Using BML for Command & Control of Autonomous Unmanned Air Systems

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ABSTRACT: *The use of Unmanned Vehicle Systems (UVS) for military and civilian operations has become more prevalent recently and these systems are often in high demand. Thus, optimizing their effectiveness and increasing their availability is of significant interest, and as highly-valued assets, it is also essential to ensure that they are able to operate effectively throughout their entire nominal lifespan. Also, with forecasts for increasing numbers of UVS and a vast range of utilization scenarios, it is important that systems can be controlled in a safe, efficient and timely manner.*

In the military domain, UVS are often operating in unfriendly Areas of Operation (AO) that may be characterized by disruptive communications environments and multiple air and land-based threats. These factors represent challenges for those responsible for successfully operating the vehicles and accomplishing the mission objectives: the UVS operators. Introducing higher levels of autonomy reduces the required human intervention and frees up the operators to perform other tasks such as operating multiple vehicles.

Introducing automation can be seen as a key component to achieving higher levels of autonomy and necessitates automation management strategies to address low-level and high-level control needs but also to mitigate possible negative side effects such as automation bias, complacency and loss of situation awareness. In the area of UVS control, much work has been done on examining automation management strategies and the implications of reducing human supervisory control associated with higher levels of autonomy, while little work has been done in the area of C2-Robotic Systems interoperability. In particular, implementing automation strategies requires flawless communication among automated systems, between the Vehicle Control System and the operator interface, and - at a higher level of abstraction - with command and control (C2) systems. This study explores the concept of utilizing a Battle Management Language as a formal language for machine-to-machine communication across systems as an enabler to satisfy requirements for C2-Robotic Systems interoperability.

The Coalition Battle Management Language (C-BML) is being developed by SISO as a digitized representation of military tasking and reporting information for exchange among C2, simulation and robotic systems. The unambiguous and digitized nature of C-BML makes it an excellent candidate for use in tasking and receiving information from UVS. More specifically, this paper considers some of the emerging requirements for the control of Unmanned Air Vehicles (UAV) and explores the possible use of C-BML as part of UAV Ground Control System (GCS) interface.

1. Introduction

In the context of emerging Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) capabilities and consistent with the shift toward net-centric approaches, the capabilities of robotic forces, and in particular Unmanned Vehicle Systems (UVS), have evolved considerably over the last decade as witnessed by their increasing presence in recent conflicts. For example modern Unmanned Air Systems (UAS) are now capable of performing complex missions with a level of autonomy that requires limited human intervention. These missions require simultaneous control of functions such as: navigation, weapons/sensors payload operation and system health management. At a higher level of operation, unmanned aerial vehicles (UAV) include other supporting systems for activities such as planning, data exploitation and logistics support. This paper explores a technical approach utilizing an XML-based computable language, the Battle Management Language[1] (BML), with Command and Control (C2) systems as an enabler for achieving higher levels of autonomy and interoperability of UVS. This work considers the case of UAVs but the approaches identified should apply to other classes of UVS as well.

1.1. Types and classes of UAVs

Different classes of UAVs are now available and offer a multiplicity of capabilities to meet mission requirements covering an increasing number of usage scenarios and Concept of Operations (CONOPS) spanning a large range of force structures. UAVs can be categorized by capability or functional area (e.g. Target and Decoy, Reconnaissance, Combat, Logistics and R&D) and by size or operating range. Specific UAV classes or tiers of UAVs are used by the United States Armed Forces for instance but vary from service to service[2].

The US Army defines three tiers for: (I) small, (II) short range tactical and (III) long range tactical UAVs, while the US Air Force for example defines the following tiers:

- Tier N/A: Micro UAVs (MUAV),
- Tier I: Low altitude, low endurance (LALE)
- Tier II: Medium altitude, long endurance (MALE)
- Tier II+: High altitude, long endurance (HALE)
- Tier III-: HALE + low observability.

The US Army Future Combat Systems (FCS) classification[3] defined a unit-based UAV class, as follows: Class I: Small units, Class II: Companies, Class III: Battalions and Class IV: Brigades.

1.2. Command and Control of UAVs

Introducing additional UAV capabilities can result in added complexity when they are integrated into new or existing military business processes. This may involve the development of new doctrines, tactics, techniques and procedures, which dictate the proper use of these capabilities, including the command and control aspects. It is reasonable to assume that C2 systems will be required to manage part of this additional complexity such that commanders can do their jobs in a timely and efficient manner.

The great diversity of UAV types and capabilities leads to a large set of C2 system requirements to meet the needs of the numerous employment scenarios. This paper considers information exchange requirements associated with the use of tier II and higher UAVs such as MALE and HALE, whose operation requires several operators and for which information exchange involving higher-echelon tactical units and includes Air Tasking Orders (ATO) and Airspace Coordination Orders (ACO). The use of BML in association with MUAV in support of dismounted soldier systems is an area of possible future work.

1.3. Battle Management Language

BML is an XML-based computable language that specifies a set information elements and a grammar (i.e. a set of production rules) that allows for the construction of expressions of plans, orders, reports and requests. The concept of BML was introduced approximately 10 years ago as a formal language to support interoperability requirements for the information exchange across C2, simulation and robotic systems [1].

In 2004, the Simulation Interoperability Standards Organization (SISO) Coalition Battle Management Language (C-BML) approved the formation of a Study Group (SG) to investigate the use of a BML approach for interoperability among C2, simulation and robotic systems. The results of this group led to the formation of a C-BML Product Development Group (PDG) in 2006. The same year, NATO chartered MSG-048 to assess the applicability of SISO C-BML to support C2-simulation interoperability for coalition operations.

This paper discusses how a BML-enabled approach could be utilized to support UAV command and control requirements in light of the increasing complexity associated with greater numbers of UAVs and new capabilities.

The structure of the paper is as follows: Section 2 highlights some of the requirements for future UAV employment in general, and will discuss in particular, new UAV capabilities, the resulting architectural, systems and process changes, the new controls that are required for these platforms as well as the role of simulation during the various phases of new capabilities development. Section 3 focuses more specifically on interoperability issues involved between systems in the three domains: C2, Robotic forces and simulation. Section 4. represents the main contribution of this paper as it discusses the concept of BML-enabled UAV systems, and section 5. highlights the main benefits that could be derived from this concept. The last section finally provides some conclusions and recommendations for future work.

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[1] BML refers to the more general class of Battle Management Languages of which C-BML is an instance.

[2] http://en.wikipedia.org/wiki/Unmanned_aerial_vehicle#United_States_military_UAV_classifications

[3] http://defensetech.org/category/fcs-watch/

2. Requirements for Future UAV Employment

The following sections highlight some of the requirements associated with the future employment of UAVs. In some instances, these requirements are based on technologies and employment scenarios that are presented in the context of ongoing research and development efforts.

2.1. Emerging UAV Capabilities

In addition to the increasing numbers of UAVs being deployed in theater, there are also a number of initiatives to utilize UAVs in new ways described below.

2.1.1. Dismounted Soldier Systems – Micro UAVs

MUAV are becoming part of the dismounted soldier equipment package[4] to provide for instance, for safe reconnaissance and allow the dismounted soldier to conduct localized reconnaissance without being exposed to hostile fire.

The US DoD Small Business Innovation Research (SBIR) call for proposals for *"[...] innovative and robust algorithms, architectures and hardware/software implementation approaches for a small unmanned air vehicle compatible targeting, prosecution and effects payload [...] Identify emerging protocols, standards, and frameworks that can simplify the interchanging of targeting/effects payload components and reconfiguration of small unmanned air vehicles for multiple platform targeting and prosecution roles and missions including real time fires adjustment, battle damage/collateral damage assessment, and potential re-targeting."* [2].

2.1.2. Swarming UAVs

The concept of swarming UAVs aims to accomplish complex mission goals through the cooperation and coordination of autonomous UAVs. This will require the automated exchange of information across UAV platforms and in collaboration with mission control software [3][4].

2.1.3. Fighter UAV Support

There also has been interest in the use of UAVs to increase the reach and coverage of an existing fleet using UAVs [5]. This study investigated the extent to which UAV might fulfil a tactical support role as "wingmen" to fighter aircraft.

2.1.4. Real-Time Target Identification & Designation

Technologies such as Automatic Target Recognition[5] (ATR) will shorten the sensor-effector loop. The US Army UAS 2010-2035 Roadmap indicates the need for real-time target acquisition associated with semi-autonomous and ultimately, fully autonomous UAS [6].

2.2. Airspace & Weapons Deconfliction

CONOPS involving swarming UAVs or joint and coalition operations involving a large number of forces operating in or near the same airspace has raised requirements for Airspace and Weapon Deconfliction, including the need to shorten the cycle for generating and updating Airspace Control Plans (ACP) and ACOs – including dynamic replanning of missions in light of evolving airspace availability [7].

2.3. UAV Operator Interfaces

As UAV operators will still be required for some time to come, there is a significant drive to improve and adapt UAV interfaces to new UAV capabilities, increasing quantities of information associated with UAV operation and introducing *intelligent*, *adaptive* interfaces and modes of operation with higher levels of autonomy [8][9].

2.3.1. Reducing UAV Operator Load

Typical UAV operators are confronted with upwards of 1400 information elements in the course of UAV operating tasks [10]. In some instances, this can lead to a situation of information overload wherein operators could benefit from automated processing of information to reduce the cognitive load and free up the operator for other tasks.

The need for Intelligent Adaptive Interfaces (IAI) has been identified wherein information is presented in a prioritized and optimized manner that is best-suited to the specific context in order to ease the operator cognitive load and facilitate execution of tasks [9].

Cummings argues that adaptive operator interfaces are required to ensure that prioritized information (including instant messaging) can be displayed in a way that is not disruptive but rather enhances operator proficiency [11].

2.3.2. Single Operator Control of Multiple UAVs

As highly autonomous UAV capabilities become available, there is a need to transition from multiple operators for a single UAV (e.g. Predator-B MALE) to single operators that control multiple UAVs [8][12].

[4] http://www.defence.pk/forums/land-forces/12558-soldier-system.html

[5] http://www.oei-edu.com/r411.htm

The relevance of this requirement is illustrated by the recent change in policy of the US Air Force that no longer requires UAV operators to be military pilots and instead provides basic simulator-based flight training[6]. It is has been noted that the flight simulator in this case replicates very closely the actual operator interface and environment, including the visual displays.

2.4. Developing New Doctrine, Tactics & Procedures

As additional UAV capabilities become available, there is a need to integrate them into the military enterprise's business processes as expressed in doctrine, tactics and procedures. There is therefore also a requirement to ensure that these new business processes are verified and validated. It has been suggested that simulation may be a means for contributing to this Verification and Validation (V&V) process [14].

2.5. Unmanned Air Vehicle System Development

Similarly, in support of these new military business processes, existing UAS and C2 systems will need to be modified and in some instances, new systems may be required. In both cases, Verification, Validation and Accreditation (VVA) is an essential part of the development and acquisition process for which simulation, again, can play a supporting role.

2.6. Autonomy & Automation

A common unifying theme with respect to the future employment of UAVs is the requirement for higher levels of autonomy supported by highly automated systems.

An UAS exhibits autonomy when the system software is capable of making - and is entrusted to make - substantial real-time decisions, without human involvement or supervision [15]. Although in the long-term robotic forces may ultimately replace human forces [6], in the short-term increasing numbers of UAVs will be present in parallel with manned aircraft and deployed human ground forces.

Autonomy implies the ability to act independently. However, a system's levels of autonomy can only be defined with respect to a specific set of goals or functions. Reference [16] proposes a framework for defining levels of autonomy based on factors related to the system's ability to: (1) achieve a set of prescribed objectives, (2) adapt to major changes, and (3) to develop its own objectives (i.e. the ability to learn and store/use knowledge).

[6] http://www.combataircraft.com/en/News/2010/01/18/Why-Send-UAV-Operators-To-Flight-School/

2.7. Airspace Deconfliction & Dynamic Re-routing

In addition to requirements for airspace & weapon deconfliction, UAVs will be required to execute decision-making tasks for collision avoidance, automated mission-route modification (e.g. based on system health maintenance, weather reports), Improvised Explosive Device (IED) detection, ATR and anti-fratricide measures (e.g. Blue Force Tracking).

The automation of information processing and dissemination associated with tasking UAVs and receiving data from UAVs will be a key enabling requirement in support of higher levels of autonomy. As discussed below, BML is one means for satisfying part of these information exchange requirements in support of automation.

2.8. Interoperability

As per reference [17], interoperability is defined as: "*The ability of Alliance forces and, when appropriate, forces of Partner and other nations to train, exercise and operate effectively together in the execution of assigned missions and tasks.*"

Lack of interoperability can have numerous and far-reaching implications. For example, significant resources are required to maintain multiple system interfaces to support similar yet different protocols and message formats. In some situations, the lack of interoperability may inhibit or delay the exchange of critical information and result in catastrophic failure and unintentional loss of life.

2.9. The Role of Simulation

Simulation technologies will undoubtedly play an increasingly important and diversified role in the development of C4I capabilities, in particular in the areas of:

- Experimentation of new concepts
- Engineering and development/acquisition of new systems/capabilities
- Analysis and
- Training of new and existing capabilities

In the case of mission planning and Decision Support Systems (DSS), simulation is a key enabler in evaluating possible Courses of Action (COA).

2.9.1. Interoperating Simulation and Other Systems

One of the challenges to achieving the above-stated purposes is ensuring the interoperability of simulation systems with other systems. The lack of interoperability comes at a cost: (1) the cost of defining and maintaining multiple interfaces and (2) the cost of additional resources and human interactors to manually translate between non-interoperable systems (e.g. swivel-chair).

2.9.2. Simulation and Robotic Systems Similarities

Although simulation and robotic systems serve different purposes and provide different functionality, they share some of the same interface requirements. In particular, *constructive* simulations and *autonomous* robotic systems must receive computable expressions that are interpreted in a meaningful and unambiguous manner. Also, both types of systems rely on behavioural models and/or decision-making algorithms.

This commonality creates an opportunity to leverage progress made on C2-simulation interoperability in the areas of C2-robotic systems interoperability. Although the applicability of a BML-enabled approach for use with robotic systems was recognized in the early works on BML [1], relatively little research has been done in this area. Exploring the applicability and practical use of this commonality is one of the principal motivating factors behind this work.

3. C2, Simulation, RS Interoperability

The following sections provide a brief overview of interoperability issues pertaining to the employment of UAVs. Before addressing UAS-specific issues, a brief description of related areas of interoperability is provided.

3.1. C2-C2 Interoperability

In the domain of C2-C2 interoperability, the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM) has been developed by the Multilateral Interoperability Programme[7] (MIP) by an independent group of nations comprised primarily of NATO countries as well as a number of NATO partners. The origins of the JC3IEDM are in land operations. For air operations, the Allied Data Publication 3 (ADatP-3), standardized by NATO under STANAG 5500, is widely utilized. For example, the NATO Integrated Command and Control (ICC) system utilizes ADatP-3. In the US, the Unites States Message Text Format (USMTF) is used by many systems for air operations, while the Over-The-Horizon–Gold (OTH-Gold) is used for maritime operations[8].

3.2. Inter-Simulation Interoperability

The Simulation Interoperability Standards Organization (SISO) has provided two widely utilized inter-simulation interoperability standards in the Distributed Interactive Simulation (DIS) [18] and the High-Level Architecture (HLA) [19]. The latter also requires the definition of the Federation Object Model (FOM) to ensure interoperability. The Real-Time Platform Reference FOM (RPR-FOM) has also been proposed by SISO as a reference FOM for defining a common tactical synthetic environment [20].

3.3. C2-Simulation Interoperability

C2-simulation system interoperability is required to support use-cases for training, mission planning and decision-support. Clearly, this has been the focus areas of SISO with the release in 2008 of the Military Scenario Definition Language (MSDL) for simulation initialization [21] and as witnessed by the C-BML standardization efforts and experimentation work [13][14].

Although not considered as part of this study, SISO also has developed a standard to address simulation requirements for Link-16 and other Tactical Data Link (TDL) protocols [22]. Previous work on C2-Simulation interoperability reports on experiments that were conducted using both C-BML and Link-16 [23].

3.4. Robotic System Interoperability

Robotic system interoperability can be broken down into the following categories:

- *Intra-system interoperability* – interoperability or interchangeability of RS components,
- *Inter-system interoperability* – the ability of several homogenous or heterogeneous RS to collaborate to achieve common mission goals,
- *Extra-system interoperability* – the ability of RS to collaborate with other non-RS as part of a larger (e.g. C4ISR) scale-capability.

The development of a multi-platform UVS operator interface is an example of intra-system interoperability [8] while a swarming UAV capability is an example of inter-system RS interoperability. C2-UVS collaboration touches upon extra-system interoperability and is the focus of this study.

Generally speaking, standardization is a key enabler - or even requirement - for attaining interoperability goals. Standards such as the Joint Architecture for Unmanned Systems (JAUS) [24] and the NATO STANAG 4586 [17] have thus far proven invaluable in addressing intra-system interoperability requirements. Currently, the possibility of merging the JAUS and STANAG 4586 are being considered as well as extending these standards to cover areas in inter-system interoperability (e.g. swarming) and to increase the support for higher levels

[7] www.mip-site.org www.mip-site.org

[8] The Global Command and Control System (GCCS-J) utilizes USMTF; GCCS-M utilizes OTH-Gold.

of autonomy[9]; the latter being a pre-requisite for extra-system interoperability involving UAVs.

3.5. C2-Robotic System Interoperability

Effective extra-system interoperability requires the successful exchange of information across heterogeneous systems of systems. For example activities such as training, planning and decision support may involve information flows among C2 information systems (C2IS), simulation and robotic systems.

This paper reports findings on research concerning the use of C-BML for C2-robotic system interoperability and explores the concept of defining a common standardized BML interface for information exchange between C2IS and robotic systems. Although not sufficient, defining this interface is a significant step toward achieving interoperability across systems.

As per the primary mandate of the SISO C-BML effort, this also would allow for information exchange between C2IS and simulation systems, and would also support information exchange between robotic and simulation systems, as shown in figure 1.

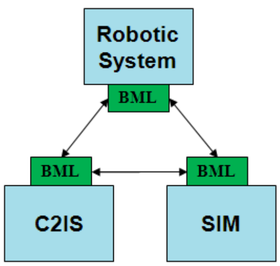


Figure 1: C2-Sim-Robotic BML Interfacing

3.6. C2-UAS Interoperability

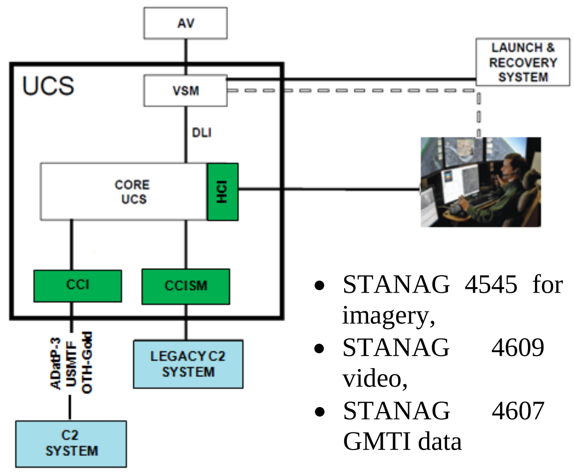
This paper considers the use of BML for information exchange between C2 systems and UAVs through the Ground Control System (GCS) Interface of STANAG 4586 compliant UAV Control Systems (UCS).

Typically, automation addresses the *control* element of command and control. As higher levels of autonomous UAV operation are reached, automated systems may be capable of performing decision-making involving *command* elements such as ATOs and taking into account parameters such as mission objectives and command intent. Indeed, when addressing C2-UAS interoperability, the question arises as to whether the shift in focus in coming years will move from the *control* of UAVs toward the *command* side, or semi-automated mission execution exploiting UAV assets.

Depicted in figure 2, the STANAG 4586 specification is an Interface Control Document (ICD) that defines the following sets of UCS interfaces:

(1) Data Link Interfaces (DLI) for communication between the UCS and the Air Vehicle (AV),
(2) Command and Control Interfaces (CCI) between the UCS and C2/C4I systems.

The CCI-Specific Module (CCISM) provides for interoperability with legacy systems [17]. In addition, STANAG 4586 defines requirements for the Human-Computer Interfaces (HCI) between the UCS and the UAV operators. STANAG 4586 also specifies the use of other STANAG for payload data transfer:



- STANAG 4545 for still imagery,
- STANAG 4609 for video,
- STANAG 4607 for GMTI data

Figure 2 – UCS Interface Functional Architecture

Also specified is the use of USMTF and ADatP-3 for the exchange of tactical messages. For STANAG 4586 compliant systems, the UCS-CCI supports the following types of information exchange: Tasking, Air Traffic Control (ATC), Collateral Data, Mission Plan, Mission Progress, Resource Availability, Payload/Sensor Data, Target Data and Mission Reporting [17].

Before describing the BML-enabled UAV C2 concept, the following section addresses some of the autonomy and automation requirements related to UAV operations.

3.7. UAV Autonomy

As discussed in the previous sections, higher levels of autonomy are required in order to satisfy requirements for new mission capabilities. Achieving higher levels of autonomy requires:

(1) advanced platform automation capabilities such as those discussed in section 2.6.
(2) the means to exchange information across platforms to remotely control these capabilities and to access data (e.g. sensor payload or system health maintenance data), and
(3) the ability to exchange information between the UAS and external systems – including at higher levels of abstraction.

[9] Private communication

Essential to autonomy, automation is discussed in the following section.

3.7.1. Levels of Automation

STANAG 4586 specifies five levels of interoperability as follows:

Level 1: Indirect receipt/transmission of UAV related payload data
Level 2: Direct receipt of ISR/other data where "direct" covers reception of the UAV payload data by the UCS when it has direct communication with the UAV.
Level 3: Control and monitoring of the UAV payload in addition to direct receipt of ISR/other data
Level 4: Control and monitoring of the UAV, less launch and recovery
Level 5: Control and monitoring of the UAV (Level 4), plus launch and recovery functions.

Cummings *et al* [26] argue that these are not sufficient to imply levels of autonomy and that although STANAG 4586 provides for interoperability of lower level control (e.g. inner loops for navigation), that high levels of autonomy require automation at a higher level which is not currently part of part of STANAG 4586.

Table 1- Levels of Automation [27]

Level	Automation Description
1	The computer offers no assistance: human must take all decision and actions.
2	The computer offers a complete set of decision/action alternatives, or
3	narrows the selection down to a few, or
4	suggests one alternative, and
5	executes that suggestion if the human approves, or
6	allows the human a restricted time to veto before automatic execution, or
7	executes automatically, then necessarily informs humans, and
8	informs the human only if asked, or
9	informs the human only if it, the computer, decides to.
10	The computer decides everything and acts autonomously, ignoring the human.

Table 1 from [27] published in 1978 defines ten levels of automation ranging from no machine intervention (level 1) to no human intervention (level 10). Note that levels 1 and 10 automation serve as references and as argued in reference [26], "*...human authority must remain a core value of any design if the autonomous system is to provide useable capability.*"

Other definitions for levels of automation and autonomy have been proposed [12][16], including a combined automation/autonomy scale devised by NASA [28] for next-generation highly autonomous space exploration vehicles that borrows from the military Observe, Orient, Decide, Act (OODA) paradigm[10] to introduce measures for automated decision-making.

[10] http://en.wikipedia.org/wiki/OODA_loop

3.7.2. Automation Management Strategies

Higher levels of autonomy require proper automation management strategies in order to effectively lessen the operator load while avoiding automation-related problems such as: *automation bias*, *complacency* and *reduced situation awareness* [12]. Consistent with [12], the following classes of Automation Management Strategies (AMS) can be defined:

A. **Human-based:** operator must perform actions and tasks,
B. **Management-by-consent:** requires operator approval for task execution,
C. **Management-by-exception:** requires operator override or task will be executed automatically,
D. **Machine-based:** tasks are executed automatically.

These AMS can be equated to the levels of automation from table 1, as follows:

Table 2- Automation Management Strategies

	Automation Mgt Strategy	LOA
A	Human-based Management	Level 1
B	Management-by-consent	Level 5
C	Management-by-exception	Level 6
D	Machine-based Management	Levels 7, 8, 9, 10

For AMS levels B, C and D, the computer takes on an increasing role. Designing systems that will implement these AMS will require exchanging information amongst machines in a manner that does not jeopardize mission critical functions or lead to undesirable situations such as fratricide or catastrophic failure. This includes, for example, information exchange between UVS and between UVS and C2IS. The use of formal languages to meet such information exchange requirements forms the basis for considering BML as the basis for implementing AMS levels.

4. BML-Enabled UAV Command & Control

This section first provides a brief overview of the characteristics of the family of languages referred to as BML.

4.1. BML Overview

BML is an XML-based formal language for exchanging military orders, reports and requests among C2, simulation and robotic systems. Reference [14] presents BML in terms of the following characteristics which are summarized as follows:

- Expressive and precise: a set of unambiguous valid expressions (i.e. based on a formal grammar or production rules),

- Computable: military information that can be parsed, validated and processed in an unique manner based on a common reference model (i.e. semantic interoperability),
- Understandable: expressions that can be interpreted by the consumer as intended by the producer (i.e. pragmatic interoperability [29],
- Multi-doctrine: is not tied to any specific doctrine (i.e. doctrine-agnostic), but supports NATO and national doctrines,
- Multi-domain: BML should support air, maritime, land and joint operations,
- Information Exchange Mechanism (IEM) independent: should not be tied to any one IEM and
- Standardized: should be an international standard to promote interoperability within and across national systems.

Many of these characteristics collectively can be found in message formats and protocols that were discussed in the previous sections. However, the focus of C-BML is on the computability of the language for use by C2, simulation and robotic systems which is not covered by any of the previous standards, many of which are based on formatted text messages.

4.1.1. On the use of Formatted Text Messages & XML

Formatted text messages (FTM) are of the structured type and can be broken down into fields, sets and segments. In fact, they can quite easily be mapped to other structured formats such as XML, discussed below.

In fact, NATO has identified the use of XML as a key interoperability enabler for information exchange among national systems [31]. For instance, it has been suggested that the combined use of the rich semantics of message protocols like ADatP-3 combined with the robust and nearly universal message structure of XML will enable for several key interoperability capabilities. These may be summarized as follows:

- Can easily generate parseable messages
- Validation functionality can be built-in
- XML storage is available, as required
- Powerful filtering/retrieval mechanisms exist
- Can map easily from existing formats to XML

Standards such as ADatP-3 use message formats that are consistent with the communication means that involve human interaction, such as teletype machines. Extremely compact and efficient, the rich semantics of the ADatP-3 allows for the communication of a great number of reports (e.g. logistics, INTEL...) and tasking, such ATOs. Consistent with NATO's decision to explore the use of XML as a standard message format there have been efforts to create an XML-based version of ADatP-3 and other tactical messages [30], but arguably, this is not sufficient for it to be considered as a formal language.

STANAG 4586 indicates that ADatP-3 messages can be used for both "manual and computer-assisted operational environments". However, FTM based standards such as ADatP-3 were likely not defined with computer consumption in mind. Nonetheless, it is possible to exchange ADatP-3 messages between systems, but validation of message completeness and correctness still requires dedicated parsers and does not preclude the possible requirement to apply manual corrections [33].

4.1.2. JC3IEDM and C-BML

The JC3IEDM is a data model developed by an independent group of nations comprised mostly of NATO countries as well as a number of NATO partners. The data model is specifically designed to quantify information related to the conduct of war. The JC3IEDM is a successor of a long line of military data models that has been developed by the MIP for over twelve years. The JC3IEDM is now a NATO accepted interoperability standard (STANAG 5525) and lends itself very well as the underlying data model for C-BML.

Based on the recommendations of the C-BML SG, the PDG mandated that the C-BML specification utilizes the JC3IEDM as the underlying reference model in order to ensure the operational relevance of the information elements comprising the C-BML.

The fundamental building blocks of C-BML, often referred as the 5 Ws (*Who*, *What*, *When*, *Where*, and *Why*) as defined in the foundational work on the Command and Control Lexical Grammar (C2LG) [34], are relatively well represented in JC3IEDM. For instance, the *Who* can be represented by an *ObjectItem* and can be attributed a unique *ObjectIdentifierDigit*. The *What* can be represented as an *ActivityCode*, *EventCode* or *EffectCode*, and the *When* can be represented as a *date-time* group or as a *TemporalAssociation*. The *Where* can be equated to a detailed *Location* and the *Why* can be expressed as a *FunctionalAssociation* to another task or as a desired effect. However, the JC3IEDM covers a broader set of requirements than C-BML and a large portion of JC3IEDM is not required in order to convey an order, a report or a request.

At the same time, the JC3IEDM was not intended to be utilized as a formal language and it cannot be assumed that JC3IEDM information elements are adequate or sufficient for machine to machine communication. Thus, C-BML aims to leverage the richness of the JC3IEDM with the expressiveness and capacity for automation of a formal language.

4.1.3. BML Support for Air Operations

Previous research involving the use of BML for air operations was conducted in the context of the XBML project, for which an extension for air operations was integrated into a prototype capability using the Air Operations BML [23]. This work highlighted some of the issues concerning the use of free-text messages for machine consumption of ATOs/ACOs and reinforced the need for a common data model; it also suggested the use of the Command and Control Information Exchange Data Model (C2IEDM), predecessor to the JC3IEDM.

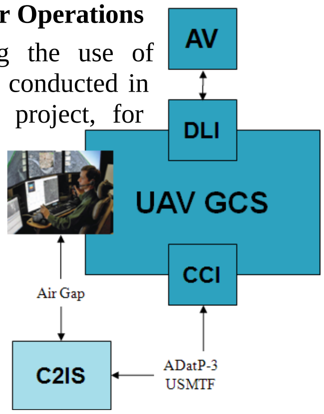


Figure 3- Operator-centric UAV Operation

Although the JC3IEDM does contain the basic information elements for describing mission routes, and basic ATOs, other constructs required for specifying ACOs and other airspace control measures are not present. Ensuring that the current draft C-BML specification includes all of the necessary elements in support of air operations is currently in work.

4.2. BML-Enabled Automation Strategies

The following sections illustrate how BML may be used in support of higher levels of automation into the C2IS-UAS communication loop. The first section briefly describes the human-based UAV operation or Level A AMS, as a reference case.

In practice, it is probable that future highly autonomous UAS will be comprised of systems that will utilize a mix of AMS across systems to meet automation requirements. For the purposes of this study, the reference cases described below refer to representative modes of operation that can be applied to specific UAS functionality or capabilities. For example, within a given UAS, a weapon system may use a management-by-consent strategy while a navigation system may use management-by-exception. Also, automation management strategies may vary for a given function within a given system depending on parameters such as operator fatigue, operational requirements, operational status and operational context.

4.2.1. Human-based UAV Operation

AMS level A essentially represents the current state-of-the-art and involves UAV operators that receive orders on one system and apply these orders on another system, typically through some form of manual intervention.

Figure 3 presents a typical UAV control scenario that relies on UAV operators who receive tasks from C2 systems via air gaps and interact with the UAV-GCS via the HCI. This case serves as the reference case to compare with higher levels of automation.

Certainly UAV systems are equipped with automated navigation systems such as autopilots and other automated systems, however from a C2 operations requirements perspective, these systems are still considered as highly dependent on human-in-the-loop operators. Autonomous UAV operations require introducing automation at a higher level than at the level of inner loop systems such as an autopilot [10]. It requires, for example, collaboration across systems and the capability to perform decision-making when faced with unexpected events.

4.2.2. Management-by-consent UAV Automation

AMS level B represents a level of automation that corresponds to semi-autonomous UAV operations or a semi-autonomous system capability. For example, navigation, health management system and external systems can collaborate to propose a revised mission route to the UAV operator based on dynamic situation updates such as: revised weather data, updated weapons deconfliction, system failures or variations between actual and predicted fuel consumptions.

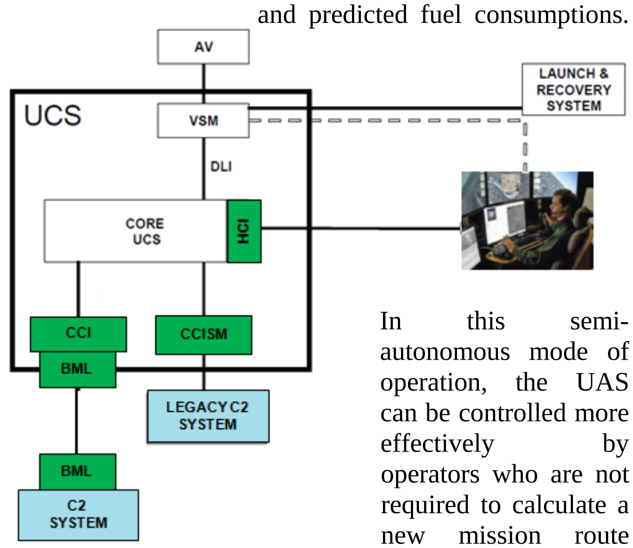


Figure 4: BML-Equipped UAV UCS

In this semi-autonomous mode of operation, the UAS can be controlled more effectively by operators who are not required to calculate a new mission route based on various parameters but who are faced with the simplified task of approving or rejecting mission routes proposed by the system.

It was suggested that this mode of operation be an enabler for single-operator control of multiple-UAVs [12]. This mode of operation may still involve air gaps wherein high level mission objectives (e.g. task matrix) are communicated via a C2IS while the operator still may be required to perform a significant number of manual tasks.

4.2.3. Management-by-exception UAV Automation

AMS level C further reduces the load on the operator by executing tasks unless the operator overrides those tasks; this is consistent with automation requirements to support highly autonomous UAV operations. For illustrative purposes, consider the following example: Navigation systems, sensor systems, target acquisition systems, health management systems, etc. are able to translate high-level tasks (e.g. Tactical Air Reconnaissance at a Named Area of Interest (NAI)) into a sequence of coordinated navigation and payload requests and also generate ATR-assisted intelligent reports (INTELREP).

In this case, the exchange of C2 information via air gaps is virtually eliminated and the operator intervention is essentially limited to monitoring the system and overriding the system, as required.

Considering the potential use of embedded simulations as part of decision support systems, management-by-exception may be best-suited for translating *command* information or tasks into *control* requests.

4.3. BML-Enabled UAV C2 Architecture

Figure 4 illustrates the concept of using BML as the common interface between C2 and robotic systems - in this case a STANAG 4586 compliant UAV-GCS which is fronted by a UAV-BML interface. This provides for delegation of tasks directly from the C2IS directly to the UAS.

In most instances, it is a straightforward task to map the STANAG 4586 message set to a set of BML expressions that can then benefit from functionality such as message validation and other features required to support automated message handling and execution.

Note that, as shown in figure 1, the BML interface can be accessed by either BML-compliant C2 or simulation systems. This approach supports various training scenarios that utilize either emulated or actual GCS. This includes UAV Operator task training, command and staff training (CAST) and could also be utilized for Live, Virtual and Constructive (LVC) training.

4.4. Autonomous BML-Enabled UAV C2

Applying the architecture described in the previous section to the case of operator-assisted semi-autonomous and highly autonomous UAV operations is shown in figure 5; this approach allows for the C2 system to task the UAV directly.

In the case of semi-autonomous operations, the operator must authorize tasks or control requests that are proposed to him by the system in management-by-consent mode. In the case of highly autonomous system capabilities, the UAV GCS provides management-by-exception information to the operator who will intervene only to override a system command.

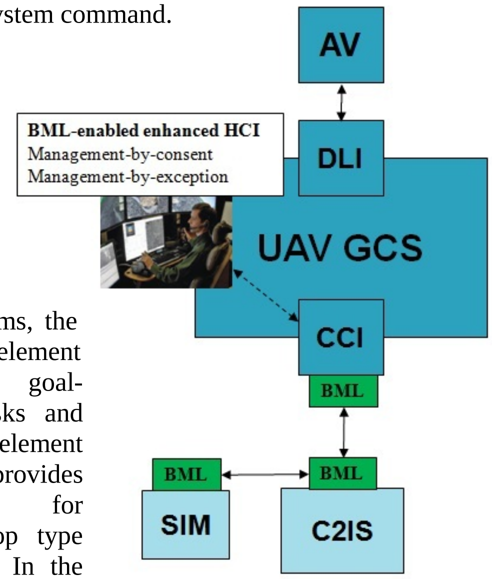


Figure 5: BML-Enabled UAV Operations

In C2 systems, the command element deals with goal-oriented tasks and the control element generally provides instructions for feedback-loop type interactions. In the context of highly autonomous UAV employment as envisioned by this study, the control activity would be performed by the UAV automated systems whereas the command element would be communicated as BML messages from the C2 system.

The dashed line between the CCI and the HCI implies that UAV-GCS likely be required to apply additional business logic in order to provide the operator with the appropriate representation of information and/or perform decision-making. This could entail, for example, prioritization and filtering, video/aural cueing or more significant changes in the Graphical User Interface (GUI) potentially involving the use of agent-based software [9].

The CCI, as defined by STANAG 4586 already enables C2 systems to send tasks and receive messages from the UAV GCS. But, as mentioned above, a computable unambiguous language such as BML may be better suited to machine-machine information exchange than using free-text formatted messages. SISO C-BML standardization efforts are currently considering UAV and other air operations information exchange requirements for inclusion in the next draft C-BML specification. The authors of this paper also have contacted the STANAG 4586 standardization team to explore possible areas of overlap and coordination of future activities.

5. Potential Benefits

As with any digitized interface, BML empowers UAV systems developers for the creation of smart, flexible, and powerful integrated systems for the command and control of UAVs, with the numerous derived benefits described hereafter.

5.1. Simulation-based Capabilities

The BML-enabled architecture depicted in figure 5 can be extended to include simulation systems and thus benefit from C2-Simulation interoperability that is the focus of many BML standardization efforts, such as SISO C-BML.

Figure 5 illustrates the 3-way communication that is possible between C2, robotic and simulation systems. In fact, based on this approach, C2IS could utilize the same interface and messages that would be used to command and/or control a simulated UAV or an actual UAV.

5.1.1. UVS Training

The extended architecture depicted in figure 5 supports many variants of training use-cases. One of the principal benefits of this approach are in the cost-savings associated with ease of integration and the relaxed requirement on maintaining multiple system-specific interfaces to compensate for the lack of a standardized interface and protocol. Additional cost reduction will be possible in some instances as simulator operators may no longer be required. In the case of UAV operator training, the simulation can provide the synthetic environment and also stimulate the C2 system with initial intelligence reports (i.e. situation awareness), ATO and/or OPORD. In the case of a joint training exercise, the UAV tasking could be originated by a command staff.

5.1.2. Decision Support Systems

Decision-making capabilities are an integral part of decision support systems and also are needed to satisfy automation requirements for autonomous operations. These capabilities may be based on internal algorithms (e.g. logic tables) or may utilize embedded or external simulations to perform Course of Action Analysis (COAA) to calculate lists of proposed actions. Thus, there are obvious benefits of being able to seamlessly integrate simulation systems as part of such C4ISR capabilities.

5.1.3. Prototyping and CONOPS Development

The ability to seamlessly integrate simulation systems with UAS and C2IS also supports prototyping and engineering activities through the use of dedicated experimentation testbeds. For example, the employment of the BML technology for UAV operations can be first assessed during concept development experiments involving C2 systems and simulations of UAVs and other entities that could exist in scenarios for UAV application. For instance, the use of simulation testbeds would support the prototyping of specific systems while using the same (BML) interface between the C2 applications and the UAV simulation - which is potentially the same as the interface of the actual system. The same prototyping and experimentation system could then be used to support other phases in the system product life-cycle, such as change requests, deficiency investigation or system evolution.

5.2. Reduced Human Errors & Increased Operator Efficiency

As UAV operation incorporates higher levels of automation, the stress and fatigue factors on the operators will be significantly reduced; this argument is best illustrated by modern aircraft flying with the assistance of autopilot systems.

Also, the direct digitized control of UAVs will necessitate less data input from the operators and less verbal communication between various actors, i.e. the C2 unit and the UAV crew, therefore reducing the risk of typing errors or communication misinterpretation.

5.3. Multiple UAV Operation

UAV are increasingly replacing fixed or rotary wing piloted aircraft, and are being used simultaneously in various roles as discussed above. The management of swarming UAVs poses new challenges, which are undeniably better addressed when platform control lies within a digital interface. The control of swarming UAVs can hence be facilitated through integration in a single application where task optimization and support tools can assist the swarming UAVs Coordination/Management Cell. The latter can then decide on the tasking of the most appropriate available UAV when called-on, or on the best routes selection for the flying platforms when they have to allocate UAVs to cover specific areas, or simply when they have to manage a dynamically changing fleet when UAVs join or leave the battlefield airspace.

5.4. New UAV C2 Architectures

In addition to the actual UAV GCSs, the control of multiple UAVs (e.g. swarming) can also be deployed throughout one or several C2 applications spread at various level of the command chain, thus allowing for faster and more timely utilization of the (UAVs) resources, as with time-sensitive targeting operations for instance, or in the case of a UAV operation authorization process such as a weapons fire request.

The integration of UVS control also offers new options in the design of new C2 architectures where resource employment could be envisioned as a service, with a UAV control transferred to requesting clients on demand, and then relinquished to a central C2 system when their task is executed and they are subsequently no longer concerned with operating the platform.

With this concept of UV employment we can foresee the utilization of simplified UAV control interfaces for troops on the ground when their concern is limited to a specific function or effect (e.g. surveillance using a given sensor, close-air support, etc.) while the remaining UAV controls would remain the responsibility of the central or otherwise remote C2 unit.

The use of C-BML for robotic systems interoperability could entail, for instance, the use of C-BML for the control of Micro UAVs using (ruggedized, secure) smart phones (see for example [25]) that encapsulate UAV-GCS functionality and use C-BML to communicate with other smartphones or with C2IS. The use of PDAs, smart-phones and tablet PCs for the control of UAVs is gaining interest and is being explored by other research efforts [35].

Another potential benefit is that the area of operations covered by the swarming UAVs could be much larger compared to individual GCS crews disseminated across the battlefield controlling the same UAVs. As it is not always possible to predict where a UAV will be needed, the concept of dynamically enabling soldiers unit to become UAV GCS crew increases the Intelligence/Surveillance/ Reconnaissance (ISR) and fire support capabilities significantly.

6. Conclusion and Future Work

Future battlefields will see increasing robotic forces deployment that will utilize varying degrees of autonomy supported by different levels of automation. Furthermore, the digitization of various systems and of their controls imposes the re-thinking of current C4ISR architectures and systems. With the observed successes of BML as a technology to interface C2 and constructive simulations, and due to the similarities between the latter and autonomous systems, it is a natural extension to consider the concept of utilising the BML technology for autonomous/intelligent UVSs, Command and Control: with the emphasis on UAVs as they are the most prevalent robotic systems in current military forces.

BML offers undeniable advantages for UAV control over current mechanisms, in particular when we envision its integration in advanced UAV-C2 systems and when complex ISR architectures are deployed involving multiples UAVs and other platforms. The management of these resources, including the planning, dynamic allocation, decision making loops, actual utilization and workload on the actual operators will all be drastically improved.

Finally, UAV technologies are still evolving and related standardization activities are currently being conducted to refine the interface for the linkage of the various intra-UVS and inter-UVS systems. The present authors propose that the approach presented in this paper be considered as a future initiative for the STANAG 4586 development activity.

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