Access 5 Project Office
NASA
P.O. Box 273
Edwards, CA 93523 USA
661-276-2440
661-276-3880 FAX
www.access5.aero

COVER SHEET
Access 5 Project Deliverable

Deliverable Number: CCC002-Rev4

Title: HALE UAS Command and Control Communications, Step 1, Functional Requirements Document *(SEIT, Policy, Flt Test IPT, SIM IPT, HSI WP)*

Filename: CCC002_C2 Communications_Functional_Requirements Document_Rev4_FINAL2.doc

Abstract:
The High Altitude Long Endurance (HALE) unmanned aircraft system (UAS) communicates with an off-board pilot-in-command in all flight phases via the C2 data link, making it a critical component for the UA to fly in the NAS safely and routinely. This is a new requirement in current FAA communications planning and monitoring processes. This document provides a set of comprehensive C2 communications functional requirements and performance guidelines to help facilitate the future FAA certification process for civil UAS to operate in the NAS. The objective of the guidelines is to provide the ability to validate the functional requirements and in future be used to develop performance-level requirements.

Status:

SEIT-Approved

.

Limitations on use:
This document does not represent an Access 5 Project position. It is a preliminary document for interim use that has been reviewed by the C3 work package team and approved by the Access 5 SEIT only. The document presents functional requirements and performance guidelines limited to enroute operations above FL430. Substantiation through simulation and flight demonstrations is needed. Operations below FL430 and terminal operations have not been addressed in this document. The performance guidelines are included for illustrational purpose up to this version. They have not been validated against any real flight test demo and/or simulations.

HALE UAS
Command and Control Communications

Step 1

Functional Requirements Document

Access 5 WP6 Team
Version 4.0
February 8, 2006

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

RECORD OF CHANGES

Revision	Date	Action
Version 1.0	Sept. 30, 2004	First version released
Version 2.0	Feb. 10, 2005	Revised for comments
Version 2.1	Feb. 23, 2005	Revised for comments
Version 3.0	May 31, 2005	Revised for comments, add requirements, revise verification matrix, change from ROA to UA and UAS
Version 3.01	June 10, 2005	Revised for comments
Version 3.1	September 26, 2005	Revised for SEIT comments
Version 4.0	February 8, 2006	Updated Appendix C Added Appendix H

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

TABLE OF CONTENTS

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

1 INTRODUCTION

This is the High Altitude, Long Endurance (HALE) Unmanned Aircraft Systems (UAS) Command and Control (C2) Communications Functional Requirements Document (FRD). This document applies to communications between HALE UA and their associated control stations, together called UAS, operating within the National Airspace System (NAS). The requirements apply to Step 1 of the Access 5 project, sponsored by the National Aeronautics and Space Administration (NASA).

1.1 Background

HALE UAS are increasingly being developed and used to support a broad spectrum of defense, civil, and commercial applications. To avoid conflict with conventional manned aircraft, these aircraft have typically been limited to flying in restricted airspace. Recently, some UA such as Global Hawk have been allowed to fly in civil airspace on a controlled case-by-case basis using the Certificate of Authorization (CoA) process. As stated in the Access 5 HALE Remotely Operated Aircraft (ROA) Concept of Operations (CONOPS) document, the ultimate objective is to allow these aircraft "to operate in all categories of airspace with the same freedom as manned aircraft … and … [be] viewed by the Air Traffic Control (ATC) system and other airspace users as just another member of the aviation community."

Access 5 is a national project leading the way in enabling UA to routinely fly with other aircraft in the NAS. It is the intent of the Access 5 project to integrate UAS operations into the NAS as efficiently as possible, such that the ability of the pilot-in-command (PIC) to control HALE UA and interact with the ATC is comparable to pilots of manned aircraft. The Access 5 project consists of a strategic government/industry alliance to develop standards, regulations, and procedures; demonstrate the technologies; and implement infrastructure necessary to meet national priorities. For example, regulations and procedures are needed to certify UAS, while technologies and procedures are needed for maintaining a level of safety equivalent to that of manned aircraft.

Access 5 plans call for integrating HALE UAS into the NAS through a four-step process:

Step 1: Routine operations above Flight Level 430 (FL430) (43,000 feet) through pre-coordinated airspace

Step 2: Routine operations above FL180 (18,000 feet) through pre-coordinated airspace with emergency landings at pre-coordinated airports

Step 3: Routine operations above FL180 through C, D, and E airspace with emergency landing at pre-coordinated airports

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Step 4: Routine operations above FL180 through C, D, and E airspace with emergency landings at any UAS designated airport

Currently, the primary issue for flying UA in the NAS is flight safety. To be accepted in the NAS, these aircraft must be flown with a level of safety equivalent to that of manned aircraft. That is, the UA must not present a hazard to people or property in the air or on the ground, and must adapt to dangerous and unexpected situations as effectively as manned aircraft. To promote safety, these aircraft must operate reliably, maintain safe separation distances, and be responsive to direction from control authorities.

To ensure flight safety, it is vital that UAS have reliable, available, high quality C2 communication links. These links are needed to transmit commands to control the UA and to receive status information and data from the UA. This information may include health and status, situation awareness, and possibly relayed digitalized voice. The security of the link must be maintained to prevent unauthorized access to the control of the UA.

1.2 Purpose

This document establishes requirements for communications that facilitate C2 of HALE UA operating within the NAS. The document applies to the general HALE UA industry, particularly civil and commercial applications.

The requirements focus on functional capabilities for elements of the C2 Communications System. The document includes standards for communications operation, reliability, and safety that apply to HALE UAS, and may propose modifications or additions to the existing aviation infrastructure.

The requirements are stated in a design- and technology-neutral manner. That is, they are not dependent on the exact design or method for providing the functionality. On occasion, text accompanying a requirement may include examples of design or technology items, intended for illustration only.

1.3 Scope

The C2 Communications System requirements in this document apply to Step 1 of the Access 5 project, which addresses HALE UA above FL430. This flight level corresponds to the en route phase of flight operations.

Requirements in this document apply specifically to C2 communications between the UA and the Air Vehicle Control Station (AVCS), called the C2 link (i.e., the UA-AVCS link). Communications between the UA and ATC (UA-ATC link) and between the AVCS and ATC (AVCS-ATC link) are covered in a separate document,

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

the HALE ROA ATC Communications Step 1 Requirements Document.

Requirements in this document apply specifically to the C2 link under normal operating conditions, including handover of control and possible predictable outages. Requirements that apply to the C2 link when it has an unplanned outage are covered in the Contingency Management Requirements Document.

.

The scope of the C2 communications requirements encompasses both the content of the communications and the mechanism of the communications. The requirements specified in this document for Step 1 address the following high level functions:

- Perform information exchanges for UA operations
- Provide communications procedures and protocols
- Provide communications to control safe flight and UA operations
- Provide secure C2 link
- Provide C2 link connectivity

It is expected that most of the requirements specified for Step 1 will apply to all subsequent steps of the Access 5 project. Requirements specific to Steps 2, 3, or 4 will be added to subsequent releases of this document as needed during the corresponding steps of the project.

1.4 Document Organization

Section 1 states the background, purpose and scope of this requirements document, including its relationship to the Access 5 program.

Section 2 lists the applicable reference documents cited in this specification.

Section 3 presents an overview of the C2 Communications System for HALE UAS.

Section 4 states the functional requirements for C2 Communications for HALE UAS. This section also provides assumptions that underlie the requirements.

Section 5 defines the verification process for the C2 Communications requirements for HALE UAS. A verification matrix for the defined requirements is included.

Appendix A provides an acronym list.

Appendix B defines terminology used in this document and is intended as a basis for consistent use of these terms.

Appendix C contains C2 communications capabilities excerpted from the Access 5 Functional Requirements Document (FRD).

Appendix D provides a brief review of the NAS Modernization Program as the background information needed for the gap analysis as appropriate.

Appendix E provides the data links currently supported in the Aeronautical Telecommunications Network (ATN) standard. Again, the purpose is to facilitate the related information in one source for the gap analysis as needed.

Appendix F provides guidelines for C2 Communications System performance.

Appendix G describes the methodology used to establish the requirements in this document.

Appendix H reports a status and comparison review on other standards activities, specifically, a review of the minutes of RTCA SC-203 and an evaluation of the draft NATO STANAG 4660. The latter is a draft standard aimed at interoperable C2 data links for Unmanned Systems.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

2 APPLICABLE DOCUMENTS

The following documents are applicable reference documents. They are considered part of this requirements document to the extent they are directly referenced by specific sections of this document.

2.1 Government Documents

2.1.1 Federal Aviation Administration (FAA) Specifications

Document No.	Title	Version/Date
FAA-E2958	System Requirements Document Next Generation Air/Ground Communications (NEXCOM)	Version 2.0, October 22, 2003
NAS-SR-1000	NAS System Requirements Specification	October 1994
NAS-SS-1000	NAS System Specification, Volume I	September 1994

2.1.2 FAA Orders

Document No.	Title	Version/Date
FAA Order 1600.54	FAA Automated Information Systems Handbook	
FAA Order 1600.66	Telecommunications and Information Security System Policy	
FAA Order 6000.36A	Communications Diversity	November 14, 1995
FAA Order 6040.15	National Airspace Performance Reporting System	
FAA Order 7610.4	Special Military Operation	19 February 2004, Change 1 dated 5 August 2004

2.1.3 Other FAA Documents

Document No.	Title	Version/Date
TSO-C169	VHF Radio Communications Transceiver Equipment Operating within the Radio Frequency Rang 117.975 to 137 Megahertz	May 17, 2004

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

2.1.4 Other Government Documents

Document No.	Title	Version/Date
14 CFR Part 1	Aeronautic and Space	
47 CFR Part 2	Frequency Allocations and Radio Treaty Matters; General Rules and Regulations	October 1998
47 CFR Part 87	Aviation Services	October 1998
NTIA (Chapters II, V, VII, X and Annex B)	Manual of Regulations and Procedures for Federal Radio Frequency Management	May 2003 Edition, May 2004 Revision
Office of Secretary Defense	Airspace Integration Plan for Unmanned Aviation	Draft
OMB Circular A-130	Management of Federal Information Resources	

2.2 Non-Government Documents

2.2.1 International Civil Aviation Organization (ICAO) Standards

Document No.	Title	Version/Date
ICAO Annex 2	Rules of the Air	9th Edition, July 1990 with Amendment 37 dated February 28, 2003
ICAO Annex 10	Aeronautical Telecommunications – Volume II, Communication Procedures	1st Edition, July 1995 with Amendment 79 dated November 25, 2004
ICAO Annex 10	Aeronautical Telecommunications – Volume III, Part I – Digital Data Communications	1st Edition, July 1995 with Amendment 79 dated November 25, 2004
ICAO Annex 17	Security	7th Edition, April 2002 with Amendment 10 dated April 2002
ICAO 9705	Manual of Technical Provisions for the Aeronautical Telecommunication Network (ATN)	3rd Edition

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

2.2.2 Industry Standards

Document No.	Title	Version/Date
ETSI EN 301 473	SES; AES Operating under the Aeronautical Mobile Satellite Service (AMSS)	V1.3.0, June 2004
RTCA DO-160D	Environmental Conditions and Test Procedures for Airborne Equipment	July 29, 1997 with Change 1 dated December 14, 2000; Change 2 dated June 12, 2001; and Change 3 dated December 5, 2002.
RTCA DO-219	Minimum Operational Performance Standards for ATC Two-Way Data Link Communications	August 27, 1993
RTCA DO-224A	Signal-in-Space Minimum Aviation System Performance Standards (MASPS) for Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques	September 13, 2000 with Change 1 dated 12 October 2001 and Change 2 dated 27 August 2002
RTCA DO-240	Minimum Operational Performance Standards for Aeronautical Telecommunications Network (ATN) Avionics	July 29, 1997
RTCA DO-258	Interoperability Requirements for ATS Applications Using ARINC 622 Data Communications	September 13, 2000
RTCA DO-264	Guideline for Approval of the Provision and Use of Air Traffic Services Supported by Data Communications	December 14, 2000
STANAG 4660	Interoperable C2 Data Link for Unmanned Systems	Draft version 1.2, January 6, 2006

2.2.3 Access 5 Project Documents

Document No.	Title	Version/Date
	Access 5 Functional Requirements Document (FRD)	Rev 3, January 2006
	Access 5 HALE ROA Concept of Operations (CONOPS)	Rev 2, March 2005
	HALE ROA ATC Communications Step 1 Requirements Document	Draft Version 3.0, May 31, 2005
	Contingency Management Requirements Document	Revision D, March 31, 2005
Memo AV50991-006	CONOPS and FRD Assumptions	June 22, 2004

2.2.4 Research Literature

Document No.	Title	Version/Date
National Institute of Standard and Technology (NIST)	Methods for Determining the Level of Autonomy to Design into a Human Spaceflight Vehicle: A Function Specific Approach	PerMIS Conference 2003
NIST Special Publication 1011	Terminology for Specifying the Autonomy Levels for Unmanned Systems	Version 1.0, January 2004

2.3 Order of Precedence

The requirements in this document are set forth to supplement or further develop requirements in FAA documents, with the objective of being integrated with FAA documents. It is expected that requirements in this document do not conflict with those in FAA documents or other Government documents. When the requirements in this document conflict with non-FAA or non-Government documents, this document shall have precedence.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

3 SYSTEM OVERVIEW

This section presents an overview of the C2 Communications System for HALE UAS, including a description of the Step 1 concept, components of the system, and types of data exchanged using the communications link.

3.1 Step 1 Capability

For this document, the C2 Communications System focuses on Step 1 of the four steps defined in the Access 5 Project Plan. Step 1 focuses on achieving safe, reliable, and routine operational access for UA at or above 43,000 feet (FL430). The ascent and descent are limited only to restricted or pre-coordinated NAS. The takeoff and landing through restricted or pre-coordinated airspace is the purview of the organization authorizing flight. Figure 1 shows the high level operational perspective for Step 1.

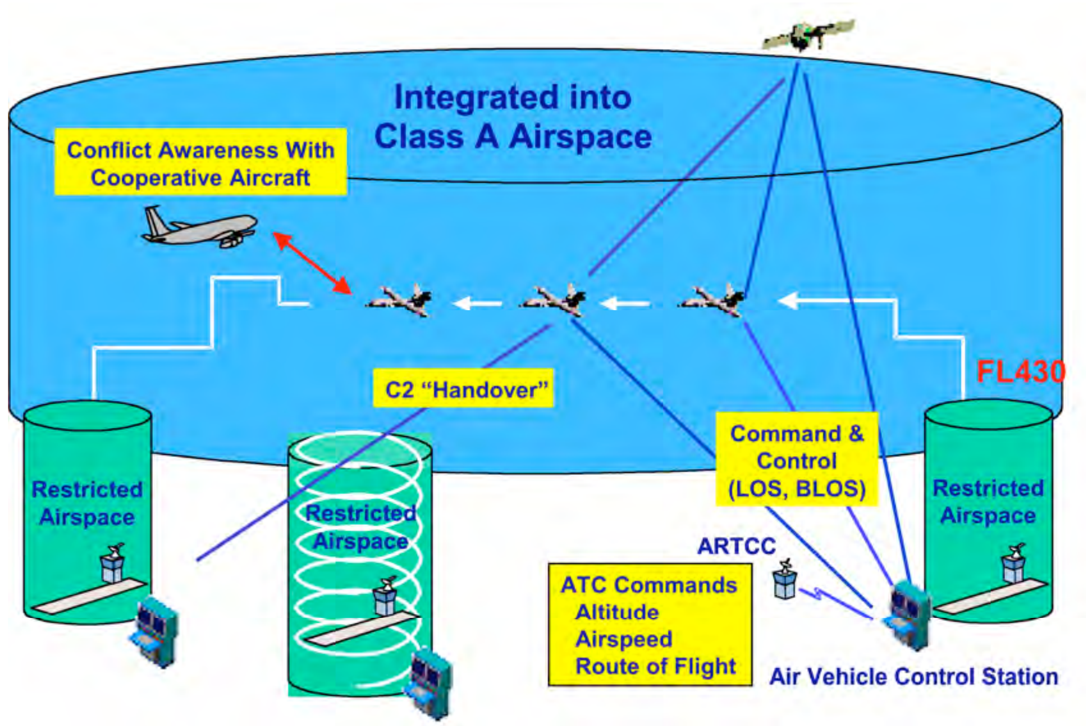


Figure 1. Step 1 Focuses on UA Operations above 43,000 Feet, with Ascent / Descent through Pre-Coordinated Airspace

For Step 1, all necessary communications are at the en route phase and are established to ensure safe and reliable HALE UA flight. The AVCS is equipped with sufficient communications means to facilitate the PIC to perform operations safely and satisfactorily.

3.2 System Components

The HALE UAS C2 Communications System provides the connection between the PIC and UA to support operations that include but are not limited to flight control, communications relay, and subsystem monitoring and control. Figure 2 shows an overview of the HALE UAS C2 Communications System, its components, and interfaces. In the figure, internal interfaces illustrate connectivity between constituent components, while external interfaces provide the context in which the C2 Communications System operates within the UAS.

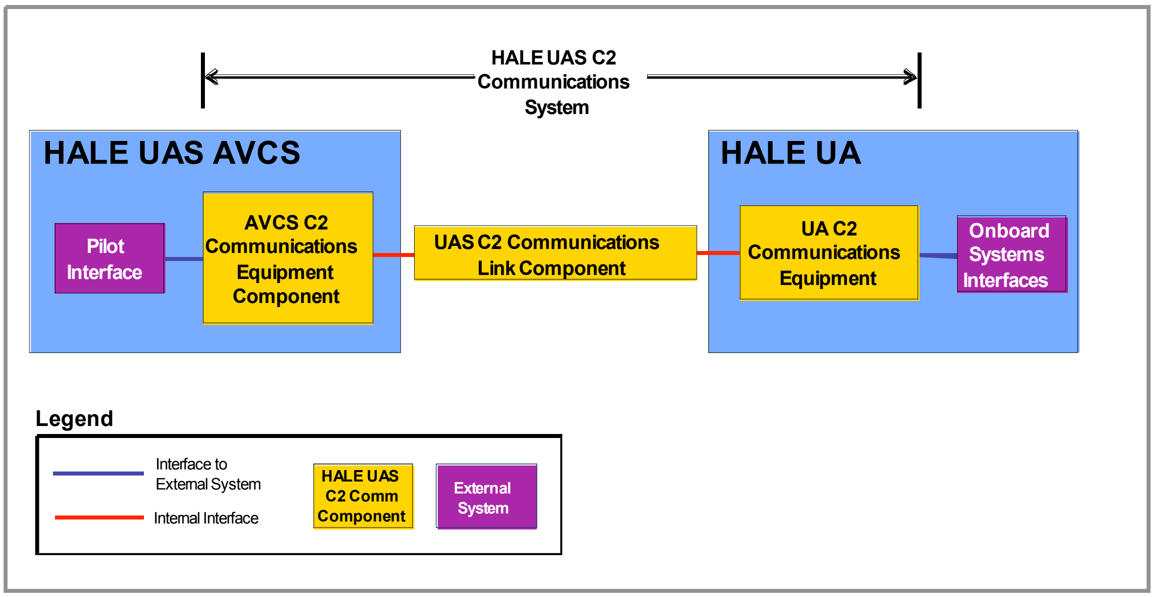


Figure 2. HALE UAS C2 Communications System

The generic components of the C2 Communications System include the following:

- **AVCS C2 Communications Equipment Component** – systems and equipment at the AVCS where the pilot supporting C2 communications is located
- **UAS C2 Communications Link Component** – communications links, systems, and equipment that provide the telecommunications connection between the AVCS and the UA
- **UA C2 Communications Equipment Component** – systems and equipment onboard the UA

The generic external interfaces to the C2 Communications System include the following:

- **UA Pilot in the AVCS** – A human-machine interface between the PIC and the

C2 communications equipment

- **Onboard Systems Interfaces** – Systems onboard the UA that 1) perform actions based on communications from the PIC and 2) provide information to the PIC

3.3 Communications Links

Figure 3 depicts a notional concept for communications links for HALE UAS. There are three links: C2 link, AVCS-ATC link, and UA-ATC link. At any given time, from one to all three of these links may be in use. As the figure shows, Line-of-Sight (LOS) communications uses direct links, while Beyond Line-of-Sight (BLOS) requires additional communications equipment or relays. This document addresses the C2 link, while a separate document addresses communications with the ATC.

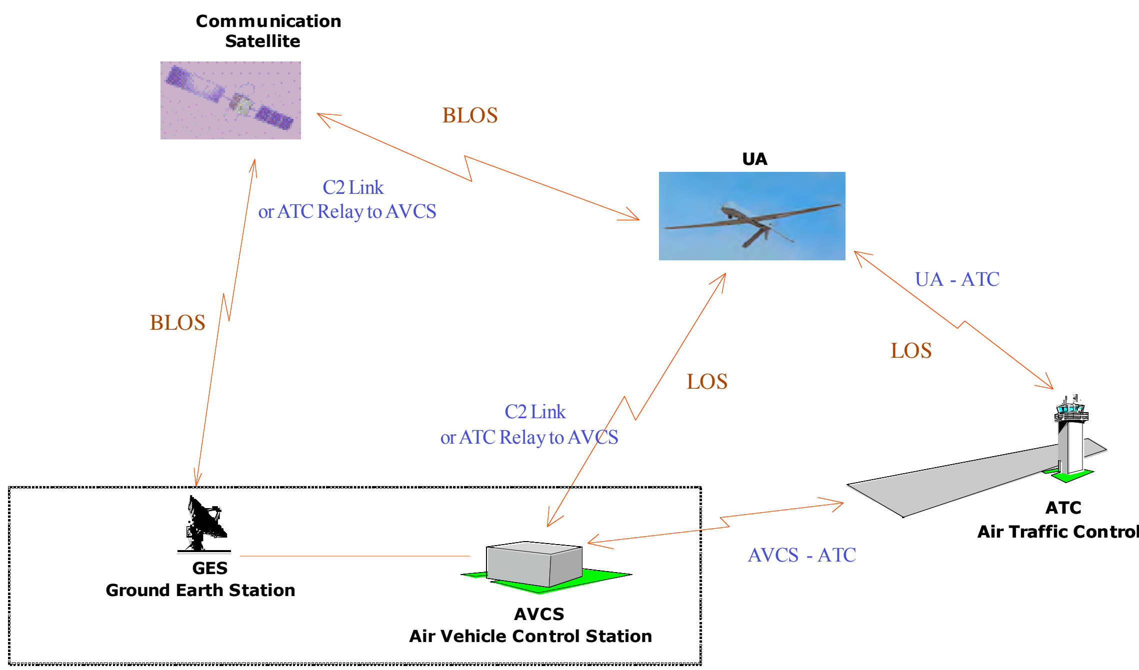


Figure 3. Notional Concept for Communications for HALE UAS

3.3.1 C2 Link

The C2 link is the mainstay C2 communications link and supports LOS and BLOS communications as needed. The PIC controls the UA from the AVCS by sending short commands (messages) to affect the dynamics (such as attitude, altitude, speed) of the UA. This link is often referred to as the uplink. The UA sends data to the pilot to keep him/her informed of the flight status. This data includes health and status of the UA and situation awareness. This communication path is often referred to as the downlink.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

3.3.2 AVCS-ATC and UA-ATC Links

The AVCS-ATC and UA-ATC links are covered in the HALE ROA ATC Communications Step 1 Requirements Document.

3.3.3 LOS and BLOS Communications

In the en route phase, there may be no direct LOS path between the HALE UA and its AVCS. Thus, C2 communications must support both LOS and BLOS configurations.

Satellite communications (SATCOM) and airborne relay are two feasible means for such C2 BLOS communications. Airborne relay, if used, can cover a limited range only and thus is often adopted for small footprint UA operation. SATCOM is the common solution for use in long haul communications. There are two types of SATCOM available today: geostationary orbit (GEO) and low earth orbit (LEO). For GEO, the channel can be available through leasing and the network can be custom designed. For LEO, only the service is available. That is, service subscribers have no way to affect the network optimization if needed. A major issue when employing any SATCOM solution is the system latency resulting from the propagation delay and the network processing delay.

3.3.4 Data Links in the NAS

Although the C2 links are intentionally separated from the ATC communication, this HALE UAS C2 communications FRD has been developed to be able to take advantage of the NAS Modernization Program to the maximum extent. More specifically, the modernized NAS infrastructure is potentially useful for the C2 links. For example, increased situation awareness, more accurate weather information, and use of satellite technology are of interest to pilot-UA communications. There have been several new private link initiatives currently under development to provide the C2 capabilities and services in the NAS. They are essentially built on the current ATN infrastructure. Appendix D briefly reviews the NAS modernization program and Appendix E provides brief information about these existing data links.

3.4 C2 Information Categories

The C2 Communications System is used to deliver information exchanges that ensure safe, reliable, and effective HALE UA flight operation. The applications for these information exchanges are being defined by the Work Packages of Access 5, such as Cooperative Collision Avoidance (CCA), Contingency Management (CM), Weather, and Human System Interface (HSI). The following types of information are exchanged:

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

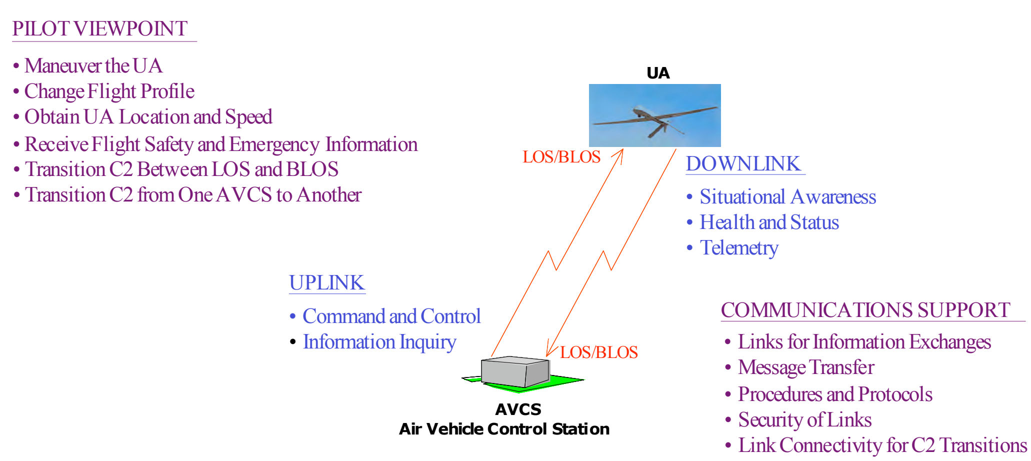
Command and Control Messages
These messages are used for flight control and task execution and usually have higher priority than other message types.

Health and Status of UA
Health and status data provides critical information about the condition of the subsystems, sensors, and hardware of the UA. The pilot at the AVCS uses this information to maintain full awareness of the ability of the UA to function and to diagnose problems. The pilot can then handle potential or actual problems by taking preventive measures or corrective actions to ensure continued functioning and thus safe flight.

Situation Awareness Data
Situation awareness data is the data regarding the operational environment of a UA, including data for any aircraft surrounding it. Examples of this data are weather conditions, terrain information, and location of surrounding aircraft. The data may come from sources such as ADS-B or Traffic Alert and Collision Avoidance System (TCAS). In general, the Common Operating Picture (COP) of any airport is accessible by the PIC. Use of situation awareness data enhances the "see and avoid" capability of HALE UAS.

Telemetry Data
Telemetry data provides information regarding the flight characteristics of the UA. This data includes items such as flight trajectory, arrival times, altimeter setting, altitude, heading, speed, route clearance, and arrival time. The pilot uses this data to maintain full awareness of the flight of the UA and to determine the changes needed to ensure safe flight.

Figure 4 illustrates information that is exchanged between the UA and AVCS, using the uplink and downlink. The figure provides the pilot viewpoint of C2 functions and the information the pilot uses to make decisions, as well as the underlying communications capabilities that support the C2 functions.



The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Figure 4. The C2 Communications Links Facilitate C2 Functions

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

4 REQUIREMENTS

This section defines the minimum functional requirements the HALE UAS C2 Communications System must meet to be deemed acceptable. Only the C2 link is addressed. All the requirements in this section are independent of design or implementation.

The requirements specified in this document for Step 1 are derived from the C2 high level functional requirements in the Access 5 FRD.

4.1 Assumptions

The Access 5 HALE ROA CONOPS provides a set of assumptions that were used for developing the Access 5 FRD. These assumptions plus the following assumptions apply to the requirements in this document:

1. The requirements apply to any HALE UA that plans to fly in the NAS in accordance with the guidelines and procedures set forth in Step 1 of the Access 5 project.

2. HALE UA take off and land at pre-designated airports.

3. The requirements apply to the en route phase of HALE UA flight and operations. That is, at FL430 and above (Access 5 Step 1).

4. The HALE UAS C2 Communications System is implemented by the UAS manufacturer and operated by a PIC.

5. Additional requirements will be added as needed for subsequent Access 5 steps.

4.2 Interfaces

Interfaces internal to the C2 Communications System are those between the UA pilot at the AVCS and on-board UA systems such as the flight control system.

At the en route phase (Step 1), the UA and AVCS perform all necessary communications with each other to ensure safe and reliable HALE UA flight. The C2 Communications System facilitates UA pilots to interact and control HALE UA comparable to the capabilities of manned aircraft pilots.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

4.3 C2 Communications System Functional Requirements

4.3.1 Information Exchanges for UAS Operations

The C2 Communications System is the conduit for exchanging information between the UA and AVCS. The communications are 2-way in order to transport information to and from both the UA and the AVCS. Each direction may carry different information, such as commands or status data that are used to ensure safety of flight. Both directions must work together in an orderly manner to achieve timely delivery and preserve message content.

Since the distance between the UA and the AVCS may exceed LOS, the C2 links must be able to handle both LOS and BLOS as needed. The C2 links are typically implemented with, but not limited to, modern digital communications via LOS or BLOS links. This internal link can be UA manufacturer-specific or any available service recommended by the FAA.

4.3.1.1 Uplink C2 Communications

The uplink is the data transmission from the AVCS to the UA. The transmissions provide directives and information to the UA, such as commands, status requests, and related messages. These transmissions may require LOS or BLOS links, depending on the location of the UA relative to the AVCS.

a. The C2 Communications System shall provide at least one uplink C2 communication path between the UA and the AVCS.

b. The C2 Communications System shall use the uplink to transfer information from the AVCS to the UA.

c. The C2 Communications System shall provide uplink communications that are LOS and/or BLOS as needed between the UA and AVCS.

4.3.1.2 Downlink C2 Communications

The downlink is the data transmission from the UA to the AVCS. The transmissions provide necessary and timely data for the pilot to conduct safe flight operations. The data may contain telemetry, situation awareness, health and status, and other data as needed. The transmissions may require LOS or BLOS links, depending on the location of the UA relative to the AVCS.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

a. The C2 Communications System shall provide at least one downlink C2 communication path between the UA and the AVCS.

b. The C2 Communications System shall use the downlink to transfer information from the UA to the AVCS.

c. The C2 Communications System shall provide downlink communications that are LOS and/or BLOS as needed between the UA and AVCS.

4.3.1.3 Cohesive and Consistent Uplink and Downlink Operations

It is critical that messages that are initiated for sending are received within enough time to be useful and with their contents preserved. The uplink and downlink operations must work together correctly in a timely manner to achieve these goals.

a. The C2 Communications System shall coordinate the uplink and downlink operations to provide orderly message transfer.

b. The C2 Communications System shall maintain message integrity for both uplink and downlink operations. That is, the received message is unaltered from the sent message.

c. The C2 Communications System shall provide a means to manage message delivery delays based on priority criteria.

4.3.2 Communications Procedures and Protocols

Procedures and protocols are the established steps and functional mechanisms that regulate information exchanges between the AVCS and UA. These procedures and protocols must provide systematic link access and parameters for data transmission. Due to the complexity of the C2 Communications System and the time criticality of many communications, it is expected that automated means will be employed for procedures and protocols where needed to achieve effective system performance.

4.3.2.1 Link Protocols for Accessing Shared Communications

Protocols must be defined for systematically accessing shared communication resources, namely the C2 links, when there are multiple requests to use the resources. These protocols typically address contention and congestion in shared resources and establish the criticality of different types of messages. These defined behaviors and criticality designations are used to support safe flight control.

a. The C2 Communications System shall provide means to resolve conflicts that

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

occur in shared communications media. Examples of these conflicts are contention, congestion, and collisions.

4.3.2.2 Procedures for Communications Assurance

Procedures for communications assurance support protection of the C2 system. Basic communications assurance functions include authentication and non-repudiation of information exchanges.

a. The C2 Communications System shall provide communication assurance procedures as needed prior to, during, and after information exchanges.

4.3.2.3 Procedures for Data Transmission

The C2 links are configured accordingly to ensure that both the AVCS and UA send and receive data correctly. Procedures must be defined to set and change the data transmission parameters, which include items such as frequency, data rate, modulation/coding, antenna usage, and transmit power.

a. The C2 Communications System shall provide means for data transmissions prior to, during, and after flight operations.

4.3.3 Communications to Control Safe Flight and UA Operations

Although the pilot and UA are physically separate, it is expected that the UA will behave as if the pilot is onboard. Therefore the C2 Communications System is vital for the pilot to transmit information that directs UA operations and ensures flight safety. When actions are time critical, the UA must receive and act on the most important information first. Comparable to onboard pilots in the current NAS, the transmitted directives must not interfere with the NAS.

4.3.3.1 Situational Awareness and Health and Status of the UA

Since the UA pilot is offboard the aircraft at all times and "flies" the aircraft from the AVCS, the UA must transfer onboard information to the pilot. This information may include health and status of the aircraft or its subsystems, as well as in-flight situation awareness information from onboard sensors and systems. The particular information that platforms transfer is manufacturer-specific.

a. The C2 Communications System shall exchange situation awareness data. The pilot at the AVCS uses this data to conduct safe flight control.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

b. The C2 Communications System shall exchange UA health and status data. Examples of health and status data are fuel remaining and landing gear status.

c. The C2 Communications System shall exchange telemetry data. Examples of telemetry data are flight trajectory, altimeter setting, altitude, heading, speed, and route clearance.

4.3.3.2 C2 Directives to the UA

Since the UA pilot is offboard the aircraft at all times and "flies" the aircraft from the AVCS, the pilot must transfer directives to the UA. These directives may include flight commands and requests for data. The particular directives that the pilot issues are manufacturer-specific.

a. The C2 Communications System shall exchange command and control messages. These messages include commands, requests, informational messages, and related data.

4.3.3.3 Capability to Prioritize C2 Information Exchanges

Several different types of messages may be conveyed via the C2 link. Some of the messages and information are more critical than others to control safe flight, depending on the operational environment and events. It is crucial that the C2 Communications System transfer higher priority messages before transferring lower priority messages. In effect, higher priority messages are transferred with less delay than lower priority messages.

a. The C2 Communications System shall be able to prioritize the C2 information.

b. In the C2 Communications System, information regarding safety of flight shall have the highest priority.

4.3.3.4 Protection Means to Coexist with Current NAS Systems and Operations

The link between UA and AVCS (i.e., C2 link) is a new addition to the NAS infrastructure and must be compatible with it. Part of this compatibility is that the C2 link must not introduce any harmful radio frequency interference (RFI) that would compromise the current NAS systems and operations.

a. The C2 Communications System shall comply with the current NAS RFI environmental requirements.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

4.3.3.5 Ability to Distinguish Each UA

For flight safety and task success, it is paramount to be able to identify, communicate with, and control each UA without any ambiguity.

a. The C2 Communications System shall be able to distinguish each UA.

4.3.4 Secure C2 Link

Security of the C2 link is important to the safety of the UA and other aircraft and personnel in the NAS. Only authorized users should be able to access the C2 link to perform message transfers to control the UA. The transmissions themselves must not be corrupted, changed, or denied, and unauthorized messages must not be inserted into the message traffic; to do so could jeopardize safety as well as success of the tasks.

4.3.4.1 Prevention of Unauthorized Access

The C2 Communications System must be capable of preventing any unauthorized C2 of the UA. As a minimum, C2 communications must be authenticated and authorized. Access requirements are particularly challenging since the C2 link is wireless and continuously moving through space.

a. The C2 Communications System shall provide safeguards that deny unauthorized users the ability to command and control the UA.

4.3.4.2 Resistance to Jamming or Interference

The consequence of unplanned loss of link use can be significant to flight safety. A major cause of unplanned loss of use is intentional and unintentional jamming or interference, such as by deliberate actions or natural effects. The C2 Communications System must be resistant to jamming and interference. For example, the UAS may have communications equipment that is anti-jam or anti-interference or procedures could be defined to handle jamming and interference. These measures result in enhanced safety.

a. The C2 Communications System shall have provisions for anti-jamming or anti-interference.

4.3.5 Link Connectivity

To ensure flight safety, it is ideal to maintain C2 communications at all times.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

During the course of operations, transitions may occur that could cause a break in C2 communications. These transitions include those between LOS and BLOS communications and between one AVCS and another. During such transitions, the goals are to maintain information continuity between the AVCS and UA and to minimize any communications dropouts. Additionally, if there is a communications dropout during such a transition, it is preferred that the system refrain from automatically launching lost link procedures. Rather, the system should be able to evaluate the dropout to determine its significance and whether or not it warrants triggering lost link procedures.

4.3.5.1 C2 Communications While Transitioning Between LOS and BLOS Operations

Typically, the UA flies away from LOS and flies to BLOS with respect to the AVCS. The C2 Communications System must be capable of providing communications for both LOS and BLOS conditions, including the transition between them. Due to physical constraints that may exist, such as during transitions between satellites or at the edge of a satellite footprint, scheduled and/or predictable link dropouts may be acceptable as long as there are contingency plans in place.

a. The C2 Communications System shall maintain the C2 link between the UA and the AVCS at all flight phases, including transition between LOS and BLOS.

b. The C2 Communications System shall allow scheduled and/or predictable C2 dropouts that result from physical constraints. These dropouts do not trigger lost link procedures unless the dropout time exceeds an acceptable threshold. Excessive dropout events are managed by the Contingency Management function.

4.3.5.2 C2 Communications While Transitioning Between Different AVCS Stations

During the course of UA flight, it is possible that more than one AVCS is employed, though there is no requirement to have more than one AVCS. The C2 Communications System must be capable of providing communications between the UA and the AVCS in control, including the transition from one AVCS to another.

a. The C2 Communications System shall maintain the C2 link between the UA and the AVCS at all flight phases, including possible handover from one AVCS to another.

b. When more than one AVCS is deployed, the C2 Communications System shall provide a C2 link between each AVCS.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

5 Verification / Validation

5.1 Responsibility for Verification

The UA manufacturer or UA provider is responsible for all requirement compliance test and verification.

5.2 Test and Evaluation Guidelines

The following list provides guidelines for verifying the requirements in this document. These guidelines provide items to consider when defining verification tests and evaluation criteria.

- The verification tests should use representative message traffic that is close to real message traffic, to ensure meaningful results. Factors to include in test message traffic are data fidelity and traffic load during nominal and peak conditions.
- The verification tests should use a sufficient quantity of data, to ensure meaningful results.
- The verification tests should be conducted using pre-collected data whenever possible, to reduce cost and schedule.
- The verification tests should be conducted using simulations and other subsystem tests rather than flight tests wherever possible, to reduce cost and schedule.
- The verification results should be evaluated for compliance with individual requirements as well as for meeting overall program goals, including safe operation of UA and seamless integration with the NAS.

5.3 Methods of Verification

The following verification methods are used to verify compliance of individual requirements identified in this document. The five verification methods, listed in increasing order of complexity, are defined as:

a. Inspection: A non-destructive static-state critical examination of the hardware, technical data, and documentation. Special laboratory appliances, procedures, or services are not used.

b. Analysis: Comparison of the design against known scientific and technical principles, procedures, and practices to estimate the capability of the proposed design to meet the mission and system requirements. This method may also include mathematical evaluation and review of the design and representative data.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

c. <u>Simulation</u>: Representation of the end item with a similar or simpler software model that is an abstraction of the end item, is more easily manipulated, or uses an alternate platform. This method uses standalone software that processes representative data for representative scenarios. The software represents the features and internal processing of the end item, while the execution results provide estimates of the true interactions, behaviors, and performance of the system.

d. <u>Test</u>: Performance is measured during or after systematic and controlled application of functional and/or environmental stimuli. Quantitative measurements are analyzed to determine degree of compliance. The process uses laboratory equipment, procedures, items, and services and includes hardware-in-the-loop testing.

e. <u>Demonstration</u>: Qualitative determination of properties of the end item, including the use of technical data and documentation. The items being verified are observed, but not quantitatively measured in a dynamic state. This method focuses on flight testing.

5.4 Verification Matrix

Table 1 is the verification matrix for the requirements defined in this document.

Table 1. Verification Matrix

Identifier	Requirement	Verification Method
4.3.1.1.a	The C2 Communications System shall provide at least one uplink C2 communication path between the UA and the AVCS.	Inspection
4.3.1.1.b	The C2 Communications System shall use the uplink to transfer information from the AVCS to the UA.	Simulation
4.3.1.1.c	The C2 link shall provide uplink communications that are LOS and/or BLOS as needed between the UA and AVCS.	Simulation
4.3.1.2.a	The C2 Communications System shall provide at least one downlink C2 communication path between the UA and the AVCS.	Inspection
4.3.1.2.b	The C2 Communications System shall use the downlink to transfer information from the UA to the AVCS.	Simulation
4.3.1.2.c	The C2 link shall provide downlink communications that are LOS and/or BLOS as needed between the UA and AVCS.	Simulation
4.3.1.3.a	The C2 Communications System shall coordinate the uplink and downlink operations to provide orderly message transfer.	Simulation
4.3.1.3.b	The C2 Communications System shall maintain message integrity for both uplink and downlink operations.	Simulation
4.3.1.3.c	The C2 Communications System shall provide a means to manage message delivery delays based on priority criteria.	Simulation
4.3.2.1.a	The C2 Communications System shall provide means to resolve conflicts that occur in shared communications media.	Analysis
4.3.2.2.a	The C2 Communications System shall provide communication assurance procedures as needed prior to, during, and after information exchanges.	Analysis

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

4.3.2.3.a	The C2 Communications System shall provide means for data transmissions prior to, during, and after flight operations.	Demo
4.3.3.1.a	The C2 Communications System shall exchange situation awareness data.	Demo
4.3.3.1.b	The C2 Communications System shall exchange UA health and status data.	Demo
4.3.3.1.c	The C2 Communications System shall exchange telemetry data.	Demo
4.3.3.2.a	The C2 Communications System shall exchange command and control messages.	Demo
4.3.3.3.a	The C2 Communications System shall be able to prioritize the C2 information.	Analysis
4.3.3.3.b	In the C2 Communications System, information regarding safety of flight shall have the highest priority.	Demo
4.3.3.4.a	The C2 Communications System shall comply with the current NAS RFI environmental requirements.	Analysis
4.3.3.5.a	The C2 Communications System shall be able to distinguish each UA.	Analysis
4.3.4.1.a	The C2 Communications System shall provide safeguards that deny unauthorized users the ability to command and control the UA.	Analysis
4.3.4.2.a	The C2 Communications System shall have protection provisions for anti-jamming or anti-interference.	Analysis
4.3.5.1.a	The C2 Communications System shall maintain the C2 link between the UA and the AVCS at all flight phases, including transition between LOS and BLOS.	Demo
4.3.5.1.b	The C2 Communications System shall allow scheduled and/or predictable C2 dropouts that result from physical constraints.	Demo
4.3.5.2.a	The C2 Communications System shall maintain the C2 link between the UA and the AVCS at all flight phases, including possible handover from one AVCS to another.	Demo
4.3.5.2.b	When more than one AVCS is deployed, the C2 Communications System shall provide a C2 link between each AVCS.	Demo

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Appendices

Appendix A - Acronym List

This appendix defines acronyms used in this document.

ACARS	Aircraft Communications and Reporting System
ADS	Automatic Dependent Surveillance
ADS-B	Automatic Dependent Surveillance - Broadcast
AMSS	Aeronautical Mobile Satellite Service
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
AVCS	Air Vehicle Control Station
BER	Bit Error Rate
BLOS	Beyond Line of Sight
CCA	Cooperative Collision Avoidance
CDM	Collaborative Decision-Making
CM	Contingency Management
CNS/ATM	Communications, Navigation, Surveillance / Air Traffic Management
CoA	Certificate of Authorization
CONOPS	Concept of Operations
COP	Common Operating Picture
CPDLC	Controller-Pilot Data Link Communications
CSMA	Carrier Sense Multiple Access
C2	Command and Control
DSR	Display System Replacement
D8PSK	Differentially Encoded 8-Phase Shift Keying
EAP	Extensible Authentication Protocol
ELOS	Equivalent Level of Safety
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FAR	Federal Aviation Regulation
FDMA	Frequency Division Multiple Access
FL	Flight Level
FL180	Flight Level 180 (18,000 feet)
FL430	Flight Level 430 (43,000 feet)
FRD	Functional Requirements Document
GEO	Geostationary Orbit
GPS	Global Positioning System
HALE	High Altitude, Long Endurance
HOCSR	Host/Oceanic Computer System Replacement
HSI	Human System Interface

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

IC2DL	Interoperable C2 Data Link
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronics Engineers
ITWS	Integrated Terminal Weather System
LAAS	Local Area Augmentation System
LEO	Low Earth Orbit
LOS	Line of Sight
MAC	Medium Access Control
MASPS	Minimum Aviation System Performance Standards
MSL	Mean Sea Level
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NEXCOM	Next Generation Air/Ground Communications
NIST	National Institute of Standard and Technology
OSI	Open System Interconnect
pFAST	Passive Final Approach Spacing Tool
PIC	Pilot-in-Command
PK	Public Key
RFI	Radio Frequency Interference
ROA	Remotely Operated Aircraft
SATCOM	Satellite Communications
SMA	Surface Movement Advisor
SSR	Secondary Surveillance Radar
STARS	Standard Terminal Automation Replacement System
TCAS	Traffic Alert and Collision Avoidance System
TDMA	Time Division Multiple Access
TKIP	Temporal Key Integrity Protocol
TMA	Traffic Management Advisor
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UHF	Ultra High Frequency
URET/CCLD	User Request Evaluation Tool/Core Capability Limited Deployment
VDL	VHF Data Link
VHF	Very High Frequency
WAAS	Wide Area Augmentation System
WARP	Weather and Radar Processor
WPA	Wi-Fi Protected Access

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Appendix B - Definitions

This appendix defines terms used in this document.

Aeronautical Telecommunications Network (ATN) – A communications network conceived by ICAO Future Air Navigation System (FANS) to support the future Communications, Navigation, Surveillance / Air Traffic Management (CNS/ATM) concept.

Air Route Traffic Control Center (ARTCC) – Provides Air Traffic Service to aircraft operating on IFR flight plans within the controlled airspace, and principally during the en route phase of flight. It is the largest component of the NAS and each ARTCC covers thousands of square miles encompassing all or part of several states.

Air Vehicle Control Station (AVCS) - A site configured to allow a pilot in command of a UA to operate and monitor all UA operations conducted under his or her authority.

Beyond Line of Sight (BLOS) – The condition where the straight line path between any pair of communication nodes are obstructed.

Command and Control Link – Two-way data link between the UA and the UA pilot-in-command at the AVCS. This link is used for flight control and all necessary information exchange for the purpose of safe flight. The link may be LOS or BLOS.

En Route – A phase of flight in which the pilot receives instructions regarding the altitude and heading to maintain, as well as the radio frequency to tune. This portion of the flight can be as short as a few minutes or as long as many hours.

Equivalent Level of Safety - An evaluation, often subjective, of a system and/or operation to determine the acceptable risk to people and property.

High Altitude Long Endurance (HALE) – Flight and operations at an altitude of 40,000-foot mean sea level (MSL) or higher with sufficient cruise capability to transit the NAS.

Line of Sight (LOS) – The condition where the path between any pair of communication nodes form an unobstructed straight line.

Pilot-in-Command (PIC) - As defined in 14 CFR Part 1, a person who:

1. Has final authority and responsibility for the operation and safety of the flight;
2. Has been designated as pilot in command before or during the flight; and

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

3. Holds the appropriate category, class, and type rating, if appropriate, for the conduct of the flight.

Remotely Operated Aircraft (ROA) – An aircraft that is operated from a remote location by an operator that issues command and control instructions to the aircraft, which are executed near real-time by an onboard autonomous flight management control system.

ROA Airport - An airport that is capable of handling ROA operations.

Unmanned Aircraft (UA) - An aircraft in which the pilot-in-command is physically located outside of the UA. ROA are a subset of UA.

UA Airport - An airport that is capable of handling UA operations.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Appendix C - C2 Communications Requirements Excerpted from Access 5 FRD

The major revision of the Access 5 FRD has been carried out during the development of this C2 Communications FRD. As a result, there have been discussions taking place between these two development processes.

Figure C-1 depicts the high-level functional partition defined in the latest version of the Access 5 FRD. C2 is a cross cutting function to interact with or facilitate all the other UAS functions that include "communicate." Command, Control, and Communicate within the UAS are the subjects of this C2 Communications FRD.

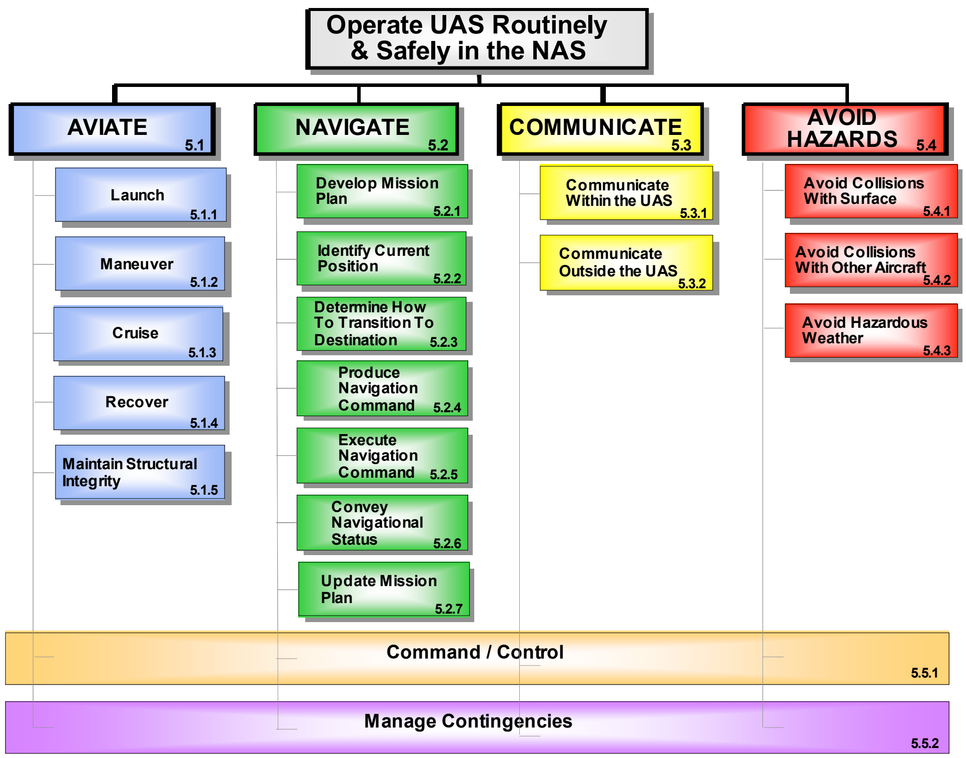


Figure C-1. UAS Functional Partition

The lower level functional requirements of the C2 are further decomposed by this work package and concurred with the Access 5 FRD process. The headings of these functions are shown in Figure C-2. The detailed functional descriptions and requirements are the main part of this C2 Communications FRD.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

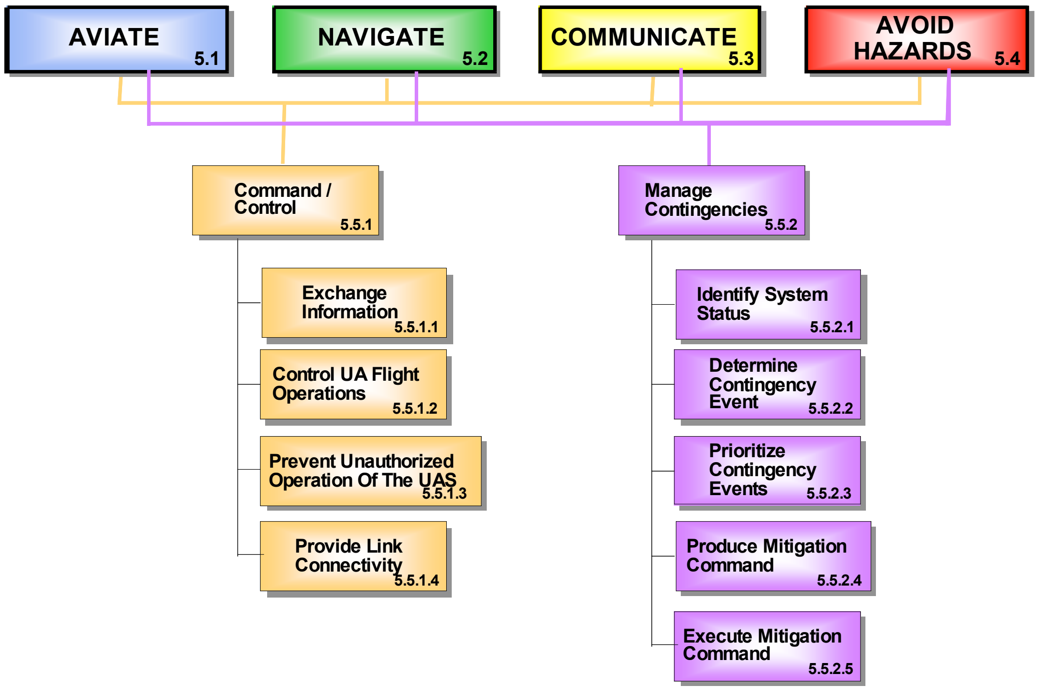


Figure C-2. Command / Control Cross-Cutting Functions

The following table is the excerption of the requirements from the Access 5 FRD that are related to C2 communications.

Table C-1. C2 Communications Requirements Excerpted from the Access 5 Functional Requirements Document (FRD)

Section Number	Description
5.3.1.1	Transmit information within the UAS.
5.3.1.2	Receive information within the UAS.
5.5.1.1	Exchange information.
5.5.1.2	Control UA flight operations.
5.5.1.3	Prevent unauthorized operation of the UAS.
5.5.1.4	Provide link connectivity.

Appendix D - The NAS Modernization Overview

This appendix presents the NAS modernization overview and its capabilities. It is anticipated that the heavily invested NAS infrastructure can be utilized as appropriate. In particular, some of the currently deployed ATN capabilities and services are also applicable to the command and control (C2) communications link for Unmanned Aircraft Systems (UAS) with technical enhancements or capability upgrades. For example, increased situation awareness, more accurate weather information, and use of satellite technology are all of interest to C2 communications in a UAS.

The following information is excerpted from the FAA website.

The FAA has been executing the NAS Modernization Program since 1998. It is a three-phase fifteen-year program that involves providing new systems to enhance capabilities and services for users:

- Clear, less congested air/ground communications using digital technology
- Accurate navigation and landing services to more airports using satellite technology
- Expanded surveillance coverage of airspace and airport surfaces
- Increased air-to-air situation awareness for pilots
- More efficient sequencing of arriving and departing aircraft through improved air traffic control decision support tools
- Accurate and timely weather data to controllers and pilots
- Sharing of real-time information between users and providers
- Increased ability of users to fly more direct routes

Modernization also includes making the critical infrastructure of air traffic control services easier and more cost-effective to operate and maintain. Critical infrastructure includes:

- Communications, navigation/landing, and radar surveillance systems
- Weather detection and reporting equipment
- Air traffic control computers and displays for controllers
- Power generation and backup systems
- Air traffic control facilities sustainment

In what follows, we provide a brief summary of key NAS systems/capabilities and their architectural improvements.

<u>Communications</u>

Aviation communications systems will be upgraded, integrating systems into a

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

seamless network using digital technology for voice and data. During the transition, the FAA will continue to support analog voice communications. Specific improvements include:

- Controller-pilot data link communications (CPDLC), which introduces electronic data exchange between controllers and the cockpit and reduces voice-channel congestion.
- Digital voice communications via new digital radios provided by the next generation air/ground communications program, which improves spectrum utilization. Ultra-high frequency (UHF) analog radios will be retained for Department of Defense users. Radios operating in the analog mode will be retained in many low-density areas for general aviation users.

Navigation

Over the next 10 years, the navigation system is expected to use satellites augmented by ground monitoring stations to provide navigation signal coverage throughout the NAS. Satellite-based navigation will support direct routes and help users meet their schedules with more predictability. Reliance on ground-based navigation aids is expected to decline as satellite navigation provides equivalent levels of service.

The transition to satellite-based navigation consists of:

- Use of the global positioning system (GPS) as a supplemental system for en route navigation and non-precision approaches.
- Deployment of the wide area augmentation system (WAAS) to augment GPS for primary means en route navigation and precision approaches. WAAS will be deployed in stages by adding ground reference stations, with operational capability improving in each stage.
- Deployment of a local area augmentation system (LAAS) to augment GPS for precision approaches in low visibility conditions.

Surveillance

Surveillance in the future NAS will provide increased coverage in non-radar areas and include aircraft-to-aircraft capabilities for greater situation awareness. The NAS Architecture calls for gradual transition from current radar systems to digital radar and automatic dependent surveillance (ADS).

Air-to-air ADS-Broadcast (ADS-B), a new avionics surveillance package, is being developed to include a cockpit display of traffic information feature that shows the position of all ADS-B-equipped aircraft to enhance the pilot's awareness of the surrounding environment. Later, a compatible ground system will be deployed to provide the same ADS-B surveillance information to controllers as seen by pilots.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Aviation Weather

The NAS Architecture contains improved ways to collect, process, transmit, and display weather information to users and providers, during flight planning and in flight. The goal is to give NAS providers and users depictions of weather information and provide more weather data in the cockpit to enhance common situation awareness. New features include:

- Integrated terminal weather system (ITWS), which provides near-term (0-30 minutes) prediction of significant weather in the terminal area. It generates products, including wind shear and microburst predictions, storm cell hazards, lightning information, and terminal area winds. ITWS integrates data from radar, weather sensors, National Weather Service models, and automated aircraft reports.
- Weather and radar processor (WARP), which receives and processes real-time weather data from multiple sources for the en route environment. It prepares national and regional weather mosaics and mosaics for the controller's displays and provides grid forecast data from the National Weather Service to other NAS automation systems.
- Delivery of weather and other flight information services to the cockpit via a private service provider primarily targeted to supporting general aviation users.

Avionics

Avionics will evolve to take advantage of new communications, navigation, and surveillance-related technologies in the NAS Architecture, including:

- GPS receivers that enable aircraft to navigate via direct routes and fly precision instrument approaches to virtually any runway. Combining GPS with cockpit electronic terrain maps and ground-proximity warning systems can help pilots avoid controlled flight into terrain.
- New multi-mode digital radios for voice and data communications among pilots, controllers, and various ground facilities.
- Digital communications technology that increases available voice channel capacity and provides a data link that enables instructions, flight information services, and graphical weather data to be sent directly to the cockpit.
- ADS-B that transmits GPS-based position, velocity, and intent information to ground stations and other aircraft.
- Multi-functional cockpit displays to present information that improves situation awareness.
- Traffic alert and collision avoidance system (TCAS), which provides pilots with advisory information to prevent mid-air collisions with other

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

transponder-equipped aircraft, will be enhanced and remain the primary safety system to prevent air-to-air collisions.

Free Flight Phase 1

New tools that give controllers, planners, and service operators more complete information about air traffic control and flight operations comprise a large part of the NAS Architecture's near-term plan. Some of these tools are embodied in a program called Free Flight Phase 1 Select Capability/Limited Deployment. The Free Flight Phase 1 tools are:

- User request evaluation tool/core capability limited deployment (URET CCLD) - an automated tool that assists en route controllers in identifying conflicts up to 20 minutes in advance of their occurrence.
- Traffic management advisor (TMA) single center - an automated tool that assists en route radar controllers with sequencing aircraft to terminal areas.
- Passive final approach spacing tool (pFAST) - an automated tool designed to work in conjunction with TMA to help controllers assign runways and sequence aircraft according to user preferences and airport capacity.
- Collaborative decision-making (CDM) - a real-time exchange of flight plan and system constraints data between the FAA and airline operations centers in order to work collaboratively to better manage NAS traffic.
- Surface movement advisor (SMA) - a system that provides information sharing to airline and airport personnel who plan and manage the sequence of taxi out and plan for arrivals in the ramp and gate areas at larger airports.

Automation Infrastructure

Free Flight Phase 1 tools and other future tools depend on infrastructure improvements already underway, such as the following, to operate:

- Display System Replacement (DSR) provides new controller workstations and a network infrastructure for the air route traffic control centers (ARTCC). DSR has the capability to show weather data from the next generation weather radar.
- Standard Terminal Automation Replacement System (STARS) is the new terminal workstation that will interface with the new sequencing and spacing tools and the advanced communications, navigation, surveillance, and weather systems.
- Host/Oceanic Computer System Replacement (HOCSR) replaces the host and oceanic processors and peripherals at the ARTCCs to solve immediate hardware supportability problems.

The NAS Architecture also plans for an integrated NAS information service for users and providers to receive and share common data and jointly make

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

operational planning decisions. This information service includes a system-wide information network, use of standardized data formats, and interoperability across applications.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Appendix E - Current ATN Data Links

This appendix introduces the current ATN data links available for use in the aviation industry, recommended by ICAO and RTCA.

Mode S

The Mode S Secondary Surveillance Radar (SSR) System is a fully digital surveillance system that provides both general (broadcast) surveillance and specific (addressed to a given aircraft) surveillance. This digital surveillance system has a data carrying capability that is utilized for the ATN. Mode S has been under development for a long time and it appears that Mode S will be introduced for surveillance, with equipment programs for Mode S in place in both Europe and North America. Nevertheless, there seems to be little support at the moment for the use of Mode S data link, perhaps due to the development of VHF Data Link (VDL). In the long run, Mode S is the only currently available air/ground technology that offers the potential for megabit data transfer.

VHF Data Link (VDL)

Mode 1: is a low risk but low capability option (600 bps is the channel rate shared amongst all using aircraft). It uses existing Aircraft Communications and Reporting System (ACARS) radio technology. The access scheme is carrier sense multiple access (CSMA) that is simple but gives rise to non-deterministic channel access times. Mode 1 is unlikely to be used operationally.

Mode 2: is an onwards development of Mode 1, uses the same frequency band with differentially encoded 8-phase shift keying (D8PSK) to give a channel rate of 31.5 kbps. However, CSMA is still used as the channel access procedure that will still result into exponentially increasing delay time in a high load system. There are thus question marks over the use of VDL Mode 2 for operational use.

Mode 3: is a significant improvement over Mode 2 using Time Division Multiple Access (TDMA) scheme for channel access, while operating the same channel rate as Mode 2. It also supports voice communications in the same channel, in spite of a significant technical risk. The use of TDMA permits a deterministic transit delay to be offered and bandwidth utilization is much improved over Mode 2.

Mode 4: uses the same frequency band as the other VDL modes and carries 31.5 kbps data capacity using D8PSK. It also uses TDMA. However, while Mode 3 replies on a ground station to provide the channel-synchronizing signal for TDMA, Mode 4 is self-synchronizing

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

and hence permits air-air communication in the absence of ground stations. The data link procedures provide a simple acknowledged connectionless service. This is the most efficient data link service for ATN use. The channel reservation protocol Mode 4 requires position information that leads to support for ADS-B readily.

Aeronautical Mobile Satellite Service (AMSS)

The AMSS uses the INMARSAT Geostationary Satellite to provide a global communications service to aircraft (albeit with coverage limitations near the pole). A dedicated set of frequencies is made available to aeronautical mobiles and these are broken down by Frequency Division Multiple Access (FDMA) into a number of discrete channels. There are four types of channel that form a network service. They are TDMA ground to air, slotted Aloha air to ground, TDMA air to ground, and bi-directional channels. Both 2.4 Kbps service and a 10.5 Kbps service are available, but they are shared by all aircraft communicating via the same satellite. The communication service provided to users is derived from ITU-T X.25.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Appendix F - C2 Communications System Performance Guidelines

F.1 C2 Communications System Performance Guidelines

This appendix provides performance guidelines for the functional requirements outlined in this document. The purpose of the performance guidelines is to provide some measurable performance indicators in connection with the UA control capability. Where quantitative values are used, they should be considered a starting point for further analysis. The ultimate goal of the performance guidelines is to be able to achieve safe and reliable HALE UA operations in the NAS.

F.1.1 Availability

High availability of the C2 Communications System is essential to successful UA flight and routine operation in the NAS. Availability applies to the bandwidth for transmission, the coverage of satellite footprints (if used), the operating frequency, the available relayed station (when adopted), and the equipment.

F.1.1.1 Availability of C2 Links

To maintain the equivalent level of safety (ELOS) as manned aircraft, the C2 link must be available for communications regarding safe separation and control of UA. The availability of the C2 link can be characterized by the severity of the impact of losing the C2 link, as defined in NAS-SR-1000. That is, C2 link availability supports the ability of the NAS to exercise safe separation and control over the UA. When the C2 link is not available, the UA cannot receive directives from the AVCS. If the UA has onboard capabilities for safe separation and control, the impact of losing the C2 link is less severe. Nonetheless, the AVCS may have a need to dispatch overriding directives, thus increasing the severity of a lost C2 link. Therefore, the C2 link should be available between the critical and essential levels.

F.1.1.2 Available Channel Capacity or Bandwidth

a. The C2 Communications System should provide sufficient channel capacity (also known as bandwidth in general) for all the data required for safe and reliable UA operations.

b. The C2 Communications System should provide channel capacity of 64 Kbps (threshold) or greater in which at least 2.4 Kbps capacity (threshold) should be reserved for flight control.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Note: The channel capacity recommended here considers all support discussed in this document that include CCA, CM, HSI functions, situation awareness, and potential redundant links, etc. This capacity is best supported by multiple physical links. The same order of magnitude of the capability has been employed by current Unmanned Aircraft (UA).

F.1.1.3 Operating Frequency

The operating frequencies of the C2 link must comply with or be approved by FCC and all other related government authorities prior to certification or approval.

F.1.1.4 Satellite Footprint

When SATCOM is employed, the satellite footprint must provide sufficient coverage for the flight plan to ensure required availability of the C2 link for safe and reliable fights.

F.1.2 Reliability

The C2 communication equipment will be in use continuously and the operating environment such as temperature may vary as a function of time. High reliability equipment is strongly desirable. Reliability refers to the number of failures in a given time period. Mean time between failures (MTBF) is a standard reliability measure widely used in the industry. The MTBF given in this section specifies the minimum and achievable system reliability for the C2 communications equipment. The MTBF is the inverse of the failure rate (failures per million hours) as defined in MIL-HDBK-217F.

Mean time to repair (MTTR) is another measure related to availability/reliability. It conventionally refers to time for a person to make a repair. When a failure occurs onboard an UA, MTTR does not apply, since a person is not onboard to make repairs. As a guideline to promote communications equipment availability/reliability, the UA manufacturer could consider providing redundant systems. The formal definition of MTTR is contained in NAS-SS-1000 and MIL-HDBK-472.

In general, the equipment vendors provide MTBF data. The UA integrator will predict the overall system reliability from the MTBFs of various subsystems or equipment.

a. The C2 Communications System equipment should provide the following MTBF performance: 8,760 hours (threshold) and 26,286 hours (objective).

Note: The suggested MTBF hours follow those required by the CPDLC equipment as a guideline. The reference is used to account for the commercially achievable hardware feasibility instead of for the CPDLC performance.

F.1.3 Link Performance

Although there are some known performance measures such as bit error rate (BER) for communications links discussed in the literature, we are also interested in other less discussed measures. These include the rate of successful message transfer and how fast the message can be delivered to the intended recipient, that is, the end-to-end message transfer delay.

BER is a good integrity indicator for equipment but cannot fully characterize the end-to-end system performance, which involves the design of message length and the network topology selected. The performance measures are usually represented in a statistical sense due to the stochastic nature of communication channels.

F.1.3.1 Signal Integrity

The BER and Message Error Rate ensure the minimum system integrity.

a. The BER in C2 equipment should be no more than one erroneous bit in one million (10^{-6}) in all operating conditions.

b. The C2 Communications System should ensure that no more than one control message in one billion (10^{-9}) is falsely interpreted.

Note: These performance guidelines are common performance levels offered by communication equipment vendors.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

F.1.3.2 End-to-End Message Transfer Delay

The end-to-end message transfer delay measures the time to deliver a message from the sender to the receiver, once the message is directed to send. This delay includes the time to pass through communications equipment at the UA and AVCS, propagation delay, and any network processing delay that has incurred. The performance depends on the type of equipment used and the design of the communications system. The network incurred delay depends on which network is used. It is often a system design issue and hence beyond the scope of this document. The propagation delay is a physical issue that we cannot change. But it can be affected by the system design depending on which solution is used. Hence, it is also beyond the scope of this document. The equipment delay ranges from 20 ms to 50 ms that is achievable. As a guideline, the end-to-end message transfer delay must be short enough to allow the UA and/or UA operator to be responsive to directives and safety issues, while allowing the UA and UA operator to function without becoming overloaded.

F.1.4 Security

a. The C2 Communications System should implement a protection scheme to prevent any hijack or any security incident that may lead to loss of control of the UA. That is, security protection should be provided to permit the pilot and UA to authenticate the source of the message, and validate that the message was not changed during transmission. In general, the issues to be addressed include the following as a minimum:

   1. Message Authentication
   2. Anti-jam or anti-interference (intentionally and un-intentionally)
   3. Key Management

b. When a public network service such as the ATN of ICAO is employed for C2, the standards in Table F-1 must be complied with. The source of these standards is ICAO 9705, Ed. 3, Sub-volume 8.

Table F-1. Security Standards for C2 Communications

Security Mechanisms	Algorithm Standard
Message Authentication	HMAC-SHA-1 RFC 2104
Encryption	AES FIPS 197
Key Agreement	ECDH ANSI X9.63
Public Key (PK) certificate	ITU-T X.509

c. When a closed or private network is employed, the standards in Table F-1 should be the threshold performance for the security measure. The IEEE

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Standard 802.11i is highly recommended for this use. The latest technology Wi-Fi Protected Access (WPA) has been developed in this standard. It addresses Wi-Fi security with a strong new encryption algorithm, known as Temporal Key Integrity Protocol (TKIP), as well as user authentication. The latter employs the 802.1X technology known as Extensible Authentication Protocol (EAP). When properly installed, it provides a high level of assurance that user data will remain protected and that only authorized users may access the network. It can protect against the most targeted hacker attacks known in the industry. The features of the WPA are summarized as follows for performance comparison:

- 128-bit keys
- Dynamic session keys: per user, per session, per packet keys
- Automatic distribution of keys
- Strong user authentication, utilizing 802.1X and EAP
- Built-in Message Integrity Check to prevent hackers

The industry standards are called out here to ensure traceable performance measures for requirements containing additional details. That is, any numerical performance parameters can be found in the respective standard.

F.1.5 Safety

a. The C2 Communications System should be designed to avoid any single point of failure.

F.1.6 Environmental Conditions

a. The C2 Communications System equipment must be operable at or above FL430 for the en route phase.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Appendix G - Methodology

The overall methodology used to develop this document is a consensus approach to progressively develop the requirements. This document is the result of many contributions from a team of UA industry leaders and draws on a number of document sources and UA activities. As shown in Figure G-1, it is developed based on NASA Access 5 project documents, FAA Regulations and Orders, and recommended standards and practices by ICAO and FAA-sponsored RTCA. Once the requirements are developed, a matrix is defined to establish the verification method for each requirement.

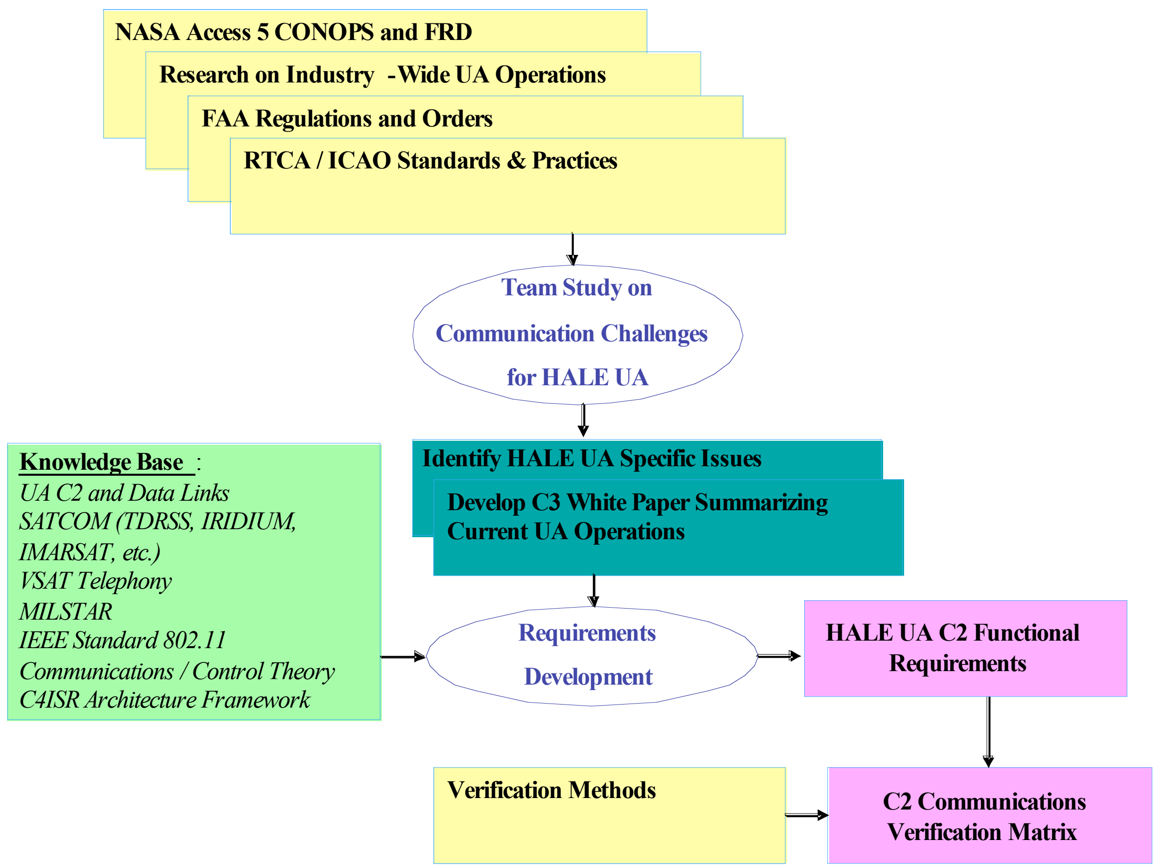


Figure G-1. Methodology to Develop C2 Communications Requirements

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

Appendix H – Technical Performance Comparisons

This appendix contains technical discussions of the performance guidelines for C2 Communications as compared to the open literature. UAS are an emerging industry and the intent is to keep up with ongoing development of requirements and standards. However, each standard development body has its own charter and thus the depth of the coverage may vary from one to another. As a result, the goal is to understand and discuss the comparisons at the high-level system and functional levels. Any design-specific discussions are for illustration only. Three standards are on our radar screen:

- RTCA SC-203
- ASTM International
- STANAG 4660: IC2DL

<u>RTCA SC-203</u>

RTCA develops recommendations to the FAA for communications, navigation, surveillance, and air traffic management system issues. Special Committee 203 (SC-203) is developing standards for UAS to operate in the NAS. This special committee formed much later than Access 5. However, they have been meeting more frequently. Due to the charter of the committee there have been significant participation from various levels of the government agencies. RTCA SC-203 began with one working group (WG1) divided into three subgroups: Document Integration, Operations, and Systems. Two additional working groups are being established at the fifth plenary meeting in January 2006. They are Command, Control, Communications (C3) and See and Avoid (S&A), named WG2 and WG3, respectively. The committee has outlined several UAS MASPS documents to be published within a year or so. At the time of this writing, there is no performance-related document ready for review. Many participants in SC-203 are contributors from Access 5. Some technical framework and subjects of interest occurring in this committee have been addressed or considered in the Access 5 documents. For example, C3 and S&A have been two active work packages in Access 5.

<u>ASTM International</u>

The organization, originally known as American Society for Testing and Materials, was founded over a century ago. In November 2004 this standard forum decided to develop standards for use by the UAV industry. One of them is "Standard Specification for Design and Performance of an Unmanned Aerial Vehicle (UAV) Data Link System." This specification includes requirements to provide radio frequency (RF) links capable of transmitting data for command and control of the air vehicle, payload data and other data between the air vehicle and control station. This is a working activity and no document is available for review at the time of this writing.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

STANAG 4660: IC2DL

The Interoperable C2 Data Link (IC2DL) is the low rate data link standard being prepared by the NATO STANAG 4660 working group for the UAV industry worldwide. The latest version is 1.2 dated on January 6, 2006 yet it is still a working draft. Although it exceeds the scope of the Access 5 program, because it addresses waveform and OSI layer specific requirements, the high level performance requirement is deemed useful information for cross referencing purposes. The following performance requirement table (Mode A) is copied from Table B-1 of STANAG 4660 to facilitate the comparison discussions that follow.

Table H.1 Detailed Performance Requirements From IC2DL Draft v1.2 (page B-9)

Parameter	Mode A Requirement	Remarks
Bit Error rate (BER)	10^{-8}	1
Availability	System Dependent	2
Environmental Conditions	System Dependent	3
Frequency	2.3 – 2.4 GHz[1]	4
Waveform Inter-node Range	0.001 – 1000 NM	5
Date rate	Variable, but suggested typical network data rate 300 Kbps	6
Encryption	External	7
LPI/LPD	Yes, 10log(BW ratio)	8
Latency Launch and Recovery Sensor	 50 – 100 ms 200 ms	9
Update Rate Launch and Recovery Sensor C2	 20 – 25 Hz 5 – 10 Hz	5
Polarization	Vertical	5
Communication Protocol Ground data terminal (GDT) Air data terminal (ADT) Digital Voice/ATC	 IP/UDP[2] TBD TBD	 10
Multiple Access Communication	TDMA	5
External Timing Source (if applicable)	1 PPS	5
Note: 1. National frequency(ies) allocations will determine the final IC2DL frequency 2. UDP was chosen in order to be compatible with STANAG 4586		

Remarks:

1) We specify BER at 10^{-6} (Section F.1.3.1) for all operating conditions as the minimum performance (worst case).
2) We agree this is a system dependent parameter particularly when the level of autonomy is not discussed. However, we also refer to NAS-SR-100 as the performance guideline (Section F.1.1.1) to consider safe separation and control of the UA.
3) We concur. In our case, we also point out our condition which is HALE

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.

UAS above FL430 (Section F.1.6).

4) As in its own note, the frequency must be approved by the respective nation. In our case, we require FCC/FAA approval (Section F1.1.3).
5) We consider this is a design-specific parameter and hence not addressed.
6) We have proposed a minimum capacity of 64 Kbps per UA (Section 1.1.2b). The data rate in the IC2DL table is the network data rate. The real data capacity per node or circuit is much lower than 300 Kbps. As a matter of fact, it is suggested 75 Kbps per uplink or downlink in Table B-7 of the same IC2DL document (page B-42). The information exchange (IER) requirement table in Attachment 1 of STANAG 4660 conveys the baseline rationale for the rate requirement.
7) We consider security as one of the primary concerns. Therefore, we recommend Federal Information Processing Standard (FIPS) 197 as the minimum performance guideline (Section F.1.4).
8) Instead of failing the attempt to specify a number in the table, we state it as a functional requirement (Section 4.3.4.1). The number is a design parameter that may be coordinated with or traded off against other design issues.
9) This parameter is related to the end-to-end message transfer delay in our document. We state "The equipment delay ranges from 20 ms to 50 ms that is achievable." (Section F.1.3.2) This is pretty consistent with 50 to100 ms when the network framing factor is included. The Launch and Recovery phase needs the most demanding requirement. We do not address any sensor related functions and performance.
10) We include this factor in the functional requirements (Section 4.3.2). According to their own note, they specify the protocol in order to be compatible with STANAG 4586. We do not have the same constraint.

In summary, the high level performance requirements recommended in STANAG 4660 are consistent with and close to the performance guidelines proposed in Appendix F. Both performance recommendations were developed independently and the findings of STANAG 4660 support our recommendations.

The following document was prepared by a collaborative team through the noted work package. This was a funded effort under the Access 5 Project.