Joint Authorities for Rulemaking of Unmanned Systems

RPAS C2 link
Required Communication Performance
(C2 link RCP) concept

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Chapter 1
INTRODUCTION

1.1 BACKGROUND

The concept of required communications performance of the C2 link (C2 link RCP) is derived from ICAO Doc 9869 to ensure the consistency if the two concepts are being used for the same technical system. This document is also in line with ICAO Doc 10019.

1.2 PURPOSE OF THIS DOCUMENT

The purpose of this guidance material is to

a) explain the concept of C2 link RCP;

b) identify C2 link RCP requirements applicable to the provision of C2 communications

c) support the use of command and control communications within a remote piloted aircraft system, and

d) provide a basis for the application of C2 link RCP in a the context of operational scenarios.

1.3 EXPLANATION OF TERMS

The development and explanation of C2 link RCP rely on the understanding of terms which are included in Appendix A.

Chapter 2
OVERVIEW OF RCP

2.1 GENERAL

2.1.1 Remotely piloted aircraft systems (RPAS) are a new type of aircraft which have to interact with the current airspace users. The main characteristic of the RPAS is that the pilot is not co-located (remote pilot: RPIL) with the remotely piloted aircraft (RPA). Another characteristic is that some automated functions may require remote machine – machine communications without the formal initiation or acknowledgement from the RPIL. A data link is supporting the interactive functions between the airborne system and the ground system. This data link may also carry information between air traffic services (ATS) and the RPIL. It is expected that RPAS are compatible with the way “manned aviation” operations are carried out, while interacting with ATS and with other aircraft, and maintain the current and foreseen safety levels in aviation.

2.1.2 In addition, the continuing growth of aviation places increasing demands on airspace capacity and emphasizes the need for the optimum utilization of the available airspace. Poor performance in the communications between the RPIL and the RPA would for example lead to increased separation and reduced airspace capacity to maintain the current safety levels. These factors, allied with the requirement for operational efficiency within acceptable levels of safety, have resulted in the need for a performance-based aviation system.

2.1.3 The transition to a performance-based aviation system is a critical aspect of the evolution to a safe and efficient global air traffic management (ATM) environment. In the context of RPAS command and control (C2), it will be necessary to ensure acceptable operational performance, taking into account changing technologies.

2.1.4 RPAS C2 is the aggregation of the airborne and ground-based functions executed between the RPS and the RPA as commanded by the RPIL or automated to achieve the interactions required to ensure the safe and efficient flight of the RPA during all phases of operations.

2.1.5 RPAS C2 is achieved through the collaborative integration of humans, information, technology, facilities and services, and is supported by communication, by detect and avoid, and by navigation and surveillance capabilities that are dependent on each other. Therefore, to determine the capability and performance requirements of the C2 system, it will be necessary to consider the system in its overall context, taking into account all its interdependencies. The automation level and the C2 system complexity are to be taken into account.

2.1.6 The communications supporting C2 functions may also support ATM functions, including interactions between the Air traffic controller and the RPIL, e.g. voice or digital messaging.

2.1.7 The C2 link RCP concept provides means to ensure the acceptable performance of communications for RPAS C2 in non-segregated airspace.

2.2 THE RCP CONCEPT

2.2.1 The C2 link RCP concept characterizes the performance required of communication capabilities that support RPAS C2 functions without reference to any specific technology and is open to new technology. This approach is essential to the evolution of operational concepts that use emerging technologies. Examples of RPAS C2 functions include, but are not limited to, the provision of commands to the RPA flight management system, the modification of the RPA and the monitoring system status, the acknowledgement of received commands, the feedback of RPA health parameters.

RPAS C2 functions are usually separated into telecommand and telemetry. Telecommand comprises information coming from the remote pilot station (RPS) where the RPIL is located to the RPA (uplink or forward link). Telemetry comprises information coming from the RPA to the RPS (downlink or return link).

2.2.2 The C2 link RCP concept assesses operational communication transactions in the context of a RPAS C2 function, taking into account human interactions, system design, procedures and environmental characteristics.

2.2.2.1 The contribution of the human can be significant to C2 link RCP. Communication is the accurate transfer between sender and receiver of information which can be readily understood by both.

2.2.2.2 In some cases, C2 information might be exchanged between the RPA and the RPS systems without a human in the loop (example: internal systems parameter monitoring involving a threshold).

2.2.2.3 An operational communication transaction is the process a human or a system initiator uses to send C2 information, and is completed when it is verified that the message was received, interpreted correctly and any action required as a result of that interpretation is correctly completed.

2.2.2.4 Because of the numerous variants in the design of a RPAS C2 system, including different levels of automation, message transmission protocols and control mode classes, the C2 link RCP concept is designed to:

- allow the same level of integrity of the C2 transactions for a given function, or group of functions, regardless of realisation of the RPAS C2 system.
- support the RPAS operator in contracting a communication service for RPAS C2 functions in a standardized way.

2.2.2.5 The C2 link RCP is designed in order that the RPAS C2 meets the performance or safety requirements and criteria of that airspace / operational context and needs to take into account the design of each C2 system. The C2 link RCP cannot be prescribed as an operational parameter only (e.g. landing).

2.2.3 The C2 link RCP concept is based upon “operationally significant” benchmarks which when attained assures confidence that the operational communications supporting the RPAS C2 functions will be conducted in an acceptably safe manner.

2.2.4 The basis for the development of the C2 link RCP concept was the need for objective operational criteria, in the form of a C2 link RCP type, to evaluate a variety of communication technologies. Once these criteria have been set and accepted, a specific implementation of a RPAS C2 function including its technical and human performance may have its viability assessed against acceptable operational criteria.

2.2.4.1 A C2 link RCP type is a label (e.g. C2 link RCP X) that defines a performance standard for operational communication transactions. Each C2 link RCP type denotes values for communication transaction time, continuity, availability and integrity applicable to the most stringent RPAS C2 function.

2.2.4.2 The C2 link RCP concept is not based on technology; however, it is not intended to promote an unrestricted number of alternative communication technologies for one RPAS C2 function. Interoperability, certification, safety oversight and cost considerations will be major items to contend with during such consultations.

2.2.5 Several factors may affect States decisions as to when a C2 link RCP type will be prescribed. These factors are based on the safety level required in a given airspace or over a populated area and may differ depending on the operation carried out.

2.2.6 In order to achieve the benefits that are advantageous to States, communication service providers and users, there is a need to ensure consistent definition and use of communication capabilities in order to apply the C2 link RCP concept on a global basis.

2.2.7 The C2 link RCP concept seeks to manage the performance of communications supporting evolving C2 systems and emerging technologies. This is achieved by:

— determining a C2 link RCP type for the communication capabilities supporting a C2 function; then

— prescribing the C2 link RCP type(s) related to the communications system(s) supporting the RPAS C2 functions within that operational environment; and

— complying with the prescribed C2 link RCP type(s) through analysis, operational assessments and performance monitoring of the communication systems.

2.3 DETERMINING AN RCP TYPE

2.3.1 To enable an RPAS C2 function within a performance-based operational environment, it will be necessary to characterize the performance required for the applicable elements. C2 link RCP will be used in conjunction with any other appropriate performance-based measures. Chapter 3 provides guidance for determining a C2 link RCP type for an RPAS C2 function.

2.3.2 For a particular RPAS C2 function, an increase or decrease in the required performance of technical communications may allow a trade-off in design complexity provided that the target level of safety is achieved.

2.3.3 It is important that States globally harmonize C2 link RCP type for the same or similar operational environment in order to guarantee interoperability resulting from confusion when operating across airspace boundaries.

2.4 PRESCRIBING AN RCP TYPE

2.4.1 After a C2 link RCP type has been determined, it may be prescribed for a set of RPAS complexity types in a given operational environment.
Potential typology to which C2 link RCP may be applied includes:

a) Control categories;
b) ATM environment;
c) Type and location of operation;
d) Class of airspace.

2.4.2 When a C2 link RCP type is prescribed, the RCP type(s) will indicate the requirements for qualification and approval of the procedures, aircraft equipage and communications infrastructure.

2.4.3 The operational environment influences the selection of the C2 link RCP type. As an example, the prescribed C2 link RCP type in terminal area airspace may be different than for en-route or oceanic airspace. Chapter 4 provides guidance for prescribing an RCP type for an operational environment.

2.5 COMPLYING WITH AN RCP TYPE

State requirements

2.5.1 In the case of the RPAS operator uses a RPAS C2 communications provider, since the C2 link RCP is a statement of required capability and of operational communication performance. If an RPAS operator uses a communications service provider (C2-CSP) for any element of the C2 service, there is an obligation on the part of the State to have oversight of the capability of the communication service to achieve the required level of safety and maintain the required communication performance.

2.5.2 The State must ensure that changes to services that rely on communication performance within a given airspace maintain the safety levels.

2.5.3 The State must ensure that communication service providers intending to support RPAS operators with a mandated C2 link RCP type are qualified and approved for such operations.

2.5.4 It should be noted that compliance with a C2 link RCP type can be achieved in many different ways, and the State may provide guidance on acceptable means through which the communications service provider and the RPAS operator can demonstrate how C2 link RCP is achieved.

RPAS operator / RPAS manufacturer requirements

2.5.5 The concept of C2 link RCP is based on the expected communication performance of all relevant communication capabilities used to support RPAS C2 functions.

2.5.6 There is an obligation on designers / manufacturers of RPAS and RPAS operators to achieve the communication performance for a specific C2-RCP type. The designer / manufacturer of the RPAS must provide the operator with details of the C2-RCP(s) which is / are required to operate safely in a given environment.

2.5.7 Since C2 link RCP is a statement of operational communication performance, there is an obligation on the part of the operator to provide the necessary procedures and the training to ensure that RPAS equipage and related communication services comply with the required communication performance.

C2 Communication service provider requirements

2.5.8 The C2 communication service provider can be internal or external to the operator. The C2 communication service provider must provide the expected performance through the appropriate legal contracting means to provide the expected performance.

2.5.9 The C2 communication service provider must inform in due time the RPAS operator of any expected [1] or current communication performance degradation outside of the C2 link RCP type parameters.

Monitoring communication performance

2.5.10 Monitoring provides objective operational data to determine that the C2 communication service provider continues to meet the C2 link RCP type. Monitoring includes data collection on a routine basis and as problems or abnormalities arise.

2.5.11 Monitoring is performed by organizations in control of or responsible for a component of the communication system in operation. Authorities shall oversee the monitoring processes in order to avoid any conflict of interest.

[1] A NoTAM could be the appropriate means to notify an expected degradation.

Chapter 3
DETERMINING AN RCP TYPE

3.1 RCP TYPE

3.1.1 In order to simplify the C2 link RCP type naming convention and to make the required communication transaction time readily apparent to airspace planners, aircraft manufacturers and operators, the C2 link RCP type is specified by a letter.

3.1.2 A C2 link RCP type comprises values assigned to the following parameters:

- communication transaction time;
- continuity;
- availability; and
- integrity.

3.1.3 C2 link RCP type parameters

3.1.3.1 Communication transaction time
The maximum time for the completion of the operational communication transaction after which the initiator should revert to an alternative procedure.

3.1.3.2 Continuity
The probability that an operational communication transaction can be completed within the communication transaction time.

3.1.3.3 Availability
The probability that an operational communication transaction can be initiated when needed.

3.1.3.4 Integrity
The probability of one or more undetected errors in a completed communication transaction.

Note: There are multiple RPAS C2 functions supported by the same C2 data link. These functions are independently assessed to determine the most stringent requirement. The global value for each parameter is based on the parameter achieving the most stringent transaction.

3.2 C2 LINK RCP TYPES – GENERAL APPLICATION

3.2.1 C2 link RCP types are designed to ensure the RPAS operator uses a communication service (internal or external) which matches the safety requirements of the operational environment.

3.2.2 Because of the large number of the C2 functions compared to the limited number of ATM functions (which the C2 link RCP concept is inspired from), the set of most used C2 link RCP types will be limited to the most significant and common ones for general RPAS operations.

3.2.3 This limitation in the number of C2 link RCP types will help the C2 Communications service provider to design communication systems which match the most common needs from the RPAS operators.

3.2.4 It does not prevent a RPAS designer to opt for other C2 link RCP types as long as they support the safety levels and operational environment requirements. In such case, tight cooperation with C2 communications service providers and aviation competent authorities will be necessary. Special awareness must then also be raised towards RPAS operators.

3.2.5 Table 3-1 specifies C2 link RCP types envisaged for general application.

C2 link RCP type	Transaction time (sec)	Continuity (Probability per flight hour)	*Availability (*Probability *per flight hour)*	Integrity (Acceptable rate per flight hour)
C2 link RCP A	3	0.999	0.9999	10^{-5}
C2 link RCP B	5	0.999	0.999	10^{-4}
…	15	0.999	0.999	10^{-4}

Table 3-1 Examples of C2 link RCP types (informative figures)

The strategy for populating table 3-1 includes cooperation from RPAS designers and communications service providers and national aviation authorities.

3.2.6 C2 link RCP types other than those provided in Table 3-1 may be established as experience is gained in C2 link RCP implementation.

Note1. C2 link RCP types are to be derived from current or assumed future traffic, RPA classes performance characteristics, ICAO control modes classification, industry standards, and other factors.

Note2. An example of the process and results related to determining an RCP type can be found in Appendix B.

3.3 ASSESSING OPERATIONAL COMMUNICATION TRANSACTIONS IN THE CONTEXT OF THE RPAS C2 FUNCTION

Operational communication transaction in the RPAS C2 function context

3.3.1 Figure 3-1 provides an overview of determining C2 link RCP type for a RPAS C2 function. A C2 link RCP type is determined from an assessment of the operational communication transactions in its operational context. System design may have to be taken into account later on in the process when dealing with integrated functions in the allocation of parameters values.
In the context of the operational environment characteristics (airspace characteristics, such as separation minima, spacing criteria and capacity limits; …), the RPAS C2 function is dependent on the C2 system design, including but not limited to transmission protocols, automation levels and message criticality prioritization.

3.3.2 Given the airspace characteristics and design, the C2 link RCP type is used to characterize the communication capability and performance that needs to exist for the remote pilot or the C2 system to perform a RPAS C2 function.

3.3.3 However, in addition to the C2 link RCP type determined for a given function, other C2 link RCP types may be appropriate for specific operations that may have different characteristics. This dependency may be related to, for example:

- functional differences in the means of control which provides an integrated remote control capability (swarm);
- an increase in communications due to a time-critical operational context;
- a contingency procedure in the event the primary communication system fails.

In such cases, it may be necessary to establish specific operational criteria using a different C2 link RCP type for the alternate means of communication to ensure that it performs as expected and to convey its performance characteristics to the remote pilot / C2 system for proper use. This C2 link RCP type is different from the C2 link RCP type established for the communications capability the remote pilot / C2 system uses to perform a C2 function.

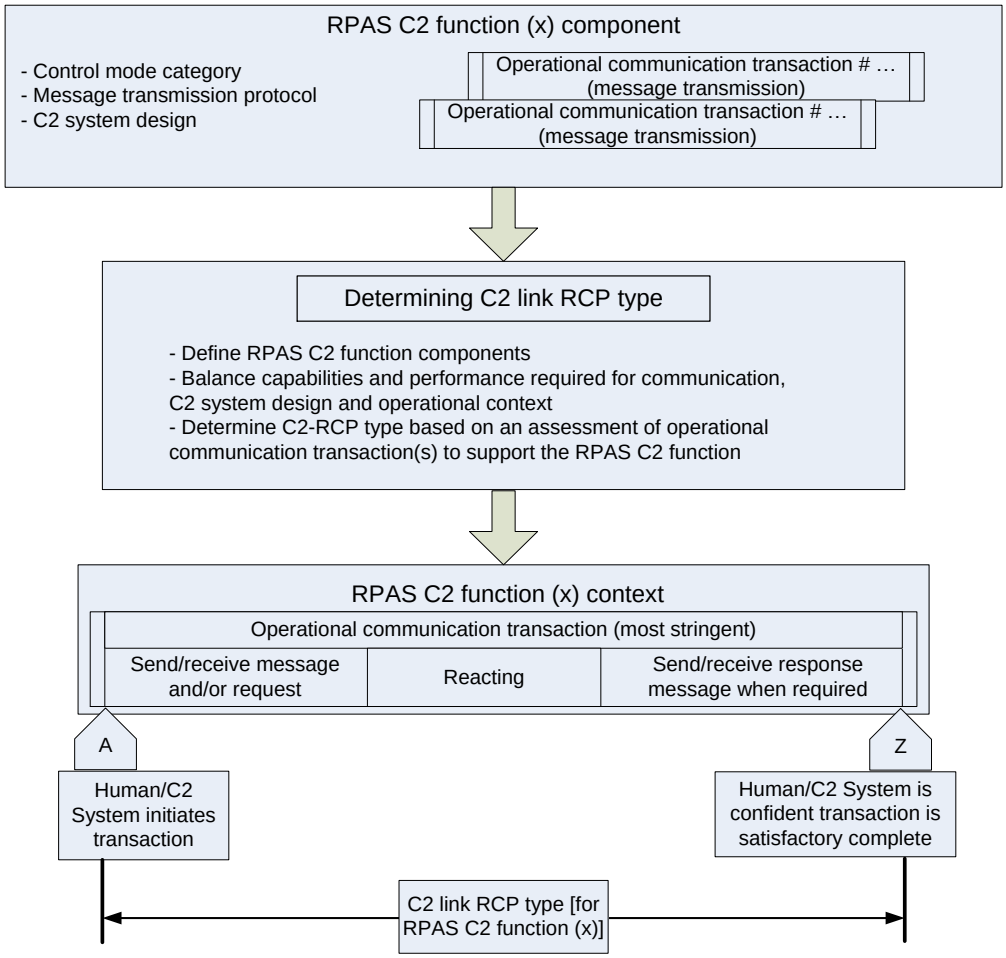


Figure 3-1 Determining RCP type for a RPAS C2 function

3.3.4 There may be multiple operational communication transactions that support a RPAS C2 function. These transactions are assessed to determine the most stringent. The value for the communication transaction time parameter is based on the time needed to complete the most stringent transaction. Other C2 RCP type parameters (continuity, availability and integrity), must also comply with the most stringent.

3.3.5 Performance of the operational communication transaction of a C2 function can be determined by safety modelling. Given the C2 function involved, appropriate safety criteria (buffer, separation, reaction time…) must be used.

3.3.6 Next figures illustrate the RPAS C2 operational communication transaction in the context of RPAS C2 communications supporting an altitude change message from the remote pilot from an ATC clearance and with a reporting feed back message automatically sent by the RPA (telemetry information not used as primary source of information). ICAO Annex 11 Chapter 3 section 3.7.3 requires that the safety-related part(s) of any clearance or instruction be read back to the air traffic controller.

3.3.6.1 If the C2 link is not used to carry the ATC-RPIL communications then C2 link RCP is solely function of the operational context. Then RCP-C2 type for the C2 commands implementing the manoeuvre will have to be determined by the expected compliance with the manoeuvre in that airspace (figure 3-2).

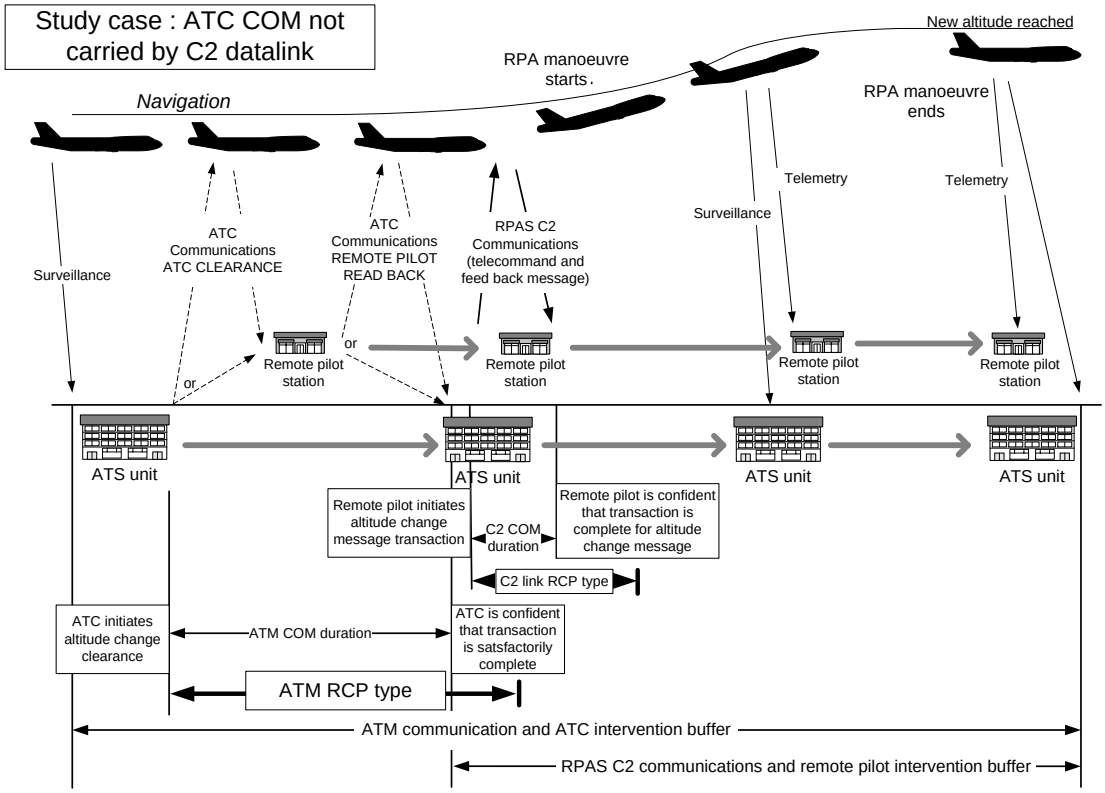


Figure 3-2 C2 link RCP type when the C2 link is not carrying ATC communications

3.3.6.2 If ATC-RPIL communications are carried by the C2 link, the RCP-C2 type for the C2 commands implementing the manoeuvre has to be shorter than the related ATM-RCP since C2 communications takes place within the timeframe of ATC intervention requirements in addition to the communication durations required between ATS and the RPA and between the RPA and ATS, which both are independent of the RPAS (figure 3-3).

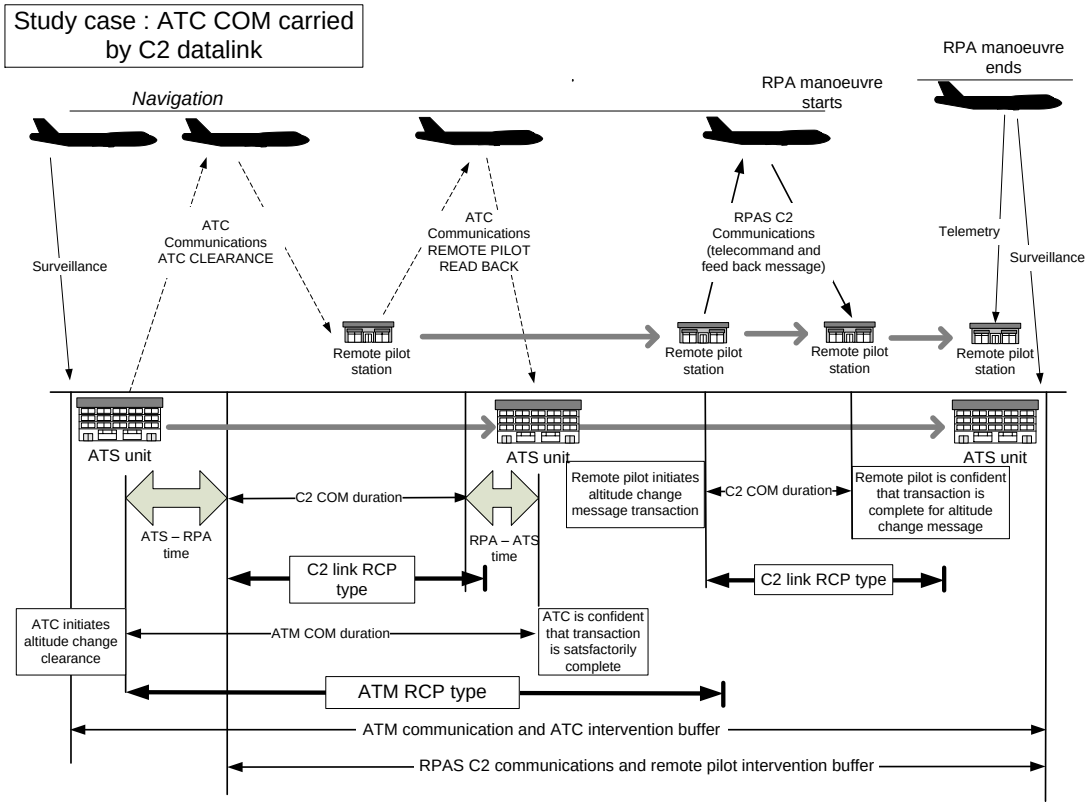


Figure 3-3 C2 link RCP type when the C2 link is carrying ATC communications

3.3.7 Figure 3-4 illustrates a similar situation of altitude change initiated by the RPIL or an automated C2 function outside of the context of an ATM clearance. Two cases are described.

3.3.7.1 First when the airborne C2 system sends back a report (feed back message) to acknowledge the altitude change initiation by the flight computer. Second when there is no automatic report (feed back message) but confidence comes from automated periodic altitude telemetry information.

3.3.7.2 Figure 3-4 aims at demonstrating by an example that the time necessary for the pilot to be confident that the manoeuvre has commenced may be different depending on the message transaction typology (in that example, reaction time is longer). This time must be anyway shorter than the RCP-C2 type for the C2 commands implementing the manoeuvre.

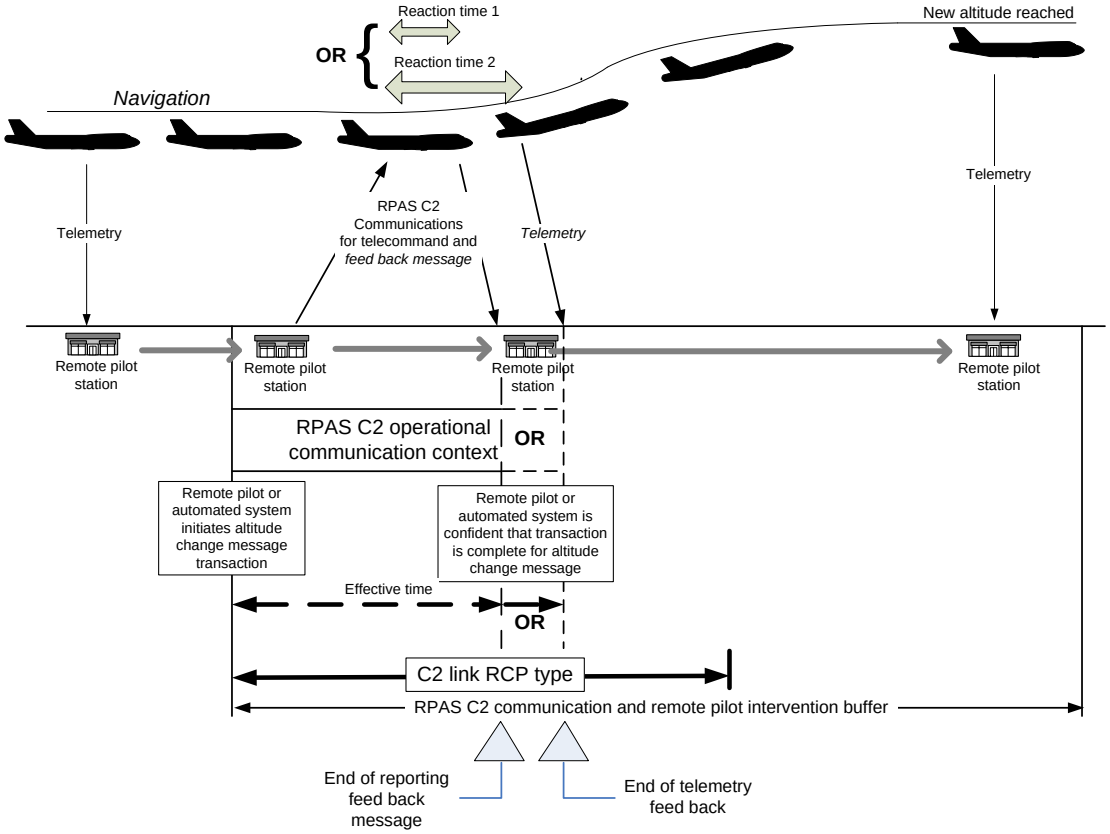


Figure 3-4 RPAS C2 Communications capabilities and performance related to an internally initiated altitude change

3.3.8 Figure 3-5 is picturing an event requiring a telecommand initiated by the telemetry of the RPA (e.g. information from the “detect and avoid” sub-system). It describes the sequence of actions and communication transactions required.

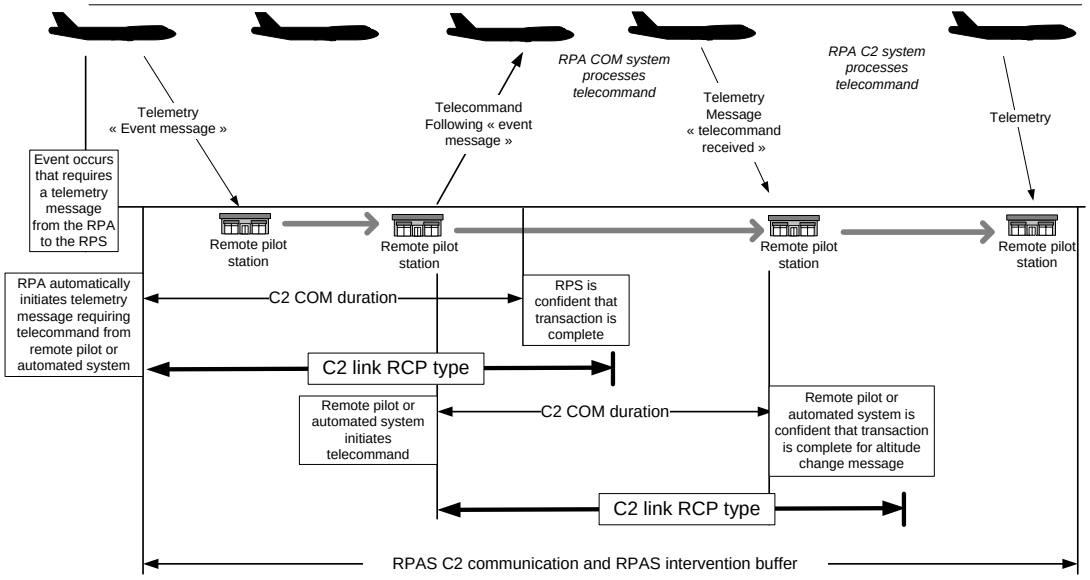


Figure 3-5 RPAS C2 Communications capabilities and performance initiated by a telemetry message

Continuity

3.3.9 The value for the continuity parameter is selected based on the results of an operational hazard assessment.

3.3.9.1 The operational hazard assessment must include a severity-of-effects analysis of detected errors within the communication transactions. Detected errors include, but are not limited to:

— detecting that the transaction has exceeded the communication transaction time;

— detecting that one or more messages within the transaction are corrupted, misdirected, directed out-of sequence or lost, and cannot be corrected to complete the transaction within the operational communication transaction time; and

— detecting loss of

- the communication service or
- the capability of the RPAS to use the service whilst transactions are pending completion.

3.3.9.2 An acceptable probability must be determined for the likelihood of occurrence of communication transactions with detected errors based on the severity-of-effects analysis.

3.3.10 The value for the continuity parameter is based on the acceptable probability of detected anomalous behaviours of the communication transaction.

Availability

3.3.11 The value for the availability parameter is selected based on the results of an operational hazard assessment. The operational hazard assessment must include a severity-of-effects analysis of the detected loss of the system which prohibits the initiation of a communication transaction.

3.3.11.1 An acceptable probability must be determined for the likelihood of occurrence of an inability to initiate a transaction based on the severity-of-effects analysis.

3.3.12 The value for the availability parameter is based on the acceptable rate of detected inability to initiate a transaction.

Integrity

3.3.13 The value for the integrity parameter is selected based on the results of an operational hazard assessment. The operational hazard assessment must include a severity-of-effects analysis of communication transactions with undetected errors. Undetected errors include, but are not limited to:

- undetected corruption of one or more messages within the transaction;
- undetected misdirection of one or more messages within the transaction;
- undetected delivery of messages in an order that was not intended;
- undetected delivery of a message after the communication transaction time; and
- undetected loss of service or interruption in a communication transaction.

Note. Undetected loss of service is associated with integrity because it is "undetected." In some operational scenarios, it is conceivable that a network could have failed with no indication provided to the users of the system.

3.3.13.1 An acceptable probability should be determined for the likelihood of occurrence of communication transactions with undetected errors based on the severity-of-effects analysis.

3.3.14 The value for the integrity parameter is the acceptable probability of communication transactions with undetected errors.

3.4 SELECTING THE RCP TYPE

3.4.1 Once all the safety and operational environment requirements have been determined in addition of the RPAS C2 design analysis, the C2 link RCP type which meets these requirements is selected from Table 3-1.

3.4.2 Separate analyses of different RPAS C2 functions may result in a number of different C2 link RCP types being determined for the different combination of RPAS C2 systems and operational environment and characteristics. See Chapter 4 for guidance on prescribing a C2 link RCP type in these situations.

Chapter 4
PRESCRIBING A C2 link RCP TYPE

4.1 DETERMINE REQUIREMENTS

4.1.1 A C2 link RCP type may be used to prescribe operational RPAS C2 communication requirements based on the operational requirements and the C2 system design. However, in practice this is likely to be an iterative process. When information for ATM functions is relayed by the RPA to the RPS using the RPAS C2 link, the global C2 link RCP must be the most stringent ATM RCP.

4.1.2 Figure 4-1 provides an overview of a single C2 data link that supports multiple RPAS C2 functions each with a different C2 link RCP type and supports ATM functions with their ATM-RCP type.

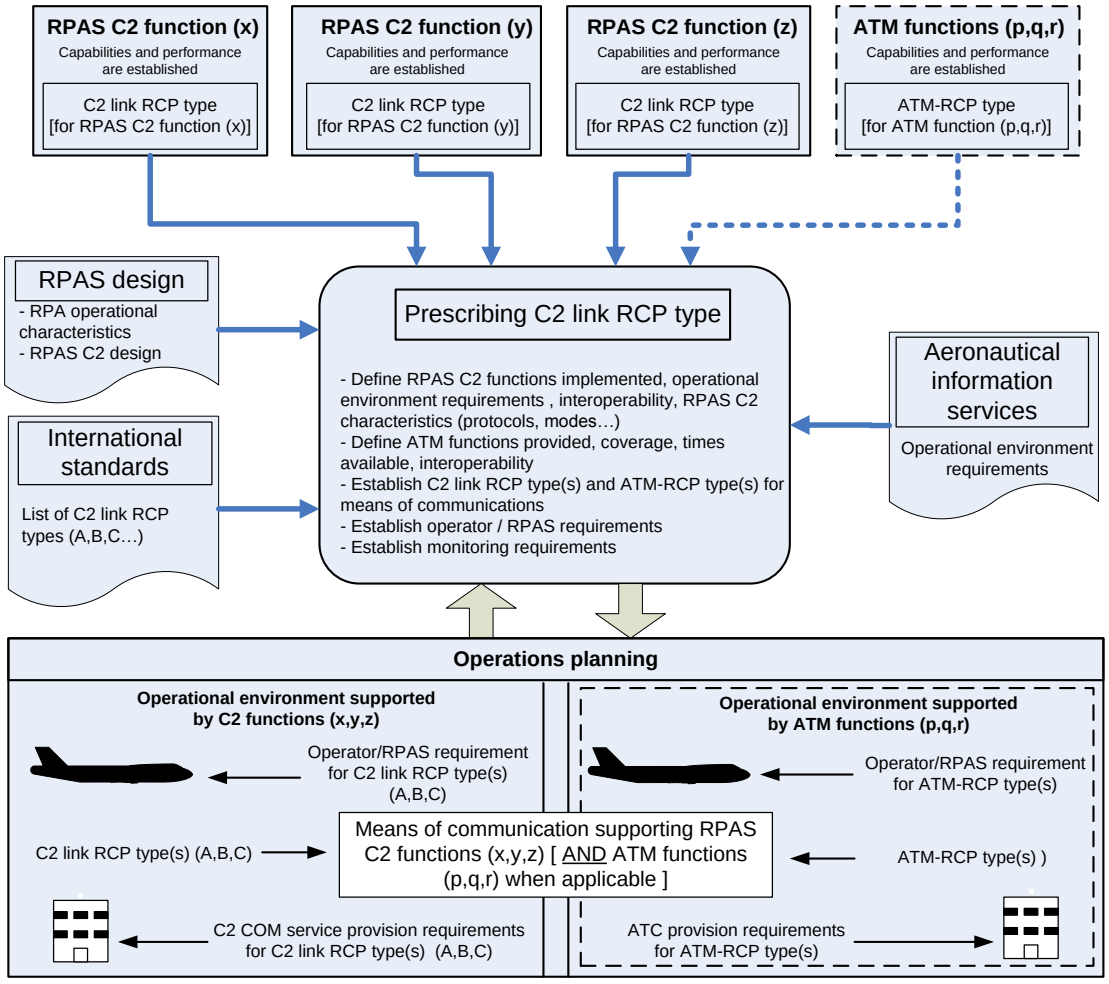


Figure 4-1 Prescribing a C2 link RCP type supporting several RPAS C2 and ATM functions on the C2 data link

4.1.3 It is not envisaged to allow an alternate means of communication for RPAS C2 communications that do not meet the C2 link RCP because C2 communications are critical for effective control of the RPA and because they safety related. In that context, figure 4-2 provides an overview of a normal means of communication and an alternate means of communication with different performance characteristics, both of which able to support a RPAS C2 function in the same operational environment. In this figure, ATM communications are not coupled with RPAS C2 communications to better demonstrate the alternate issue. Each means of communication has performance characteristics associated with it to ensure

that it performs as expected. For example, those two means could be satellite communications and a ground communications network.

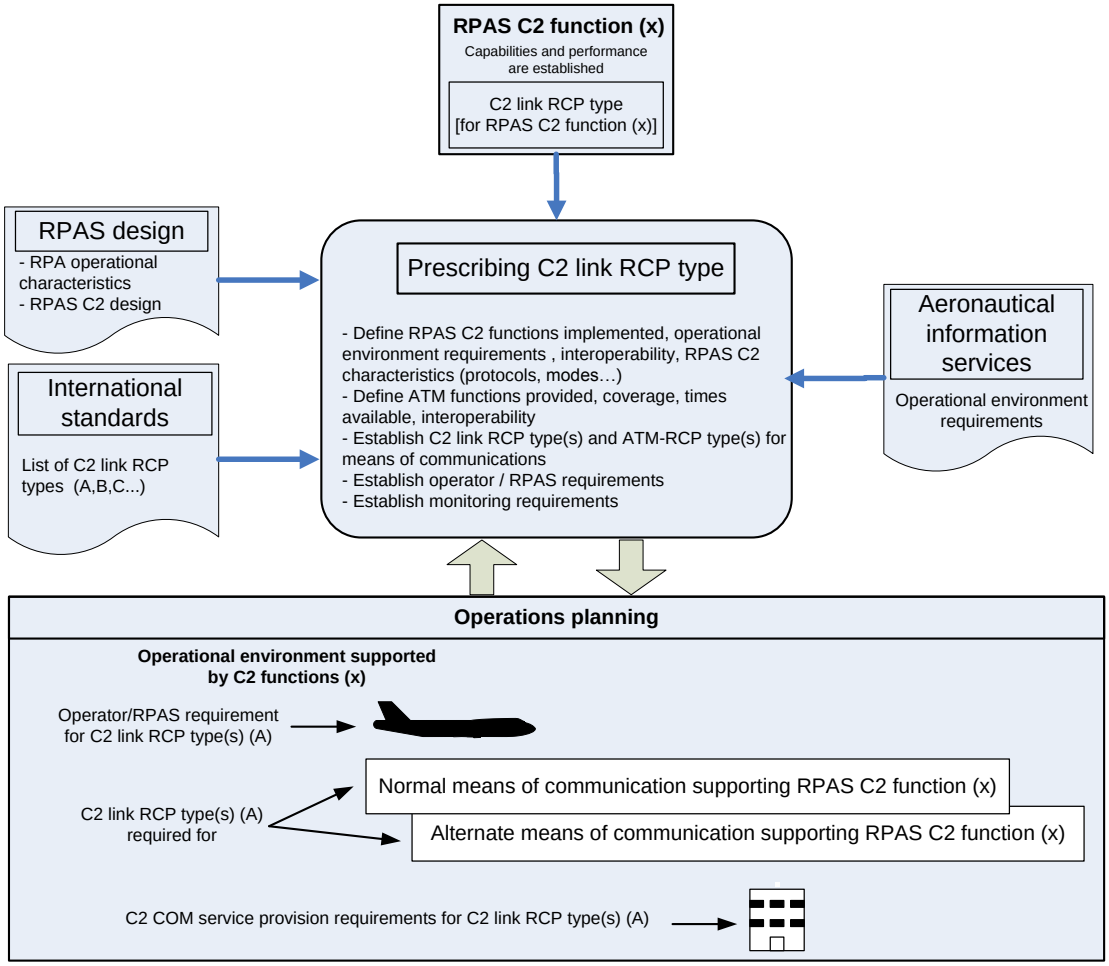


Figure 4-2 Prescribing an C2 RCP type (Normal and alternate means of communication)

4.1.4 Once the RPAS C2 functions and the associated C2 link RCP type(s) for a particular set of operational environment requirements are established, they should be published in the appropriate documentation. Care should also be taken to ensure that any potential users of the RPAS are provided with an unambiguous definition of the procedures, aircraft equipage and training requirements necessary to operate in that operational environment as well as the performance monitoring processes.

4.1.5 In order to ensure that problems do not arise when these requirements are introduced, it is recommended that early liaison in the appropriate forum takes place between RPAS operators, C2 communications service providers and the competent authorities.

4.1.6 When a C2 link RCP type(s) is prescribed, the C2 link RCP type(s) will provide the basis for qualification and approval of the procedures, aircraft equipage and communication infrastructure. The basis for each type of approval is provided in the form of a C2 link RCP type allocation.

4.2 C2 LINK RCP TYPE ALLOCATION

4.2.1 C2 link RCP type allocation is the process of apportioning the various C2 link RCP type values to the various sub-systems. The results of this process are C2 link RCP type allocations that are used to:

a) assess viability of different technologies to meeting operational requirements;

b) design, implement and qualify communication services;
c) approve the provision of C2 communication services;
d) determine when to initiate contingency procedures;
e) design, implement, qualify and approve RPAS type designs;
f) approve RPAS operators for operations; and
g) operationally monitor, detect and resolve non-compliant performance.

4.2.2 C2 link RCP type allocations may need to be established by the competent authority or on the basis of regional air navigation agreements. However, in such cases, the competent authority should initiate appropriate action to document the C2 link RCP type allocations appropriate for each C2 link RCP type in line with international standards.

4.2.3 C2 link RCP type allocations are documented in ICAO manuals or industry-developed minimum aviation system performance standards which specify allocations for various communication system elements. Figure 4-3 provides a template for allocating capability and performance to RPAS C2 data communication. In systems where there is no automatic feedback message functionality, confidence in the completed transaction is provided by indirect feedback such as telemetry information (e.g. altitude measurement parameter). Responder performance includes the RPA flight dynamics delays and the telemetry latency due to its periodicity.

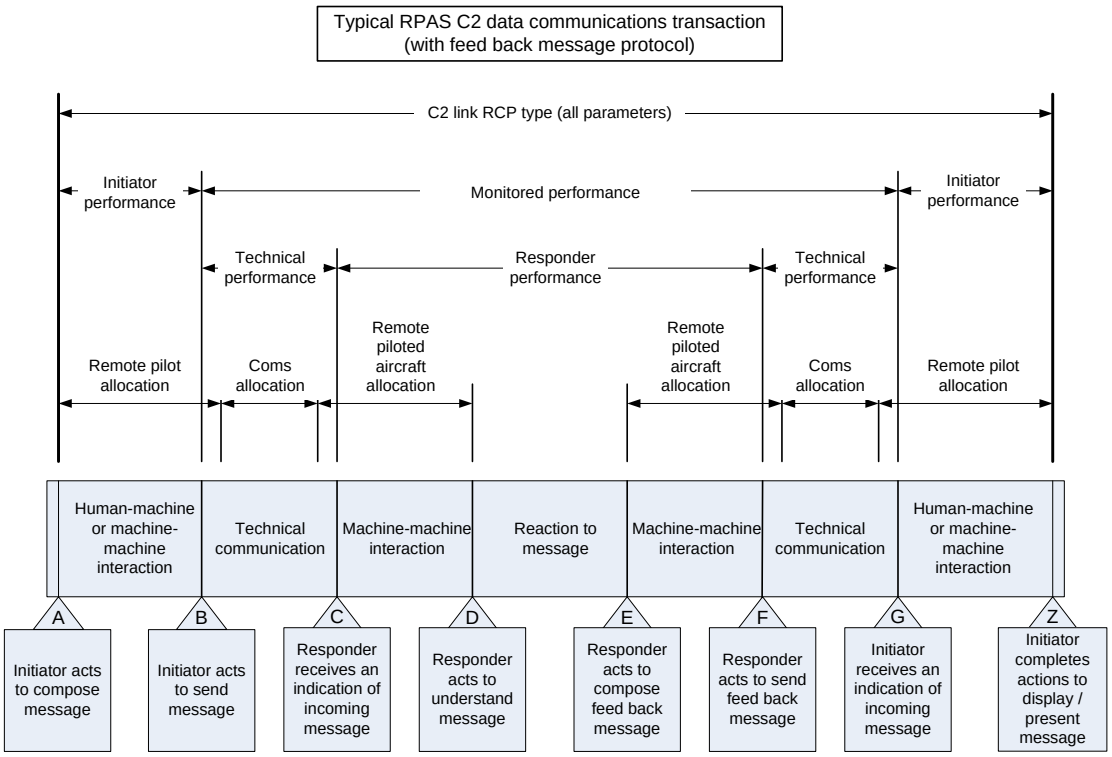


Figure 4-3 C2 link RCP type allocation template for typical RPAS C2 data communications

Appendix A
Glossary of terms

Air Traffic Management.
The aggregation of the airborne functions and ground-based functions (air traffic services, airspace management and air traffic flow management) required to ensure the safe and efficient movement of aircraft during all phases of operations.

ATM function.
An individual operational component of air traffic services. Examples of ATM functions include, but are not limited to, the application of separation between aircraft, the re-routing of aircraft, and the provision of flight information.

Availability.
The probability that an operational communication transaction can be initiated when needed.

Buffer.
The period of time between initiation of a maneuver and its completion. This is longer than the transaction completion time.

Communication transaction time.
The maximum time for the completion of the operational communication transaction after which the initiator should revert to an alternative procedure.

Continuity.
The probability that an operational communication transaction can be completed within the communication transaction time.

C2 link.
The datalink used for the purpose of command and control functions in a RPAS.

C2 link RCP type.
A label (e.g. C2 link RCP X) that represents the values assigned to C2 link RCP parameters for communication

C2 link RCP type allocation.
The process of apportioning the various C2 LINK RCP type values to the various parts of the system.

Command and control required communication performance (C2 link RCP).
A statement of the performance requirements for operational communication in support of specific RPAS C2 functions (including ATM functions when relayed by the RPA and supported by the C2 link).

Communication system.
A means that allows transmission and reception of data between the remote control station and the RPA.

Integrity.
The probability of one or more undetected errors in a completed communication transaction.

Operational communication transaction.
The process a human uses to send an instruction, a clearance, flight information, and/or a request. The process is completed when that human is confident that the transaction is complete.

Qualification.
The process through which a State, approval authority and applicant ensure that a specific implementation complies with applicable requirements with a specified level of confidence.

RPAS C2 function.

Function = Intended behaviour of a product based on a defined set of requirements regardless of implementation (from SAE ARP 4754A).

Examples of RPAS C2 functions include all the functions by which a remote pilot is effectively having control over the RPA navigation, attitude and the RPA airborne systems.

Appendix B
Example of determining a C2 link RCP type (informative)

The RPAS C2 function in this example is a routine remote pilot input changing the RPA altitude using a data link communications to send a single message to the Flight Management System (FMS) of the RPAS. Modification of altitude could result from a demand from ATC for separation assurance or from a mission requirement.

To maintain separation minima at an acceptably safe level, the remote pilot must convey in the minimum time the appropriate actions to achieve the change in altitude.
Additionally, with proper integration into the RPS, the C2 link system will enable the remote pilot to maintain an acceptable level of workload.
According to the message typology, an altitude change message will be event driven and it will require a feed back message.

The transaction time for the C2 link system can be determined using an iterative process to determine the allowable increase in air traffic demand, the amount of C2 communications performed using the C2 link, and viable options offered by the enabling technologies and implementations. Analysis of empirical data and simulations can determine the types and volume of transactions.
The continuity, availability and integrity can be determined based on severity of effects analysis, using the criteria provided in Chapter 3 of this manual.

The scenario involves the use of data communications by the RPIL to ensure an acceptably safe manoeuvre compatible with the ATC expectations.

To determine the C2 RCP type one should:

a) Define the C2 RPAS function components
   i) describe the operational environmental characteristics in which the function will be performed;
   ii) describe the operational communication transaction associated with that function and other RPAS system performance (control mode category, automation level, …)

b) Balance capabilities and performances required for the control mode and automation of the RPAS by:
   i) determining the operational performance expectations associated with performing that function;
   ii) determining any safety requirements associated with the effects of failures arising during the performance of the function;
   iii) determining the values for the C2 link RCP parameters associated with performing the function; and

c) Select the C2 link RCP type based on the determined values.

Define the RPAS C2 function components

The C2 function process must be described in details for later budget calculation and assessment of possible failure conditions.

In the example of an altitude change table B-1 describes the control and communication process for RPAS fitted with the control mode category “B” (vector control).

Figure B-1 provides a pictorial reference of the time sequence that occurs during the steps used to complete the operational communication transaction for a routine RPAS C2 function communication using the C2 link system connecting the RPS and the RPA. The numbers shown in the diagram map to steps described in Table B-1.

Step	Operating step
0	The remote pilot is notified by voice / data ATM communications to change the RPA altitude and has sent a respond (WILCO) or has to perform the change altitude manoeuvre as planned or must perform this manoeuvre for self separation.
1	The RPIL uses the RPS HMI to set the control parameters performing the altitude change
2	The RPIL initiates the manoeuvre by a voluntary action (sending the control information to the RPA)
3	The RPS C2 processing system formats the control information into a C2 message and send it for transmission to the RPS communication system
4	The RPS communication system formats the control message by applying the appropriate communications protocols and interfaces with a communication system / network providing the RPS-RPA C2 link
5	The formatted information is sent to the RPA
6	The formatted information is received by the RPA
7	The FMS understands the content of the formatted information and prepares an acknowledgment message
8	The acknowledgment message is ready to be sent back to the RPS
9	The acknowledgment message is received / forwarded by the communication system / network to the RPS
10	The acknowledgement message is received by the RPS communication system and send to the C2 RPS HMI
11	The message is understood by the RPS C2 system and presented to the RPIL

Table B-1

Communications or information processing are involved from step 2 to step 11.

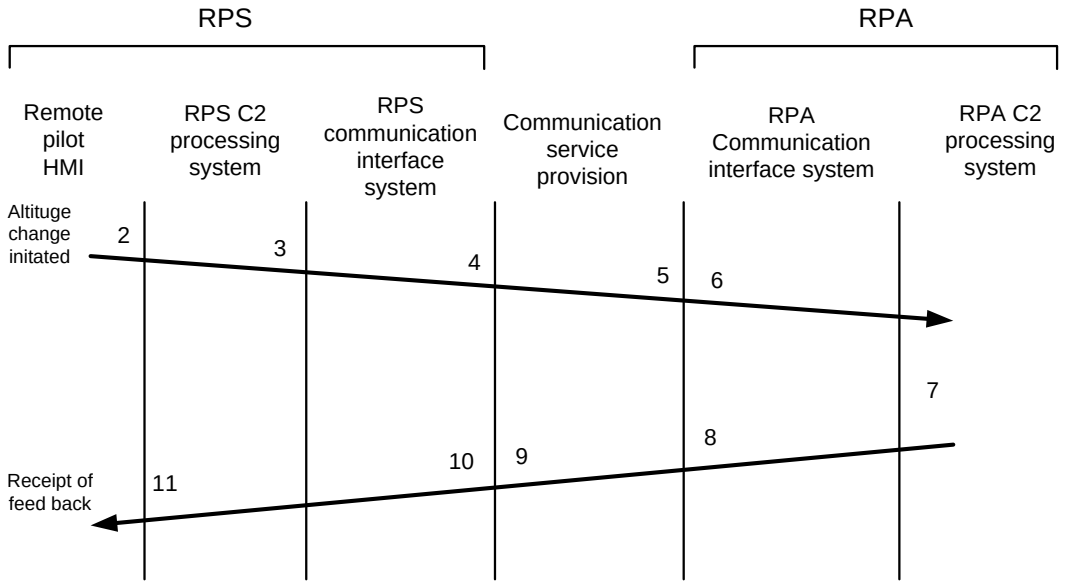


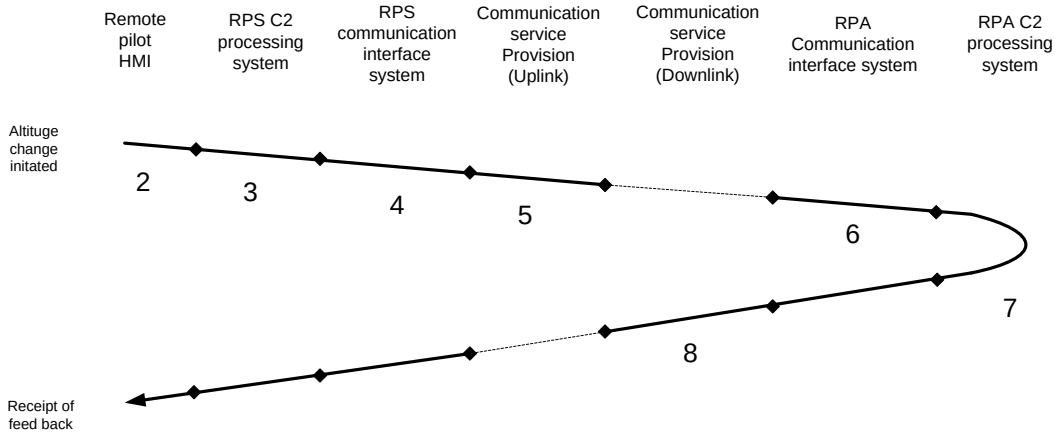
Figure B-1. Sequence of operating steps

The continuity, availability and integrity are assessed based on severity-of-effects analysis, considering the operational hazards that can occur during the operational communication transaction for routine RPAS C2 functions communications. These operational hazards and their effects are shown in Table B-2. The hazards were generalized to the worst possible case to determine the hazard level.

Operational hazard	Operational effect	Hazard classification (or severity effect)
Loss of ability to provide the altitude change message to the RPA C2	Change altitude will not be performed and no feed back message will be sent by the RPA C2 system. The RPIL does not know if it is a RPA failure or a C2 link failure unless the C2 link is continuously monitored independently of the operational transmissions.	*Hazardous*
Loss of ability to provide feed back message to the remote pilot	The RPIL does not know if the message has been received and processed until some telemetry information physically confirms the RPA manoeuvre. The RPIL may send again an altitude change request that would end up with doubling the initial command. HMI must be designed avoid such situation.	*Major*
Detected late or expired altitude change message	The RPA C2 system receives the message late or expired (based on time stamping information); the RPA C2 system disregards the message and informs the remote pilot.	*Minor*
Detected misdirection of the altitude change message	The RPA C2 system receives an inappropriate message (misaddressing). Message is disregarded. The RPIL is not informed.	*No effect*
Detected corruption of the altitude change message	The RPA C2 system realizes the message is corrupted. It disregards the message and informs the RPIL.	*Minor*
Undetected late or expired altitude change message	The message arrives as the altitude change is no longer to be performed and no mitigation systems realized this situation. The RPA C2 system orders the FMS to perform the manoeuvre. It results in unexpected flight level transition. Separation issue with surrounding traffic is expected.	*Major / hazardous*
Undetected misdirection of an altitude change message	The RPA C2 system receives an inappropriate message (misaddressing) and acknowledges it as valid. The RPA C2 system orders the FMS to perform the manoeuvre. It results in unexpected flight level transition. Separation issue with surrounding traffic is expected.	*Major / hazardous*
Undetected corruption of the altitude change message	The RPA C2 system received a message with wrong information resulting in a different altitude change than expected (core message error) or in a different command affecting another subsystem (C2 message header error). The RPA has an expected behaviour.	*Major / hazardous*

Table B-2

For RPAS, the C2 link RCP operational communication breakdowns as follows:



Transaction time	T2	T3	T4	T5	T8	T6	T7
Continuity	C2	C3	C4	C5	C8	C6	C7
Availability	A2	A3	A4	A5	A8	A6	A7
Integrity	I2	I3	I4	I5	I8	I6	I7

Where:

- Step 2 Remote pilot HMI: Time it takes for a remote pilot to set up the RPAS C2 altitude change instruction or to display the feed back information.
- Step 3 RPS C2 processing system: Time taken to convert the instruction into the appropriate format (i.e. a C2 message) or to interpret the feed back message.
- Step 4 RPS communication system: The time taken to multiplex the C2 messages and initiate the communication with the Communication service provision or vice versa (demultiplex with downlink).
- Step 5/step 8 Communication provision service: Time taken to deliver the message from the RPS transmission communication interface to the RPA reception communication interface whether that be direct or via a terrestrial, airborne or satellite link or vice versa
- Step 6 RPA communication system: Time taken to demultiplex the messages and pass them to the RPA C2 system or to multiplex the feed back message and to initiate the communication with the Communication service provision.
- Step 7 RPS C2 processing system: Time taken by the RPA C2 system to analyze the message and tag it as appropriate or not. Prepare the feed back message. If a feed back message function is not part of the C2 system, return information will come from regular telemetry information and will follow step 6, 4, 3 and 2.

Total transaction time = 2 x (T2 + T3 + T4 + T6) + T5 + T7 + T8 in sec

Note: this calculation is valid only for functions which require a feed back message. It must not be used for those with no feed back message.

Table B-3 presents typical safety objectives associated with the hazards classified in Table B-2 for operational communication transaction for routine RPAS C2 functions communications.

The likehood of a loss of ability to provide C2 messages for the RPA shall not be greater than probable
The likehood of late or expired C2 message delivery shall be no greater than probable
The likehood of misdirection of a C2 message shall be no greater than probable

The likehood of undetected misdirection of a C2 message used for altitude change shall be no greater than remote
The likehood of undetected corruption of a C2 message used for altitude change shall be no greater than remote
The likehood of undetected out of sequence C2 messages used for altitude change shall be no greater than remote

Table B-3 safety objectives

Table B-4 presents examples of safety requirements resulting from the hazard assessment performed on the sequential operational communication transaction for an altitude change request by the remote pilot.

When a clearance requires execution of a manoeuvre to be done in more than one message in a specific order, the messages shall be put in order that they are executed in a single uplink transmission
Each message shall be time stamped
The time stamp shall indicate the time that the message is released by the initiator for onward transmission
Any processing (data entry/encoding/transmitting/decoding/displaying) shall not affect the intent of the message
The receiver shall reject messages not addressed to its end system
The initiating system shall be capable of indicating to the end user when a required response is not received within the required time
When a received message contains a time stamp that indicated the time has been exceeded, the receiving system shall either discard the message and inform the initiator or display the message with the appropriate indication
When the remote pilot is informed that a response has not been sent within the required response time, the remote pilot shall apply an appropriate procedure
The recipient shall be capable of detecting a corrupted message
The message prioritization process shall be dynamic to use the information of messages which have timed out or were received corrupted

Table B-4 Safety requirements

The performance objectives associated with operational communication transaction for an altitude change request from the remote pilot are shown in Table B-5. This table only considers performance objectives for major hazards.

Description of parameter	Value
Unexpected interruption of a transaction	10^{-4} per aircraft per flight hour
Loss of communication transaction	10^{-5} per aircraft per flight hour
Loss of service	10^{-6} per aircraft per flight hour
Undetected corrupted transaction	10^{-5} per aircraft per flight hour

Table B-5 Performance objectives (informative figures)

Select the RCP type

Based on the results of the simulations, empirical data and analyses, as indicated in Table 3-1 of Chapter 3, the C2 link RCP type applied to the RPAS C2 link system for a RPAS C2 altitude change request communication is C2 link RCP “A”.

— END —