NATO MSG-085 Standardisation for C2-Simulation Interoperation: Autonomous Air Operations Experiments

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ABSTRACT: *This paper presents recent work by members of NATO Modelling and Simulation Group 085 Autonomous Air Operations Common Interest Group (MSG-085 AAO CIG). MSG-085 commenced in 2010 with the goal of identifying and addressing issues relating to interoperability between Command and Control and Modelling and Simulation systems and autonomous systems, particularly using the SISO C-BML and MSDL standards. In 2012, the MSG-085 experimentation activities have been split into a number of CIGs, each of which is focusing on a particular problem domain: technical infrastructure, maritime operations, land operations, joint mission planning and autonomous air operations. MSG-085 promotes standards-based systems engineering processes to help raise the technology readiness levels of C-BML-enabled systems, engaging with industry, government, academia and the military along the way.*

Earlier work on air operations by MSG-085 and its predecessor, MSG-048, has examined specific issues relating to representing higher level air operations C2 information such as implementing Air Tasking Orders (ATO) , Airspace Control Orders (ACO) and Airspace Control Means Requests (ACMR) using C-BML. This work has included integration of air planning and tasking tools including NATO's Integrated Command and Control system (ICC) into a heterogeneous C2/Simulation federation. Current work is looking at integrating simulated fixed-wing (FW), rotary-wing (RW) and, in particular, unmanned aircraft systems (UAS) into a representative, networked air operations environment. Aircraft simulation is performed principally by the Joint Semi-Automated Forces (JSAF) constructive simulation and bespoke aircraft models. The AAO CIG has been able to draw on experience gained in earlier Canadian national research on the use of agents to support the use of autonomous UAS in a net-centric environment. The CIG also is investigating how C-BML could be used to direct lower-level, more dynamic air tasking such as air-to-air refuelling, troop deployment/recovery using helicopters and close air support.

One of the main goals of CIGs is to reach a stage whereby new capabilities developed under the CIG activities can be integrated with the work of the other CIGs as part of the 2013 MSG-085 experimentation activity leading to the MSG-085 Final Experimentation event.

1. Introduction and CIG Overview

This paper describes recent work of the Air Operations Common Interest Group (AO CIG) of NATO Modelling and Simulation Group 085 (NMSG-085). It outlines the rationale, aims and activities of the CIG and includes example cases how C-BML can be used for specific air operations. NMSG-085 has a remit to:

- Advance the state-of-the-art of C2-simulation interoperation for:
  - Air, Land and Maritime domains;
  - Joint, Multi-national and Coalition Operations; and
  - Force readiness, Support to Operations and Capability Development.

In early 2012 NMSG-085 formed a number of CIGs: Technical Infrastructure; Maritime Operations; Land Operations; Joint Mission Planning and Autonomous Air Operations. Each group comprising operational and technical specialists from across the MSG whose principal aim was to study requirements, use cases and identify solutions relating to the use of C-BML and MSDL in these domains. An important aim of all the CIGs has been to work towards developing supporting knowledge and complementary skills which will be used in NMSG-085's final experimentation programme contribute to the group's legacy.

Over the period the Autonomous Air Operations CIG expanded its remit to cover Air Operations in general. The principal contributors to the AO CIG came from Canada (requirements capture, UAV tasking and reporting software, and system development), the USA (SBML and CBMS infrastructures) and the UK (C-BML translation and tasking software for ICC and JSAF).

A number of specific use cases have been addressed in support of national research programmes of which one, the tasking and coordination of air operations, forms the technical focus of this paper.

2. Capabilities Achieved

The Air Ops CIG has worked on C-BML expressions with the aim of implementing current and future air operations capability using C-BML and to help inform the SISO C-BML PDG in its work. For instance, if an operational message is required which cannot be formulated in the current instantiation of C-BML, say the Phase 1 'Full' schema then this is fed through to the Drafting Group for consideration in future standards developments. Similar work has been undertaken with MSDL.

A number of operational messages have been covered. Three terms which are well-defined for air operations are particularly important: Airspace Control Means, Airspace Control Orders and Air Tasking Orders (ACMs, ACOs and ATOs). Respectively these correspond to geographical overlay components, overlays, i.e. collections of ACMs, and collections of aircraft missions relating to the ACOs. Two main ACO/ATO formats are used, these are US Message text Format (USMTF) and NATO APP-11(C) (ADatP-3) and they differ only in minor details. NATO's Integrated Command and Control (ICC), an air operations planning tool, has been used to prepare the 'raw material', the ACMs/ACOs/ATOs, for these investigations. Other air operations planning and coordination tools have also been used for related work. A basic requirement for the current work is that the C2IS should not be specially modified for this work, hence the standard operational message formats are used and separate message translators provided.

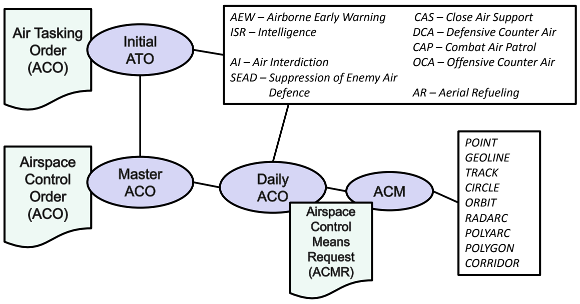

Figure 1 - C-BML-Enabled Air Operations: Operational Messages Covered

Figure 1 shows the relationship between ACMs, ACOs and ATOs and indicates which have already been implemented in the AO CIG testbed architecture.

The study work has been supported by a number of experiments using:

- National and NATO operational planning and execution tools: NATO ICC, TBMCS, JADOCS and a UAV ground control station;
- Various simulations, principally JSAF but also OneSAF and a generic UAV simulation;
- C-BML/MSDL middleware: CBMS (VMASC) [1] and SBML (GMU) [2];
- C-BML translator applications for legacy C2 and simulation – various CAN-UK developments; and
- A Dynamic Multicast Virtual Private Network to permit secure multi-national distributed experimentation to take place.

The experimentation architecture has led to the design of an infrastructure and process description to support the needs of Coalition air operations experiments.

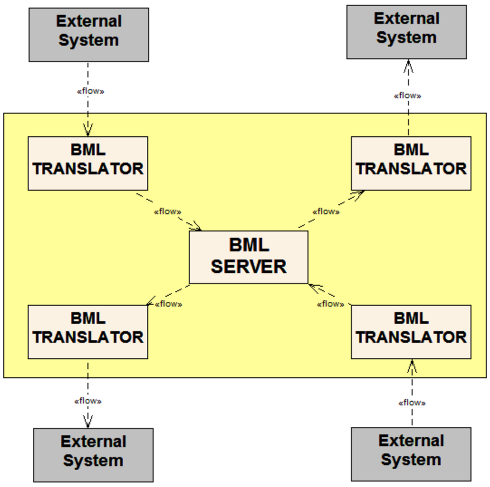

Figure 2 - Generic C-BML Experimentation Architecture

The system architecture is based on a standard, generic architecture as shown in Figure 2 - Generic C-BML Experimentation Architecture. The external systems are the C2 systems, simulations and various supporting client applications. Few of the systems yet have native C-BML capability hence bespoke translation modules are required, e.g. C-BML/MSDL ↔ JSAF. Similarly, the architecture permits either CBMS or SBML BML middleware to be used; both systems have their advantages and drawbacks. Finally, the system is designed to operate across distributed, multi-national network nodes.

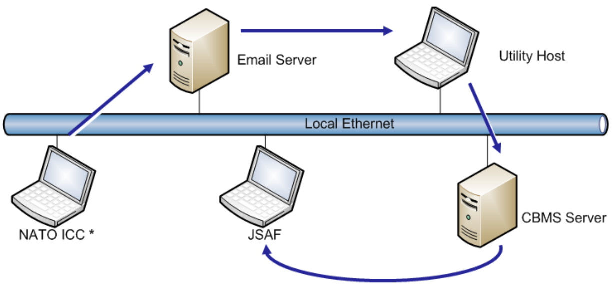

Figure 3 - Example C-BML Experimentation Architecture

Figure 3 shows the basic information flow in the AO CIG experimentation architecture for air operations tasking. ACOs and ATOs are prepared using ICC, emailed to a utility host where they are translated into C-BML and passed via a CBMS system for execution on a C-BML-enabled JSAF simulation.

The experimentation test-bed has implemented parsers for both the 'full' and 'light' versions of SISO Phase 1 C-BML specification. Experiences here are helping to set the requirements of the Phase 2 standard definition.

3. Use of C-BML to coordinate low-level tasking of air operations

C-BML may be used to define low-level tasking for air units. It is relatively straight forward to assign tasks to individual units and execute them as a simple sequence of activities or according to pre-defined time plans. This has been a long-standing capability, e.g. it was demonstrated in the experimental work of MSG-048 in 2009 [3][4].

However, it becomes more difficult when tasks need to co-operate and a coordination system becomes necessary. How should this be achieved: autonomously within the simulation; signalling to a CGF operator or back to a C2 operator, possibly in a white cell?

In this section three such task sets are examined, all of these involve representative interactions between units and task coordination. A number of questions need to be addressed:

Can the tasks be expressed in C-BML using the standard 5W paradigm?

How should the tasks be coordinated?

Can or should the coordination be expressed at the level of the C-BML order or is this better achieved using the CGF behaviour model or through human intervention?

Human intervention is not precluded in C2-Simulation systems, if the simulation is a Semi-Automated Force (SAF) model, such as VR-Forces, JSAF or OneSAF, then human intervention is almost certainly necessary from time to time. The use of C-BML, together with MSDL, however removes a great deal of drudgery and error-prone setting up processes. However other CGF simulations exist which are specifically designed for air operations and these may lead to different, possibly more intricate, tasking requirements. This is because any C-BML system giving orders to a simulation requires that the latter implements behavioural agents to represent, in particular, the missing human element – the trained, experienced and up-to-date aircrew in this case.

JC3IEDM Action-task-activity-code	Description
AERRFL - Aerial refuelling	To conduct refuelling operations involving an airborne tanker and another aircraft.
RNDZVB - Rendezvous procedure bravo	To rendezvous using a heading based procedure which utilises air-to-air equipment of both tanker and receiver. The tanker controls the procedure.
AIRLND - Airland	To move a unit by air and disembark or unload it, after the aircraft has landed or while a helicopter is hovering.
EMBARK	To put personnel and/or vehicles and their associated stores and equipment into ships or aircraft.
CLARSP - Close air support	Air action against hostile targets which are in close proximity to friendly forces and which require detailed integration of each air mission with the fire and movement of those forces.
FRWDAC - Forward air control	To direct the action of combat aircraft engaged in close air support of land forces from a forward position on the ground or in the air.
MARK	To make visible (by the use of light/IR/laser/arty) an object in order to allow its identification by another object (usually as a precursor to the use of direct fire weapons).

Table 1 – Representative JC3IEDM Action Task Activity Codes associated with Example Use Cases

Table 1gives a small subset of JC3IEDM *action-task-activity-codes* which relate to the three use cases discussed next. SISO C-BML uses these codes to define the C-BML *WHAT* terms.

3.1. Air-to-Air Refuelling

Air-to-air refuelling requires a tanker to be given a refuelling mission defined in the ATO, typically, but not necessarily, flying a race track pattern (long, parallel inbound and outbound straight sections, co-level, connected by semi-circular sections to form a loop). JC3IEDM defines an aerial refuelling task and a number of rendezvous tasks (Table 1) associated with air-to-air refuelling. Thus these are available in C-BML for use by the tanker and recipient aircraft.

So, in C-BML the tanker (C-BML *TASKEE WHO*) is given an AERRFL task (*WHAT*) relating to a particular ACM (*WHERE*) in the ATO. The receiver aircraft is given a rendezvous task, e.g. RNDZVB. (JC3IEDM in fact gives seven variants of the RNDZV task all relating to variations which could be used for this task.) The rendezvous, as in real life, can be simulated in two ways: go and meet a specific person (the tanker) or go to a specific place and meet anyone who can provide the required service (any valid tanker).

In C2LG [5] notation these would be represented by:

OB → ***aerial refuelling*** **Tasker Taskee AirRouteWhere StartWhen (EndWhen) Mod Why Label**

OB → ***refuelling rendezvous*** **Tasker Taskee AffectedWho (AirRouteWhere) StartWhen (EndWhen) Mod Why Label**

or

OB → ***refuelling rendezvous*** **Tasker Taskee AirRouteWhere StartWhen (EndWhen) Mod Why Label**

Where **OB** → ***<task type>***, the order body, requires the subsequently listed mandatory and (optional) language components.

The recipient's task, RNDZVB, can thus refer either to the same ACM (*WHERE*) as the tanker's in its AERRFL task or to an *AFFECTED WHO* referencing a chosen or specific tanker. Ideally the rendezvous would be at a location, an ACM in the ACO, where the recipient would expect an 'active' tanker to be operating rather than a specific tanker. It is worth noting that some of the rendezvous tasks require third parties such as C2 aircraft or ground-based radar guidance. The degree of fidelity of representation will be dictated by factors including: the capability of the simulation and the specific user requirements, e.g. is simulation of refuelling an end in its own right requiring doctrine to be followed closely, or is it representative of one activity in a wider course of events?

It has been assumed that when a tanker is on station that its primary function is to provide a refuelling service and so it may be tasked to do that. This is not the usual case for the recipient; refuelling training apart, why would an aircraft's main mission be to go and refuel? The refuelling is incidental to achieving some other purpose: to transport personnel or supplies farther, to remain on station longer, etc. This means that the refuelling tasking of the recipient will not be the main mission objective. It could either form a secondary objective or it could come in a relatively ad hoc manner. In the former case the C-BML task sequence for the mission would be:

1. Fly from take-off base on ingress route
2. Undertake primary mission
3. Scheduled rendezvous with tanker and refuel – (this can be planned as a request)
4. Fly to next mission, etc
5. Fly egress route to landing base

In the second case the rendezvous will temporarily replace the current mission of the recipient who will then resume after replenishment. Initiation of *ad hoc* or emergency refuelling can be triggered automatically by the simulation or in the C2 cell through monitoring C-BML status reports or alerts, for example through C-BML Requests.

Tanker relief is specified by a new tanker (AERRFL) task. Tanker 1: go somewhere // Tanker 2 : go somewhere and relieve tanker 1 // Tanker 3: go somewhere and relieve Tanker 2. This does cause problems in C-BML if the *AFFECTED WHO* is used to refer to a specific tanker. Ideally it should refer to the tanker which will be at the rendezvous when the replenishment is required or the unit to which that tanker belongs.

The logistics of refuelling is another area where C-BML offers potential benefits. An ATO for refuelling includes information about quantities of fuel which are to be transferred. Concurrent work by the NMSG-085 Land Operations CIG has developed C-BML and MSDL to cover a number of logistics-related activities which will readily apply to this use case [8].

Standard NATO TTPs for refuelling [7] are defined and can readily be incorporated in an ATO. Refuellings can be coordinated using pre-defined requests. The ATO provides for this and includes coordinated periods where this can occur. In the above example, item 3, is specified as a pre-defined REQUEST. The mission is composed of a sequence of Tasks with an air-to-air refuelling Request inserted. This is not currently possible in C-BML. C-BML can be used to define requests but it does not permit Requests and Tasks to be mixed in the same C-BML Order structure. Here is an example, therefore, of how understanding of operational usage can affect standards development.

3.2. Troop Transport

Troop transport by helicopters or fixed wing aircraft is another area where task coordination is required. Here there is a requirement to coordinate the air and the ground plans. At a high level, e.g. at Division or Brigade, details may be sketchy – move Unit X from A to B. Should they fly, drive or walk? That is mere detail as long as they arrive on time, well prepared with all their kit. At a lower echelon if air transport is chosen then it is necessary to provide a C-BML ATO to detail transport missions and a corresponding (army) order prepared using a land planning tool to control the embarkation and disembarkation of the troops. Good use can be made of the ability to exchange MSDL overlays between planning tools – there is no excuse for misunderstanding about where the events are planned to occur. Of course an integrated Joint Mission planning tool would obviate this requirement.

In joint operations the coordination planning is a staff function so the ground ops planner will need to schedule a "move unit by helicopter" task in the synch matrix for the ground operation and the air planner will have to do something similar in his ATO.

Table 1 also includes a selection of JC3IEDM C-BML tasks appropriate for troop transport. In this case only AIRLND (the full set includes a number of variations on AIRLND) and EMBARK will be used.

Troop embarkation/flight/disembarkation needs to be coordinated with events triggered by the interaction between aircraft location and control measures. Although C-BML Phase 1 can define dependencies between Order tasks and Reports (e.g. using *ActionCurrentState* elements) it does not do so between Orders.

There is a potential operational issue with coordinate systems. Traditionally soldiers use MGRS or UTM-based coordinate systems for their day-to-day work whereas airmen and sailors use geodetic (lat/long) systems. Currently SISO C-BML Phase 1 uses geodetic coordinates for all messages, orders, reports and requests relying on the client implementations to provide the coordinate transformation services. This is at variance with MSDL which permits coordinate systems to be specified as required.

3.3. Close Air Support

In the earlier work with MSG-048 C-BML [4] air tasks were defined by the air missions given in an ADatP-3 ATO which was prepared using ICC. At MSG-048's final technical experiment it was also shown possible to issue one-off tasking to represent close-air support missions. Here targets identified by the operator of a simulated UAS could be handed over to a simulation for engagement using aircraft simulated in the CGF. This resulted in an event sequence:

1. Target seen by CGF ground recce unit – C-BML spot report returned to C2 cell;
2. UAS operator re-tasks his UAS to fly over and identify suspected target;
3. UAS operator identifies the target and, if appropriate, requests an air strike against it;
4. C-BML air task issued to a specific aircraft, interrupting its current task, to engage the target; and
5. UAS operator performs damage assessment operation.

This sequence does not include the requisite C2 cell staff work relating to rules of engagement, deconfliction, coordination, target prioritisation, etc. It does, however, provide a basic means to stimulate and respond to a C2 cell for this use case.

Further investigations have included how a simulated Forward Air Controller can be integrated. The FAC is required to coordinate available strike aircraft. In JSAF this coordination is achieved through a combination of external tasking and internal messaging. For the external tasking C-BML is used – the necessary *WHAT* codes are FRWDAC and CLARSP, (ref: Table 1, again), replacing the role of the JSAF operator. The internal messaging is achieved using simulated radio messages sent between FACs and aircraft. More complex coordination is required if target marking or designation is required. A separate marker needs to be simulated or role-played and integrated with the other components.

3.4. Common Themes

These use cases provide examples of *pre-planned*, *on-call* and *immediate* missions, examples may be found in [9]. Pre-planned missions such as Air Interdiction (AI) generally can be simulated in a highly automated manner whereas the execution of support missions such as Close Air Support (CAS) requires coordination between the aircraft and the supported unit (i.e. the Forward Air Controller (FAC)), who may be human or simulated. Finally, immediate missions cannot be planned for in advance and result in *dynamic tasking* that refers to missions that arise to meet evolving battle-space requirements. For example, an aircraft performing an ISR task may report the position of a High-Value Target (HVT) and subsequently may be re-tasked to engage the target.

An ATO can specify how or when missions are initiated *on alert* or at a given time. On alert missions can have a readiness status defined in their tasking, for example, on alert with 30mins readiness. In a C2-Sim C-BML system the alert could be called by any of a player in the C2 cell, a white force operator or a simulation agent.

In reality, military planners and operations staff use free text to augment the information in their plans. In the case of an ATO this includes “Amps & Spins” – amplifications and special instructions. A typical example includes their use to give target notes. This is an area which is the subject of much debate and interest in the C-BML community.

4. Way Forward

Future work based on the experiences, challenges and findings of this CIG will investigate further:

Dynamic interactions, e.g.:

- Coordination among units;
- Requires Message Structure and Metadata;
- Airspace Control Means Requests;
- Air Support Requests;

Further supporting the SISO Phase 2 PDG with such activities as building a UML Object Model to simplify the phase 1 C-BML product for use in phase 2.

5. Exploitation

It is important to keep in mind how the C2-simulation interoperation and C-BML will be exploited to benefit the end user. The potential exploitation areas currently targeted include:

a. Training through C2 systems – Simulation and C2 systems are used separately and integrating them will provide more realistic collective operational training through C2 systems. It will reduce costs in CPXs and MRXs by reducing the number of Exercise Support Staff by supporting exercise cells and provide enhancements by introducing ISTAR information into joint and component HQs.

b. Mission planning through C2 systems – integration of faster-than-real-time simulation integrated with C2 systems would allow more comprehensive Courses of Action (CoA) using familiar C2 systems, aiding commanders to make decisions knowing likely outcome and casualties.

c. Capability development and experimentation – a C2-Simulation test-bed would allow investigations of how greater autonomy in unmanned systems could provide more direct control to C2 systems using C-BML. This would reduce the Ground Control Station footprint and associated costs.

d. C2-C2 Interoperability – there is no current standard method to achieve this and C-BML may provide the opportunity to integrate disparate coalition C2 systems more readily. The C2 community would greatly benefit by leveraging the work done by the simulation community for their needs

6. Conclusions

The NMSG-085 Air Operations CIG has extended the existing capability to execute manned and unmanned air operations in constructive simulations based on operational messages sent by actual Air C2IS.

This capability is based on a generic architecture that can utilize SBML or CBMS servers with no code changes. This architecture also easily can integrate future C-BML messaging infrastructures or servers.

This work has been executed using the SISO C-BML Phase 1 Full Schema for which a recommendations report has been issued, to be taken into account in Phase 2.

A set of Air Operations requirements for C-BML has been established as part of a comprehensive C-BML/MSDL requirements model that includes requirements from AIR, LAND and MARITIME CIGS.

The work of the CIG has thus shown the applicability of C-BML to training for Joint and Coalition air operations using operational air C2IS systems. It has helped inform SISO of Requirements for C-BML and it has provided a good basis for cooperative experimentation within NMSG-085 and nationally.

7. References

[1] Diallo, S, CBMS An Introduction to the Coalition Battle Management Services, Presentation, Presentation at BML Conference, Boston, MA, April 2011

[2] Pullen, J.M, SBML Open Source Software for BML, Presentation at BML Conference, Boston, MA, April 2011

[3] NATO RTO Technical Report, TR-MSG-048, Coalition Battle Management Language (C-BML), February 2012

[4] Brook, R.A. Developing Coalition BML for Air Operations, Presentation to NATO MSG-079, February 2010

[5] http://mipsite.lsec.dnd.ca/ - JC3IEDM reference documents available here

[6] Schade, U, Hieb, M, Frey, M, Rein, K, Command and Control Lexical Grammar (C2LG) Specification, Fraunhofer-Institut, 2010

[7] NATO Publication ATP-56(B), Air to Air Refuelling

[8] Liberg, Maj. D., NLD Armed Forces, NMSG-085 Land Operations CIG, NATO MSG-119 C2-Simulation Interoperability Workshop Presentation

[9] http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf

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