OVERVIEW OF A CARGO TRANSPORT UAS/RPAS INSERTION IN NON-SEGREGATED AIRSPACE, CONOPS, RELATED CRITICAL OPERATIONAL AND REGULATORY ISSUES

BY
Cesare Ing. DIONISIO and Panagiotis Ing. XEFTERIS
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PART A
UAS/RPAS FUNDAMENTALS AND REPRESENTATIVE CONOPS
WHAT IS A REMOTELY PILOTED AIRCRAFT SYSTEM OR REMOTELY PILOTED AIRBORNE SYSTEM (RPAS) ?

In accordance with the ICAO Doc. No. 10019 AN/507 a Remotely Piloted Aircraft System (RPAS) is a major subset category of the Unmanned Aircraft Systems (UAS) family.

RPAS is an integrated aerial system which is composed of an aircraft without a human pilot aboard (RPA), a ground-based controller or Ground Control Station (GCS) or Remote Pilot Station (RPS), and a link system of Command, Control and Communications (C3 Link) Data/Voice between the RPA-RPS-ATC/ATM.
Typical UAS/RPAS Design Configuration Categories

Note: RPAS are generally categorized according to their mission and flight rules under which they have to operate.
In accordance with ICAO the Remotely Piloted Aircraft (RPA) as an aircraft shall be piloted by a licensed Remote Pilot (RP) who operates at a Remote Pilot Station (RPS) located external to the aircraft (i.e. ground).

The RP controls and monitors the aircraft most of the time of flight and can respond to instructions issued by Air Traffic Control (ATC) under an Air Traffic Management (ATM) system in a regulated airspace environment as at least manned aircraft do.

The RP communicates via Voice/Data Link during the operations, and has direct responsibility for the safe functional and operational conduct of the RPA throughout the flight envelope of its mission profile.

It is expected that RPASs are compatible with the way “manned aviation” operations are carried out, while interacting with ATS and with other aircraft (Manned and/or Unmanned), and maintain the current and foreseen safety levels in aviation.
Some Examples of UAV/RPAS Missions

MILITARY

- Intelligence, Surveillance, Reconnaissance (ISR);
- Weapons Platform;
- **Cargo Transport and Logistics Management**
- Natural Disaster Support

STATE (Non-Military)

- Border Surveillance;
- Police and Security support;
- Rescue Support;
- Fisheries Patrol;
- Meteorological Research and hurricane/typhoon monitoring;
- Natural and disaster support:
- **State Special Transport**

CIVIL AVIATION AND SUPPORT SERVICES

- **Air Cargo Transport and Logistics**
- Advertising; Aerial Photography; Cinema/Media applications;
- Agricultural Monitoring; insecticide and Fertiliser application;
- Forest Fire Operations; wildlife census;
- Critical infrastructure inspection; terrain mapping;
- Oil and Gas Pipeline Monitoring
- Emergency Medical Support
Advantages of RPAS

The advantages of using an RPAS, relative to use of a manned aircraft, are that the RPAS:
- does not contain, or need, a qualified pilot on board
- can enter environments that are dangerous to human life
- reduces the exposure risk of the aircraft operator
- can stay in the air for up to 30 hours, performing an aerial work day-after-day, night-after-night in complete darkness, or, in fog, under computer control
- performing a variety of missions as manned aircraft do but with more operational cost-effectiveness
- can be programmed to complete the mission autonomously even when contact with its RPS is lost.

Disadvantages of RPAS

- May cause the collateral damage such as killing the civilians and damaging the civilian property
- Loss of Link
- Subjected to Cyber Attack
- Costly Technology to substitute human abilities and interactions on board of the aircraft (manned A/C)
- Complex Infrastructure to satisfy Aviation Safety Requirements
A.2 UAS/ RPAS Categorization, Missions and Airspace Class Insertion Overview
Typical Unmanned Aircraft Systems (UAS) Categorization by MGTW and Operational Performance

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>SIZE</th>
<th>MGTW* (Kg)</th>
<th>N.O.A.** m / Mission Radius (km)</th>
<th>AIRSPEED (Knots)</th>
<th>TYPICAL UAS/RPAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP 1</td>
<td>Nano</td>
<td>&lt; 1</td>
<td>&lt; 120 AGL*** / 1.6</td>
<td>&lt;50</td>
<td></td>
</tr>
<tr>
<td>GROUP 2</td>
<td>Micro</td>
<td>1-5</td>
<td>&lt;1000 AGL / &lt; 8</td>
<td>&lt;100</td>
<td></td>
</tr>
<tr>
<td>GROUP 3</td>
<td>Small</td>
<td>6-55</td>
<td>&lt;3500 AGL / &lt; 40</td>
<td>&lt;100</td>
<td></td>
</tr>
<tr>
<td>GROUP 4</td>
<td>Light</td>
<td>56-150</td>
<td>&lt;5.500 MSL**** / &lt; 1.000</td>
<td>&gt;100</td>
<td></td>
</tr>
</tbody>
</table>

GROUPS Considered for the Preliminary CT-RPAS CONOPS Study

<table>
<thead>
<tr>
<th>GROUP 5</th>
<th>Medium</th>
<th>&gt;150 – 5.000</th>
<th>&gt;5.500 MSL / &lt; 3.000</th>
<th>Min. 80 KTAS Max. 400 KTAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUP 6</td>
<td>Large</td>
<td>&gt;5.000</td>
<td>&gt;5.500 MSL / &gt; 3.000</td>
<td>Any Airspeed</td>
</tr>
</tbody>
</table>

* MGTW = Maximum Gross Take-off Weight, ** N.O.A. = Normal Operating Altitude, *** AGL = Above Ground Level , **** MSL= Mean Sea Level
UAS/RPAS Categories by Operational Designations, Altitude and Endurance
(Source: NASA)

Airspace Classes in Accordance with ICAO Annex 11, Appendix 4
ATC and Collision Avoidance issues in the various Airspace Classes

ECAC has classified the airspace up to FL660 as follows:

- Above FL 195 harmonized classification (Class C).
- Below FL 195 predominance of Class C and D
- Terminal Maneuvering Area (TMA) and Control Zone (CTR) prevalence of Class C and D with some cases of Class A
- Few cases of Class B and E
- Class G available normally below FL 135
<table>
<thead>
<tr>
<th>Role</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>Supports the national state system by providing access to national and international routes in multiple states. It provides Passenger and Cargo Services.</td>
</tr>
<tr>
<td>Regional</td>
<td>Supports regional economies by connecting communities to state markets. It provides Passenger and Cargo Services.</td>
</tr>
<tr>
<td>Local</td>
<td>Supplements communities by providing access to primarily state markets. It may also provide some cargo services.</td>
</tr>
<tr>
<td>Basic</td>
<td>Links the community with the national airport system and supports general aviation activities (e.g., emergency services, charter or critical passenger service, cargo operations, flight training and personal flying).</td>
</tr>
<tr>
<td>Unclassified</td>
<td>Provides access to the aviation system. It may include aerodromes with prepared and/or unprepared runways and/or minor airfields.</td>
</tr>
</tbody>
</table>
A.3 UAS/RPAS General Functional Architecture and Critical Enabling Technologies Issues
UAS/RPAS Notional Airspace Insertion Operational Interfaces (Source: RTCA DO-344)
Generic Cargo Transport RPAS over 150kg MGTW System Segmentation

Integrated System Level

TYPICAL CARGO TRANSPORT RPAS INTEGRATED SYSTEM

CT-RPS SEGMENT

CT-RPAS SUPPORT SEGMENT

- Operations Support Facility
- Assets Maintenance
- Operations Supply Support
- Ground Support Equipment
- Operations Training
- Operations Informatics
- Off Aircraft Mission Planning
- Launch/Recovery Equipment
- PHS Cargo Goods
- Cargo PHS Tools/Equipment

CT-RPA SEGMENT

- Airframe
- Airframe Systems
- Powerplant
- AMS/Flight Control
- Communications
- Navigation/Guidance
- Detect and Avoid
- Aircraft CNPC Link
- Ancillary
- Cargo System

Pilot /Pilot System Interfaces
- Remote Cockpit
- Flight Control/Monitoring
- Ancillary Systems Control/Monitoring
- Alerts, Warning Caution, Monitoring
- Communications Control/Monitoring
- Nav/Guidance Control/Monitoring
- Detect and Avoid
- CNPC Link Terminal
- CNPC Link Control/Monitoring
- Mission Planning
- Flight/Voice Recorders
- Cargo Payload Control / Monitoring
- RPS Environmental
- RPS Facility/Facility Systems
The Cargo Transport RPAS over 150Kg. MGTW Remote Pilot Station (RPS) will usually be of three (3) types (common also to all RPAS) depending on the size, configuration, mission, operational need and/or operational flexibility, namely:

1) **Fixed RPS** which is a permanent station with facilities usually located to a centralized operational hub and can handle an elevated number of the same type and/or different type CT-RPAs at the same time.

2) **Transportable RPS** which is a fixed station after has been transported by air or sea or road and installed in a preselected location for CT-RPAS operations. Depending on its characteristics it can handle 2 or more CT-RPAs at the same time.

3) **Mobile RPS** is a self-propelled station which, depending on its design, can usually handle two (2) CT-RPAs at the same time doing Aerial Work and one (1) probably in Ferry Flight.
A.4 CT-UAS/RPAS Concept of Operations (CONOPS) in LOS and BLOS and Representative Scenarios
The overall parameters of the CT-RPAS CONOPS Scenarios that will be involved and are used in this document, are the:

- Operator’s (User) Concept of Operations (including Infrastructures and Logistics),
- CT-RPAS Capabilities and Performance to carry out the operator’s Cargo Transport missions, and
- Overall Airspace Insertion Scenario during the various Phases of Flight.
The Cargo Transport RPAS (CT-RPAS) shall be considered for the time being as a new addition and complementary element of the overall current Air Cargo Transport system. In this context, the Air Cargo Transport Concept of Operations (CONOPS), utilizing dedicated RPAS configurations, it is assumed to be composed of three (3) Main Physical Operational Elements, namely:

1) **The Operating CT-RPAS* Element** encompasses the Remotely Piloted Aircraft (RPA) in a Cargo Transport Configuration and Remote Pilot Stations (RPS) operating in LOS and/or BLOS mode by means of a Control and Non-Payload Communications (CNPC) Link (UP and DOWN Data and Voice Link) utilizing for this purpose a Terrestrial and/or Satellite based Network for Command, Control, Communications, Sense and Avoid (or Detect and Avoid) services covering all non-segregated airspace classes, all integration cases and flight phases.

1) **The CT-RPAS dedicated Integrated Logistic Support (ILS) Infrastructure* Element** will guarantee system supportability, availability and safety throughout the CT-RPAS Operational Life-Cycle.

1) **The dedicated Air Cargo System Operational Infrastructure (ACSOI) Element** will guarantee the RPAS Air Cargo Services Business Model at Regional, Continental and Inter-Continental Levels within the current Air Cargo System and its established regulatory requirements. The ACSOI segment also includes the operational interfaces with aerodromes and their Infrastructures.

*NOTE: The Elements 1) and 2) together compose the Totally Integrated CT-RPAS Segment which in its turn is fully integrated with the ACSOI Element in order to satisfy the RPAS Air Cargo Services Business Model.*
Cargo Transport RPAS Operations Main Stakeholders and Functional Interfaces

The main Stakeholders (actors) of the RPAS CONOPS are those who are directly and indirectly involved in the Air Cargo Operations which are the:

1. Direct CT-RPAS Stakeholders
a) Cargo Transport RPAS Provider (Industrial Actor)
b) Cargo Transport RPAS Operator (Air Cargo Carrier Actor)*
c) Cargo Transport Logistics (Packaging/Handling/Storage) Services Provider*
d) CNPC Link Services Provider(s) (Terrestrial and Satellite Network Actor(s) support to the CT-RPAS Operator)
e) Cargo Content Provider (Owner/Deliverer of the Cargo Content)**
f) Cargo Content End Customer (Recipient of the Cargo who can be a Private and/or Institutional Entity)**

NOTE: * The Cargo Transport Logistics Provider may coincide with the Cargo Transport RPAS Operator
** The Cargo Content Deliverer may coincide with the Cargo Content Recipient

1. Indirect CT-RPAS Stakeholders
a) ATC/ATM Traffic Separation and Management Services Provider(s) who supports the CT-RPAS Operator
b) Airport Authority and/or Airport Services Provider who supports the CT-RPAS Operator
c) Regulatory/Operations Authorization Provider(s) (Civil Aviation Authorities who Certify both the Industrial and Operator Actors)
## CT-RPAS CONOPS- Requirement Categories and Management Functions Overview

<table>
<thead>
<tr>
<th>Requirements Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operational Scenario</strong></td>
<td>Operations Typology, Flight Phases, RPAS Segments, Airspace, Aerodromes, Flight Envelope, Safety, Coverage Area, Cargo Transport Scenarios, Air Cargo Transport Services and Logistics</td>
</tr>
<tr>
<td><strong>Functional</strong></td>
<td></td>
</tr>
<tr>
<td>Performance</td>
<td>RPA, RPS, Link Availability, Latency, Continuity, Integrity, Capacity, Throughput.</td>
</tr>
<tr>
<td>Security</td>
<td>Confidentiality, authentication, integrity, availability.</td>
</tr>
<tr>
<td>Regulatory</td>
<td>Spectrum, Frequency Mechanism, Bandwidth</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicate</td>
<td>Voice, data and light signal exchanges between ATC and the RPS to communicate instructions and responses</td>
</tr>
<tr>
<td>Control</td>
<td>Relates to the control link between the RPA and the RPS, and includes telemetry information confirming aircraft control status and health.</td>
</tr>
<tr>
<td>Navigate</td>
<td>Pertains to any reference cues used by the RPA or pilot to determine orientation.</td>
</tr>
<tr>
<td>Avoid</td>
<td>Any action taken by the aircraft to keep safely away from moving and stationary objects (e.g. terrain, clouds, aircraft, people, structures, etc.) and from unauthorized surface areas or airspace.</td>
</tr>
</tbody>
</table>
An over 150kg MGTW Cargo Transport RPAS depending on its configuration, endurance and performance characteristics, it will be mainly capable to perform a cargo transportation mission in both LOS and BLOS modes of operation utilizing a C3 Data Link at allocated specific Terrestrial and Satcom Band frequencies spectrum within an adequate non-segregated (controlled and uncontrolled) airspace class at a:

a) Regional and/or National Level
b) Continental Level (i.e. ECAC Countries)
c) Inter-Continental Level (including Over Oceanic Flights such as from EU to Africa or EU to N. America etc.)

The key issue for the Cargo Transport RPAS operations at whatever of the above levels is to reassure aviation authorities that Air Cargo Flight by an RPAS flight within civilian air traffic will:

a) Integrate seamlessly into current air traffic control (ATC) procedures;
b) Maintain civil aviation safety-of-flight levels.

For safe operations of the Cargo Transport RPA under LOS and BLOS conditions, three types of radio-communications between the RPA and the CGS/RPS are required, (depending on the RPAS design characteristics) which are as follows:

a) Radio-communications in conjunction with air traffic control relay;
b) Radio-communications for RPA command and control;
c) Radio-communications in support of the Sense and Avoid or Detect and Avoid (DAA) function.
UAS/RPAS Airspace Insertion Link System Overall Architecture in LOS and BLOS Operations

- Collocated or Remote, Direct Terrestrial Pilot Station
- Point-to-Point RLOS CNPC Link
- Point-to-Point Satellite CNPC Link
- Infrastructure - could include wired and wireless (terrestrial or satellite) connectivity

- Collocated or Remote, Networked Terrestrial Pilot Station
- Satellite CNPC Network(s)

- Satellite Network Operations Center(s)
- Collocated or Remote, Networked SATCOM Pilot Station
- Satellite Network Operations Center(s)
- Spot Beams
- Regional Beam

Pilot Stations may be connected in any of the four configurations shown with each configuration having the Pilot Station either Collocated or Remote from the GRS or Network

Note: For clarity supporting Air Traffic Management and Navigation services are not shown

Note: Air Traffic Management and Navigation Services could go directly to the Pilot Station or be relayed via the UA
### Various Examples of Fixed Wing Cargo Transport RPAS of over 150Kg. MGTW Payload Access Doors and Stores Configurations

<table>
<thead>
<tr>
<th>Cargo Transport RPA Configuration (Fixed Wing)</th>
<th>Operational Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Main Cargo and AFT Fuselage Ramp Access Doors</td>
<td>A CT-RPA in this type of configuration has full Cargo Air-Drop and Ramp to Ramp Delivery Operational Capability.</td>
</tr>
<tr>
<td>2. Main Cargo Access Door (no Ramp)</td>
<td>A CT-RPA in this type of configuration will have only a Cargo Delivery Ramp to Ramp Operational Capability.</td>
</tr>
<tr>
<td>3. Single FWD and/or AFT Fuselage Ramp Cargo Door</td>
<td>A CT-RPA with only FWD Ramp Door will have only a Cargo Delivery Ramp to Ramp Operational Capability. A CT-RPA with AFT Ramp door will have full Cargo Air-Drop and Ramp to Ramp Delivery Operational Capability.</td>
</tr>
<tr>
<td>4. Multiple External Cargo Store (Fuselage/Wing Aerodynamically Shaped External Stores)</td>
<td>A CT-RPA in this type of configuration has full Cargo Air-Drop and Ramp to Ramp Delivery Operational Capability. The external cargo stores are fixed on the wing stations.</td>
</tr>
<tr>
<td>5. Single Access Internal Cargo Store</td>
<td>A CT-RPA with an external (Pod) or internal cargo store has only Ramp to Ramp Delivery Operational Capability.</td>
</tr>
<tr>
<td>6. Low Fuselage Cargo Bay or Lower Fuselage Cargo Pod</td>
<td>A CT-RPA with a lower Fuselage Cargo Bay can deliver in both ramp to ramp and air drop modes. A CT-RPA with a lower Fuselage Cargo Pod can deliver goods from ramp to ramp only.</td>
</tr>
</tbody>
</table>
Total Medium and Large RPAs and CT-RPAs (in red) Operating Population Numbers and Densities that Need to be Supported during Operations

<table>
<thead>
<tr>
<th>CAT.</th>
<th>RPA SIZE</th>
<th>No. OF OPERATING RPA IN NON-SEGREGATED AIRSPACE BY 2030 (60% OF THE TOTAL)</th>
<th>No. OF OPERATING CT-RPAs IN NON-SEGREGATED AIRSPACE BY 2030 (20% OF THE TOTAL OPERATING RPAs)</th>
<th>DENSITY OF ALL RPA/ Sq.Km</th>
<th>DENSITY OF CARGO TRANSPORT RPA/ Sq.Km</th>
<th>LOS SCENARIO FOR CARGO TRANSPORT RPAS</th>
<th>BLOS SCENARIO ALL RPA/CT-RPA PER SPOT BEAM (GEO-SAT WITH 40 SPOT BEAMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Medium</td>
<td>2028</td>
<td>406</td>
<td>0,000156</td>
<td>0,0000521</td>
<td>406/0,0000521</td>
<td>51/10</td>
</tr>
<tr>
<td>6</td>
<td>Large</td>
<td>837</td>
<td>167</td>
<td>0,000064</td>
<td>0,0000214</td>
<td>167/0,0000214</td>
<td>21/4</td>
</tr>
</tbody>
</table>
Non-ATC Participating Aerodrome- UAS/RPAS Operational View Schematic
Non-ATC Participating Surface-UAS/RPAS Operational View Schematic

- RPA
- SAT
- Visual Alignment
- Restricted Areas

**Communication**
- Communicate (Voice, Data and Light Signals)

**Control**
- Control (Telecommand and Telemetry)

**Navigate**
- Navigate (Reference Course and Route Cues)

**Avoid**
- Avoid (Detection, Surveillance & Awareness)
Non-ATC Participating Airborne-UAS/RPAS Operational View Schematic
UAS/RPAS Operational Scenario and Modes
1) in Point-to-Point Aerial Work and 2) Planned Aerial Work

[Diagram showing different operational modes and stages of flight]
Example of an UA/RPA Cargo Transport Mission from Hub (Airport A) to Hub Connection (Airport B) Representative Scenario (ATC-Participating)
Example Cargo Delivery Scenario from Hub (Airport A) to not-Hub Connection (Airport X) and not-Hub (Airport X) to Hub Connection (Airport A) CONOPS Representative Scenario.
Cargo Emergency Delivery from Hub (Airport A)/not-hub (Airport X) to Air Drop Zone(s) CONOPS Representative Scenario
Representative Cargo Air Drop Pattern (Plane View)

AERIAL WORK B
(CARGO AIR-DROP)

CRUISING (FROM AERODROME A) ENTERING LOITERING PATTERN

HIGH OR LOW VELOCITY PRECISION CARGO AIR-DROP

8-10 NM
4-5 NM
10-12 NM

DROP ZONE

EXIT PATTERN-HOMING TO AERODROME A

DOWNDOWN TO THE DROP TARGET

FINAL APPROACH TO TARGET

DESCENT

LOITERING PATTERN

ON-TO-TO AERODROME A
Air to Land Side Import Flow Process

1. Ramp Handling
2. Cargo breakdown
3. Cargo delivery
4. Pick up & transportation

AIR SIDE

IN-AIRPORT WAREHOUSE

LAND SIDE

Consignee
Radiocommunication Requirements for Safe UAS/RPAS Operations

In accordance with ITU-R M.2171 Methodologies, specifically with Methodology 2. Deployment of UAS/RPAS requires access to both terrestrial and satellite spectrum for LOS and BLOS modes of operation in the non-segregated airspace. The maximum amount of spectrum required for UAS/RPAS are:

a) 34 MHz for terrestrial systems,
b) 56 MHz for satellite systems.

The key issue for UAS/RPAS operations of whatever mission scenario is to secure that UA/RPA flight within civilian non-segregated air traffic shall:

a) integrate seamlessly into current air traffic control (ATC) procedures;
b) maintain safety-of-flight levels.

<table>
<thead>
<tr>
<th>UA/RPA Type/Ops</th>
<th>Airspace Class</th>
<th>Detect and Avoid</th>
<th>Transponder</th>
<th>2-way ATC Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA/LOS</td>
<td>Class G</td>
<td>Not Required</td>
<td>Not Required</td>
<td>Not Required during Operation</td>
</tr>
<tr>
<td>LA/BLOS</td>
<td>Class G</td>
<td>Required</td>
<td>Required</td>
<td>Not Required during Operation</td>
</tr>
<tr>
<td>MA (LOS/BLOS)</td>
<td>Class A-E</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>HA (LOS/BLOS)</td>
<td>Above FL 600 (60,000ft)</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
</tbody>
</table>

LA = LOW ALTITUDE, MA=MEDIUM ALTITUDE, HA=HIGH ALTITUDE

Summary of Radio-communication Services Required per UAS/RPAS Type/Ops Mode and Airspace Class
Link Redundancy Considerations

Safe operations of UAS/RPAS in non-segregated airspace may need independent back-up communications to ensure high reliability of the critical communications links. Configuration options may include, “cold standby”, “hot standby” and “dual operation”.

1) **Cold Standby:** where one link is working and carrying all the message traffic, the other link is powered down. In the event the first link is lost, before the standby link can be used, it needs to power up and initiate the link connection/log-in procedure to establish a connection to the other end of the link (e.g. at the GCS/RPS or UA/RPA). This may involve a sign-in protocol with any third party network provider. The time delay associated with this procedure should be sufficiently short to avoid the need to trigger the lost Link procedure;

2) **Hot Standby:** where both links are powered and connected and immediately available, although only one is being used to transfer Link data at any time. (The standby may be transferring low rate data to keep the link immediately ready to take over.); and

3) **Dual Operation:** where all link data messages are sent on both links simultaneously and the flight computer chooses the message from the link with the best integrity. This mode of operation minimizes the probability that there will be an interruption in link data flow in the event of a single link interruption or failure.

It is recommended that the two links employ different frequencies/technologies (e.g. terrestrial radio line of-sight and satellite-based BRLOS) as this will provide significantly greater protection against possible loss of the link. The GCS/RPS should be provided with a continuous indication of the operational status of all links.
A.5 CT-UAS/RPAS Overview of Critical Regulatory Issues
CARGO TRANSPORT RPAS FUNDAMENTAL REQUIREMENTS DOMAINS FOR OPERATIONS IN THE AIRSPACE

Any Cargo Transport RPAS Project contains eleven (11) Fundamental Action or Requirements Domains which currently represent the thematic and technological challenges of all RPAS Worldwide and on which the entire work of any Cargo Transport RPAS Project shall be oriented. These eleven (11) Requirement Domains have as follows:

1) Cargo Transport RPAS Initial e Continuous Airworthiness
2) Cargo Transport RPAS Flight Conditions and Limitations
3) Cargo Transport RPAS Remote Pilot Stations (RPS)
4) Cargo Transport RPAS Remote Pilot Qualification
5) Cargo Transport RPAS Human Factors
6) Cargo Transport RPAS Operation and Operator’s Responsibilities
7) Cargo Transport RPAS Command and Control (C2) Link
8) ATC Communication with the Cargo Transport RPAS
9) Rules of the Air and Detect and Avoid (DAA) Systems
10) Integration of Cargo Transport RPAS Operation into ATM
11) Use of Aerodromes, dedicated Logistics RPAS Systems and Maintenance

NOTE THAT THE CT-RPAS DESIGN, AIRSPACE OPERATIONS AND ITS RELATED REGULATORY FRAME WILL BE BASED ON THE RESULTS OF GAP ANALYSIS AND TRADE-OFFs WITHIN ALL 11 REQUIREMENT DOMAINS BETWEEN MANNED AND UNMANNED AIR CARGO SYSTEMS AND IN TERMS OF COMMONALITIES, NON-COMMONALITIES AND/OR NEW DEVELOPMENTS.
The International Civil Aviation Organization (ICAO) has determined that the C3 link must operate over protected aviation spectrum. Therefore, protected aviation spectrum must be allocated for this function, approved through the processes of the International Telecommunications Union Radio-communication Sector (ITU-R).

Actions taken at the ITU-R 2012 World Radio-communication Conference (WRC-12) have established spectrum resources to address the RLOS spectrum requirement among others also in the C-Band, at 5030-5091 MHz.

At the ITU-R 2015 WRC (WRC-15), BRLOS spectrum requirements were addressed by providing allocations specifically for UAS/RPAS in Ku-Band and Ka-Band in Fixed Satellite Service (FSS) allocations. The FSS allocation is not aviation safety spectrum, hence the use of these bands for C2 links will require a number of special considerations in order to meet an equivalent level of safety. With WRC-15 actions completed, it is currently possible to begin experimental studies of UAS/RPAS C2 links in Ku-Band and Ka-Band, and such studies will be necessary to fulfill requirements imposed by WRC-15 before the UAS/RPAS C2 allocations can be finalized probably in WRC-19 and/or WRC-23.

For C-Band, there are currently no satellites in operation providing services in the aviation band so no experimental investigations are possible yet and therefore analytical assumptions are only possible for the time being especially when considering UAS/RPAS operational scenarios.
PART B
UAS/RPAS LOS AND BLOS OPERATIONS SYSTEM ARCHITECTURE
C-band communications for UAS/RPAS
(AMS (R) S: Aeronautical Mobile Satellite (R) Service)
Ideas for an operational system architecture

List of contents:

• Introduction
• Current Requirement and architectural Overview
• Data link frequency allocation & management issues
• Data link LOS and BLOS main design issues
• Conclusions
Introduction

The World Radio Conference 2012 has allocated protected spectrum for UAV C2, so far no European UAV C2 civil data links have been proposed for frequency bands 5030–5091 MHz.

This band was therefore internationally recognised as one of the bands that can be used for the implementation of unmanned aircraft (UA) Control and Non-Payload Communications (CNPC) links via both terrestrial and satellite systems.

Civil aviation authorities will not allow UAV operations without certified LOS and BLOS links and terminals therefore it is important that new standardized and integrated data link for certification is conceived and designed.

Scope of this presentation is to provide the system design status of the C-band application for UAV communications as described in the public documentation from the relevant organizations (ICAO, ITU, RTCA, etc). Currently no satellite exists in this C-band.
Technical/Regulatory barriers for UAV operations in non segregated areas

- Separation Assurance/Sense and Avoid issues implementation (interoperation with ATC and keep separation)
- Human Systems Integration (lack of rules and adequate ground stations)
- Certification (lack of airworthiness requirements and safety-related data)
- Communications (lack of standard, certifiable data links and aviation safety spectrum to operate such links for civil UAS control communications.)

The loss or compromise of the CNPC link supporting safety critical functions has potentially catastrophic consequences.

It is important the safe integration of UA into the Airspace system in both the LOS (Line of Sight) and BLOS (Beyond Line of Sight) segments.

Internationally discussed frequencies for LoS CNPC on the World Radiocommunication Conference (WRC) in 2015 are, amongst others, 960/977 MHz and 5030/5091 MHz

Airworthiness is the measure of an aircraft's suitability for safe flight
The simplest communications system for a UAV operating in segregated airspace consists of the UAV and the Ground Control Station (GCS) with exclusive frequency assignment for the direct UAV-to-GCS and GCS-to-UAV links, i.e., downlink and uplink.

The situation changes in non-segregated airspace as UAVs and manned aircrafts will need to share airspace. In addition to the GCS and UAV link, communication between ATC and GCS, a direct link or a relay link through the UAV, is required.

The existing satellites in the Fixed Satellite Service (FSS) to provide BLOS CNPC have been evaluated. Although some UASs have used FSS for their CNPC links, this has occurred only by exception through the Certificate of Waiver or Authorization (COA) process, which occurs once per UAS operation and does not allow routine access of UAS. However, this past use of FSS demonstrates the feasibility of this approach. As mentioned above, ICAO has determined that the CNPC link must operate over protected aviation spectrum, which the FSS allocation does not meet.

ICAO has deemed the CNPC function to be safety critical and has mandated that aviation safety spectrum must be used for this function.
Control and non-payload communications (CNPC) function
Requirement categorization

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational Scenario</td>
<td>Flight phases, UAV segments, airspace, flight envelope, coverage area.</td>
</tr>
<tr>
<td>Performance</td>
<td>Availability, latency, continuity, integrity, capacity, throughput.</td>
</tr>
<tr>
<td>Security</td>
<td>Confidentiality, authentication, integrity, availability.</td>
</tr>
<tr>
<td>Aeronautical Earth Station</td>
<td>Certification, SWaP, design characteristics, coexistence with on-board electronics/avionics.</td>
</tr>
<tr>
<td>Regulatory</td>
<td>Spectrum, EIRP limits, out of band emissions, coordination with /protection of other in-band systems.</td>
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</tbody>
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Main System design issues

- Satellite orbit = GEO vs LEO
- Power density and spectrum constraints $\rightarrow$ interference
- MLS (Microwave Landing System) compatibility
- Duplexing mechanism (share of BW/time between Tx and Rx) and Communication sharing Ground-Space
- Channel access mechanism & Modulation
- Power Amplifier operation (saturated-not saturated)
- Ground station configuration
- Number of UAV antennas/rx chains
PROPOSED SATELLITE COVERAGE BY A GEO SATELLITE (OVER ECAC COUNTRIES)
SPECTRUM SHARING MECHANISM
SCENARIO

The spectrum requirements are based on at least two factors: the amount of bandwidth needed in a single sector, and the separation required between sectors to allow frequency reuse.

The mitigation techniques for service compatibility include:

• frequency planning,
• geographical separation
• power control.
POTENTIAL DUPLEXING (sharing BW/Time between tx and rx) SOLUTIONS

<table>
<thead>
<tr>
<th>Duplex Types</th>
<th>Satellite</th>
<th>Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Division Duplex</td>
<td>diplexer</td>
<td>diplexer</td>
</tr>
<tr>
<td>Half-duplex FDD</td>
<td>diplexer</td>
<td>switch</td>
</tr>
<tr>
<td>Time Division Duplex</td>
<td>switch</td>
<td>switch</td>
</tr>
</tbody>
</table>

**Diagram:**
- **Diplexer**
  - Feed
  - OMT
  - Rx Filter
  - Tx Filter
- **Switch**
  - Rx Filter
  - Tx Filter
ACCESS AND SHARING MECHANISMS MAY PRESENT SEVERAL OPERATIONAL SOLUTIONS

Sharing FDD and TDD in the available BW simplyfing sat diplexing

**BW**

MIXED

- FDD up
- TDD
- FDD down

5030 MHz — 5091 MHz

SATELLITE BW’s

**TIME**

5-20 ms

TDD

ALL TDD

TDMA up

FDMA down

TDD but with different channel access mechanisms TDMA for UE Tx and FDMA for sat and GS tx

**LET’S CONSIDER THAT TRAFFIC IS ASYMMETRIC !**

**TRAFFIC TYPOLOGIES**

- Broadcast/Multicast
- Signalling
- Sporadic
- Normal
IMPORTANT ISSUES FOR UAV COMMUNICATIONS

Availability
Measures against asset denial. It includes detection of interference and attacks (dynamic power control narrow channels, dynamic frequency selection, frequency hopping, etc)

Integrity and Confidentiality by authentication and cryptography

In today’s telecommunication environment, marked by various threats, jamming, unauthorised transmission monitoring / eavesdropping, misuse of the existing communication networks and outright theft of the identity of the parties involved in communications and of the information they exchange, there is an ever increasing need to protect the security of the communications

Potential counter measurement to improve integrity:

• Authentication
• Cryptography
• Improvement of link power budget
• Time diversity (only if separate tx are statistically independent)
• Space diversity (ie multiple antennas, to avoid blockage or multipath)
• Frequency diversity (with independent fading mechanism ie L+C)
QUALITY of SERVICE

Quality of service should be adaptive to the difference classes of services and to the environment characteristics. It includes:

• QoS adaptation due to interference → ACM (Adaptive Code Modulation)
• Support traffic priorities and maximize spectrum utilization
• Support different class of traffic
• Reliability mechanisms at data link layer
• Dynamic BW allocation → DAMA (On DEMAND ASSIGNMENT MULTIPLE ACCESS)
• Provide statistics (optional)

Demand Assigned Multiple Access (DAMA) is a technology used to assign a channel to clients that don’t need to use it constantly. DAMA systems assign communication channels based on requests issued from user terminal to a network control system. When the circuit is no longer in use, the channels are then returned to the central pool for reassignment to other users. Not to confuse with Multiple Access mechanism like TDMA.
The loss of a data link must be addressed by a link-loss procedure. It is important that the aircraft always operates in a predictable manner. From the survey, it was revealed that the most common link-loss procedure is for the aircraft to fly to a predefined location. Once at the predefined location, the UAS can either loiter until the link is restored, it can autonomously land, or it can be remotely piloted via secondary data link.

For additional secure communication proof one approach is for the UAV to acknowledge or echo all commands it receives. This will ensure the pilot-in-command that all commands sent are received and acknowledged. Such an approach will also notify the pilot in control if the aircraft receives commands from an unauthorized entity. In case the commands can be simultaneously received from both BLOS and LOS links an a priority setting will define priorities.
SATELLITE for C–Band communications

C-Band 6 meters antenna diamer with 40 beams
Ku/Ka antenna for feeder link communications
UAV TERMINAL CONFIGURATION

- LNA
- PA
- Filters
- Diplexer

Signal conditioning/AGC
UP/Down conversion
Filtering
ADC/DAC

UAV FUNCTIONAL BLOCK DIAGRAM
Conclusions

• UAV communication in the C-band can be a good opportunity to conceive an integrated satellite and ground communication system since the beginning embedded with high degree of safety, availability and integrity.

• The solution should take in considerations several constraints coming from frequency spectrum, interference, geography, international & national rules and stds.

• The availability of certified data links is essential to operate UAV in non segregated areas ie leave them to operate in civil aviation traffic.