MTR090082
MITRE TECHNICAL REPORT

MITRE

Unmanned Aircraft System (UAS) Exercise to Assess Common Data Link (CDL) Technology

Department of Defense Unmanned Systems Interoperability Profile and UAS Imagery and Data Dissemination Technologies

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Executive Summary

On Friday, 31 October 2008, a MITRE-led team that included MITRE and Mark Schon, Limited Liability Company (LLC) engineers, government and vendor personnel successfully exercised the Unmanned Systems Interoperability Profile (USIP) 1 in the field. Mark Schon, LLC in collaboration with Virginia Commonwealth University (VCU) provided the Unmanned Aircraft System (UAS) integration and flight services for the exercise. The exercise was conducted at Finnegan's Field in the military restricted airspace of the Fort A.P. Hill ranges near Bowling Green, Virginia.

Vendor participants in the exercise included Cubic Defense Applications (Cubic), the Mini-Common Data Link (CDL) provider; Cornet Technology, Inc (Cornet), the Moving Picture Experts Group (MPEG) – 2 and H.264 Video Encoder/Decoder provider; and Lead Technologies, a video Software Developers Kit (SDK) provider.

The exercise was observed by key Marine Corps personnel from Marine Corps Systems Command (MCSC), the Marine Corps Warfighting Lab (MCWL), the Marine Corps Intelligence Activity (MCIA) and Headquarters, Marine Corps (HQMC). Key Navy and Marine Corps personnel from Naval Air Systems Command (NAVAIR) were also on hand to observe. Fort A.P. Hill Range Operations and Aviation Operations personnel were on hand to observe the exercise, as well. Vendor participants, who generously provided support and equipment for the exercise, and their company representatives, also attended for a total of more than forty people observing the exercise.

In June 2008, USIP 1 was approved by the Office of the Under Secretary of Defense (OUSD) for Acquisition, Technology and Logistics (AT&L), the Assistant Secretary of Defense (ASD) for Networks and Information Integration (NII), and the Joint Services UAS representatives. USIP 1 pertains to the direct communication and receipt of data from the Air Vehicle (AV) to the Ground Control Station (GCS) or Remote Video Terminal (RVT) operating in the Ku Band. The operational context for this profile is the Transmission, Collection, Production, Exploitation and Dissemination (TCPED) chain of operational activities. Accordingly, the USIP 1 profile specifically mandates, defines and standardizes the implementation conventions required for interoperability of line of sight transmission of motion imagery for battle space awareness using the Standard Common Data Link (STD-CDL). USIP 1 accomplishes this using the following layers of the Open Systems Interconnection Model: (1) Physical, (2) Data Link, (3) Network, (4) Transport, and (7) Application.

Team activities leading up to the exercise involved the integration of multiple USIP 1-compliant components into the Outlaw AV and the ground systems. Two Outlaw Unmanned Aircraft (UA) were outfitted with the VCU Flight Control System (FCS) autopilot and flight tested in July 2008. During this period, the FCS was also configured to output twelve of the USIP 1 standard Key Length Value (KLV) metadata keys to be time synchronized with the analog video from the onboard digital camera. In August 2008, the video and the corresponding KLV metadata were fed to the MPEG-2 encoder to generate the MPEG-2 transport stream on the encoder's Ethernet output. In September 2008, the transport stream was provided to the Ethernet input on a commercial-off-the-shelf Microhard VIP 5800 digital data link for testing onboard one of the

Outlaws. This data link served as a backup and was used for flight testing until the Cubic Mini-CDL and Team Portable CDL (TP-CDL) equipment was made available. The Cubic Mini-CDL is a miniature STD-CDL transceiver that is compliant with the STD-CDL Specification (Revision F, Annex B).

On 17 October 2008, an encoded transport stream was provided to the Ethernet input on the Mini-CDL platform communications equipment (PCE) and flight tested on the Outlaw with the TP-CDL equipment serving as the surface communications equipment (SCE) on the ground. This flight was the first time the Department of Defense (DoD)-mandated USIP 1 was flown on any UAS with synchronized video and KLV metadata in the MPEG-2 transport stream over the Common Data Link (CDL) Ku band link at 10.71 megabits per second (Mbps).

MITRE engineers simultaneously developed applications to parse the metadata from the transport stream and generate Cursor-on-Target (CoT) messages, thus providing a "glass-to-glass," sensor to Command and Control (C2) system implementation of the USIP 1 profile. The CoT schema was used to provide the metadata to the standard Marine Corps Joint Tactical Common Operational Picture (COP) Workstation (JTCW), FalconView and Google Earth 3-D displays. The video, metadata, and CoT messages were multicast on the Local Area Network (LAN) and displayed on multiple LAN clients.

For the final exercise on 31 October 2008, a total of three Outlaw flights were flown. The Outlaws were launched from the test site, flown at altitudes up to 4,000 feet above ground level (AGL), while successfully down-linking video and KLV metadata to various ground systems through an extended Internet Protocol (IP)-based LAN. Although the GCS client was able to control/update the FCS server and payload configuration over the Ku band extension of the IP-based LAN, a separate 900 Megahertz (MHz) UA control and status link was used to send commands and to receive status updates from the FCS. The primary focus of the USIP 1 implementation was to transport the video and associated metadata from the UA using IP over the Ku band CDL link to the TP-CDL terminals.

The early preparations through the final exercise of the USIP 1 in operation on the Outlaw, with TP-CDL and the Combat Operations Center (COC) C2 systems receiving the video and KLV metadata for display, was completed in only four months time. The Outlaw UAs were made autonomous; USIP 1 protocols were implemented in the FCS; data link and payload equipment integrated and flight tested; and the exercise successfully conducted in record time while achieving the three goals and supporting objectives set in late spring of 2008. The resulting success of this MITRE Special Initiative is indicative of the kinds of achievements possible through innovative and challenging endeavors undertaken in close collaboration with our team partners.

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1 Introduction

This report describes the work performed and the results obtained from an Unmanned Aircraft System (UAS) Exercise conducted by The MITRE Corporation and Mark Schon, Limited Liability Company (LLC). The project was conducted to implement and investigate the state-of-the-art in miniature Common Data Link (CDL) terminal technology for digital video downlink from an operational UAS. The Department of Defense (DoD) – mandated Unmanned Systems Interoperability Profile (USIP) 1 for streaming UAS metadata with associated video was also implemented and investigated.

1.1 Goals and Objectives

The project had three high-level goals:

- Investigate the current state-of-the-art in miniature CDL transceivers for Category 3 (Tier II/Small Tactical UAS) unmanned aircraft (UA) data link terminals. This includes link robustness and speed, range and power tradeoffs, interoperability between different manufacturer's miniature CDL transceivers, and ease of integration of miniature CDL equipment into existing UAS systems.
- Evaluate the maturity and effectiveness of the DoD-mandated USIP 1 Implementation Convention designed and published in June 2008 to insure cross-platform interoperability of Full-Motion Video (FMV) and metadata.
- Gain experience with the integration of back-end systems for UAS imagery and data dissemination.

The objectives in support of the goals were:

- Integrate miniature and other CDL transceivers from multiple vendors into an existing surrogate UAS system with Electro-Optical (EO) sensor capability.
- Provide USIP 1 – compliant video and metadata to the CDL link.
- Receive, decode and display the UAS data and imagery on a Team Portable CDL (TP-CDL) ground terminal.
- Provide the UAS imagery and metadata to ground Command and Control (C2) systems for immediate situational awareness (SA) and video services over a Local Area Network (LAN).

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2 Exercise Systems and Architecture

The hardware required for this project included a suitable UAS aircraft to carry the digital video and CDL equipment aloft; a Flight Control System (FCS) to make the aircraft autonomous and provide metadata for the video downlink exercise; a digital video system and a CDL; TP-CDL to receive, display and disseminate the down-linked video; and metadata and a Ground Control Station (GCS), operating at 900 Megahertz (MHz), to control and monitor the Outlaw during the exercise. The overall architecture of the system is shown in Figure 1.

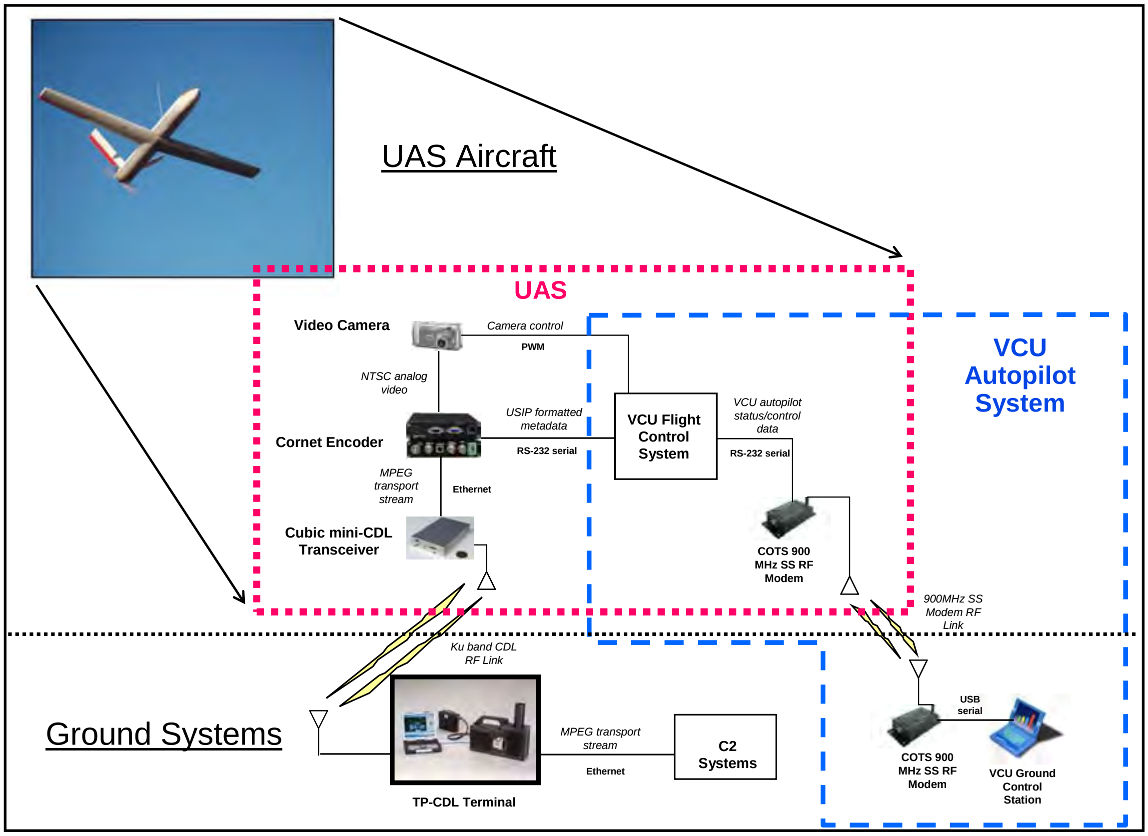
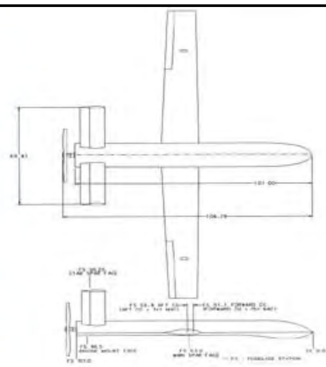


Figure 1 CDL Exercise System Architecture

2.1 UAS Aircraft

The Unmanned Aircraft (UA) used for this exercise is the Outlaw Remotely Piloted Vehicle Target (RPVT) manufactured by Griffon Aerospace. The Outlaw, shown in Figure 2, has a 9 foot fuselage and a 13.6 foot wingspan. It is powered by a 17 horsepower (HP) gasoline engine mounted in the tail. As normally equipped, the Outlaw does not have landing gear. Instead, it is pneumatically launched from a rail launcher and it skids to a landing on its belly. That latter aspect of the Outlaw caused a few difficulties in this exercise and is described later.



- Wingspan: 13.6 feet
- Length: 9.0 feet
- Weight: 85 lbs empty
  120 lbs max.
  97 lbs as equipped
- Engine: DA-150 (17 hp)
- Propellor: Xoar 28 x 14
- Fuel: Gas/oil mix (2 gal. - approx. 7.5 gal.)
- Endurance: 3-4 hours max.
  45 minutes as equipped
- Speed: 110 knots max. – 40 knots min.
- Electrical Power: 3.7 Ah, 18 V NiMH batteries (payload)
  3.0 Ah, 7.2 V NiCD dual-redundant batteries (RC system)
  1.7 Ah, 12 V NiCD batteries (FCS)

Figure 2 CDL Griffon Aerospace Outlaw UA

Compared to other similar-sized UAs, the Outlaw is fast and maneuverable. These characteristics are desirable in a target vehicle; however, one of the tradeoffs of this design is a limited payload. The Outlaw UA weighed approximately 84 pounds (lbs) for this exercise. The nominal video payload, flight control system, and batteries brought the empty weight up to 87 lbs. When fueled for a one hour flight, the Outlaw weighed approximately 97 lbs. The rated maximum takeoff weight is 120 lbs. Thus the Outlaw, in spite of its size, had a useful payload capacity of approximately 25 lbs. The manufacturer originally delivered the Outlaw with a fixed landing gear that allowed normal soft-field landings without skidding on the belly – although the aircraft still needed to be rail-launched for unimproved field operations. However, the performance of the aircraft with the landing gear in place was so degraded during hot, humid days that, in the interest of safety to the aircraft, the landing gear were removed early in the flight testing.

The Outlaw, as produced by Griffon Aerospace, is not an autonomous vehicle. It is equipped to operate manually (similar to a model Radio Control [RC] aircraft) using a Commercial-off-the-Shelf (COTS) RC controller. The RC controller provides six channels of proportional control and operates using a frequency-hopping spread-spectrum transmission mechanism on the 2.4 gigahertz (GHz) Industrial, Scientific and Medical (ISM) band.

2.2 Flight Control System

The addition of an FCS to the Outlaw was required for the exercise. The FCS is needed to make the aircraft fly autonomously. While manual flying for an exercise like this is possible, it is very tedious for the controller/pilot, especially for an extended period of time and at the extended range and altitudes flown. It is also nearly impossible for a pilot to manually fly a repeatable pattern and maintain a stable altitude, which are optimal for testing antenna or payload effectiveness. In addition, an FCS is required to provide the metadata necessary to implement the USIP 1-compliant transport stream that includes both video and metadata.

2.2.1 Aircraft Control

The FCS architecture implemented on the Outlaw is shown in Figure 3. This FCS has been under development at the Virginia Commonwealth University (VCU) since 2003.[1]

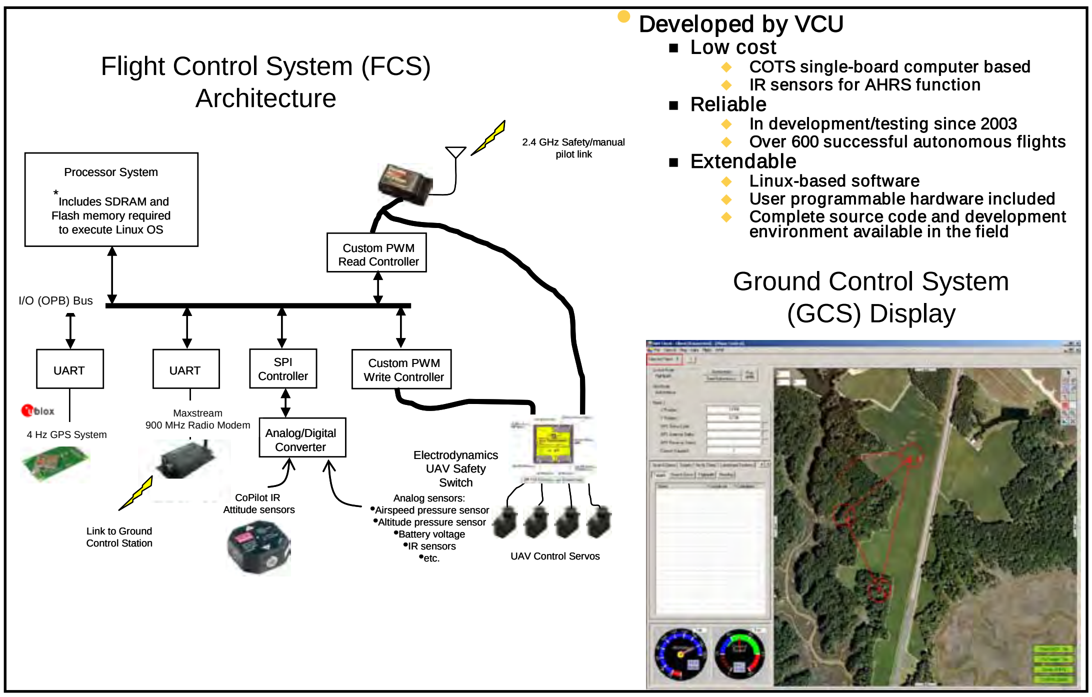


Figure 3 Flight Control System Architecture

The FCS is based on a commercial single board computer called the Suzaku. The Suzaku includes a Field Programmable Gate Array (FPGA) device that allows the user to design and implement custom digital hardware. Inside this FPGA is a 32-bit microcontroller called a Microblaze. The Microblaze on the Suzaku runs a version of the Linux operating system called uCLinux.

[1] Klenke, R. H., J. C. McBride, H. C. Nguyen, "A Reconfigurable, Linux-based, Flight Control System for Small UAs," Proceedings of the AIAA Infotech@Aerospace Workshop, Conference and Exhibit, May 2007

The Microblaze receives navigation information at 4 Hz from a Ublox Global Positioning Service (GPS) receiver. The navigation information includes position, in the form of Latitude, Longitude, and Altitude (LLA), and velocity, in the form of East, North, and Up (ENU) speeds. This information is used to control the aircraft and navigate it to the specified waypoints in the desired flight path.

Aircraft state information, including attitude (pitch, roll, and yaw), airspeed, and barometric altitude are provided to the Microblaze through Analog to Digital Converters (ADCs). The sensors for altitude and airspeed are standard pressure transducers used in most commercial, small UA autopilots. The sensors for aircraft attitude are somewhat unique for this application. Most commercial autopilots use a multitude of sensors such as rate gyros, angular accelerometers, and magnetometers to generate an attitude solution. However, this method, unless implemented carefully, can result in an attitude solution that can be "tumbled" by maneuvers of the aircraft often ending with disastrous results. In most cases this tumbling, or failure of the instrument to indicate the correct aircraft attitude, is caused by some aspect of the aircraft's motion, such as angular rates or linear accelerations, going over that which the instrument can handle. This is a significant consideration with the Outlaw as it undergoes a longitudinal acceleration of over 12 G's when pneumatically launched – which can tumble even the most robust attitude systems.

The FCS attitude solution was provided by Infrared (IR) sensors. The IR sensors sense the difference between the earth (warm) and the sky/space (cold) to determine the position of the horizon. This method of measuring pitch and roll is more robust, albeit somewhat less precise, than a gyro/accelerometer/magnetometer-based attitude solution. The Outlaw yaw or heading is derived from the velocity measurements provided by the GPS system and the determination that, in most cases, a fixed wing aircraft is generally pointed in the direction that it is traveling.

The FCS can communicate with a ground operator through a 900 MHz bi-directional data link. The operator views the state of the vehicle and communicates commands to the FCS through a GCS. The GCS, also developed by VCU, allows the operator to change the UAs altitude or airspeed. The flight path can be changed by providing a new sequence of waypoints to follow. The operator can also monitor the performance of the vehicle and the FCS through the GCS displays. These displays include an altitude, attitude, and airspeed indication, as well as a moving map display that shows the vehicle's position and track over the ground and the current desired flight path determined by the waypoint sequence.

Finally, the FCS can monitor the aircraft commands from the ground-based safety pilot and provide commands to the aircraft's control surfaces through custom designed Pulse-Width Modulation (PWM) interfaces. These interfaces, implemented in the FPGA along with the Microblaze, allow the FCS to read the safety pilot's PWM commands from the RC receiver, including the command signal that allows it to take over aircraft control from the ground-based safety pilot. The interfaces also allow the Microblaze to generate the necessary PWM signals to control the aircraft surfaces when in autonomous mode.

A COTS UA "safety switch" is used to select the command mode to the Outlaw's surface actuators. This switch, manufactured by Electrodynamics, Inc., uses one input from the ground safety pilot receiver to switch command of the surface actuators between the remaining channels in the ground safety pilot receiver and the FCS. Thus, the ground-based safety pilot must "relinquish" control of the aircraft to the FCS for autonomous control and can take back command of the aircraft from the FCS at any time. This capability is needed as a safety feature to allow the ground-based safety pilot to steer the aircraft away from personnel and vehicles or to prevent a "fly-away" in the event of an FCS failure.

2.2.2 Metadata Generation

In addition to controlling the aircraft, the FCS is responsible for generating properly formatted metadata for inclusion in the Moving Picture Experts Group (MPEG)-2 transport stream (TS) transmitted to the ground. The metadata is transmitted using the USIP 1 format.[2] The USIP 1 implementation convention uses the Standard-CDL (STD-CDL) waveform and includes standards for video compression, metadata format, and TS generation. For this exercise, the metadata was formatted in compliance with the Motion Imagery Standards Board (MISB) Engineering Guideline (EG) 0601.1, UAS Data link Local Metadata Set standard.[3] EG0601.1 is a Key-Length-Value (KLV) metadata specification. It specifies an initial byte code (the key), which identifies the type of data to follow, the length (in bytes) of the data to follow, and then the bytes of the actual data. All of the KLVs outlined in the EG0601.1 standard need not be present in every implementation to be compliant with the standard. The subset of KLVs selected for implementation in this exercise is listed in Table 1.

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[2] US DOD Unmanned Systems Interoperability Profile (USIP) 1, 04 June 2008
[3] MISB Engineering Guideline EG 0601.1, UAS Data link Local Metadata Set, 13 December, 2007

Table 1 USIP 1 Metadata KLVs Provided by the FCS

Information	Key Value (hex)	Length (hex)	Decoding	Example value
Checksum	01	02	Lower 16-bits of summation. Performed on entire LDS packet, including 16-byte UDS key and 1-byte checksum length.	
Unix Time Stamp	02	08	Microseconds elapsed since midnight, January 1, 1970	
Mission ID	03	var	Null terminated string, maximum length is 127 bytes	4a 49 50 2f 55 41 53 20 44 65 6d 6f 00 = "JIP/UAS Demo"
Platform Tail Number	04	var	Null terminated string, maximum length is 127 bytes	53 31 00 = "S1"
Platform Heading Angle	05	02	Map unsigned integer, 0..(2^16-1) to 0..360°	CC 15 = 286.99°
Platform Pitch Angle	06	02	Map signed integer, -(2^15-1)..(2^15-1) to +/-20°	0b d8 = 1.851°
Platform Roll Angle	07	02	Map signed integer, -(2^15-1)..(2^15-1) to +/-50°	0d 0a = 5.094°
Platform True Airspeed	08	01	0..255 meters/sec	1e = 30 m/s
Sensor Latitude	0d	04	Map signed integer, -(2^31-1)..(2^31-1) to +/-90	36 2e 0b 00 = 38.095211
Sensor Longitude	0e	04	Map signed integer, -(2^31-1)..(2^31-1) to +/-180	c9 0e 2a 00 = -77.265945°
Sensor Altitude	0f	02	Map unsigned integer, 0..(2^16-1) to -900m..19000m	0b 8f = -1.4862m below MSL
Platform Ground Speed	38	01	0..255 meters/sec	1e = 30 m/s

Because of the hardware and software architecture used by the FCS, it was relatively simple to add a serial port and the software required to generate accurate metadata in the EG0601.1 format.

2.3 Digital Video System

The digital video system for the exercise was designed to meet specific requirements without being overly complex and expensive. The system was not intended to obtain actual actionable intelligence, just simulate the data requirements of such a system and have the necessary resolution to allow evaluation of the quality of the overall video delivered to the ground. The requirements included a system that supported a minimum 720 X 480 full D1 resolution, 30 frames per second, and had some type of optical zoom that could be externally controlled. The latter requirement was necessary to obtain useable pictures of the ground from an altitude of 4000 feet. For this exercise, an externally controlled pan and tilt camera/gimble was not needed.

The video system consists of the camera, which outputs National Television System Committee (NTSC) analog video, an MPEG-2 encoder provided by Cornet Technologies, Inc., and the Cubic Defense Applications (Cubic) Mini-CDL downlink transceiver in the aircraft. On the ground, the TP-CDL transceiver serves as the Radio Frequency (RF) link to the aircraft for the video downlink. The complete video system, as mounted in the Outlaw aircraft, is shown in Figure 4.

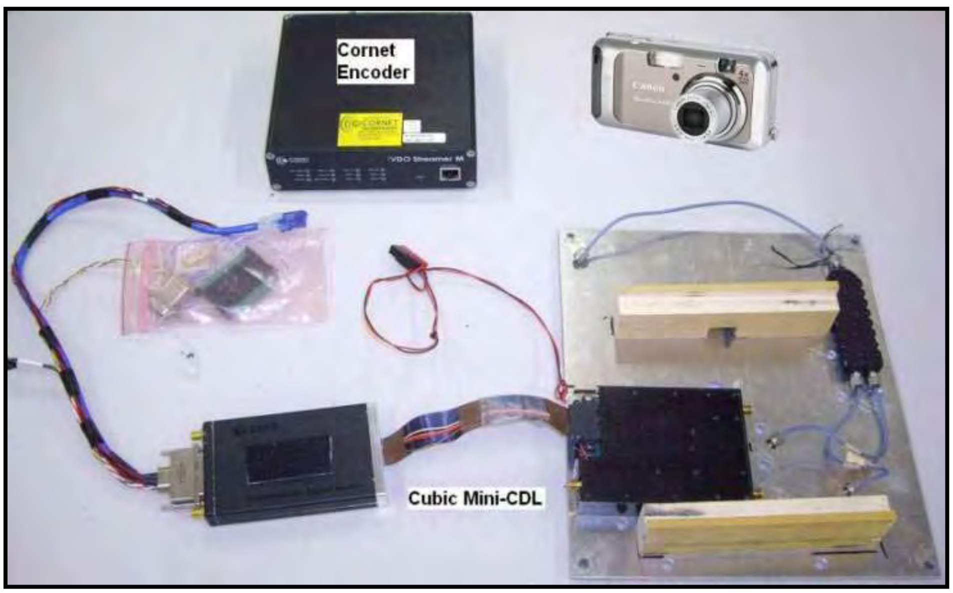

Figure 4 Digital Video Equipment Mounted in the Outlaw

2.3.1 Camera

The camera installed in the UA was a Cannon PowerShot A460 Digital Camera. The A460 is a 5 mega pixel digital camera with a built-in optical zoom. The zoom lens has a focal length equivalent to 38 - 152mm in 35mm format. In addition, there is a 4X digital zoom. The camera was modified for this exercise to allow the optical zoom and still picture capture functions to be controlled from the ground via commands to the FCS. To do this, the firmware in the camera was replaced with a modified version (available on the web) that reads commands into the camera from PWM signals input to the power connection on the camera's Universal Serial Bus

(USB) port. The FCS was modified (both in hardware and software) to receive commands from the GCS, such as “zoom in,” or “zoom out,” and translate them to the appropriate PWM signals on a USB output connector. In addition, the camera could also be shut down upon command from the ground. This was done at the end of each flight so that the camera’s lens would be retracted into the case for landing, thus reducing the chance that the camera would be damaged during the Outlaw’s skid landing.

The A460 can be setup in a mode where it outputs the picture in the viewfinder, which normally appears on the built-in Liquid Crystal Display (LCD) screen, as 720 X 480 resolution NTSC color video. This NTSC video stream is then fed into a digital video encoder before moving to the Mini-CDL.

2.3.2 Video Encoder

Obtaining an MPEG-2 encoder with the ability to combine both video and metadata into a transport stream was one of the more challenging tasks. Three vendors were identified as having products suitable for use with the Level 2, USIP 1: Cubic, Delta Digital Video, and L-3 Communications. These vendors had demonstrated some success with MPEG-2 transport stream encoding and decoding but were unable to support our exercise at the time the encoding/decoding equipment was needed.

Fortunately, Cornet Technology, Inc (Cornet) was able to develop an MPEG-2 encoder in time to meet our demanding schedule. When Cornet was first contacted, their product line did not include an MPEG-2 encoder capable of metadata ingestion; however, they were developing a beta version H.264 (MPEG-4) encoder with this capability. Cornet was able to immediately provide this encoder, as well as a hardware decoder, for testing. Although the Joint Interoperability Profile (JIP) calls for MPEG-2 encoding rather than H.264, the technologies are similar, and the USIP 1 which expands on the JIP, calls for both MPEG-2 and H.264 capability. Availability of the H.264 equipment from Cornet allowed the team to move forward with field testing while waiting for development of the MPEG-2 capability.

Concurrently, Cornet developed the metadata ingestion capability for their MPEG-2 iVDO Streamer M encoder. The initial implementation of this capability required some modification to handle the Packetized Elementary Stream (PES) format. PES packets, which are variable length, were initially forced into fixed–length packets and any remaining bytes were filled with 0xFF. This worked well with the Cornet-provided hardware decoder, but did not work as well with third party decoders. Cornet subsequently provided a revision of the iVDO encoder firmware that implemented a modified algorithm and enabled the metadata to be successfully decoded by third party decoders. Cornet also introduced new encoder firmware to enable the modification of Packet Identification (PID) for the elementary streams. The encoder firmware provided a capability to set the PIDs for both the video and metadata elementary streams to ensure compatibility with third party decoders looking for streams on specific PIDs.

2.3.3 Mini-CDL and TP-CDL

The actual CDL RF link was implemented using a developmental Mini-CDL unit provided by Cubic. The Cubic Mini-CDL was developed under an Air Force Research Laboratory (AFRL) contract designed to spur development of STD-CDL compliant terminals for smaller size tactical UAS. The Mini-CDL is compliant with the STD-CDL Specification (Revision F-1, Annex B).

Configuration settings for the Mini-CDL are provided in Table 2.

Table 2 Mini-CDL and TP-CDL Configuration Settings

Parameter	Setting
Forward Link Frequency	15250 MHz
Return Link Frequency	14615 MHz
Forward Link Waveform	BR-0.2
Return Link Waveform	BR-10.71B
Executive Function Handshake	IDL
P/N Code	A6
Data Processing	Annex B (Ethernet/Generic Framing Procedure)
COMSEC	N/A
Video Encoder/Decoder Multi-cast Address	239.192.168.1
Video Encoder/Decoder User Datagram Protocol (UDP) Port	16400
USIP Metadata Fields Displayed	Automatically decoded- Mission ID, Vehicle Location (latitude, longitude and altitude) and Tail ID.

The CDL transceiver was installed in the Outlaw on the same mounting plate as the Cornet decoder. The aluminum plate also served as a heat sink for the CDL transceiver. During ground testing, it was found that this plate became quite warm in a fairly short period of time, so an air scoop to draw in cooling air in flight was fabricated on the side of the Outlaw just forward of the equipment mounting plate. Several holes were cut into the hatch cover of the equipment bay to allow the hot air to exit the compartment. No problems with equipment overheating occurred during the flight testing or exercise.

Cubic provided the CDL antenna, which was a ¼ wave dipole with an integral ground plane. For optimum performance, the antenna needed to be mounted on the bottom of the aircraft. However, this presented somewhat of a problem for the belly-landed Outlaw aircraft. To solve this problem, a raised skid was fabricated on the bottom of the Outlaw just forward of the antenna mounting area. This skid was approximately 1-1/2" higher than the antenna and was protected by replaceable aluminum scuff plates. This proved more than adequate to prevent any damage to the antenna during normal landings. The mounting of the antenna and the skid on the bottom of the aircraft is shown in Figure 5.

Figure 5 CDL Antenna Mounting and Landing Skid

The CDL transmissions were received on the ground by the Cubic-developed TP-CDL transceiver. The TP-CDL was provided by the Marine Corps Systems Command's TP-CDL Project Officer. The TP-CDL relayed the video transport stream onto a local network. The address of the transport stream was set to "broadcast," so any address on the LAN could receive the stream. A local client program, running on the laptop used to control the TP-CDL transceiver, was used to display the video for the TP-CDL operators. This program was developed by the Cubic engineers and is an extended version of the VCD software viewer that includes the capability to de-multiplex, decode, and display the metadata in an MPEG-2 transport stream. A screenshot from one of the test flights is shown in Figure 6.

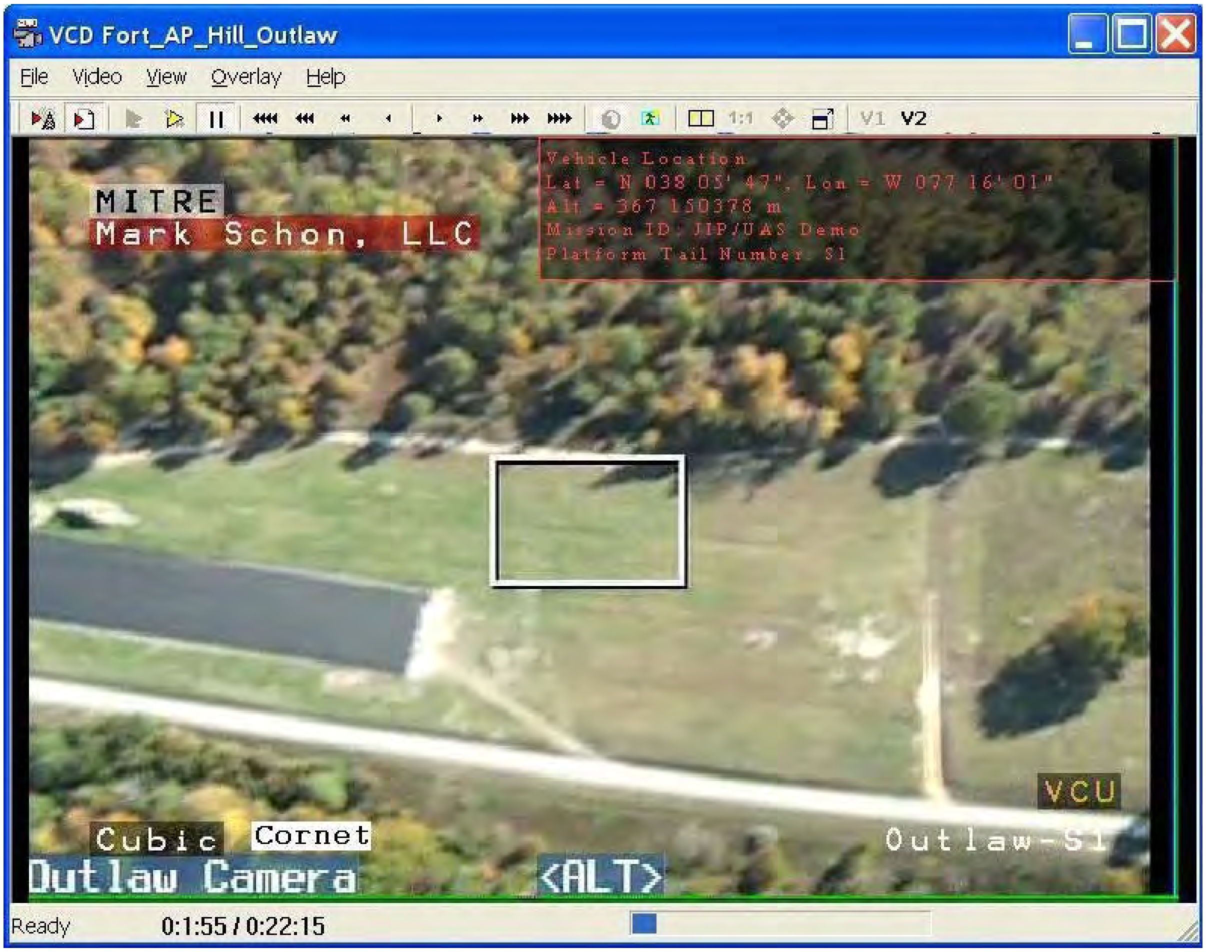

Figure 6 Digital Video Stream Ground Display – with Metadata

2.4 Ground Systems

The Joint Tactical Common Operational Picture (COP) Workstation (JTCW) and VideoScout® ground systems used in the exercise represented the C2 situational awareness (SA) and Intelligence, Surveillance and Reconnaissance (ISR) visualization systems designed for battalion Combat Operation Centers (COCs) and Company–level Fires Support Teams. The exercise involved integrating these systems with the STD-CDL transceiver and USIP-formatted data stream to present the video and metadata in real-time.

2.4.1 C2 Ground Systems Architecture

The C2 ground systems architecture as shown in Figure 7 included multiple networked components to facilitate communication and data dissemination. The TP-CDL and a "controller" laptop comprised the ground receive station. The TP-CDL receives the data stream from the aircraft and multi-casts it on the network as a UDP stream. Using this multi-cast configuration, any number of devices can connect to the network and receive the data stream. For the exercise, C2 applications and data conversion software were hosted on two laptops. A desktop Personal Computer (PC) was used to host the VideoScout® system.

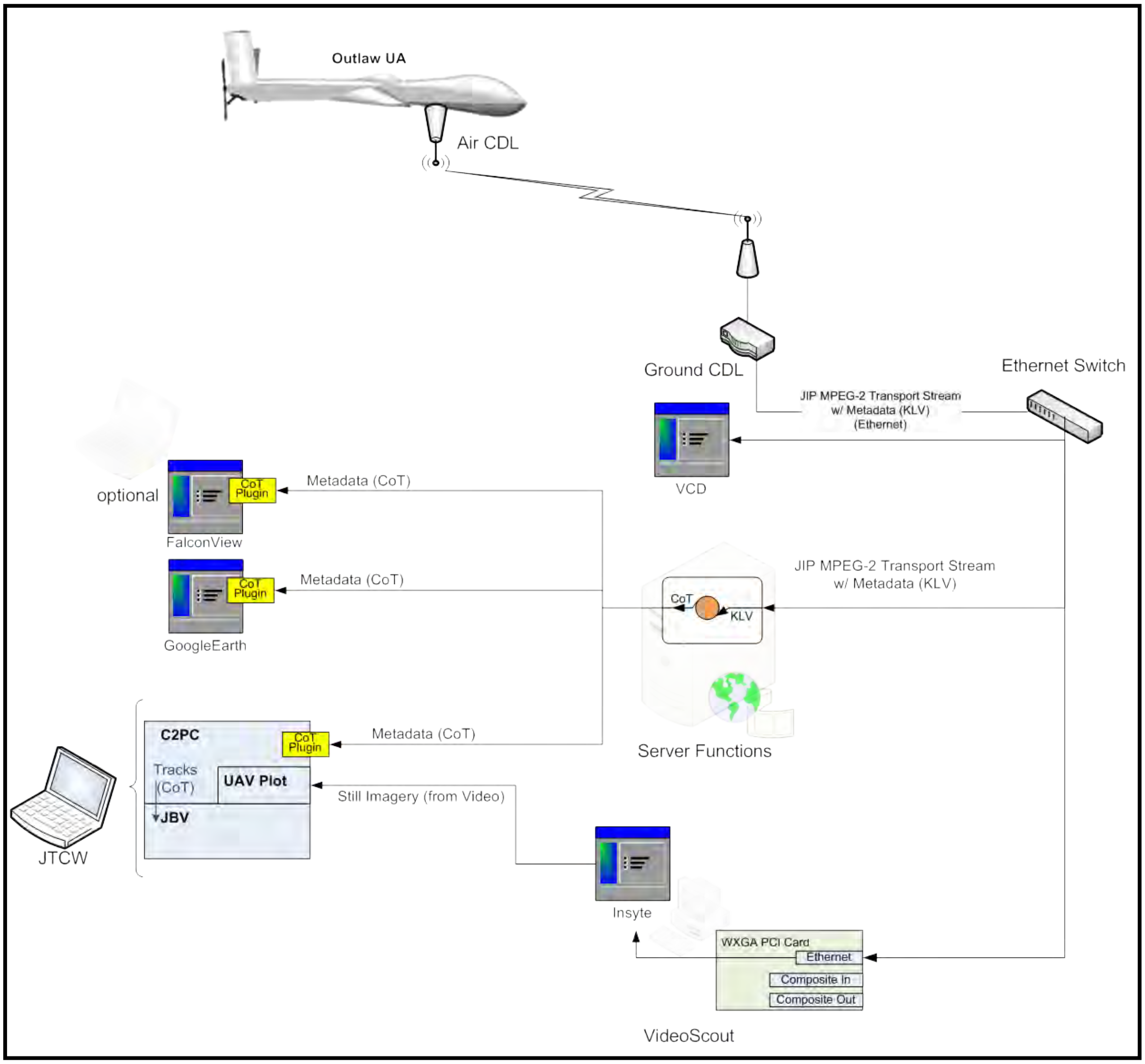

Figure 7 Ground Systems Network

2.4.2 C2 and Video Exploitation Systems

The software applications used in this exercise were divided into two main categories: C2 software and video exploitation software. The video exploitation applications are more than simple video players/viewers. These applications provide video clipping and still frame capture, Digital Video Recorder (DVR) functions, and display textual information contained in video metadata. A summary of the C2 and video exploitation applications evaluated in the exercise is provided in Table 3.

Table 3 C2 and Video Exploitation Applications

Software	Version	Capability
Command and Control PC (C2PC)	6.1.1 P4	Mapping
Joint Battlespace Viewer (JBV)	6.1.1	Mapping (3D) w/ Video Overlay
FalconView	3.3.1	Mapping
Google Earth	4.3.7284.3916	Mapping (3D)
VideoScout® Insyte	3.3	Video Exploitation/Server
PAR® GV™	3.0 Build 945A	Video Exploitation
VCD	beta	Video Exploitation

2.4.2.1 C2 Applications

The JTCW version 1.0 is a Windows XP – based suite of applications designed for battalion and above to facilitate military C2 functions by improving SA and enhancing operational and tactical decision-making. JTCW includes multiple COTS (e.g. Microsoft Office) and Government-off-the-Shelf (GOTS) [e.g. C2 Personal Computer (C2PC)] software applications, and application extensions that provide additional functionality. Hardware meeting the target system specifications for a complete software load of JTCW was not available at the time of the exercise, so specific C2 applications were selected and used. These were C2PC and Joint Battlespace Viewer (JBV). In addition, the Cursor-on-Target (CoT) injector application extension for C2PC was installed.

The JBV is a 3-D visualization program that provides the user with a whole earth representation on a PC. It provides visualization capabilities similar to those offered with C2PC, such as the display of map and terrain data, tracks and overlays in a 3-D environment. JBV also provides video exploitation capabilities, such as the ability to display geo-rectified video overlaid on a map; however, JBV is not capable of interpreting the USIP EG0601.x format metadata. The JBV User Manual for version 6.6 states, "Currently, only video data streams which conform to Motion Imagery Standards Board (MISB) Engineering Guideline (MISB EG) 0104.4 and Predator Closed Caption Electronic Software Distribution (ESD) System have been tested."

While the primary focus of the exercise was to interface with JTCW applications, integrating other software tools (e.g., FalconView and Google Earth) was a fairly easy task because of simple CoT provided tools, such as the CoT FalconView Driver and the CoT Keyhole Markup Language (KML) Server (Beta).

2.4.2.2 Video Exploitation Applications

PAR® GV™ supports nearly all of the DoD formats for still and motion imagery. Its ability to parse KLV metadata was of particular interest. PAR® GV™ also provides an Application Programming Interface (API) so developers can create plug-ins to access the KLV metadata (e.g., a MITRE CoT tool described in Section 2.4.3 uses the API to generate CoT messages from video metadata).

VideoScout® Insyte is developed by L3 Communications, Inc. One important note about Insyte is that the DVR functions are only available when the software is on a system that contains the VideoScout® hardware. VCD is a video viewer developed by Cubic to accompany the TP-CDL. It is able to display a small subset of EG0601.x metadata keys.

The primary challenge faced with the ground systems was the integration of the C2 and video exploitation systems with video containing metadata in the newer EG0601.1 format. CoT was identified early in the planning stages as key to system interoperability. Also of consideration was the fact that while the video exploitation systems could playback the USIP video, they could not make use of various capabilities that required metadata, such as Insyte's geographic search capability.

2.4.3 Video and Metadata Processing

One approach for integrating the USIP-compliant video data with the C2 applications was to convert the video metadata from the EG0601.1 format to the older EG0104.5 format. The C2 and ISR applications were capable of exploiting video with EG0104.5 formatted metadata, either through native capabilities or through additional plug-ins and tools.

Collaboration with MITRE CoT engineers revealed that they had developed a method for generating CoT messages from metadata in MPEG-2 video. The method uses PAR® GV™ and its API that exposes KLV metadata. MITRE developed a prototype plug-in that uses the GV API to access the metadata, convert it to a CoT message, and publish the message via a UDP or Transmission Control Protocol (TCP) port. MITRE engineers had verified that this method worked for EG0104.5 metadata, but not for EG0601.1 because they did not have any videos containing EG0601.1 metadata. (The prototype was developed in 2007, prior to MISB posting sample videos with EG0601.1 metadata.) The exercise verified that while this method could be used for EG0601.1, it would require software changes to PAR® GV™ and the MITRE plug-in.

Concurrent with the exploration of the MITRE CoT approach, the team identified a Software Developers Kit (SDK)/Toolkit from LEAD Technology called LEADTools. The LEADTools suite provides functions and interfaces to process imagery: Coders/Decoders (CODECs), multiplexers, filters, etc. At that time, the software supported parsing and manipulation of KLV metadata, including specific tags for the EG0104.x metadata format.

The lack of support for the new metadata format led to the team's decision to integrate the systems by converting the EG0601.x metadata to EG0104.x to create an MPEG-2 transport stream compliant with the older standard. The EG0601.x document provides instructions on how to convert the data for each individual key; however, in order to be utilized by current C2 applications, the entire MPEG-2 transport stream has to be converted.

Five major functions of the converter were identified: de-multiplex KLV Private Data Stream (PDS) from transport stream, parse KLV, convert keys, construct EG0401.x PDS, and multiplex PDS with MPEG-2 video stream. Using the LEADTools SDK, the team developed software to accomplish the first four functions; however, the team also determined that the functions available in LEADTools could not multiplex the streams into the required MPEG-2 transport stream (this was verified with LEADTools developers). Additional custom software would have to be developed to multiplex the PDS and video streams. However, time constraints dictated an alternative, stopgap solution to create CoT messages directly from the parsed EG0601.x metadata.

Only a subset of the EG0601.1 keys was used in the CoT message. A sample CoT message is shown in Figure 8. The conversion from EG0601 metadata to CoT was done in accordance with MISB EG 0805 - CoT Conversions for KLV Metadata[4] (a draft EG at the time of development). The complete set of EG0601.1 CoT keys is provided in Table 5 at Appendix A.

```
<?xml version="2.0" standalone="yes" ?>
<event
        access="US+FOUO"
        how="m-g-d"
        opex="e-MITREJIP"
        time ="2008-10-
31T23:52:45.41Z"
        start="2008-10-
31T23:52:45.41Z"
        stale="2008-10-
31T23:53:45.41Z"
        type="a-s-A-M-F-A"
        uid=" JIP/UAS Demo_Outlaw.010"
        version="2.0">
        <point
                        ce="9999999"
                        hae="514.3"
                        lat="42.4252514"
                        le="9999999"
                        lon="-
71.1870502" />
</event>
```

Figure 8 Example CoT Message

As a parallel effort, the LEAD Technologies team developed software to parse and display EG0601.x metadata. LEAD Technologies also began developing a multiplexing capability with an end goal of parsing, converting, and multiplexing metadata from an MPEG-2 transport stream with EG0601.x metadata to an MPEG-2 transport stream with EG0104.x metadata.

There are video systems that are EG0601 capable, but these are mainly found at the battalion and above. These systems include Global C2 System-I3 (GCCS-I3), Primary Image Capture Transformation Element (PICTE) from Science Applications International Corporation (SAIC),

[4] MISB Engineering Guideline EG 0805, Cursor on Target (CoT) Conversions for Key-Length-Value (KLV) Metadata, 16 December 2008

Multimedia Analysis and Archive System (MAAS) from General Dynamics, and Image Product Library (IPL) from National Geospatial-Intelligence Agency (NGA).

3 Exercise Test Plan

A test plan was developed for component testing, integration, and final flight testing, exercise and demonstration. A risk reduction plan that included backup subsystems and systems was implemented. It required the team to approach and gain the cooperation and material assistance of vendors who were working on prototype mini-CDL transceivers (air vehicle) efforts, and to leverage existing government development programs for ground CDL terminals to build the required end-to-end interoperability solution. Several CDL vendors were contacted and offered the opportunity to participate in the exercise, but few were willing to support the effort required.

The test plan included the requirement to have at least one Mini-CDL vendor with an MPEG-2 encoder/decoder to allow us to get started by late June 2008. As a backup, other vendors were asked to participate if they had components available and the resources to participate. Cornet Technology joined the effort in July by providing an H.264 encoder with a promise of an MPEG-2 encoder to follow in August. Additionally, a COTS 5.8 GHz digital data link system was procured as a backup to cover those times when the Mini-CDL was not available. This allowed for all but the lowest layers of the USIP protocol stack to be exercised (Ku band STD-CDL replaced by surrogate C band link, if needed). This also helped to substantiate the claim that the end-to-end system was truly "plug and play" compliant.

The test plan also included a desire for the government or a vendor to provide Remote Video Terminal (RVT) systems capable of receiving and processing the USIP 1 protocols. The Army PM UAS with their One System RVT (OSRVT) was invited to participate and showed early interest in the project, but later backed out due to other commitments. Fortunately, the TP-CDL project office made a substantial commitment to fully participate in the exercise after several planning meetings and discussions.

The exercise test schedule is presented in Table 4 below.

Table 4 Exercise Test Schedule

1	Install VCU autopilot system in the Outlaw UA, checkout, and flight test.	1-18 Jul
2	Outline the detailed metadata format (JIP/USIP) required for insertion into TCDL.	21-25 Jul
3	Outline the EO sensor and digitization/compression capability required to operate with JIP and USIP.	21-25 Jul
4	Determine the RVT requirements to receive and display the data and video from the Outlaw UA. Obtain/develop the capability to receive/display this data locally at the Mark Schon, LLC location for testing.	28 Jul - 8 Aug
5	Extend the VCU autopilot system to output the metadata in the format outlined in Task 2.	4-8 Aug
6	Outfit the Outlaw UA with the EO sensor identified in Task 3.	11-15 Aug
7	Benchtest and debug the complete system, minus the actual TCDL transceivers (wired bench test), using the RVT capability developed in Task 4.	18-22 Aug
8	Integrate the TCDL transceivers into the system and bench test.	18-22 Aug
9	Flight test the complete UAV-to-RVT system.	25-29 Aug
10	Determine the requirements to distribute the UAS video and data beyond the local RVTs to back end JTCW and video servers. FBCB2? Video Services Approach - USMC vs Army	25-29 Aug
11	Develop or obtain required capabilities determined in Task 10 locally within MITRE and/or Mark Schon, LLC.	25-29 Aug
12	Benchtest the backend systems with the system resulting from Task 7.	2-5 Sep
13	Flight test the complete distribution solution, with the JTCW and video server with the system resulting from Task 9.	8-12 Sep
14	Perform the final exercise at Ft. A.P. Hill for the entire team and invited observers.	22-26 Sep
15	Analyze the results and document the entire exercise and results in the final report.	29 Sep - 3 Oct
16	Flight Demonstration at Ft. A.P. Hill for the entire team and invited observers.	27-31 Oct

4 Results

Team activities leading up to the exercise involved the integration of multiple USIP 1–compliant components into the Outlaw and the ground systems. Two Outlaws were outfitted with the VCU FCS autopilots and flight tested in July 2008. In addition, numerous flights were conducted specifically for pilot training, aircraft checkout, and launch and recovery training. A total of 25 Outlaw flights were conducted from July 2008 until the final exercise in October 2008.

During this period, the FCS was configured to output twelve of the USIP 1 standard KLV metadata keys to be time synchronized with the analog video from the onboard digital camera. In August 2008, the video and the corresponding KLV metadata were fed to the Cornet provided encoders (MPEG-2 and H.264) to generate the MPEG transport stream on the encoder's Ethernet output. In September 2008, the transport stream was provided to the Ethernet input on a COTS Microhard VIP 5800 digital data link for testing onboard one of the Outlaws. This data link would serve as a backup and be used for flight testing until the Cubic provided Mini-CDL and government provided TP-CDL equipment could be made available.

On 17 October 2008 the Cornet encoded transport stream was provided to the Ethernet input on the Cubic provided Mini-CDL platform communications equipment PCE and flight tested on the Outlaw with the TP-CDL equipment serving as the SCE on the ground. This flight was the first time the DoD–mandated USIP 1 was flown on any UAS with synchronized video and KLV metadata in the MPEG transport stream over the STD-CDL Ku band link at 10.71 megabits per second (Mbps). Cubic engineers participated in the initial integration and testing efforts as shown in Figure 9.

Figure 9 Jose Ortiz (Mark Schon, LLC), Randy Cross (Cubic), Dr. Robert Klenke (Mark Schon, LLC) and Rich Wayman (Cubic) Integrate the Mini-CDL in Outlaw UA

The final exercise was conducted on Friday, 31 October 2008 at Finnegan's Field in the military restricted airspace of the Fort A.P. Hill ranges near Bowling Green, Virginia. Vendor participants in the exercise included Cubic Defense Applications, the Mini-CDL provider, Cornet Technology, the MPEG-2 and H.264 Video Encoder/Decoder provider, and Lead Technologies, a video software development tool provider for the ground C2 systems integration completed by MITRE engineers (Figure 10).

Figure 10 Jon Roth and Rob Gleich (MITRE E403), and Mark Schon Welcome Guests, Recognize Key Participants, and Describe Exercise Goals and Objectives

The exercise was observed by key personnel from Marine Corps Systems Command (MCSC), the Marine Corps Warfighting Lab (MCWL), the Marine Corps Intelligence Activity (MCIA) and Headquarters, Marine Corps (HQMC). Also present were key Navy and Marine Corps personnel from Naval Air Systems Command (NAVAIR), and vendor participants (and their company representatives) who generously provided support and equipment for the exercise. Finally, Fort A.P. Hill Range Operations and Aviation Operations personnel were on hand to observe the exercise in action. In total, more than forty people observed the exercise.

After receiving a briefing on the systems being demonstrated, the roles of the participants, and an outline of the exercise to be conducted, the assembled viewers were given a safety briefing on the day's operations (Figure 11).

Figure 11 Key Personnel, Guests and Participants Receive Safety Briefing

A total of three Outlaw flights were conducted for the exercise. The first flight was conducted using the backup Outlaw configured with USIP 1 capability except for the CDL data link. It was configured with a commercial 5.8 GHz digital data link from Microhard and it displayed video at the GCS. The second flight was conducted using the Mini-CDL equipped Outlaw with the USIP 1 operational at altitudes of up to 2500 feet. The Outlaw was flown in various patterns above Finnegan's Field (Fort AP Hill) so that the guests could view the video and metadata displays. Plenty of time was allotted for the guests to see each type of display and talk with the operators and ask questions. The Mini-CDL Outlaw was recovered after a flight of approximately 30 minutes.

The third flight was conducted at altitudes up to 4500 feet. During this flight, one of the TP-CDL transceivers was moved to a point approximately 4 miles from the launch site. The purpose of this relocation was to test the ability of the data link to operate over extended distances. At the selected location, the TP-CDL transceiver was able to receive video and metadata. Further tests of the range capability of the Mini-CDL with various power settings, pointing algorithms, ground antenna configurations and UA navigation data provisions are being proposed as possible future flight test work. A picture of a launch of the Outlaw from its pneumatic launcher is provided in Figure 12.

Figure 12 Outlaw is launched with USIP 1 Video, KLV Metadata and the Ku Band STD-CDL

The early preparations through the final exercise and demonstration of the USIP 1 in operation on Outlaw S1 with TP-CDL and the COC C2 systems receiving the video and KLV metadata for display, was completed in only four months time. The Outlaw aircraft were made autonomous; USIP 1 protocols were implemented in the FCS; data link and payload equipment integrated and flight tested; and the exercise successfully conducted in record time while achieving the three goals and supporting objectives set in late spring of 2008. The resulting success of this MITRE Special Initiative is indicative of the kinds of achievements possible through innovative and challenging endeavors undertaken in close collaboration with our team partners.

5 Recommendations for Additional Research

Recommendations for additional research are listed below. These recommendations represent logical extensions of work that build upon the success of the exercise described in this report. Each of these recommendations, if implemented, would provide tremendous value to, and inform, those involved in the acquisition process.

Recommendation #1: Conduct a research effort and experiment that combines the capability for radio relay with the inherent control offered by the USIP-compliant CDL. This implementation could allow payload products (such as FMV) to be offered both via the CDL or by a radio relay, with capabilities similar to the AN/PRC-117G, an IP-capable multi-band radio. With the proper interface to the radio relay via the CDL, this could potentially allow "on-the-fly" operating mode changes to the radio (e.g., from radio relay to video download) that could make real-time video products available to dismounts at the tactical edge, that would otherwise only be available where RVTs were located.

Recommendation #2: Conduct a research effort and experiment that leverages the architecture developed as part of Recommendation #1, except that the transmission mode would be via satellite. The experiment would allow the exercise of a UAS to C2 system end-to-end interoperability exercise over a geographically dispersed field exercise. This exercise could easily be conceived of with UAS assets flying at Fort A.P. Hill and/or other dispersed locations, and the data being transmitted via the Internet link to C2 systems at remote locations.

Recommendation #3: Conduct testing of an unmanned system configuration that implements the complete set of KLVs in the USIP definition, as well as Standardization Agreement (STANAG) 4586 Vehicle Specific Module (VSM) compliance and interoperability. Field testing prior to the release of new standards would serve to validate the proposed updates to these standards prior to their final approval and release by the Office of the Secretary of Defense (OSD) or North Atlantic Treaty Organization (NATO). This would help answer questions such as: Is the standard, as written, implementable within reasonable cost and schedule constraints? Are new components from two vendors, who test to the standards, able to interoperate? What are the appropriate and effective test approaches?

Recommendation #4: Conduct testing of directional antennas to determine areas for range capability improvements beyond what current applications can provide. Electronic and mechanical antenna pointing applications on the ground and in the air should be evaluated in the field to understand which are most suitable and operationally effective. Frequency, spectrum and power considerations, and their effects on range, size and weight, can also be validated early in the development cycle. This information, proven or disproven in a field environment, would be extremely useful for those writing capabilities documents or system specifications.

Other areas to consider include:

- Investigate "white-boarding" (practice of sending a Joint Photographic Experts Group [JPEG] up with a potential target circled, etc). How would this be relayed, and how would it be used in combination with voice/chat?

- British Aerospace (BAE) has special software that enables high resolution, fast updates in areas within the view of interest, while trading off resolution and updates in other parts of the screen of less interest. With limited spectrum/bandwidth this approach will be increasingly attractive going forward.
- What is the path to High Definition (HD)? USIP 1 says the ground receivers must support Motion Imagery System Matrix-Level 9 (MISM-L9), but not the air. What's the path forward?

A slide extracted from an AFRL Mini-CDL briefing given at NATS # 20 on 4 June 2008 is provided in Figure 13 to show another example of future areas that can be field demonstrated to reduce risk in the development cycle of tactical UAS.

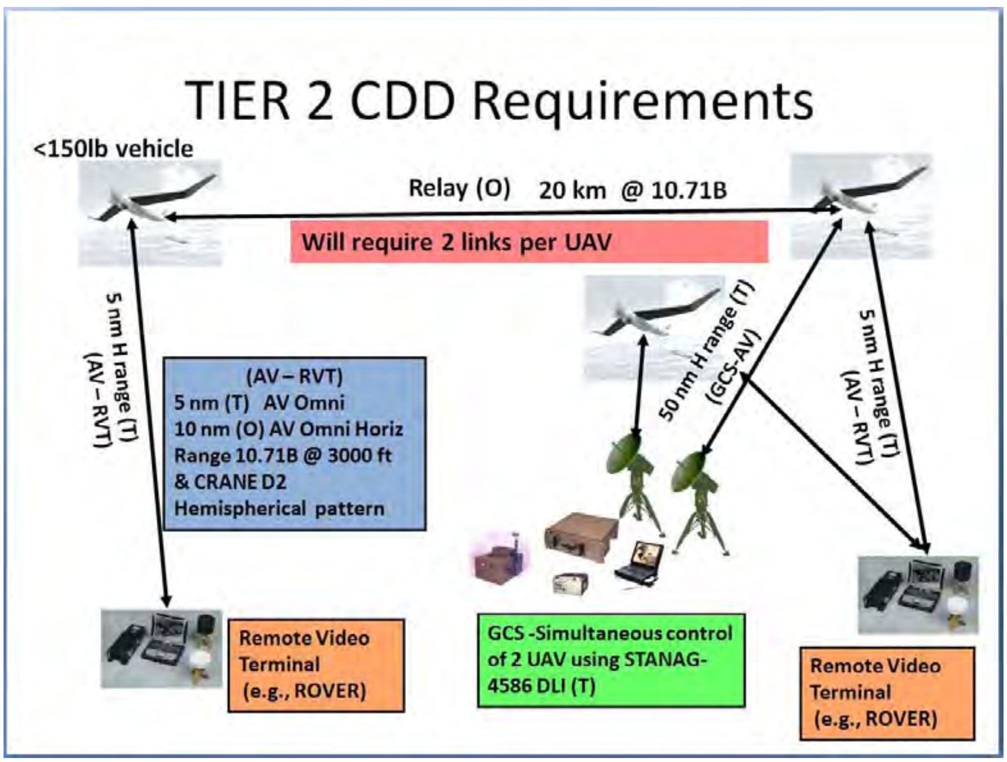

Figure 13 Possible Future Field Exercise with Outlaw and TP-CDL or OSRVT

Appendix A Cursor on Target Key

Table 5 CoT Key from EG0601.1

CoT Key	EG 0601.1 LDS Tag # and Name or Notes	Notes
point/lat	13 Sensor Latitude	CoT requires WGS-84 decimal degrees with North positive
point/lon	14 Sensor Longitude	CoT requires WGS-84 decimal degrees with East positive
point/hae	15 Sensor True Altitude	The KLV key is altitude; it must be converted to Ellipsoid Height; given in meters
point/ce	9999999	This represents “no value given”
point/le	9999999	This represents “no value given”
version	2.0	CoT Version Number
type	a-f-A-M-F (as an example)	Atom-friendly-Air AOB- Military-Fixed Wing (Reference CoT definitions in Event.xsd v 1.4 2007/02/27 for other “types” as applicable to other platforms)
uid	10 Device Designation 3 Mission ID	… for 0601.1 implementations, concatenate Tags 10 and 3 separated by an underscore (“_”) character.
time	2 UNIX Time Stamp	Convert to ISO 8601 YYYY-MM-DDThh:mm:ss.ssZ (Fractional seconds are optional and number of decimal places unbounded); this is the time the message is generated
start	2 UNIX Time Stamp	Convert to ISO 8601 YYYY-MM-DDThh:mm:ss.ssZ this is the time the message becomes valid (should be the same as Time)
stale	Time of next CoT platform position message	This is the time at which the position message is no longer valid; use ISO 8601
how	m-p	How the position was obtained (machine-passed). Reference CoT definitions in Event.xsd v 1.4 2007/02/27 for further explanation and other possible values.
detail/_flow-tags_	Current Time	Indicates that system “touched” the event and at what time. Format as EG0601.1CoT or EG0104.5CoT = ’YYYY-MM-DDThh:mm:ss.ssZ’ with the current time.
sensor/azimuth	5 Platform Heading Angle 18 Sensor Relative Azimuth Angle	Sensor absolute azimuth obtained by adding platform heading angle and sensor relative azimuth angles together; CoT requires decimal degrees
sensor/fov	16 Sensor Horizontal Field of View	Sensor Horizontal Field of View; CoT requires decimal degrees
sensor/vfov	17 Sensor Vertical Field of View	Sensor Vertical Field of View; CoT requires decimal degrees
sensor/model	11 Image Source Sensor	Image Source Device
sensor/range	21 Slant Range	CoT requires this be in meters

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Appendix B Acronym List

ADC	Analog to Digital Converters
AFRL	Air Force Research Laboratory
API	Application Programming Interface
ASD (NII)	Assistant Secretary of Defense (Networks & Information Integration)
AT&L	Acquisition, Technology and Logistics
AV	Air Vehicle
BAE	British Aerospace
C2	Command and Control
C2PC	Command and Control Personal Computer
CDL	Common Data Link
COC	Command Operations Center
CODEC	Coder/Decoder
COP	Common Operational Picture
CoT	Cursor on Target
COTS	Commercial-off-the-Shelf
CS	Control Station
DoD	Department of Defense
DVR	Digital Video Recorder
EO	Electro-Optical
EG	Engineering Guideline
ENU	East, North, and Up
ESD	Electronic Software Distribution
FCS	Flight Control System
FMV	Full Motion Video
FPGA	Field Programmable Gate Array
GCCS	Global Command and Control System
GCS	Ground Control Station
GHz	Gigahertz

GOTS	Government-off-the-Shelf
GPS	Global Positioning Service
HD	High Definition
HP	Horsepower
HQMC	Headquarters, Marine Corps
IP	Internet Protocol
IPL	Image Product Library
IR	Infrared
ISM	Industrial, Scientific and Medical
ISR	Intelligence, Surveillance and Reconnaissance
JBV	Joint Battlefield Viewer
JIP	Joint Interoperability Profile
JTCW	Joint Tactical COP Workstation
KLV	Key Length Value
KML	Keyhole Markup Language
LAN	Local Area Network
Lbs	Pounds
LCD	Liquid Crystal Display
LLA	Latitude, Longitude, and Altitude
LLC	Limited Liability Company
MAAS	Multimedia Analysis and Archive System
Mbps	Megabits per Second
MCIA	Marine Corps Intelligence Activity
MCSC	Marine Corps Systems Command
MCWL	Marine Corps Warfighting Lab
MHz	Megahertz
MISB	Motion Imagery Standards Board
MISB EG	MISB Engineering Guideline
MISM	Motion Imagery System Matrix
MPEG	Moving Picture Experts Group

NATO	North Atlantic Treaty Organization
NAVAIR	Naval Air Systems Command
NGA	National Geospatial-Intelligence Agency
NTSC	National Television System Committee
OSD	Office of the Secretary of Defense
OSRVT	One System Remote Video Terminal
OUSD	Office of the Under Secretary of Defense
PC	Personal Computer
PCE	Platform Communications Equipment
PDS	Private Data Stream
PES	Packetized Elementary Stream
PICTE	Primary Image Capture Transformation Element
PID	Packet Identification
PWM	Pulse-Width Modulation
RC	Radio Control
RF	Radio Frequency
RPVT	Remotely Piloted Vehicle Target
RVT	Remote Video Terminal
SA	Situational Awareness
SCE	Surface Communications Equipment
SDK	Software Developers Kit
STANAG	Standardization Agreement (NATO)
STD-CDL	Standard Common Data Link
TCP	Transmission Control Protocol
TCPED	Transmission, Collection, Production, Exploitation and Dissemination
TP-CDL	Team Portable – Common Data Link
TS	Transport Stream
UA	Unmanned Aircraft
UAS	Unmanned Air System
UDP	User Datagram Protocol

USB	Universal Serial Bus
USIP	Unmanned Systems Interoperability Profile
VCD	Video CD
VCU	Virginia Commonwealth University
VSM	Vehicle Specific Module

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