Air-to-ground targeting – UAVs, data links and interoperability (project Extendor)

K. L Edwards
QinetiQ
Farnborough, UK

ABSTRACT

Time-critical targets will generally be observed or 'sensed' by personnel inadequately equipped to shoot at them. Since time may be a critical parameter, the passage of information from the 'sensor' to the 'shooter' must be rapid and accurate. QinetiQ has developed and integrated airborne and ground equipment to facilitate the passage of targeting data digitally over standard air and ground radios. The UK and Holland have selected an integrated rugged PC, internal modem card and purpose-designed software to equip Forward Air Controllers (FACs) to enable digital forward air control. This gives direct interoperability with UK and NATO assets equipped with Improved Data Modem (IDM) technology.

A large, and growing, number of air, land and sea assets employ Link-16. This entails entirely different frequency, data rate and, generally, protocol, from the IDM. The UK MoD's recently-ended applied research EXTENDOR programme was a three-year operational concept demonstrator for the purpose of translating in near-real-time between selected key Link-16 and IDM-based messages. The intention was to demonstrate the viability and utility of translation between disparate data links. This staged programme centred around a translation engine designed to be flown in a Predator UAV. The programme was entirely successful, demonstrating the capability to translate both own position and nine-line target data. Thus the position of a non-Link-16-equipped asset could be seen in real time in the Link-16 recognised air picture (RAP). Also, a Link-16 asset was shown to be able to task an IDM-equipped asset with a nine-line brief via the translation engine. The high equipment readiness level offers considerable potential for near-to-medium term operational exploitation.

NOMENCLATURE

AAA	anti-aircraft artillery
AFAPD	Air Force applications programme development
BNG	British national grid
CAS	close air support
C^3I	command, control, communication and intelligence
CCRP	continuously computed release point
CEP	circular error probable
CRUAV	communications relay UAV
DERA	Defence Evaluation and Research Agency
FAC	forward air controller
FTI	fast tactical imagery
GBAD	ground-based air defence
GCS	ground control station
GPS	global positioning system
GUI	graphic user interface
HMS	helmet-mounted sight
HOTAS	hands on throttle and stick
HUD	head-up display
IMC	instrument meteorological conditions
IDM	improved data modem
INS	inertial navigation system
IP	initial point
IPT	integrated project team
JDAM	joint direct attack munition
JSTARS	joint surveillance and target attack radar system
JPEG	joint photographic experts group
JVMF	joint variable message format
LAN	local area network

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LVT	low volume terminal
MFD	multi-function display
MMR	military microRIT
NATO	North Atlantic Treaty Organisation
NTSC	National Television Systems Committee
OFP	operational flight programme
PAL	phase alternation line
PCMCIA	personal computer memory card international applications
PGM	precision-guided munition
PPLI	precise participant location information
PRISM	photo reconnaissance imagery strike module
RAP	recognised air picture
ROE	rules of engagement
RTIC	real-time information into the cockpit
SAM	surface-to-air missile
SEAD	suppression of enemy air defences
SPGR	specialist personnel GPS receiver
SPTCIM	serial port tactical communications interface module
STANAG	standard NATO Agreement
TacGA	tactical ground-to-air
TACP	tactical air control party
TDL	tactical data link
TIALD	thermal imager airborne laser designator
TLE	target locator equipment
TRN	terrain-referenced navigation
UAV	uninhabited aerial vehicle
UOR	urgent operational requirement
UTM	universal transverse mercator
VHF	very high frequency (30 – 300MHz)
VMF	variable message format
WAN	wide area network
WAH-64	Westland attack helicopter 64
WGS	World geodetic standard

1.0 INTRODUCTION

1.1 Ground-based air defences (GBAD)

GBAD includes anti-aircraft artillery (AAA) and surface-to-air missiles (SAMs). NATO aircraft have shown an increasing state of readiness, awareness and training to counter GBAD. Fixed AAA and SAM sites are highly potent but, since they are fixed, may be avoided or attacked after careful forethought and planning, and thus lend themselves to more deterministic destruction. Mobile and man-portable SAMs are another problem. The 78 day Kosovo air war logged the firing of 477 mobile SA-6s (such as shot down Scott O'Grady's F-16 over Bosnia in 1995) and 124 confirmed man-portable infrared missiles[1]. In modern age confrontations nominally poorly educated troops have shown not only initial knowledge but also the ability to learn swiftly in the cat and mouse game of the employment of GBAD. During the final week of Kosovo operations NATO spokesmen conceded that they could confirm the destruction of only three of Serbia's approximately 25 known mobile SA-6 batteries[1].

Even the possibility of SAM existence can force the attacking aircraft to attack at very low level and high speed: the RAF trains for this. For CAS in particular, and forward air work in general, irrespective of whether the attacking aircraft 'pops up' to launch its weapon it is quite possible that there will on occasion be no opportunity, or at least insufficient opportunity, for the shooter to verify with high probability that the target is an enemy and that there is no friendly force nearby. For this reason, and due to insufficient sensor performance, poor weather and small or obscured targets, target information from a third party may be invaluable.

1.2 Sensor-to-shooter

Recent years have seen the emergence of the phrase 'sensor-to-shooter', which encompasses the fact that there may well be friendly forces ('sensors') in a position to locate and identify an enemy, but with insufficient firepower to attack. Thus the 'sensors' may transfer their intelligence to a 'shooter'. Responsibility, then, for target identification, to the extent that may be required in rules of engagement (ROE)[2-4], is taken by a different party than that which is doing the shooting. The requirement then becomes to transfer from sensor to shooter the requisite targeting information with sufficient accuracy to ensure that the attack can be prosecuted with high confidence of hitting the right target and with acceptable collateral damage.

1.3 Real time information into the cockpit

The extent to which a target is time-critical depends upon the typical response speed of the attacking party, including the response system (command, control, communication and intelligence [C^3I]) and associated rules and requirements. Time-critical targets are highly demanding in that they require the passage of information into the cockpit not only accurately but also in close to real-time, thus the emergence of the acronym RTIC, standing for real time information into the cockpit. Although falling from favour as an acronym in recent years (apparently for no good reason other than that military research enjoys enveloping itself in unnecessary new-speak) the concept of RTIC is highly relevant to modern warfare and this paper in particular. Any method of fulfilling the sensor-to-shooter requirement by accurately transferring real time information into the cockpit will enhance the shooter's role and increase precision. This paper describes one particular method of third party targeting researched and provided by QinetiQ. This fulfills the sensor-to-shooter requirement not only with high accuracy, but also speed of transmission, clarity of presentation and ease of data handling.

This paper also describes how one aspect of the following statement[5] is being fulfilled;

'The biggest change in the conduct of future military operations is likely to come not from weapons alone but from the application of information technology to military command and control. There is a growing body of opinion, particularly in the US, that we are approaching a 'revolution in military affairs' in which we will see a step change in military capabilities resulting from the synergistic combination of long-range precision weapons with networks of advanced sensors and data processors. Radically improved capabilities in the field of information processing and communications systems will increase situational awareness (knowing where hostile and friendly forces are, and where they are not) by combining information from all available sources and rapidly distributing it to those who need it, thus permitting more effective and efficient use of our forces. Smart long-range precision weapons will enable us to attack targets accurately from distance, thereby reducing our own and civilian casualties.'

2.0 DIRECT RAPID TARGETING

2.1 Precision-guided munitions (PGMs)

Ground defences against attack from the air can be highly potent. Over Yugoslavia the average air crewman faced radar-guided SAMs at three times the rate of those in the Gulf[6]. This threat may be mitigated by attacking such targets by approaching low and fast, thus staying below radar coverage and invoking the element of surprise. In such circumstances the requirement to acquire, identify and release a weapon accurately against the target, on the first pass, is highly

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Table 1
Percentage of precision-guided munitions employed in recent operations

Operation Place/Date	No of weapons	% Precision-Guided
Desert Storm Gulf 1991	155,186	7
Deliberate Force Bosnia 1995	1,026	70
Allied Force Kosovo 1999	23,000	35
Enduring Freedom Afghanistan 2001	17,471	57
Iraqi Freedom 2003	28,000	68

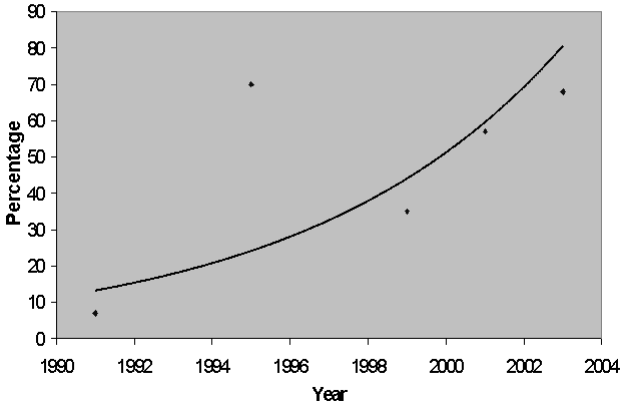


Figure 1. Graph of percentage of precision-guided munitions employed in recent operations against date of operation.

demanding. The move towards the use of stand-off weapons renders the task yet more difficult since the greater range militates against the attacking aircraft being able to bring its sensors to bear against, and thus locate and identify, the target. Yet more difficult is the use of an anti-armour weapon with a limited cross-track search corridor, fired at a stand-off range against moving armour: in this case it may be necessary to aim ahead of the moving vehicle to ensure coincidence of vehicle and weapon cross-track search pattern. The trend to the greater use of PGMs (with some degree of implicit stand-off) is shown quantitatively in Table 1[7] and graphically in Fig. 1.

Perhaps the most surprising statistic from a UK perspective is that the most recent, although not necessarily final, figure for RAF air-launched ordnance in Operation Telic (Iraq 2003) shows 84% to be precision-guided[8], whereas in Kosovo it was 25%[9] and in Operation Corporate (Falklands, 1982) the UK employed no precision-guided munitions. Thus is may be seen that the move toward standing off from a target, so on occasion requiring third party assistance, is rapid.

When ground defences have been sanitised the task of the attacking aircraft is less dangerous but not necessarily easier. The recent war in Iraq highlighted a number of areas of concern in the CAS role, including urban CAS[10]. This was particularly in the command chain between coalition forces (US and UK) who speak (fundamentally) the same language. The difficulty is exacerbated in NATO operations, when the FAC and pilot may be of different nationalities and communicating in English, which may be foreign to both[11]. Thus even in a direct and short 'command chain', CAS may not be easy. The situation is worse at night, when the attacking aircraft may require some tens of minutes to confirm the FAC data and locate the target.

Thus circumstances militate strongly against precision targeting in both low and medium level air-to-ground operations, and the potential for collateral damage and fratricide frequently exists. Urban CAS is yet more difficult, and exemplified by the use of precision-guided non-explosive (concrete-filled) bombs in the 2003 Iraq war[12] in order to minimise collateral damage.

Consequently it is becoming increasingly important to assist the pilot of the air-to-ground attack aircraft by passing accurate and timely targeting information from a third party directly into the cockpit. The third party may be, for example, a FAC, an uninhabited aerial vehicle (UAV) or a stood off radar platform. Such a third party, or 'sensor', may be far better placed to confirm target data than is the attacking aircraft, the 'shooter'. In a 'digital' aircraft the pilot may accept the information into the mission and targeting computers, slave the sensors immediately and accurately and prosecute an attack with confidence just tens of seconds after receipt of the data, although rules of engagement (ROE) still apply. Pilot confirmation of the target is yet easier if the received targeting data include an image of the target. The entire targeting task, including the weapon aiming phase, may thus be performed accurately, quickly and more easily.

2.2 The improved data modem (IDM)

2.2.1 FAC equipment

UK tactical data link (TDL) research has been described extensively elsewhere[13-15]. Research and development have matured to the point where the UK MoD has contracted for the supply of digital FAC equipment[16] which facilitates the composition of the NATO (almost) standard STANAG 3325 nine-line brief. This carries the information required by the attacking aircraft, as follows:

- initial point
- target bearing
- target distance
- target position
- target elevation
- target description
- attack heading
- closest friendly forces position
- time on target

The target may be mensurated via hand-held in-service GPS (giving own position) and in-service laser-ranging (designation) binocular or monocular equipment (giving inclination, azimuth and range from own position to target). Both equipments connect to a rugged PC (MBM's Termite) which then automatically calculates the target position. Manual entry of target position is also possible. The additional nine-line data are then manually entered into the PC. Finally, the PC connects to a standard in-service ground-to-air radio (including the PRC-113, PRC-346, PSC-5, and the PRC 117-F satcom/encrypted radio). The nine-line brief may then be transmitted digitally to the attacking aircraft (the shooter). Thus digital forward air control may be effected with only the addition of a small PC to standard ground equipment. The latest standard of Windows-based termite graphic user interface (GUI) for the MoD FAC purchase is shown in Fig. 2.

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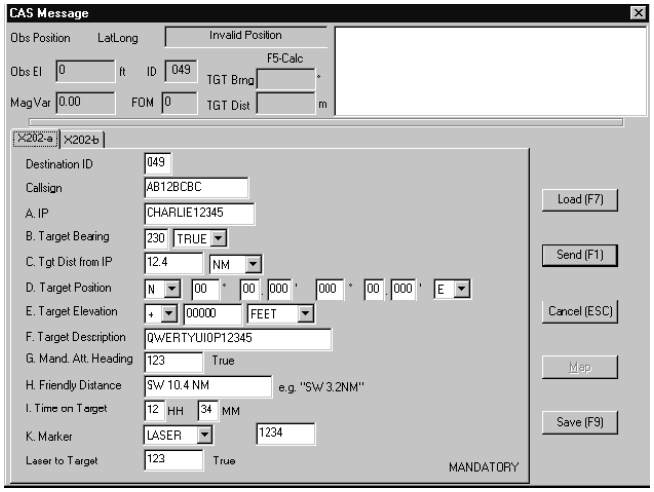


Figure 2. FAC Digital nine-line brief composition Windows graphic user interface.

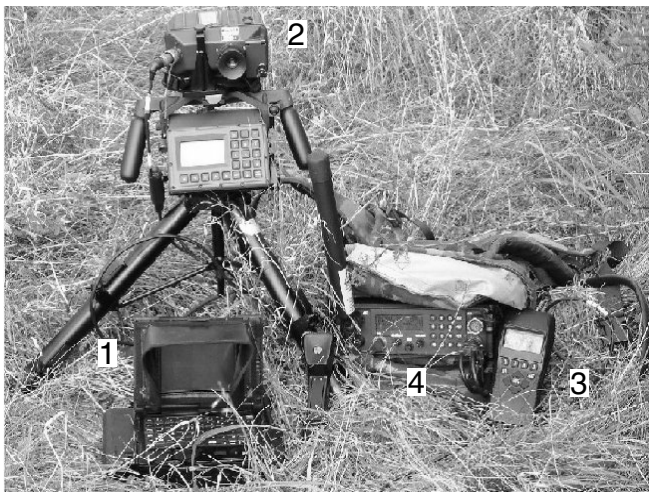


Figure 3. Complete FAC digital equipment.

The message described was designed to be compatible, and has been tested, with the UK WAH-64 attack helicopter (AH). This was deliberately planned by QinetiQ since the AH was already ordered, was the only UK aircraft fitted with an IDM, and it made sense to perform research in a fashion directly compatible with current equipment. The FAC equipment is shown in Fig 3. with the component parts numbered as described.

1. MBM Termite rugged PC plus serial port tactical communications interface module (SPTCIM)
2. Eloptro LH40C Target Locator Equipment (TLE) (on an Instro 'Viking' tripod)
3. Rockwell specialist personnel GPS Receiver (SPGR)
4. UK PRC346 TacGA V/UHF radio

2.2.2 Dangers of (digital) forward air control

The method of joint use of the SPGR and laser ranging binoculars is standard military practice. The danger is that the FAC may inadvertently laser range on an object in the foreground which provides a stronger return than the far-ground target, and the equipment will automatically calculate a 'target' latitude and longitude which is not only incorrect but also dangerously close to the FAC. This is the type of error which could lead to fratricide such as occurred in the fatal US training accident in Kuwait in March 2001 when six military personnel conducting FAC training were killed by a USN F/A-18C which dropped three Mk 82 500lb gravity bombs[17]. A further 'friendly fire' incident with a JDAM 'smart' bomb resulted in the loss of US life at the Qala-l-Jhangi mud fort near Mazar-l-Sharif in Afghanistan in November 2001[18]. 'Finger problems' which may be trapped and annunciated by the laptop are: foreground laser reflections, the FAC's omission to enter his own position, or a large discrepancy between FAC and target position. In general, the everyday problems associated with automation and repetition are potential problems for digital forward control, too, but with possibly disastrous consequences, i.e. dropping a bomb in the wrong place, but very precisely in the wrong place. Thus QinetiQ's operational version of the FAC software traps and displays possible errors; these errors are:

- long distance from FAC to target
- very short distance from FAC to target
- no FAC position entered (an example of which is shown in Fig. 4)

2.2.3 Co-ordinate system

The potential for error in the measurement and transmission of target position to the attack aircraft is large. Errors may occur due to incorrect maps, incorrect measurement, different coordinate systems, human transcription error etc. Although these may appear simple to overcome they are actually pervasive and difficult to eliminate. The problem is well described in the following quote from, and during, the Kosovo campaign[19].

"…One worrying trend noted during the campaign, according to US officials, is the GPS 'sensor-to-shooter error budget' that can increase between surveillance systems tracking mobile Serb targets in Kosovo and 'shooters' – strike aircraft – involved in attacks.

The 'error budget' is described as the cumulative effect of small discrepancies that can build up over time when standard map co-ordinates are converted on to a GPS 'grid'. These errors can magnify via platforms such as the E-8 joint durveillance target attack radar system (Joint STARS) and computer-based mission-planning systems all the way down to the GPS sensor in an autonomous bomb or missile system.

While a GPS-aided munition is advertised as being accurate to around 10m, this unforeseen 'error budget' can degrade accuracy significantly. The problem becomes critical when attacks are planned and carried out in real time…."

(Underline emphases by this author.)

As an example of co-ordinate systems Table 2 shows two position (in London) just 5m apart. The table shows how a small difference is depicted in various axis systems, but, more particularly, how any one axis system is so different from any other. Possibly the most insidious occurs between the use of minutes and seconds on the one hand, and minutes and decimal minutes on the other – 59 59 minutes/seconds could be as much as 0·4nm from 59·59 minutes/decimal minutes (at zero latitude).

Thus the ability for a third party to send target co-ordinates, in a standard reference frame, to a 'shooter', who may then accept them digitally into the weapon aiming system, cannot be overstated. Such 'shooter' acceptance must follow whatever 'sanity checks' are required in operating procedures.

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Figure 4. Typical FAC Digital Mensuration Warning.

2.2.4 Jaguar aircraft integration

An IDM was installed into a research Jaguar TMkIIa in 1998. Its attractions at the initial stage of the research programme were manifold, in particular it:

- enabled digital communication via standard aircraft radio
- was flight-proven
- was available for loan from the UK attack helicopter Integrated Project Team (IPT)

After productive testing in the research aircraft, an installation was performed in a Jaguar GR3a to enable operational evaluation of the IDM. Successful research and development resulted in a Jaguar fleetwide fit with the IDM, which is in fact line replaceable with the AH IDM. The Jaguar installation is highly integrated and allows the aircraft to receive and send various air-to-ground targeting data, particularly the NATO standard nine-line brief (STANAG 3325). This is achieved largely through HOTAS (hands on throttle and stick) control.

Not all the nine-line data are used on the Jaguar: the Initial Point (IP) and target bearing/distance are less important now aircraft navigation aids are more accurate. Nowadays it is rarely necessary for well-equipped aircraft to fix their position via an IP. Additional data displayed in the Jaguar CAS page are laser code and various freetext information. An example Jaguar display is shown in Fig. 5, with the parametric data reflecting the FAC's input at the top of the display and the target position (central triangle), attack heading (Three o'clock line from the East to the target) and closest friendly troops (short ten o'clock line) shown on the moving map.

The CAS nine-line message is sent to the Jaguar using the Airborne Fire Request message of the Tacfire protocol. Receipt of the message is annunciated on the head-up display (HUD). Upon pilot command the message itself is displayed on the multi-function display (MFD). Pilot acceptance of the message/mission is by key press. Target co-ordinates are digital and in the same co-ordinate set (WGS-84) as that in which the aircraft is navigating. Pilot command transfers these target co-ordinates into the aircraft's Weapon Aiming System and a continuously computed release point (CCRP) Planned Attack may be selected, with HUD steering commands facilitating pilot navigation to the point of weapon release. The aircraft navigates by mixed INS/GPS/TRN and generally has a position accuracy of under 10m. The target may be mensurated to a similar accuracy, leading to an aircraft/target relative accuracy of approximately 15m.

From the pilot perspective this leads, to all purposes, to the HUD target marker being automatically positioned perfectly over the target. Furthermore, if required, TIALD steers directly to the target and the helmet-mounted sight (HMS) displays pointing commands to bring the pilot's eyes onto the target. This has all been flight-proven. Weapon release could be performed in instrument meteorological conditions (IMC) or, in practice, above a complete undercast: indeed a demonstration test flight with a senior RAF officer drew the unsolicited comment that, with the confidence engendered by the system, he would have been able to fly the whole process and release a weapon without ever seeing the target. This is not as impractical as it may sound – the example of UK Harriers bombing blind through cloud in Kosovo was described by the UK media and aviation press in 1999[20]. For this reason live 'dumb' bomb releases were subsequently conducted from Jaguars against target positions received digitally, but subsequently unrefined by the pilot, even though it was his natural inclination so to do. These were performed in good, clear weather conditions, with the target confirmed by the pilot to be within the HUD aiming marker. Circular error probable (CEP) accuracies were good.

Table 2
Example of two adjacent positions described in different co-ordinate systems

Co-ordinate System	Position 1	Position 2
MGRS	29U QS 12129 13696	30U TB 87872 13695
Lat/Long DD/MM.MM	N 500 38.188 W 0060 00.001	N 500 38.188 W0050 59.997
Lat/Long DD/MM/SS	N 500 38 11 W 0060 00 00	N 500 38 11 W 0050 59 59
UTM	29 712129 5613695 Northern	29 712133 5613695 Northern
BNG numeric	117277 E 089505 N	117281 E 089504 N
BNG alphanumeric	SW 17277 E 89505 N	SW 17281 E 89504 N

2.2.5 Jaguar integration – ease of use

The Jaguar IDM integration has a well-designed man-machine interface. During operational test flying it became apparent that the pilot could receive a digital nine-line message, review and accept it, and prosecute the target very quickly. The pilot was then idle whilst the FAC completed entry of the new target details. This was subsequently overcome by the FAC pre-mensurating and storing a number of targets before the aircraft came on station. A multitude of attacks could then be completed with maximum aircraft efficiency by the FAC recalling the next stored nine-line immediately the aircraft came off target. Ease of pilot use of the Jaguar IDM installation is confirmed by the very minimum amount of training required by the pilot.

2.2.6 Harrier aircraft integration

By the time of Operation Telic the UK had appreciated the utility of digital CAS. This prompted an urgent operational requirement (UOR) for a digital CAS capability on the Harrier. Since there was insufficient time to provide an integrated equipment fit (i.e. modify the aircraft operational flight programme (OFP), *à la* Jaguar) a pure display solution was fitted. This at least allowed the aircraft to receive and display the CAS nine-line message (the time-consuming aspect), although the pilot then had to enter the appropriate data manually into the nav/attack system. The solution comprised an iPAQ-based display mounted in the right lower coaming as shown in Fig. 6.

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Figure 5. Example of display of Jaguar moving map and nine-line brief.



Figure 6. Harrier nine-line Brief Display.

3.0 OPERABILITY WITH SIMILAR (IDM-EQUIPPED) ASSETS

All the research work which led to the ground and airborne systems described heretofore was performed not just with a view to verifying a research aim. From the very beginning cognisance was taken of other UK and NATO platforms with which interoperability was highly desirable. Unclassified consequences of this are described in the following.

3.1 Protocols

3.1.1 Tacfire

The IDM and associated equipments enable communication via a variety of protocols (communications languages). The main protocol for which information was freely available was Tacfire, a US Army artillery support protocol. This protocol was already employed on the UK attack helicopter. Tacfire, then, was selected by the (then) Defence Evaluation and Research Agency (DERA) as the protocol of choice for the transmission of the nine-line brief to the Jaguar. Care was taken from the very beginning to ensure that the nine-line data, carried in two messages (airborne fire request and freetext), was compatible with the UK attack helicopter. This was performed and verified. Thus the FAC equipment is capable of sending nine-line target data to the AH. Tacfire is a secondary protocol on the F-16. Although its IDM is capable of receiving a full Tacfire nine-line message, the aircraft operational flight programme only handles the target type, position and altitude carried within the nine-line message. It has been demonstrated that this information can be received and displayed by the (Block 40) F-16 aircraft.

3.1.2 AFAPD

The other primary extant protocol used for the transmission of targeting data was AFAPD (air force application program development). This was used in a reasonably 'pure' form on the F-16 aircraft for both nine-line and SEAD (suppression of enemy air defences) data and in a customised form for the exchange of intra-flight station-keeping information. It was also used in a customised (by Boeing) form on the AH.

Recent experience has shown that in a coalition deployment UK FACs are more likely to be calling in US aircraft than UK aircraft. For that reason the UK FAC equipment has been developed to support AFAPD; thus a UK FAC will have a Termite rugged PC capable of digitally calling in a US aircraft to a ground target.

Since the US has more assets than the UK the obverse of the above is that in a coalition environment UK aircraft are more likely to be called onto a target by a US FAC than a UK FAC. Thus it makes sense to replicate the Jaguar's current capability in AFAPD.

3.1.3 Variable message format (VMF)

VMF was at one time known as joint VMF (JVMF). VMF is essentially a wireless ethernet-type local area network/wide area network (LAN/WAN). For the US this will be the backbone of an over-the-air tactical internet.

QinetiQ (DERA) performed its original research using the two primary protocols described above. These are in some quarters dismissively described as 'legacy' protocols, with the terminological

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Figure 7. Example of a typical monochrome frame-grabbed image (~ 0·5MB).



Figure 9. Dashed area in Fig. 7 as detailed example of a typical monochrome frame-grabbed image.



Figure 8. Example of a 100 times wavelet-compressed image (5kB).

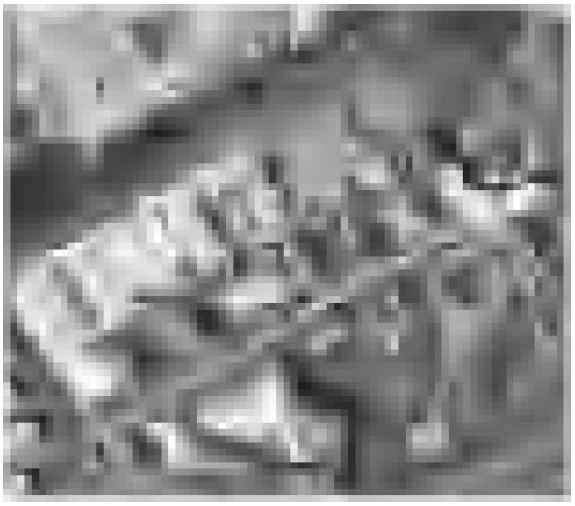


Figure 10. Dashed area in Fig. 8 as detailed example of a 100 times wavelet-compressed image.

implication that they are an unwanted inheritance. The fact is, however, that they are no more obsolescent than thousands of other in-service aircraft and equipments, including software. Thus the original QinetiQ research tenet was that provision of interoperability with NATO aircraft over the next five years or so was more important than providing digital targeting communication via what was then the equivalent of the Euro in currency, i.e. nobody was using it but it was planned in a few years' time.

Due to the success of the original work using in-service protocols, digital targeting over standard air and ground radios has become an accepted fact of high utility in the UK. Thus QinetiQ is now turning its attention to migration to VMF for the future.

4.0 THE USE OF IMAGERY IN THE RAPID TARGETING PROCESS

While the QinetiQ scientists were implementing digital targeting using parametric data, and talking to the user community, it became apparent that there was a strong rationale for a modem which would facilitate the passage of imagery over aircraft radios. Of the two prospective technical candidates QinetiQ chose the more mature, that being the US company which manufactured the F-14 fast Tactical imagery (FTI) system[21]. That company (PhotoTelesis) and the 3·02 IDM manufacturer (Symetrics) worked together to manufacture a board which was compatible with all other PhotoTelesis products and which would locate in one of the free card slots in the IDM. This form, fit and functionality was achieved rapidly, and correctly the first time. This imagery transmission technique utilises cryptographic radios for two purposes. Firstly it enables images to be transmitted securely, and secondly the crypto timing pulses facilitate synchronous data transmission, thus enabling the full 16kbit/second bandwidth of the radios to be used. Equally, ground capture, transmission and reception was achieved with existing equipment, namely the hand-held military micro-rit (MMR) or a PCMCIA card in a PC.

QinetiQ then upgraded the research Jaguar with the imagery-capable IDM (the photo reconnaissance imagery strike module [PRISM] IDM) and installed a KY-58 crypto unit and associated cabling. Also the aircraft OFP was modified in order to provide control of image capture within the aircraft, and recall, manipulation and display of both captured and received images. In the year 2000 the transmission of still images both to and from the in-flight aircraft

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was demonstrated. The source of imagery from the aircraft could have been any aircraft video (HUD camera, multi-function display image, or TIALD). In fact the TIALD image was chosen in that it was potentially the most operationally useful image. One of the functions available in the aircraft is burst capture, i.e. the ability to 'grab' still images from live video at a set rate (maximum 5Hz) for a set time. Since the TIALD pod will implicitly be imaging a laser-designated target, it is possible to set up a burst capture to bracket the predicted weapon impact. When clear of the target area the aircrew may then recall and review the captured images and select the one immediately before and immediately after weapon impact. These may then be transmitted off-board, e.g. to the aircraft in the following strike passage or to an airborne or ground command and control unit. Clearly this does not provide high resolution battle damage assessment imagery, but it does provide a good indication of where the weapon actually landed, from which battle damage indication intelligence may be rapidly gleaned. This is certainly far more rapid than taking and replaying a video tape from the aircraft when it lands.

The imagery-capable IDM, which is fitted to the UK Jaguar fleet, is entirely backward compatible with the UK Apache IDM, i.e. it has precisely the same hardware and software functionality as the Apache IDM, plus it has an additional connector through which the imagery functionality is achieved. The video capture, transmission and reconstitution technique is compatible with both UK PAL and US NTSC video. Thus a UK Jaguar PAL-derived image may be sent to and displayed in a US NTSC-based Tomcat (F-14) aircraft (or F-18, AH-64A or OH-58D).

4.1 Image compression

In order to speed transmission, IDM images may be pre-compressed by a user-selectable factor. Experience to date has shown that a typical compression factor of 50 maintains sufficient pictorial information upon image reconstitution. User-selectable compression techniques are wavelet[22] and JPEG. A typical monochrome image (768 × 614 pixels, 8 bit grey scale) occupies 462 kilobytes (kB) and is shown in Fig. 7. In order to exemplify the effects of compression a 100:1 compressed wavelet image, occupying approximately 5kB is shown in Fig. 8. Experience to date has indicated that a 50:1 compression is typically the highest compression ratio above which there becomes noticeable image loss or image artefacts, although this may only be unacceptable above 100:1 compression.

In order to exemplify the compression effect (as shown in the small, printed images in this paper), a selected 'busy' part of the image, in the square, is shown from the uncompressed and compressed images in Figs 9 and 10 respectively.

Transmission of the compressed image alone takes approximately six seconds at 16kbit/s. A one-off crypto pre- and post-amble takes approximately 8 seconds, within which any number of images may be sent. Thus the entire crypto radio time taken to transmit one 50× compressed image is approximately 14 seconds: two images would take 20 seconds.

5.0 INTEROPERABILITY WITH DISSIMILAR ASSETS

5.1 Link-16

Notwithstanding the utility of digital targeting using standard air and ground V/UHF clear, HaveQuick and encrypted radios, there is a strong body of feeling, some informed and some not, that there is only one airborne datalink to be used for the targeting and station-keeping applications described above. It is common to find people in all areas of the MoD and Industry who believe that Link-16 is the only datalink which could and should be used for the tactical applications described. In favour of the Link-16 protagonists it must be stated that the IDM technology does have its drawbacks, the primary one of which is that the use of the IDM is limited by standard radios. However, for the two reasons described below, hard facts militate against the use of Link-16 for these applications. Firstly no UK front line ground attack aircraft is fitted with Link-16, nor will that occur in the near future. Secondly, no man-portable Link-16 terminal yet exists, nor is there any plan that UK FACs and tactical air control parties (TACPs) will be issued with them. It must, however, be stated that it is not the intention of this paper to decry Link-16 (it is far more capable than the IDM) – it is simply not yet appropriate to the local, tactical targeting problem. Link-16 is well established, with greatly accepted operational utility, enabling a large network of users to exchange a variety of data in near-real-time in a secure fashion. Its capability to advertise the presence of all users in the battle area is so well accepted that the US policy is becoming that if you do not have Link-16 you cannot join the party (battle). In general IDM and Link-16 are complementary in their functionality and application.

The independent utility of IDM and Link-16 have been discussed.

6.0 THE EXTENDOR PROGRAMME

EXTENDOR was an incrementally phased three-year Operational Concept Demonstration Programme which ended in March 2003. It comprised three distinct phases of flight demonstration – one in each of the three years of the programme. Its aim was to demonstrate the utility of a medium altitude Communications Relay UAV (CRUAV). The selected UAV in which the communications payload was installed was an 'A' model Predator. The work was performed under a UK/US Memorandum of Understanding within which the UK hired a Predator through the USAF and the US paid for China Lake and Edwards Air Force Base Range and Range facilities for the flight trials in November 2000 and October 2001. The payload was designed and built by QinetiQ and installed in the Predator by General Atomics. The final year of the programme was originally planned for the Predator to fly in a UK range. However, due to the US response to the 11 September act of terrorism a Predator was at late notice unavailable for the third phase demonstration. Thus the payload was installed in a QinetiQ BAC 1-11, albeit still remotely ground-controlled as if it were in a UAV. The three phases of the programme are summarised below.

6.1 EXTENDOR Phase 1

This initial phase led to flight demonstration with the Predator after eight months, during which time much had to be learnt about the UAV itself and also the regulations concerning its flight in the Edwards and China Lake ranges. As far as the payload was concerned this phase was a 'keep it simple' period. Therefore the Phase 1 payload comprised two back-to-back ARC-210 radios with Mil Std 1553 frequency control via the predator ground control station (GCS) C band (direct) and Ku band (satellite) control links.

The demonstration comprised a FAC mensurating targets in both the Edwards and (primarily) China Lake ranges and tasking two UK Jaguars holding low on the other side of the mountains. The tasking was performed via a digital nine-line brief through the communications relay. This worked flawlessly – all dry attacks were good and. the practice bombs yielded a good CEP. In addition, in support of the UAV Battlelab, Predator imagery was 'grabbed' at the GCS, annotated and sent via the communications relay to an F-16. The F-16 was trial-fitted with a UK-type imagery-capable IDM. Furthermore, both the F-16 LANTIRN pod and the UK FACs captured weapon impact images and passed them to Predator GCS and to a Point Mugu F-14C fitted with the compatible fast tactical imagery (FTI) system.

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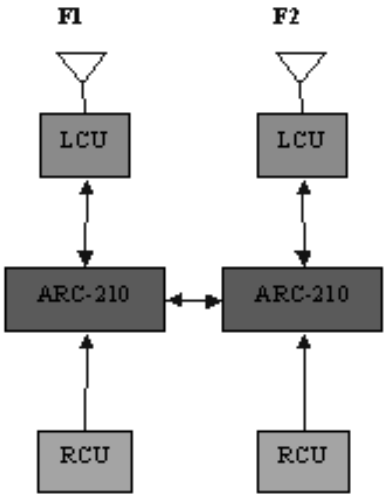


Figure 11. EXTENDOR Phase 1 payload schematic.

6.2 EXTENDOR Phase 2

Flight demonstration of this phase was one year after Phase 1, this time just in a China Lake range. The payload maintained the capability to switch the radios into back-to-back mode but included the incremental addition of an IDM and a store-and-forward computer. The store-and-forward mode and sub-modes were selectable from the GCS. These enabled the ability to store an IDM message addressed to the payload, and re-broadcast it to one or more GCS-selectable destination addresses. A store-and-forward message addressed to the payload could, for example, be broadcast via a global address. It was transparent to the final recipient whether the message had been received directly or via back-to-back relay. Furthermore the only difference in a received stored-and-forwarded message was in the sender's address. Otherwise, all three types of message (direct, relayed and re-broadcast) were identical. Once again the message of choice was the Tacfire nine-line to task one or more Jaguars onto a target.

Two further aspects were demonstrated at this time. Firstly the Jaguars demonstrated their new capability to exchange intra-flight position, height and velocity to facilitate station keeping and situational awareness. This was not only a useful operational facility (particularly since it was compatible with the Apache), but it was also a good engineering advance since it employed 16kbit/s AFAPD data exchange for the first time on the Jaguar. Secondly, the UAV payload enhancement enabled a Predator image to be captured within the payload IDM, downloaded to the GCS for confirmation of correctness, and transmitted directly from the Predator. The great advantage of this architecture over the Phase 1 configuration was that the Predator would at times be operationally a considerable distance from its GCS, and being controlled in the Ku waveband via satellite. In particular it would not be possible to send a GCS-derived still image via the back-to-back radios. The Phase 2 payload architecture catered for a situation where the Predator and its GCS could be hundreds of miles apart, but the Predator, in the target area, could send appropriate target images directly to the friendly ground attack aircraft. The imagery capability was exercised particularly for the UAV Battlelab demonstration, once again supported by UK engineers and of clear interest to the UK's EXTENDOR programme.

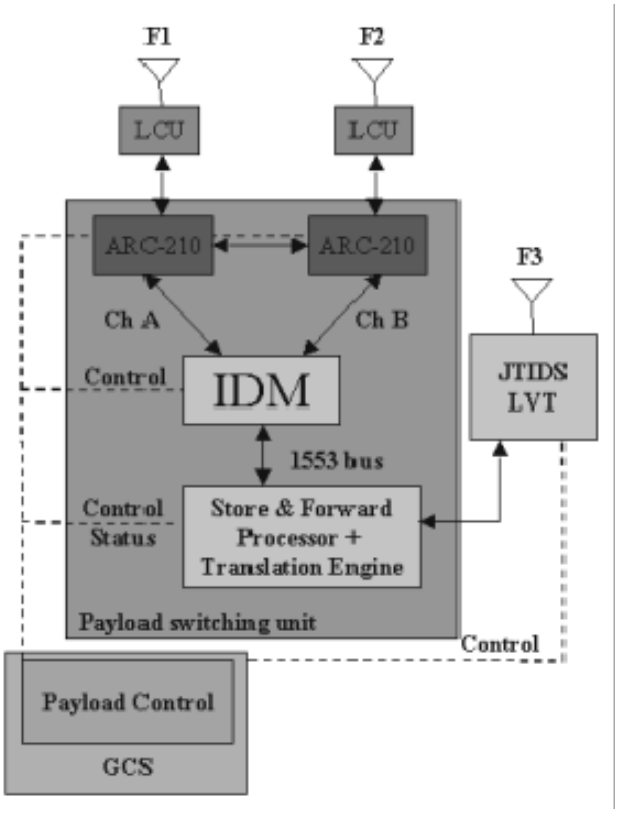


Figure 12. EXTENDOR Phase 2 payload schematic.

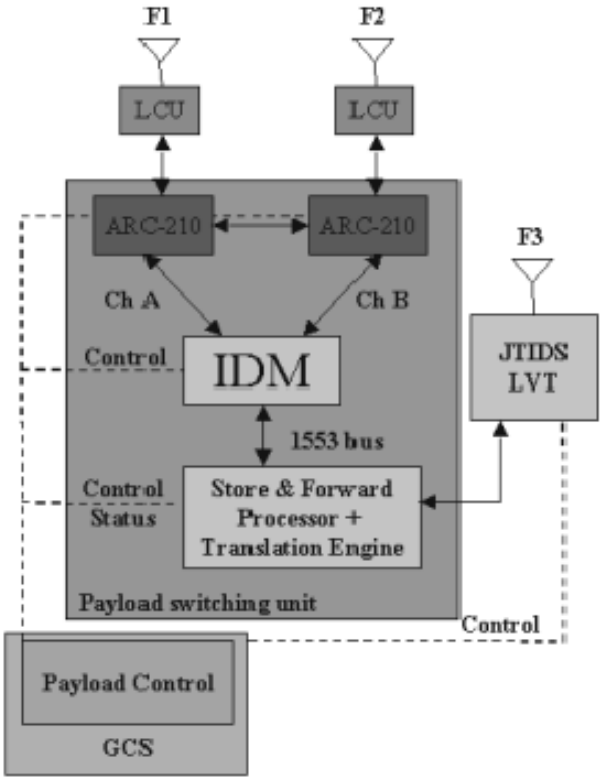


Figure 13. EXTENDOR Phase 3 payload schematic.

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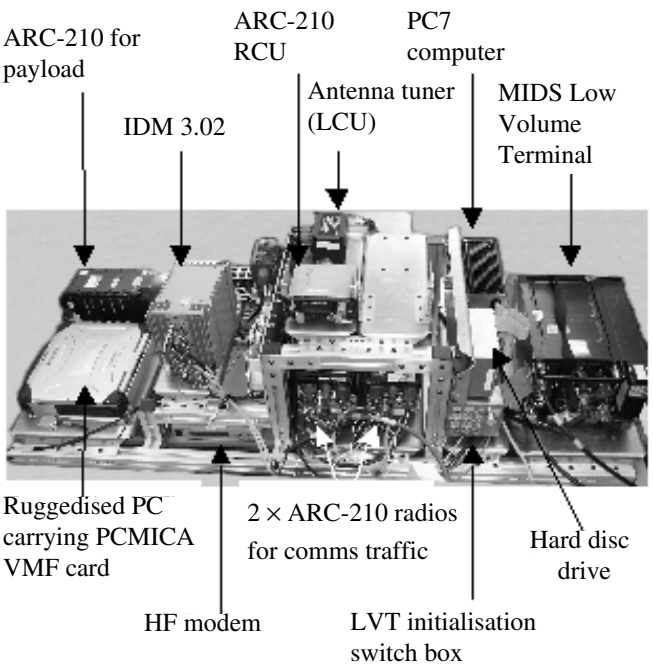


Figure 14. EXTENDOR Phase 3 payload hardware.

6.3 EXTENDOR Phase 3

Phase 3 took place in the UK's salisbury plain training area. Once again the Predator EXTENDOR payload capability was incrementally updated. Thus the back-to-back radios and the IDM store-and-forward capability were maintained, still GCS-selectable. However the extra capability in the Phase 3 payload was a significant engineering and operational improvement.

The utility and complementary nature of Link-16 and the IDM have been described. The improvement of the Predator payload from Phase 2 to Phase 3 enabled data not only to be received, stored and forwarded, but to be received, translated between IDM and Link-16 formats and forwarded in a different format (on a different datalink) from which it was received. The payload progression from Phase 1 to Phase 3 is shown schematically in Figs 11 to 13 respectively.

The payload itself was designed to be mounted directly into a Predator. Due to the unforeseen, late-notice unavailability of a Predator it became necessary to locate a cabin-environment aircraft into which to mount the payload. The most appropriate aircraft available was a BAC 1-11. Despite being in a manned aircraft and carrying payload engineers the payload was still operated remotely by ground control via a VHF link. The payload and primary component parts are shown in Fig. 14.

Data translation was seen to be important for a variety of reasons: in particular, within the EXTENDOR programme there were two particular message types, the translation of which offered great operational utility.

Firstly the two primary UK IDM users were the Jaguar and the Apache, neither of which was fitted with Link-16. As far as being 'seen' by friendly forces is concerned the Jaguar at least would be visible to an E-3D (Sentry) radar. The Apache, however, when operating among trees, would not even be visible to the Sentry radar. The translation payload offered the ability for these two aircraft to advertise their position (and height, speed etc.) via their IDM and have this information translated so that they might become 'visible' to the Link-16 community, i.e. they could become a part of the recognised air picture (RAP). This was a Phase 3 goal.

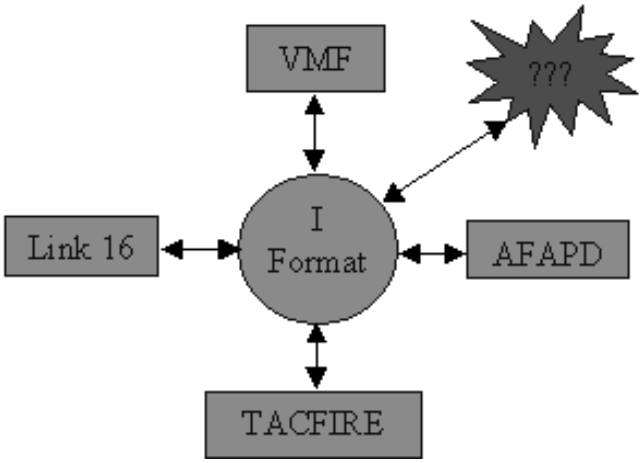


Figure 15. EXTENDOR Phase 3 translation concept.

Secondly, the E-3D is an excellent asset for data availability and for potential command and control. In Kosovo, for example, user opinion of the AWACS was "The aircraft is a distribution system. We fuse data and distribute it.", and "Everybody wants to talk to the AWACS."[23]. Notwithstanding the workload at the operator stations, particularly on the RAF E-3D, there is potential for the aircraft to increase its utility yet further. Therefore one of the goals of EXTENDOR Phase 3 was to demonstrate the capability to task an IDM-equipped asset with a nine-line brief originating from a Link-16-equipped asset, such as the E-3D.

6.3.1 Data translation

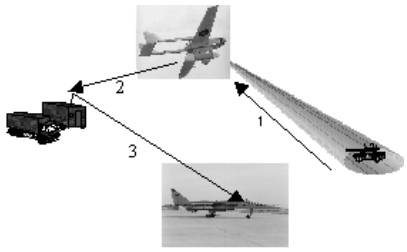
EXTENDOR handled four types of data: Tacfire, AFAPD, VMF and Link-16. The data translator was written by QinetiQ and at the beginning of the programme it was necessary to consider and define the data translation logic to be employed. Initially the most obvious translation logic was to convert directly from the input to the output protocol, for example Tacfire to VMF. However, each protocol carries data in a different format, and some protocols carry a certain element of an overall message which is not defined in other protocols. In other words there is not a one-to-one mapping between messages in different protocols. Indeed the full population of a message in one protocol may require various data elements from three or four messages in another protocol. Therefore the decision was made to translate all incoming messages into an intermediate data format which would be common, irrespective of how many protocols the translator was initially built to handle. One of the further advantages of this approach was that the later addition of a further protocol to the translator would require only one more translation set of rules, i.e. between the new protocol and the intermediate format. This would then enable complete translation between the new protocol and all others already mechanised. This simple translation concept, showing the pivotal part played by the intermediate format (I format), is shown schematically in Fig. 15.

6.4 Capability demonstrated

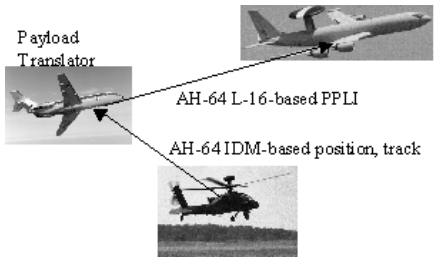
EXTENDOR Phase 3 comprised a considerable number of discrete capabilities. Firstly, all of the Phase 1 relay capability was demonstrated. Secondly, all of the Phase 2 store-and-forward capability was demonstrated. Thirdly, the primary explicit Phase 3 functions demonstrated were as follows:

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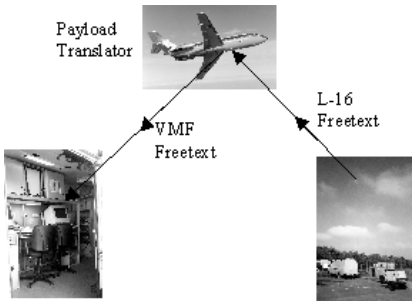
- Phoenix imagery sent to Jaguar.



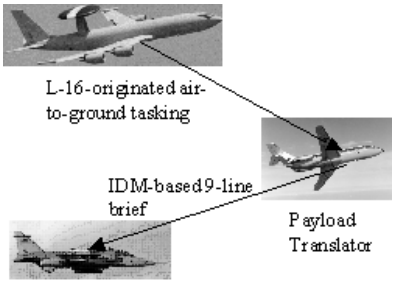
- IDM-output (AFAPD) position translated to L-16 as Precise Participant Location Information (PPLI), enabling IDM-equipped asset to appear in L-16 Recognised Air Picture.



- L-16/VMF Freetext Translation



- Elements of various L-16 messages aggregated via Translator to constitute an IDM nine-line tasking messag



- AFAPD/Tacfire/L-16 Freetext translation between various terminals

7.0 SUMMARY

Time-critical targeting targets are a known problem. There is now an acknowledged requirement for the passage of time-critical targeting data from a third party to an attacking aircraft. The requirement has strengthened recently, causing it now to be highly advantageous to pass targeting data accurate1y and quickly. This is due to:

- relocatable targets
- moving targets
- need for precision, particularly in peace-keeping, low collateral damage situations with non-combatants in proximity
- potent surface to air defences
- the desire to maximise weapon stand-off range
- the lack of long range sensors on board the attacking aircraft
- the requirement to satisfy the rules of engagement.

Third party targeting by voice is obsolescent, although it will remain for a long time. Third party targeting by digital means is a highly viable method of satisfying the need to pass data accurately, quickly and safely, insofar as the potential for human error in the shooter cockpit, due to transcription or data entry errors, is then limited. Nevertheless, great care must be taken to ensure that the potential for operator error at the sensor end is minimised, otherwise the sensor could accurately send an incorrect target location. QinetiQ has developed and tested such an IDM-based system, including passing to the shooter a target image.

Link-16 is becoming more widespread, although it is not yet used in UK ground attack aircraft. Even if it were, there are not yet any man-portable Link-16 terminals, thus UK foot-mounted FACs could not digitally call in a ground attack aircraft by this means.

Link-16/IDM translation offers the ability for an IDM-equipped aircraft to be visible in the Link-16 Recognised Air Picture. Such translation also offers the ability for a Link-16-equipped aircraft or (e.g.) ground headquarters to task an IDM-equipped ground attack aircraft. This capability has been demonstrated in the UK/US EXTENDOR programme.

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