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Operator-in-the-Loop Experimentation: ~~Providing Combat~~ Utility Measures

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ABSTRACT

This paper describes an experiment to assess the operational effectiveness of airborne platforms employing candidate advanced tactical data links (ATDL) and representative network-enabled applications in support of Close Air Support (CAS) missions. Results showed that increased network throughput reduced the total time required to build shared situational awareness (SA) between the aircrew and the Joint Terminal Attack Controller (JTAC), and ultimately shortened mission timelines. The ability to send and receive current imagery in a timely manner from and to the cockpit significantly enhanced SA for the air / ground team, particularly in a high clutter environment. For the Baghdad scenario, the average difference in time to build situational awareness was reduced by 7 minutes, 10 seconds by using Tactical Targeting Network Technologies (TTNT) versus Link 16.

I. INTRODUCTION

Program offices are under increasing pressure to demonstrate combat utility. For communications networks, this is difficult because the network only accounts for one small component of overall mission effectiveness. It is possible for the network to perform brilliantly and for the mission to fail, just as it is possible for the mission to succeed despite numerous network failures. Operator-in-the-loop methodology uses high-fidelity cockpit simulators to create a realistic environment in which to test a network's military value. It allows us to objectively measure network performance and subjectively determine its contribution to mission success, thus deriving mission utility.

This paper describes an experiment conducted by MIT Lincoln Laboratory to assess the operational effectiveness of F-15Es employing candidate ATDLs and representative network-enabled applications in support of CAS missions. The experiment included seven CAS scenario cases and compared two tactical data link environments, Link 16 and TTNT. Scenario design was drawn from actual tactical engagements in Iraq and Afghanistan. Urban (Baghdad) and non-urban (Konar Valley) locations were used as operational context. Operational aircrews with recent OIF/OEF experience from the 4th Fighter Wing at Seymour Johnson AFB "flew" each mission, and two JTACs from the 10th Air Support Operations Squadron at Ft. Riley provided terminal control. Missions were "flown" at Boeing's Defense Simulation Laboratory in St. Louis, Missouri and were recorded using Boeing capture tools.

The experiment explored both Type 1 and Type 2 terminal control procedures. This is significant because execution and Rules of Engagement (ROE) are different under each level of control.[1] Under Type 1 control, the JTAC was located with the ground troops coming under fire and had direct voice communication with the ground commander. Under Type 2 control, the JTAC was co-located in a Tactical Operations Center (TOC) with the ground commander. Available to the JTAC in the TOC was a remotely piloted aircraft (RPA) deployed above the patrol. A key difference between the Type 2 operational view and the Type 1 view is that under Type 2 conditions, the JTAC had an aerial view of the Troops in Combat (TIC) situation and was not physically present.

II. METHODOLOGY

The simulation architecture is depicted in Figure 1. The experiment was supported by several simulation and network enabled applications (NEA). One such NEA, the Embedded Proxy (EP) was installed on the F-15E simulators. Two human-in-the-loop F-15E high fidelity aircraft simulators were used to replicate a two-ship element, the standard tactical element for combat aviation[2]. The EP onboard the aircraft was connected to the "ground" over either a simulated Link-16 (red line) or TTNT (blue line) link. The Link-16 message protocol and bandwidth were implemented using a Boeing model. The TTNT link was simulated via Government-provided USAF ASC/XRA Simulation and Analysis Facility (SIMAF) software. The only difference between the two simulation architectures was the link between the Platform Adaptor (PA) and the EP onboard the

[1] A standardized CENTCOM ROE was the same for both locations. *Joint Publication (JP) 3.09-3 Close Air Support* was in effect; "Digital CAS" did not negate the need for proper application of CAS procedures. Imagery was sent in all cases; imagery confirmation was not required.

[2] Both F-15E simulators reflected upgrades including Suite 6 Operational Flight Program (OFP); PGMs including GBU-31, GBU-39, and GBU-12; a Sniper advanced targeting pod; and enhanced network-enabled applications.

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F-15E simulators. All other simulation and network enabled software was identical for both cases.

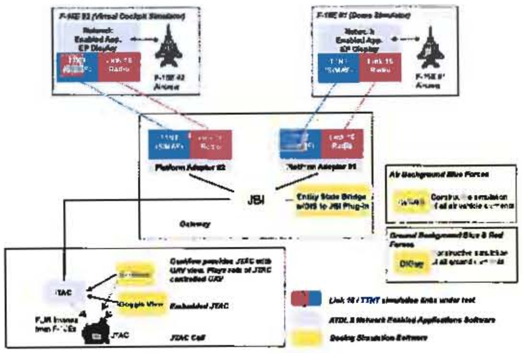

Figure 1: Systems Interface Description

The EP connected to the ground gateway using either the Link 16 or the TTNT link through the PA software. The PA provided an information bridge between the assumed ground tactical networks and information management. The JTACs used a network application called "iTAC". iTAC enabled the JTACs to create and publish digital 9-Lines and to send images to the aircraft. For Type 1 control, an application called "Goggle View" was used. This software provided an immersive view of the surrounding area as if the JTAC were embedded with the patrol that was under attack. The Goggle View software view was driven by the positions of friendly and hostile elements generated in the IWARS (for airborne assets) and DiGuy (for ground assets) constructive simulations. For Type 2 control, the JTAC had a UAV view of the battlefield via the GenView application. The JTAC could take "snap shots" from GenView and use iTAC to publish these to the F-15E aircrews. For the Link-16 case, the information was published to the JBI, picked up by the PAs and transmitted to the aircraft over the simulated Link-16 connection. The Joint Battlespace Infosphere (JBI) was used as a representative Information Management (IM) system. An application called the Entity State Bridge, published received airborne and ground blue force positions to the JBI. Both PAs subscribed to blue forces in the operational area and then published these tracks to the EP located on its respective F-15E simulator.

For both scenarios actual terrain models were used and impacted flight patterns. However, the simulators did not model the communications system or physical (RF) propagation hence link connectivity was not impacted by transmission range limitations, body masking effects, and potential terrain blockage. This is an area for improvement in future efforts.

In order to effectively design an experiment to highlight the impact of network performance on combat outcomes, the variability of non-network related variables must be minimized to the extent possible. The experiment was designed to minimize potential differences in crew performance, support platforms, platform performance and enemy actions.

To level out the impact of specific skills, training, and experience levels of the participating operators, the crews and JTACs were mixed into different combinations, effectively creating five different mission crews. Additionally, to minimize the effect of a "learning curve" by the aircrew and JTACs, crews and JTACs were rotated between simulator runs so that no aircrew / JTAC pair saw the same scenario twice. In addition, the locations of the insurgents were varied from run to run, so the operators could not predict where the targets would be located. Twenty-eight total sorties / runs were "flown". A summary of the runs, indicated by the x's, is provided in the chart below (Table 1).

Scenario	Link	Control	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5
Iraq 1a	Link 16	Type-2	X		X		
Iraq 2a	Link 16	Type-2		X		X	
Iraq 3a	Link 16	Type-1	X				X
Iraq 4a	Link 16	Type-1		X	X		
Iraq 1b	TTNT	Type-2		X			X
Iraq 2b	TTNT	Type-2	X		X		
Iraq 3b	TTNT	Type-1		X	X		
Iraq 4b	TTNT	Type-1	X			X	
Afghan 1a	Link 16	Type-1	X		X		
Afghan 2a	Link 16	Type-2		X		X	
Afghan 3a	Link 16	Type-1	X				X
Afghan 1b	TTNT	Type-1		X			X
Afghan 2b	TTNT	Type-2	X				X
Afghan 3b	TTNT	Type-1		X		X	

Table 1: Summary of Test Plan

Support platforms were not a part of the equation by design. Simulation runs started with the fighters located about 40 nautical miles from the fight, just after the Air Support Operations Center (ASOC) had passed a tasking and contact

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data. At this distance, crews were just out of sensor range, but were close enough to enable the execution of multiple runs without "wasting" simulation time on ingress.

The real-time and interactive nature of the scenarios provides a realistic environment for testing mission effectiveness as a function of network performance, but prevents a direct one-to-one experimental comparison between mission runs. Because of the rapidly-developing nature of the fight on the ground, the presence of other air vehicles, both neutral (civilian) and host nation friendly forces differed for each run, resulting in different scenarios from similar starting conditions. There are outliers in the data that can be explained tactically.

III. CLOSE AIR SUPPORT (CAS) SCENARIO

Before delving into network performance measures, it is important to understand the goals, procedures, and timeline for a generic CAS mission. Once a two-ship has been assigned to a Forward Air Controller (FAC) (or in our case, JTAC) by C2, they fly to a specific point, change radio frequencies, and "check-in" using a tactical voice radio. This is called the fighter-to-FAC check-in/brief, and it is basically where the run timing started. The check-in is a standardized brief: mission number, type and number of aircraft, munitions, and "playtime" (amount of on-station time). At this point the aircrew is first made aware of the tactical situation of the engaged friendly forces. This happens generally outside of sensor range, so crews are developing their SA via voice. The CAS brief, also known as the "9-Line Briefing," or 9-line, is a standardized briefing that specifies the target and authorizes an attack. The 9-line contains, unsurprisingly, nine fields, of which three are mandatory and two must be read back. Mandatory fields consist of target elevation, target coordinates, and *relative* location of friendly forces (*never* in coordinate form). Aircrews can determine target elevation via laser rangefinder. Tactical options available to the air-ground team are directly dependent on the level of shared situational awareness. For example, with limited knowledge of friendly disposition and enemy disposition/positive identification (PID), a show of presence or a show of force[3] may be the only options available, whereas, with greater shared SA the full range of employment options are made available to the ground commander.[4] It was not uncommon during this experiment for the crews to execute a show of presence/show of force prior to the 9-line being completed. This is a common tactic employed today by operational forces.

During the first CAS operator-in-the-loop experiment[5], aircrews discussed the value of imagery to the CAS mission. The availability of current imagery increases in value with both increased battle space "clutter" (e.g. urban CAS) and the proximity of friendly forces because it is more difficult to sync visual and/or sensor imagery with a voice description in a complex environment. This concept is visualized in Figure 1.

Figure 1: Value of Imagery to CAS

The Afghan scenario falls in the upper left corner, where ground clutter was low, but proximity to Blue forces was Danger Close[6]. The Iraq scenario falls in the lower left corner, where ground clutter was extremely high and proximity to Blue Forces was Danger Close. For CAS missions in a cluttered and dynamic environment, SA must be continuously updated using voice and (where available) imagery.

IV. NETWORK PERFORMANCE

To measure network performance, the average transfer time of images was compared for CAS missions supported by Link 16 and missions supported by TTNT. Images, taken by both the aircraft sensor pod and the iTAC tool, ranged from 300-400 Kbyte and were sent as JPEGs

[3] These options differ in altitude only.

[4] Options include warning shots, strafe, or employment of various free-fall munitions with optimized fuse settings. The best option may be to gather additional sensor data to support ground commander's tactical execution.

[5] DASD Forces Transformation & Resources (FTR) executed the first CAS operator-in-the-loop study in May 2008 under the auspices of the third ADTL Study.

[6] Danger close is an indication that friendly forces are within close proximity to the target for CAS, artillery, mortar or naval gunfire support.

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with no additional compression. The time to transfer imagery was a function of both the data link and the scenario as shown in Table 2.

Network Type / Scenario	Average Transfer Time	Transfer Time Range
Link 16, Iraq	240 seconds	173 to 336 seconds
Link 16, Afghanistan	180 seconds	59 to 289 seconds
TTNT, Iraq	6 seconds	1 to 19 seconds
TTNT, Afghanistan	6 seconds	1 to 19 seconds

Table 2: Image Transfer Times

There is a substantial difference in transfer times between the Link 16 and TTNT networks. This basic result was expected. We did not expect the significant difference in transfer times between scenarios. However, since imagery is more valuable in a high-clutter environment, aircrews were more likely to flood the network with images in the Baghdad scenario, thus slowing overall performance in the Link 16 network. High volume did not impact TNTT performance because TTNT capacity was not overwhelmed by the desired image transfer data rates.

The throughput of the datalink directly impacted the tactics employed by the air-ground team. Several runs into the experiment, once the aircrews realized that they were on a Link 16 network (after they sent the first image), *they stopped sending imagery altogether and moved to voice*. Whereas, when they realized they had TTNT, they sent – and used – images early and often, in conjunction with voice.

To address military utility, we calculate the time it took to build shared SA. Situational Awareness Achieved is defined as the time from the fighter-to-FAC check-in to the time a 9-Line was sent. This metric was selected because once the 9-line has been sent the aircrew has been tasked to prosecute a target and they have the SA (target location, neutral location, friendly location, and approach restrictions) to do so.

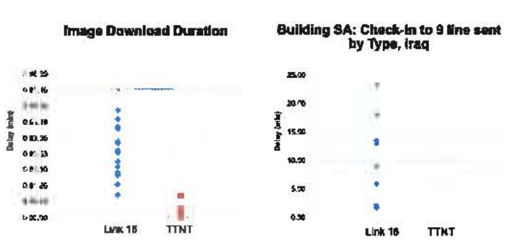

Figure 2: Direct Correlation Between Image Download Time and Time to Build SA

Figure 2 shows a direct correlation between imagery transfer time and SA for the Iraq runs. The table on the left, Image Download Duration, shows the time it took for each image[7] to reach its destination across both scenarios. As previously discussed, most of the TTNT times are in the 4-8 second range, while the Link 16 transfer times vary from about 60 seconds to as many as 336 seconds (over 5 minutes). The chart to the right, Building SA: Check-in to 9-Line Sent, shows an almost direct correlation between the transfer times and the the time it took to build SA.

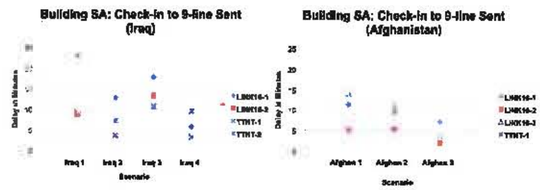

Figure 3: Building Situational Awareness

Figure 3 shows the difference in time between the fighter-to-FAC check-in and the time a 9-line was sent for both the Iraq and Afghanistan runs. For the Iraq runs, the average difference in time to build SA between Link 16 runs and TTNT runs was 7 minutes and 10 seconds. The Afghanistan runs initially show a counter-intuitive result, with Link 16 runs often taking the least amount of time to build SA. Lack of clutter in the Afghan environment is the most likely reason for this result. In most cases, imagery was not required for the timely execution of the mission, particularly as Afghan insurgent forces were much more likely to break contact early than their Iraqi counterparts.

This experiment highlighted the importance of the speed and throughput of the datalink imagery delivery in a dynamic environment. The timeliness of image transfer was often the difference to whether it was used or not used. With almost all Link 16 image transmissions, by the time the image arrived, it was overcome by events – the crews had already used voice radio to describe the situation and conditions then present. A careful review of the transcripts shows that images that arrived within 40 seconds were used; most that arrived between 40-60 seconds were not. While slower for describing terrain, voice was nevertheless effective and

[7] This sampling uses up to three images per run.

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remained the primary method of building SA regardless of datalink or network type.

Another way to parse the data is by type of CAS control (Figure 4).[8] Across all Type 2 scenarios, the time to build SA is generally faster. Both JTACs learned quickly that when executing Type 2 control with a TTNT network, they could send an overhead image of the friendly position to the fighters long before the fighters were in sensor range, and be discussing the tactical picture before the fighters were close enough to get useful data from their own sensors. By comparison, pictures sent by Link 16 were obsolete by the time they arrived, as the fighters already had better data from their own sensors. Similarly, we surmise that it was easier and faster for the JTAC and fighter crews to "sync up" their respective aerial sensor pictures when they had a reference image to use, particularly when the JTAC had annotated the images prior to transmission.

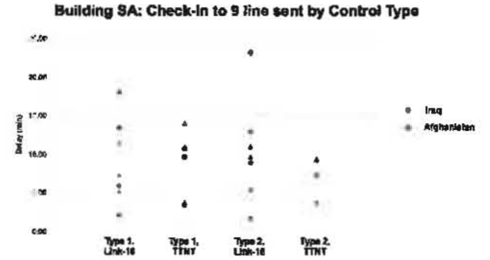

Figure 4: Type 1 Versus Type 2 Control

Another slightly different metric is total talk-on time, defined as the time from first contact, which is just before the fighter-to-FAC check-in, to 9-line read-back, which is when the aircrew has completed the read-back on the mandatory read-back items. Increased network throughput reduced the total talk-on time required between the aircraft and the JTAC. The average talk on time for Link-16 runs was 757 seconds, while for TTNT runs the average time was 581 seconds. This represents a 24% reduction in talk-on time using a higher bandwidth TTNT network over Link 16.

How the overall mission was affected by network performance requires an examination of first weapons effect.[9] This metric measures the time from first contact to the time the aircrew announces that they are making their target run.[10] First weapons effect (Figure 5) tracks very logically with the time to build situational awareness (Figure 2) demonstrating that the amount of time required to develop situational awareness directly impacts mission timelines.

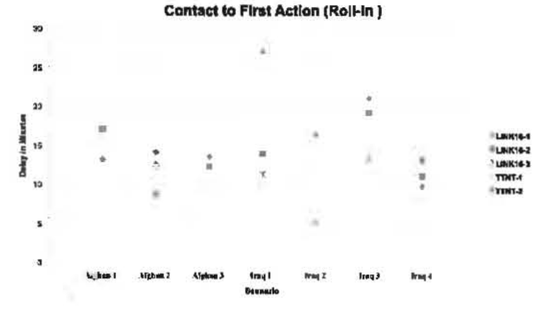

Figure 5: Contact to First Action (Roll In)

V. TACTICAL PERFORMANCE MEASURES

In addition to network metrics, there are other tactically observable metrics. This experiment looked specifically at tactical decision points including: correct identification of hostiles within the ROE; targeting movers, stationary targets, and assigning weapons; number, type and sequence of weapons employment, and fuse settings; determining risk of fratricide and/or collateral damage. It also looked at the following tactical objectives: 100% correct target identification, 100% weapons on target/desired effect, no fratricide, and minimum Collateral Damage. These were the objectives briefed, and debriefed, to the aircrews

The datalink had little to no impact on either the ability to positively identify hostiles or the speed at which a hostile declaration may be made. There were no identification mistakes, and in fact, aircrew often identified both hostiles and friendlies of which the ground commander was not aware. Aircrew commented that PID for hostile and neutral elements was *much* easier in the simulator, due to the clarity of the computer-generated images and the lack of ambiguity associated with dress, uniforms and weapons. ROE adherence was 100%, exemplified by one

[8] Type 1 control occurred when the JTAC was with the ground force; Type 2 generally occurred when the JTAC was at the TOC viewing the situation through a RPA feed.

[9] First weapons delivery was not often the first effect delivered by airpower. Show of presence / force, which does not require the same level of SA, was often executed prior to an actual weapons run.

[10] We used the "roll-in" call as the measure for a couple of reasons: 1) to eliminate the time spent positioning the aircraft for the attack run, and 2) accurate weapons flyout models were not used for the simulation.

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simulator run in Afghanistan where there was no drop conducted on a legitimate target because the aircrew had not maintained continuous track on a moving group of insurgents, and could not therefore maintain PID. In terms of tactical objectives, no attacks were conducted on unidentified, friendly or neutral targets: the datalink had little to no impact on the tactical metrics or crew ROE compliance.

Increased network throughput did result in a number of differences in tactics driven by network performance:

–**Number of images sent**: The number of images sent differed between the networks. When the network could support timely transfers, operators took full advantage.

–**Effects options available**: An advanced datalink enabled aircraft to provide important support to ground commanders who were not yet engaged in the form of an on-demand overhead look. This enabled the ground commander to avoid an engagement altogether or to accept an engagement on more favorable terms. It may also enhance other options (such as finding an alternate route) under conditions where maps are poor, terrain is rough and infrastructure is primitive.

–**Ground commander level of confidence**: The ability to pass imagery in timely manner enabled the ground commander to make better decisions from a wider range of tactical options. Imagery not only supports immediate engagement decisions, but can also support plan development before an engagement starts and after an initial engagement is over (BDA).

–**Type of Control**: The availability of imagery to the JTAC can change the way a JTAC is able to control an engagement. Significantly, availability of imagery can change a Type 2 control to Type 1, resulting in a higher confidence, which may allow a less restrictive ROE. Also, imagery could enable Type 2 control in situations where previously only killboxes (Type 3) were an option.

SUMMARY AND DISCUSSION

Discussions with experienced aircrews subjectively validate that the availability of current imagery shortens CAS mission timelines by building familiarity during ingress and enabling collaboration. This is especially salient for reactive CAS missions and when aircraft have sensor systems with shorter ranges (e.g. LANTIRN versus Sniper). For our most recent event, the ingress was significantly shorter by design. However, our results show that in a highly cluttered environment, the ability to send and receive imagery consistently decreased the amount of time required to develop SA and therefore ultimately shortened mission timelines. Additionally, we discovered when we parsed the data by type of CAS control that across all scenarios, the time to build SA is generally faster under Type 2 control (when the JTAC is in the TOC). The fundamental takeaway from this experiment is that increased network throughput reduced the total time required to build shared situational awareness between the aircrew and the JTAC. This is important because the more rapidly air delivered effects can be delivered, the greater the chance of terminating the engagement on favorable terms, and the greater the chance of maintaining PID when the enemy disengages.

Finally, it is important to remember that since the images sent during this experiment were large and transfer times are relatively long overall, the low latency, small message delivery capability of TTNT was not relevant for this application. In fact, while TTNT is one possible waveform that can provide the throughput necessary to make the kinds of tactical impacts we saw during experiment possible, it is by no means the only one. Link 16 Enhanced Throughput could be an option. There could be others. What this experiment demonstrated is that, in the context of a highly cluttered environment, for the CAS mission, the ability to transfer images in 40 seconds or less made a significant tactical impact that could be measured. It also demonstrated that this capability has other applications that could increase the range of tactical options available.

REFERENCES

Joint Staff, "Joint Publication 3-09.3: Close Air Support", 08 July 2009.

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