AVIONIC SYSTEMS STANDARDISATION COMMITTEE

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# STUDY OF THE APPLICATION OF THE MPEG-2 DIGITAL VIDEO COMPRESSION STANDARD FOR USE IN UNINHABITED AERIAL VEHICLE SYSTEMS *

## SUMMARY

The investigation reported herein follows on from work reported in ASSC/130/6/2 "Investigation of Digital Video Compression Standards", issued in April 2001. That report compared the characteristics of various digital video compression standards with the requirements for compression in military avionics.

This report sets out the results of a brief study aiming to identify and define the issues effecting the application of the MPEG-2 digital video compression/decompression standard in Uninhabited Aerial Vehicle (UAV) systems.

The report summarises a wide variety of of UAV types and missions and briefly outlines the sensor systems used where this information has been determined.

A search has been undertaken aimed at identifying tactical data links (TDLs) in use or coming into service within NATO. This has identified a wide variety of TDLs, some of which might be used to convey data between UAVs and surface systems, and their principal features and areas of application have been summarised. The tactical common data link (TCDL) has been identified as that whose characteristics appear to most nearly meet the needs of conveying digital video compressed using MPEG –2.

The study failed to identify a 'typical UAV requirement' and it seems unlikely that such an entity exists. However, the parameters of various UAV sensor systems, particularly with

regard to image format and frame rate, have been established either quantitatively or qualitatively to a sufficient degree to permit a comparison with the characteristics of MPEG-2. The results of this comparison have been summarised for issues including:

- Image Format
- Frame Rate
- Compression Ratio
- Latency
- Image Quality
- Data Rate Mbps
- Error Resilience
- Functionality
- Processing Power
- Complexity
- Maturity
- Cost
- Hardware/soft-ware availability

Conclusions are presented, followed by a list of references, including URLs for over twenty web sites identified as useful sources of information during the investigation.

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**RELATED DOCUMENTS**

ASSC/130/6/2* – Issue 1 April 2001, Investigation of Digital Video Compression Standards

ASSC/130/2/77*Issue 1 April 1997, ASSC Advisory Document on Avionic Video Compression Technology (now integrated into Chapter 4 of ASSC/130/2/97 - Issue 2)

ASSC/130/2/134* Issue 1 May 2000, Digital Video Techniques and the Possible Adoption of Commercial Video Standards in Future Military Avionic Systems

ASSC/130/2/116*-Issue 1 December 1999, Requirements for Distribution and Transmission of Video Images for Airborne Platforms

ASSC/130/2/122 Image Fusion

ASSC/130/2/97*-Issue 2 June 2000, Guide to Avionic Video Systems

ASSC/130/6/1-draft 5, Chapter Five: Video Data Processing**

* These documents are available on the ASSC web site at www.era.co.uk/assc.htm

** This document has now been included in ASSC/130/2/97-Issue 2.

**GLOSSARY**

| | |
|---|---|
| ACLS, | Automatic Carrier Landing System |
| AFAPD | Air Force Application Program and Development |
| AIC | Air Intercept Control |
| ASTAMIDS | Airborne Standoff Mine Detection System |
| ATC | Air Traffic Control |
| ATDL | Army Tactical Data Link |
| ATHS | Automatic Target Handover System |
| AWACS | Airborne Warning and Control System |
| BER | Bit Error Rate |
| BLOS | Beyond Line of Sight |
| bps | bits per second |
| $C^2$ | Command and Control |
| CAINS | Carrier Aircraft Inertial Navigation System |
| CCD | Charge-Coupled Device |
| CDL | Common Data Link |
| COFDM | Coded Orthoganal Frequency Division Multiplexing |
| COMSEC | Communications Security |
| COTS | Commercial off the Shelf |
| CRC | Control and Reporting Centres |
| DAMA | Demand Assigned Multiple Access |
| DARPA | Defense Advanced Research Project Agency |
| dB | deciBel |
| DoD | Department of Defense |
| DTDMA | Dynamic TDMA |
| EADS | European Aeronautic Defence and Space Company |
| ECM | Electronic Counter Measures |
| ED | Enhanced Definition |

| | |
|---|---|
| EDTV | Enhanced Definition TV |
| ELINT | Satellite Communications and Electronic Intelligence |
| EO | Electro-optical |
| EPLRS | Enhanced Position Location Reporting System |
| EW | Electronic Warfare |
| FOPEN | Foliage Penetration |
| FPS | Frames Per Second |
| GBDL | Ground Based Data Link |
| GCBS | Strike Control, Ground Control Bombing System |
| GMTI | Ground Moving Target Indicator |
| GOP | Group of Pictures |
| HDTV | High Definition TeleVision |
| HF | High Frequency |
| HIDL | High Integrity Data Link |
| I | Intraframe coded picture |
| IAI | Israeli Aircraft Industries Ltd. |
| IBDL | Inter Battery Data Link |
| IDL | Intra-flight Data Link |
| IJMS | Interim JTIDS Message Specification |
| InSb | indium/antimonide |
| IR | Infrared |
| IRST | Infrared Search and Track |
| ISO | International Standards Organisation |
| JRE | JTIDS Range Extension |
| JTIDS | Joint Tactical Information Distribution System |
| kB | Thousand bytes |
| kbps | Thousand bits per second |
| LADAR | Laser Radar |

| | |
|---|---|
| LAMD | Lightweight Airborne Multispectral Countermine Detection System |
| LOS | Line of Sight |
| MAV | Micro Air Vehicle |
| MB | Megabytes |
| MBDL | Missile Battery Data Link |
| Mbps | Megabits per second |
| Mbytes | Megabytes |
| MHz | Million Hertz |
| MIDS | Multi-functional Information Distribution System |
| MOSP | Optronic Stabilized Payload |
| MPEG | Motion Picture Experts' Group |
| MSIS | Multisensor Integrated System |
| MTI | Moving Target Indicator |
| MTS | Marine Tactical System |
| MWIR | Medium Wave Infrared |
| NADGE | NATO's Air Defence Ground Environment |
| NIIRS | National Image Interpretability Rating Scale |
| NILE | NATO Improved Link Eleven |
| NRL | Naval Research Laboratory |
| OAV | Organic Air Vehicle |
| OFDM | Orthoganal Frequency Division Multiplexing |
| OLOSP | Optical Steerable Line-of-Sight Payload |
| PADIL | PATRIOT Digital Information Link |
| POP | Plug-in Optronic Payload |
| PPDL | Point to Point Data Link |
| PSNR | Peak Signal to Noise Ratio |
| PSNR | Peak Signal to Noise Ratio |
| SADL | Situation Awareness Data Link |

| | |
|---|---|
| SAM | Surface to Air Missile |
| SAR | Synthetic Aperture Radar |
| SATCOM | Satellite Communications |
| S-TADIL J | Satellite Tactical Information Link J |
| STDL | Satellite Tactical Data Link |
| TACFIRE | Tactical Fire |
| TCDL | Tactical Common Data Link |
| TDL | Tactical Data Link |
| TDMA | Time Division Multiple Access |
| TIBS | Tactical Information Broadcast System |
| TICM | Thermal Imaging Common Module |
| UAV | Uninhabited Aerial Vehicle |
| UHF | Ultra High Frequency |
| USMC | United States Marine Corps |
| USN | United States Navy |
| UWB | Ultra Wide-Band |
| VMF | Variable Message Format |
| VTOL | Vertical Take-off and Landing |
| VTUAV | Vertical Take-off and Landing UAV |
| WAR HORSE | Wide Area Reconnaissance Hyperspectral Overhead Real-Time Surveillance Experiment |
| WAS | Wide Area Search |
| WASAD | Wide Area Surveillance and Detection |

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## 1 INTRODUCTION

This report sets out the results of a brief study of the technical issues involved in the application of the MPEG-2 digital video compression standard for compressing images during transmission from an Uninhabited Aerial Vehicle (UAV). It follows on from work reported in Ref. 1 that compared the characteristics of various digital video compression standards with the requirements for compression in military avionics.

## 2 BACKGROUND

Ref. 1 sets out the results of an investigation aimed at comparing the characteristics of various digital video compression standards with the requirements for compression in a variety of military avionics applications. It includes as Table 5 a pro-forma to be used to summarise requirements for video compression in various applications against the capabilities of various compression standards. For convenience this table is reproduced here as Table 1. Such a table, when completed, would provide a checklist and a structured and regulated comparison of requirements and capabilities, although it does not readily allow for representing the various trade-offs that can be made between many different performance aspects. The investigation reported in Ref. 1 found that insufficient definition of application requirements currently exists within ASSC to permit a comprehensive comparison with the capabilities of video compression standards.

At the ASSC Video Subcommittee meeting held on 15 November 2001 it was agreed that as a next step a study should be made of the requirements for conveying digital video from UAVs and the characteristics of the MPEG-2 video compression standard, and it was suggested that LINK 11 and LINK 16 tactical data links (TDLs) should be considered for the air to ground link. This report sets out the results of that study.

| **Application:-** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Compression Standard:->** | | **MPEG-1** | **MPEG-2** | **MPEG-4** | **JPEG** | **MJPEG** | **JPEG-2000** | **MJPEG2000** | **H261** | **H263** |
| **Requirement** | | | | | | | | | | |
| Image Format | | | | | | | | | | |
| Frame Rate | | | | | | | | | | |
| Compression Ratio (lossless) | | | | | | | | | | |
| Compression Ratio (lossy) | | | | | | | | | | |
| Latency | | | | | | | | | | |
| Image Quality | | | | | | | | | | |
| Data Rate Mbps | | | | | | | | | | |
| Error Resilience | | | | | | | | | | |
| Functionality | | | | | | | | | | |
| Processing Power | | | | | | | | | | |
| Complexity | | | | | | | | | | |
| Maturity | | | | | | | | | | |
| Cost | | | | | | | | | | |
| Hardware/soft-ware | | | | | | | | | | |
| Comments | | | | | | | | | | |

**Table 1: Application Requirements versus Characteristics of Standards (after Table 5 of Ref. 1)**

## 3 STUDY FINDINGS

Figure 1 is a simplistic representation of the elements that make up a UAV system using compressed digital video.

The main issues involved in the type of system under review are:

1. UAV types and missions
2. Sensors types and characteristics
3. Wireless data link types and characteristics
4. Characteristics of the on-board signal processing for sensor fusion, panoramic imaging, target acquisition and tracking, data networking and relay, mapping and (most importantly) in the present context digital video compression to reduce the volume of data to be transmitted

Clearly these are all interrelated, and their performance requirements subject to trade-offs. However they are discussed separately in the following sub-sections.

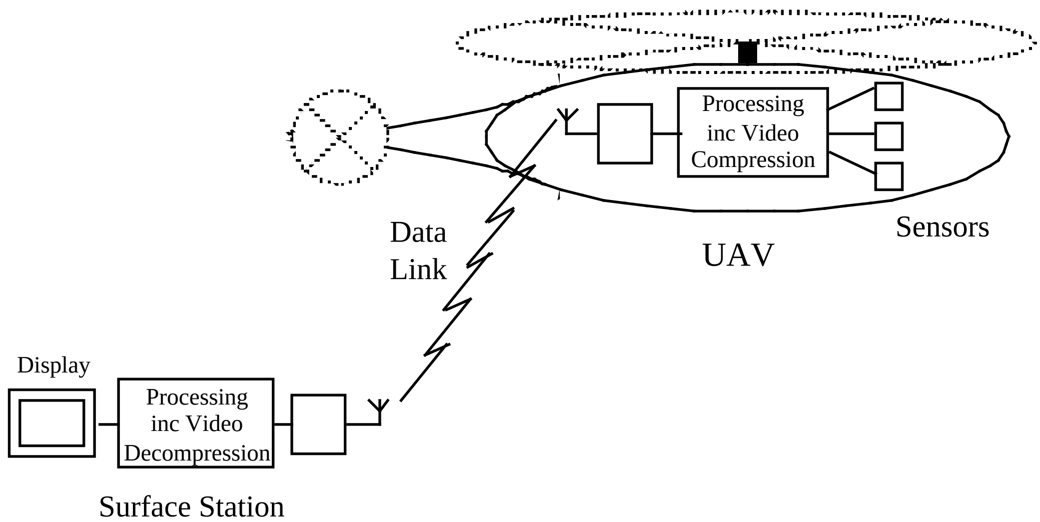


**Figure 1: Elements of a UAV System**

## 3.1 UAV Types

UAVs vary enormously in their concept, size, performance, missions and payloads.

UAV Forum Ref. 2 provides an undated listing of approximately fifty US organisations having in total one hundred and fifty UAV designs. One hundred and fifteen of these are said to have reached at least flying prototype stage and twenty-six more UAV types are either in production or ready for production.

A table lists the UAV companies and their products and categorises each of the as:

- Tactical
- Endurance - capable of extended duration flight, typically 24 hrs or greater
- Vertical Takeoff and Landing (VTOL) typically, but not exclusively, rotary wing
- Man Portable - light enough to be back-packed by an individual and launched by hand-throwing or sling-shot mechanism, larger than micro air vehicles
- Optionally Piloted Vehicle (OPV) - capable of manned or unmanned flight operations, typically an adaptation of a general aviation aircraft
- Micro Air Vehicle (MAV) - defined as having no dimension larger than 15 cm
- Research

Links are provided to UAV vendors web sites and in many cases to brief descriptions of vehicles.

Other sources describe UAV concepts including rotary wing, fixed wing and unconventional designs such as flapping wing. These are combined with jet, propeller, rocket and electric propulsion. Degrees of complexity and sophistication also vary widely.

Sizes range from tiny (<1' wingspan) vehicles, such as the Black Widow and Micro Bat prototypes developed under the Defense Advanced Research Project Agency (DARPA) Micro Air Vehicle (MAV) programme, to the 247' wingspan NASA Helios. However, the latter is the current ultimate extreme of size and is intended for very high altitude (100,000') long duration (target 96 hours at 50,000') scientific applications and is not as such strictly relevant to a study of military UAVs.

More typically larger UAVs tend towards the size of small manned aircraft and in some cases are conventional manned aircraft modified to operate as UAVs. For example the U.S. Navy (USN) and US Marine Corps (USMC) vertical takeoff and landing UAV (VTUAV) Fire Scout is essentially an unmanned Schweitzer 333 helicopter designed to take off and land on warships.

Performance is, predictably, tailored to mission requirements and varies from high altitude, long range, and long duration to sub treetop altitude short-range short duration. Other variables include, speed and agility.

Ref. 3 outlines the objectives, pay offs, challenges etc. of the DARPA Micro Air Vehicles (MAV) programme. This aims to develop flight-enabling technologies, and conduct demonstrations of low-cost MAVs capable of autonomous, sustained flight. MAVs are defined as vehicles less than 15 cm in any dimension. Fixed-wing MAVs will be capable of flight durations up to 1 hour, with 3–10 km range. Missions will include real-time video reconnaissance and biochemical sensing. Hovering or flapping MAVs will be capable of performing missions in urban canyons and even in the interior of buildings.

Ref. 4 states that the DARPA Organic Air Vehicle (OAV) program is developing cylindrical VTOL vehicles from 15 to 91 cm in diameter as part of the Future Combat Systems programme developing technologies for the US Army "objective force" concept to provide services for small, platoon-like units.

Ref. 5) describes as the General Atomics Aeronautical Systems, Inc Pelican OPV that may operated as conventional piloted aircraft or UAV.

Ref. 6 provides an outline of the Qinetiq ‘Observer’ development programme. This has produced a small (40kg, 2.5m wingspan) delta configuration, gust insensitive, simple to use UAV with intuitive human control interface and a variety of user definable flight plan modes. Observer is launched from a mobile ramp and uses parachute retrieval.

### 3.2 UAV Missions

Ref. 7 provides, among other information, a detailed summary of the missions in which the USN and USMC VTUAV is expected to be employed, together with relevant operational concepts. The envisaged land, sea and littoral roles include:

- Reconnaissance
- Detection of floating mines
- Battle damage Assessment
- Weapon impact versus intended target reporting
- Extension of ship’s fire control systems
- Artillery spotting
- Close air support - detection, identification, and video of the target area and laser target designation.
- Deep air support

- Evaluation of complex military training exercises e.g. observing Special Forces training operations and providing video for debrief.
- Communication and data relay, extending communications range beyond line-of-sight.
- Psychological operations to convey selected information and indicators to influence emotions, motives, objective reasoning, and behaviour; accomplished with loudspeakers, broadcast, and pamphlet dispenser mission payloads.
- Rescue and recovery assistance by providing live video.
- Harbour defence and port security.
- Support of law enforcement detachments e.g. for military police and for monitoring prisoner of war (POW) compounds.
- Target Detection.
- Target Identification/Verification.

Since Ref. 7 focuses on USN and USMC applications it is likely that many more roles will exist. A novel type of mission under research is reported in Ref. 8 wherein a UAV is used to drop sensor pods to the ground from where they transmit sensor information (in this case from magnetometers used to detect vehicles) back to base. Another type of mission, with obvious implications for tactical data links, that has been explored is the teaming of manned helicopters with UAVs, see Ref. 9.

Ref. 10 predicts that likely future UAV missions will include:

- All-weather target acquisition
- Electronic surveillance
- Communications intelligence
- Battlefield communications relay
- Chemical/biological agent detection
- Minefield detection/delimitation
- Multi-platform coordinated operations
- Search and rescue
- Battle damage assessment

Ref. 11 summarises the ASTAMIDS Airborne Standoff Mine Detection System in which an IR electro-optical sensor provides detection and boundary identification of patterned, scatterable, recently buried, and surface laid anti-tank minefields.

Ref. 12 outlines the objectives, pay offs, challenges etc. of the Lightweight Airborne Multispectral Countermine Detection System (LAMD) programme, scheduled to run until 2003. This aims to build upon the results of ASTAMIDS and other programmes to demonstrate an airborne detection system integrated into a tactical UAV to provide standoff minefield detection.

### 3.3 Sensors

This section of the report attempts to summarise some of the sensor types and systems identified during the study.

The basic mission payload for many military UAVs will be an equipment package with visible light and infrared sensors and probably a laser target designator. To these will be added signal processing electronics and data link equipment etc. Some UAVs will also carry radar for surveillance and/or for UAV navigation and collision avoidance. Lasers will be carried for illumination, range finding and target designation.The characteristics of the sensors etc. will vary widely depending on the intended missions.

Ref. 10 suggests that the roles listed in 3.2 above will be undertaken using sensors and systems such as:

- Foliage Penetration (FOPEN) and pointable radars
- Hyperspectral imaging
- Cross-cueing sensors
- Laser Radar (LADAR)

There appears to be significant interest in hyperspectral systems wherein sensors record reflected light in numerous narrow contiguous wavelength bands in the visible/near infrared wavelength region.

Finally some UAVs also carry sensors for nuclear, chemical and biological detection.

The remainder of this section briefly summarises a variety of programmes, products and systems found during the investigation, with emphasis on sensor issues.

#### 3.3.1 Observer

The Qinetiq Observer (Ref. 6) can carry a tri-camera payload with 3 CCD cameras each with a 30x40 degree field of view and boresights set at 30, 60 and 90 degrees to horizontal. A single image is electronically re-assembled on the ground.

Observer may also carry a 384 x 288 pixel, 8-14um uncooled thermal imaging sensor.

### 3.3.2 Global Hawk

The reconnaissance sensor suite developed by Raytheon for the for the Global Hawk high altitude endurance UAV (Refs. 13 and 14) includes electro-optical (EO), infrared (IR) and synthetic aperture radar (SAR) sensors.

The SAR operates simultaneously with either the EO or the IR sensor to enable coverage of wide geographic areas.

The EO sensor incorporates a third-generation IR sensor with a charge coupled device (CCD) visible wavelength camera.

The image quality allows users to distinguish types of vehicles, aircraft, and missiles. The SAR has three imagery collection modes 0.3m resolution spot mode, 1m resolution wide area search (WAS) mode and a moving target indicator (MTI) mode with minimum detectable velocity of 2.1m/s (7.56km/h).

SAR imagery is processed on board the UAV and transmitted with EO/IR imagery over satellite or line-of-sight data links in near real time.

The Global Hawk Sensor Suite is said to have all weather day and night capability at altitudes exceeding 21,000m.

The Global Hawk Sensor Suite data sheet (Ref. 14) gives sensor parameters, reproduced here in Table 2 below.

| Sensor | Specification | | Performance | |
|---|---|---|---|---|
| ***EO/IR*** | Focal length | 1.75m | WAS | 138,000 $km^2$/24hrs |
| | Aperture | 0.28m | NIIRS[1] | MWIR 5.0<br>Visible 6.0 |
| | Array | IR InSb: 3.7 – 5um<br>EO CCD: 0.55 – 0.8m | Spotlight | 1900 2x2km spot images per 24 hrs |
| | Field of view | Pixel instantaneous:<br>11.4 urad, MWIR<br>5.1 urad visible<br>Array:<br>5.5x7.3urad, MWIR<br>5.1x5.2urad, visible | | |
| ***Radar*** | Frequency | X band | WAS | 138,000 $km^2$/24hrs, 10km wide strip, at 1m resolution out to 200km range |
| | Bandwidth | 600MHz | GMTI | 15,000$km^2$/min<br>min detectable velocity 2.1m/s |
| | Antenna Field of Regard | +/- 45 deg squint either side of aircraft | | |

**Table 2: Global Hawk Sensor Suite Data Sheet Sensor Parameters**

### 3.3.3 Panospheric Systems

Ref. 4 states that DARPA requires uncooled infrared (IR), "panospheric" electro-optical (E/O), laser radar (ladar), and ultra wide-band (UWB) sensors for its Organic Air Vehicle (OAV) program. The reference describes current commercially available sensors with detector elements measuring 50 microns across and with temperature discrimination of 100

[1] NISS = National Image Interpretability Rating Scale

and 200 mK and mass between 100 to 200g. It is claimed that DARPA is aiming for temperature discrimination of 5 to 10 mK, pixel size of 15 microns and mass of 10g in 2002.

Ref. 4 also discusses a 4-million-pixel, panospheric, 360-degree view, electro-optical camera using a spherical stainless steel mirror under development by Athena and Carnegie-Mellon University. The camera will have a field of view from 10 degrees above the horizon to 80 degrees below. Sophisticated processing will be required to correct the distorted image created by the sensor's mirror at an adequate rate. Also selection of picture area to be transmitted within the constraints imposed by tactical data links will be a challenge, the reference suggests a 640x480 image picture format.

### 3.3.4 Jigsaw

Ref. 4 also refers to a laser Ladar system named Jigsaw. The Ladar could, for example, capture images of a potential target from different angles through gaps in foliage. These "multiple glances" capture different parts of a target vehicle and a processing system then assembles these into a single image for human interpretation. Jigsaw is expected to register the position of targets within centimetres.

### 3.3.5 WAR HORSE

Ref. 15 describes real-time hyperspectral target detection system flown aboard a Predator UAV as part of a Naval Research Laboratory (NRL) demonstration entitled WAR HORSE (Wide Area Reconnaissance Hyperspectral Overhead Real-Time Surveillance Experiment).

A hyperspectral sensor records reflected light in sixtyfour narrow contiguous wavelength bands in the visible/near infrared wavelength region (450-900 nm). This push-broom sensor consists of a grating spectrometer and a 1024x1024 custom charge-coupled device (CCD) camera. Operating at a frame rate of 40 Hz it provides 1024 cross-track spatial pixels.

The UAV also carries a panchromatic imaging sensor operating in the visible wavelength region. It consists of a CCD line scanner and a large format (300 mm) lens. This sensor operates at a frame rate of 240 Hz and provides high-resolution imagery via 6000 cross-track spatial pixels.

Data from the hyperspectral sensor was analysed by an on-board real-time processor. On detection of a target a high-resolution image was collected from the bore-sighted panchromatic visible sensor. A three-band false-colour waterfall display of the hyperspectral data with overlaid target cues, along with the corresponding high resolution image chips, was transmitted to a ground station in real time via an RS-170 data link.

The WAR HORSE system was flown on a USN Predator UAV typically at an altitude of 10,000 feet and an airspeed of 70 knots providing a hyperspectral imager ground sampling dimension of approximately one metre and a high-resolution line scanner ground sampling dimension of approximately 15cm.

#### 3.3.6 Multispectral Solutions (US)

Multispectral Solutions Inc is reported to have developed for the DARPA OAV programme a prototype miniature, lightweight, ultra wideband 6 to 6.5GHz radar operating in non-restricted spectrum and capable of detecting a tree branch at 15m.

#### 3.3.7 Lightweight Airborne Multispectral Countermine Detection System (LAMD)

The LAMD programme (see 3.2 above and Ref. 12) will focus on exploring a variety of new component and focal plane array technologies, multi/hyperspectral imaging, active illumination, passive polarization, passive millimeter wave foliage penetration synthetic aperture radar, and electronic stabilization.

#### 3.3.8 Miscellaneous

Avionics Magazine for October 2001 (Ref. 16) discusses a variety of UAV projects mostly outside the US with mentions of the following sensor capabilities.

##### 3.3.8.1 Phoenix (UK)

Two-axis stabilised sensor turret housing a thermal imaging common module (TICM II), providing a 60-by-40 degree field of view. Optical element is a Pilkington telescope with 2.5-to-10x magnification.

##### 3.3.8.2 Sagem (France)

OLOSP, a steerable line-of-sight payload incorporating a "near-IR day camera," which detects infrared wavelengths that are close to the visible spectrum.

##### 3.3.8.3 European Aeronautic Defence and Space Company (EADS)

In development medium-altitude, low-endurance Eagle UAV based on the Israeli Aircraft Industries Ltd. (IAI) Heron UAV, 250-kg payload will include a TV camera, IR sensor, laser illuminator, synthetic aperture radar with moving target indicator (MTI), satellite communications and electronic intelligence (ELINT) systems.

##### 3.3.8.4 Polytech AB (Sweden)

Gyrostabilized payload options in which EO and IR sensors are interchangeable. The options include a Sony EVI CCD (charged coupled device) camera with a 12 to 1 zoom ratio and a minimum illumination threshold of 6 lux. Another option is a Sony three-chip digital colour camera with a 20-to-1 zoom ratio, minimum 4-lux illumination, and horizontal resolution of more than 500 TV lines, plus a one-hour recording capability.

#### 3.3.8.5 Advanced Sensor Options for Predator (US)

Northrop Grumman and General Atomics have proposed advanced sensor options for the Predator, such as two-colour, daylight TV with variable zoom, high-resolution IR with six fields of view between 0.19 and 51 cm, laser rangefinder/designator, and electronic support and countermeasures. Possibility of adding foliage penetration radars and hyperspectral imaging. Predator can carry payloads up to about 200kg.

#### 3.3.8.6 Tamam (Israel)

##### U-MOSP

Multimission Optronic Stabilized Payload U-MOSP combines TV and forward-looking IR (FLIR) with a laser rangefinder/designator in a 91kg payload all boresighted, or aligned, with each other and integrated into a turret or ball. The third-generation FLIR has a high-resolution, 3-to-5-micron (mid-wave) indium/antimonide (InSb) thermal sensor. Mid-wave thermal detectors are said to suit many UAVs and be better than the 8-to-12-micron band at penetrating hot, humid atmospheres. Typically, the InSb sensor is said to deliver 2.5 times the resolution of long-range devices with optics of the same size. The FLIR provides three fields of view, from 0.75 to 13.5 degrees, and the TV camera has a broadly overlapping zoom capability. The diode-pumped laser will both designate targets and determine the exact range to the target. The E/O camera will identify targets as small as 2.3 by 2.3 metres from at a range of 11 km.

##### POD

The Plug in Optronic Payload (POP) 200 combines daylight colour TV from a 320-by-240-pixel InSb focal plane array with FLIR on an 28 cm gimbal. The 27kg payload is said to meet U.S. Army detection requirements at 3 km.

#### 3.3.8.7 Controp Precision Technologies (Israel)

The Controp Precision Technologies product family for UAVs includes turreted EO systems, the FSP-1 high-resolution, stabilised FLIR system, and the DSP-1 compact, dual-sensor day/night observation system.

The DSP-1 has a 786 x 494 pixel colour, daylight TV camera with a 22.5x zoom lens and a focal plane array detector for night operations. The thermal camera reportedly has sufficient resolution to detect trucks at 25 km and identify them at 7.5 km. The two sensors are mounted on a stabilised platform, that can be tilted to +10 and -105 degrees and rotated through 360 degrees.

#### 3.3.8.8 ELOP-Electronics (Israel)

The ELOP “Compass” system combines colour-zoom CCD with FLIR and a laser rangefinder/designator on a four-axis platform, all within a 34kg package. A heavier (100kg), military capable, multisensor integrated system (MSIS) has day/night, all-weather capability for search and tracking of land and sea targets.

#### 3.3.8.9 Denel (South Africa)

The Goshawk family of sensors includes TV cameras, a 3 to 5 micron or 8 to 12 micron imager, laser rangefinder and automatic tracker. The gyro-stabilised, turreted system weighs 24 to 35kg depending on the sensors chosen.

#### 3.3.8.10 Pchela (Russia)

The dual-sensor payload carried by the Pchela-1T aerial vehicle combines a TV camera for transmitting real-time imagery with a field of view remotely controlled between 3 and 30 degrees plus an IR sensor with 3 milliradian resolution and linear scanning.

### 3.3.9 ASSC document 130/2/116 Requirements for Distribution and Transmission of Video Images for Airborne Platforms

ASSC document 130/2/116 (Ref. 17) includes a table (reproduced here as Table 3) of sensor image formats and other parameters gathered during earlier work by the ASSC video subcommittee. While it is not clear how many of the listed sensor image formats are relevant to UAV applications, the table does illustrate the very wide range of image formats in use.

| | Sensor Type<br>Image Array Size | Width<br>(pixels) | Height<br>(pixels) | Total pixels<br>(pixels) | Frame Rate<br>(Frames/s) | Video Rate<br>(Mpixels/s) | Sample rate<br>(MHz) | Pixel Resolution<br>(bits per pixel) | Data Rate<br>(Mbits/s) | Timescale | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Thermal Camera | 320 | 240 | 76800 | 30 | 2.30 | | 14 | 32.26 | Now | |
| 2. | Thermal Camera | 320 | 240 | 76800 | 60 | 4.61 | | 14 | 64.51 | Now | |
| 3. | Thermal Camera | 320 | 240 | 76800 | 200 | 15.36 | | 14 | 215.04 | Now | |
| 4. | Thermal Camera | 384 | 288 | 110592 | 25 | 2.76 | | 14 | 38.71 | Now | |
| 5. | Thermal Camera | 384 | 288 | 110592 | 50 | 5.53 | | 14 | 77.41 | Now | |
| 6. | Thermal Camera | 640 | 480 | 307200 | 30 | 9.22 | | 14 | 129.02 | Now | |
| 7. | Thermal Camera | 640 | 480 | 307200 | 60 | 18.43 | | 14 | 258.05 | Now | |
| 8. | Thermal Camera | 640 | 480 | 307200 | 200 | 61.44 | | 14 | 860.16 | Now | |
| 9. | Thermal Camera | 768 | 576 | 442368 | 25 | 11.06 | | 14 | 154.83 | 2000 | |
| 10. | Thermal Camera | 768 | 576 | 442368 | 50 | 22.12 | | 14 | 309.66 | 2000 | |
| 11. | Thermal Camera | 1280 | 768 | 983040 | 25 | 24.58 | | 12 | 294.91 | Now | |
| 12. | Thermal Camera | 1280 | 768 | 983040 | 50 | 49.15 | | 14 | 688.13 | 2000 | |
| 13. | Thermal Camera | 1280 | 768 | 983040 | 100 | 98.30 | | 14 | 1376.26 | 2000 | |
| 14. | Thermal Camera | 1280 | 1024 | 1310720 | 30 | 39.32 | | 16 | 629.15 | 2003 | |
| 15. | Thermal Camera | 1280 | 1024 | 1310720 | 60 | 78.64 | | 16 | 1258.29 | 2003 | |
| 16. | Thermal Camera | 1280 | 1024 | 1310720 | 200 | 262.14 | | 16 | 4194.30 | 2003 | |
| 17. | Thermal Camera | 1600 | 1600 | 2560000 | 30 | 76.80 | | 16 | 1228.80 | ? | |
| 18. | Thermal Camera | 1600 | 1600 | 2560000 | 60 | 153.60 | | 16 | 2457.60 | ? | |
| 19. | Thermal Camera | 1600 | 1600 | 2560000 | 200 | 512.00 | | 16 | 8192.00 | ? | |
| 20. | Daylight Camera | 640 | 480 | 307200 | 30 | 9.22 | | 24 | 221.18 | Now | |
| 21. | Daylight Camera | 640 | 480 | 307200 | 60 | 18.43 | | 24 | 442.37 | Now | |
| 22. | Daylight Camera | 640 | 480 | 307200 | 200 | 61.44 | | 24 | 1474.56 | Now | |
| 23. | Daylight Camera | 768 | 576 | 442368 | 25 | 11.06 | | 24 | 265.42 | Now | 625 line standard |
| 24. | Daylight Camera | 768 | 576 | 442368 | 25 | 11.06 | 13.50 | 30 | 331.78 | Now | 625 line, SDI, 4:4:4 |
| 25. | Daylight Camera | 768 | 576 | 442368 | 50 | 22.12 | | 24 | 530.84 | Now | |
| 26. | Daylight Camera | 1280 | 1024 | 1310720 | 30 | 39.32 | | 30 | 1179.65 | 2000 | |
| 27. | Daylight Camera | 1280 | 1024 | 1310720 | 60 | 78.64 | | 30 | 2359.30 | 2000 | |
| 28. | Daylight Camera | 1280 | 1024 | 1310720 | 200 | 262.14 | | 30 | 7864.32 | 2000 | |
| 29. | Daylight Camera | 4000 | 4000 | 16000000 | 30 | 480.00 | | 48 | 23040.00 | 2000 | |
| 30. | Daylight Camera | 4000 | 4000 | 16000000 | 60 | 960.00 | | 48 | 46080.00 | 2003 | |
| 31. | Daylight Camera | 4000 | 4000 | 16000000 | 200 | 3200.00 | | 48 | 153600.00 | 2003 | |
| 32. | WASAD System | 768 | 360 | 276480 | 2 | 0.55 | | 12 | 6.64 | Now | |

**Table 3: Table 1 from Ref. 17**

3.3.10 Summary of Sensor Related Findings

It will be seen from the above that, although numerous references to sensors used in UAV systems and other avionics applications have been identified, the investigation uncovered only limited technical information on issues such as resolution, image format and frame rate etc. Such information as was found is summarised in Table 4.

It can be seen from Table 4 and from Table 3 above that (even allowing for the fact that some of the sensors listed in Table 3 may not be appropriate to UAV applications) there is a very wide range of sensor characteristics and it seems unlikely that there is a 'typical sensor'.

| Programme / Product etc. | Image Format | Frame Rate | Section - |
|---|---|---|---|
| Observer | 384 x 288 | Not Defined | 3.3.1 |
| Athena and Carnegie-Mellon University panospheric, camera | 640x480 | Not Defined | 3.3.3 |
| War Horse:<br>1. Hyperspectral sensor<br>2. CCD line scanner panchromatic imaging sensor. | 1. 1024x1024<br>2. 6000 cross-track spatial pixels | 1. 40Hz<br>2. 240 Hz | 3.3.5 |
| Polytech AB | 500 TV lines | Not Defined | 3.3.8.4 |
| Tamam POP 200 daylight colour TV camera | 320x240 | Not Defined | 3.3.8.6 |
| Controp Precision Technologies DSP-1 daylight colour TV camera | 786x494 | Not Defined | 3.3.8.7 |

**Table 4: Summary of Sensor Image Formats**

## 3.4 Tactical Data Links

There is a considerable variety of Tactical Data Links (TDLs) in use or coming into service in the US and various NATO and other nations, some of which could possibly be considered for UAV applications. Detailed information on these, at least that readily available from the World Wide Web, tends to be rather sparse and it is apparent from the MIL-STD web site (Ref. 18) that some of the relevant standards are classified.

The STASYS web site Ref. 19 provides a useful overview of a range of different TDLs and related standards and this is supplemented by details contained in Refs. 6 and 20.

These are briefly summarised in the following sub-sections with the aim of placing the various TDL standards/systems in context. Data rates are shown where these have been determined.

### 3.4.1 MIDS/JTIDS

Multi-functional Information Distribution System (MIDS) was a term coined by NATO to describe a requirement that was met by the US Joint Tactical Information Distribution System (JTIDS)

MIDS/JTIDS is a high capacity, ECM-resistant, UHF communications link with a Time Division Multiple Access (TDMA) architecture for use in air and surface roles and on all platform types. UHF limits the range to direct line of sight (LOS), but relay capabilities are included to achieve beyond line of sight (BLOS) communications.

MIDS/JTIDS supports the message standards Link 16, IJMS and Variable Message Format (VMF).

### 3.4.2 Link 16/TADIL J

Link 16, known as TADIL J in the US, has been designed to optimise the use of the MIDS/JTIDS architecture. Link 16 supports the exchange of surveillance data, electronic warfare (EW) data, mission tasking, weapons assignments and control data. Platforms that are or will be equipped with Link 16 include airborne surveillance and intelligence systems, command and control ($C^2$) systems, fighter and bomber aircraft, surface to air missile (SAM) systems, ships etc. The UK has implemented Link 16 in its E-3D airborne warning and control system (AWACS) & Tornado F3 fleet, with implementation underway for Royal Navy (RN) ships and aircraft and other RAF $C^2$ platforms and aircraft. Link 16 provides a raw data rate of 300kbps.

### 3.4.3 IJMS

Interim JTIDS Message Specification (IJMS) was developed to provide an initial JTIDS operating capability for USAF and was installed in various US and other E-3 Sentry AWACS aircraft pending availability of the US TADIL-J message standard.

### 3.4.4 VMF

Variable Message Format (VMF) uses Link 16 data elements to create variable length messages suitable for near real time data exchange with limited bandwidth. The final Joint Service version is still under development.

### 3.4.5 Link 11/TADIL A

Link 11, known as TADIL A in the US, employs netted communication techniques with standard message formats. It provides a half duplex link over which data is exchanged at 1364bps in the HF band or 2250bps in the UHF band. Subsequently a more ECM resistant transmission method has been introduced with a data rate of 1800 bps. Operation in the HF band provides a BLOS capability with a theoretical range of approximately 300nm. Link 11 normally operates on a polling system, but may be operated in broadcast mode.

Within NATO Link 11 is primarily used as a Maritime Data Link. It supports the exchange of air, surface and subsurface tracks, EW data and limited command data among C2 units.

Link 11 supports raw data rates of 1364 and 2250bps.

### 3.4.6 Link 11B/TADIL B

Link 11B/TADIL B employs a dedicated, point-to-point, full-duplex digital data link. Data rates are 600, 1200, 2400, 4800 and 9600bps.

### 3.4.7 NILE/Link 22

NILE (NATO Improved Link Eleven)/ Link 22 is in part a hybrid between MIDS Link 16 and Link11. Link 22 is an ECM resistant, BLOS tactical data communication system utilising fixed frequency or frequency hopping techniques in the HF and/or UHF bands. TDMA or Dynamic TDMA (DTDMA) may be used, for increased flexibility and decreased net management overheads. The Link 22 bit rate appears to be classified.

### 3.4.8 Link 1

Link 1 is a point to point duplex digital data link primarily used by NATO's Air Defence Ground Environment (NADGE), was designed in the late 1950s with a data rates of 1200 and 2400 bps. .

### 3.4.9 Link 14

Link 14 is a broadcast HF teletype link for maritime units designed to transfer surveillance information from ships with a tactical data processing capability to non-tactical data processing ships. The design of the teletype transmission allows reception over very long ranges. Link 1 operates at 600 or 1200bps.

### 3.4.10 Link 4/TADIL C

Link 4/TADIL C is a non-secure data link used for providing vector commands to fighters at 5,000 bits per second. There are two variants Link 4A and Link 4C.

Link 4A is the controller to aircraft data link supporting Automatic Carrier Landing System (ACLS), Air Traffic Control (ATC), Air Intercept Control (AIC), Ground Control Bombing System (GCBS) and Carrier Aircraft Inertial Navigation System (CAINS). It has no ECM resistance, and caters for only eight participants.

Link 4C is a fighter-to-fighter data link, providing limited ECM resistance and intended to complement Link 4A, although the two links cannot communicate with each other directly.

It is expected that Link 16 will take over most Link 4 roles.

#### 3.4.11 CDL

Common Data Link (CDL) is the US DoD designated standard for imagery and signals intelligence. It consists of a secure, jam resistant uplink operating at 200kbps and a down link that can operate at 10.71 Mbps, 137 Mbps or 234 Mbps (currently (January 2002)) only the first of these downlink rates is understood to be secure).

The CDL family defines five classes of link to provide both LOS and BLOS using relay for communications between surface based units and aerial platforms operating at various speeds and altitudes, including satellites.

#### 3.4.12 TCDL

Tactical Common Data Link (TCDL) is a relatively new CDL compliant system ( see also Refs. 21, 22, 23, 24 and 25). The TCDL programme aims to provide a family of interoperable, secure, digital data links for both manned and unmanned airborne platforms. It will transmit radar, imagery, video and other sensor information at rates from 1.544Mbps to at least 10.7 Mbps over ranges of 200km. It is also intended that TCDL will in time support the required higher CDL rates of 45, 137 and 274 Mbps.

The USN and USMC Fire Scout VTUAV will be equipped with TCDL.

The outline specification for the L3 Communications and the Rockwell Collins TCDL Airborne Data Terminal products (Refs. 22, 23 and 25) include the following relevant parameters:

- Bit Error Rate $10^{-6}$ with COMSEC (Communications Security) and $10^{-8}$ without COMSEC
- Data Rates
  - Variable up to 45 Mbps
  - CDL interoperable at 10.71 Mbps
- Full duplex symmetric or asymmetric link

- Video
  - RS-170a Colour
  - MPEG-2 compression
  - Other interface options available

3.4.13 HIDL

High Integrity Data Link (HIDL) is currently under evaluation by the UK in a programme sponsored by NATO Naval Armaments Group's Projects Group 35 for use with UAVs. It will provide a full-duplex narrow-band jam-resistant air to ground data link operating in broadcast mode to communicate with two (or possibly more) UAVs simultaneously at ranges up to 200 km with a 100kbps data bandwidth.

3.4.14 ATDL-1

Army Tactical Data Link 1 (ATDL-1) is a secure full duplex point-to-point link for exchanging information among SAM systems and between Command and Control systems and SAM units. ATDL-1 is capable of using HF or UHF radio bands, satellite communications (SATCOM), or landlines. ATDL-1 uses the Link 11 message catalogue.

Ref. 20 shows ATDL-1 with bit rates of 600, 1200 and 2400 bps.

3.4.15 PADIL

PATRIOT Digital Information Link (PADIL) is a secure full duplex point-to-point link for exchanging information between PATRIOT battalions and batteries and is capable of using HF or UHF radio bands, SATCOM, or landlines at a data rate of 32kbps.

3.4.16 MBDL

The Missile Battery Data Link (MBDL) provides a 750bps limited capability, non crypto secure, point to point link for roles including data transfer between NADGE Control and Reporting Centres (CRCs) and NIKE Battalion Operations Centres.

3.4.17 GBDL, IBDL, PPDL

Ground Based Data Link (GBDL), Inter Battery Data Link (IBDL) and Point to Point Data Link (PPDL) are USMC HAWK specific TDLs that are expected to be replaced by VMF In the near future.

3.4.18 TIBS

Tactical Information Broadcast System (TIBS) is an intelligence data link that is used by US forces and some other nations to in conjunction with Theatre Missile Defence operations to provide information on Ballistic Missile launches, launch positions, impact points etc. It is used to provide non-Link 16 units with a near real time tactical information.

3.4.19 SADL

The Situation Awareness Data Link (SADL) provides secure, jam-resistant and contention-free fighter-to-fighter, air-to-ground and ground-to-air data communications. It integrates US Air Force close air support aircraft with the digitised battlefield via the US Enhanced Position Location Reporting System (EPLRS).

3.4.20 EPLRS

Enhanced Position Location Reporting System (EPLRS) is the US Army's current data networking system for the digitised battlefield, it is said to provide on-the-move, high-speed, automated data exchange using a contention-free networking architecture.

3.4.21 Other systems

Other systems used with US originated aircraft such as F16, F18 and the Apache helicopter include:

- Air Force Application Program and Development (AFAPD)
- Marine Tactical System (MTS)
- Intra-flight Data Link (IDL)
- Tactical Fire (TACFIRE)
- Automatic Target Handover System (ATHS 1 & 2)

These are expected to be replaced by Link 16 or VMF.

3.4.22 Satellite Data Links

3.4.22.1 STDL

The Satellite Tactical Data Link (STDL) will use the Link 16 message standard on a satellite bearer to overcome the LOS limitations of JTIDS by providing BLOS communications primarily for exchange of surveillance and mission management data operating in broadcast or network mode. STDL is part of the Royal Navy (RN) Ship System requirement and is to be implemented at the same time as MIDS/JTIDS/Link 16 on a variety of ship types.

3.4.22.2 <u>S-TADIL J</u>

The USN has also investigated satellite Link 16 and its chosen solution is known as Satellite Tactical Information Link J (S-TADIL J*)*. However STDL and S-TADIL J are incompatible, as is the USAF solution known as JTIDS Range Extension (JRE).

S-TADIL J has been demonstrated with bit rates of 2400 & 4800 bps with Demand Assigned Multiple Access (DAMA) and 2400, 4800 and 9600 bps for non-DAMA operation.

The USN also use a system known as S-TADIL A to carry Link 11 data.

3.4.22.3 <u>Qinetiq Observer</u>

The Qinetiq Observer presentation (Ref. 6) mentions a 10Mbps digital down link system developed by Racal Research carrying three video channels and including video encoder/decoder with approximately 16:1 compression ration.

3.4.22.4 <u>Satellite Related Issues</u>

Data links via satellite have drawbacks that are of specific interest for video transmission, especially for real time applications. Firstly, the data bandwidth available is likely be less than for some modern terrestrial systems. Secondly communication via satellite introduces propagation delays. Clearly trade-offs to cater for reduced bandwidth will potentially have adverse impacts on parameters such as resolution, picture quality and frame rate. Propagation delays have obvious implications for real time applications. Furthermore, depending on the trade-offs made, the limited bandwidth may also lead to further time delays e.g. as a result of processing time related to high compression ratios and/or use of low frame rates.

3.4.23 <u>Orthoganal Frequency Division Multiplexing (OFDM)</u>

In OFDM digital radio systems (Refs. 26 and 27) the available spectrum is divided into numerous carriers (typically thousands) and a low bit rate data stream modulates each carrier. A single high bit rate data stream may be divided between the multiple carries to achieve a link with high aggregate bandwidth. OFDM uses the spectrum efficiently by keeping the carriers close together. This is achieved by making all the carriers orthogonal to one another to prevent interference between them. Since with multiple carriers each carrying a low bit rate data stream the symbol duration may be made relatively long compared with the carrier period OFDM can provide superior multipath immunity compared with other techniques.

An extension of OFDM known a Coded OFDM (COFDM) (Ref. 28) provides enhanced performance in the presence of interfering signals and is used in digital broadcasting in standards such as Digital Audio Broadcasting (DAB) (Ref. 29) and terrestrial Digital Video Broadcasting (DVB-T) (Ref. 30).

It is highly probable that OFDM and/or COFDM will have a role in future tactical data links and it is understood that such applications are being investigated under the DARPA Future Combat Systems (FCS) Communications Program. (Ref. 31).

### 3.4.24 Summary of TDL Findings

For digital video transmission, available data rate is clearly a dominant factor with regard to feasibility. Table 5 below lists the data rates for the various TDL systems summarised above, where these have been determined.

No allowance has been made for overheads due to, for example, handshake protocols, error protection, inter-message gaps or for possible data bandwidth sharing between multiple users. It is also likely that images may need to be transmitted from multiple sensors (e.g. radar plus IR or visible light), unless onboard UAV sensor fusion is performed. Hence useful bit rates may be considerably less than those listed.

The objective of the task reported herein is to consider the use of MPEG-2 for retrieval of video from UAVs. MPEG-2 is intended for use at bit rates between 1.5 and 60Mbps and it is clear that none of the TDLs listed in Table 5, except TCDL (which is a CDL compliant standard) provide data rates in this range.

| Name | Bit Rate(s) (bps) |
|---|---|
| MBDL | 750bps |
| LINK 1 | 600 or 1200 |
| LINK 14 | 600 or 1200 |
| LINK11 | 1364 or 2250 |
| ATDL-1 | 600, 1200, 2400 |
| LINK 4 | 5000 |
| STDL | 2400, 4800, 9600bps |
| LINK 11B | 600, 1200, 2400, 4800, 9600 |
| PADIL | 32kbps |
| HIDL | 100kbps |
| LINK 16 | 300kbps |
| TCDL (from Refs. 22, 23 & 24) | Variable up to 45Mbps<br>CDL interoperable at 10.71Mbps |
| CDL | 10.71, 137 or 234Mbps |
| Observer | 10 Mbps |

**Table 5: TDL Data Rates**

It might be possible to transmit a stored MPEG-2 video sequence at low bit rate for recording and subsequent replay at its original speed on the ground. However, this is unlikely to be acceptable for many operational requirements. Alternatively other, low bit rate, video compression standards such as H263 or MPEG-4 might be used with some of the other data links listed in the table. Also such data links might prove acceptable for transmission of still images using standards such as JPEG 2000.

It is likely that in future techniques such as OFDM and COFDM discussed in 3.4.23 will be used to implement high performance digital data links.

### 3.5 Comparison or Requirements for UAV Applications with the Characteristics of MPEG-2

Table 6 is a similar table in concept to Table 1, but modified to allow tabulation of the characteristics of MPEG-2 only, with respect to the requirements for UAVs. This section attempts to characterise the requirements for UAV applications, based on the investigations reported above and compare these with the capabilities of MPEG-2 systems.

Sections 3.5.1 to 3.5.13 provide further discussion.

| Application:- | | *Uninhabited Aerial Vehicle* |
|---|---|---|
| **Compression Standard:->** | | ***MPEG-2*** |
| **Requirement** | | |
| Image Format | There appears to be a very wide range of image formats in use (see Table 3 and Table 4) and no 'typical UAV sensor'.<br>See 3.5.1 for further discussion. | The video bit stream specification for MPEG-2 implies image resolutions up to 16,383 x 16,383 pixels. However, the limits on resolutions actually implemented are unclear. It would appear that there is a reasonable probability of a significant number of UAV sensor image formats being capable of use with MPEG-2. |
| Frame Rate | There appears to be a wide range of frame rates in use (see Table 3).<br>See 3.5.2 for further discussion. | The video bit stream specification for MPEG-2 implies frame rates from 24 to 200 FPS. However, the limits on frame rates actually implemented are unclear.<br>Frame rates used for relatively small field of view real time UAV systems may be appropriate for MPEG-2. However, high altitude systems covering very wide areas may not generate suitable frame rates. |

| Application:- | | *Uninhabited Aerial Vehicle* |
|---|---|---|
| **Compression Standard:->** | | ***MPEG-2*** |
| **Requirement** | | |
| Compression Ratio (lossless) | High altitude wide area missions such as those undertaken using the Global Hawk Integrated Sensor Suite (see Ref. 14 and 3.3.1 above) will certainly require very high image quality and may therefore require lossless compression.<br><br>See 3.5.3 | MPEG-2 does not provide lossless compression. |
| Compression Ratio (lossy) | True real time applications, possibly involving lower altitude operations with restricted fields of view, are likely to generate high uncompressed data rates necessitating lossy compression.<br><br>See 3.5.3 | MPEG-2 provides for trading off compression ratio versus other characteristics such as image resolution, frame rate, image quality etc.<br><br>It is considered likely that in most applications the maximum compression achievable would be (very approximately) in the order of 20:1. |
| Latency | May vary from 10's ms to minutes depending on application. Much less significant where the UAV flight path is controlled autonomously than when the video is used for pilotage.<br><br>See 3.5.4 | MPEG-2 uses interframe coding and is thus subject to its limitations, in particular with regard to latency. |

| **Application:-** | | ***Uninhabited Aerial Vehicle*** |
|---|---|---|
| **Compression Standard:->** | | ***MPEG-2*** |
| **Requirement** | | |
| Image Quality | Requirements are highly application dependent. High altitude reconnaissance and surveillance systems will require high image quality to represent features forming a small part of a large picture.<br><br>It is likely that true real time applications will, perhaps of necessity, have to sacrifice image quality to achieve frame rates and latency required.<br><br>See 3.5.5 | It seems probable that MPEG-2 may permit adequate (or possibly the best that can readily be achieved) image quality for some real time applications with limited data bandwidth, but is less likely to allow image quality of the standards required in high altitude reconnaissance and surveillance missions. |
| Data Rate Mbps | Data rate is constrained by the performance of the UAV to ground data link.<br><br>It appears likely that many future systems will use TCDL discussed in 3.4.12 above. This provides a data bandwidth of 10.7Mbps.<br><br>See 3.5.6 | MPEG-2 is intended to operate at data rates ranging from 1.5 to 60Mbps.<br><br>Data rate needs to be consistent with frame rate, resolution and compression ratio. |

| Application:- | | ***Uninhabited Aerial Vehicle*** |
|---|---|---|
| **Compression Standard:->** | | ***MPEG-2*** |
| **Requirement** | | |
| Error Resilience | A high degree of error resilience is clearly desirable. The actual requirements for error resilience will, to a significant extent, depend upon the performance of the data link used to transmit compressed video, and this may in turn depend on the environment in which the UAV operates. Error correction involves overheads that consume bandwidth.<br><br>See 3.5.7. | MPEG-2 is widely, and successfully, used for digital TV broadcasting and this is consistent with good error resilience. However, the electromagnetic environment in which a UAV operates may be significantly worse than for broadcast applications and may include deliberate interference from the enemy. It seems probable that MPEG-2 will be able to provide adequate error resilience for at least some UAV applications.<br><br>The use of interframe coding in MPEG-2 may result in propagation of errors over multiple frames. |
| Functionality | Functionality is defined as the provision of means by which the user may tailor the system to the specific needs of the application. The wide range of UAV applications identified points to a wide range of configurations requiring a significant degree of functionalility.<br><br>See 3.5.8 | MPEG-2 includes a large number of options, enhancements and extensions, and therefore considerable scope for optimisation in order to meet the requirements of a particular application. |

| Application:- | | Uninhabited Aerial Vehicle |
|---|---|---|
| **Compression Standard:->** | | ***MPEG-2*** |
| **Requirement** | | |
| Processing Power | The compression technique should be readily capable of implementation with adequate performance using the processing power available within the vehicle.<br>Processing power relates to electrical power consumption. This may become an issue particularly in small UAVs with battery powered avionics.<br>See 3.5.9 | It is most probable that MPEG-2 compression/decompression will be achieved using dedicated COTS hardware. Hence it is sufficient for present purposes to say that a wide range of MPEG-2 products is available offering adequate processing power for satisfactory implementation of MPEG-2 systems. |
| Complexity | The compression technique should be readily capable of implementation with adequate performance without adding undue complexity to the vehicle avionics.<br>See 3.5.10 | See Processing Power above. |

| | | |
|---|---|---|
| **Application:-** | | ***Uninhabited Aerial Vehicle*** |
| **Compression Standard:->** | | ***MPEG-2*** |
| **Requirement** | | |
| Maturity | The compression/decompression standard under consideration must not be so new that it might soon disappear due to lack of support, but not so old that support for it (especially in terms of available hardware and software) may soon cease.<br>See 3.5.11 | It should be possible to regard MPEG-2 as a mature standard with a high degree of support with (by digital video standards) a significant ongoing life expectancy. However, military avionic system lifetimes are measured in decades, contrasting markedly with the domestic market where product 'operational' lifetimes may be measured in a few years. However, given its very widespread acceptance MPEG-2 may be less likely to suffer from rapid obsolescence than some other video standards. |
| Cost | The cost of digital compression/decompression must be a very small fraction of the total avionic cost.<br>See 3.5.12 | The very wide spread use of MPEG-2 in domestic broadcasting strongly suggests that this requirement can be met. However, there will be additional costs associated with use of COTS hardware in a military avionic environment and these would be difficult to quantify in any generic way. |

| Application:- | | *Uninhabited Aerial Vehicle* |
|---|---|---|
| **Compression Standard:->** | | ***MPEG-2*** |
| **Requirement** | | |
| Hardware/software availability | Hardware and/or software required to implement the selected compression/decompression process must be readily available and ideally should remain so for a substantial period in order to avoid obsolescence problems.<br><br>See 3.5.13 | The very wide spread use of MPEG-2 in domestic broadcasting strongly suggests that this requirement can be met. However, there must be concerns about obsolescence. |
| Comments | | |

**Table 6: Application Requirements versus Characteristics of MPEG-2**

### 3.5.1 Image Format

Table 3 gives an indication of the variety of image formats identified during previous work (although these may not all be relevant to UAV applications) and Table 4 gives a summary of the image formats identified during the current study. From these it appears that there is unlikely to be a ‘typical UAV image format’. This view is borne out by the very wide range of UAV missions and sensors identified in this study.

However, MPEG-2 supports resolutions up to 16,383x16,383. ASSC report 130/6/2 (Ref. 1) includes a brief summary of a presentation given to the ASSC Video Subcommittee in February 2001 on the use of MPEG-2 to Compress UAV Gathered Enhanced Definition TV Video. The presentation suggested that future UAVs will gather enhanced-definition (ED) and high-definition (HD) colour TV video. EDTV video is defined as colour images of at least 720 by 480 pixels, progressively scanned at rates of 50Hz or greater. HDTV video is defined as colour images of 1280 by 720 pixels, progressively scanned at 24Hz or greater.

It was found that a data rate of 4Mbps gave reasonable image quality with a Group of Pictures[2] (GOP) size of 12 and almost acceptable picture quality at 2Mbps and a GOP size of 48 pictures. The uncompressed data rate is 497Mbps, these data rates represent compression factors of approximately 125 and 250 respectively. The picture type was found to effect the image quality.

Ref. 1 compared the image formats listed in Table 3 and found that all but No 32 in the table were capable of being processed in accordance with the requirements of MPEG-2. In summary, the above suggests that there is a reasonable probability of a significant number of UAV sensor image formats being capable of use with MPEG-2.

### 3.5.2 Frame Rate

As with image format it seems likely that there is a very wide range of frame rates in use in UAV applications. Ref. 1 compared the frame rates listed in Table 3 with those permitted for MPEG-2 and found that all but No. 32 in the table could be handled by an MPEG-2 system. However, the investigations carried out under the present task suggest that while the frame rates used for relatively small field of view real time systems may be appropriate for MPEG-2, systems such as the Global Hawk Integrated Sensor Suite (Ref. 14) covering very wide areas would not be suitable. For example the reference states that

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[2] Group of Pictures: a set or group of encoded frames representing part of a video sequence and starting with an I frame. Hence, generally speaking the smaller the GOP the more frequent the I frames, the lower the compression and the better the picture quality. (See also Ref. 1.)

in spotlight mode the sensor system captures 1900 2x2 km spot images per 24 hours, and this equates to 1.3 images per minute. This appears to be inappropriate for MPEG-2 where the minimum frame rate is 24 FPS.

### 3.5.3 Lossless and Lossy Compression

Only lossless compression can provide a guaranteed retrievable image quality (i.e. the same as before compression). Lossy compression inevitably results in loss of image quality, to an extent dependent on the compression process and the degree of compression.

MPEG-2 does not provide lossless compression, but does provide for various degrees of lossy compression and the effect on image quality is likely to depend both on the compression ratio and the image content and rate of change etc. Compression ratios achievable with MPEG-2 will depend greatly on subject matter, image quality requirements and configuration etc. Compression ratios are very application/implementation dependent, but it is considered likely that in most applications the maximum compression achievable would be (very approximately) in the order of 20:1.

The required image quality will vary widely with UAV applications and missions. High altitude wide area missions such as those undertaken using the Global Hawk Integrated Sensor Suite (see Ref. 14 and 3.3.1 above) will certainly require high image quality and may therefore require lossless compression. However, it appears that for this type of application very slow frame rates are currently tolerated; partly it has to be suspected as a result of requirements for high quality high resolution images.

True real time applications, possibly involving lower altitude operations with restricted fields of view, are likely to generate high uncompressed data rates necessitating lossy compression in order to bring the required data rate within the bandwidth currently available from tactical data links. Hence lossless compression is unlikely to be feasible in these types of application.

### 3.5.4 Latency

Like most other requirements under consideration those for latency will vary widely depending on the UAV type and mission etc. High altitude reconnaissance and surveillance systems like those targeted by the Global Hawk Integrated Sensor Suite are likely to be able to tolerant relatively long delays. At the other extreme systems using human pilots to control the flight of the UAV via a data link will require very low latency. Hence tolerable latency is likely to vary from 10’s ms to minutes depending on the application.

MPEG uses interframe coding and is thus subject to its limitations, in particular with regard to latency. Before encoding can commence an MPEG encoder must be presented with the first I frame and first P frame, from which to encode the intervening B frames. Hence latency is dependent on the make up of the MPEG-2 GOP. However, the MPEG-2 algorithm allows the encoder to choose the frequency and location of I-frames, and by implication the 'acquisition latency'. Furthermore MPEG-2 supports a Low Delay Mode in which no B frames are generated to eliminate frame reordering delay at the decoder, this is aimed at applications such as video conferencing, but might offer a solution to latency problems in some UAV applications.

Processing or 'pipeline' latency, the time taken to encode and decode the image stream, must be added to the 'acquisition latency' discussed above to give a total latency due to the encoding and decoding process. Processing latency will depend upon the performance of the encoder/decoder processor. Furthermore, for UAV applications the propagation delay in the UAV to ground data link adds to the overall latency and for systems using a satellite link this may be significant.

Ref. 7 suggests that the US Fire Scout programme may be first to use MPEG-2 in near real time and is "tweaking" the MPEG-2 standard in order to minimise latency to allow payload control from the ground. It is not clear just what "tweaking" consists of, but it may be speculated that this is more likely to mean careful selection and configuration of the options etc. permitted by the standard, rather than modifications to the standard.

### 3.5.5 Image Quality

The end user will be concerned only that the quality of the image he is presented with is adequate for operational purposes (e.g. permits the identification of potential targets). The quality of the image presented to the end user will depend on numerous factors including most importantly the performance of the sensor(s), image processing, display characteristics and the compression/decompression technique. The latter can only have an adverse effect on image quality. A well known example of the adverse effects on image quality is the classic 'blocking' effects seen with images that have been compressed using the discrete cosine transform algorithm that forms part of MPEG-2.

As with most of the requirements under review, that for image quality will be expected to vary markedly depending on the application. High altitude reconnaissance and surveillance systems like those targeted by the Global Hawk Integrated Sensor Suite will require high image quality to represent features forming a small part of a large picture. It is likely that true real time applications (especially those concerned with pilotage) will, perhaps of necessity, have to sacrifice image quality to achieve frame rates and latency required. The designer must endeavour to determine the degree of corruption of image quality that is acceptable for the particular application.

Ref. 32 reports on an investigation into the use of MPEG-2 to compress UAV gathered enhanced definition TV video. It was found that a data rate of 4Mbps gave 'reasonable image quality' with a GOP size of 12 and 'almost acceptable picture quality' at 2Mbps and a GOP size of 48 pictures. The uncompressed data rate is 497Mbps, these data rates represent compression factors of approximately 125 and 250 respectively. The picture content was found to effect the image quality.

The definition of image quality requirements for a particular application is likely to prove difficult and will need to take into account the principal objectives and purposes of the system under review. e.g. high altitude photo reconnaissance and real time pilotage will almost certainly have very different requirements for image quality.

Predicting the actual quality of the pictures produced by various implementations and configurations for various image subject matters may also prove difficult, particularly since in many cases it will be both scene and movement dependent.

On the evidence available it seems probable that MPEG-2 may permit adequate (or possibly the best that can readily be achieved) image quality for some real time applications, but is less likely to allow image quality of the standards required in high altitude reconnaissance and surveillance missions.

### 3.5.6 Data Rate Mbps

Data rate is constrained by the performance of the UAV to ground data link. As has been seen in 3.3.10 above this varies widely with the type of data link in use. However, it appears most likely that future systems will use TCDL discussed in 3.4.12 above. This provides a data bandwidth of 10.7Mbps and MPEG-2 is intended to operate at data rates ranging from 1.5 to 60Mbps. As already mentioned above, Ref. 32 found that a data rate of 4Mbps gave 'reasonable image quality' and at 2Mbps 'almost acceptable picture quality'. Hence it seems likely that MPEG-2 would provide an adequate performance over a TCDL data link for at least some applications. Indeed Refs. 21 - 24 show that MPEG-2 is already being used in conjunction with TCDL in two proprietary systems.

### 3.5.7 Error Resilience

MPEG-2 is widely, and successfully, used for digital TV broadcasting and this is consistent with good error resilience. However, it is probable that the electromagnetic environment in which UAV avionics are required to operate (including the data link) will be more severe than that in which broadcasting applications of MPEG-2 operate and may include deliberate interference from the enemy..

A high degree of integrity, probably in an onerous electromagnetic environment, is clearly essential for UAV imaging applications. Probably the two most important determining factors are the integrity of the data link and the error resilience of the compression/decompression technique.

Error Resilience may be defined as the ability of the coding system to limit the adverse effects of errors on image quality. This may be expressed in terms of Peak Signal to Noise Ratio (PSNR) v Bit Error Rate (BER). Hence to assess the error resilience of a coding technique in a given application it is first necessary to define the probable BER of the data link that conveys the coded image(s) in the application. This would entail definition of the data link used to convey the compressed video, plus an estimate of its BER in military avionic applications.

Ref. 32 gives an indication of the error resilience of MPEG-2. The effect of corrupting the compressed bitstream on the decompressed images was explored and it was found there was an approximate linear relationship between the mean square error and bit error rate, although this relationship was strongest for higher data rates. The acceptable bit error rate was found to be below $10^{-6}$ and to be data rate dependent. The outline specification for the L3 Communications and the Rockwell Collins TCDL Airborne Data Terminal products (Refs. 22, 23 and 25) gives the BER rate as $10^{-6}$ with COMSEC and $10^{-8}$ without COMSEC. Although the conditions under which these BERs are achieved are not stated, this suggests that TCDL and MPEG-2 may be compatible in terms of BER. This possibility is supported by the fact that both the above suppliers off MPEG-2 colour video compression as parts of their TCDL products.

A useful discussion of error detection and concealment for MPEG-2 may be found in Ref.33.

In summary, the requirements for error resilience will, to a significant extent, depend upon the performance of the data link used to transmit compressed video, and this may in turn depend on the environment in which the UAV operates. It seems probable that MPEG-2 will be able to provide adequate error resilience for at least some UAV applications.

### 3.5.8 Functionality

For present purposes functionality is defined as the provision of means by which the user may tailor the system to the specific needs of the application.

MPEG-2 includes a large number of options, enhancements and extensions, and therefore considerable scope for optimisation in order to meet the requirements of a particular application. Ref. 1 provides a summary of these options etc. In short there is a significant probability that MPEG-2, in terms of functionality at least, would cater for the requirements of a wide range of UAV applications.

### 3.5.9 Processing Power

The processing power required to implement a given compression/decompression technique is a difficult parameter to quantify and like most other issues may be the subject of a complex trade off with other requirements and parameters. Some techniques such as fractal compression require large volumes of computation and hence the processing power available is a critical determining factor for the speed with which compression/
decompression may be achieved.

However, it is likely that in most cases the most practical way of implementing MPEG-2 compression in a UAV would be by adopting a COTS hardware solution. Hence it is probably sufficient for the purposes of the present discussion to say that a wide range of MPEG-2 products is available offering adequate processing power for satisfactory implementation of MPEG-2 systems. However, environmental and obsolescence concerns clearly cannot be ignored.

### 3.5.10 Complexity

The comments above in regard to processing power may be paralleled with respect to complexity and again it is probably sufficient to point to the wide range of MPEG-2 hardware products is available.

### 3.5.11 Maturity

The requirement for maturity is taken to mean that the standard under consideration must not be so new that it might soon disappear due to lack of support, but not so old that support for it (especially in terms of available hardware and software) may soon cease.

MPEG-2 was issued in 1994 and is the standard now used in the majority of digital broadcast TV systems. In the longer term MPEG-2 is likely to give way to MPEG-4. However, it should be possible to regard MPEG-2 as a mature standard with a high degree of support with (by digital video standards) a significant ongoing life expectancy.

However, military avionics, where system lifetimes are measured in decades, contrasts markedly with the telecommunications/commercial/entertainment/domestic worlds which have spawned virtually all current digital video technology, and where product ‘operational’ lifetimes may be measured in a few years. Bridging the gap between these two worlds will be a difficult task, particularly since it is most unlikely that the military world will be able to exert any influence whatever upon the producers of modern digital video technology. However, given its very widespread acceptance MPEG-2 may be less likely to suffer from obsolescence than some other video standards.

3.5.12 Cost

A detailed survey of the cost of MPEG-2 products is beyond the scope of the present study, but it may reasonably be assumed that, given the widespread use of MPEG-2, products are available at costs that would be readily absorbed within the overall cost of most UAV programmes. One source puts the price of a typical UAV at $3M each.

3.5.13 Hardware/soft-ware availability

Hardware and/or software required to implement the selected compression/ decompression process must be readily available and ideally should remain so for a substantial period in order to avoid obsolescence problems.

As already indicated MPEG-2 products are very widely used in the domestic broadcasting industry and hence are readily available. MPEG-2 is asymmetrical. That is to say the encoding process requires about two orders more computing power than the decoding. Hence encoders are likely to be significantly more costly than decoders, although single chip encoders are now becoming available, thus considerably reducing cost.

However, the comments made above regarding obsolescence should be heeded. Furthermore, as with all COTS products used in military systems, environmental issues are also a major concern.

## 4 CONCLUSIONS

The study reported herein has sought to identify and define the issues effecting the potential application of the MPEG-2 digital video compression/decompression standard in UAV systems. In the course of the work a wide variety of UAV types and missions has been identified and briefly outlined together with the sensor systems used in UAVs.

Similarly a wide variety of tactical data links, some of which might be used to convey data between UAVs and surface systems has been identified and briefly outlined. The tactical common data link (TCDL) has been identified as that whose characteristics appear to most nearly meet the needs of conveying digital video compressed using MPEG –2.

The study failed to identify a ‘typical UAV requirement’ and it seems unlikely that such an entity exists. However, the parameters of various UAV sensor systems, particularly with regard to image format and frame rate, have been established either quantitatively or qualitatively to a sufficient degree to permit a comparison with the characteristics of MPEG-2 and the results of this comparison have been summarised.

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