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Flexible Use of Limited Airspace (FULA)

Track 1 - C2 Concepts, Theory and Policy

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ABSTRACT

This paper describes how limited airspace, when creatively optimized as a continuum, will allow for flexible usage across military warfighters. For a country without geographical depth, airspace is a premium resource. Therefore it is critical to ensure that this limited resource is managed flexibly and dynamically. Flexible Use of Limited Airspace (FULA) is an experimental concept that deviates from current modus operandi of "Divide and Operate" rule. The latter is sub-optimal and inflexible in meeting dynamic airspace demands arising from changing operational scenarios.

In FULA, we re-look at the basic assumptions of airspace management in both centralised and de-centralised mode to solve airspace congestion and conflicts at various levels. Under centralised management, we incorporate the use of logic engine to detect conflicts and provide de-confliction options. In aiding superior battlespace orchestration, Advance Cognitive Visualizations are designed to assist controllers in focusing their attention on potential conflicts. Under decentralised management, we see a necessary role for automated platform-to-platform deconfliction among the slow-movers (helicopters and Unmanned Aerial Vehicles or UAVs). It is envisaged that FULA concept, supported by our Integrated Knowledge Command Control (IKC2) backbone, will help to flexibly and dynamically manage airspace, leading to breakthroughs in C2 processes and operational concepts.

INTRODUCTION

AIRSPACE IS A CRITICAL BUT LIMITED RESOURCE

For a big country with relatively huge geographical areas, airspace is usually perceived to be limitless and the notion of a congested airspace seemed only remotely possible. However our analysis tells us that even in big countries, airspace congestion can still exist for as long as there is a convergence within a geographical area. For example, traffic arriving and departing out of a busy airport or military traffic converging into designated area and having to fly through civil air traffic zones or transit corridors for mission training. As such, realistic considerations were made in our studies on various operations involving entities from both civilian and military traffic patterns and demands. Our conclusion shows that the volume of airspace residing within the area of operations is indeed limited and bounded because of traffic convergence. In fact, peering deeper into the requirements of these operations, one can appreciate that at various phases of missions, many competing demands for airspace exist across services and sometimes even cross coalition during joint operations. Examples of such operations include Humanitarian efforts in areas of operations that are affected by natural disasters, Peace Support Operations in troubled areas and Maritime Security along Sea Lines of Commerce. Essentially the point of convergence within a mission area could be small and congested even though the entire area of operations or country could be big. Moreover apart from broad spectrum of operations, the

increasing proliferation of unmanned platforms operating alongside manned aircraft could only add complexity during operations. The airspace therefore becomes a critical resource. This resource must be efficiently and optimally allocated in real-time among various users based on mission priorities and competing demands and yet being able to ensure air safety.

LIMITATIONS OF "DIVIDE AND OPERATE" CONCEPT

The classical approach towards airspace management is to exercise tight control over usable of available airspace and managing the demands according to pre-planned allocation and approved activities through a central clearing house. By strictly segregating airspace into lanes, channels and zones and rigidly enforcing the used of hard-wall boundaries between these lanes/channels, many agencies have adopted the conventional airspace management method known as the "Divide and Operate" (DnO) rule. Under predictable and full compliance of DnO, this concept of operation is limiting but otherwise popularly adopted because of air safety concerns. Examples of such mode of operations are in abundance. We find that to manage air traffic safely in Operation Allied Force (OAF), North Atlantic Treaty Organisation (NATO) mission planners have to carefully divide the airspace so that only a small number of aircraft operated in specific areas (Wall, 1999).

More often than not, this concept is limited to certain dimensions and does not take into cognisance the full suite of airspace users ranging from manned and unmanned flights to various categories of weapons, for example, artillery fire, surface to surface, surface to air, and air to surface. Cross utilisation is limited due to stringent enforcement of allocated boundaries and long planning cycles. Hierarchical and sequential clearing of requests and re-planning new requirements make it time consuming and inflexible. Efforts to improve communication linkages and bandwidths at most lead to reduce coordination times. But without a radical change in airspace management concept, improvement provided by technological development could only result in no more than just tasks automation.

So how did the DnO concept meet up to expectations in the recent conflicts? Empirical and anecdotal evidence from recent conflicts in Operation Desert Storm (ODS), OAF, Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) suggested that the DnO concept had very challenging problems handling airspace control in the area of operations. In ODS alone, for example, 37 Near Mid-Air Collisions (NMACs) occurred and this is believed to be a fraction of the actual number that actually happened (USGAO, 1997). And as (Jean, 2006) noted, the issue of airspace congestion is not only restricted in the altitudes where campaign level aircraft operates; the issue of congested airspace pervades even the airspace above the army area of operations. (Jean, 2006) noted that in 2003 there were a lot less drones but 3 years later in 2006, drone pilots need to acquire the navigational ability to get the platforms in and out of the operating areas safely. In fact, (Lambeth, 2001) went as far as suggesting that as a result of the aerial traffic jams, lost of aircraft during ingress and egress is more probable than losing them to threat presented by Serbia's Surface-to-Air Missiles (SAMs) and Anti-Aircraft Artillery (AAA) which were very formidable. This is operationally unacceptable.

In OEF, a significantly lesser number of platforms were involved. The number was down to 200 sorties a day, as opposed to 3,000 sorties a day (GlobalSecurity.org, 2005) in ODS. Did the airspace problem recede? No. As (Lambeth, 2005), noted, the area of operations was very small and sudden and unexpected demand for air support led to major airspace congestion problems. Allied aircraft frequently stacked eight miles high over the combat zone. B-52s at the highest altitude of 39,000 feet dropped Joint Direct Attack Munitions (JDAMs) through the flight paths of B-1 bombers and formations of fighters orbiting at 22,000–25,000 feet, EP-3s at lower altitudes, and AC-130s lower still at night, all followed by Predator UAVs, A-10s, and attack helicopters at the lowest altitudes. The overriding concern was not running out of aircraft but rather out of usable airspace. Airspace became a bottleneck.

(Lambeth, 2005)p. 196 -197), further highlighted that often lower-priority requests would be denied because of a lack of sufficient airspace. To add further worry, (Lambeth, 2005)p. 196 - 197) noted that with multiple JDAMs repeatedly falling through this densely occupied airspace, only the most exacting air discipline, combined with a significant measure of good luck, prevented major in-flight disasters. Air Force terminal attack controllers later reported that coordinating and de-conflicting all of those aircraft to allow them to drop bombs on multiple targets within such a confined battle area created a “nightmare”. In OIF, it was not much better. (Wathen, 2005) highlighted that a total of 1801 aircraft flew 41,404 sorties in a 720-hour period. Planning staffs often briefed changes as crews were stepping out the door to fly, resulting in confusion that often-complicated departure routings from host nation fields.

FLEXIBLE USE OF LIMITED AIRSPACE AS A CONCEPT

Networked Forces - The key to FULA lies in the assumption that highly networked forces with persistent Blue-Force tracking and pervasive sensing could develop superior knowledge on intentions concerning the use of airspace. With robust networks and comms architecture, the investment in both the physical and information domains will allow warfighters to build common & recognised knowledge on current and future airspace usage. In the context of the Singapore Armed Forces, this is known as Integrated Knowledge-Based Command & Control (IKC2). IKC2 is essentially about network-enabled and knowledge-based capabilities for warfighters. It strives to achieve dominant battlespace awareness and battlespace understanding by exploiting C4ITC technologies in the areas of sensing, shooting and communications. A pre-requisite for IKC2 is the ability to collect relevant battlespace data and fusing both sensors and non-sensors derived data into correlated information. With IKC2 capabilities, forces will have the capacity to share information, have improved situational awareness, self-synchronised their actions whilst achieving commander’s intent. Warfighters with IKC2 capabilities will find the ease to elevate themselves from mere executioners of tasks to “mission orchestrators” against an adaptive opponent force.

Cognitive Capability - Beyond information and physical domains, FULA develops a logic that is capable of leveraging on strong Blue-Force tracking to project airspace confliction whilst at the same time providing de-confliction solutions based on time and space calculations. This cognitive capability is further enhanced by superior visualisation tools that will allow air traffic, air defence controllers and battlespace commanders to make superior decisions on using airspace

responsibly without barriers and boundaries. This logic and visualisation capabilities shall be described in subsequent paragraphs.

Application of FULA Concept - FULA concept calls for airspace to be flexibly used as a continuum. Initial planning will still need to be done based on spectrum of mission demands, and platforms optimisation that would fit into the overall campaign plan and strategy. Two levels of utilising limited airspace could be facilitated.

a. **Co-operative Planning -** The FULA logic does allow for ***co-operative planning*** across domains prior to launch of campaign plan and doing it in a transparent manner with conformance to the overall campaign strategy. Based on phases of campaign plan, airspace demands and utilisation by air, land and sea component forces could be better prioritised both in time and space. This task could be centrally managed to ensure conformance to campaign strategy whilst campaign plans are still being shaped and formalised.

b. **Collaborative C2 -** However once the campaign is launched, the logic will allow for real-time changes of plan against an elusive enemy. A change in plan could result in real-time conflict of airspace utilisation among warfighters. Instead of going through a central agency for airspace clearance which will result in a bottleneck during operations, FULA logic allows C2 centres and Commanders to collaborate across domains. Commanders and C2 agencies could make real-time anticipatory moves as opposed to sticking to old plans on airspace utilisation. Warfighters at the seams and across respective services could now be empowered to collaborate and self-synchronise in real-time on the use of airspace without fear of fratricide. This is possible because warfighters will have common and recognised air, land and sea pictures to apply the FULA logic for quick-time decisions against a thinking and adaptive opposing force. With strong logic and visualisation techniques, FULA will allow timely collaboration. Sequential C2 processes for clearance of airspace could be de-layered. OODA loop cycle could then be compressed thus allowing for battle tempo to be quickened.

C2 Paradigm Shift – *Co-operative Planning* and *Collaborative C2* using FULA as a concept could cause a paradigm shift in the way C2 concepts are being developed. In the face of competing demands, the traditional C2 view has often led to functional specialisation and tight control. Hence in the face of limited and competing demands for airspace, a naturalistic and convenient way to manage airspace would be one of centralised airspace management and using DnO rule as a blunt instrument. But tighter control does not equate to better C2 of limited resources against an elusive enemy. In fact, it could result in sub-optimisation of resources particularly when the instruments of war have inherent flexibility; a good example being a multi-role platform which could be employed for more than one mission while on station. For the same platform to be flexibly used for missions other than what was initially assigned, a whole host of flexible C2 concepts including flexible utilisation of airspace would need to be developed. Turning inside the enemy's OODA loop cycle becomes critical and this is where airspace management has to be shifted from one of closed control to that of flexible orchestration in the battlespace.

ENABLING TECHNOLOGIES

The realisation of FULA as a transformational airspace management concept is underpinned by 3 key enabling technologies, namely IKC2, Airspace Conflict Detection and De-confliction Logic Engine (hence-forth termed as Logic Engine) and Cognitive Visualisation. All 3 areas are currently undergoing spiral development via Experimentation and Research & Development (R&D) efforts. The assumed eventual capabilities provided by these 3 technological developments will create a sound platform to propel the conceptual and organisational changes envisaged under FULA.

LOGIC ENGINE

The Logic Engine plays an important role of defining the airspace occupancy model for all types of airspace users, including aircraft and munitions. Each type of aircrafts is requires vertical and lateral safety boundaries during flight, in the form of "safety bubbles". Similarly, the airspace occupancy of each type of projectiles and munitions can be defined by the projected flight trajectory circumvented with the Circular-Error-Probable (CEP) of the projectile, hence forming a tunnel when the airspace utilisation is visualised in 3-Dimensional (3-D) manner.

Conflicts occur when the safety bubbles of flying platforms are infringed by the safety bubbles of other flying platforms or by the projected paths of projectiles. This means that even though the platforms and the munitions would not physically collide with each other based on their projected positions, as long as their safety bubbles are breached, conflicts are detected. The Logic Engine contains a set of algorithms to compute and detect these conflicts based on the real-time streaming data of the air and land pictures of the area of operation provided by IKC2.

The Logic Engine also contains sets of algorithms to resolve conflicts by exploring the lateral, vertical and time dimensions of the airspace. The logic explores solutions in the lateral and vertical dimensions and calculates possible lateral and vertical displacements of the aircrafts in conflict that will resolve the airspace infringements. The logic also explores solutions in the temporal dimension and calculates possible speed variations of the aircrafts in conflict that will help resolve the airspace infringements. The logic explores possibilities in all 3 dimensions and presents the solution options to the decision makers.

With these options available and knowledge of the intent of the operations, the decision makers may execute one of these solutions, combine these solutions or implement more strategic decisions.

Under decentralised mode of airspace management, FULA envisaged that the Logic Engine can reside within low level flying entities, especially those of helicopters and UAVs. Occupying the lower realms of airspace, these entities may operate with great uncertainty and dynamism within small pockets of airspace within the area of operations. Centralised management may not be the best way to resolve airspace conflicts for these airspace users. As such, by having an on-board Logic Engine, the management can be decentralised and each entity can self-synchronise based on their common situation picture in the local context and resolve airspace conflicts based on locally optimal measures.

COGNITIVE VISUALISATION

The Visualisation capability envisaged under FULA includes 2D and 3D air picture displays that not only serve as air situation updates for the operators, but it seek to provide information and C2 applications that enable operators make quick decisions while reacting to conflicts and managing airspace flexibly.

A common feature across all airspace management C2 applications is to direct the operator's attention to certain information. This alerts the operator to a problem (i.e., hazard) or shows the matching objects in response to a query. At present, flashing is one of the most prevalently used attention cueing technique for alerting operators to such information. However, studies have found that flashing brings about poorer performance than a less dynamic highlighting technique, possibly because flashing disrupts other aspects of the visual search task (Fisher and Tan 1989). In addition, continual flashing may also unnecessarily cause attention to be captured (Thackray and Touchstone, 1991) resulting in attention tunneling, which operators may overlook other more critical events at other locations (Yeh, et al., 1999; Merlo, et al., 1999; Ockerman and Pritchett, 1998). This will indirectly lead to a loss of situation awareness which is undesirable.

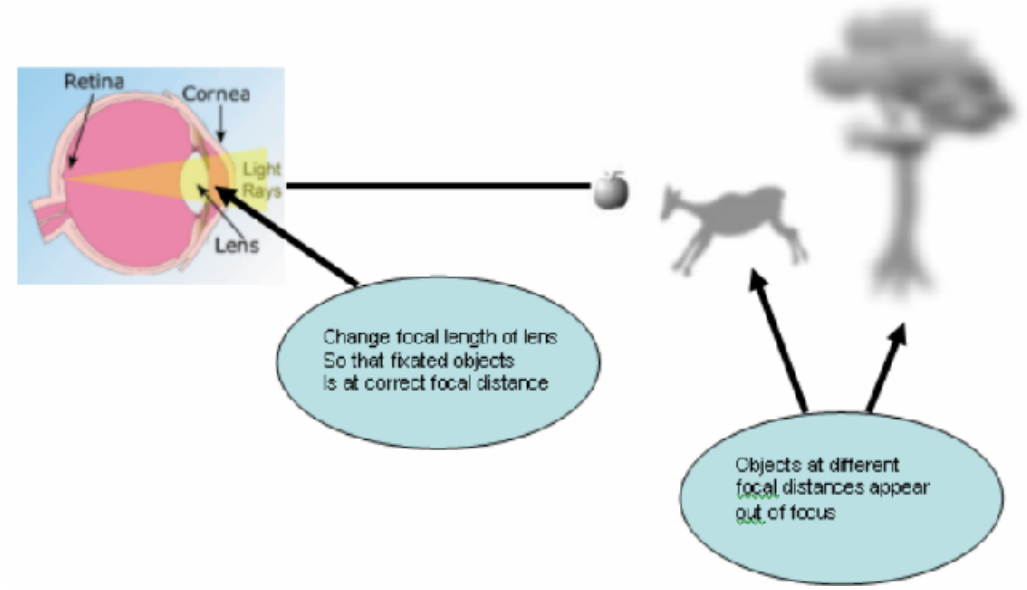

Figure 1 - Dynamic focusing ability of the human eye as a novel attention cueing metaphor

It is envisaged that novel Attention Cueing Techniques (ACT) borne out of cognitive design methodologies will enhance the conflict detection and de-confliction capabilities of Logic Engine and allow the operators to:

- discover the conflicts at a shorter time,
- acquire better situation awareness, and
- derive better and more varied de-confliction measures.

Drawing inspirations from the dynamic focusing ability of the human eye to depict objects in and out of focus depending on their distance from the eye (see Figure 1), a novel ACT visualization called "Aided Focus" was designed. In Aided Focus, the sharpness of objects is controlled by their current relevance, rather than their distance. The envisaged technique dynamically displays the affected data in focus at full detail, while dimming (i.e. reducing intensity) the rest of the unaffected information around the focus (the context). In other words, dimming can be used to highlight important information by dimming irrelevant information. Intensity is also one of the known pre-attentive features (Healey 1992) that are detected very rapidly and accurately by the low-level visual system as shown in Figure 2.

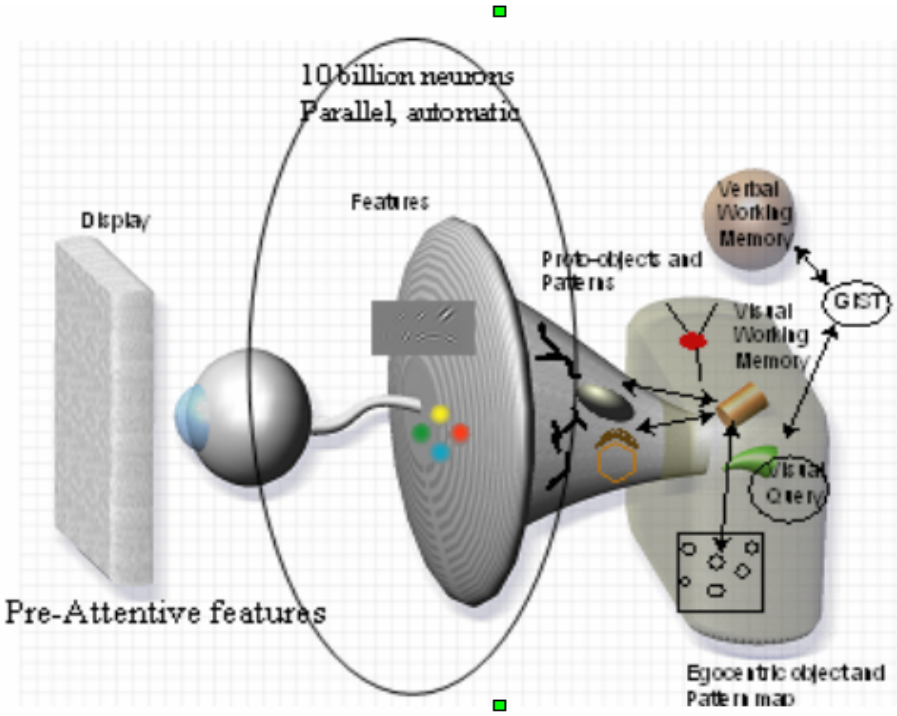

Figure 2 - The Human Information Processing Model

The Aided Focus concept could ensure optimal attention is directed to the affected information, particularly the conflicted airspace while enabling discernment of changes, if any, in the surrounding airspace situation picture and making sense of how the conflicted areas are related to the entire airspace situation picture.

A second novel ACT called "Kinetic Visualisation" (KV) was inspired by the nature of ants marching in a linearly form and orderly manner. The human visual information processing system is very sensitive to motion. Perceptual research studies have found that motion provides strong visual cues for the perception of shape and depth, and most importantly in attracting attention (Ware 1999). The idea is to develop some form of dynamic and random supplemental motion particles that mimic the way ants move along a column. This could rapidly cue operators' attention to perceive and understand the spatial relationships (i.e., links) between conflicting entities.

Applied to the case of FULA, "Aided Focus" concept seeks to help direct the attention of the airspace controller to aircrafts in conflict (Figure 3) and KV allows the airspace controller to quickly identify aircrafts affected by the conflicts (Figure 4). In doing so, the nature of these novel ACTs do not cause tunnelling of controllers attention and still allows the controllers to maintain continuous situation awareness of air situation picture that are not in conflict. Hence the airspace controller can derive safe alternative de-confliction solutions by considering the entire layout of all other dimmed air platforms and munitions that are in the area vis a vis the affected platform

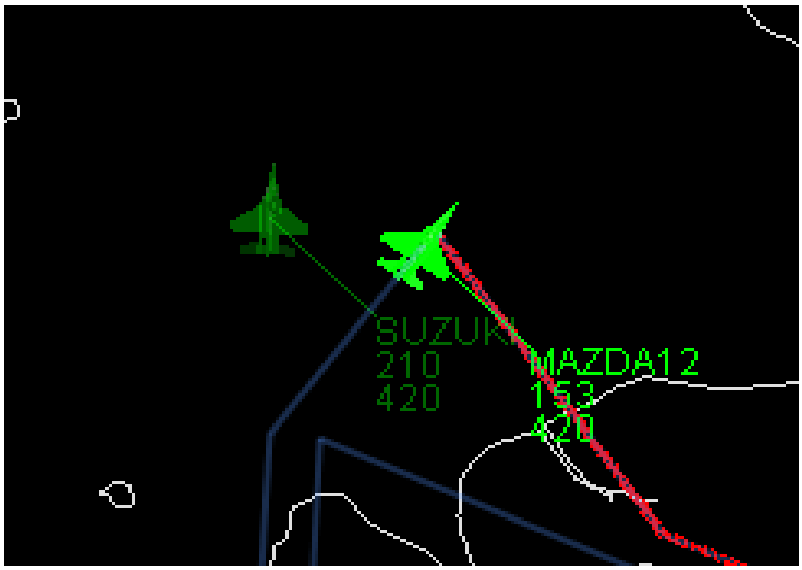

Figure 3 - Aided Focus featuring highlighted Aircraft in Conflict

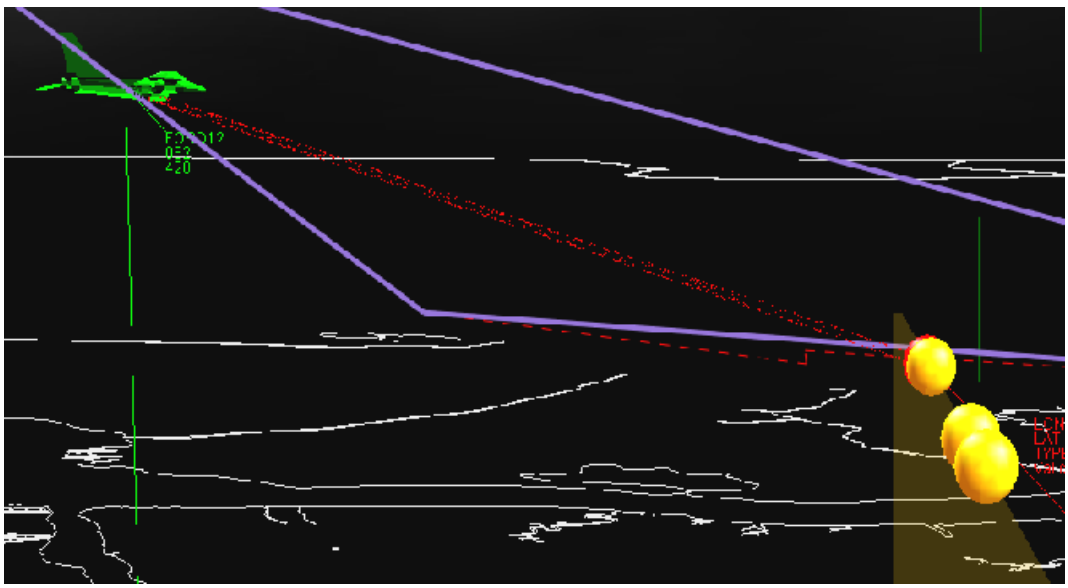

Figure 4 - Kinetic Visualisation featuring moving dotted beam linking Aircraft to Conflict Location

DESCRIPTION OF EXPERIMENT

An experiment involving live airspace controllers was conducted with the objective of verifying the hypothesis that airspace can indeed by managed more flexibly with the support of the 3 enabling technologies, namely IKC2, Logic engine and Advance 2D/3D Visualisation Capability enhanced with Cognitive Visualisation Techniques.

EXPERIMENT DESIGN

Given a constraint of manpower resources, a within-participants design was employed to study 2 test cases involving 12 airspace controllers as subjects. In the first test case (**Test Case 1**) the participants were subjected to airspace management conditions ***without*** IKC2, Logic Engine and Cognitive visualisation capability. In the second test case (**Test Case 2**) the participants were subjected to airspace management conditions ***with*** IKC2, Logic Engine and Cognitive Visualisation capability. In both cases, adhoc requests to utilise airspace outside of pre-allocated airspace due to perturbated mission plans and for the purpose of time critical missions were injected into the scenario play. Subjects' reaction to these injects were noted and qualitative results were collected via surveys and performance observed during the experiment.

RESULTS & FINDINGS

Under **Test Case 1**, the participants were observed to practise the DnO concept when managing the airspace demands. Adhoc requests to utilise airspace outside of the pre-planned allocation and for the purpose of time critical missions were mostly not facilitated due to uncertainty in airspace conflicts and lengthy decision cycles. Safety was ensured but mission effectiveness was compromised. Under **Test Case 2**, the participants were observed to facilitate these adhoc requests more readily. Observations and survey feedbacks showed that because of the availability of information via IKC2, conflict detection and de-confliction capability offered by the Logic Engine and Cognitive Visualisation, the participants were able to appreciate the real time airspace situation better and flexibly allow cross utilisation of allocated airspace as demanded by the adhoc requests. The Cognitive Visualisation aided participants' appreciation of active and inactive airspace at 'one glance' and cued the participants to dynamically manipulate both the 2D and 3D displays to acquire information of active and inactive airspace.

The outcome of the short experiment provided sufficient evidence and insights to give confidence that the concept of FULA can be achieved with the support of IKC2, Airspace Conflict detection and De-confliction Logic Engine, and 2D/3D Visualisation aided by Cognitive Designs techniques.

FULA LEADS TO POSSIBILITIES

With demand for forces to fight on the move against a non-static force, military organisations are increasingly developing distributed C2 capabilities including Distributed Command Posts (DCP). Commanders are no longer static in that they want to be able to get into the C2 centre-of-gravity (C-of-G) in order to shape the battle and to make decisive actions on the fly. FULA logic can be

transportable in plug-and-play module for mobile C2 such as Airborne Command and Control Post, DCP and Naval Joint Task Forces. No longer will C2 be restricted to an arrangement of just a centralised mode. Depending on where the C2 C-of-G is best placed, FULA allows component commanders up in the air, land and sea to self-synchronise flexible usage of airspace for its resources and doing it in a collaborative C2 manner with higher C2 centre. FULA logic and engine also allows commanders to optimise resources such as multi-role platforms. Whenever platforms are being re-roled, FULA allows a change in airspace usage to fit into the new mission assigned. Forces across the AO will have clarity of the change in mission and collaboratively self-synchronised their actions.

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