the non-laser GPS mode, permitting delivery in poor weather conditions, is totally dependent upon accurate target co-ordinates. The greater the inaccuracy of the co-ordinates, the greater the inaccuracy of the weapon. So, if the weapon can be delivered to an accuracy of 10 m, which is not unreasonable, then it follows that the target co-ordinates programmed into the weapon must also be provided — ideally — to 10 m accuracy.[63] These co-ordinates are sourced from the sensor element of the S2S loop, so the weapon accuracy requirement in turn drives the degree of accuracy with which target locations need to be obtained from the sensor's image of the target. In the laser-guided, man-in-the-loop mode the case is very different.

In a laser mode, typically guided using an on-board TIALD pod, then the target co-ordinates need to be known to a much lower order of accuracy. This is because the operator of the laser designator must acquire the target through the optics of the pod and only if and when he has done so will the LGB be released. The operator will acquire the target by knowing what the target looks like, and its approximate co-ordinates, so that the field of view of the guidance optics can be brought to bear on that area with sufficient accuracy to allow target acquisition and confirmation. The requirement to bring the optical field of view into the approximate target area is much less demanding in terms of target location accuracy, with perhaps 500-1000 m rather than the 10 m accuracy being quite sufficient. However, the vital requirement for this type of delivery is for the laser

*In the UK's inventory, the standard PGM is the Paveway II laser-guided bomb (LGB)*

**A Paveway II LGB under the wing of a Harrier GR7 aircraft**

operator to know what the target looks like, so he or she needs to have an image of it. Therefore, if an LGB is going to be employed then the requirement on the sensor portion of the S2S loop is to provide an image for the shooter's use and not merely target co-ordinates.

Employment of an LGB not only requires an image to be provided to the DM in the C4 process, i.e. from the sensor system into and up the command chain, but also to get the approved target image back down the command chain and finally to the shooter to deliver the desired effect. Needing to do so has an attendant impact on connectivity, bandwidth and data formatting considerations and once again, the complexity, timeliness and overall effectiveness of the S2S loop.

**E-3 AWAC**

*A voice-data message will be relatively easy to get to the shooter platform (typically via an E-3 AWAC aircraft) but ensuring a target data file can get to the platform is not nearly so simple*

If an approved target image needs to be sent back to the cockpit, then it might be possible if the aircraft was fitted with an imagery-compatible Improved Data Modem (IDM). The IDM would allow a ground agency to take the target image, ensure it was in an appropriate data format to allow efficient transmission to the aircraft (format issues again!) and then transmit it to the platform via radio. The RAF Jaguar is now fitted with an imagery capable IDM and therefore such a capability could be employed relatively easily. Operational scenarios where Tornado / RAPTOR sensor and Jaguar shooter combinations are tasked to conduct S2S operations on the battlefield could thus be employed to great effect.

The analysis so far shows that there are two principal cases of PGM employment: either man-in-the-loop laser guidance or GPS-guided delivery with no man-in-the-loop (post weapon release). The decision or ability to employ either of the two-weapon employment methods drives the sensor product requirement at the very beginning of the S2S cycle. In the first case, the man-in-the-loop is reliant upon the image of the target in order to be able to work from the image to his view of the real world as seen through the guidance equipment optics, to find and acquire the target and then laser mark it for the weapon. His requirement for the target image (and only approximate target co-ordinates) drives the need for the sensor and the intermediate command chain to provide an image file.

In the GPS-guidance mode however, the operator need not receive an image of the target. The weapon delivery is totally dependent on the accuracy of the target location co-ordinates. In this mode, the operator will need to receive a data file or voice message. Therefore, the requirement on the S2S chain is to provide and distribute data and not imagery. If it is assumed that the sensor system produced an image on which the target was found, thus beginning the S2S loop, then at some point this image can be translated into the simpler requirements of a data message. Once the DM has seen, assessed and approved the target on the image, the image is largely redundant as only the target co-ordinate data now needs to be sent to the shooter. In this case, the imagery format considerations are greatly simplified, the bandwidth requirement reduces and timeliness should improve. A voice-data message will be relatively easy to get to the shooter platform (typically via an E-3 AWAC aircraft) but ensuring a target data file can get to the platform is not nearly so simple.

In most of the UK's current front-line aircraft fleet, ground target data files are not routinely transferred to or from an aircraft; however, the recent integration of the IDM into the Jaguar was carried out to provide exactly such a capability. The Jaguar IDM fit was born from the requirement to receive target data from a ground Forward Air Controller (FAC). The FAC can be equipped with a radio linked to a computer equipped with an IDM card. In this manner, the FAC can enter target co-ordinates into a task message, which can then be sent via the IDM and radio to the aircraft. This method could also be used to send S2S target data messages from a suitable point in the C2 chain once engagement had been authorised. This does mean that the C2 node needs to have such equipment but this should certainly be possible. Such a solution provides for the case where the engagement decision must be taken off-board the sensor platform. However, in the case where the decision can be taken on-board then the target data must be sent from the sensor / DM platform to the shooter.

Target data could be sent from the sensor platform via a simple voice message but doing so is susceptible to the normal vagaries of air-to-air voice communications and success is reliant on the shooter crew receiving the target co-ordinates completely and accurately, noting them down and then entering them into the weapon computer with no mistakes or inaccuracies. This process is neither ideal nor efficient, so, if the sensor platform could send a data message to the shooter, and that data message could be accepted, read and entered directly into the weapon aiming computer, then this would offer far less likelihood of error and a much higher probability of success. This process is exactly the functionality that the Jaguar IDM has in order to carry out IDM-based FAC operations. The S2S requirement is for the sensor platform to be capable of sending such a target data message. If the sensor system is Tornado with RAPTOR, this would entail integration of IDM into Tornado so that a targeting message could be sent to a shooter. If this integration was carried out, then it might also be possible to send a RAPTOR target image through the IDM, which might offer sufficient flexibility for both man-in-the-loop and GPS-guidance shooter operations.

It has been shown that is possible to get the vital target data message to the shooter, whether directly from the sensor platform or from the C2 / DM chain once an engagement decision has been taken by the empowered commander. In both cases, IDM is potentially capable of carrying this out; it simply needs to be at a suitable point in the C2 chain, or to permit direct data transmission to a shooter, also in the sensor platform. If fitted in the sensor platform, IDM should also permit imagery transmission from sensor to shooter platforms.[64]

Earlier discussion showed how the GPS weapon is dependent on the accuracy of the target co-ordinates for success and in the S2S scenario, that these co-ordinates will be extrapolated from the sensor image of the target. Accordingly, the sensor system must be able to provide coordinates to the level of accuracy required for the weapon as if not, then an imagery-based, man-in-the-loop, laser-guided weapon operation may be the only type of attack that can be carried out.

Geo-coordinate data of a location viewed on imagery has only quite recently become available.[65] At one time, inaccurate platform location data was all that was available, but often today even the sensor system has its own GPS fitted, RAPTOR once again being such an example. A complex reconnaissance management system fed with such accurate positional data and linked to an inertial sensor system, allows the sensor to be pointed and scanned very accurately. Imagery embedded with accurate co-ordinate data can then be obtained, whether viewed in the cockpit or in the ground station. Two particular factors affect the accuracy of the geo-coordinate data embedded within the imagery file. Firstly, a problem arises from the fact that the accurate positional data is GPS based, which does provide accurate location, but only in the two-dimensional plane; it is relatively inaccurate in the 3rd, vertical plane.[66] Secondly, the location data is determined by algorithms in the reconnaissance management system that assume a flat earth: there is no allowance made for the real world or terrain profiling.

These two problems can induce quite significant geo-coordinate errors. Any sensor-system height error is approximately replicated in positional error on the ground, thus (if the sensor is looking about the 45 degree depression angle) a 1,000 ft height error in the sensor system will translate to a 1,000 ft positional error in ground location data and even more at shallower depression angles (which would be more typical for medium stand-off ranges). Therefore, any improvement that can be made to the system height accuracy will also benefit the geo-coordinate data accuracy of the imagery.

*Kosovo is reported as the first truly joint conflict, an information revolution with significant employment of PGMs, flexible surveillance and reconnaissance and real-time situational awareness*

The second factor, the flat earth problem, means that if the imaging is carried out over a portion of the earth's surface which consists of relatively flat terrain, such as the Arabian desert, then the geo-coordinate accuracy should be quite good as the real world will more closely resemble the flat earth software model. However, if the imaging is carried out over the hills of Kosovo, then an image of a target located in such terrain will be quite inaccurate as the location data on the imagery will still be based upon flat earth even though the target is situated well above it on the actual terrain present. Any reduction in this inaccuracy would require representation of the earth's surface within the reconnaissance management system so that points on the image could be correlated with the real world terrain elevation beneath and an accurate geo-coordinate position for the target would be derived.

Such a terrain profile is already widely available in a dataset called Digital Terrain Elevation Data (DTED): this is a grid system of area squares covering the earth's surface with a post at each gridline intersection that reflects the terrain elevation at that point.[67] This grid of posts and their elevations is held in the DTED loaded into the aircraft. If such data could be embodied into the sensor system, then a significant improvement to the target geo-coordinate accuracy might be achieved. Modification work would be required to the sensor system and this would involve some cost outlay, but it should be a relatively simple upgrade and certainly more cost effective than procuring a whole new sensor system.

Overall, improving the height accuracy of the sensor system would reap some benefit in imagery target location accuracy. If DTED could also be incorporated into the sensor system, then a further and probably more significant improvement of the imagery target location accuracy should be achievable.[68]

**Conclusion**

The aim of this paper was to demonstrate how ISR effectiveness could be maximised. Capable ISR systems are already in service, so making better use of what we already have would bring benefits free from procurement expense and time delays. The paper reviews the past decade of conflict, drawing out what was possible, what remains challenging and the implications borne out of the changing nature of conflict and its impact on ISR capability.

The Gulf conflict showed an overall lack of ISR capability. Very few assets offered night, all-weather or stand-off imaging, being largely still configured for the Cold War. The rapid pace of the conflict demanded faster intelligence, but the lack of data links and effective communications meant information demand outstripped supply. A poor communications structure also hindered the intelligence sharing so vital in a coalition conflict. BDA was poor, partially because analysts were not trained to analyse weapons effects nor to make re-strike recommendations, but particularly because ISR assets were not managed effectively to ensure imaging was closely co-ordinated with strikes. This also hampered the media campaign, as unexpected demands were placed on the military to provide pre- and post-strike imagery.

In Bosnia, the environment, terrain and force disposition were all very different to the Gulf. A much wider range of targets were tasked for ISR coverage. Although imaging was often severely hampered by the environment, new capabilities such as J-STARS and Predator SAR could provide night, all-weather imaging and real-time transmission via data links. In more conventional areas, dissemination had still not been solved, with the task-to-imagery cycle still taking as long as 48 hrs. Commanders needed to show those targets attacked and the damage caused but poor BDA tasking hindered this requirement. Such coverage was increasingly important given the political drive to ensure minimum collateral damage and civilian casualties and to quash false enemy claims. Showing post-strike imagery also demanded pre-strike imagery for comparison, but it was the increasing use of PGMs that was really driving the demand for immediate pre-strike imagery, particularly against mobile or semi-mobile targets. Such targets demanded imagery offering accurate target locations which could be downloaded rapidly into the intelligence system. New digital ISR systems offered such possibilities but were also placing increasing and significant demands on communications bandwidth.

Kosovo is reported as the first truly joint conflict, an information revolution with significant employment of PGMs, flexible surveillance and reconnaissance and real-time situational awareness. The campaign was also characterised by unprecedented high-level political interest with much tighter control of targeting. Such political, and legal, oversight drove the need for significant pre-strike target imaging so that collateral damage and civilian casualty risk could be assessed before authority to strike was given. Timely post-strike imagery was then required, both for military BDA and also because winning the media campaign was vital. The key issue was the desire to find and strike difficult fleeting targets rapidly before they disappeared. The ability to find and engage such a demanding target was seen as vitally important, requiring effective sensor-to-shooter operations. Overall, the growing importance of ISR and the increasing digitisation of ISR systems placed an increasing burden on communications and reduced interoperability.

The shortfalls seen in these recent conflicts, placed in the context of the changing way in which the ISR product is being used, showed two key areas in which to focus: ISR product dissemination and sensor system employment to bring desired offensive effect to bear. Product dissemination comprises two components: the product itself and its means of dissemination. The latter — the communications architecture — will require time and significant financial investment to improve, ensuring the product can be fully used by those that need it should be more easily solved. The key is IMINT interoperability through appropriate data formatting. If every user, especially in an increasingly joint environment, can access the data and use it, then this element of ISR effectiveness can be maximised.

Standardised IMINT data formats do exist but do not necessarily ensure interoperability as nations interpret and mandate standards in differing ways. As a result, two key allies may not be interoperable at all. Correct implementation of standards should offer interoperability but do not necessarily offer usability. Bespoke software is likely to be required to open and exploit such data and few users are likely to have such IMINT exploitation software on their computer systems. If imagery products were converted into a format such as the common JPEG, then notwithstanding the likely time penalty in doing so, all end-users could exploit the file. Such a format also offers data compression, the significant benefit of which is that less burden is placed on the communications architecture. In this way, maximising ISR effectiveness can be seen as mandating data formats which offer maximum ease of use, both for the military and for the media while minimising the communications bandwidth burden. Delivering effect, especially against difficult targets is the second significant challenge. To find and strike effectively demands reduced links and timeliness across the sensor-to-shooter process. Firstly, ISR assets search for targets in tasked areas, perhaps cued by other assets. With a target found, an image of the target and co-ordinates are available but still on-board the ISR platform. This data must be acted upon and sent off-board to the next actor, the DM. In the simplest case though, this is not so, the 'sensor actor' can also be the DM and may have sufficient delegated authority to allow engagement. If not though, the data must be passed to the DM who, given today's legal imperatives, will need to assess the target for collateral damage and civilian casualty risk in accordance with prescribed criteria. An approved target then needs to be sent from the DM to the shooter. The level of command where the target engagement authority rests therefore partly dictates the complexity of the S2S process.

Risk of collateral damage and civilian casualties is also driving the preference for PGMs. The UK's PGMs are either laser or GPS guided: the latter is totally dependent on accurate target co-ordinates. These are derived from the original sensor image. Such accuracy is not required in the laser mode as the operator guides the weapon, but he / she must identify the target to do so and therefore needs a target image. Weapon choice, laser or GPS-guided, dictates whether a target image or target co-ordinates are needed, which in turn, drives the link complexity, and thus timeliness and overall effectiveness. The RAF Jaguar is now fitted with the IDM, offering the potential for receipt of either target data or an image. Equivalent equipment in the C2 / DM chain or integrated onto the sensor platform would enable such an operation.

For the GPS weapon, imagery data accuracy is vital. Two particular factors reduce such accuracy, inaccuracy in sensor platform altitude and earth surface modelling. At medium altitudes, the sensor system is deriving altitude from GPS yet this is inherently inaccurate in height. The sensor's management system will model the earth's surface as flat whereas in reality the target sits above it on real terrain; both factors lead to inaccuracies in image target location co-ordinates. The former factor is less significant but the latter may be. Integration of DTED into the sensor software would permit significantly more accurate target co-ordinate derivation.

In summary, maximising ISR effectiveness could firstly be achieved by adopting suitable data standards allowing both ease of use and minimal communication system burden, and secondly, by focussing on the interplay between shooter weapon data requirements, delegation of DM and sensor-to-DM-to-shooter links. If these two aspects are understood and actively managed, then maximising ISR effectiveness will ultimately maximise delivery of effect in the battle space.

*The RAF Jaguar is now fitted with the IDM, offering the potential for receipt of either target data or an image*

## Notes

1 Sweetman (1991), p.329
2 Waters (1993), pp.37-50
3 Ibid. p.41
4 Ibid. p.42
5 Id.
6 Id.
7 Waters (1993), p.46
8 Ibid. p.42
9 Id.
10 Id.
11 Id.
12 Ibid. p.49
13 Wanstall (1991), p.833
14 Waters (1993), p.42
15 Ibid. p.44
16 Id.
17 Mann (1994), p.4
18 Ibid. p.7
19 Waters (1993), p.48
20 Covault (1996), pp.44-46
21 Id
22 Id. Also Fulghum (1996), p.24
23 Id.
24 Covault (1994), pp.27-28
25 Lum (1995), p.57
26 Fulghum (1996), p.41
27 Ibid. p.25
28 Covault (1994), p.28
29 Bailey interview
30 Id.
31 Sweetman (1994), p.34-36
32 Covault (1994), p.27
33 Lum (1995), p.54
34 Id. p.54
35 Id.
36 Sweetman (1994), p.36
37 Covault (1994), p.27
38 Fulghum (1996), p.40
39 MOD Kosovo: Lessons, Chap 6
40 Ackerman (1999), p.49
41 MOD Kosovo: Lessons, Chap 6, p.4
42 Ibid. Chap 7, p.1
43 Ibid. Chap 6, p.8
44 Ibid. Chap 7, p.2
45 Ibid. Chap 6, p.5
46 Id.
47 Ackerman (1999), p.49
48 MOD Kosovo: Lessons, Chap 6, p.7
49 MOD Kosovo: Lessons, Chap 7, p.2
50 Ibid. p.6, e.g. on only 21 out of the 78 days of the campaign was the weather judged to be favourable for air operations.
51 Ibid. p.8
52 MOD Kosovo: Lessons, Chap 7, p.4
53 Ackerman (1999), p.49
54 Ibid. p.50
55 Ibid. p.51
56 Boyce (2002), p.3
f57 Cook, N et al JDW, Sep 11, 2002
58 Ibid. pp.67-69
59 DSTL advice.
60 Fulton (2002), p.69
61 Targeting advice from JFHQ J3 Tgts
62 JFHQ J3 Tgts
63 Simplification: there will be additional flexibility as a result of the weapon’s lethal damage radius e.g. if the lethal damage radius of the weapon is 100 m then co-ordinates with a 100 m accuracy, less the inherent inaccuracy of the weapon (10m in this example) should still result in achievement of the desired effect; many other factors come into play too.
64 Goodrich technical advice.
65 From tactical, not strategic imagery.
66 http://www.nima.mil/publications/specs/printed/89020B/89020B.pdf: vertical accuracy for ‘P’-code GPS is 27.7m, 156m for C/A code.
67 www.nima.mil
68 Goodrich technical advice.