Applying NEC to UAS Operations Using an Evolutionary Approach

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Introduction

Unmanned Aerial Vehicles (UAVs) are controlled from UAV Control Stations (UCSs). Part of the information that is contained in the data transmitted over the control link is the result of communication with Air Traffic Control (ATC) and with Command & Control (C2). The Unmanned Systems roadmap [1] foresees an integration of UAVs, UCSs and C2 in a larger network, enabling seamless access to the desired platform and payload on a time-shared basis. The resulting Network Enabled Capabilities (NEC) should enable the command to achieve coherent effects through the effective use of all observation and weapon capabilities. Clearly such an increase in capabilities will not happen overnight. A stepwise approach is expected in which NEC will evolve as the connectivity between systems is increased.

Similar to the embracement of NEC in the military community, future Air Traffic Management (ATM) concepts rely on System Wide Information Management (SWIM) [2,3]. Connectivity between aircraft and ATC is one of the cornerstones of future ATM, and a specific challenge concerns the seamless integration of unmanned aircraft into controlled airspace. Here too, an evolutionary approach is being used which relies on existing networks and a stepwise increase in capabilities that are enabled through upgrades of the functionality of the aircraft and ground systems.

An important commonality between the use of NEC in the military environment and SWIM based ATM is that it concerns the coordinated navigation of many entities and a need for local synchronization. The goal of the research described in this paper is to initiate an evolutionary approach for the integration of a UCS with ATC and C2 systems by taking advantage of existing technologies which are not yet fully exploited, taking into account the similarities with the developments in civil aviation.

Where to start and how?

A brief summary of the envisioned future NEC architecture could be *'a range of functions that can be used to manage and share data in a SWIM environment in order to achieve coherent effects'*. Such a capability is being pursued in the development of the Global Information Grid (GIG[1]). Although the capabilities of the desired future system are often outlined in terms of high-level requirements, the roadmap describing how to get there contains holes between the current situation and the envisioned one. At present, the required SWIM environment is not available, but the potential connectivity that can be achieved using existing networks provides opportunities to already realize NEC for a range of functions. Clearly, a difference in capabilities will exist between systems that were retrofitted with some networking capability and systems that were designed around a networking concept. The research discussed in this paper focuses on the opportunities that arise when connectivity from a UCS with ATC and command and control C2 is realized. These opportunities are discussed in relation to the functions needed to integrate the data into the existing systems.

Because many, if not most of today's UCS, ATC and C2 systems were not designed with connectivity to the other ones in mind, the development, evaluation and refinement of the required functions that will benefit from the future connectivity is far from trivial. The challenges are similar to the ones identified by Hazlett [4] who states: *'In the near term we must live with the separate systems we have today. But we can take steps, using modeling and simulation, to test and tune future integration'*. To achieve the desired simulation environment needed to test and tune future integrated concepts, the recommendations include:

[1] The GIG is defined as a "globally interconnected, end-to-end set of information capabilities for collecting, processing, storing, disseminating, and managing information on demand to warfighters, policy makers, and support personnel".

1. Start to use modeling linkages to tie together the disparate elements that make up our non-system of systems, to begin to develop the non-existent interchanges that take advantage of potential synergies.
2. Use models and simulations to develop ‘wrappers’ to encapsulate unruly and uncooperative system elements so that they can interact with other elements in the most opportune manner.
3. Use simulations as ‘fillers’ or ‘placeholders’ for not-yet-developed system elements, to take the fullest possible advantage of asynchronous system developments, allowing system elements to come ‘on-line’ when they are ready, rather than waiting for the entire system(s) maturation.

The results of such an approach contribute to the definition of a roadmap for the functions that will benefit from an increase in connectivity (e.g. in terms of bandwidth, security, availability, integrity) and refine the requirements for the final SWIM environment. In this way, an evolutionary, spiral-based approach to NEC can be achieved.

UAS operations, NEC and C2

An important goal of future UAS operations is the seamless integration into controlled airspace. The use of a network to share trajectories between the aircraft and the ground as foreseen in both the Next Generation Air Transportation System (NextGen[2]) and the Single European Sky ATM Research (SESAR), is the main enabler to achieve this goal. Similar to the advantages that result when connectivity is realized between ATC and the UCS, the integration of UCSs into a C2 network can significantly reduce the amount of voice communication needed to coordinate and synchronize events. This translates into the possibility to act faster.

This paper starts with an overview of related developments in commercial aviation. After this, different levels of connectivity are discussed and the NEC levels are related to functions and connectivity. Next, both the concept and the simulation environment are discussed in more detail. For the experiments that addressed connectivity with ATC and C2, it will be

[2]NextGen is the Federal Aviation Administration’s (FAA) plan to modernize the National Airspace System (NAS) through 2025

illustrated what NEC levels have been achieved for the functions that have been implemented. Based on the results, an analysis of existing datalink standards, the feasibility and the potential of the evolutionary approach will be discussed.

Network Developments in commercial aviation

The network-based approach to future ATM started in the early nineties. Based on the results from the research performed in the Program for Harmonized Air Traffic Management in Europe (PHARE), the need for *'a generic protocol for information sharing between system components and their offered services, so that interaction of services can be standardized and operate on a global basis'* is stated [5]. It is concluded that the Total Information Sharing Protocol (TISP), a generic software protocol for client-server software architectures offers a solution. Nowadays, System Wide Information Management (SWIM) is being heralded as the enabler for future Air Traffic Management [6]. SWIM has been described as: *'an international concept resulting from FAA and European recognition of the need for network centric operations to meet future traffic demands'*, see [2]. In [3] it is stated that *'the core of SWIM is a framework enabling authorized applications and services to reliably and securely share information'*.

Use of the network

For the envisioned future concept of operations, the benefits obtained through the sharing of information result from the increase in accuracy of information (trajectory data) which provides increased predictability, thus allowing optimization over a longer time horizon. In [7] this is explained as follows: *'By letting the aircraft Flight Management System (FMS) communicate with the ground the Air Traffic Controller could receive information about what the aircraft intends to do, i.e. what flight path it will take including the time at the different positions. By providing exact four dimensional data to the ground, the pilot and the Air Traffic Controller have the same accurate information about the aircraft flight path'.* In terms of data, the required interaction is of low bandwidth. This allows for an early implementation with gradually increasing capabilities on existing infrastructure through evolving software.

In [7] the following results are reported: *'On March the 19th 2006, the first Green Approach was performed by flight Scandinavian Airlines (SAS)*

SK007 from Lulea to Stockholm Arlanda. The flight took 58 minutes and when the flight reached the runway at Arlanda it was only 2 seconds after the time that had been reported from the aircraft and FMS 42 minutes earlier'. The same concept is being pursued for the operation of UAVs in controlled airspace. Mueller and Jardin [8] discuss 4-D operational concepts for UAV/ATC integration. In [9] it is indicated that *'The developments in the area of 4D operations do not only pertain to manned aviation. Uninhabited Aerial Vehicles (UAVs) are planning machines par excellence, producing predictability by definition. A SWIM/CDM based ATM concept using shared 4D data would therefore principally enable interoperability between traditional and UAV traffic'*. In 2009, GE Aviation demonstrated a UAV flight controlled with a modified commercial FMS with 4-D trajectory capability [10].

Initial implementations

To test initial implementations, connectivity with the ground system is required. In the commercial aviation domain this has been partly addressed through the use of existing networks that, although not meeting the requirements envisioned in the future SWIM environment, already provide a significant leap in capabilities. In [7] it is reported that *'For the initial flight trials the ACARS was used to communicate the 4DT to the ATCC'*. and *'When the new VMMR is certified and approved all the messages will be sent over VDL Mode 4 instead'*. In [11] a similar connectivity challenge was addressed for the simulation based evaluation of a network enabled concept for enhanced airport surface navigation. As a result we have, that rather than waiting for the SWIM environment to 'happen', existing datalinks and networks are being used to demonstrate the potential of SWIM.

From Connectivity to NEC

Table 1 provides an overview of the five levels of NEC as presented in [12]. From level 2 to 5, connectivity is the basic requirement, but the actual level is determined by the ability of the networked participants to synchronize their local processes with the higher-level processes. An analogy in the control theoretical domain is the synchronization of multiple closed-loop processes in a larger control loop, which in turn can be part of another loop. An analogy with Star-Trek would be the Borg that with their collective mind may qualify for NEC Level 5.

Table 1: NEC Levels [12].

Level	State	Action
1	Isolated	Exchange of information through conventional means
2	De-confliction	Limited coordination, No common picture of the situation
3	Coordination	Coherent and efficient communication, Information sharing, Common picture of the situation
4	Integration	Integrated and coherent cooperation Efficient, interactive planning and execution
5	Coherent effects	Effective use of all observation and weapon capabilities

When starting to tie together systems that were not designed with the envisioned networking concept in mind, the resulting connectivity that can be achieved may be more limited than desired. Yet, it often allows the NEC level to be increased from 1 to at least 2. Hence, to take advantage of existing technologies which are not yet fully exploited, it is important to understand the possibilities and limitations for a particular configuration. Figure 1 illustrates the different types of connectivity for a UCS that have been explored.

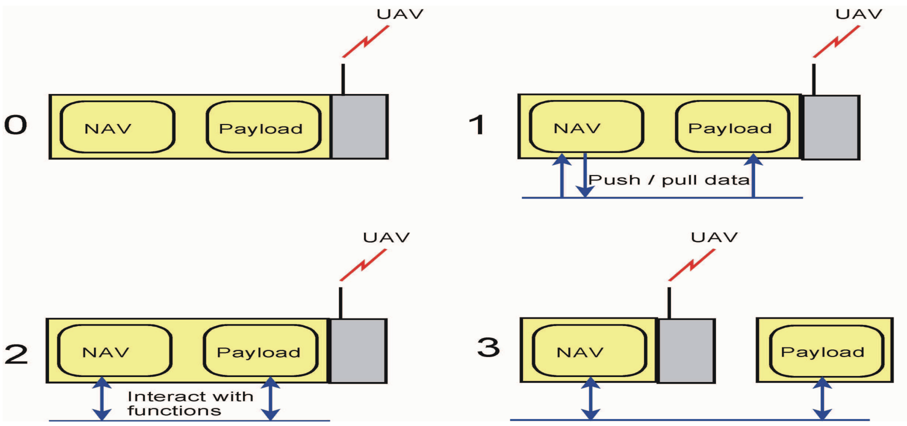

Figure 1: Different types of connectivity between a UCS and a network.

In Figure 1, (0) represents a UCS configuration without any connectivity. Both the navigator and the payload operator communicate with ATC and C2 by means of voice. (1) represents a configuration where there is a possibility to use additional data, but no functionality to interact with other participants on the network. An example is the ability to connect to a network on which data about other traffic, weather and similar data is available. Also, a data-out possibility may exist, in which for example the position of the UAV is put onto the network, providing ATC with additional surveillance data. The important characteristic of (1) is that no coordination with other systems is required to obtain or provide data, so no real dialogue capability which is needed to coordinate and synchronize events is available and hence no interaction is possible. Configuration 1 typically can be found with systems that started in configuration (0) and obtained connectivity during an upgrade, based on the availability of existing datastreams. (2) represents a configuration that contains functionality to interact with ATC and C2 systems on the network, and thus can both request and provide data. The connectivity shown in (2) is the basis for NEC levels 3 to 5. The specific NEC level is determined by the overall integration of the systems, and the ability to coordinate and synchronize execution of events. In (0), (1) and (2), the navigator and the payload operator are co-located and communication is direct.

Typically, the control of the functions (payload and navigation) is performed from a single location. This has always been the case with the manned counterparts, and if a single manned platform could not perform all required functions, multiple platforms would be used. Although in general an important advantage of an unmanned platform is that the environment from where it is controlled is less constrained than the typical cockpit, in certain situations the need arises to minimize the footprint of the control system. One possibility to reduce the system footprint is to try to minimize the overall set of functions that require an operator in the loop and also minimize hardware. Alternatively, one can consider separating the functions in such a way that only those that are required at the location with footprint constraints are available, while the other ones are managed from a separate location. Configuration (3) enables such a reduction in local system footprint through a re-allocation of functions that are presently co-located. It represents a configuration in which the navigator and the payload operator are geographically separated and the network is also used to facilitate communication between them.

Development of NEC functions

Connectivity does not automatically provide NEC, but there is no NEC without connectivity. To relate potential improvements in terms of NEC to the available connectivity, the research is structured to identify and explore opportunities for configurations 1, 2 and 3. To explore the potential of such an evolutionary integration, a simulation environment consisting of both real and simulated systems, connected over a network has been created.

The UCS baseline system (which represents configuration 0 in Figure 1) is research UCS that has been developed and refined in the context of several research projects at the Netherlands Defence Academy.

UCS baseline system

The research UCS shows a graphical depiction of the position of the UAV, the planned route and the environment[3] in both two and three-dimensional reference frames [13]. A graphical specification and modification of the route using drag-and-drop functions to insert or move waypoints is available. Figure 2 provides a schematic overview of the functionality that is implemented to manage the route.

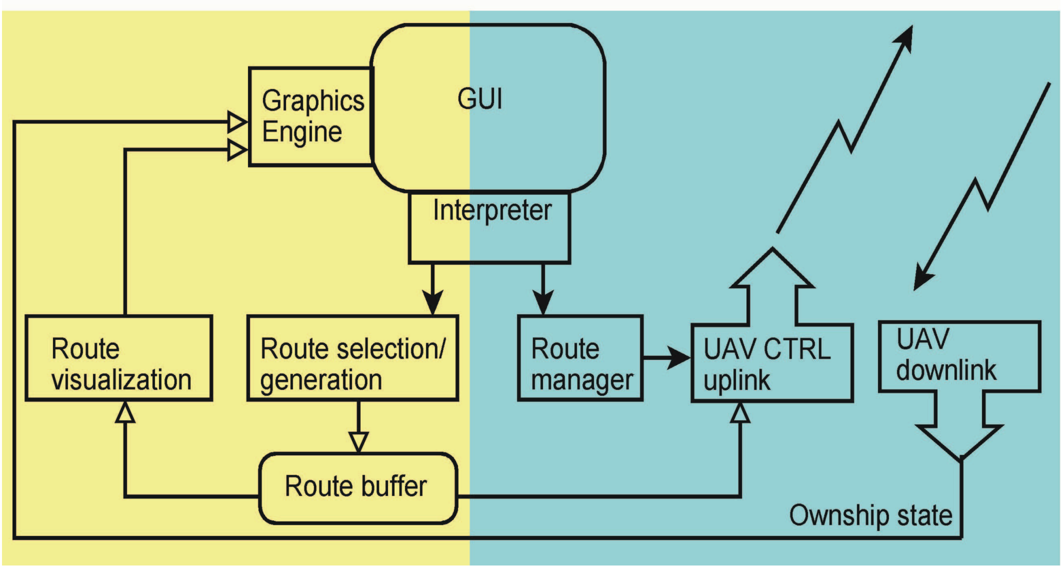

Figure 2: Overview of the functionality used to manage the route of the UAV.

The functions in the left block represent the functionality to support real-time interaction with the route (through direct manipulation). The functions in the right block comprise the functionality that ensures that the selected route (contained in the route buffer in the right block) is uploaded to the navigation system of the UAV. The position of the UAV that is received from the UAV downlink is used for route conformance monitoring.

To allow direct manipulation of the route through the graphical user-interface (GUI), the process in the left block has a high update-rate during

[3]Data that is used to describe the environment comprises Digital Terrain Elevation Data, data about the location and type of threats and specific data about the target environment.

the route definition and route modification process, and the definition of the draft route in the buffer will change with every change in location of a waypoint and/or constraints. The actual navigation, guidance and control loops of the UAV are not connected to this loop. Once an acceptable route has been defined, the draft route is changed into the active route and subsequently uplinked to the UAV.

This route is used by the Guidance, Navigation and Control (GNC) system onboard the UAV to close the position, directional and orientation loops. When a mission starts, the GNC system is loaded with a route. During a mission, the operator will need to make changes to this route by ATC and by C2. In today's operations (configuration 0 in Figure 1) the information about required changes is obtained through voice communication. The required changes are communicated as a set of vectors (speed, direction, altitude) or a target location. Even if at ATC or C2 a more strategic definition of the required changes is available (e.g. a path defined by waypoints), this will be communicated as a set of vectors.

Opportunities for different levels of connectivity

As indicated in the previous section, a main characteristic of configuration 1 is the lack of sufficient functionality to interact with other systems in the network. Because the ability to interact with other systems requires functionality on both sides, a situation can also exist in which from a UCS perspective configuration 1 applies in relation to ATC and configuration 2 in relation to C2 or vice versa.

In general, configuration 1 can be used to provide the system with a larger amount of real-time data than can be input by the user. This provides the opportunity to use the system functions to integrate this real-time data with other, related data, serving as an enabler for increased Situation Awareness (SA), reduced workload and support for decision making.

The interaction that is enabled in configuration 2 provides the possibility to request specific data and/or actions. This can be used to more effectively use the available bandwidth of the network, and to coordinate and synchronize events. The separation between navigator and payload-operator shown in configuration 3 provides opportunities to distribute the system footprint, which may be of benefit in environments where there are limitations in this area. To create a roadmap from today to a future with

GIG-like connectivity, our research aims to systematically explore the potential of all three types of connectivity. Table 2 provides an overview of the functions that have been designed and implemented for three different applications. The functions are referenced by the capitals A to G and will be addressed in the following subsections.

Table 2: Functions implemented on top of network to support an application.

	Connectivity						
Connected with	ATC			C2			payload nav
Config (Fig.1)	1		2	1		2	3
Application	From	To	Interaction	From	To	Interaction	Interaction
Airspace integration	A A1	B	E E1				
Faster OODA loop				C	B	F F1	
Control from geographically separated locations	A						G

Connectivity with ATC

Network connectivity with ATC forms the basis for the integration of UAVs into tomorrow's controlled airspace. In terms of the potential to realize the desired connectivity with ground systems, UAVs are actually ahead of commercial aviation. However, this advantage is not yet being exploited for ATC purposes because current UCSs lack direct connectivity with ATC. Many of today's UCSs were not designed with network connectivity in mind. Still, possibilities to communicate certain information often exist, but the likelihood that several systems all use the same protocol is rather low. In the future this is expected to change because of the emergence and acceptance of standards to provide interoperability such as STANAG 4586 [14] and the developments in the area of SWIM. But also for today's systems, so-called wrappers can be implemented that provide connectivity with which level 2 and level 3 NEC is achievable. Concerning the connectivity with ATC, the following assumptions have been made:

- In the minimum network configuration, the UCS has access to a network on which data about the location of other traffic is available. This forms the basis for blocks [A] and [A1] in Figure 3.

- This network allows trusted entities to provide information about traffic, as illustrated by [B] in Figure 3.

- With the appropriate functionality on the UCS and ATC side, the network can be used to exchange route data, forming the basis for [E] and [E1] in Figure 3.

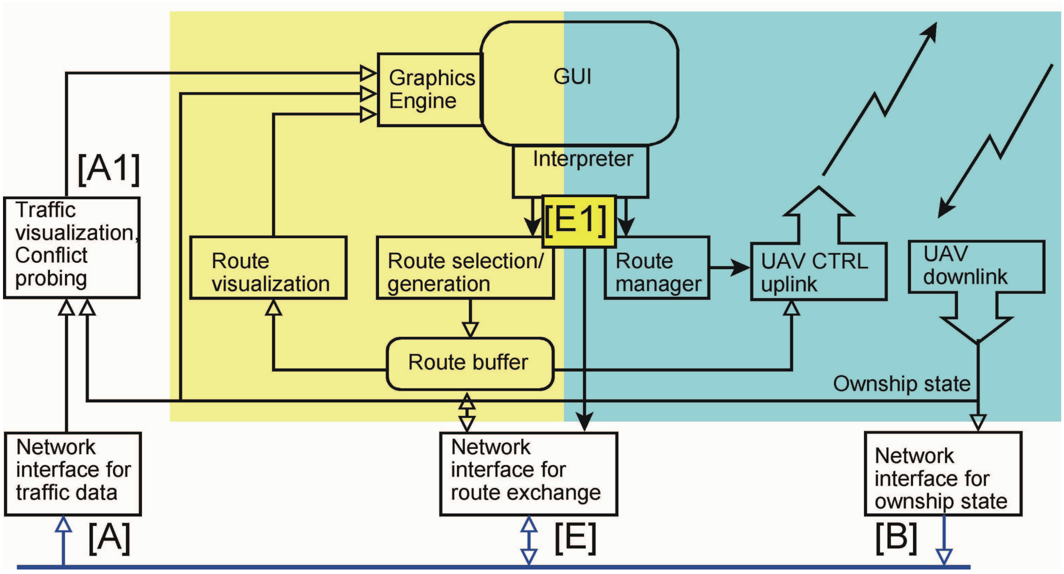

Figure 3: Connectivity to the system shown in Figure 3.

Module [A] reads all traffic data and filters out the traffic that is not relevant (based on distance and altitude). Level 2 traffic awareness is supported through the depiction of the location of the traffic in the same reference frame as own ship and the current route. This goes beyond the information that is available to pilots on today's Traffic alert and Collision Avoidance System (TCAS) displays, and is similar in presentation to a Cockpit Display of Traffic Information (CDTI) as proposed in RTCA DO-317 [15]. Also, conflict probe functions such as discussed in [16] are implemented in module [A1]. The conflict probe provides data to the operator about the impact of a change in current direction in the separation with other traffic. Through the integrated presentation of the results level 3 traffic awareness is supported[4]. Hence, even limited connectivity (configuration 1) can already yield a significant increase in SA, which in turn can contribute to a more efficient interaction with ATC.

[4]Level 3 Situation Awareness is indicative of the ability to anticipate how the situation will develop.

The connectivity in module [B] is intended to contribute to the surveillance capability of ATC. A particular strength of this configuration is the exchange of the planned and the measured own ship position in case of a lost down link. In such a situation, the estimated location of the UAV (obtained through the primary radar used by ATC) can be presented to the operator, and the planned location of the UAV (computed in the UCS from the 4-D route and the current time) can be provided to ATC. In this way, it is still possible to perform conformance monitoring. In the section 'Simulation Studies' the functionality in the UCS that supports this capability will be discussed.

Similar to the developments in commercial aviation, a big leap in capabilities is expected once a dialogue capability for the exchange of route data becomes available. On the research UCS, the required level of connectivity to explore this concept is realized by functions in the modules [E] (the network interface) and [E1]. Module [E1] represents the additional functionality that has been implemented in the GUI to realize a digital dialogue capability with ATC.

Connectivity with C2

Like other platforms, a UAV is an asset that contributes to a successful closure of the Observe-Orient-Decide-Act (OODA) loop. An important factor that determines the time within which the OODA loop can be closed is the time spent in the Orient and Decide phases. At present, the communication between the UCS and C2 is performed by means of voice, and the limited information exchange bandwidth that can be achieved also imposes constraints on the bandwidth of the OODA loop.

Regarding the OODA loop of armed UAVs, Gibbs [17] indicates that *'The desire to compress the kill chain time line led to discussions about the targeting cycle CONOPS, especially regarding time sensitive targets (TSTs). Leadership decided that, to improve success against pop-up and especially mobile targets, the targeting cycle of find, fix, track, target, engage, and assess (F2T2EA) must be reduced from hours to minutes'*. In [17] it is also indicated that for the armed Predator operations this been achieved by computer enhancements and changes in processes.

Besides the possibility to significantly reduce the time within which the OODA loop can be closed, connectivity between the UCS and C2 provides the possibility to achieve more accurate coordination and synchronization. Similar to the connectivity with ATC, this is achieved through the use of an accurate description of the desired location of the UAV as a function of time, defined in the 4-D route. The first phase of our research has focused on exploiting these advantages for Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR), Battle Damage Assessment (BDA) and Time-Sensitive Re-tasking.

The connectivity that has been realized between the UCS and C2 is similar to that between the UCS and ATC depicted in Figure 3. Besides the modules [E] and [E1] shown in Figure 3, two additional modules, [F] and [F1], are implemented. Module [F] contains functionality to provide the UCS with data concerning updated target locations, target areas and threat locations. The use of 4-D routes now serves as the enabler for better synchronization of assets on the C2 side. Module [F1] contains the functionality needed to support the dialog with C2. The route buffer and the route visualization function have been extended with the capability to store and visualize targets and target areas. Although the implemented functionality mainly yields a replication of existing procedures by digital means, the resulting coherent and efficient communication increases the accuracy, efficiency and flexibility. The fact that all data is digitally available instead as pieces of information in the memory of the operators (because it was communicated by voice) makes it possible to integrate the data into the frame of reference used at the UCS and C2, supporting a common operational picture.

Reduction in local system footprint

To combine maximum flexibility in terms of payload control with a minimum total manning and equipment footprint on a naval vessel, the concept that is explored using configuration 3 in Figure 1 pursues geographically separated control of the UAV and its payload. In this concept of operation, the navigation process is not managed from the vessel, but at a central, off-board location. Similar to current UAV operations that are controlled from a ship (e.g. the RQ-2 Pioneer), the management of the payload is performed from the naval vessel.

In the foreseen concept, the main tasks of the navigator remain the same. They comprise coordination with Air Traffic Control and translating the requests from the payload operator into route segments that can be inserted into the current flightplan within all existing constraints and flight safety issues (e.g. emergencies). Because the payload operator and the navigator are not co-located, the direct, intuitive way of communication that is used to change the flightplan based on new, payload-related requirements is no longer possible. This reduces shared Situation Awareness (SA) and operational efficiency. Furthermore, it is no longer guaranteed that both crew members have the same information available, which also has a negative effect on shared SA and operational efficiency. The goal of the research was the development of a dialogue capability to provide the payload operator and the navigator with a means of interaction through their networked control stations that supports a level of coordination equivalent to that of co-located operators.

The connectivity between the navigation and the payload management station allows a replication of all relevant data on both systems. The navigator can provide the payload operator with a specification of the target area within which the payload operator has the freedom to plan the route needed for (optimal) employment of the various sensors. Part of this route definition comprises the insertion of specific flight patterns that can be scaled in terms of leg-length, spacing between legs and height. The concept of direct manipulation of the route, including the ability to insert the payload-based navigation patterns which are scaled based on specific payload properties and information requirements, enables the payload operator to specify the desired path in the target area. This path is provided to the navigator who integrates it into the overall flightplan of the UAV.

Simulation studies and concept demonstrations

At the beginning of this paper it was pointed out how this has been done in the civil aviation domain. In the military domain, similar approaches using linkages and wrappers to integrate multiple ‘stove-pipe’ systems into a single, distributed simulation environment for UAV missions have successfully been applied. Twesme and Corzine [18] describe the development and initial use of a distributed simulation infrastructure to develop and exploit the capabilities and interoperability of UAVs and UCAVs. In their evaluation the command and control (C2) node was essentially excluded. For our simulation studies, existing interfaces of a MASE C2 system have been used for information exchange with a research UCS.

UCS-C2 simulation infrastructure

To evaluate the ideas and concepts discussed in the previous sections, the identified functions have been designed and implemented. The simulation studies that have been performed addressed the coordination between ATC, C2 and the UCS regarding airbase operations, traffic deconfliction, ISTAR and BDA missions, time-sensitive retasking and lost comms procedures.

Figure 4 provides a schematic overview of the components of the simulation environment. It comprises several separate simulation systems, which through a combination of wrappers and linkages are connected to each other. As can be seen, several types of message wrappers are used to enable interaction between the different subsystems.

Given the limited possibilities to modify the MASE simulation functionality, the UAV simulator and the traffic simulator needed to provide the data in the format expected by the MASE simulator, the Distributed Interactive Simulation (DIS) protocol. The UAV position and altitude including Mode 3A were provided by the UCS to the MASE simulation program and converted into the Radars Southern Region and Portugal (RSRP) protocol. This is the protocol that the MASE uses to process radar data from different sensors. In this way, the UCS was connected to the MASE in a similar way as the normal simulation assets. The second one mimics a real link that provides the UCS with an air picture (simulated or live). This air picture data is based on primary and secondary sensor data from the MASE sensor(s) which is also used for display at the MASE (C2 and ATC) consoles. Furthermore, a virtual link for 4-D route and airspace info (UAV routes, C2 and ATC commands and airspace boundaries) to support strategic deconfliction is used. This functionality was available at the UCS but, due to MASE interface limitations, had to be pre-loaded at the MASE. In this way the UAV routes and areas could be displayed for the ATC and C2 controller at the MASE.

With this setup it is possible to use the (simulated and live) traffic provided by the MASE system, in this way integrating a simulated UAV into a mission with otherwise live, real players. As an alternative it is also possible to use the UAV research environment to simulate other traffic and provide it to the MASE. This allows for more controlled simulated missions.

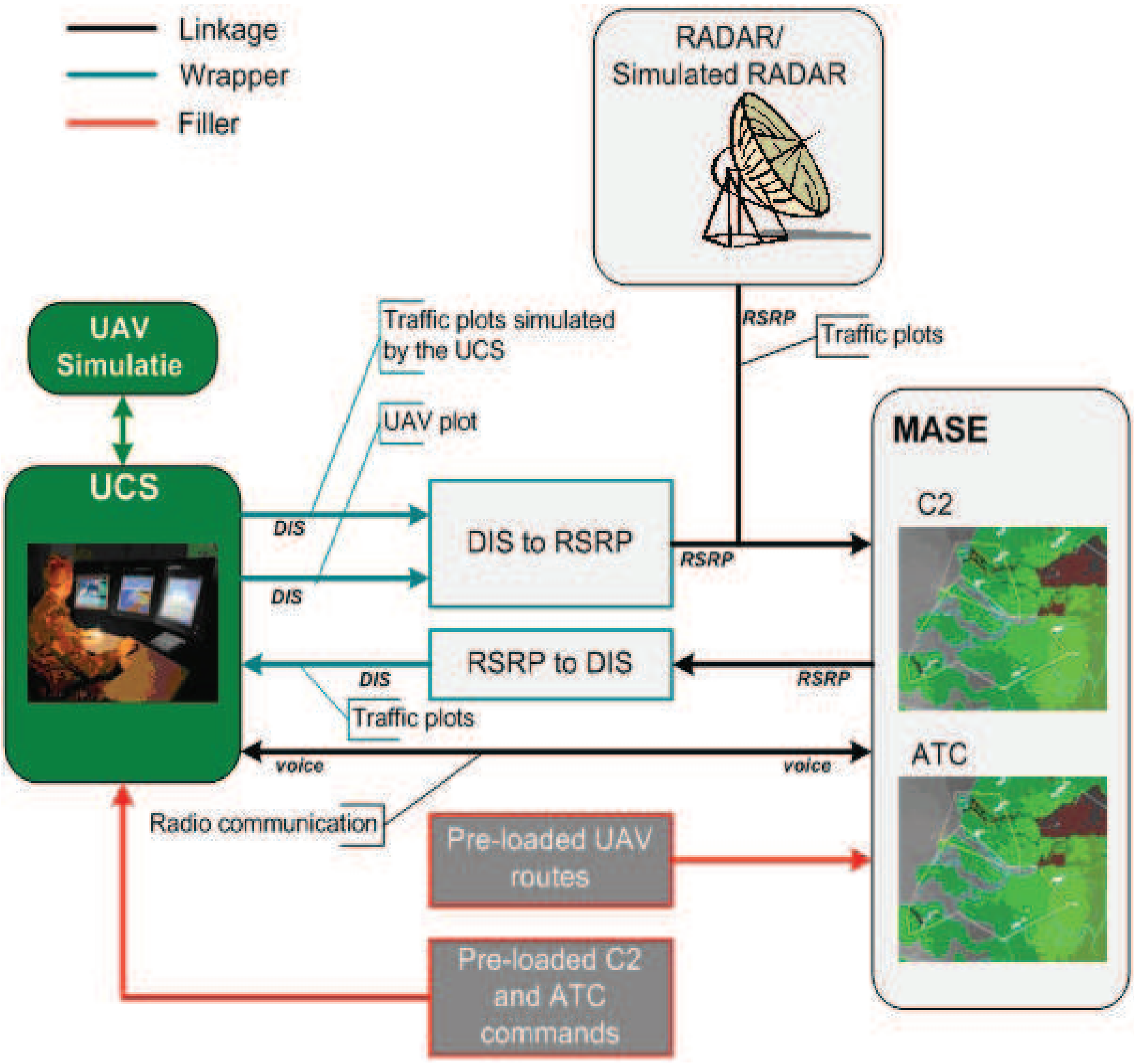

Figure 4: Overview of the different simulation components and how they are connected.

Topics

To explore the different types of capabilities discussed in the previous section, several simulation-based missions have been performed. During a simulated mission above Zeeland and Rotterdam, airspace integration, ISTAR, BDA and time-sensitive retasking have been addressed using scripted scenarios to trigger a range of events. The five-level NEC scale was used to rate the level of each function.

Airspace Integration

To explore concepts for traffic deconfliction as a function of available connectivity and functionality, four different set-ups were used. In the first set-up the conventional means of voice communication was used to deconflict traffic, and connectivity of type 1 (modules [A] and [B] in Figure 3) for the exchange of traffic data. On the UCS side, the traffic is integrated into the plan view display and as a conformal sensor overlay. This supports the UAV operator with the visual acquisition once the traffic is within the field of view of the sensor. Although the communication between ATC and the UCS is still performed by voice, the common picture of the situation supports the coordination and it was concluded that the functionality provided through modules [A] and [B] allows NEC level 3 to be reached for normal deconfliction.

The second and third set-up are triggered by the ACAS system in the UAV and use the available information generated by the ACAS and ATC system for SA and coordination. Because the ACAS information is not directly available for ATC, for collision avoidance only NEC level 2 is achieved.

In the fourth set-up, the connectivity represented in Block [E] of Figure 3 is also used. This enables conflict resolution to be achieved through integrated and coherent coordination between ATC and the UCS. If the conflict prediction function indicates that at a future location along the planned path a loss of separation will occur, the operator can prevent this by modifying the flightplan (through a direct manipulation of the location of waypoints or the reference speed along one or more legs of the flightplan). The modified flightplan is passed to ATC for approval. If approval is received, the flightplan is uplinked to the UAV. Also, ATC has the possibility to add some additional constraints to the flightplan, before it is passed to the UCS. This process of interactive planning, made efficient through the possibility of digitally exchanging 4-D flightplans of available information yields NEC level 4 for this setup.

To explore lost comms procedures, a scenario was designed in which the UAV operator would lose all status information about the UAV and its location. By receiving the UAV position information from ATC or via TDL, the UAV operator could assess whether the UAV adhered to the pre-planned route. This is also the case for the ATC controller who will have the lost link routes in his system and can monitor the UAV behavior by means of the radar or transponder returns. Both operators still have a common picture of the situation, yielding NEC level 3 for the lost comms situation.

ISTAR, BDA and Time-Sensitive Retasking

In the ISTAR part of the scenario, the UAV is flying towards the target area for which the UAV operator will insert an observation pattern (by means of the touchscreen). Upon entering the loiter area, the UAV will provide last minute target information to a flight of two F-16s. These aircraft simulate a targeting run after which the UAV operator will descend in the loiter area to perform a Battle Damage Assessment (BDA) run.

To support a common operational picture between the UCS and C2, during the ISTAR task and BDA phases, an exchange of the orbits of the UAV and the location of the target is performed between the C2 controller and the UAV controller using the functionality in module [F]. Furthermore, module [A] is used to provide the data needed to display the location of the cooperating assets (e.g. the F-16 flight). The associated functions in modules [A] and [F] contribute to achieving NEC level 3. To evaluate the functionality for Time Sensitive Retasking, the scenario includes a phase in which a re-tasking is received from the higher command echelon to support a calamity in the Rotterdam harbour area. To determine whether the re-tasking can be accepted, the UAV operator checks the request against the constraints (e.g. remaining endurance and reaction time). Only feasible scenarios were used. Both the data specifying the manoeuvering area and the area of interest are received through block [F] and translated into geographical objects that are subsequently presented on the display used to plan and modify the flightplan.

Similar to the process used to deconflict with traffic through the modification of the 4-D flightplan, the UAV operator re-routes the flightplan to the new area by moving and adding waypoints using the touchscreen. This new route is linked back to the ATC system for approval. Between the entry and exit waypoints of the target area, an optimized sensor pattern is inserted by the UAV operator over the area of interest to minimize crew workload during the support of the calamity. Once the UAV enters the pattern the operator can focus on the operation of the sensor and providing on-scene commanders on the ground with the requested information.

The coordination of the re-tasking by exchanging of the areas and the re-planned route during the Time Sensitive part of the mission confirmed the expected efficiency of this cooperative interactive planning. The associated functions for modules [F] and [F1] contribute to achieving NEC level 4.

Control from geographically separated locations

Clearly, shared control from geographically separated locations is only possible if the connectivity allows for a level of interaction between the navigator and the payload controller that is similar to the interaction when co-located. So, whereas the connectivity in the previous two applications is compared to a baseline that only comprises voice communication through a radio channel, in this case the baseline is the situation where the two operators are sitting next to each other when coordinating how payload-driven navigation requirements can be realized through modifications to the flight plan.

To test the concept, two existing research operator stations have been extended with functionality to support the payload operator and enable the communication between the two stations. One of the research operator stations (shown in Figure 5) is located at the Netherlands Defence Academy (NLDA) in Den Helder.

Figure 5: UCS research station at NLDA in Den Helder.

As can be seen in Figure 5, the UCS research station has two positions. The left one is for the pilot flying, and the right one for the payload operator. For the current research, only the payload operator position was used. The second UCS research station is located at Delft University of Technology. This research station has a single position and was configured for the pilot flying.

The mission management software used in the research operator stations already had the capability to connect to other systems. Only minor enhancements were needed to establish the basic dialogue capability needed to exchange routes and areas. Although the communication between the two stations did not use the STANAG 4586 protocol, the message content used was quite similar. An analysis of the current version of STANAG 4586 indicates that with minor additions to the message set, the basic functionality to support geographically separated, payload driven navigation can be achieved.

Initial tests were performed in April 2006. Those tests were mainly focused on the technical implementation of the concept, rather than evaluation. During those tests, an interesting observation was that when only the datalink for cooperative control is present, and no voice communication, the feedback on the status of requests becomes very important. When operators are co-located, their dialogue includes timing information (e.g. on when to expect a particular result). Especially when a certain task takes some time, e.g. the re-planning of a route, timing information becomes important for the operator awaiting the results. When no voice communication is available, this information must be provided through the network connection. Such process-related timing information is not included in the current datalink message set, but it is regarded as an important addition.

The tests demonstrated the feasibility of the concept, but also showed the need for further evaluations to be able to better identify the additional information needed to support the dialogue.

Demonstration of connectivity with ATC and C2

Between October 2005 and March 2006, the simulation environment was used in a total of four demonstration sessions to various groups of subject matter experts. These included representatives from the Chief of Royal Netherlands Air Force Command, Military Air Traffic Control Centre, Defence Materiel Organization (Projects Branch), C2 Knowledge Centre (Army, Navy, Air Force), Defence Research & Development and National Knowledge Centers and Laboratories.

These demonstration sessions covered airspace integration, ISTAR, BDA

Figure 6: Setup in the auditorium of the AOCS-NM used for the demonstrations of the simulated missions using a UCS networked with C2 and ATC.

and time-sensitive re-tasking. Figure 6 shows the setup in the auditorium of the Air Operations Control Station Nieuw Milligen (AOCS-NM). The research UCS was located in the auditorium and the audience could observe the C2 and ATC controllers on a large video screen. Also, some of the UCS displays were replicated on larger screens. During these demonstrations, the subject matter experts commented on the high degree of operational realism that was achieved.

Demonstration of geographically separated control

The concept as outlined above was successfully demonstrated at the UAV thematic day of the NLDA in May 2006, with the payload operator located at the NLDA in Den Helder and the pilot flying in Delft. The demonstration used a scenario comprising a retasking of the UAV to a new mission area and was situated in the environment of Kabul, Afghanistan to create a plausible UAV reconnaissance environment.

Discussion

The concepts discussed in this paper are not new, but the implementation of the integrated simulation environment and the subsequent use to explore these concepts is still quite rare.

In terms of open systems and standards, the future is not yet here.

Standards for the protocols needed to realize the envisioned NEC concept of operations do not yet exist. Also, the current generation C2 systems still have proprietary interfaces. The increased adherence to standards for the exchange of route data will reduce the amount of wrappers needed to integrate different, non-standard systems into a common network. Once this is achieved and interaction between systems becomes possible, the challenge becomes how to evolve to NEC level 4 for all functions. Achieving NEC level 5 goes beyond the integration of a UCS with C2 and ATC and requires a consideration of the overall system of which all these elements are part.

Impact of standards and open systems

Today's UCSs are dedicated to one type of UAV and typically use proprietary protocols for communication with that particular type of UAV. Similar to manned platforms, different mission types will yield a range of different unmanned platforms, optimized for a particular set of missions. Hence, on the platform side it will be hard to benefit from an economy of scale. The physical separation between the platform and the UCS provides the opportunity to achieve an economy of scale on the UCS side. This requires a change from the proprietary communication protocols to standardized protocols. To allow the UCS to be independent from the type of UAV, STANAG 4586 has been introduced. When UAVs comply with this standard, a handover of navigation and payload control between different (types of) UCSs is possible.

The use of STANAG 4586 for the control link protocol is more and more becoming a requirement in the acquisition process. Current developments in the area of UCSs also point towards a future where an open system architecture is required. Within certain certification constraints, this will allow third party software to be added to the Original Equipment Manufacturer (OEM) UCS, a development which is already taking place in the world of commercial avionics. The impact of this development is that it significantly increases the possibilities to enhance overall system capability during the lifecycle.

Beyond NEC level 3

At present, the two driving factors for standardization are to achieve system interoperability and to enable information sharing needed for increased battlespace awareness and a Common Operational Picture (COP). However, information sharing in itself will only allow NEC level 3 to be reached. Level 4, integrated and coherent cooperation, requires the development of concepts defining how multiple users interact with the data. Clever use of ICT-enabled opportunities will result in a force-multiplier effect once NEC level 4 is achieved. Clearly, these capabilities will not just 'happen'. Focused research is needed to identify possibilities and explore them.

Summary and Conclusions

Connectivity does not automatically provide NEC, but there is no NEC without connectivity. The integration of UCSs into a C2 network can significantly reduce the amount of voice communication needed to coordinate and synchronize events. The integration of UCSs into an ATM network provides the basis for UAV operations in future controlled airspace, as foreseen in NEXTGEN and SESAR. By taking advantage of existing technologies which are not yet fully exploited and taking into account the similarities with related developments in civil aviation, an evolutionary approach for the integration of a UCS with ATC and C2 systems is being pursued. When starting to tie together systems that were not designed with the envisioned networking concept in mind, the resulting connectivity that can be achieved may be more limited than desired. Yet, it often allows the NEC level to be increased from 1 to at least 2.

In order to identify feasible opportunities, it is important to understand the possibilities and limitations for a particular configuration. To explore NEC for UAV missions, existing connectivity together with wrappers, linkages and fillers has been used to create a simulation environment in which C2, ATC and a UCS are integrated. In this way, the opportunities can be explored for a range of possible configurations in terms of connectivity and functions.

The results illustrate that the opportunities which can be realized using existing connectivity already provide significant operational benefits. Hence, it is concluded that waiting with the development and implementation of functions that increase the NEC level until the 'promised' connectivity becomes available, will unnecessarily delay the moment at which significant operational gains can be realized.

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