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Command and Control (C2) Data Link Minimum Operational Performance Standards (MOPS) (Terrestrial)

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FOREWORD

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EXECUTIVE SUMMARY

With this update to DO-362, the RTCA continues to develop the minimum operational performance standards (MOPS) needed to support Unmanned Aircraft (UA) flights within the U.S. National Airspace System (NAS). This standard is envisioned to apply to unmanned aircraft operated under the 14 CFR Part 91 "General Operating and Flight Rules." The standard is not intended for aircraft operated under 14 CFR Part 107 Small UAS rules.

In 2013, the RTCA initiated SC-228 to develop the MOPS needed for UAS detect and avoid (DAA) systems (focus of SC-228 Working Group 1) and terrestrial based Control and Non-Payload Communications (CNPC) Link Systems (focus of SC-228 Working Group 2).

CNPC Link Systems are unique to UAS. The International Telecommunications Union has identified multiple frequency bands, including aeronautical allocations in the L Band and C Band, as candidates for use for these CNPC Link Systems. DO-362 and its update DO-362A prescribe the MOPS for these, terrestrial based (i.e.,non-satellite), UAS CNPC Link Systems that are intended to provide capabilities supporting the command and communication functions of the UAS. The DO-362A capability supports the UAS information exchanges that allow the remote pilot to safely control, monitor, and manage the UA utilizing the C band spectrum allocation. The CNPC Link System may also provide services that support other information exchanges associated with communication between the remote pilot and controller, as well as between the remote pilot and the detect and avoid, weather radar, and/or video systems carried in the UA.

The DO-362 MOPS, published in 2016, specified CNPC Terrestrial Link System characteristics that should be used by designers, manufacturers, installers, and users of the system. That MOPS document supported a wide range of UAS Command and Control architectures, from the simplest point-to-point radio line of sight application to more complex multi-aircraft and networked solutions.

In this update, DO-362A builds from the first MOPS to improve the use of the spectrum available by enhancing system performance in several areas. These improvements include the description of an additional waveform, support for multiple aircraft from a single ground radio system, a compatible high altitude airborne relay capability and support significantly closer separation between ground radio systems than was available in the first MOPS. Additionally, DO-362A removes reference to use of the L Band as the US Government has determined that, at this time, the use of L Band for CNPC poses an unacceptable risk of interference to incumbent systems in the band.

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1 PURPOSE AND SCOPE

1.1 Introduction

This document contains Minimum Operational Performance Standards (MOPS) for the Unmanned Aircraft Systems (UAS) Command and Control (C2) Data Link hereinafter in this document referred to as the Control and Non-Payload Communication (CNPC) Link System used to support the Command and Control functions of a UAS. The words "Non-Payload Communications" includes the CNPC Link System supporting remote pilot-to/from-ATC voice communications, also referred to as ATC relay. Payload communications specifically include communications associated with the UA mission payloads, which do not contain safety-of-flight information[1]. Therefore, payload communications do not require the use of aviation safety protected spectrum[2] and are thus prohibited from using the CNPC Link System as described in this MOPS.

The focus of this MOPS is the technical standards describing how CNPC Link Systems can compatibly share the spectrum that has been allocated for their use yet remain waveform agnostic (i.e., unspecified). Through the flexibility afforded in this MOPS, manufacturers may select either the GMSK waveform standards in the GMSK waveform standard in Section 2.2.2 of this MOPS or the QPSK waveform standard in Section 2.2.3. Optional waveform modes aimed at supporting point to multi-point communications may be selected by manufacturers based on the selected waveform. These optional modes are found in Section 2.2.4 for GMSK Multiple Uplink Subframe and Section 2.2.5 for QPSK Multiple Uplink Subframe. Each UA's CNPC Link System will need access to different amounts of spectrum depending on the functions being provided (command & control, ATC relay, DAA, onboard weather radar, and onboard remote pilot video). Therefore, the needed spectrum bandwidth will vary based on UA functions. In the development of this MOPS, efficient and effective use of the C Band spectrum allocated to UAS operations has been a primary consideration. This MOPS supports a wide range of UAS C2 Link Systems architectures, from the simplest point-to-point radio line of sight (RLOS) application to more complex multi-aircraft and networked solutions. These architectures are explained in Section 1.2.2, DO-377 [1], and potentially in a future revision of that document. DO-362A addresses spectrally efficient coexistance of different manufacturers C-Band systems but does not address interoperability between different manufacturers implementations.

These standards specify equipment characteristics that should be used by designers, manufacturers, installers, and users of a "terrestrial" based (i.e., not satellite-based) CNPC Link System. Compliance with these standards is recommended as one means of assuring that the equipment will perform its intended function(s) satisfactorily under the conditions specified herein. Any regulatory application of this document is the sole responsibility of appropriate governmental agencies.

The word "equipment," as used in this document, includes all components necessary for the CNPC Link System to properly perform its intended functions. This MOPS considers a CNPC Link System to consist of the following:

1. CNPC Link Airborne Radio System (ARS) consisting of
    a. CNPC Link System Airborne Radio(s)

[1] Safety-of-flight information is any information/data sent to or received from the UA that is necessary to ensure the UAS is operated/operating in a manner that protects people and/or property from harm due to unintentional events.

[2] This portion of the spectrum is designated Aeronautical Mobile Route Service (AM(R)S) for use by safety critical systems.

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   b. One or more CNPC Link System airborne antennas
   c. Associated cables connecting the radio(s) and antennas

2. CNPC Link Ground Radio System (GRS) - to include fixed, or mobile, i.e., truck or boat mounted – consisting of
   a. CNPC Link System Ground Radio(s)
   b. One or more CNPC Link System ground-based antennas
   c. Associated cables connecting the radio(s) and antennas

This MOPS applies to a minimum set of specifically defined functions; see Section 1.5. The equipment in a CNPC Link System may provide additional functions beyond those addressed in this MOPS.

This CNPC Link System MOPS document is divided into the following sections:

Section 1 provides information needed to understand the rationale for the equipment characteristics and requirements in Sections 2 through 4. It describes typical equipment operations and operational goals as envisioned by the members of the RTCA Special Committee (SC)-228 and establishes the basis for the standards stated herein. Key definitions and assumptions essential to proper understanding of this document are also provided in this section.

Section 2 contains the minimum standards for the CNPC Link System characteristics and operational limitations of the system. These standards specify the required performance under nominal environmental conditions. Also included are recommended bench test procedures necessary to demonstrate compliance with the stated minimum requirements.

Section 3 describes the installed performance required of the CNPC Link System. Flight tests for the CNPC Link System are included when performance cannot be adequately determined through bench testing.

Section 4 describes the system power input, controls and displays that are necessary for the performance of UAS pre-flight and flight checks to ensure the-CNPC Link System is powered up and operating correctly.

Appendix A, Abbreviations, Acronyms and Definitions: This appendix includes a list of the acronyms and terms used in this document with definitions as appropriate.

Appendix B, Bibliography and References: This appendix lists citation information for documents referenced in this MOPS or that provide other relevant information.

Appendix C, C Band Nationwide Capacity: The text that was in this appendix within DO-362 has been removed. This text has been refined and should be included within two appendices (G and H) of a planned update to DO-377 [1].

Appendix D, The text that was in this appendix has been superseded by material to be included in an Appendix to DO-377 [1].

Appendix E, Video Considerations: The text that was in this appendix within DO-362 has been removed. This text has been refined and should be included within an appendix of a planned update to DO-377 [1].

Appendix F, UAS CNPC Link System Operational Capbilities and Implementation Considerations, The materail in this appendix has been removed and is ssuperseded by material included in DO-377 and which may be update in planned revision to DO-377 [1].

Appendix G, Interference Analysis (SATCOM only): This appendix describes a notional C Band satellite system design that is compatible with the proposed terrestrial system. That satellite system utilizes the same Time Division Duplex frame structure discussed herein,

ensuring compatibility between terrestrial and satellite systems. The satellite-based system utilizes a Geo Stationary satellite in orbit between 95 and 110 degrees west longitude and a satellite ground Earth station to send signals to and receive signals from the UA.

Appendix H, Spectrum Capacity Analysis: This appendix provides estimates of the instantaneous capacity of the available spectrum to accommodate terrestrial UAS CNPC Link Systems, i.e., the maximum total numbers of such links that can operate simultaneously without mutual RF interference. Separate capacity estimates are provided for CONUS airspace as a whole, and a local setting such as an airport where multiple UA are landing and taking off.

Appendix I, Dynamic Spectrum Resource Assignment: The text that was in this appendix within DO-362 has been removed. This text has been refined and should be included within an appendix (J) of a planned update to DO-377 [1].

Appendix J, Data Rates: The text that was in this appendix within DO-362 has been removed. This text has been refined and should be included within an appendix (E) of a planned update to DO-377 [1].

Appendix K, CNPC Link System Required Performance: The text that was in this appendix within DO-362 has been removed. This text has been refined and should be included within a planned update of DO-377 [1] within portions of appendices (C, D, and F).

Appendix L, Link System Budgets, Conclusions and Recommendations: This appendix contains example link budgets that provide the justification for some of the requirements and operational constraints in this MOPS. The appendix includes a list of assumptions upon which the link budgets are based. And it also provides a list of conclusions and recommendations derived from analyses of the link budgets.

Appendix M, Reserved: The text within this section has been moved into the normative requirements under Section 2.2.4, GMSK Optional Requirements for Multiple Uplink Subframe Implementation.

Appendix N, Reserved: The planned text describing the Bench Test Data MOPS for the GMSK and QPSK was determined to no longer be needed.

Appendix O, Flight Test Data for MOPS CNPC Link Systems: This appendix presents data measured during flight tests of the MOPS CNPC Link System operating in a bi-directional, air-to-ground arrangement. Data is presented for test flights over flat, hilly, and open water settings at various altitudes, ranges, and ascent/descent angles. Excess path loss, availability, and average fade duration data calculated from the flight test results are presented. Data in this appendix has been used to validate (see Appendix S) the technical requirements in Section 2.2 of this MOPS, to serve as the basis for the link budget analysis in Appendix L, and for the desired/undesired signal analysis in Appendix R.

Appendix P, TACAN Interference: The text that was in Appendix P were removed from this version of the MOPS and not placed elsewhere.

Appendix Q, Summary of NASA Air-Ground Channel Measurements and Models: The text that was in Appendix Q has been removed from this version of the MOPS and not placed elsewhere.

Appendix R, Undesired-to-Desired Signal and Signal-to-Noise Plus Interference Ratios: The appendix contains a detailed description of the methods that have been used to derive and/or calculate some of the entries in the Appendix L link budgets. These include the following:

- A description of the calculation of the desired received signal level, the undesired received signal level and the ratio of undesired-to-desired signal required to achieve a target link availability.

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- A description of the physical and statistical models used to determine the link margins required to mitigate fading of the desired signal. The physical model is used to define LOS link channel models that CNPC Link System radio designers must use to verify that the radio implementations are able to operate under slow multipath fading and fast multipath fading. The former is typical when the UA is operating at altitudes above 1000 feet above ground while the latter is more likely to occur during take-off and landing and airport surface operations.
- A description of the mechanisms that contribute to harmful interference and how they are included in the link budget calculations and/or mitigated by a robust radio design.
- A description of how the link budget/link margin and interference may be used to determine the range coverage and service volume of a CNPC Link System as well as the minimum frequency separation between channel assignments to CNPC Link Systems given the geographical spacing between their ground radio stations (GRSs). These include an illustration of rules that could be used to determine the minimum GRS separation for assignment of adjacent channels and for reuse of frequency assignments.

Appendix S, Validation of the CNPC Link Systems ability to deliver the Required Link Technical Performance under the desired operation conditions: This appendix takes the flight test data from Appendix O and uses it to provide a validation that, while the aircraft is operating within the limits described in this MOPS, the normative requirements of RLP contained in DO-377 [1] are met by the CNPC Link described in this MOPS.

Appendix T, C Band Interference Environment and Adjacent Channel Required Performance: This appendix provides estimates of how much radio-frequency (RF) filtering is needed between a terrestrial C Band CNPC Link System transmitter and its antenna to protect radionavigation-satellite services (RNSS) and AeroMACS receivers that may be present in frequency bands adjacent to 5030–5091 MHz. It also presents possible filter design solutions for several operational cases and shows for each case how much of the 5030–5091 MHz C Band would remain usable by terrestrial CNPC Link Systems after subtracting the necessary guard bands at each end.

Appendix U, High Altitude Relay System Interference Analysis: This appendix describes the overview of a High Altitude Relay System based CNPC Link System that utilizes the same C Band spectrum to provide two-way communication between a beyond line of sight GRS and UA via a High Altitude Airborne Relay UA. It also demonstrates compatible operations with the terrestrial CNPC Link System specified in this MOPS, the radio characteristics of the High Altitude Relay System, and the consideration of sharing the C Band spectrum in the same airspace with UAS using the terrestrial CNPC Link System.

Appendix V, Ground Radio Station Siting and CNPC Link Frequency Channel Usage Rules: This Appendix describes the rules and constraints that must be followed when siting the Ground Radio Station (GRS) component of a CNPC Link System and the rules that must be followed when assigning channels to a CNPC Link System to ensure compatibility between systems.

1.1.1 Structure and Use of the MOPS

The structure of this MOPS is as indicated in the following:

1. The CNPC Link System addressed in this MOPS includes two radios (a ground radio and an airborne radio), their antennas, the cabling between the antennas and the radios, and the propagation path between them, not just individual avionics equipment as addressed by most MOPS.

2. The CNPC Link System addressed in the MOPS includes a description and the data for a CNPC Link System using a GMSK waveform and a CNPC Link System using a QPSK waveform that can compatibility share the same spectrum.
3. Section 2.2 of this MOPS includes six types of requirements, not all of which will apply to every TSO applicant, these six are:
    a. Requirements that are common and apply to all systems (Section 2.2.1).
    b. Requirements for systems designed against the parameter values used for the MOPS CNPC Link System based on a GMSK waveform (Section 2.2.2).
    c. Requirements for systems designed against the parameter values used for the MOPS CNPC Link System based on a QPSK waveform (Section 2.2.3).
    d. Requirements for systems designed against the parameter values used for the MOPS CNPC Link System supporting Multiple Uplink Subframe implementation for the GMSK waveform (Section 2.2.4).
    e. Requirements for systems designed against the parameter values used for the MOPS CNPC Link System supporting Multiple Uplink Subframe implementation for the QPSK waveform (Section 2.2.5). This section is currently reserved but may be updated in future versions of this document.
    f. Requirement for systems designed against the parameter values used for the MOPS CNPC Link System based on a High Altitude Relay System (Section 2.2.6).

This MOPS approach was adopted because:

1. The UAS market and approaches to design and operation of CNPC Link Systems are still maturing,
2. The range of UA levels of automatic operation and the range of UAS operational environments require different levels of CNPC Link System performance so one design would not optimally satisfy all applications, and
3. There now is a Minimum Aviation System Performance Standards (MASPS) (DO-377 [1]), and there may be available a future revision) document to which key assumptions in this MOPS are referenced to help justify their viability.

This standard was developed as a continuation of the work done by RTCA Special Committee 203 in support of the U.S. positions at the World Radio Conference in 2012 and subsequent conferences. Operational and system constraint assumptions from that work were continued into the current MOPS. Starting in late 2015, there have been new concerns raised that the assumed level of permitted L Band output power may cause operationally unacceptable interference with some existing aircraft systems (specifically the Tactical Air Navigation (TACAN). Due diligence to evaluate these concerns was initiated, and there are further studies and tests being conducted as of this writing. As such, L Band performance requirements and any L Band based CNPC Link Systems were not considered in this standard.

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1.1.2 Scope of this MOPS

The RTCA has supported the FAA for several years in developing the MOPS needed to support UA flights within U. S. Airspace for unmanned aircraft operated under 14 CFR Part 91 "General Operating and Flight Rules."[1] Between 2006-2012 the RTCA Special Committee (SC)-203 sought to develop a MASPS document; although it was not completed, there was sufficient progress to provide much of the needed groundwork for this MOPS. In 2013, the RTCA initiated SC-228 with a narrower scope, namely to develop MOPS needed for a UAS detect and avoid (DAA) system (the focus of SC-228 Working Group 1) and a UAS C2 Link System (the focus of SC-228 Working Group 2). This section provides a description of the UAS terrestrial-based (i.e., not satellite-based) CNPC Link System MOPS.

Figure 1-1 depicts the general operational concepts addressed in this MOPS, i.e., terrestrial-based point-to-point links represented by the yellow and red radio frequency (RF) links (the yellow links between the ground antenna and the UA and multiple red links between the tower antenna(s) and the UA. It also depicts the links from the High Altitude Relay System ground (BGRS) antenna up to and down from the High Altitude Relay System UA (see the blue solid links)) and then down to or up from other UA (flying at lower altitude) using the High Altitude Relay System (see the blue links). It should be noted (as depicted by the dotted blue RF links) that this MOPS supports the ability for UA to transfer between the Hight Altitude Relay System and a terrestrial ground based (red tower system) CNPC Link System. The networking reqirements can be found in the DO-377 [1] and that tests and other materials to certify a networked system are not part of this standard.

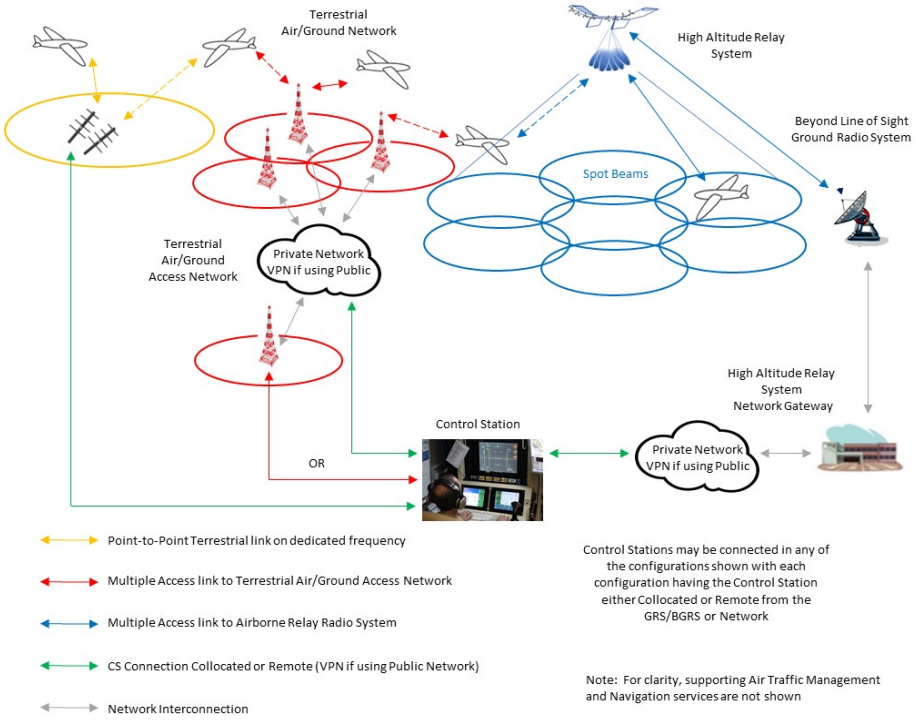


Figure 1-1: C2 Link System – Example Operational View

[1] The current limits placed on small UAS are described in the FAA's June 29, 2016 in the Federal Register (Volume 81, No. 124/Rules and Regulations) which announces amending of regulations to allow for the operation of small unmanned aircraft systems in the National Airspace System. This adds a new Part 107 to Title 14 Code of Federal Regulations (14 CFR).

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1.2 System Overview

As noted in Section 1.1, this CNPC Link System MOPS document addresses only the CNPC Link System, which is part of a larger system that seeks to exchange information between a UA and its Control Station (CS). Figure 1-1 showed an operational view of that larger system. Four possible ways to implement the various links are shown in Figure 1-2.

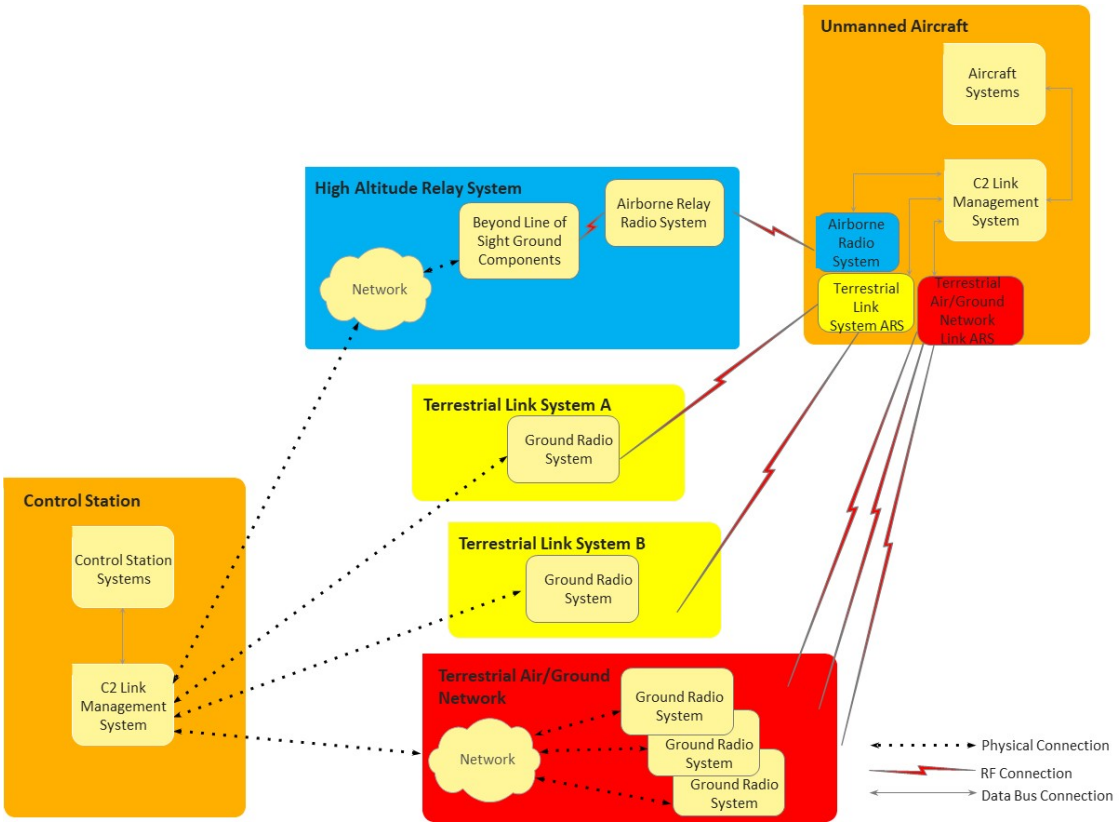


Figure 1-2: Possible C2 Link System Configurations

The Terrestrial Link Systems A and B (shaded yellow within Figure 1-2) each represents a point-to-point functionality contained in this MOPS. Terrestrial Link System C (shaded in red) is representative of C2 Link Systems using terrestrial networks to link a CS with multiple Ground Radio Systems; this supports multiple UA or a single UA as they/it fly over long distances. The High Altitude Relay System (shaded in blue) is representative of C2 Link Systems using a relay UA to connect CS with multiple UA as they fly over operational distances.

The CNPC Link System components and interfaces for this MOPS are shown in Figure 1-3. It includes the set of equipment in the list given in Section 1.1.1, CNPC Link System Airborne and Ground Radios, corresponding antennas, and the cabling between them.

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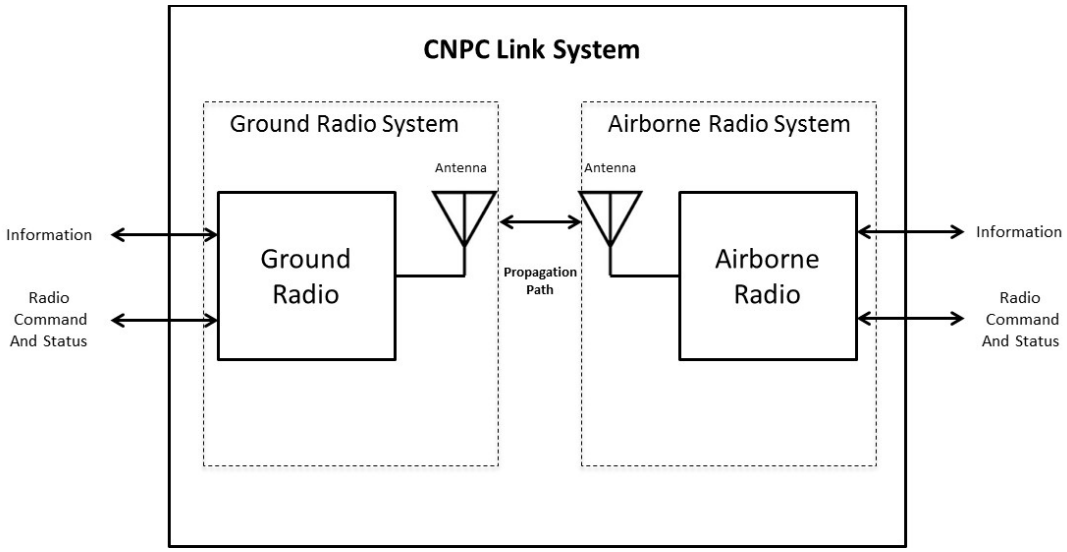


Figure 1-3: CNPC Link System Major Components and External Interfaces

Simulations and flight tests using the MOPS CNPC Link System have been conducted to confirm the validity of this MOPS. This MOPS also includes verification methods that can be used to show compliance of proposed CNPC Link System designs with the requirements in this MOPS.

This MOPS does not include all CNPC Link System design characteristics; for example, it does not support one CNPC Link System GRS communicating with a CNPC Link System ARS with the air and ground components manufactured by different companies; such a capability would require interoperability among all GRS and ARS. This does not prohibit individual companies from working together and establishing their own interoperability capabilities yet still meeting the standards developed in this MOPS.

1.3 CNPC Link Operational Applications

A CNPC Link System which meets this MOPS would support the appropriate C2 Link System requirements described in the C2 Link System MASPS DO-377 [1], i.e., sending and receiving information exchanges between a UA and a CS. These exchanges would support the remote pilot performing aviate, navigate, communicate, integrate, and manage C2 Link activities.

This CNPC Link System MOPS supports the transmission and reception of CNPC Link System information exchanged between the following operational applications:

1. C2 Link User Applications (i.e., the Aircraft Systems and Control Station Systems are shown in Figure 1-2) that exchange data to support the remote pilots aviate, navigate, communicate, and integrate activities. This includes the following types of information exchanges:
    a. C2 information which Addresses DO-377 [1]. Operational Requirements (OR)-1.1, 1.2, 1.3, 2.1, 2.2, 2.3, 3.1, 3.2 and Functional Requirements (FR)-1.1, 1.2, 1.3, 1.4[1]
    b. Information from systems onboard the UA such as the weather radar and video system Addresses DO-377 [1] OR-1.1 and FR-1.1

[1] The OR and FR references are to Operational and Functional Requirements for a C2 Link System as described in DO-377.

c. User Data regarding the UA's operational status Addresses DO-377 [1] OR 1.1 and FR-1.1

2. C2 Link Management Applications (see Figure 1-2) that exchange data to support the safe and effective management of the CNPC Link System. This includes the following types of information exchanges:

   a. Safe and effective management of the CNPC Link System. Addresses DO-377 [1] OR-1.5, 4.1, and FR-2.1, 3.1, 3.2.

   b. External management to establish/terminate, switchover, and handover the link. Addresses DO-377 [1] FR-2.2, 2.3, 3.2.

   c. CNPC Link Management System status reports. Addresses DO-377 [1] OR-1.1 and FR-3.1.

3. Applications that encrypt and authenticate the C2 link User Data and C2 Link Management Data to provide resistance to potential security threats. Addresses DO-377 [1] OR-4.2.

A UAS equipped with a CNPC Link System may need to be compliant with other requirements not specified directly in this MOPS in order to safely operate within the NAS. These include such requirements as the UA airworthiness is not compromised by the installation of the CNPC Link System, the UAS complies with applicable rules set up to govern the use of the frequency spectrum, and any and all controls needed for the operation of the CNPC Link System so as to not reduce the reliability of the other equipment onboard the aircraft or in the CS.

1.4 Operational Goals

This MOPS prescribes minimum operational performance standards for CNPC Link Systems using the 5030–5091 MHz band (C Band). Based on analyses conducted by the SC-228, a CNPC Link System developed using this MOPS will be able to support individual UA flights within all airspace classes when they utilize a terrestrial point-to-point or point-to-multipoint communication scheme.

The concepts of operations (CONOPS) of this system is to support those activities in rows 1-4 of Table 1-1. This table is an updated version of Table A-1 of DO-377 [1]. A description of each CONOPS and example scenarios are included within this MASPS revision. The range and altitudes that the CNPC Link System will need to support for UA to operate in each of the CONOPS and scenarios given within that table in this document.

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Table 1-1: Support CONOPS and Example Scenarios

Number	CONOPS Title	Example Scenarios	Related SC-203 Scenarios[c]	Related FAA CONOPS Scenarios[d]
1	**Linear Sensing**	Point-to-Point flight along: 1. Power line 2. Rail line 3. Pipeline		
2	**Local Area Operations**	1. Media and incident Reporting 2. Local Cargo Delivery	1. Media and Incident Reporting (#4)	Loiter for Surveillance Grid Pattern Search Pattern Maneuvering in High-Traffic Density Airspace (Media and Traffic Reporting)
3	**Extended Aerial Work**	1. Remote Area Operations 2. Maritime Surveillance 3. Coast-to-Coast Aerial Work Surveys 4. Not Used 5. Regional Cargo Delivery	1. Maritime Monitoring (#2) 2. Environmental Sensing (#3) 3. Cargo Delivery (#5) 4. Border Surveillance Tracking (#6) 4. Hurricane Research (#7) 5. Mining Exploration (#8)	
4	**High Altitude Long Endurance (HALE)**	1. High Altitude Puesdo Satellite Operations (HASPS) 2. High Altitude Relay System	Agricultural Environmental Monitoring – High Altitude Long Endurance (HALE) (#9)	Point-To-Point Oceanic Point-to-Point
5	Point to Point Package[a] Delivery	Point-to-Point flights transporting smaller packages for compensation[b]		Vertical Transit (and Operations Above Class A)

a: Includes UAS operating below 400' AGL and in all classes of airspace except Class A; thus all operating under 14 CFR Part 91 rules
b: Smaller aircraft would include those within and larger than those identified within the FAA's Small UAS Rule (14 CFR Part 107 rules)
c: RTCA DO-320 "Operational Services and Environmental Definition (OSED) for Unmanned Aircraft Systems (UAS)," June 10, 2010
d: FAA report, "Integration of Unmanned Aircraft Systems into the National Airspace System Concept of Operations," V2.0, September 28, 2004

To support the CONOPS and scenarios in Table 1-1, the CNPC Link System will need to provide the following operational goals:

1. Support taxi, take-off, and landing at private and public airports except for Class B airports which is planned to be included in future versions of DO-377.
2. Support a HALE UA conducting area operations at an altitude of 75,000 ft Above Mean Sea Level (MSL) and a range of at least 100 nmi from a GRS.
3. Support enroute flight operations down to 500 ft Above Ground Level (AGL).
4. Support switchovers among GRS as the UA flies along extended enroute operations.
5. During all phases of flight, support multiple UAs connecting to the same GRS.

The Link Budgets captured in Appendix L, the Spectrum Capacity analysis that is described in Appendix H, and the Validation assessment in Appendix S are based on these range/altitude coverage operational goals.

1.5 Intended Function

To support the Operational Application, Goals, and CONOPS described in the previous section, SC-228 WG2 determined that the primary intended function of CNPC Link. Systems addressed in this MOPS is to provide:

The means to exchange C2 Link User/Application Data (see Section 1.3) by encoding the user input data into modulation symbols that modulate the frequency or phase of an RF carrier in the 5030-5091 MHz band, radiating and propagating that signal, and demodulating and decoding the received signal in such a way that reliable two-way transmission and reception of such data can be achieved.

This primary function includes only capabilities and services associated with the Physical Layer of a typical datalink communications system (i.e., RF carrier modulation and

demodulation, user data forward error correction encoding and decoding, frequency, and time synchronization, and transmit/receive duplex operation).

The higher-layer protocols (Radio Link Layer, network/Link Access Layer, and Security Layer) required of a complete datalink communications system capable of supporting UAS command and control data exchanges are left to the manufacturer and or network system designer. Such higher-layer protocols are allocated to systems that are external to the CNPC Link System. They include the means to uniquely address each UAS, switch and route the C2 Link messages over dissimilar air/ground links, as well as to authenticate and otherwise protect the integrity of the C2 Link messages. They also enable the system to multiplex and prioritize the transmissions of command and control data from various sensors so as to make efficient use of the data throughput afforded by the CNPC Link System.

To support C2 Link Systems with different throughput requirements, this MOPS includes the specifications for CNPC Link Systems that employ GMSK or QPSK modulation with Turbo Convolutional Coding (TCC) for error correction and selectable modulation and/or error correction code redundancy referred to as Modulation Classes and Data Service Classes or Data Modes that support different user data throughput. The relationship between Modulation Class, Data Service Class, user data throughput, and user input/output packets sizes (User Data Payload) are shown in Table 1-2. The user input/output packet sizes are the packet sizes with which the external Radio Link Layer that interfaces to the CNPC Link System ARS and GRS must comply. They include the overhead associated with headers appended by the Radio Link Layer, Network/Link Access layer and Security Layer to the Application Data described in Section 1.3.

Table 1-2: CNPC Link System Modulation & Data Service Classes

Modulation Class	Data Service Class	User Data Payload	User Data Throughput
GMSK	34.5 ksps symbol rate with rate 5/8 TCC	352 bits / 50 ms	7.04k bits / sec
	69 ksps symbol rate with rate 5/8 TCC	800 bits / 50 ms	16.0k bits / sec
	103.5 ksps symbol rate with rate 5/8 TCC	1280 bits / 50 ms	25.6k bits / sec
	138 ksps symbol rate with rate 5/8 TCC	1728 bits / 50 ms	34.56k bits / sec
QPSK	20 ksps symbol rate with rate 1/3 TCC	200 bits / 50 ms	4.0k bits / sec
	20 ksps symbol rate with rate 5/9 TCC	360 bits / 50 ms	7.2k bits / sec
	80 ksps symbol rate with rate 1/3 TCC	1032 bits / 50 ms	20.64k bits /sec
	80 ksps symbol rate with rate 5/9	1744 bits / 50 ms	34.88k bits / sec

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Modulation Class	Data Service Class	User Data Payload	User Data Throughput
	TCC		

To support C2 Link operational scenarios with different operational range/altitude coverage requirements, this MOPS also includes specifications for CNPC Link System GRS with different antenna gains, referred to Antenna Classes. The relationship between GRS Antenna Classes and the operational ranges and maximum altitude supported by the CNPC Link System are shown in Table 1-3.

Table 1-3: CNPC Link System GRS Antenna Classes & Range/Altitude Service Coverage

GRS Antenna Class	Modulation & Data Service Class	Maximum Range @ Low Elevation	Maximum Range @ 3º el.	Maximum Range @7º el
22.5 dBi (private airfield / remote area)	GMSK @ 138 ksps or QPSK @ 80 ksps	32 NM @ 1,750 ft (0.25º el)	170 NM @ 79,500 ft	125 NM @ 106,000 ft
22.5 dBi (public airport)	GMSK @ 138 ksps or QPSK @ 80 ksps	12 NM @ 1,070 ft (0.75º el)	53.5 NM @ 19,500 ft	39.5 NM @ 30,500 ft
16 dBi (public airport)	GMSK @ 138 ksps or QPSK @ 80 ksps	11 NM @ 1,000 ft (0.75º el)	50 NM @ 18,000 ft	37 NM @ 28,500 ft
13 dBi (public airport)	GMSK @ 138 ksps or QPSK @ 80 ksps	11 NM @ 1,070 ft (0.85º el)	47 NM @ 17,000 ft	34.5 NM @ 26,500 ft
13 dBi (private airfield / remote area)	GMSK @ 138 ksps or QPSK @ 80 ksps	17 NM @ 1,155 ft (0.5º el)	84 NM @ 33,000 ft	62 NM @ 49,000 ft

Note: The service coverage when the CNPC Link System GRS is located in a public airport is limited by the mutual interference between CNPC Links Systems operating out of the same airport. Greater range and altitude service are possible when the GRS is located in a private airfield or remote area where there is no other CNPC Link System equipped UA operating nearby. Appendix L provides detailed explanations and link budgets.

The specifications in this MOPS include the functional performance required of ground-based point-to-point and point-to-multipoint CNPC Link Systems that support UAS operations. A point-to-point CNPC Link System is defined as a system where a GRS is used to support datalink communications with a single UA/ARS. A point-to-multipoint CNPC Link System is defined as a system where a single GRS supports the operation of multiple UA/ARSs. Functional performance requirements for point-to-point CNPC Link Systems are described in Sections 2.2.1, 2.2.2 and 2.2.3. Point-to-multipoint operation can be accomplished in multiple ways, including employing multiple point-to-point links or by utilizing the Multiple Uplink Subframe mode described by the requirements in Section 2.2.4 and Section 2.2.5.

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Point-to-multipoint CNPC Link Systems may employ a terrestrial-based GRS or use a High Altitude Relay System Airborne Relay Radio System (ARRS) as specified in Section 2.2.6.

The CNPC Link System functions specified in this MOPS address the following C2 Link Operational Requirements specified in DO-377 [1]:

1. Support effective propagation between the ARS and a GRS during all possible UA maneuver limits. Addresses DO-377 [1] OR-3.1.
2. Not cause co-site interference with other electronic safety systems on the UA or on the ground. This could be from the radio, antenna, and/or cabling components. This would include communications, navigation, and surveillance systems. Addresses DO-377 [1] OR-4.1.
3. Not cause interference with other systems, e.g., communications, navigation, and surveillance systems, within the "radio horizon" of the CNPC Link System antennas. Addresses DO-377 [1] OR-4.1.
4. Provide efficient spectrum utilization to support multiple UA operating in the same area at the same time. Addresses DO-377 [1] OR-4.3.

1.6 Assumptions

The following assumptions are based on the Subject Matter Experts who contributed their expertise to determine the impact of current regulations on future operations of UAS and the impact on a CNPC Link System. The C2 Link radio design and operational performance requirements and guidelines presented in Sections 2.1 and 2.2 of this MOPS were developed based on the following assumptions and limitations, none of which should be construed as levying design requirements on the unmanned aircraft configuration. Unmanned aircraft configurations must address any differences during the aircraft certification and/or operational approval processes.

1. All UAS operating in the U.S. Airspace have a type design approval (14 CFR Part 21) and operational approval for the remote pilot, aircraft, and a waiver for the specific operation being conducted (14 CFR Part 91).
2. The UAS complies with all applicable 14 CFR Part 91 regulations.
3. The UAS, including its avionics systems, has been determined to be airworthy, to conform to its type design in compliance with instructions for continued airworthiness, and to been deemed in a condition for safe operation, including meeting appropriate regulatory maintenance actions and inspections.
4. The remote pilot has the ability to control the flight path of the UA under normal operating conditions.
5. The UAS operator has been issued a Certificate of Waiver or Authorization by the FAA that authorizes the UA to operate in the U.S. airspace. This authorization is currently required for all UAS because of their inability to comply with 14 CFR Part 91 §91.113 that requires the remote pilot to "see and avoid" other aircraft. When the FAA promulgates new rules for UAS to allow compliance with this rule using a DAA system, this authorization will no longer be necessary. Until then, individual authorizations will need to be issued, and they will contain specific information about the limitations on time and locations where the UA will be authorized to operate.
6. The UAS is operated by a remote pilot who has responsibility for the safety of flight operations and is appropriately trained, rated, and qualified for navigation by sole reference to instruments.

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7. The remote pilot is qualified to file an instrument flight plan and capable of accepting and complying with any instructions or clearances as directed by ATC, using an ATC radio onboard the UA, with the exception that the remote pilot would not accept some visual clearance requests.
8. The remote pilot maintains continuous two-way communication with the required ATC facilities while in controlled airspace using a voice radio onboard the UA, on the Common Traffic Advisory Frequency (CTAF) when operating at no-towered airports, and if necessary, re-establish that communication by other means if a Lost C2 Link state occurs.
9. It is assumed that a frequency management organization has determined an initial set of channel assignments for use by the terrestrial and/or airborne relay system CNPC Link connections during the flight of the UA. The remote pilot may request real time changes to those channels during the flight of the UA. The channels would be among the frequency assignments approved for UAS usage by the FAA and FCC.

   It is also assumed that the UAS operator will provide sufficient information about its operations to allow the Frequency Management Organization to select an appropriate frequency that is compatible with the channels already being used by other UAS operating in the area. These CNPC Link Systems could be developed, operated, and maintained by the UAS operator or by a 3rd party.

   Appendix V of this MOPS describes the rules and constraints that must be followed when siting the Ground Radio Station (GRS) component of a CNPC Link System and the rules that must be followed when assigning channels to a CNPC Link System to ensure compatibility between systems.

   This assumption is not intended to exclude networked operations using radios built to this standard.
10. The C2 Link Management System provides inputs such as C2 Link System Control Messages and User Data to the CNPC Link System and receives outputs such as CNPC Link System Status Reports and User Data from the CNPC Link System so that it can both manage the CNPC Link System and support the higher layer UAS applications that need to exchange information between the CS and the UA.

1.6.1 Operational Limits

Although the normative requirements in Section 2 provide a robust and efficient solution to delivering the desired operational capabilities, there are certain operational limitations imposed on the use of UAS equipped with CNPC Link Systems to ensure that UAS equipped with CNPC Link Systems operating in C Band does not cause unacceptable interference into other CNPC Link Systems sharing the C Band. The description of those limitations can be found in Section 2.1.18 and 2.1.20.

1.7 Test Procedures

The general test procedures specified in this document are intended to be used as one means of demonstrating compliance with the performance requirements defined in Section 2.2. Users of this document should not infer performance requirements based on these test procedures. These test procedure descriptions are provided to aid the reader to better understand how these standards were developed and what was accomplished and as a reference for developing and testing similar systems.

The order of tests specified suggests that the equipment be subjected to a succession of tests as it moves from design, and design qualification, into operational use. For example, it is expected that compliance with the requirements of Section 2 has been demonstrated as a precondition to satisfactory completion of the installed system tests of Section 3.

1.7.1 Environmental Tests

Environmental test requirements are specified in Section 2.3. The procedures and their associated limits are intended to provide a laboratory means of determining the electrical and mechanical performance of the equipment under environmental conditions expected to be encountered in actual operations.

Unless otherwise specified, the environmental conditions and test procedures contained in the latest revision of RTCA/DO-160, *Environmental Conditions and Test Procedures for Airborne Equipment* will be used to demonstrate aircraft equipment compliance.

1.7.2 Bench Tests

Bench level equipment test procedures are specified in Section 2.4. These tests provide a laboratory means of demonstrating compliance with the requirements of Section 2.2. Test data and results may be used by equipment manufacturers as design guidance for monitoring manufacturing compliance and, in certain cases, for obtaining formal approval of equipment design.

1.7.3 Installed Equipment Tests

Tests for the installed equipment are included when performance cannot be adequately determined through bench testing.

The installed equipment test procedures and their associated limits are specified in Section 3. Although bench and environmental test procedures are not included with the installed equipment tests, their successful completion is a precondition to completion of the installed tests. In certain instances, however, installed equipment tests may be used in lieu of bench test simulation of such factors as power supply characteristics, interference from or to other equipment installed on the aircraft, etc. Installed tests are normally performed under two conditions: (1) with the aircraft on the ground, using simulated or operational system inputs, and (2) with the aircraft in flight, using operational system inputs appropriate to the equipment under test.

Test data and results may be used to demonstrate functional performance in the intended operational environment. In addition, the procedures may be used as an operational check of equipment performance following corrective maintenance.

1.7.4 Operational Tests

Operational tests are specified in Section 4. These test procedures and their associated limits are intended to be conducted by operating personnel as one means of ensuring that the equipment is functioning properly and can be reliably used for its intended function(s).

1.8 CNPC Link System Information Vulnerabilities

Information vulnerabilities such as cybersecurity risks have been present for digital systems since the development of the personal computer (PC) in the late 70's and even longer for RF systems.

Specific information security-related performance requirements for the CNPC Link System and the systems that use the CNPC Link System for UAS C2 Link connectivity are contained in Section 2.1.10 and Section 2.1.11 of this MOPS.

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1.9 Definition of Terms

The following key terms are used throughout the MOPS document.

Airborne Relay Radio System (ARRS): The system that resides in the High Altitude Airborne Relay UA to relay signals transmitted from the BGRSs to the ARSs and signals transmitted from the ARSs to the BGRS. The ARRS consists of the Airborne Relay Radio, one or more airborne antennas and all associated cabling.

Airborne Relay Radio (ARR): The radio that is part of the ARRS. The radio supporting the communication between the ARS and the ARRS and the radio supporting the communication between the BGRS and the ARRS may be the same radio or separated radios.

Beyond LOS Ground Radio: The radio that is part of the BGRS.

Beyond LOS Ground Radio System (BGRS): The system that resides on the ground to transmit and receive C2 data to and from the ARRS and that to and from the ARSs via the ARRS. The BGRS consists of the Beyond LOS Ground Radio, one or more antennas, and all associated cabling.

CNPC Link System: The combination of airborne and ground UAS radios, antennas, and cabling between them that support the data and information exchanges between the UA and the CS for the purposes of managing and controlling the flight and operation of a UA.

***CNPC Link Airborne Radio System (ARS)*:** The system that resides on the UA to transmit and receive C2 data to and from the CNPC Link Ground Radio System. The ARS consists of the CNPC Link System Airborne Radio, one or more airborne antennas, and all associated cabling.

CNPC Link System Airborne Radio: The CNPC radio that is part of the CNPC Link Airborne Radio System (ARS).

***CNPC Link Ground Radio System (GRS)*:** The system that resides on the ground to transmit and receive C2 data to and from the CNPC Link Airborne Radio System. The GRS consists of the CNPC Link System Ground Radio, one or more antennas, and all associated cabling.

CNPC Link System Ground Radio: The CNPC radio that is part of the CNPC Link Ground Radio System (GRS).

Command and Control (C2): The activities performed by the remote pilot to manage the operation of the UA.

Control Station (CS): The equipment used by the remote pilot to maintain control, communicate, guide, or otherwise manage the UA.

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