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DATA FUSION AS SOFTWARE SOLUTION FOR 2018 OIR LESSONS LEARNED AND JADC2

by

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Biography

Lieutenant Colonel Brent N. Harms is assigned to the Air War College, Air University, Maxwell AFB, AL. Prior to his assignment to the Air War College, Lt Col Harms was assigned to Kirtland Air Force Base where he commanded an Operations Support Squadron providing support to Air Force Special Operations Command and Air Combat Command mission qualification training. Lt Col Harms is a command pilot with over 2,500 combat hours in four different mission design series aircraft and over 5,900 flight hours. He has spent much of his career in Air Force Special Operations, deploying numerous times in support of U.S. combat operations, counter terrorism efforts, and small-scale contingencies worldwide. Lt Col Harms also completed Air Command and Staff College, holds a Master's Degree in Business from American Military University, and a Bachelor's of Science Degree in Physics from Virginia Military Institute.

Abstract

Reports from the Air Force Lessons Learned (AFLL) agency educate and correct deficiencies from occurring again. Education dissuades history from negatively repeating itself, however, recommendations have a way of supporting change and inspire result-based efforts that change for the better. Those that research and compile information for distribution and submit recommendations are true professionals, but not everyone on these teams have all the answers.

Out of the analyzed 2018 Chief of Staff of the Air Force (CSAF) directed report, this research paper shows that there were a few missed opportunities using data fusion or software solutions. Data fusion or software solutions could have solved challenging issues for the Air Force during Operation Inherent Resolve (OIR) in 2018, but these solutions have since integrated into current forward operations. This research was not only to provide if there were any solutions that the AFLL team missed, but also how it can enhance Multi-Domain or Joint all Domain Command and Control (MDC2/JADC2). Since MDC2/JADC2 is a high emphasis topic, this research fell behind other agencies working further and faster than anyone could keep up with. Instead of staying on the innovative and cutting edge, the research below captures relevant opportunities that any Airman could read, attend, or engage with, to broaden their own education. Some concepts and recommendations may already be occurring among senior leaders that are keen on preparing today for tomorrow's conflict. However, this paper will highlight the myriad of organizations that are attempting to develop, train, and enhance current data fusion or software solutions for the warfighter. If no one has a grasp on data fusion or what it provides, I hope this can increase a knowledge base and enhance software solutions instead of hardware solutions for data integration and sharing. Data fusion and software solutions will be key to MDC2/JADC2.

Introduction

In 2018 the Chief of Staff of the Air Force (CSAF), General Goldfein, directed the Air Force Lessons Learned (AFLL) directorate to conduct a high priority collection regarding "Air Operations and Support to OIR. The resulting report focused on numerous lessons from United States Air Force (USAF) contributions to OIR, specifically on Operation EAGLE STRIKE (battle of Mosul) and Operation SHIRAKA (defeat of Da'esh in middle Euphrates river valley) between February to March of 2018. To ensure streamlined efforts, AFLL used three questions to orient its focus of research:

1. Was JTF/OIR supported with, by, and through defensive counter air (DCA) via Suppression of Enemy Air Defenses (SEAD), Command and Control (C2), and counter land missions with CAS?
2. Was there provision for effective operational support, Intelligence, Surveillance, and Reconnaissance (ISR), and lethal and non-lethal fires to ground maneuver?
3. Did the USAF address, plan for, and engage air advising as an emerging mission and how did the air component enable ground force advise, assist, and accompany roles in Iraq?[1]

This paper focuses on questions 1 and 2 above. By analyzing OIR lessons learned with capabilities available during this time, such as Talon Thresher discussed latter; I will show that data fusion and software solutions were available for employment during OIR in 2018. In conjunction with highlighting current solutions, my analysis will increase software solution awareness for future opportunities toward Multi-domain or Joint All-domain Command and Control (MDC2/JADC2). By explaining data fusion and techniques using data fusion, my recommendations will support current and future conflicts for better management of assets and amplify command and control (C2) capabilities.

Thesis

By analyzing OIR lessons learned with capabilities available during this time, I will show that data fusion and software solutions were available for employment during OIR in 2018. In conjunction with highlighting solutions, my analysis will increase software solution awareness for future opportunities toward Multi-domain or Joint All-domain Command and Control (MDC2/JADC2).

OIR LESSONS

Of the OIR lessons learned in the 2018 AFLL report, six identified items dovetailed into data fusion solutions. The first lesson revolved around strike cells providing adaptive C2 elements, but a lack of standardization resulted in operations and training challenges. Established was an ad hoc construct named "strike cells" built with minimal guidance in joint, service, or multiservice doctrine to expediate the non-deliberate target process. Due to the lack of standardization "strike cells" blurred command relations that led to decisions that sub-optimized airpower employment, despite them tied to the combat operations division. The inset vignette highlighted operational area boundaries drawn by the TEA without adequate coordination across the operational area. The fog and friction of moving fast created issues with execution authorities and control of strike assets, but still gained positive results. The AFLL team recommended an organization solution for a flexible option to provide doctrinal capabilities to C2 elements for non-doctrinal application within a unique operational environment.[2] Instead of an organizational change, software solutions in the form of data fusion, would display strike assets and visual operational boundaries on a common operating picture.

A forward deployed Director of Operations (DO) is overseeing the day's efforts and the status of targets while inside the combat operations division. The DO is inside an ad hoc "strike cell," which is located on the combat operations floor, tasked with monitoring targets off the joint targeting list in the assigned area of operations. Special Operation Forces (SOF) are on a mission and the Joint Task Force (JTF) commander is requesting combat air support during SOF ground movement. The DO is not aware of the exact position of the SOF troops nor if a request had processed off the Air Tasking Order (ATO) to support with assets on this seemingly no-notice JTF request. The DO requested the Combined Forces Air Component Commander (CFACC) approval for assets to provide combat air support (CAS) to the SOF team. As aircraft maneuvered toward the SOF team, the Chief of Combat Operations (CCO) reshuffled the ATO and built space to fill gaps and briefed the DO on adjustments. Just then, a valid time-sensitive target appeared from an unarmed Information, Surveillance, and Reconnaissance (ISR) asset in the same sector as the SOF team. The DO re-tasked another armed asset in the vicinity of the ISR platform and notified the CFACC for authorities to strike. The CFACC confirmed with his staff and the Joint Terminal Attack Controller (JTAC) for a collateral assessment. The target was in the open desert with no buildings or additional people traveling and was a valid target within boundaries of the contested environment with low collateral. The CFACC then directed the JTAC push strike authorities and modified 9-line information to conduct the strike. The strike asset confirmed the location and deconflicted airspace to maneuver for attack. The CFACC notified the JTF commander that they had a target in the open near their CAS and was attacking a target. The JTF commander reported back that the CFACC's target was the JTF's target and was intercepting it on the ground for capture instead of kill under Target Engagement Authority (TEA). The CFACC aborted the strike within seconds of launch and watched the ISR video-feed as the SOF troops captured the target in the open, with no friendlies injured, and released armed overwatch. After the mission, a discussion between the JTF commander and CFACC ensued over blurred command relations and sub-optimized airpower employment without adequate coordination across the operational area.

A similar, but separate lesson identified, was the lack of continuity and expertise of the Special Operations Liaison Element (SOLE) in coordination and integration between the air component and Special Operations Joint Task Force (SOJTF). There was a lack of interface to prevent the potential for fratricide and coordinate appropriate fire support for SOF air, surface, and subsurface operations. An additional lack of SOF operations in the Air Tasking Orders (ATO) and Air Control Orders (ACO) contributed to this lesson to coordinate and deconflict with the air component. This applied not only to US SOF, but coalition SOF between the Joint Air Operations Center (JAOC) and SOF Headquarters with conventional air operations. While dynamic targeting and accelerated strike cells were active, the lack of integration and identification of real-time Restricted Operating Zones (ROZ) increased risk. The AFLL team recommended an organization solution for sustained, habitual SOLEs assigned, similar to the Battlefield Coordination Detachment (BCD) model, with consistent presence to better communication.[3] However, like above, fused data on a common picture with not only Blue Force Trackers (BFTs) of soldiers and Low Probability Identifications (LPI) for SOF aircraft would have increased awareness. A common integrated picture does not remove the need for communication from the SOLE, but software solutions are available. These solutions could also visually integrate Army artillery path of fire and impact, along with quick representation of activated ROZ's activated.

Three additional lessons identified limited levels of coordination and changing intents between Area Air Defense Commanders (AADC) and battle-tracking partner forces in congested airspace. These lessons centered around time constraints to plan, coordinate, and execute Defense Counter Air (DCA), to include real time battle management of sectors that the AADC was controlling. During OIR with Pro-Syrian regime air forces in proximity of US coalition aircraft the situation was extremely fluid and caused higher level of risk acceptance during operations. As the battle space changed, the C2 and Intelligence teams were assessing the Air Order of Battle (AOB) while waiting on confirmation of friend or foe identification. The

Common Operating Picture (COP) was incomplete; C2 relied heavily on voice communications to track and identify aircraft. One commander during the battle of Mosul mentioned there was no data-link in or over Mosul which complicated matters. Without an automated airspace picture, the situational awareness slowed to the speed of relayed voice communication for target recognition and manually updated on the COP. The AFLL recommendations emphasized both training, regarding roles and authorities, and material, regarding hardware engineered for a specific operation.[4] However, software solutions were available for immediate use during this time for battle space awareness, in the air and ground with existing hardware. Data fusion techniques with existing Automatic Dependent Surveillance-Broadcast (ADS-B) Commercial Off the Shelf (COTS) software would have heightened air awareness. ADS-B does not have an Identification Friend or Foe (IFF) interrogator; however, ADS-B would have shown aircraft using Global Positioning Satellite (GPS) information with limited details for early awareness. Combined with additional data available and a drawing tool for identification concerns, it would deconflict civilian or International Civil Aviation Organization (ICAO) abiding aircraft. This at least would align resources in time and intel requirements for possible threats to a base or aircraft.

The final lesson learned was integrating Non-Lethal Effects (NLE) with JTF planning cells that Electronic Warfare Components (EWC) may not be aware of for better dynamic support with fused capabilities. An increased integration of capabilities during joint and component planning can enhance target development and exploitation.[5] While integration can leverage organizational and doctrine solutions with imbedding liaisons or synchronize planning, organization and doctrine solutions fail to represent future challenges. Understanding the environment is essential and increasing awareness is paramount in future conflicts. Data fusion techniques provide levels of confidence and highlights additional needs to refine objective analysis which will aid in cuing sensors. With limited resources to achieve desired effects, a method to allocate or adjust support is essential for time critical data tied to justification and priority for appropriate authorities. Deploying individuals with classified capabilities "just in case" is not feasible until a process identifies the justified requirement. Using data fusion techniques and presented to planners will support cuing data appropriately with the correct sensor or effect desired to enhance understanding the environment in a timely manner.

ALL DATUM IS NOISY

Without the capability to cue data resources, most that surrounds analysts and the warfighter is noise.[6] Unique platforms built specifically for a single type of information gathering leaves windows of opportunities closed without fusing all capabilities into an all domain awareness. Without tying all available information into a fused system of systems, data may be over looked or lost due latency. While in Iraq, General Stanley McCrystal had both issues of lost and overlooked data from the amount of information taken from raids and stacked in a closet waiting for analysis.[7] This event revealed how much data we have, what is lost and how data fusion can link and retains details for current or future queries. Data from a sensor is processed information and when combined with similar information creates knowledge that humans can infer or learn from.[8] Data is also time sensitive and without added technology to process, link and manage, runs a risk of its useful information.

Data fusion can take processed information or raw information from a sensor, the difference is processing speed to correlate information. Sensors that provide specific analysis, such as a Radar Warning Receiver (RWR) can speed-up data fusion. A sensor can passively detect, run signals through a processor, deconflicts from an onboard database of signals and resolves ambiguity for the operator. Humans are accustomed to relying on machines in time critical situations to give us their best estimates vice waiting on an analyst. Instead of an analyst listening to a Pulsed Repetition Frequency (PRF) and using their own memory to decern a signal, a machine can do in seconds.[9] However, confidence in machines build over time with human interaction that validate and manage logic responsible for processing data accurately. Data fusion is no different and calculated risks between speed and accuracy, based on desired effects, will have similar confidence issues. As humans work to build confidence in new methods of combining information to knowledge, data storage is essential. Not only is storage vital for the massive amount of digital information available, but also arranging information into the varied typology that visualizes data.[10]

DATA FUSION EXPLAINED

To provide a meaningful representation of fused sensor output, an understanding of multi-dimensional information derived from sensors through data fusion techniques needs discussed. Suggested recommendations to OIR lessons learned are based on technological advances using network capabilities and sensor integration. An overview of data fusion techniques and software algorithms used to interpret and cue sensor data will extend into future MDC2 applications.

Data fusion combines information from multiple sensors and related details from databases to improve interpretations than the use of a single sensor alone.[11] While the use of data fusion is not new, technology in new sensors and processing hardware, along with software techniques, make real-time fusion possible.[12] Today, data fusion systems are used for target tracking, automated target identification and limited automated reasoning applications. Over the past five years, the Department of Defense has advanced data fusion applications to an emerging engineering discipline with standard terminology (see fig. 1.)

FUSION	The integration of information from multiple sources to produce specific and comprehensive unified data about an entity.
ALIGNMENT (Level 1)	Processing of sensor measurements to achieve a common time base and common spatial reference.
ASSOCIATION (Level 1)	A process by which the closeness of sensor measurements is completed.
CORRELATION (Level 1)	A decision-making process which employs an association technique as a basis for allocating sensor measurements to the fixed or tracked location of an entity.
CORRELATOR-TRACKER (Level 1)	A process which generally employs both correlation and fusion component processes to transform sensor measurements into updated states and covariance for entity tracks.
CLASSIFICATION (Level 1)	A process by which some level of identity of an entity is established, either as a member of a class, a type with a class, or a specific unit within a type.
SITUATION ASSESSMENT (Level 2)	A process by which the distributions of fixed and tracked entities are associated with environmental, doctrinal, and performance data.
THREAT ASSESSMENT (Level 3)	A structured multi-perspective assessment of the distributions of fixed and tracked entities which result in estimates of (e.g.): • Expected courses of action • Enemy lethality • Unit compositions and deployment • Functional networks (e.g., supply, comms) • Environmental effects

Fig. 1. Table of terminology and definitions.

Applications for remote sensing, automatic threat recognition, and Identification of Friend or Foe (IFF) use multi-sensor data fusion.[13] Data fusion provides significant advantages and reduces error in location or effect identifying an object based on observed attributes.[14] These attributes observed include direction, range, velocity, or radar cross sections to classify target identity and with respect to the observer determine intent of the target (e.g. threat or no-threat).[15]

The determination of position and velocity from a noisy environment creates a statistical estimation problem.[16] Techniques such as the Kalman filter apply estimation from attributes and a labeled identity from pattern recognition techniques based on clustering algorithms or decision-based methods such as Bayesian inference.[17] The interpretation of a target's intent involves automated reasoning using understood and obvious information from knowledge-based methods such as rule-based reasoning systems.[18] Approaches based on Bayes theorem relate the probability of a hypothesis occurring given observations or features already occurring.[19] Bayesian methods enable the inclusion of past probabilities that are known and updated based on current observations.[20] The Naïve Bayes classifier is common for inferring activity from sensor data.[21] Despite performing well, an argument against Bayesian inference identification is it assumes independence between attributes.[22] The assumed independence of attributes brings about competing hypotheses that are mutually isolated due to independence and considered a weakness.[23] The arguments are based on not how humans assign belief, but allows logic to rule out less-than-likely outcomes for a better representation of data by providing confidence levels. In practice, when building any data fusion system for a specific application, programmers must include additional analysis techniques.[24]

Data Fusion Process Model

Historically, technology transfers have had barriers due to a lack of unifying terminology. In 1986, system developers from the Joint Directors of Laboratories (JDL) Data Fusion Working Group, codified terminology to improve data fusion in connecting military applications and communications.[25] The result was a Data Fusion Lexicon and a process model that is a two-layer hierarchy for data fusion shown in Fig. 2.[26] The JDL process model is very general for a functionally oriented model of data fusion intended for use across multiple applications.[27]

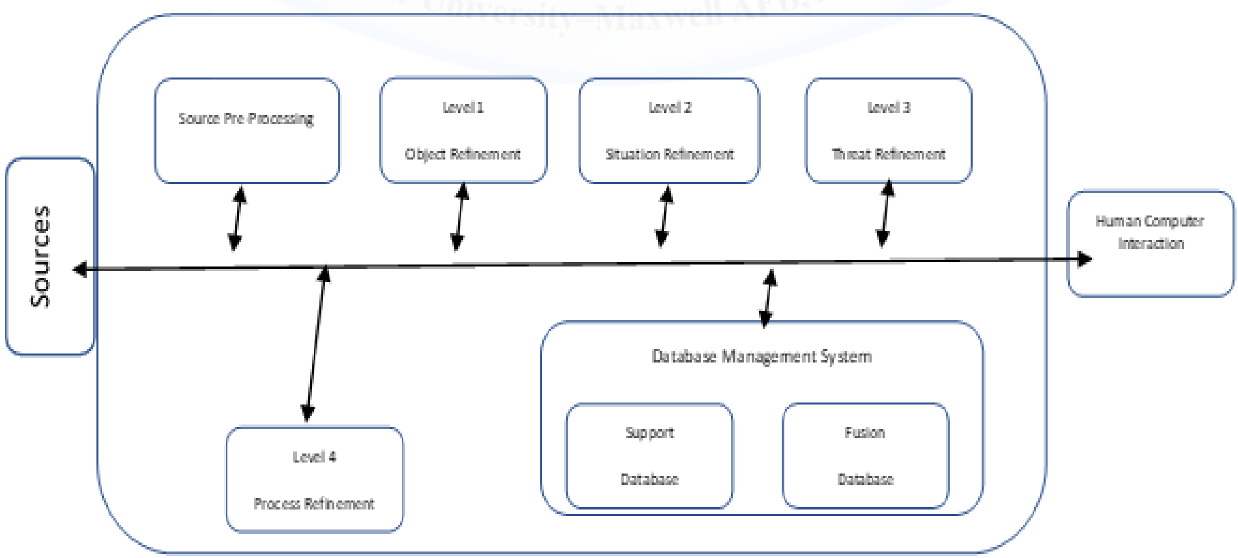

Fig. 2. Top level data fusion process model.

The conceptual JDL model identifies process, functions, categories of techniques, and specific techniques related to data fusion. A summary of the JDL data fusion components are shown in Fig. 3.[28]

SOURCES	The sources provide information at a variety of levels ranging from sensor data to a priori information from databases to human input.
PROCESS ASSIGNMENT	Source preprocessing enable the data fusion process to concentrate on the data most pertinent to the current situation as well as reducing the data fusion processing load. This is accomplished via data pre-screening and allocating data to appropriate processes.
OBJECT REFINEMENT (Level 1)	Level 1 processing combines locational, parametric, and identify information to achieve representatives of individual objects. Four key functions are: • Transform data to a consistent reference frame and units; • Estimate or predict object position, kinematics, or attributes; • Assign data to objects to permit statistical estimation; and • Refine estimates of the objects identity or classification.
SITUATION REFINEMENT (Level 2)	Level 2 processing attempts to develop a contextual description of the relationship between objects and observed events. This processing determines the meaning of a collection of entities and incorporates environmental information, a priori knowledge, and observations.
THREAT REFINEMENT (Level 3)	Level 3 processing projects the current situation into the future to draw inferences about enemy threats, friendly and enemy vulnerabilities, and opportunities for operations. Threat refinement is especially difficult because it deals not only with computing possible engagement outcomes, but also assessing an enemy's intent based on knowledge about enemy doctrine, level of training, political environment, and the current situation.
PROCESS REFINEMENT (Level 4)	Level 4 processing is a meta-process, i.e., a process concerned about other processes. The three key Level 4 functions are: • Monitor the real-time and long-term data fusion performance; • Identify information required to improve the multi-level data fusion product; and • Allocate and direct sensor and sources to achieve mission goals.
DATABASE MANAGEMENT SYSTEM	Database management is the most extensive ancillary function required to support data fusion due to the variety and amount of managed data, as well as the need for data retrieval, storage, archiving, compression, relational queries, and data protection.
HUMAN-COMPUTER INTERACTION	In addition to providing a mechanism for human input and communication of data fusion results to operators and users, the human-computer interaction includes methods of directing human attention as well as augmenting cognition, e.g. overcoming the human difficulty in processing negative information.

Fig. 3. JDL process model components.

In addition, each component can break down into subprocesses. The first level breakdown and associated problem-solving techniques are shown in Fig. 4.[29] For example, Level 1 processing is divided into four types of functions: data alignment, data/object correlation, object position, kinematic, and attribute estimation, and finally, object identity estimation. The object position, kinematic, and attribute estimation function is further subdivided into system models. At the lowest level (shown in third column of Fig. 4), a Kalman filter or other multiple hypothesis trackers perform each function to resolve any ambiguity.

JDL Process	Processing Function	Techniques
Level 1: Object Refinement	Data alignment	• Coordinate transforms • Units adjustments
	Data/object correlation	• Gating techniques (52) • Multiple hypothesis association probabilistic data association (63,64) • Nearest neighbor
	Position/kinematic and attribute estimation	• Sequential estimation (19,73,75) - Kalman Filter - αβ filter - Multiple hypothesis (79) • Batch estimation (69,70,71) • Maximum likelihood (80) • Hybrid methods (76,77,78)
	Object identity estimation	• Physical models • Feature-based techniques - Neural networks - Cluster algorithms (56,57) - Pattern recognition (87,88,89) • Syntactic models
Level 2: Situation Refinement	Object aggregation Event/activity interpretation Contextual interpretation	• Knowledge-based systems - Rule-based expert system - Fuzzy-logic (60) - Frame-based • Logical templating (114,115) • Neural networks (96,97,98,99) - Blackboard systems
Level 3: Threat Refinement	Aggregate force estimation Intent prediction Multi-perspective assessment	• Neural networks (96,97,98,99) - Blackboard systems (122) • Fast-time engagement models
Level 4: Process Refinement	Performance evaluation	• Measure of evaluation (2) • Measures of performance (2) • Utility theory (59)
	Process control	• Multi-objective optimization (59) - Linear programing - Goal programming
	Source requirement determination	• Sensor models
	Mission Management	• Knowledge-based systems

Fig. 4. Examples of data fusion algorithms and techniques

The JDL model described is generic and intended as a basis for common understanding. The separation of processes into Levels 1-4 is artificial and during data fusion it integrates and combines functions into a processing flow. To improve the process even more, an ordered arrangement identifies categories of techniques and algorithms performing the identified functions.[30]

Finally, interpretation of fused data for situation assessment requires automated reasoning techniques that leverage knowledge-based systems (KBS) to interpret Level 1 processed results.[31] The goal in building an automated reasoning system is to capture human expert reasoning by specifying rules which represent the essence of the informative task.[32] Within a knowledge base, an inference or evaluation is developed to use knowledge in a formal process on how to use the knowledge base to gain a conclusion or estimation. Deep learning offers an alternative approach at multiple levels of a deep network by training machines based off an abundance of data.[33] This approach is already underway in AF TENCAP programs with potential to populate results into a knowledge management tool to increase predictive analysis.

The amount of knowledge needed to capture reasoning on an event or action is vast. Information requires a repository that leverages rules assigned to algorithms to ensure fused data provides the best estimation or conclusion. This means the most extensive support function required in supporting the data fusion process is data management. Data management provides access to, and management of, databases for retrieval, storage, protection, and related queries for data fusion. Due to the particularly large amount of sensor data ingested and required rapid retrieval, elastic computing solves this problem.

ELASTIC COMPUTING

Elastic computing or cloud-based technology solves storage, retrieval of data from cuing, and supports different typology for visual depiction of data.[34] Developed out of physics and economics, the term elasticity in computing refers to the ability of a system to automatically allocate and reallocate computing resources on demand as computing demand changes.[35] The concept of elasticity has transferred to the context of cloud computing and elasticity is one of the central attributes to cloud computing. Due to a customer’s need, elasticity shares computing power with other resources and scales capacity.[36] Elasticity can also manage, measure, predict, and adapt applications based on real-time demands placed on resources using a combination of remote computing resources.[37] Scaling a system and the ability for a system to sustain increased workloads with adequate performance make elastic computing unique to data management along with computing applications.[38] This shift from mainframe to client services integrates globally distributed resources into seamless computing platforms ensuring if one center loses power the other servers can automatically pick up the computing load.[39]

Clouds or elastic computing capability have five characteristics that provide data fusion a powerful tool: on demand self-service, broad network access, resource pooling, rapid elasticity, and measured service.[40] The benefits of elasticity for the combat cloud are immense and a great step towards amplifying capabilities. The ability for data fusion in a Web viewer that originates from elastic computing means more storage of data and access wherever members are at with web connectivity.[41] There is no longer an Information Technology (IT) problem keeping software or servers up to date allowing organizations to use manpower effectively, or innovate in a flexible medium for applications in computing methods.[42] The only responsibility for the client is paying for the utilization of the service.

TALON THRESHER

A history of Talon Thresher begins in 2012 with a team from the Air Force Tactical Exploitation of National Capabilities (AF TENCAP) that set off to provide a tool for the warfighter on airborne threats.[43] The mission of AF TENCAP is to provide warfighter capabilities by exploiting current and future space and air-breathing national, commercial, and civil systems as quickly as possible. AF TENCAP assists commanders by providing situational awareness for decisions, while providing intelligence preparation of the battlefield, targeting assistance, and threat location and avoidance tools for the tactical warfighter.[44] The idea of Talon Thresher matured between 2013-2014 and was ready for small trails in 2016 for Pacific Air Command (PACOM).[45]

Talon Thresher used previous niche concepts designed to present centralized fused data at the highest level of security, but leveraged sanitization for real-time use at the warfighter level.[46] Since 2012 technology had elastic computing and cloud base services stored data as the centralized fusion hub. Using cloud capabilities, the information is scalable and uses commercial management similar to that used by Twitter and LinkedIn for reliable access and data protection.[47] As stated previously, fusion through Bayesian inference gives a best assessment or estimates based on collaborated information from sources. Sanitization then helps to mitigate classification to the lower evaluation due to plausible deniable attribution (examples: visual observations, open source news, or Twitter).[48] Estimates on knowledge, sources, or evidence fused together includes dissension efforts which aids in the human assumptions and judgement for comfort in data presented.[49]

The AF TENCAP team designed Talon Thresher to be both a COP and Common Intelligence Picture (CIP) instead of two programs, one for operations and a separate one for the intelligence community.[50] Talon Thresher is a blend between Title 10 (role of armed forces) and Title 50 (role of intelligence) because it uses sources from both and fuses data for each directorate to work from one picture.[51] There are four elements needed for situational awareness that helped develop Thresher's strategic framework: 1) Accountability (track custody); 2) Identification (consistent); 3) Activity (relationship between accountability and what the platform is doing); and 4) Predictions (what will element do next? redeploy, logistic mobilization, etc.).[52] A fifth effort added is cuing, or information management to resolve ambiguity based on today's technology and use of air, space, and cyber tools. The fifth effort highlights the importance of the right information at the right time and managing unique assets for a wholistic approach instead of stove piped for one use.[53] This fifth effort is essential for C2, giving priorities to all sensors by cuing to aid find and fix, but requires a consolidated picture to display for the warfighter.[54] Due to limited resources in OIR, cuing and sharing information was rudimentary at best and task forces exhausted internal resources by way of aircraft and manpower due to centralized control and execution of owned sensors. Finding the right data and protecting it is critical, but how does one get more data if their air component or Joint Force Commander (JFC) does not own their own data or sensors? Better sharing of information is what Talon Thresher set out to solve and this capability has significant growth potential.

As previously discussed, all datum is noisy, but once processed, information can provide greater inference through behavior-based identification. In the RWR example, Talon Thresher uses the RWR processed information, then estimates though logic from a machine data base of behaviors for precise identification. These behaviors include: acts like a formation, appears as a reconnaissance or tanker orbit, or moves laterally to align an Inertial Navigation Unit (INU) for a radar guided missile shot. Any one of these behaviors, between contextual and kinematic features, provide fused data better resolution and confidence on identifying the questionable target or what the target is preparing to do.[55] This is where Bayesian and behavior based identification is useful to provide estimates for the human interaction on the best deduction that the machine resolved from multiple pieces of processed information.

During development of Thresher, AF TENCAP leveraged relationships between the National Reconnaissance Office (NRO) and other agencies over competing assets as a successful recipe between Title 10 and Title 50. Thresher was a collection orchestration for operations to C2 hostilities and developed a "declare" application for additional information to determine if an act was aggressive or not.[56] An interactive identification gave the same interface for authorities to gain or cue required information on details of the platform in question. To be clear, Talon Thresher is an air-centric interface, but there are applications for maritime and ground forces that sister services can leverage. Talon Thresher is a web-based program that can overlay or blend with similar web-based programs for a global analysis from every service.[57] The web-based program uses log in tools and radio buttons to declutter visual displays which leverages intuition to overcome Talon Thresher's complex program. Web-based capabilities also promote coalition integration through a second party gateway with considerations imbedded for partner-nations.[58] In the interest of sharing information, data protection is a primary concern under Talon Thresher's program and utilizes sanitization protocols to protect and display data at the appropriate level.

To protect data during fusion, the Talon Thresher team developed a high-level secure cloud-based repository that can sanitize information down to the lowest acceptable security level of secret. The cloud-based system gives the ability to add, change and upgrade, or correct information while inside. The cloud repository also leverages future capabilities of machine learning, but more importantly, provides curators an opportunity to update information based on human knowledge, behavioral changes, or forensic analysis.[59] Having the cloud and fusion at the same level provides for object-based production or one object displayed from multiple sources and sensors.

The machine in the loop provides logic-based sanitization with machine level track messaging, plausibility, and uncertainty.[60] Detailed reports have "tear lines" that provide a sanitized version of classified activities while protecting sources, these "tear lines" also exist in data. Protocols set within machine logic ensures that the machine strips out methods or sources prior to displaying classified information at the appropriate level. The machine can then estimate further through logic if "plausible" data exists that the object could have a non-classified reporting source. Fused data from Link 16, partners, and Open Source Intelligence (OSINT) aids in tailoring levels releasable, instead of a data owner bookkeeping or denying releasable data for any reason.[61] The sanitization protocols built between AF TENCAP, NRO, and other agencies supplying data into the AF TENCAP cloud bolstered trust and solidified relationships.[62] These relationships are not only a success story of collaboration between inter agencies and partners, but new methods in protecting data for future requirements. By using plausible attribution of non-classified reporting and fusing with OSINT, Thresher provides timely estimates based off sources. Uncertainty integrated into sanitization also provides an additional level of data protection by changing or limiting the number of coordinates (10 digit grid to 5), timing (lag or predictive), or refresh rates to protect sources.[63] Through machine logic-base from sanitized rules of track messaging, plausibility, and uncertainty, protected data is releasable at an appropriate level for both the warfighter and intelligence analysts. Having solved some internal issues with classification, this same construct could alleviate information sharing between partner and coalitions and collaborate for information dominance. However, this raises requirements for new policies regarding fused data release authority, necessary to ensure freedom of information sharing at the appropriate time and space with partners and coalition.

WARFIGHTER USE OF DATA FUSION

At Fort Bragg in North Carolina, the Joint Staff J7 Joint Interoperability Division (JID) teaches two courses essential for the warfighter and commanders overseeing battle space. They train Joint Integrated Control Officers (JICO) and Joint Data Network Officers (JDNO) in duties assigned to a Combined Air Operations Center (CAOC) or JAOC for commanders' situational awareness and managing data feeds. The JICO is responsible for non-tactical and multi-tactical data links to communicate and exchange information between sensor operators along with resolving any ambiguity during fix and track of airborne assets on a COP. JICOs link in with the Joint Interface Control Cell (JICC), which develops and manages the multi-tactical data link architecture.[64] The JDNO manages all data feeds assigned to a CAOC or JAOC. These data feeds can be from any sensor, radar, weather, or Unmanned Aerial Vehicles (UAVs). The JICO course has been available for over ten years, but the JDNO course has had a varied tenure and recently reinstated from a four-year vacancy.[65] Only 60 JICO's graduate a year between all services and building subject matter experts on COPs and how best to manage or build future information displays takes time. There are no software solutions discussed in training and the two courses are separate for some reason. Nevertheless, the JICO and JDNO training is vital to current operations, but may perish if training does not adapt and integrate with software solutions through data fusion for operational use.

United Stated Air Force Central (AFCENT) has employed data fusion in the past years including Talon Thresher and additional programs. Major General Chance Saltzman, AF Deputy Combined Forces Air Component Commander (D/CFACC), led the Enterprise Capability Collaboration Team (ECCT) responsible for MDC2 design. Gen Saltzman leveraged his space and research experience on the subject to amplify what resources were available to increase awareness in his CAOC. In the past five years, there have been major advancements in data fusion and visualization within the Department of Defense.[66] AFCENT is utilizing these advancements with commander's awareness and requesting teams to learn and employ new programs. The team forward are providing fused data to tactical crews, but consistent education occurs based on human nature to believe what the machine provides. The running theme teaching crews on interpreting data is "the absence of intelligence data does not mean an absence of activity."[67] AFCENT is not using Talon Thresher as a COP due to latency issues and classification restrictions among coalition partners in a CAOC. AFCENT sees Talon Thresher as a vital supplement to awareness and may provide future common architecture for coalition aircraft and ships.[68] As time and requirements progress, the AFCENT team continues to work with agency partners to differentiate and correlate activities along with increasing bandwidth for Tactical C2 assets. AFCENT leadership is leveraging data fusion and capabilities that will test future concepts and applying innovative software solutions appropriately.

Another location which is utilizing Talon Thresher is the combined United States Air Forces Europe and Africa Command's 603rd Air Operations Center (AOC). Unfortunately, with coalition partners established on their floor, Talon Thresher and other data feeds are in the Sensitive Compartmented Information Facility (SCIF) with the Senior Intelligence Duty Officer (SIDO) and Intelligence, Surveillance, and Reconnaissance Director (ISRD). The 603rd trains new analysts on Talon Thresher and use it more as a CIP instead of a COP, which is not the original design for Talon Thresher.[69] Having the Intelligence Community (IC) using a program designed for operations more than operators highlight which directorate is aware of capabilities or is promoting an evolution of the program. However, not every unit that uses Talon Thresher knows how to provide feedback or receive updates in the field. Despite reach-back concerns, it is positive for any directorate that amplifies training and education on data fusion capabilities or software solutions for future Joint All-Domain Command and Control (JADC2).

AF TENCAP has been providing applications of data fusion capabilities to the warfighter since 2016 when the development team launched its Talon Thresher program in PACOM.[70] Since that time, Thresher has acquired over 600 subscribers, including the development team, and employed throughout PACOM, AFCENT, and the 603rd AOC in Ramstein AB, Germany.[71] AF TENCAP is willing and able to provide training to any force that is wanting the capability and hosts forums for any warfighter to gain experience in data fusion or software solutions. AF TENCAP is not the only force supporter that can provide software solutions, but has a reputable program that leverages designs and working toward supporting the Advanced Battle Management System (ABMS).[72] A view point, similar how the 603rd AOC is using Talon Thresher, is the J2 elements are harnessing data fusion and data networks faster than the J3 ops divisions.[73] This is not a wrong approach, but limits tactical considerations and JADC2 capabilities if common architecture is not available in commanders main operations centers.

Recommendations

Senior leaders are keen on developing JADC2 for Joint Warfighting.[74] JADC2 is a priority for the Chairman of the Joint Chiefs, General Mark Milley, and General Goldfein echos his priority as "First and foremost, you have to connect the joint team… to have access to common data so that we can operate at speeds and bring all domain capabilities against an adversary."[75] JADC2 needs a software solution to connect and fuse data, which the National Command has at its disposal today. However, this can't mature without education and training at the Major Command (MAJCOM) levels on where to go for solutions or individual duties closely tied to software intensive operations. Another view is a centralized organization to collaborate among other agencies and support software development is key. Finally, the Air Force must invest software solutions and data fusion capabilities into Wings, not only to defend the base, but practice operating dis-integrated with technology so Airmen are ready for future conflicts.

General Hyten has taken software solutions to new levels in the Joint Capabilities Integration Development System (JCIDS).[76] Risks to failure in the past have driven decisions higher in the military structure, despite authorities written to allow quick acquisition. He is aware that in the 21st century, capabilities are heavily dependent on software.[77] Data fusion is a small piece to what General Hyten is concerned with and highlights getting solutions is not hard, but individuals and leadership need to know where to turn too. The lack of training and education exposed to the warfighter regarding data solutions is a large part of why multidomain or multisensory integration has not caught mainstream. This research revealed that the data link and data fusion community is very small and varies because of the complex issue in the AF's C2 construct. AF TENCAP is one of many obscure offices that handles unique problems, but these offices do not need hidden from other agencies that need solutions to identified challenges. Information must be interoperable and is one of the tenets of C2 in Joint Publications 3-0.[78] This is the first recommendation that all Major Commands (MAJCOMs) 5,8, and 9 directorates should have a list of offices that can provide unique capabilities for current and future requirements. Instead of units hunting on their own, MAJCOM staffs should link units to problem solving offices the Air Force or joint agencies already have.

In addition, as information is becoming more widely distributed with higher demands, the two current JICO and future JDNO courses may show greater wealth in combined training instead of separated. Cyberspace Officers and Air Battle Managers, predominately attend the courses. With the limited amount of JICOs and JDNOs produced, combined schools will amplify capabilities and synchronize effects. These courses, when combined, may also harness professional development and joint growth for the new 13O career field.

The next recommendation is streamlining joint solutions, by recognizing methods of information sharing, data fusion and sanitization protocols as gateways to link knowledge among services, agencies, and partners. The JCIDS must link NRO and multi-service software solutions such as AF TENCAP to begin the process of discussing data fusion with all intelligence and information platforms. This will leverage the art of the possible and begin challenging classification concerns along with sanitization protocols to get the warfighter and the IC on the same AOC common picture. Declassification and policy regarding information sharing with agencies and partners is a separate discussion, but a discussion that will certainly come up and needed. With the right amount of knowledge displayed, cuing options will increase the warfighter's resources available to reconcile ambiguity and speed up the kill chain. With data fusion and sanitization protocols the ability to share among allies and partners in the same JAOC or CAOC will enhance a robust toolkit to compete against information competitors.

Finally, the last recommendation is all Air Force's Wing Operation Centers (WOCs) or command post, must increase their relationships with their internal IC and leverage daily interactions regarding emerging technologies for Wing Commander awareness. The defense of bases are the first line of growth and development for C2 resources and familiarity. The Air Force must ensure how we train is how we fight and Wing Commanders are an integral part to maintaining readiness. Defending bases and continuing current operations with available technology and innovative thinking will make interoperability to mission command seamless in future conflicts. With one Air Force common picture for each base to utilize, add information, and update will synergize how the Air Force fights in the future with all domains integrated. The IC shows it is leading the way and the Operations directorate can easily learn from and delegate awareness through harnessing what the IC is already using and managing for a decentralized C2.

Conclusion

By reviewing the AFLL 2018 OIR report and discussing with current and former forward deployed commanders, it was clear software solutions or data fusion solutions did not occur or were aware of during 2018. This was not due to any negligence or failure to use every tool at their disposal. Those forward or writing the report either did not know about software and data fusion solutions, or the art of the possible. However, capabilities were available during this time, such as Talon Thresher and have gained use since 2018 with an increase in data fusion technologies and software solutions. Understanding what data fusion is and what it needs to enhance current capabilities into a warfighter's toolkit is the first step to realizing what data fusion can and cannot provide. Data fusion is a software tool that combines the myriad of information for today's CAOC or JAOC in presentable data to commanders. The term "common" is no longer common since the Director of Operations (DO) and the SIDO decide what to use based on individual preference or a staff's familiarity and comfort to understand their Area of Operations (AO). By using data fusion in a single web-based viewer it can display multiple assets instead of multiple screens giving unique information managed by an Airmen. Once software solutions are aware of and embraced, the use of fused data from multiple domains will enhance the warfighters awareness.

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Appendix A.

ACRONYM LIST

AADC - Area Air Defense Commanders

ABMS - Air Battle Management System

ACO - Air Control Order

ACSC - Air Command and Staff College

AF – Air Force

AFCENT - United Stated Air Force Central

AFLL- Air Force Lessons Learned

AO – Area of Operations

AOB - Air Order of Battle

AOC - Air Operations Center

ATO - Air Tasking Orders

AWC - Air War College

BBID - Bayesian Interference Identification

BCD - Battlefield Coordination Detachment

BFT - Blue Force Trackers

C2 - Command and Control

CAOC - Combined Air Operations Center

CAS - Combat Air Support

CFACC - Combined Forces Air Component Commander

CIP - Common Intelligence Picture

COP - Common Operating Picture

COTS - Commercial Off the Shelf

CSAF - Chief of Staff of the Air Force

DCA - Defense Counter Air

DO - Director of Operations (J3)

ECCT - Enterprise Capability Collaboration Team

EWC - Electronic Warfare Components

GPS - Global Positioning Satellite

IADS - Integrated Air Defense Systems

IC - Intelligence Community

ICAO - International Civil Aviation Organization

IFF - Identification Friend or Foe

INU - Inertial Navigation Unit

ISR - Information, Surveillance, and Reconnaissance

ISRD - Intelligence, Surveillance, and Reconnaissance Director

IT - Information Technology

JADC2 - Joint All-Domain Command and Control

JAOC - Joint Air Operations Center

JCIDS - Joint Capabilities Integration Development System

JDNO - Joint Data Network Officers

JICO - Joint Integrated Control Officers

JID - Joint Interoperability Division

JIIC - Joint Interface Control Cell

JKO - Joint Knowledge Online

JFC - Joint Force Commander

JTAC- Joint Terminal Attack Controller

JTF - Joint Task Force

JOA - Joint Operations Area

LPI - Low Probability Identifications

MDC2 - Multi-Domain Command and Control

NLE - Non-Lethal Effects

NRO - National Reconnaissance Office

OIR- Operation Inherent Resolve

OSINT - Open Source Intelligence

PACOM - Pacific Air Command

PME - Professional Military Education

PNT - Precision, Navigation, and Timing

PRF - Pulsed Repetition Frequency

RWR - Radar Warning Receiver

ROZ - Restricted Operating Zones

SCIF - Sensitive Compartmented Information Facility

SDE - Senior Development Education

SEAD - Suppression of Enemy Air Defenses

SIDO - Senior Intelligence Duty Officer

SOF - Special Operations Force

SOLE - Special Operations Liaison Element

SOJTF - Special Operations Joint Task Force

TEA - Target Engagement Authority

TENCAP - Tactical Exploitation of National Capabilities

TOD - Time Of the Day

UAV - Unmanned Aerial Vehicles

USAF - United States Air Force