STANAG 4586 –Standard Interfaces of UAV Control System (UCS) for NATO UAV Interoperability

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ABSTRACT

Unmanned Aerial Vehicles (UAV) are changing the way military and civil operations are carried out. New types of vehicles, from different providers, each with its own specifications and characteristic, are continuously being developed. This diversity leads to an increased level of difficulty in terms of interoperability. The objective of STANAG 4586 is to specify the interfaces that shall be implemented in order to achieve the required Level of Interoperability (LOI) between different UAV systems, so as to meet the requirements of the concept of operations (CONOPS) defined by NATO countries*. STANAG 4586 establishes a functional architecture for Unmanned Aerial Vehicle Control Systems (UCS) with the following elements and interfaces: Air Vehicle (AV), Vehicle Specific Module (VSM), Data Link Interface (DLI), Core UCS (CUCS), Command and Control Interface (CCI), Human Computer Interface (HCI), and Command and Control Interface Specific Module (CCISM). Besides STANAG 4586, there are already a number of existing or emerging Standardization Agreements (STANAGs) that are applicable to UAV´s. They provide standards for interoperable data link (STANAG 7085), digital sensor data between the payload and the UAV element of the data link (STANAG 7023, 4545, 4607, and 4609), and for on-board recording device(s) (STANAG 7024 and 4575). Although not providing a complete solution for interoperability, STANAG 4586 is certainly a crucial step taken in that direction, providing a roadmap for future developments.*

1.0 INTRODUCTION

During the last years, Unmanned Aircraft Vehicles (UAV) became a niche in continuous expansion within the aerospace market. With an investment that may exceed billions of dollars by 2015, it is predictable that the next generation will possess even more capabilities than today's [1].

The UAV´s are changing the way military and civil operations are carried out. This technology is gaining increasing awareness and promises to bring a higher level of efficiency to tasks such as data and image acquisition of areas of interest, localization and tracking of specific targets (target detection, classification and identification), map building, communication relays, pipeline surveying, border patrolling, military operations, policing duties, persistent wide area surveillance, search and rescue, and traffic surveillance. Therefore, the use of such systems provides a credible alternative to manned aircraft. They operate in conditions more dangerous with more autonomy and can be very cost-effective when compared to manned aircraft.

A North Atlantic Treaty Organisation (NATO) Interoperability Design Study was conducted in the early 1990s to investigate ways to enable interoperability of electronic systems. One of the approaches considered was to mandate that all nations procure and operate the same systems. However, it was emphasised at this time that NATO could not mandate interoperability of national reconnaissance systems, but that interoperability among national systems would be purely voluntary. It was not considered a good idea to have one contractor monopolise the reconnaissance systems in NATO. Instead, a comparison was drawn between communications between reconnaissance systems and computer-to-computer communications. By carefully defining an interface between two computers we can be assured of a successful exchange of data between them [2].

The evolution leads to the development of even more types of vehicles, from even more different providers, each with its own specifications and characteristics. This diversity leads to an increased level of difficulty in terms of guaranteed interoperability in teams of heterogeneous vehicles [3]. Most of the times the current operations with multiple vehicles and with multiple countries are as seen in Figure 1.

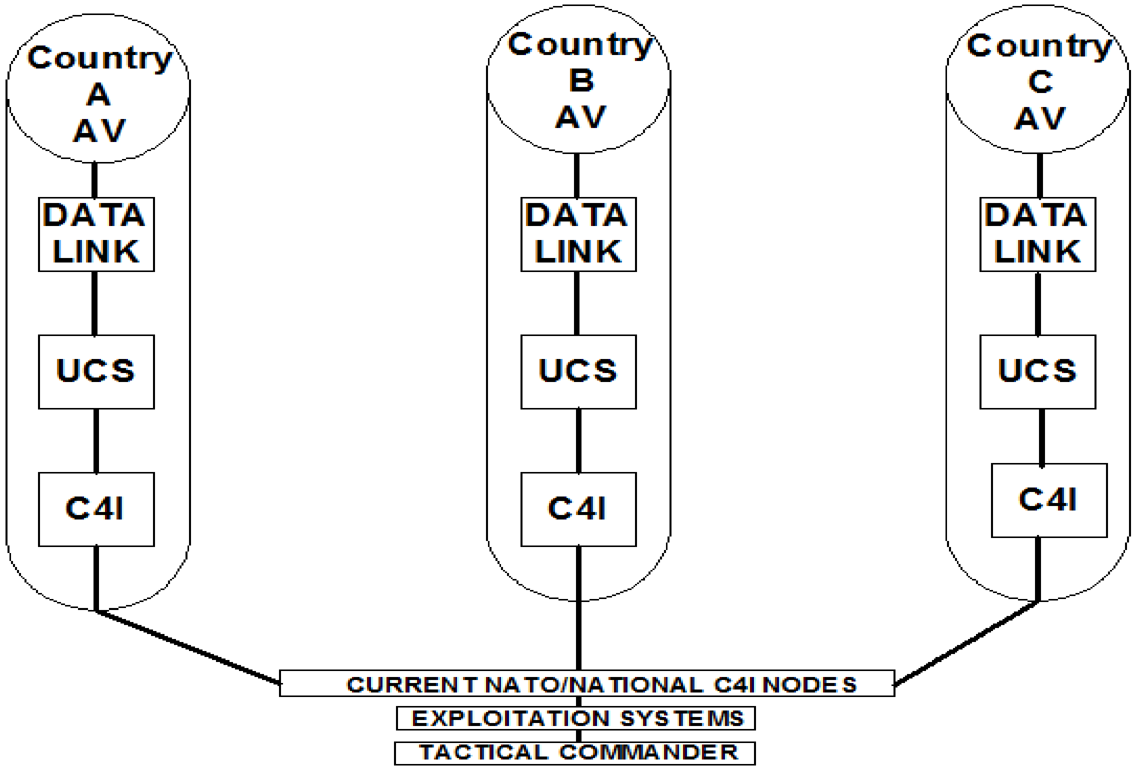

Figure 1: Current UAV´s Operations Example [4].

The UAV´s have become valuable assets in helping Joint Force Commanders (JFCs) meet a variety of theatre, operational and tactical objectives. The optimum synergy among the various national UAV´s deployed requires close co-ordination and the ability to quickly task available UAV´s assets, the ability to mutually control the UAV´s and their payloads, as well as rapid dissemination of the resultant information at different command echelons. This requires the employed UAV´s to be interoperable [4].

Often, UAV's are used for reconnaissance missions, which make them the predominant collection systems across virtually every echelon of command. As a consequence, the need to coordinate, share and integrate the UAV into the larger war fighting community is becoming painfully apparent [5].

UAV can be divided into these five different elements: vehicle (propulsion unit and avionics unit), payload (mission payload and payload recorder), data link (vehicle data terminal and control data terminal), UAV Control System (UCS) and launch/recovery, as shown in Figure 2.

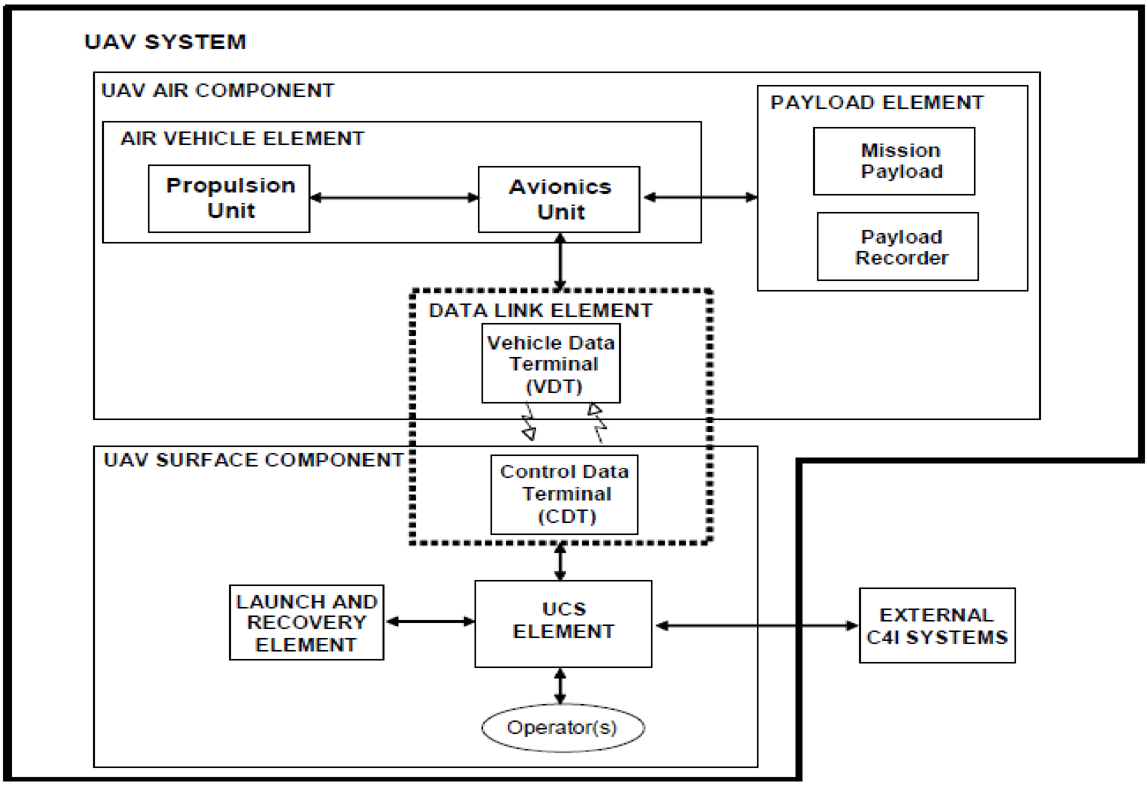

Figure 2: UAV System Elements [4].

Nowadays cooperative missions are in great demand. Missions using heterogeneous vehicles to perform complex operations are demanding more complex infrastructures to support them. There are many issues to address when working with different kinds of vehicles from different vendors, different capabilities and more important different interfaces to the end user. Interoperability is one of the most problematic issues. This is because there is no common acceptable interface. There are several interoperability efforts at several stages of development, but still not one widely accepted and used [6].

1.1 Standard and interoperability

International Organization for Standardization (ISO) defines a standard as a set of "requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose" [7]. To ensure an appropriate level of development, advantage should be taken from existing standardization approaches while avoiding the risk of inheriting undesirable or restrictive complexity. The existing standards for interoperability are a mean to provide rules for the robots inner/outer communications. They define data and message types, operation modes and optionally transport protocols.

Interoperability can be defined as the ability of robots to operate in synergy to the execution of assigned missions and the capability of diverse systems and organizations to work together, sharing data, intelligence and resources. The use of interoperability standards implies a secondary advantage. It also facilitates the compatibility with existing or future platforms and Command, Control and Intelligence (C2I) systems from other providers. Interoperability standards provide a common framework, working as the "glue" for unmanned systems. They minimize the integration time and development costs by avoiding custom implementations. A common interface helps to easily integrate new technologies with minor or no modifications to the existing systems, and to expand existing systems with new sensors or capabilities.

1.2 NATO Standardization Agreement (STANAG)

Shortly after the establishment of NATO, it was recognized that the co-ordinated development of policies, procedures and equipment of the member nations held great potential for enhancing the military effectiveness and efficiency of the fledgling Alliance. As a result, the Military Agency for Standardization (MAS) was established in London in January 1951 for the purpose of fostering the standardization of operational and administrative practices and war material [8].

In 1971 the MAS moved to NATO Headquarters in Brussels, Belgium, where, following the 1998-2000 review of the NATO Standardization Process, it was combined with the Office of NATO Standardization (which addressed broader standardization issues such as identifying overall Alliance standardization goals and co-ordination between operational and material activities). The Charter of the resultant NATO Standardization Agency (NSA), approved in August 2001, gave the NSA expanded responsibilities for the co-ordination of standardization activities within NATO [8].

In July 2014, as a result of the NATO Agencies Reform, the NSA became without change in its mission the NATO Standardization Office (NSO). It is an integrated NATO Headquarters staff element, reporting to the Military Committee and the Committee for Standardization [8].

The STANAG (Standardisation Agreement) standards are published in English and French by NATO to provide common military or technical procedures for NATO members. They define processes, procedures, terms, and conditions for common procedures or equipment between the member countries of the alliance. STANAGs also form the basis for technical interoperability between a wide variety of communication and information systems (CIS). Some are publicly available in NATO's online library [8].

2.0 STANAG 4586

In 1998, a NATO Specialist Team comprising members of government and industry (including CDL Systems) began work on NATO Standardization Agreement 4586 (STANAG 4586), a document conceived to standardize UCS interfaces to help enable UAV systems interoperability. STANAG 4586 Edition 1 was completed in 2003 and ratified by the member countries by 2004, Edition 2 was promulgated in 2007 and Edition 3 was promulgated in 2012 [4].

STANAG 4586 is divided into two annexes: the first annex provides a glossary to support the second annex, the second annex provides an overview of the communication architecture, which is supported by three appendices: appendix B1 discusses the **data link interface**, appendix B2 discusses the **command and control interface** (more specifically B2 covers the military architecture that connects the ground control station with the military command hierarchy), appendix B3 discusses the **Human and Computer Interfaces** (HCI) [4].

Current or "legacy" UAV´s have been designed and procured nationally and contain system elements that are generally unique and system specific. They do not have standard interfaces between the system elements. This results in a variety of non-interoperable "stovepipe" systems. Although commonality of hardware and software would be a solution to achieve interoperability and may be desirable from an economic standpoint, commonality is not mandatory [4].

The objective of STANAG 4586 is to specify the interfaces that shall be implemented in order to achieve the required Level of Interoperability (LOI) according to the defined concept of operations (CONOPS). This will be accomplished through implementing standard interfaces in the UCS to communicate with different UAVs and their payloads, as well as with different Command, Control, Communication, Computers and Intelligence (C4I) systems. The implementation of standard interfaces will also facilitate the integration of components from different sources as well as the interoperability of legacy systems. Compliant UAV´s shall be certified and will increase NATO joint flexibility through the sharing of assets [4].

The standards in STANAG 4586, which are identified as mandatory, shall be implemented as a whole in order to achieve the required LOI. It is assumed that air safety regulations will require the certification of systems, which result from combining the operation of assets from different UAV´s. Compliance with STANAG 4586, will ease this process and likely UAV system combinations can be certified in advance. [4].

On this basis, UAV´s that are compliant with STANAG 4586 will increase NATO Combined/Joint Service flexibility and efficiency to meet mission objectives through the sharing of assets and common utilization of information generated from UAV´s [4].

2.1 Level of Interoperability

This standard also identifies five levels of interoperability (LOI) to accommodate operational requirements [4]. The respective operational requirements and CONOPS will determine or drive the required LOI that the specific UAV System will achieve.

- Level 1: **Indirect receipt and/or transmission of sensor** product and associated metadata, for example Key Length Value Metadata Elements from the UAV.
- Level 2: Direct **receipt of sensor product data** and associated metadata from the UAV.
- Level 3: **Control and monitoring of the UAV payload** unless specified as monitor only.
- Level 4: **Control and monitoring of the UAV**, unless specified as monitor only, less launch and recovery.
- Level 5: **Control and monitoring of UAV launch and recovery** unless specified as monitor only.

LOI 2 monitor is conditional on the type of payload (station) and the number of payloads (stations) implemented onboard the UAV. It is also conditional on the type of payload data format used by the UAV [4].

LOI 3 monitor only or control and monitor is conditional on the type of payload (station) and the number of payloads (stations) and the payload data format used by the UAV [4].

LOI 4 monitor only or control and monitor is not affected by the payloads onboard the UAV [4].

2.2 UCS Functional Architecture

This architecture establishes the following elements and interfaces: Air Vehicle (AV), Vehicle Specific Module (VSM), Data Link Interface (DLI), Core UCS (CUCS), Command and Control Interface (CCI), Human Computer Interface (HCI), Command and Control Interface Specific Module (CCISM), as shown in Figure 3.

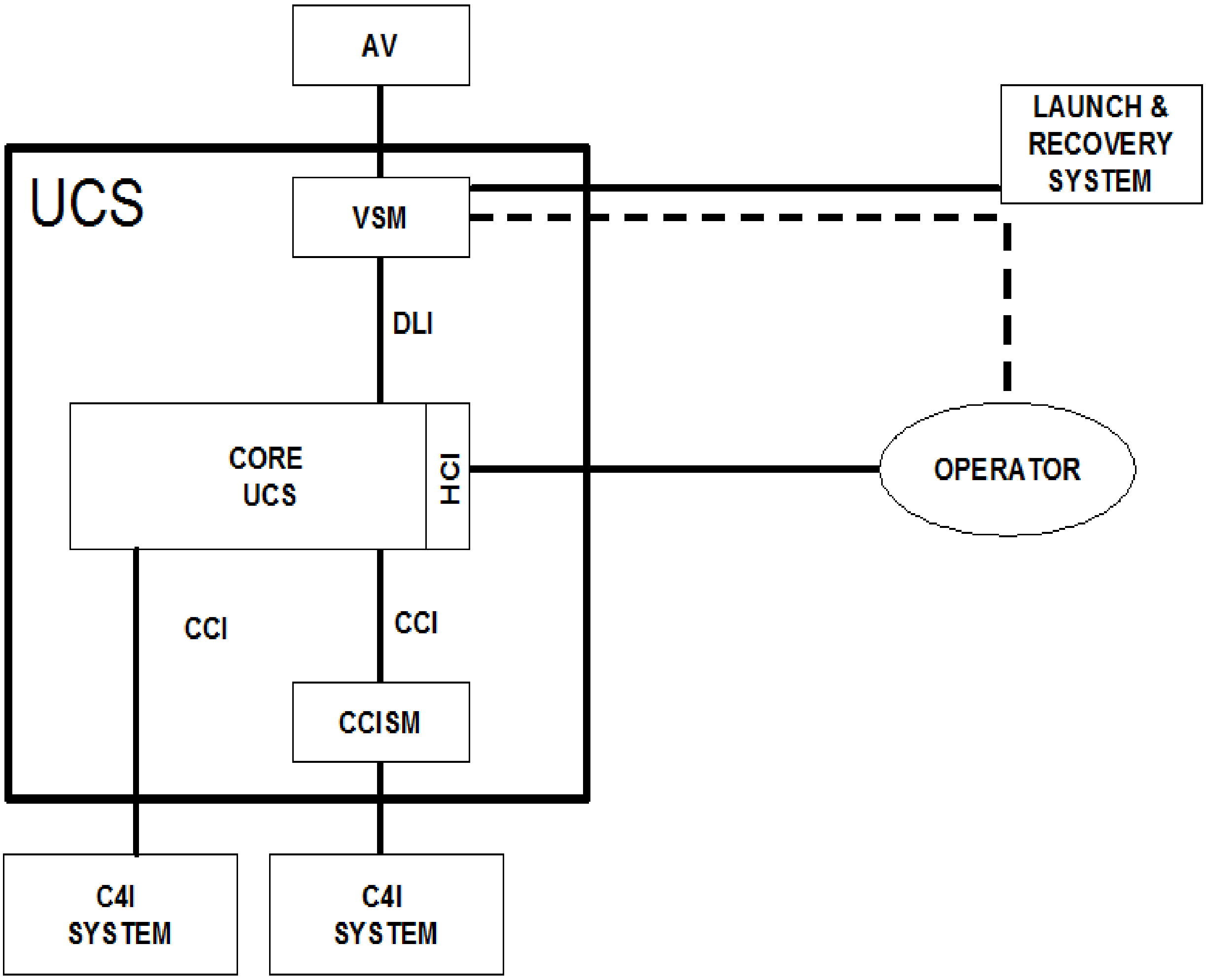

Figure 3: UCS Functional Architecture [4].

2.2.1 Vehicle Specific Module (VSM)

Provides unique/proprietary communication protocols, interface timing, data formats and "translation" of the DLI protocols and message formats that the respective Air Vehicle (AV) requires. This software provides a set of functions, such as [4]:

- Translation of STANAG 4586 messages from the CUCS from/to the AV via DLI;
- Packs/unpacks data to optimize transmission bandwidth;
- Act as database;
- Manage interfaces for data link messages control and monitoring;
- Manage interfaces for launch and recovery operations;
- Analogue to digital conversion of sensor data.

VSM module is usually vehicle specific, provided by its manufacturer. However, this module is not necessary if the data links used by the vehicle are STANAG 4586 compatible [4].

2.2.2 Data Link Interface (DLI)

The DLI, between the CUCS and the VSM element, enables the CUCS to generate and understand specific messages for control and status of air vehicles and payload [4]. DLI specifies the mechanism to process and display specific messages, which are air vehicle and payload independent.

2.2.3 Core UCS (CUCS)

The CUCS should provide a user interface that enables the operator to conduct all phases of an UAV mission, and support all requirements from the DLI, CCI and HCI [4]. The computer generated graphic user interface should also enable the operator to control different types of UAVs and payloads.

Depending on the desired level of interoperability in the respective UAV system, the CUCS should [4]:

- Receive, process and disseminate payload data from the AV and its payload;
- Perform mission planning;
- Monitor and control the AV, payloads, and data links;
- Support additional future AV and payload capabilities;
- Provide the UAV operator the necessary tools for computer related communications, mission tasking, mission planning, mission execution;
- Be able to host VSM and CCISM functions.

2.2.4 Command and Control Interface (CCI)

CCI defines the standard message set and accompanying protocols that have been selected to be C4I System/node independent, avoiding placing additional requirements on the C4I System [4].

The CCI is intended to cover all types of messages and data that need to be exchanged in both directions between the CUCS and the C4I systems during all the phases of a UAV mission, including [4]:

- Before the flight: tasking messages, tactical situation, environmental data, general mission constraints and mission plans;
- During the flight: status and service messages, payload data, progress reports;
- After the flight: status and service messages, payload data, post-flight exploitation reports, mission reports.

The networks and communications used to support the CCI interface should be NATO C3 Technical Architecture (NC3TA) compliant, which is a framework that provides interoperability among military command, control and communications systems, maximizing the exploitation of commercial off-the-shelf (COTS), and reducing proliferation of non-standard systems [4].

2.2.5 Human Computer Interface (HCI)

The STANAG specifies the requirements levied upon the CUCS, and does not impose any design requirements on human factors (HF) and ergonomics, (e.g., number of displays, manual controls, switches etc.)[4].

The HCI establishes the operator display and input requirements that the CUCS shall support. Although not specifically defining the format of the data to be displayed, there are some identified requirements that the CUCS shall provide in order to ensure an effective operation of the UAV system [4], such as display and operator interactions imposed on the CUCS by the CCI and DLI [4].

2.2.6 Command and Control Interface Specific Module (CCISM)

The CCISM provides a function similar to the VSM, that is, the encapsulation of the CCI data and any translation required to be compatible/interoperable with the physical communication links between the UCS and the C4I systems [4].

The CCISM is mainly intended for communication with legacy C4I systems that are not directly compatible with STANAG 4586 specified standards, protocols or physical layer and can be hosted on and collocated with the UCS. The UCS architecture shall make provision for the integration of a CCISM [4].

The CCISM provides the encapsulation of the CCI data and translations required ensure interoperability with physical communications links between the UCS and C4I systems [4].

3.0 OTHER STANDARDIZATION AGREEMENTS RELEVANT FOR UAV

As illustrated in Figure 4, there are already a number of existing or emerging Standardization Agreements (STANAGs) that are applicable to UAV´s. They provide standards for interoperable data links (STANAG 7085), digital sensor data transfer between the payload and the UAV element of the data link (STANAG 7023, 4545, 4607, and 4609), and for on-board recording device(s) (STANAG 7024 and 4575) [4].

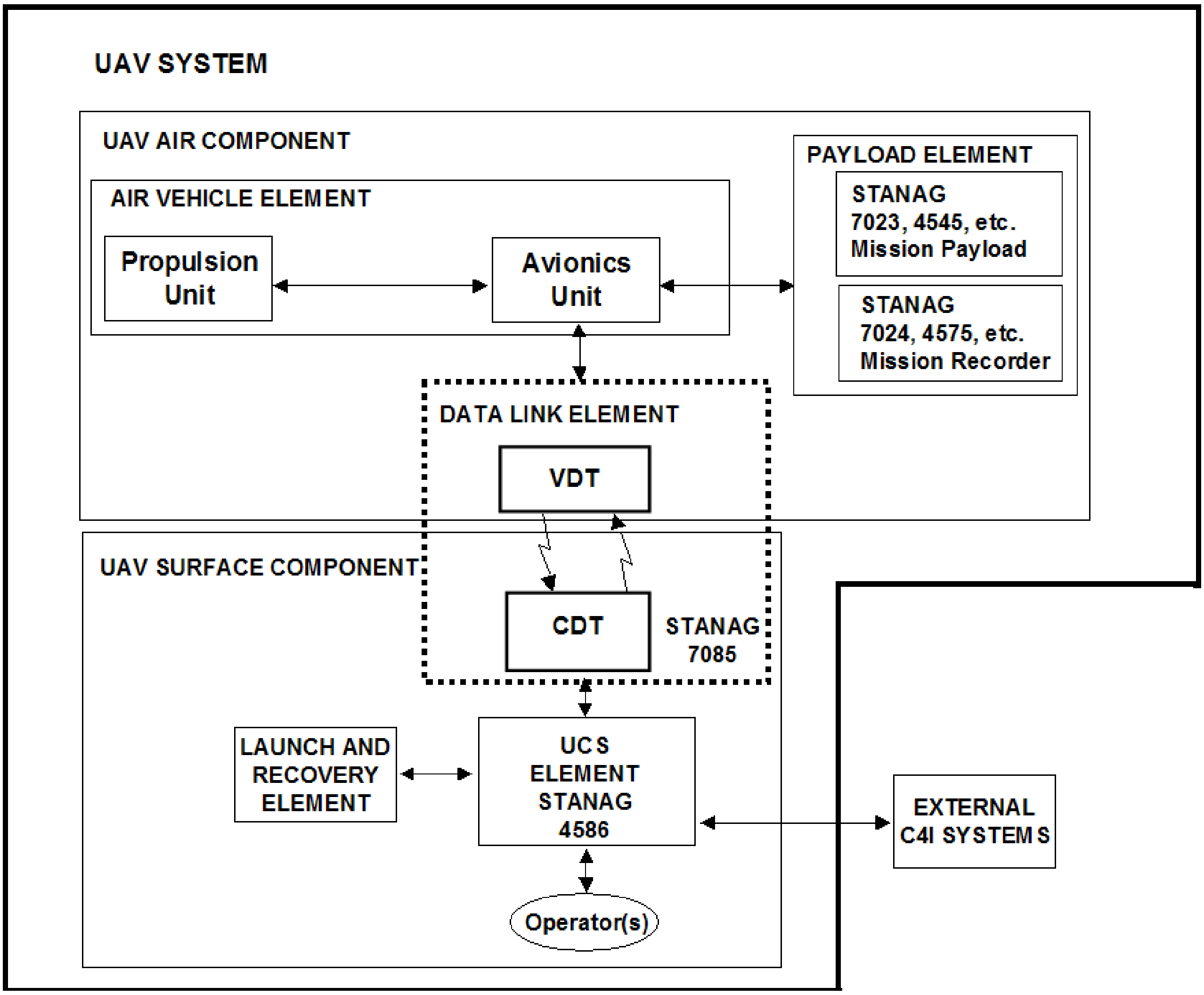

Figure 4: UAV Interoperability Architecture [4].

3.1 STANAG 4545: NATO Secondary Imagery Format (NSIF)

The NATO Secondary Imagery Format (NSIF) is the standard for formatting digital imagery files and imagery-related products and exchanging them among NATO members. The NSIF is part of a collection of related standards and specifications, known as the NATO ISR Interoperability Architecture (NIIA), developed to provide a foundation for interoperability in the dissemination of intelligence-related products among different computer systems [9].

Secondary imagery is sensor data that has been previously exploited and/or processed into a human readable picture. This format enables an operator at one workstation to compose and capture a multimedia image on his workstation, and send it to another workstation where it is capable of being reproduced exactly as it was composed on the first workstation [9].

The NSIF format can be composed of images, graphics and text. Because of the wide variety of display capabilities, the implementations of NSIF readers and writers are classified by their level of complexity, where the highest level will handle very large images with many bands of data, and the simplest level will only handle small, single band images [9].

The NSIF standard alone does not guarantee interoperability. Other aspects of the interface between systems (e.g. recording media, transmission protocols, etc.) must be considered based on other standards [2].

3.2 STANAG 4575: NATO Advanced Data Storage Interface (NADSI)

NATO Advanced data storage interface defines the standard for an interface to allow cross-servicing of ISR platforms by NATO nations´ground stations. The NADSI defines a multiple layer protocol for the lower levels of the interface channel as defined in the International Standards Organizations – Open Systems Interconnection model (ISO/IEC 7498-1) [10].

The interface is a high data rate port to allow direct download of the imagery and auxiliary data, either at the air platform or at the ground station. Once the memory has been transferred to a reconnaissance exploitation ground station, it can be exploited using normal tools [2].

This STANAG also defines the physical, electrical data/control, and power interface as well as the connector specifications [10].

The NADSI standard alone does not guarantee interoperability. Compatibility must also be assured at other protocol layers. Certifiable implementation of the NADSI for support of interoperability is subject to constraints not specified i**n this STANAG [10].**

3.3 STANAG 4607: NATO Ground Moving Target Indicator (GMTI) format

The NATO Ground Moving Target Indicator Format (GMTIF) defines a standard for the data content and format for the products of ground moving target indicator radar systems and a recommended mechanism for relaying tasking requests to the radar sensor system [11].

The GMTIF is a binary, message-oriented format for the prompt dissemination of Moving Target Indicator (MTI) data. It may be sent as a stand-alone format or it may be embedded in a frame-oriented format, such as the NATO Secondary Imagery Format (NSIF, STANAG 4545) or the National Imagery Transmission Format (NITF, Military Standard-2500) for the dissemination of secondary imagery, or in a message oriented format such as the NATO Primary Imagery Format (STANAG 7023) for the dissemination of primary imagery [11].

This STANAG includes a notional employment concept for using the GMTIF, a suggested technique for embedding GMTIF data into NATO imagery formats, suggested groupings of GMTIF data fields to support three data exploitation classes, and tutorial information pertaining to the GMTIF [11].

The format provides a flexible format for target information, such that simple GMTI systems can use a small subset of the format with limited bandwidth channels, while robust systems can encode all aspects of the output data for use with wideband channels, including high range resolution (HRR) and pulse Doppler modes. It is also configured to be used as a stand-alone format, or can be encapsulated in either STANAG 4545 or 7023 data streams. Target reports include such information as target location and radial velocity. Further value-added processing of the target movement can produce track histories of the individual targets [2].

3.4 STANAG 4609: NATO Digital Motion Imagery Standard

Motion Imagery (MI) is a valuable asset for commanders that enable them to meet a variety of theatre, operational and tactical objectives for intelligence, reconnaissance and surveillance. STANAG 4609 is intended to provide common methods for exchange of MI across systems within and among NATO nations [12].

This standard addresses the applicability of commercial digital video standards and defines the metadata requirements for airborne motion imagery collection. The standard specifies the commercial standards to be used for the military community within NATO. In addition, careful consideration was taken to define the relationship between the motion imagery standard and STANAG 7023 and STANAG 4545 [12].

The military-unique metadata considerations for motion imagery were analysed and included in the standard [12].

3.5 STANAG 7023: Air Reconnaissance Primary Imagery Data Standard

STANAG 7023 establishes a standard data format and a standard transport architecture for the transfer of reconnaissance imagery and associated auxiliary data between reconnaissance Collection Systems and Exploitation Systems [13].

NATO STANAG 7023 is not a communications protocol. NATO STANAG 7023 works in conjunction with other NATO STANAGs 7085, 7024, 4575, 4545, 4559, 4607, 4609 and 3377 to complete the interface between the Collection System and the Exploitation System [13].

The following list of top level design aims for NATO STANAG 7023 establishes a basis for the design [13]:

- promote interoperability;
- handle primary imagery;
- handle mission/intelligence data;
- work in real time;
- minimise platform processing;
- assume exploitation of imagery has no prior knowledge of source;
- image format does not handicap sensor performance;
- digital and analogue versions;
- layered/modular architecture;
- end-to-end protocol;
- self-describing sensor data format;
- addressable data files;
- multi-sensor/multispectral;
- hardware independent;
- expandable.

NATO STANAG 7023 is a self-describing format. The auxiliary data defines the format of the image data. This enables NATO STANAG 7023 to handle any image from any type of sensor [13].

3.6 STANAG 7024: Air Reconnaissance Tape Recorder Interface

Reconnaissance systems have been film based. Now in the era of electo-optical digital (EO), radar reconnaissance sensors and exploitation technology, common/standardised data exchange formats are necessary to assure interoperability between a multiplicity of sensor and exploitation systems [14].

STANAG 7024 was established to ensure the ability to exchange air reconnaissance sensor recordings and associated auxiliary data within NATO and Allied users, by the use of recording standards for media and recording footprints [14].

This STANAG establishes the physical format for the exchange of magnetic tape cartridges for 4 different technologies of recorders [14]:

- 19mm helical scan ANSI ID-1 digital instrumentation recorder with large, medium and small tape cartridge formats;
- 8 mm helical scan Hi-8 digital, and 8mm analogue;
- 12.65 mm helical scan SVHS analogue recorder;
- 25.4 mm transverse scan AMPEX DCRSi digital instrumentation recorder).

All the recorders in STANAG 7024 are sequential access[14].

3.7 STANAG 7085: Interoperable Data Links for Imaging Systems

This STANAG provides the interoperability standards for 3 classes of imagery data link used for primary imagery data transmission: analogue links described in Annex A, point-to-point digital links described in Annex B, and broadcast digital links described in Annex C. Command and control of the sensors and platform is an auxiliary mission. Annex B is organized in 2 chapters “General Requirements” and “Implementation Directives” which describe point-to-point digital links. Different implementation profiles are possible: the U.S. Common Data Link (CDL) is described in Implementation 1 [2].

This standard is structured to provide a number of options for the specific data link configuration, such as simplex or duplex operation, data rate, carrier frequency, channel multiplexing, interleaving, encryption, and many others that must be matched prior to passing data from transmitter to receiver [2].

STANAG 7085 data links can handle any form of data (e.g. 7023, 4545, or GMTI), and can operate in different configurations, including two way (half or full duplex) modes.

Sensitive information such as real-time terminal position that is transmitted via the data link may require protection. This protection may be provided by encrypting all or portions of the data stream using any equipment or technique that has been approved by the NATO Consultation, Command and Control Agency (NC3A) [15].

4.0 CONCLUSIONS

STANAG 4586 is a message based standard that was originally developed to meet the requirements of long endurance UAV’s.

This standard includes messages that are specifically written to support communication with a UAV’s payload. Since payload is not incorporated into the certification process, these messages may be eliminated or modified. Fortunately, few messages incorporate both control and payload aspects.

NATO Standardization Agreements are constrained to NATO member states and may become a limitation to intervene in non-NATO countries. For instance, STANAG 4586 is NATO "UNCLASSIFIED". This may (or may not) become a barrier to many global suppliers & non- traditional innovators from non-NATO countries such as robotics leaders in Japan [4].

STANAGs are predominantly military standards, and even though they have been promoted for civil applications, their requirements are heavily demanding in terms of compliance. For instance, certifying a platform against the STANAG 7085 Interoperable Data Links for Imaging Systems is costly and probably a barrier for small platforms providers. In this sense, STANAG is perhaps very relevant for the interoperability of military asset across the different NATO members, but it is hard to be adopted by civil or research platforms without strong investment.

STANAG does not define a specific Common Operating Environment (COE), but only specifies that the operating environment supports/ integrates the specified network/transport protocols and supports the specified user applications [5]. Moreover, STANAG doesn't take into account that the vehicles can be part of a network with dynamic topology where communications can be unreliable and vehicle actions may be tied to communication constraints.

Although not providing a complete solution for interoperability, STANAG 4586 is certainly a crucial step taken in that direction, providing a roadmap for future developments.

5.0 ACKNOLEDGMENTS

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