ISTITUTO ITALIANO DI NAVIGAZIONE
GRUPPO TEMATICO-TRASPORTO AEREO

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

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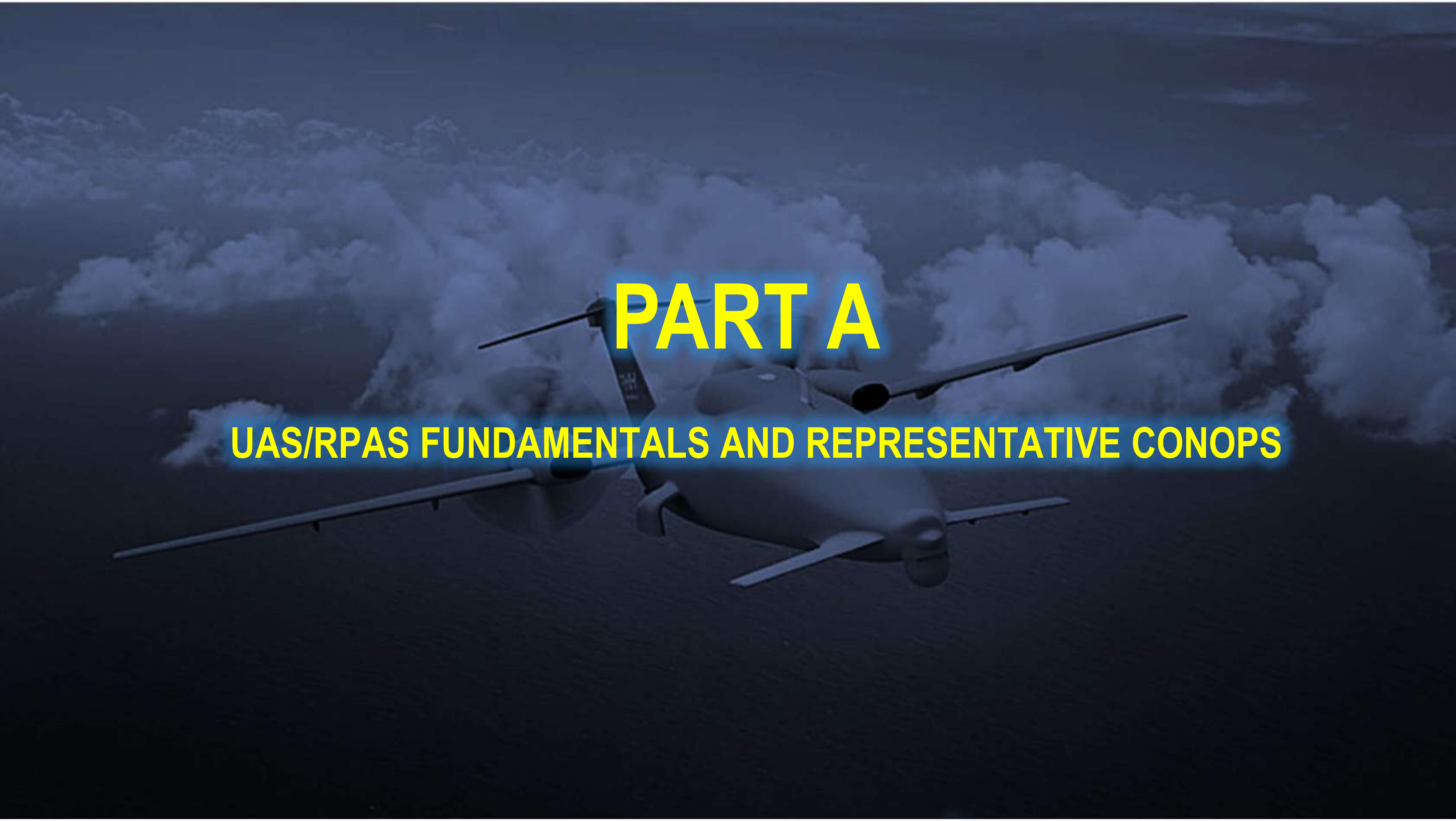


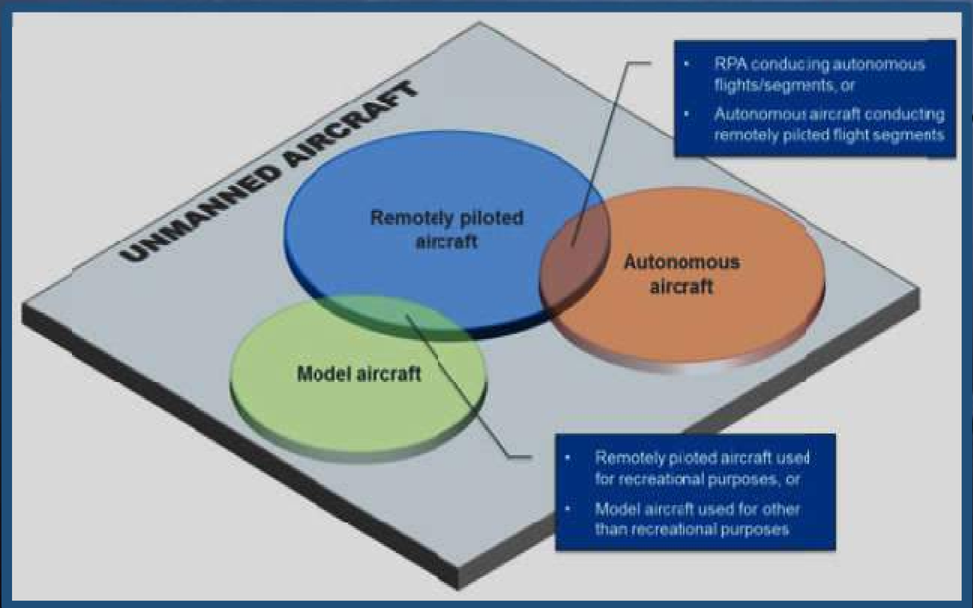
PART A

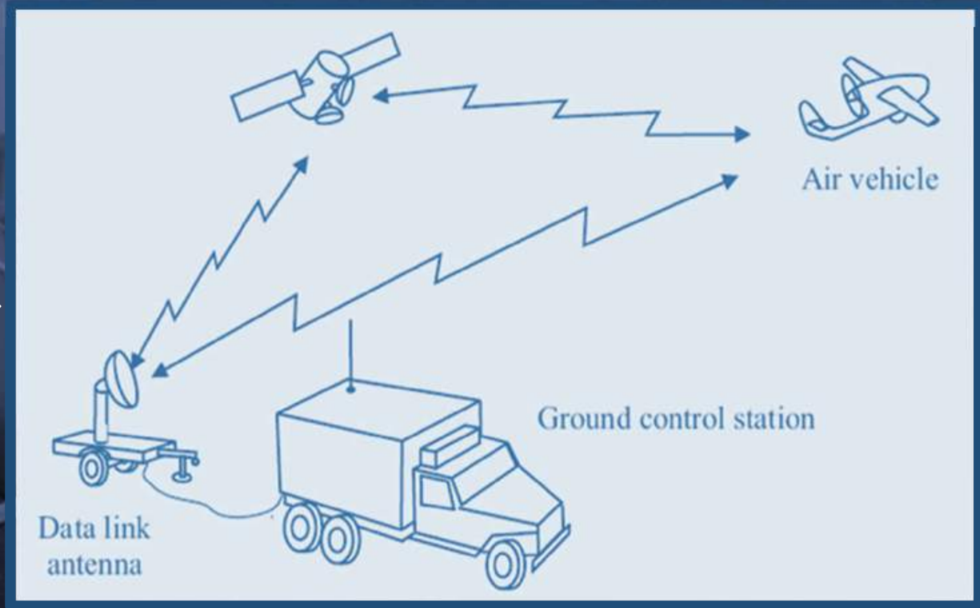
UAS/RPAS FUNDAMENTALS AND REPRESENTATIVE CONOPS

A.1 UAS/RPAS BasicsBasics-Functional, Operational Definitions and Terminology

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

FIXED WING

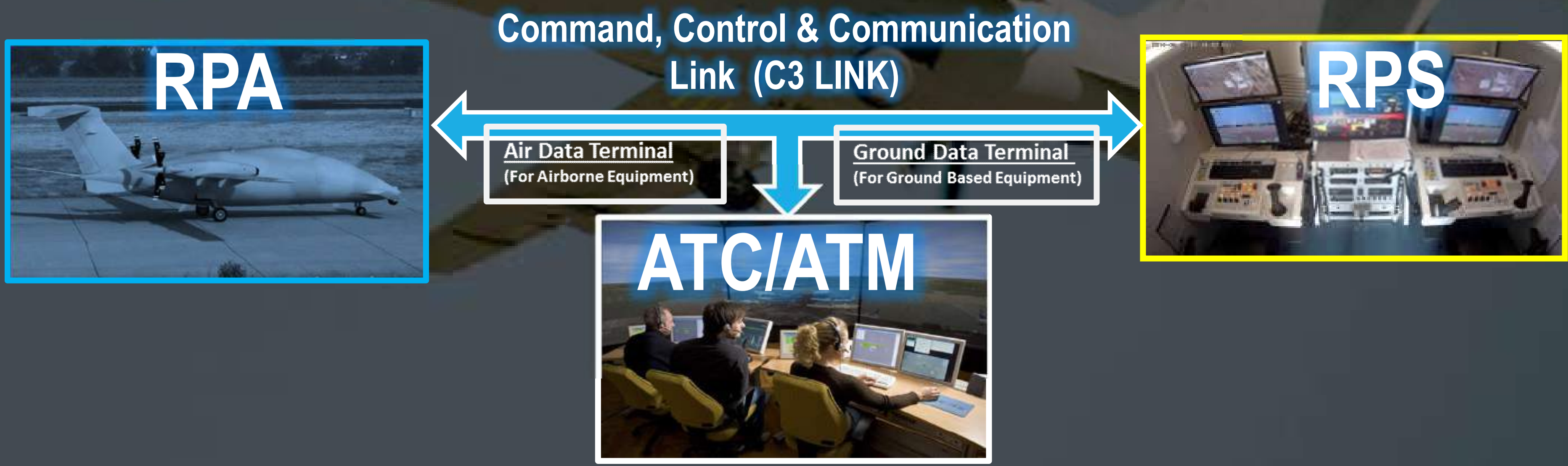
ROTARY WING

HYBRID ROTORCRAFT
(TILT ROTOR)

AIRSHIPS

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

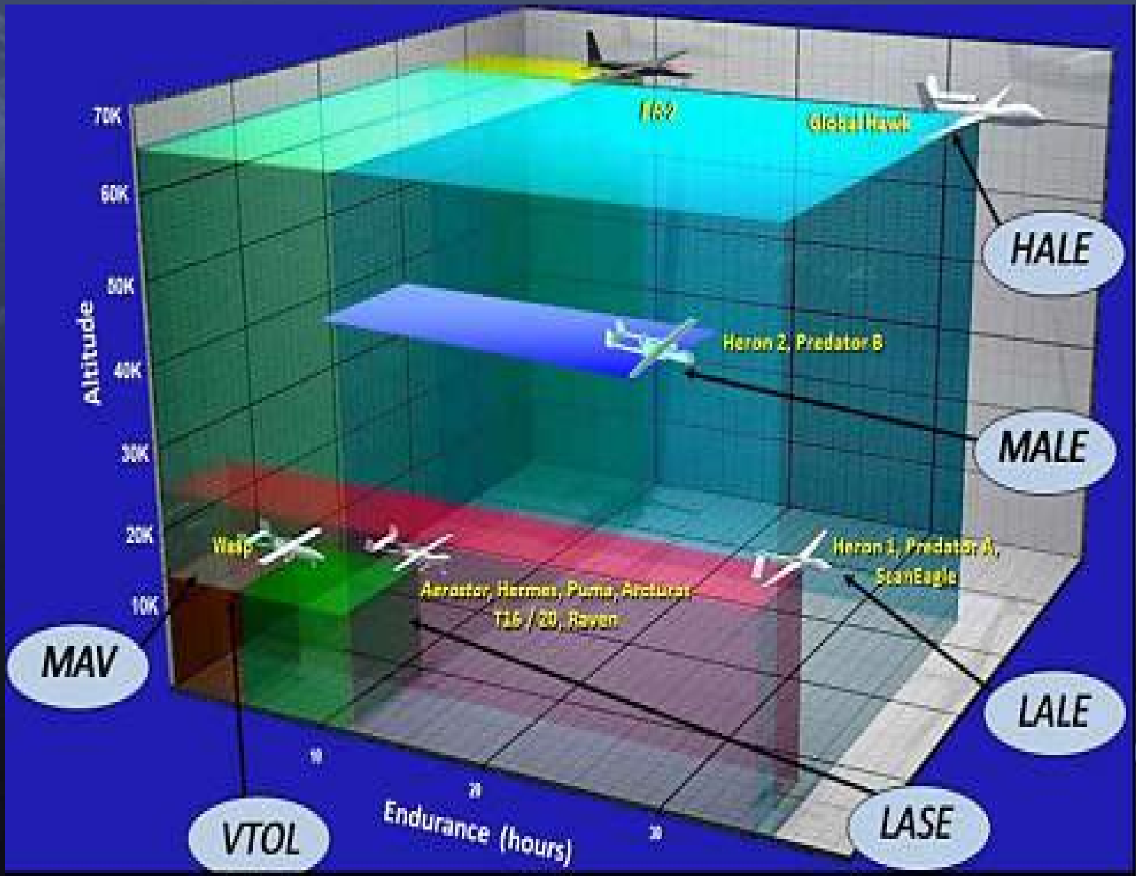
A.2 UAS/ RPAS Categorization, Missions and Airspace Class Insertion Overview

Typical Unmanned Aircraft Systems (UAS) Categorization by MGTW and Operational Performance

CATEGORY	SIZE	MGTW* (Kg)	N.O.A.** m / Mission Radius (km)	AIRSPEED (Knots)	TYPICAL UAS/RPAS
GROUP 1	Nano	< 1	< 120 AGL*** / 1.6	<50	
GROUP 2	Micro	1-5	<1000 AGL / < 8	<100	
GROUP 3	Small	6-55	<3500 AGL / < 40	<100	
GROUP 4	Light	56-150	<5.500 MSL**** / < 1.000	>100	
GROUPS Considered for the Preliminary CT-RPAS CONOPS Study					
GROUP 5	Medium	>150 – 5.000	>5.500 MSL / < 3.000	Min. 80 KTAS Max. 400 KTAS	
GROUP 6	Large	>5.000	>5.500 MSL / > 3.000	Any Airspeed	

* 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)



HALE=High Altitude Long Endurance
MALE=Medium Altitude Long Endurance
LALE = Low Altitude Long Endurance
LASE = Low Altitude Short Endurance
VTOL= Vertical Take-Off and Landing
MAV = Micro Air Vehicle

CLASS	TYPE OF FLIGHT	SEPARATION PROVIDED	TRAFFIC INFORMATION	RADIO COMMs REQUIRED	SUBJECT TO ATC CLEARANCE	SPEED LIMIT (kts) AND ALTITUDE(ft)
A	IFR	IFR/IFR	YES	YES 2-WAY	YES	Not applicable 18,000-60,000 ft
B	IFR VFR	IFR/IFR IFR/VFR VFR/IFR VFR/VFR	YES YES	YES 2-WAY YES 2-WAY	YES	Not applicable Not applicable 0-10,000 ft
C	IFR VFR	IFR/IFR IFR/VFR VFR/IFR	YES VFR/VFR	YES 2-WAY YES 2-WAY	YES	250kts below 10000ft 250kts below 10000ft 0-10,000 ft
D	IFR VFR	IFR/IFR NIL	IFR/VFR VFR/IFR VFR/VFR	YES 2-WAY YES 2-WAY	YES	250kts below 10000ft 250kts below 10000ft 0-2,500 ft
E	IFR VFR	IFR/IFR NIL	YES As far as practical	YES 2-WAY NO	YES NO	250kts below 10000ft 250kts below 10000ft All undefined airspace below 18,000 ft, everything above 60,000 ft
G	IFR VFR	NIL NIL	Flight information Services	YES 2-WAY NO	NO NO	250kts below 10000ft 250kts below 10000ft 0-1200 ft up or 1200ft over mountain peaks

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

Airspace classes

Types of flight	A	B	C	D	E	F	G
IFR/IFR separation	ATC	ATC	ATC	ATC	ATC	UAS_{ATC}	UAS_{ATC}
IFR/VFR separation		ATC	ATC	UAS_{ATC}	UAS_{ATC} UAS	UAS	UAS
VFR/VFR separation		ATC	UAS_{ATC}	UAS_{ATC}	UAS_{ATC} UAS	UAS	UAS
ALL collision avoidance	UAS	UAS	UAS	UAS	UAS	UAS	UAS

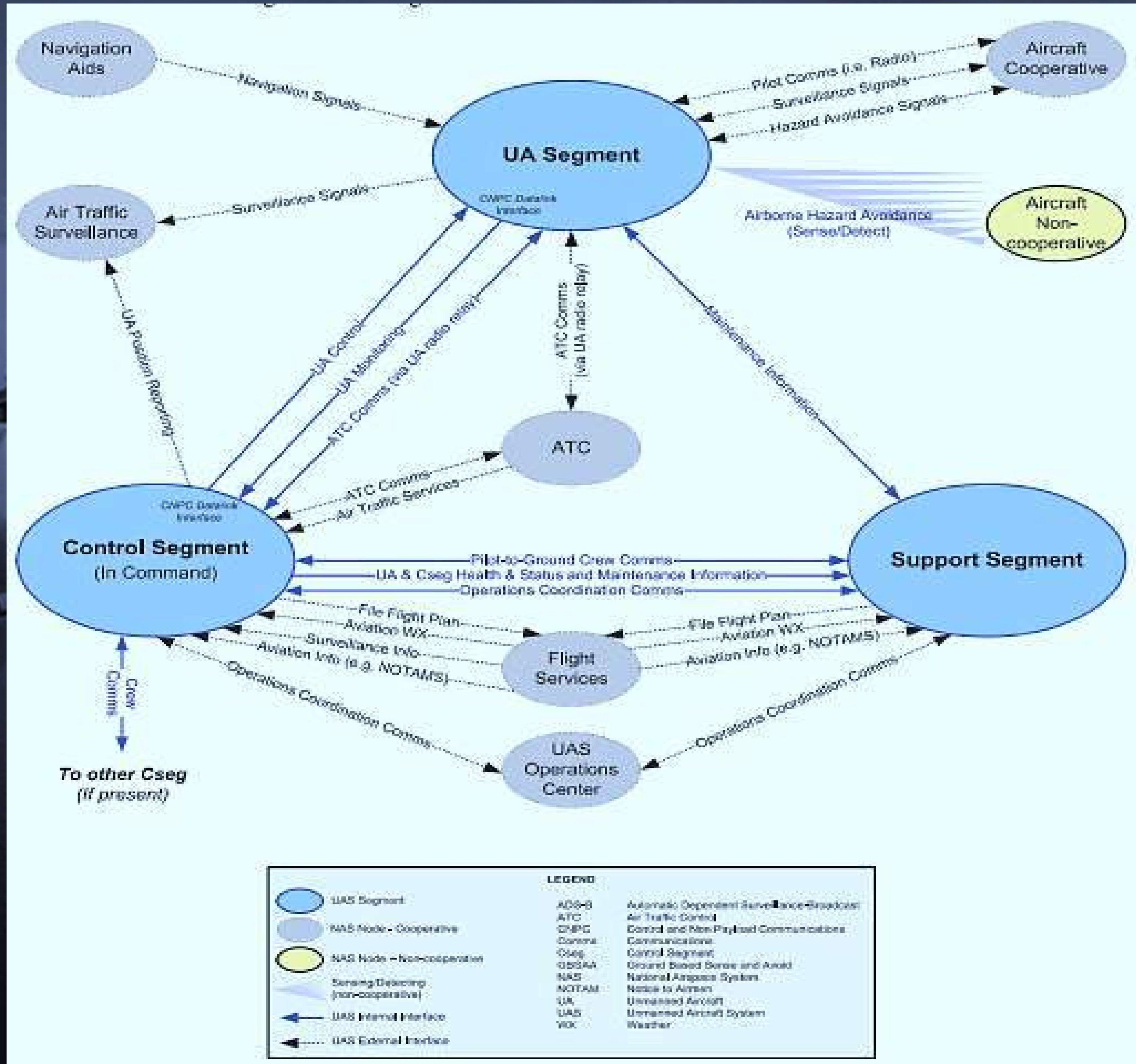
Controlled AS (A–E)
Uncontrolled AS (F–G)

Source : ICONUS, SESAR JU Project, 2012

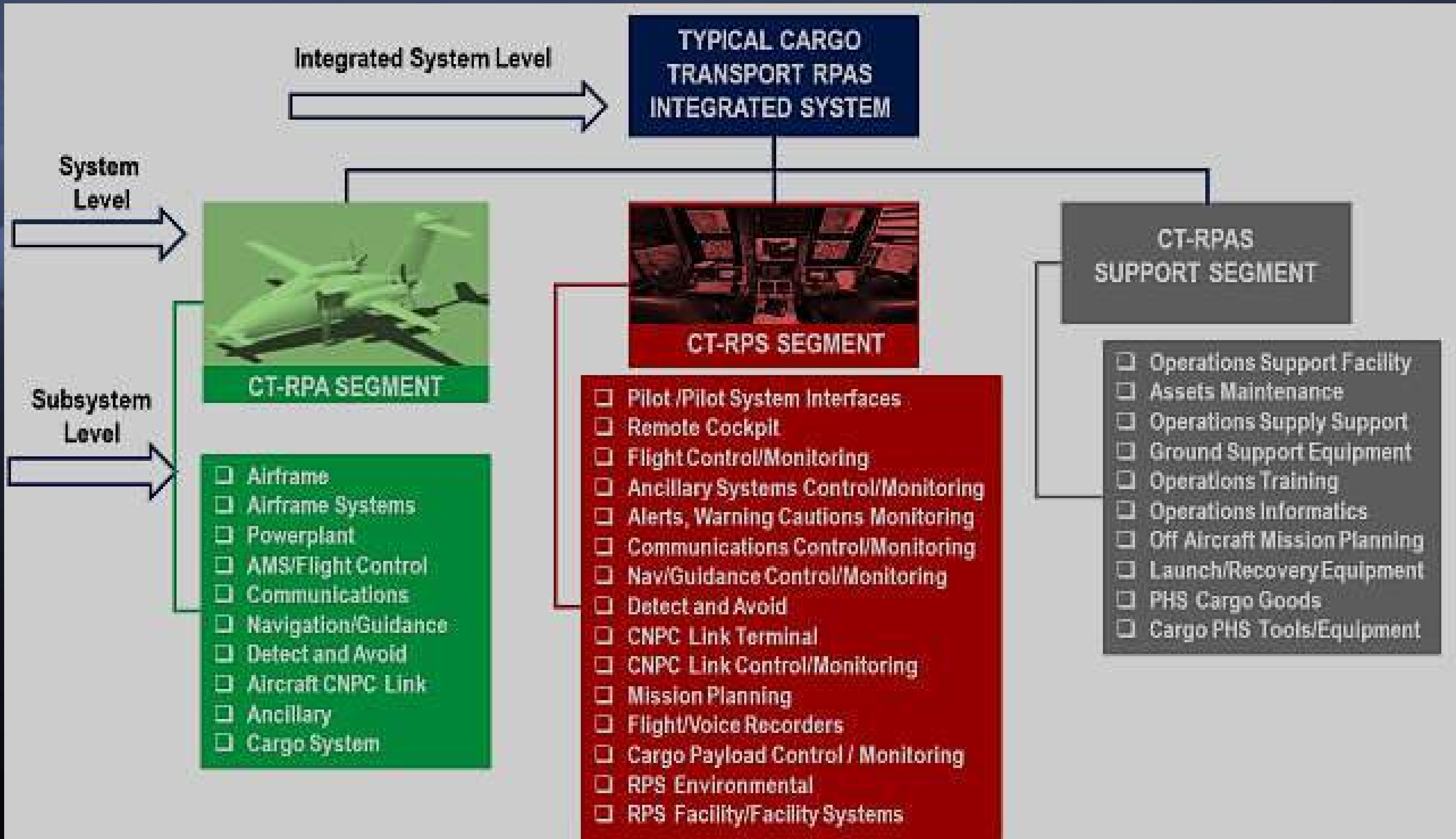
General Aviation Airport Categories (ICAO ANNEX 14)	
Role	Description
National	Supports the national state system by providing access to national and international routes in multiple states. It provides Passenger and Cargo Services.
Regional	Supports regional economies by connecting communities to state markets. It provides Passenger and Cargo Services.
Local	Supplements communities by providing access to primarily state markets. It may also provide some cargo services.
Basic	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).
Unclassified	Provides access to the aviation system. It may include aerodromes with prepared and/or unprepared runways and/or minor airfields.

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

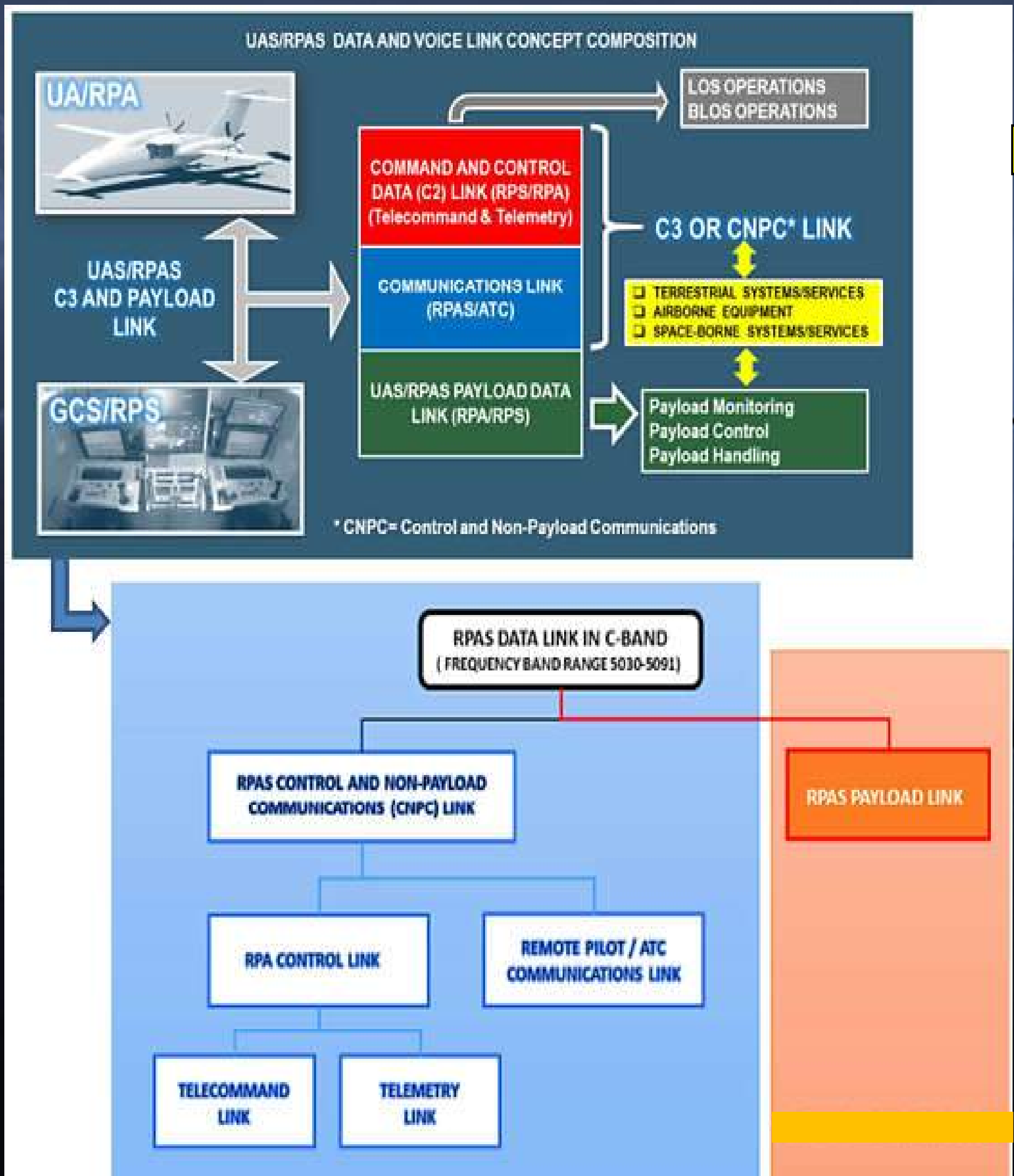


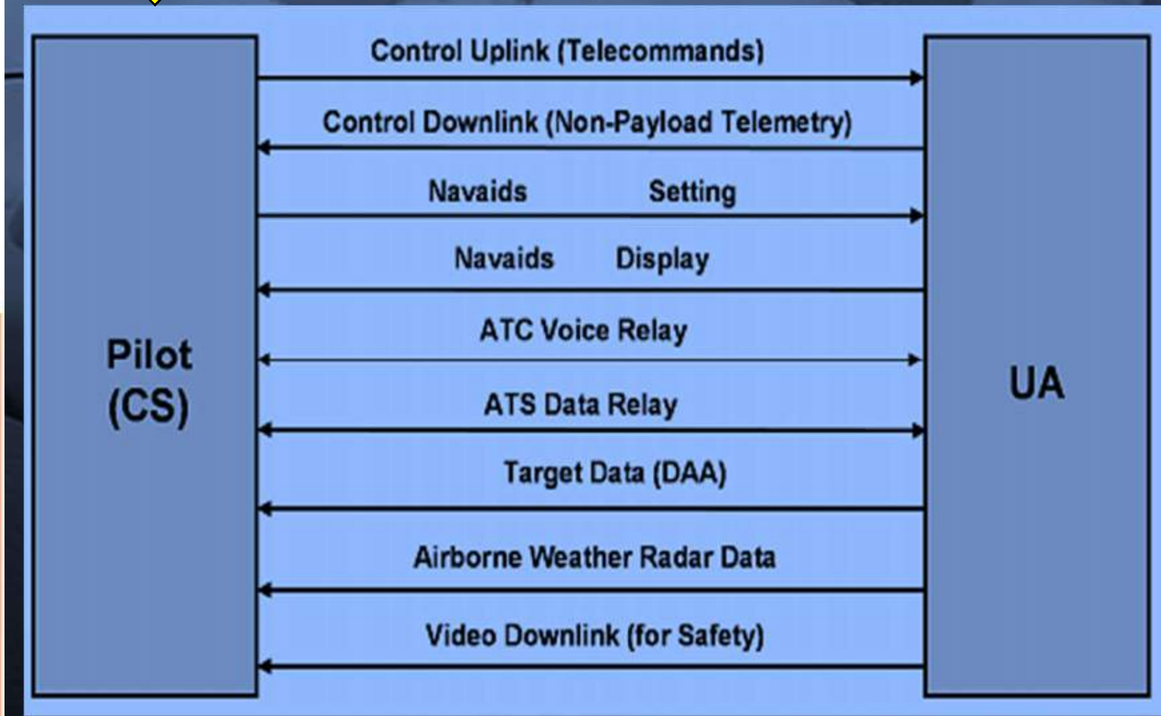
RPAS Remote Pilot Station (RPS) Typology

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

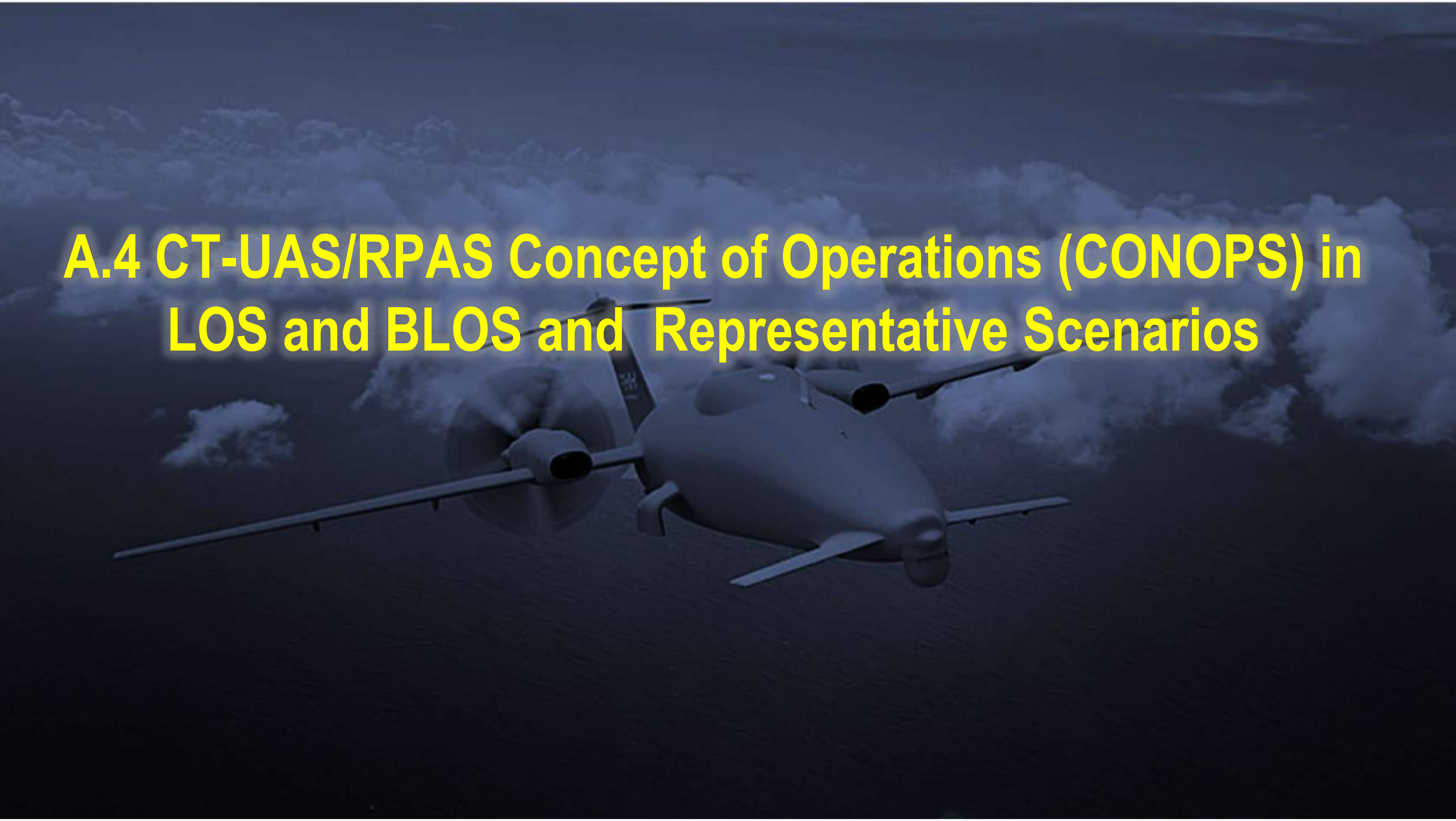
UAS/RPAS Data Links Classification and Operational Description Schematic





UAS/RPAS CNPC Information Flows between Pilot and UA Schematic (Source RTCA 228)

A.4 CT-UAS/RPAS Concept of Operations (CONOPS) in LOS and BLOS and Representative Scenarios



CT-RPAS CONOPS SCENARIOS MAIN PARAMETERS

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.

Cargo Transport RPAS CONOPS- Main Physical Operational Elements Definition

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

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

Function	Description
Communicate	Voice, data and light signal exchanges between ATC and the RPS to communicate instructions and responses
Control	Relates to the control link between the RPA and the RPS, and includes telemetry information confirming aircraft control status and health.
Navigate	Pertains to any reference cues used by the RPA or pilot to determine orientation.
Avoid	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.

Cargo Transport RPAS Required Operational Coverage Capability Issues

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.)

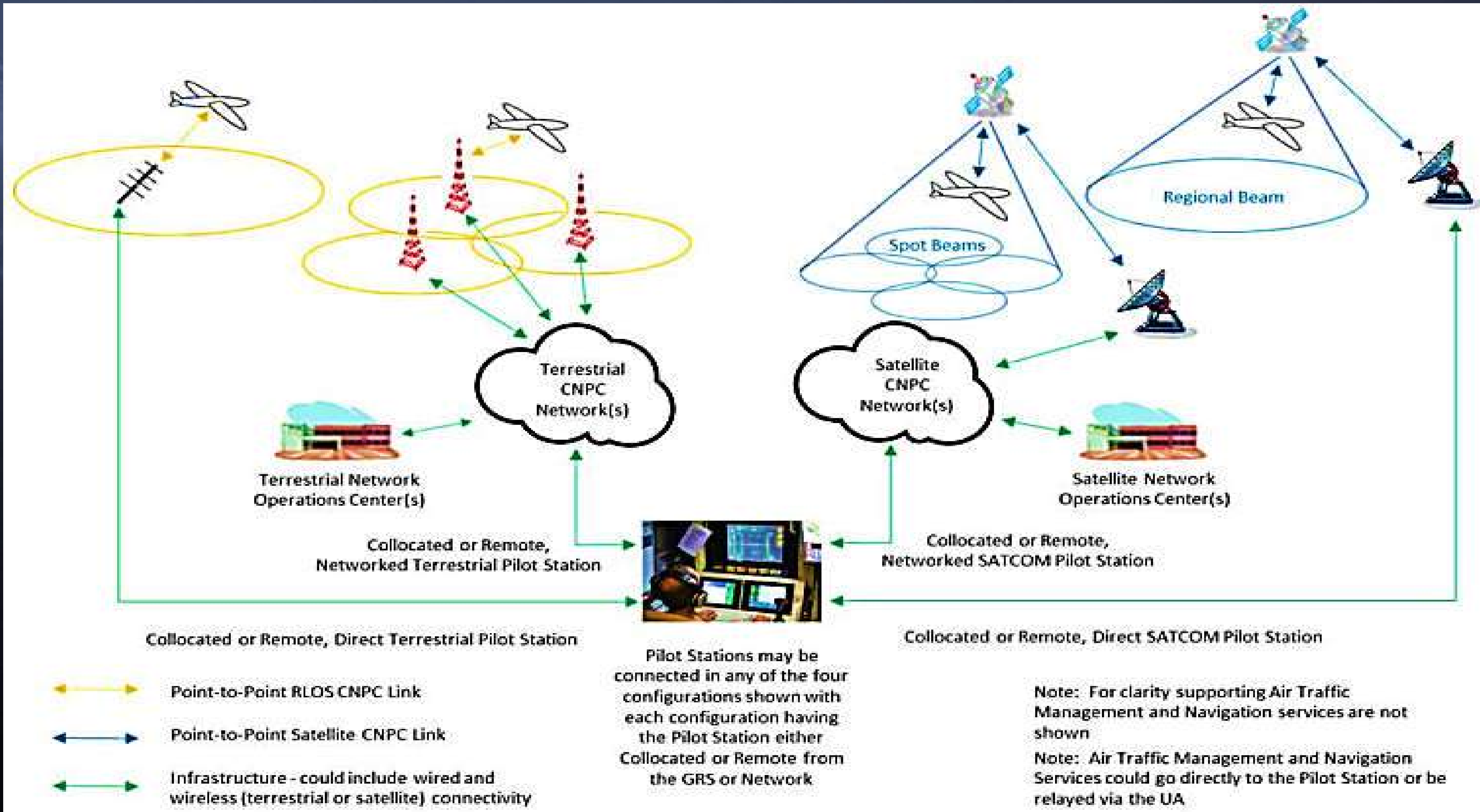
The key issue for the Cargo Transport RPAS operations at whatever of the above levels is to reassure aviation authorities that Air Cargo Flight by an RPAS flight within civilian air traffic will:

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



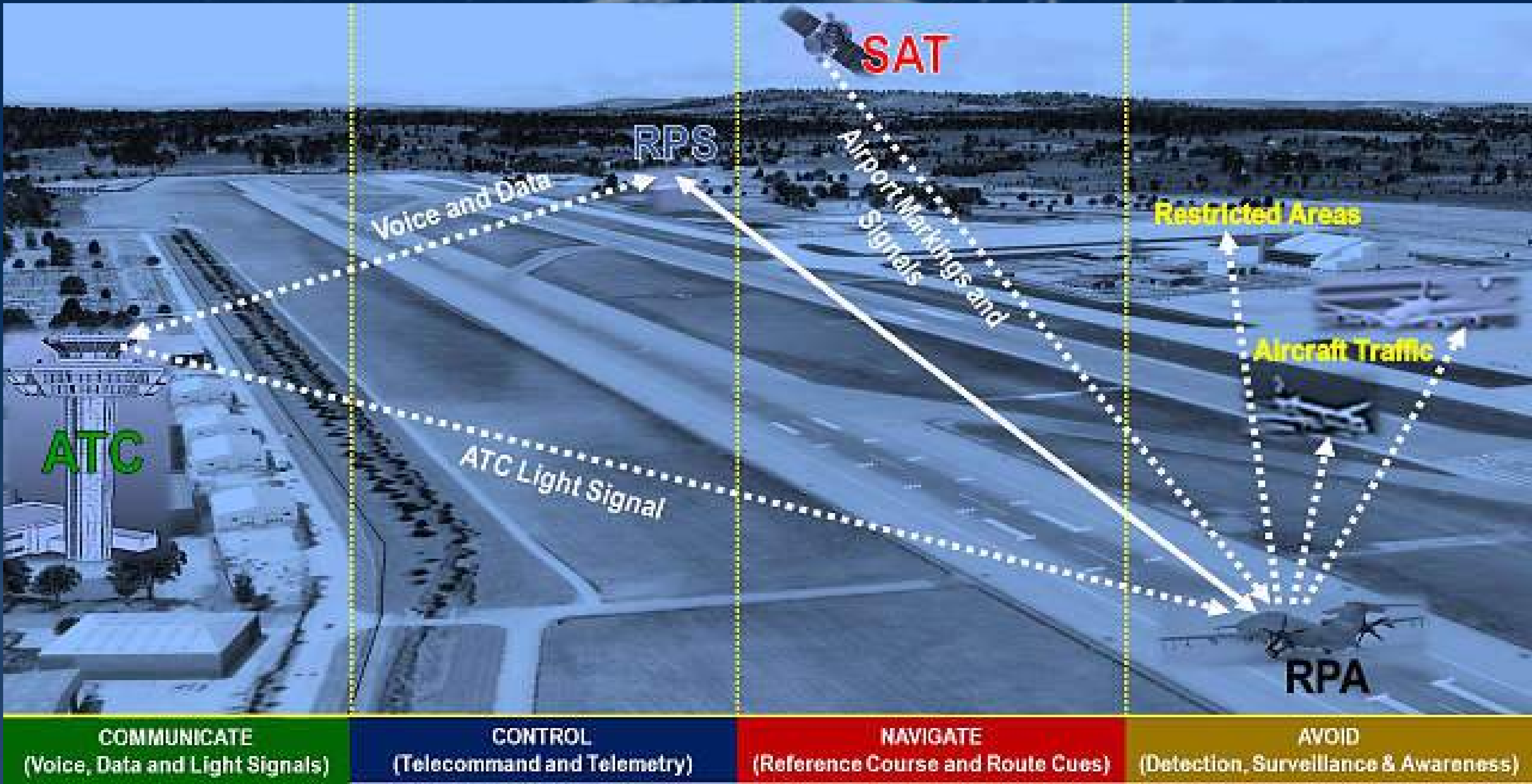
Various Examples of Fixed Wing Cargo Transport RPAS of over 150Kg. MGTW Payload Access Doors and Stores Configurations

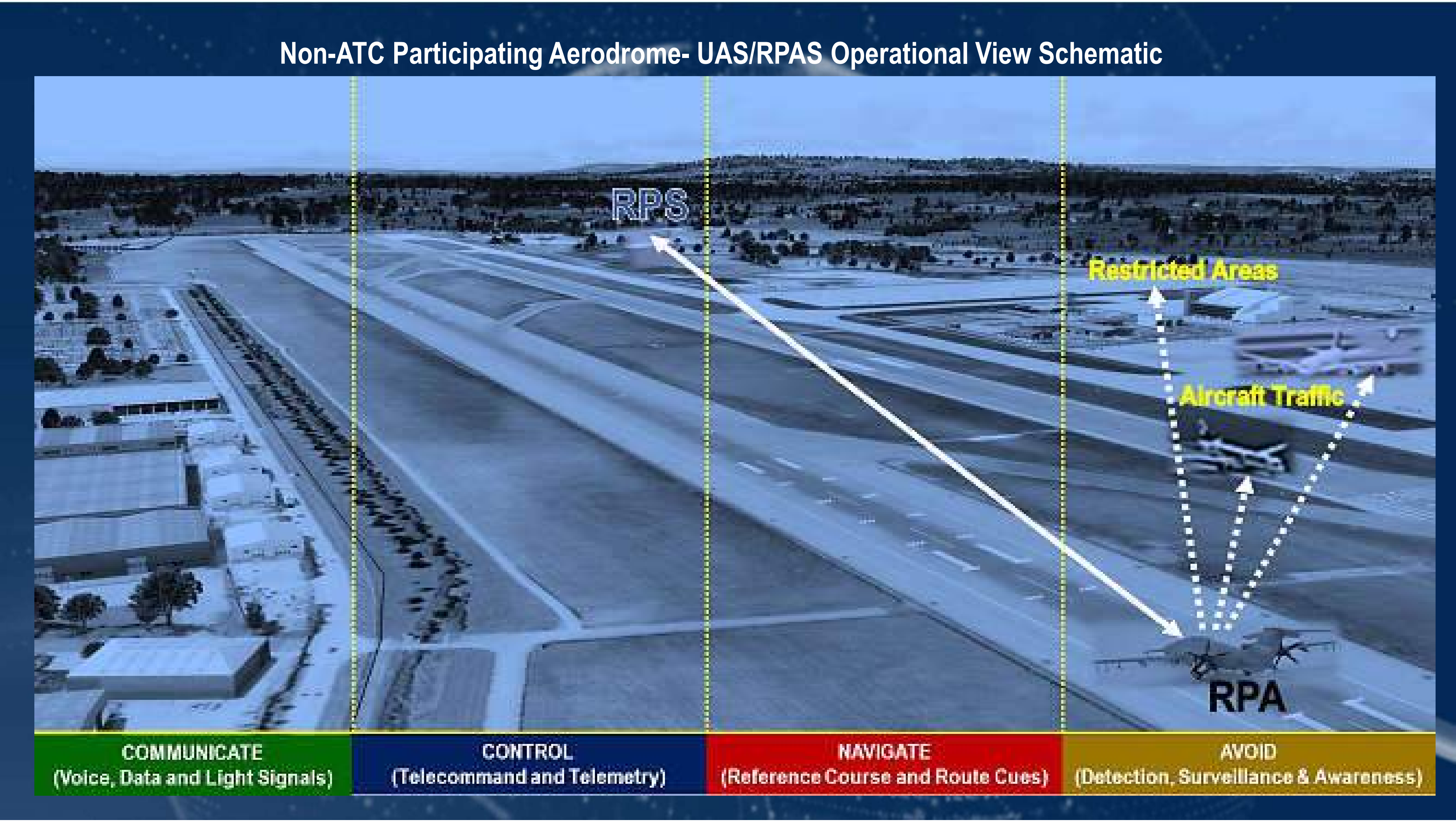
Cargo Transport RPA Configuration (Fixed Wing)		Operational Capability
1.Main Cargo and AFT Fuselage Ramp Access Doors		A CT-RPA in this type of configuration has full Cargo Air-Drop and Ramp to Ramp Delivery Operational Capability
2.Main Cargo Access Door (no Ramp)		A CT-RPA in this type of configuration will have only a Cargo Delivery Ramp to Ramp Operational Capability.
3.Single FWD and /or AFT Fuselage Ramp Cargo Door		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.
4.Multiple External Cargo Store (Fuselage/Wing Aerodynamically Shaped External Stores)		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.
5. Single Access Internal Cargo Store		A CT-RPA with an external (Pod) or internal cargo store has only Ramp to Ramp Delivery Operational Capability.
6. Low Fuselage Cargo Bay or Lower Fuselage Cargo Pod		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.

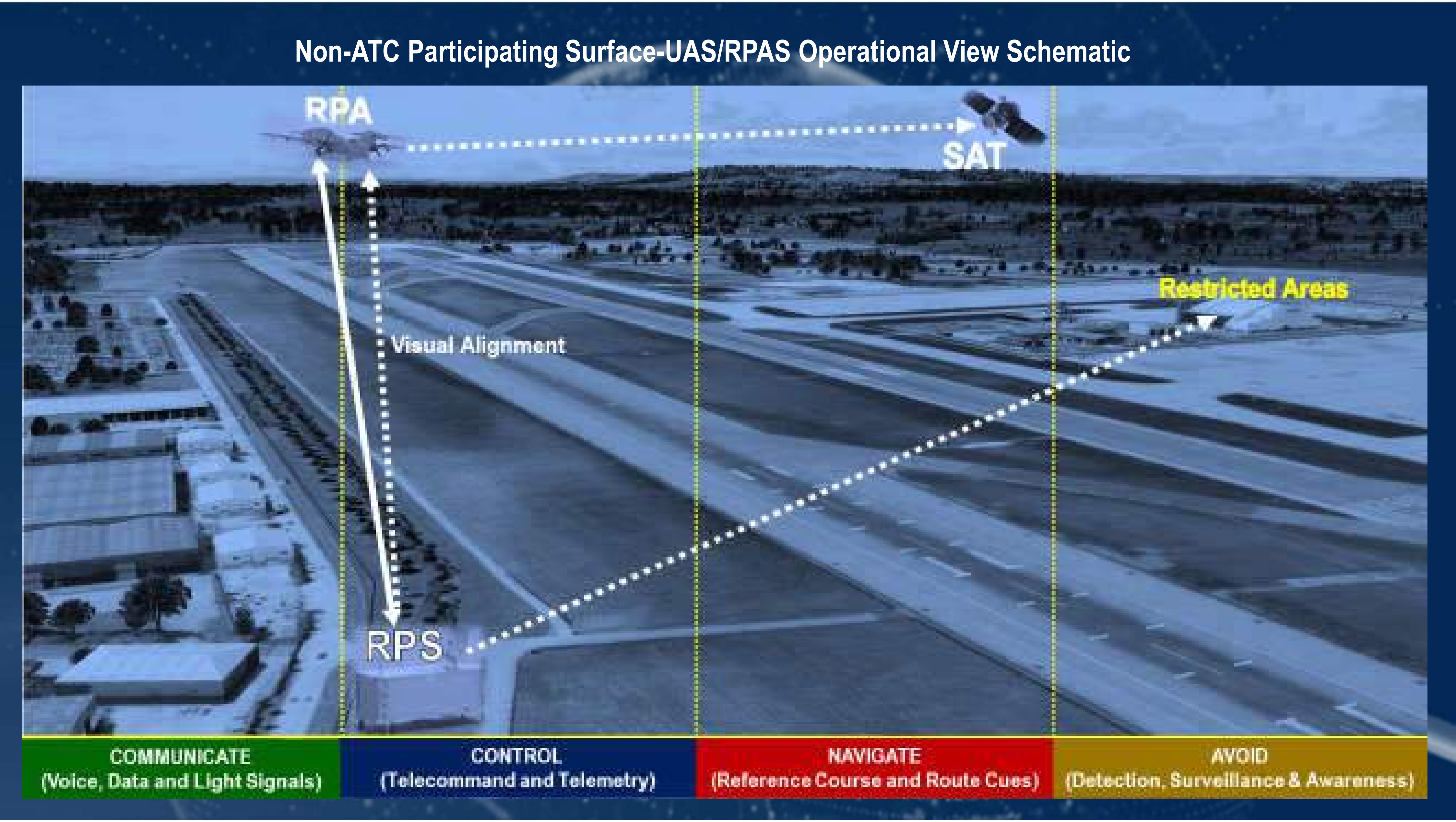
Total Medium and Large RPAs and CT-RPAs (in red) Operating Population Numbers and Densities that Need to be Supported during Operations

CAT.	RPA SIZE	No. OF OPERATING RPA IN NON-SEGREGATED AIRSPACE BY 2030 (60% OF THE TOTAL)	No. OF OPERATING CT- RPAs IN NON-SEGREGATED AIRSPACE BY 2030 (20% OF THE TOTAL OPERATING RPAs)	DENSITY OF ALL RPA/ Sq.Km	DENSITY OF CARGO TRANSPORT RPA/ Sq.Km	LOS SCENARIO FOR CARGO TRANSPORT RPAS	BLOS SCENARIO ALL RPA/CT-RPA PER SPOT BEAM (GEO-SAT WITH 40 SPOT BEAMS)
5	Medium	2028	406	0,000156	0,0000521	406/0,0000521	51/10
6	Large	837	167	0,000064	0,0000214	167/0,0000214	21/4

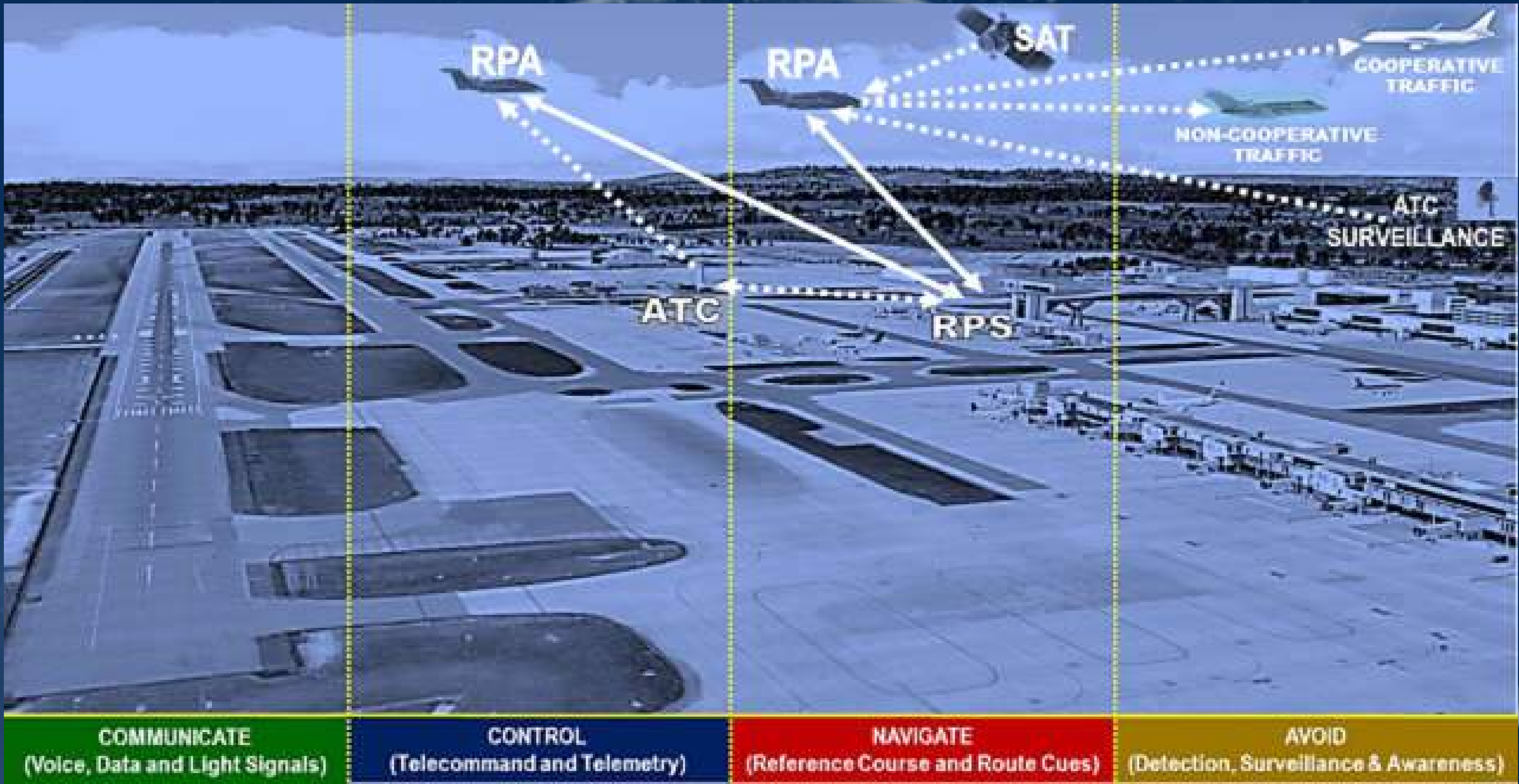
ATC Participating Aerodrome- UAS/RPAS Operational View Schematic

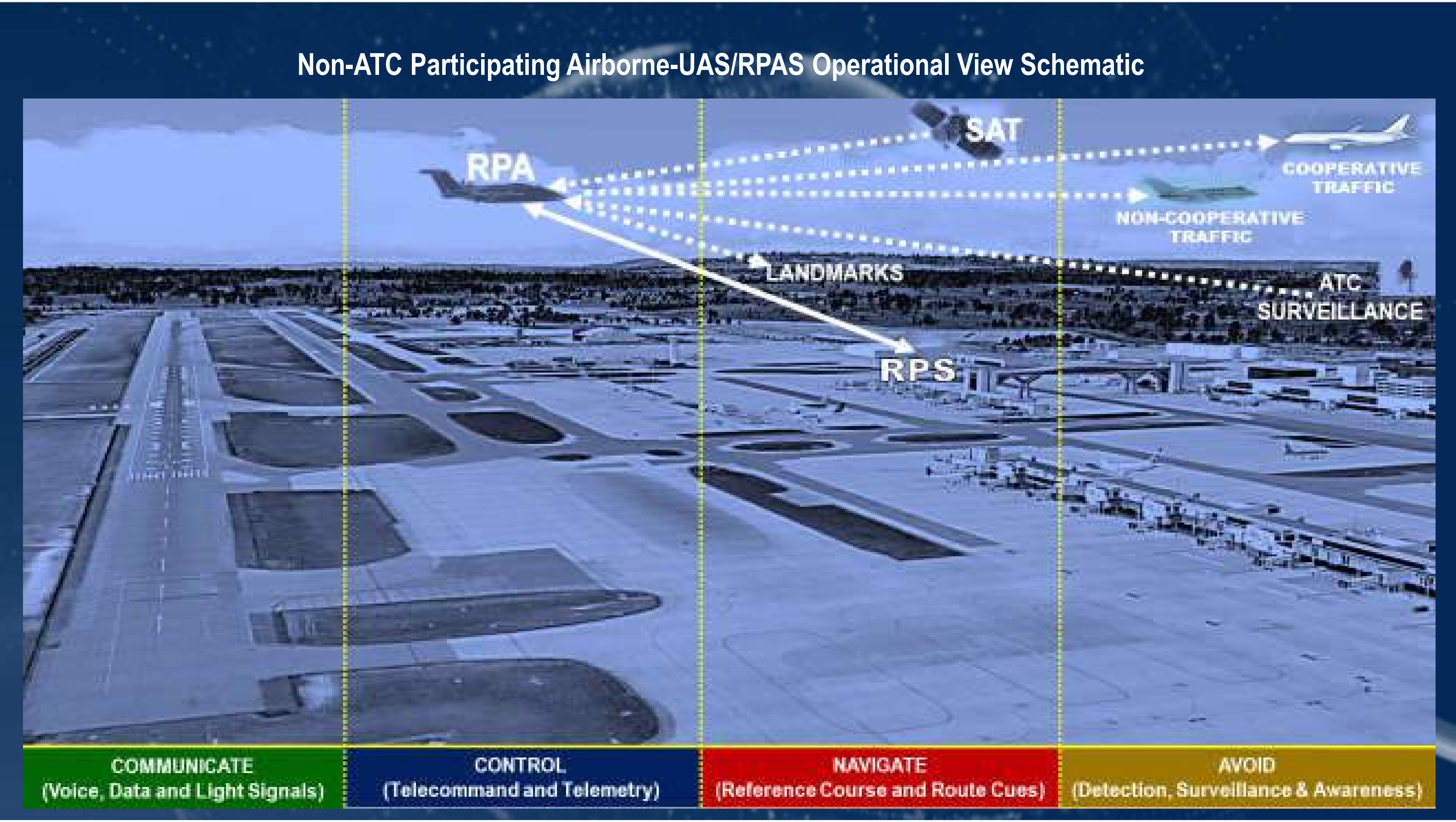


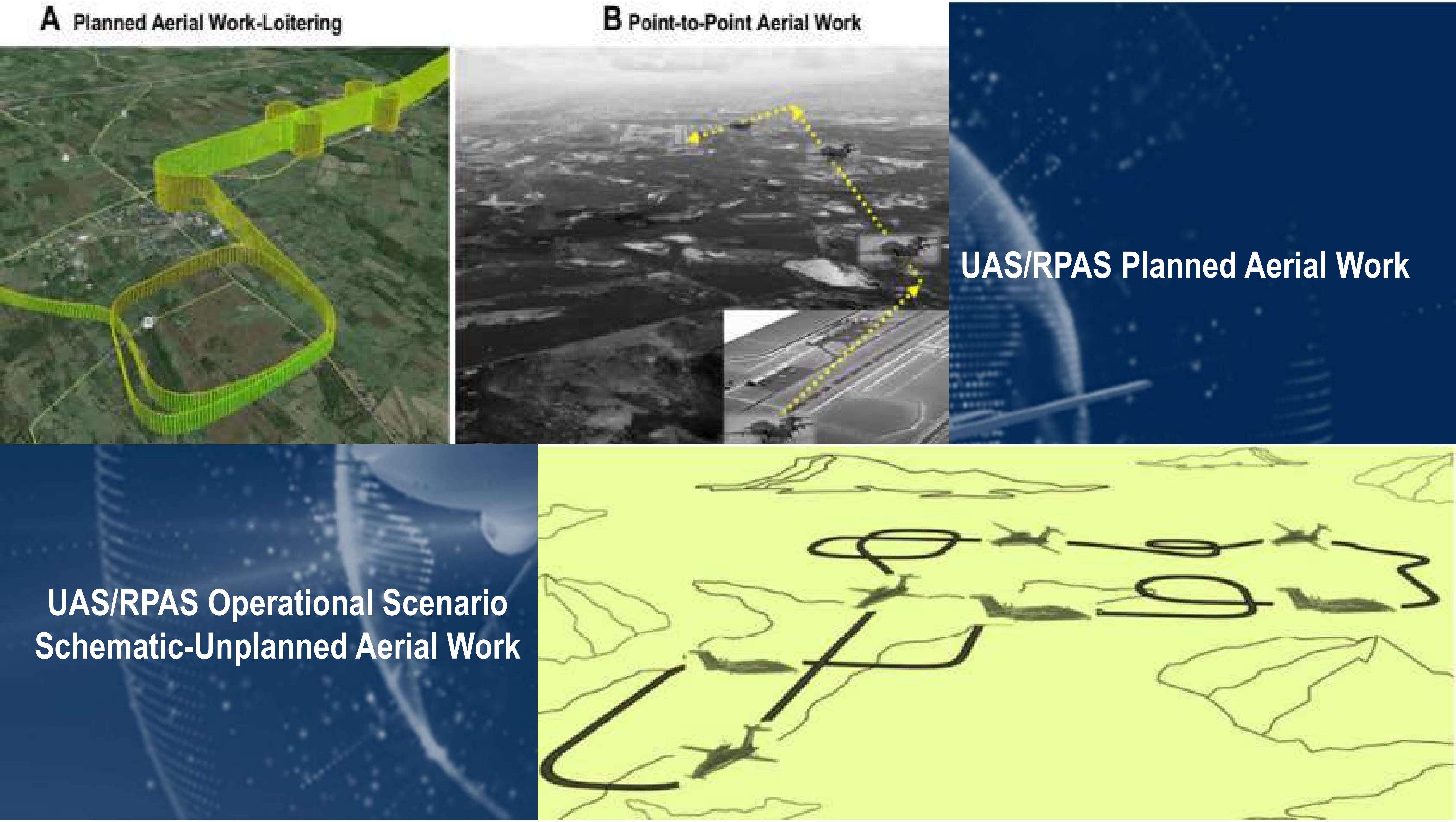

Non-ATC Participating Aerodrome- UAS/RPAS Operational View Schematic
RPS
Restricted Areas
Aircraft Traffic
RPA
COMMUNICATE
(Voice, Data and Light Signals)
CONTROL
(Telecommand and Telemetry)
NAVIGATE
(Reference Course and Route Cues)
AVOID
(Detection, Surveillance & Awareness)


Non-ATC Participating Surface-UAS/RPAS Operational View Schematic
RPA
SAT
Visual Alignment
Restricted Areas
RPS
COMMUNICATE
(Voice, Data and Light Signals)
CONTROL
(Telecommand and Telemetry)
NAVIGATE
(Reference Course and Route Cues)
AVOID
(Detection, Surveillance & Awareness)

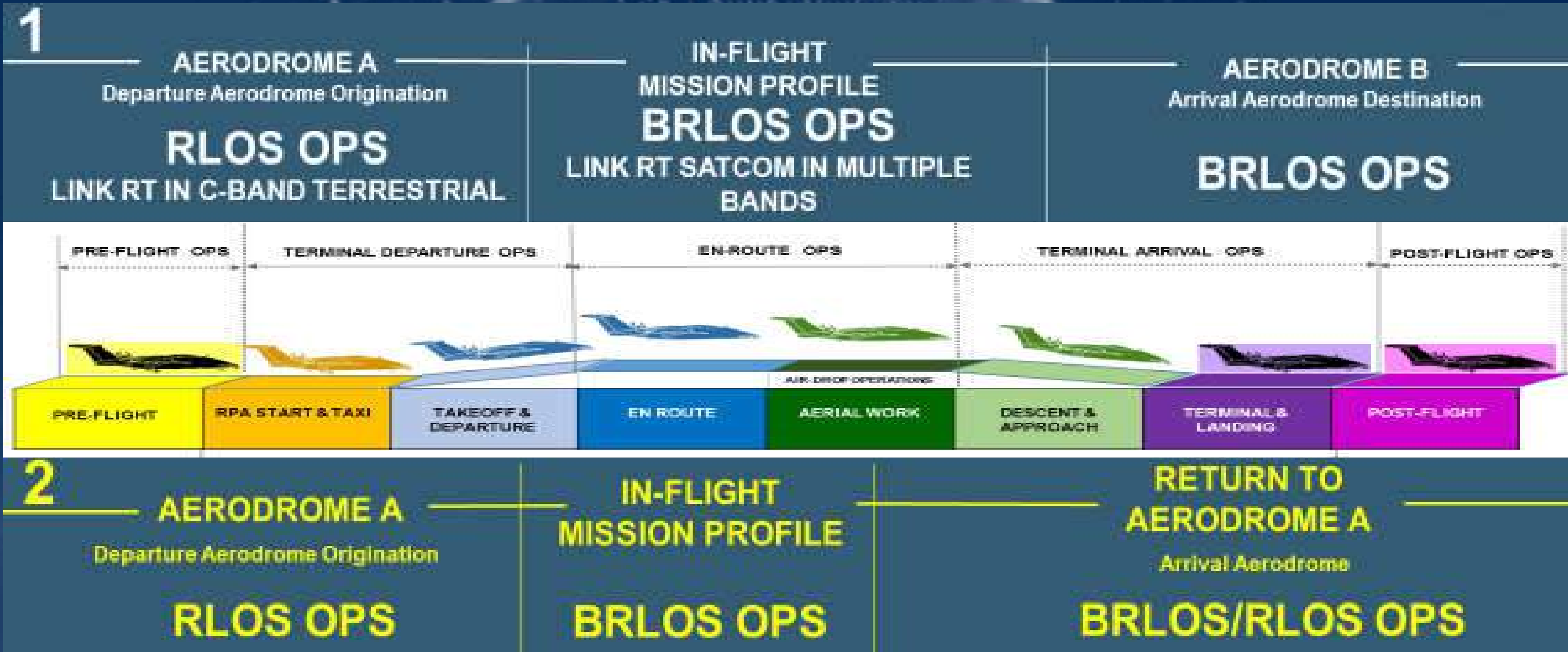
ATC Participating Airborne-UAS/RPAS Operational View Schematic



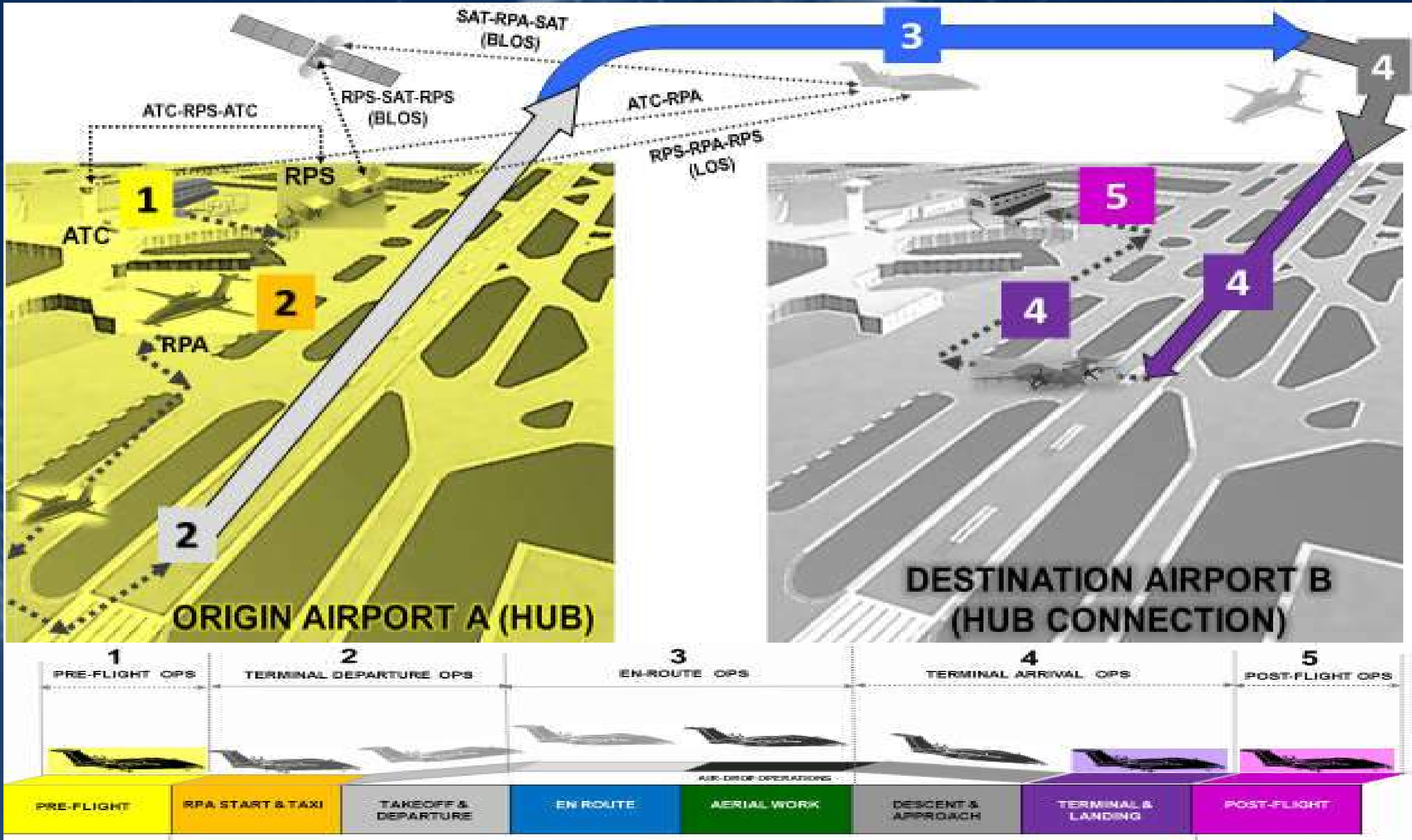

Non-ATC Participating Airborne-UAS/RPAS Operational View Schematic
RPA
SAT
COOPERATIVE TRAFFIC
NON-COOPERATIVE TRAFFIC
LANDMARKS
ATC SURVEILLANCE
RPS
COMMUNICATE (Voice, Data and Light Signals)
CONTROL (Telecommand and Telemetry)
NAVIGATE (Reference Course and Route Cues)
AVOID (Detection, Surveillance & Awareness)


A Planned Aerial Work-Loitering
B Point-to-Point Aerial Work
UAS/RPAS Planned Aerial Work
UAS/RPAS Operational Scenario
Schematic-Unplanned Aerial Work

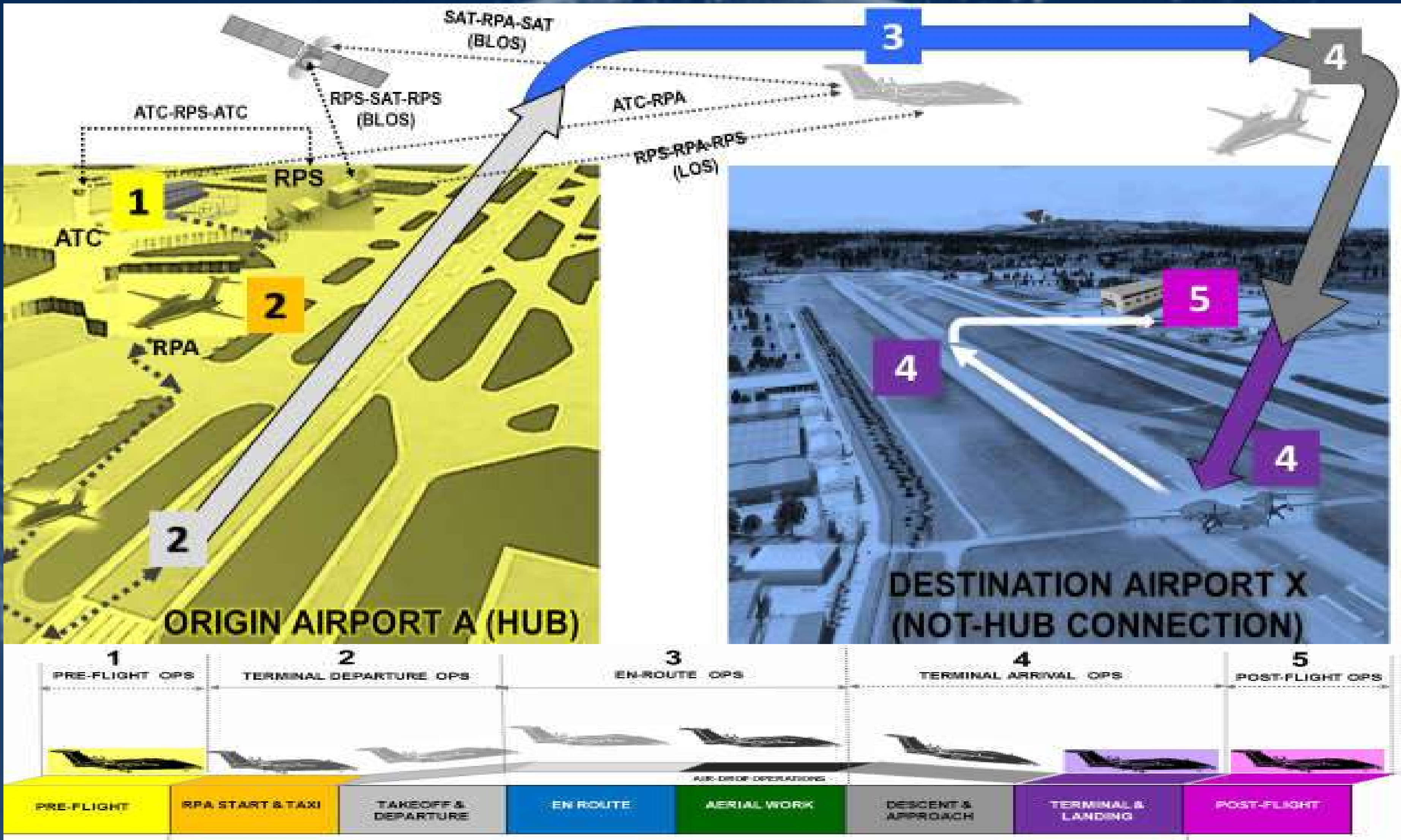
UAS/RPAS Operational Scenario and Modes
1) in Point-to-Point Aerial Work and 2) Planned Aerial Work



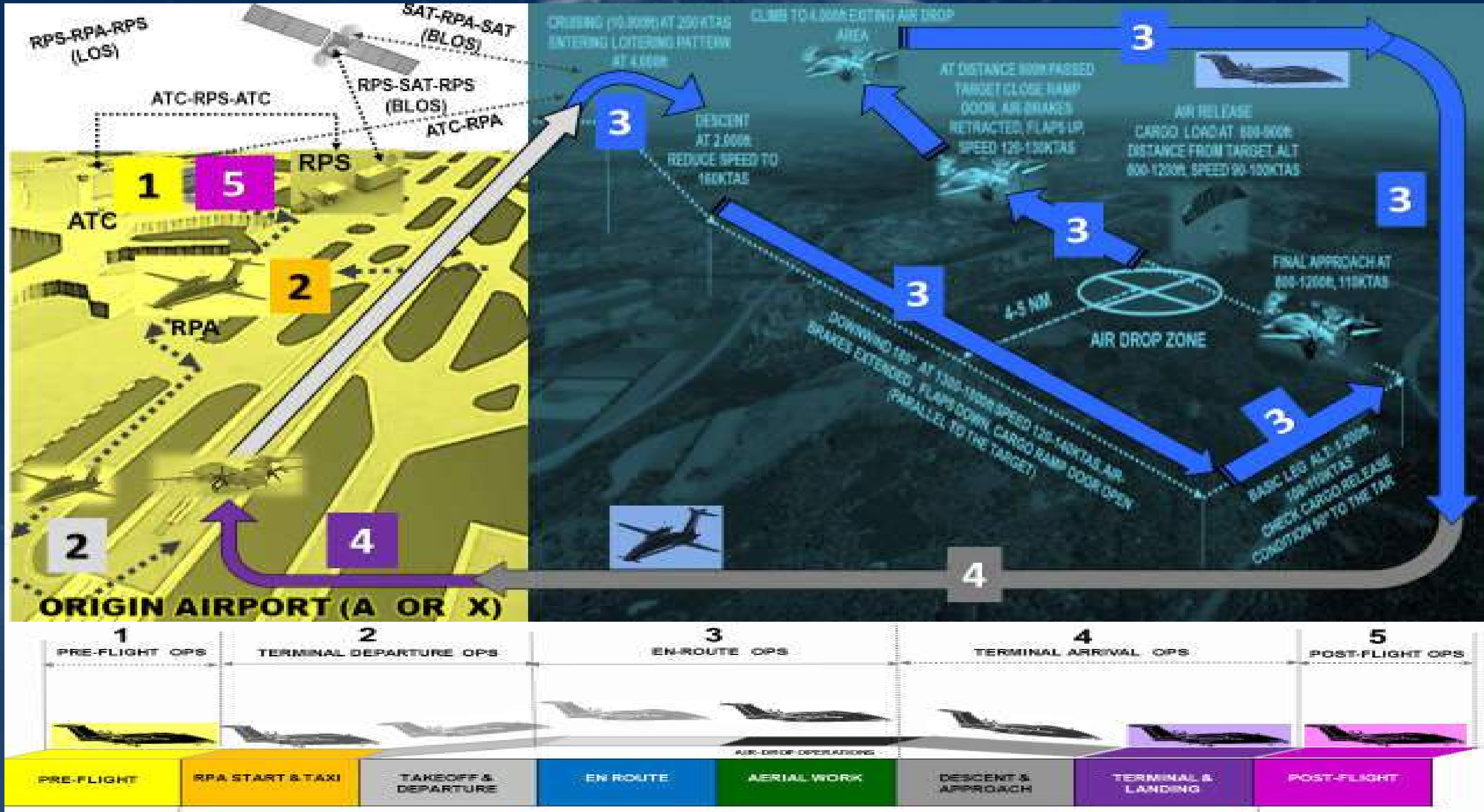
Example of an UA/RPA Cargo Transport Mission from Hub (Airport A) to Hub Connection (Airport B) Representative Scenario (ATC-Participating)



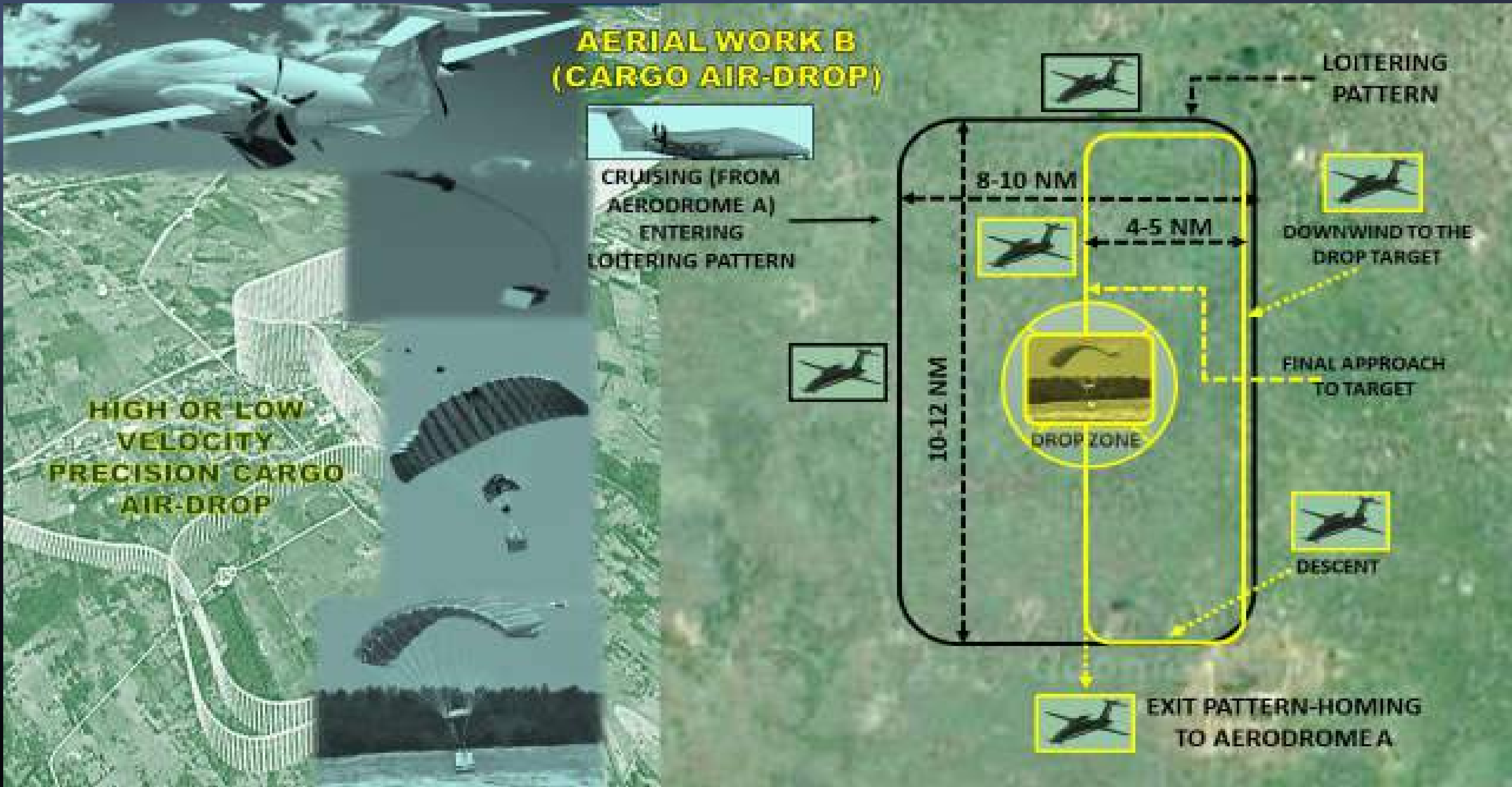
Example Cargo Delivery Scenario from Hub (Airport A) to not-Hub Connection (Airport X) and not-Hub (Airport X) to Hub Connection (Airport A) CONOPS Representative Scenario



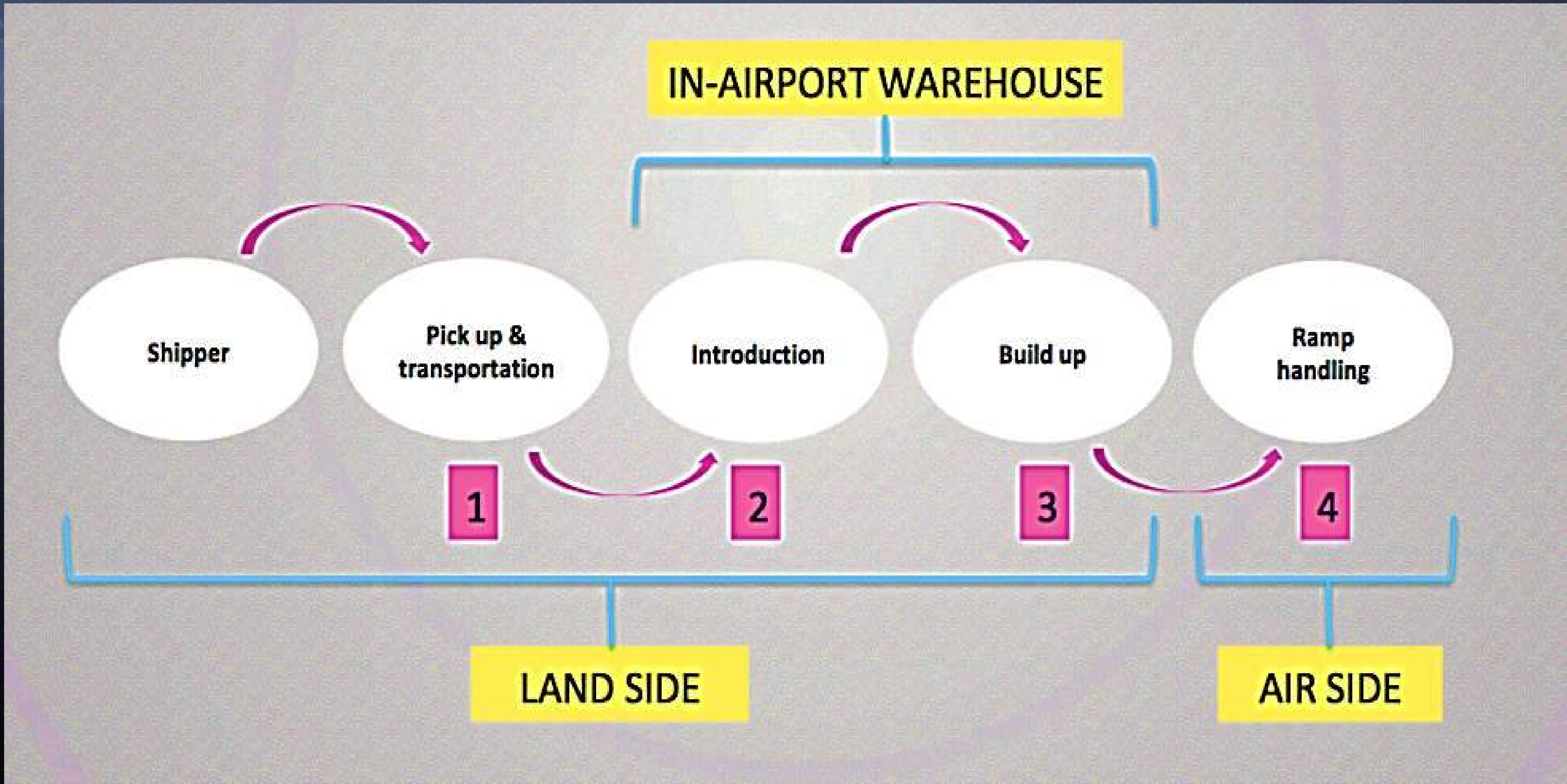
Cargo Emergency Delivery from Hub (Airport A)/not-hub (Airport X) to Air Drop Zone(s) CONOPS Representative Scenario



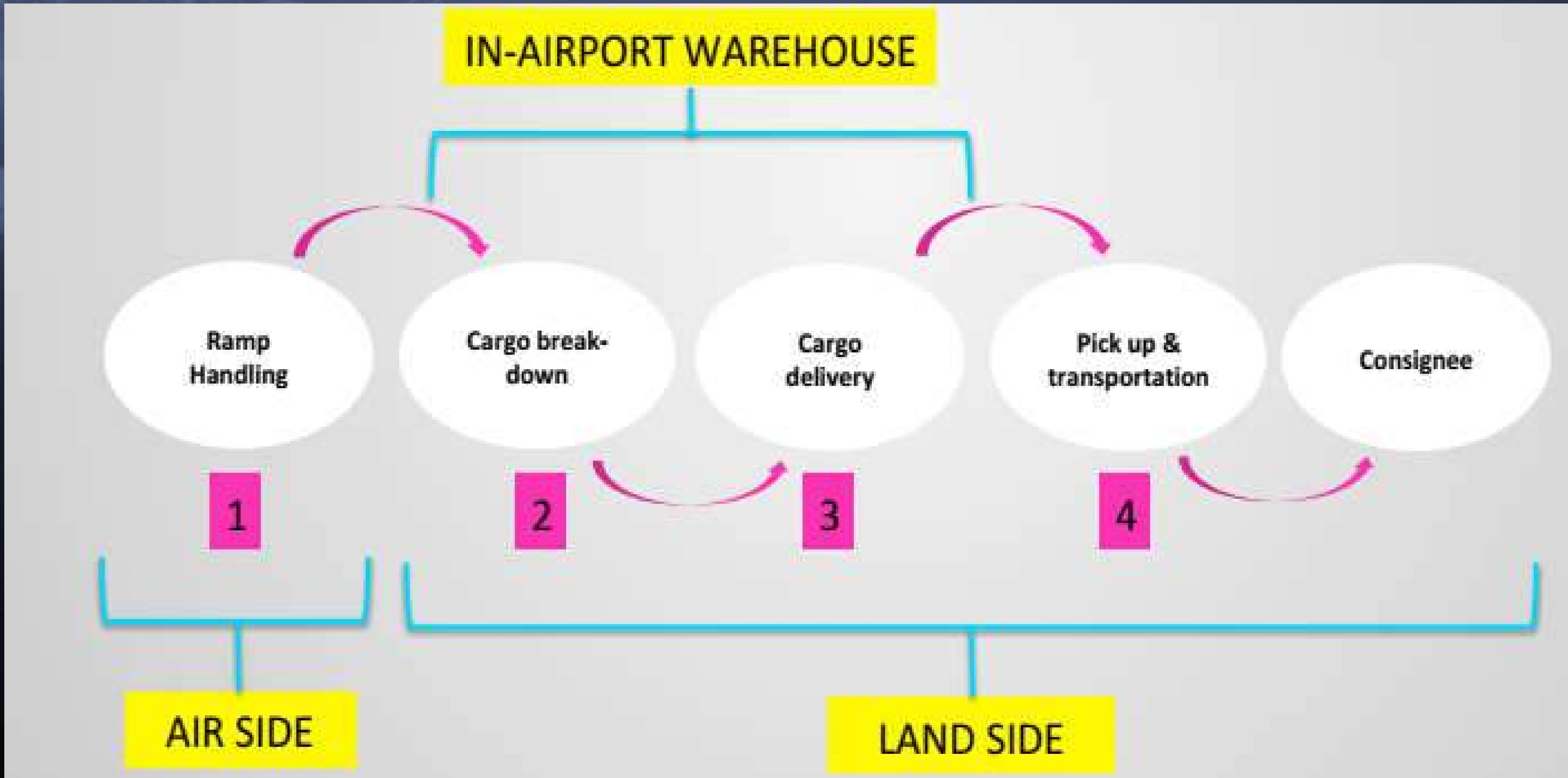
Representative Cargo Air Drop Pattern (Plane View)



Land to Air Side Export Flow Process



Air to Land Side Import Flow Process



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.

UA/RPA Type/Ops	Airspace Class	Detect and Avoid	Transponder	2-way ATC Communication
LA/LOS	Class G	Not Required	Not Required	Not Required during Operation
LA/BLOS	Class G	Required	Required	Not Required during Operation
MA (LOS/BLOS)	Class A-E	Required	Required	Required
HA (LOS/BLOS)	Above FL 600 (60.000ft)	Required	Required	Required

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.

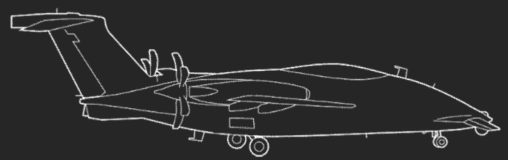
It is recommended that the two links employ different frequencies/technologies (e.g. terrestrial radio line of-sight and satellite-based BRLOS) as this will provide significantly greater protection against possible loss of the link. The GCS/RPS should be provided with a continuous indication of the operational 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:

CARGO TRANSPORT RPAS PROJECT ACTION DOMAINS



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).

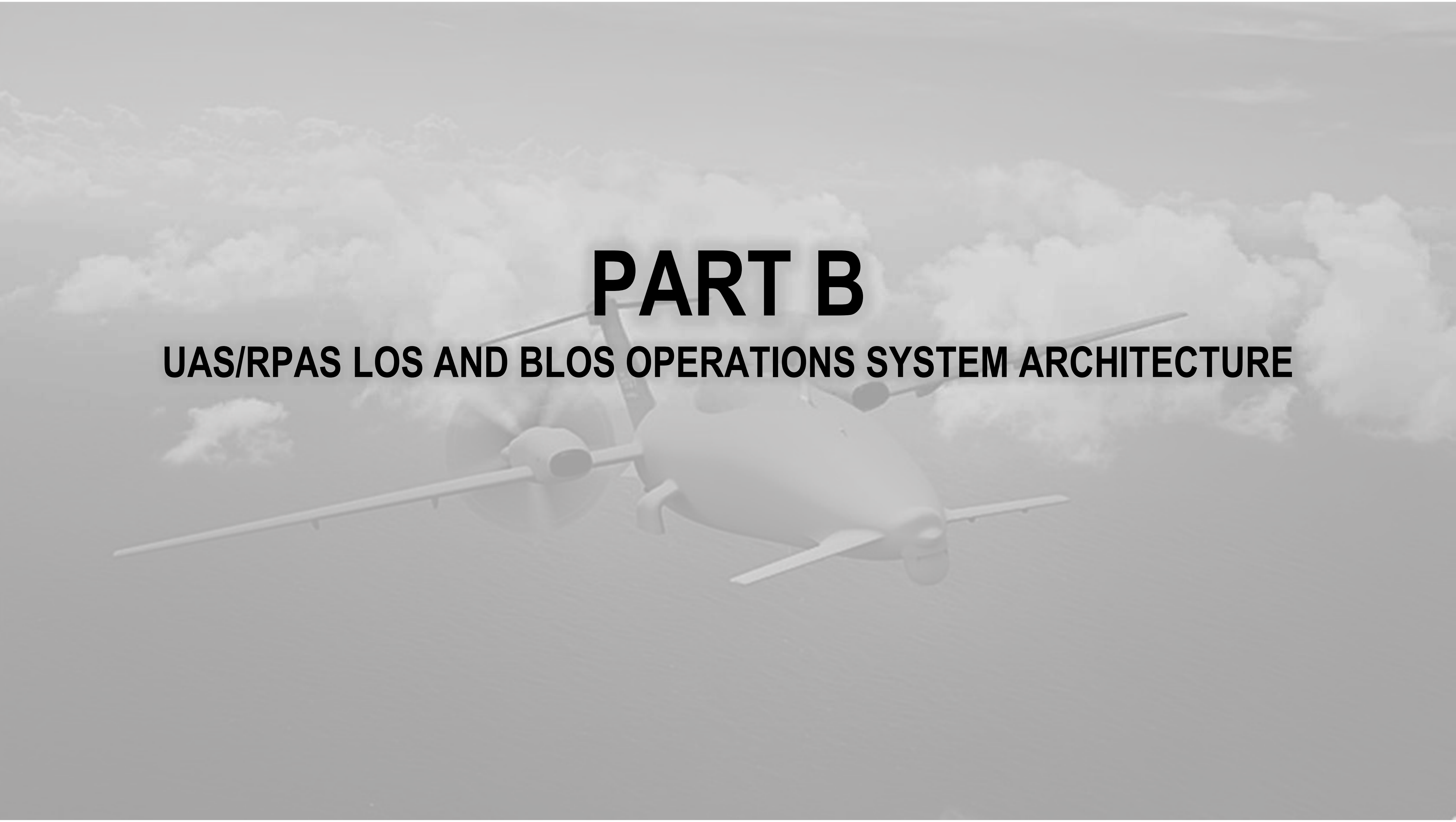
- Actions taken at the ITU-R 2012 World Radio-communication Conference (WRC-12) have established spectrum resources to address the RLOS spectrum requirement among others also in the C-Band, at 5030-5091 MHz.

- 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**

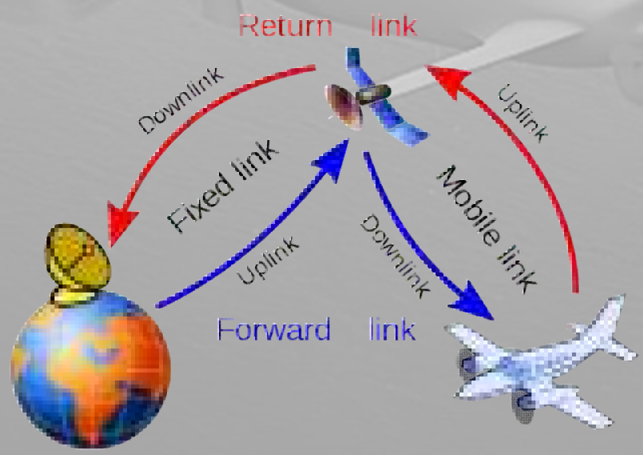
Introduction

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, ect) . 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

WHY segregated and non segregated communication are different

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 evalueted 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

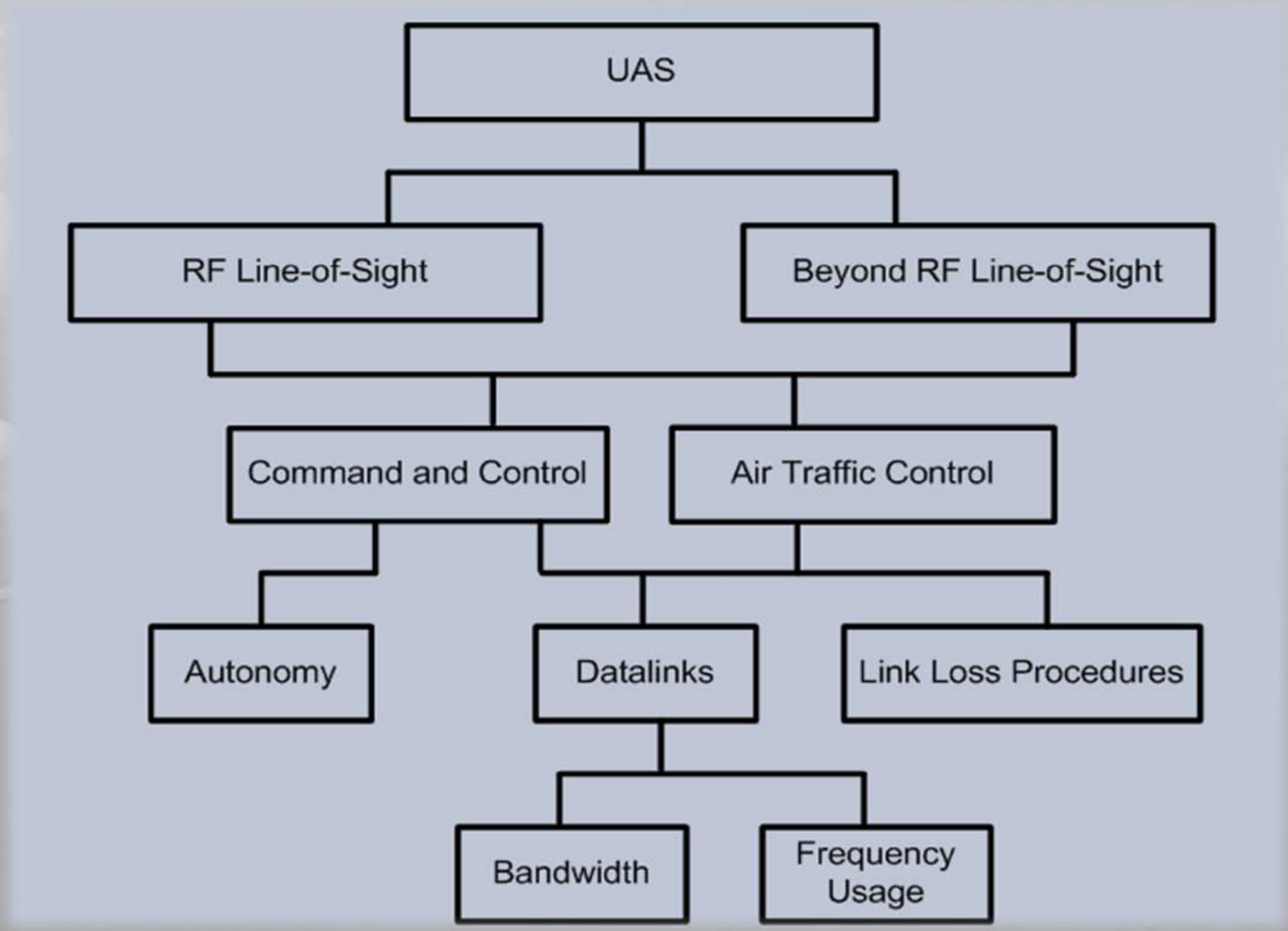
ICAO has deemed the CNPC function to be safety critical and has mandated that aviation safety spectrum must be used for this function

Control and non-payload communications (CNPC) function
Requirement cathegorization

,

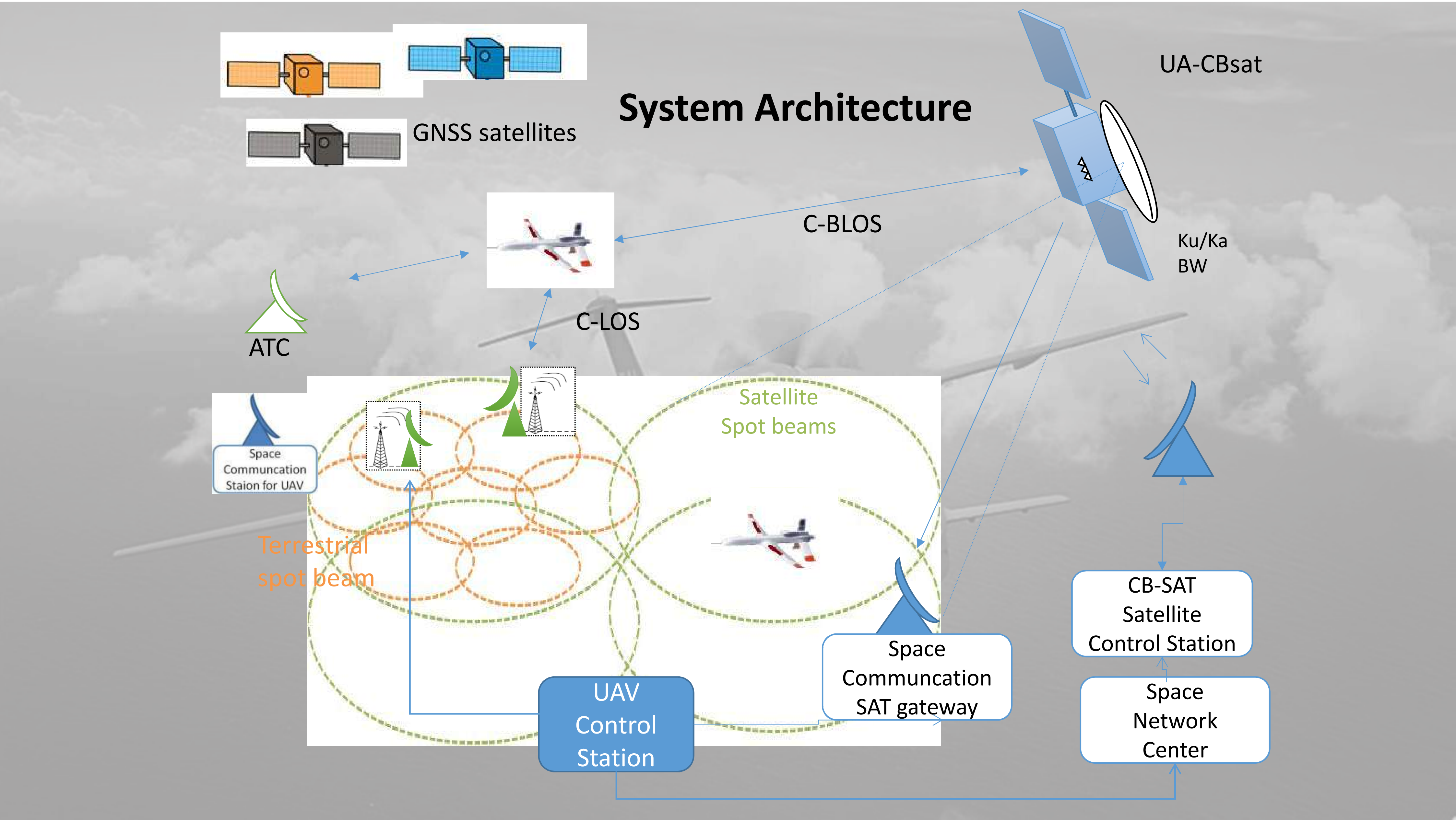
Category	Description
Operational Scenario	Flight phases, UAV segments, airspace, flight envelope, coverage area.
Performance	Availability, latency, continuity, integrity, capacity, throughput.
Security	Confidentiality, authentication, integrity, availability.
Aeronautical Earth Station	Certification,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

CNPC COMMUNICATION MODEL



Main System design issues

- Satellite orbit= >GEO vs LEO
- Power density and spectrum constraints→ interference
- MLS (Microwave Landing System) compatibility
- Duplexing mechanism (share of BW/time between Tx andRx) and Communication sharing Ground-Space
- Channel access mechanism & Modulation
- Power Amplifier operation(saturated-not saturated)
- Ground station configuration
- Number of UAV antennas/rx chains

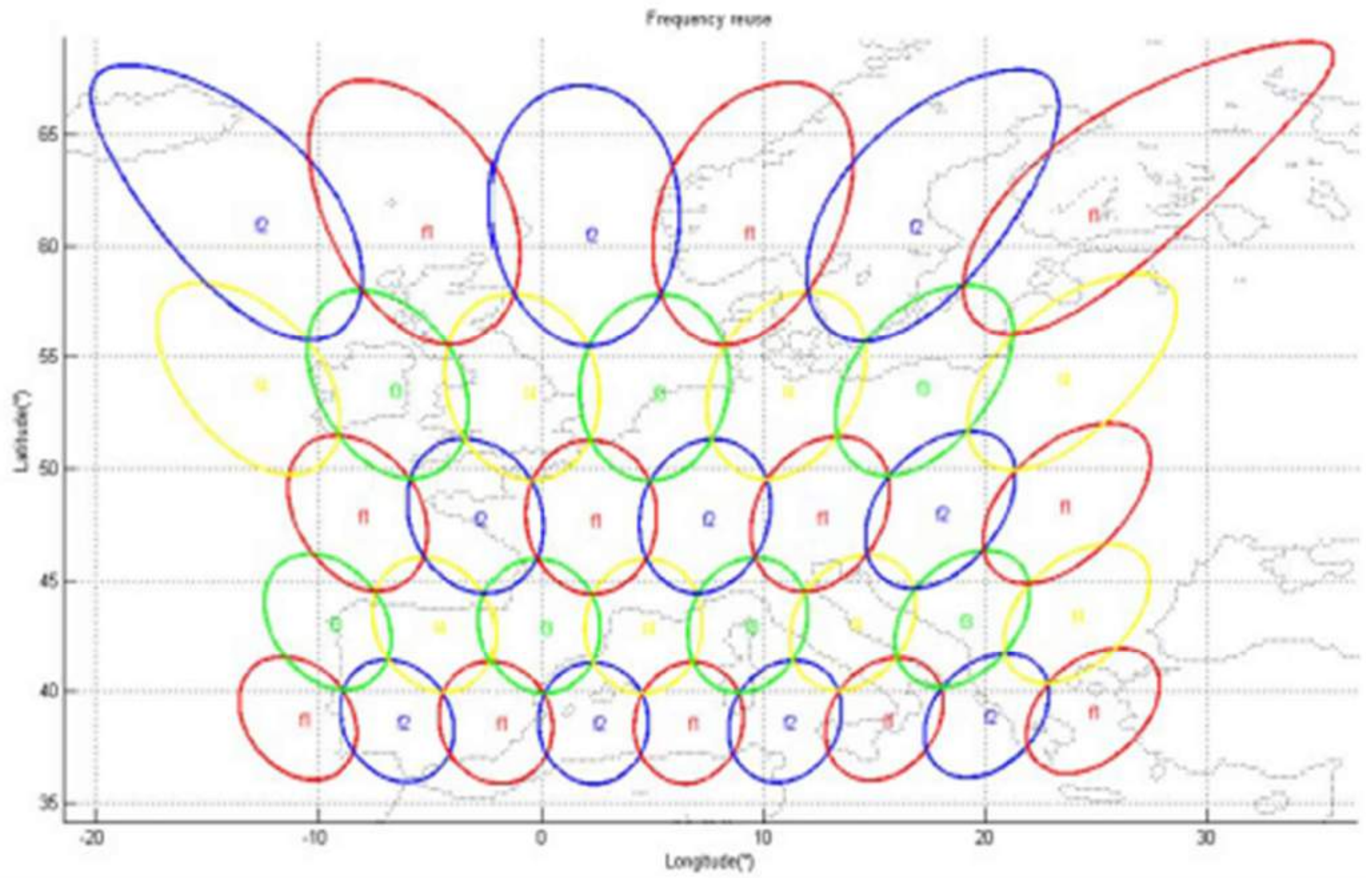


System Architecture
GNSS satellites
UA-CBsat
C-BLOS
Ku/Ka
BW
ATC
C-LOS
Satellite
Spot beams
Space
Communcation
Staion for UAV
Terrestrial
spot beam
CB-SAT
Satellite
Control Station
Space
Communcation
SAT gateway
Space
Network
Center
UAV
Control
Station

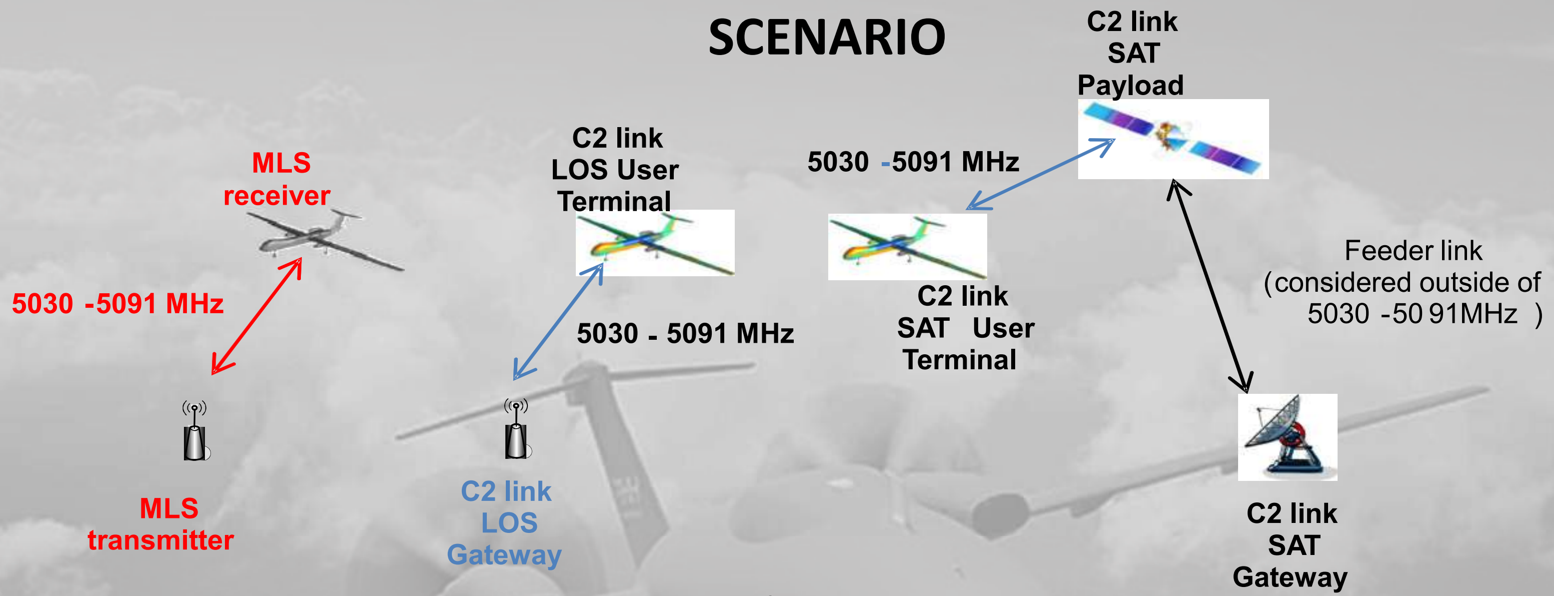
PROPOSED SATELLITE COVERAGE BY A GEO SATELLITE (OVER ECAC COUNTRIES)

FIGURE 3-2

Illustrative state-of-the-art spot beam satellite antenna and frequency reuse pattern



SPECTRUM SHARING MECHANISM SCENARIO



TOTAL BW requirement

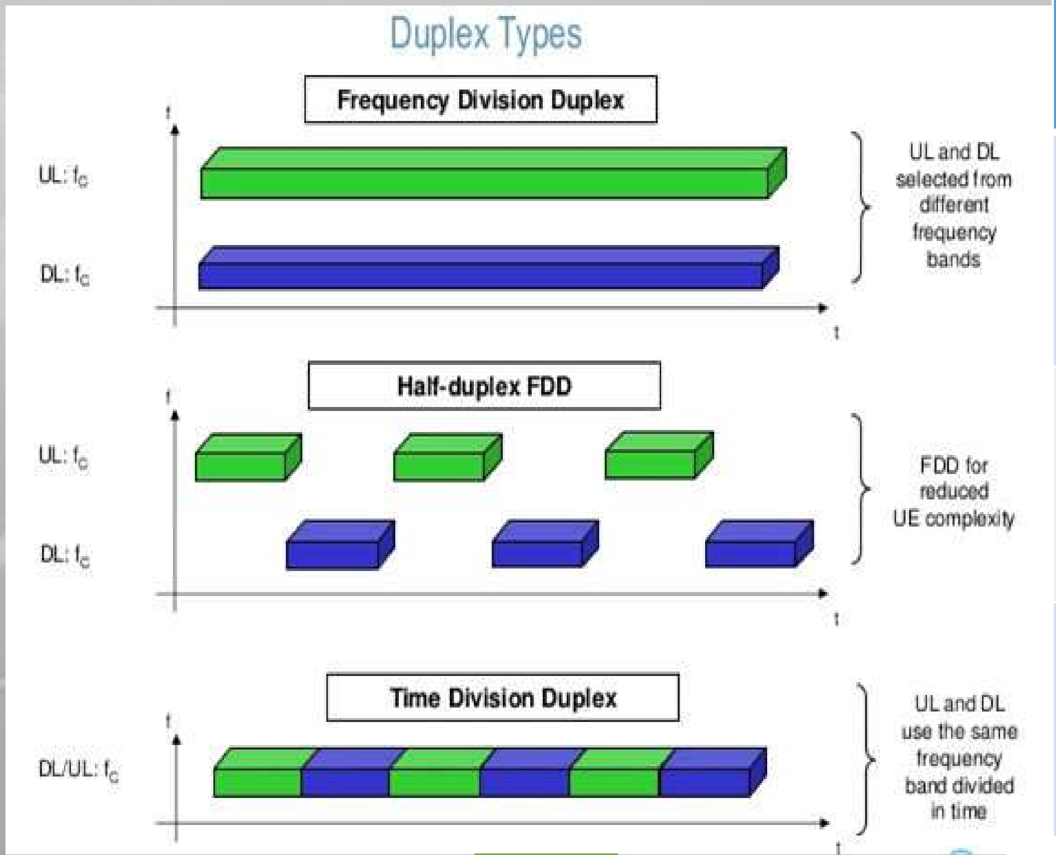
LOS: 34 MHz **BLOS: 56 MHz**

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:

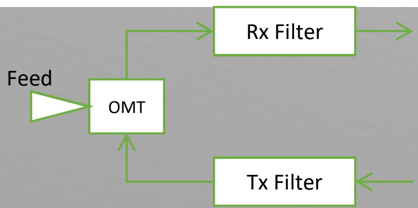
- **frequency planning,**
- **geographical separation**
- **power control.**

POTENTIAL DUPLEXING (sharing BW/Time bewteen tx and rx) SOLUTIONS

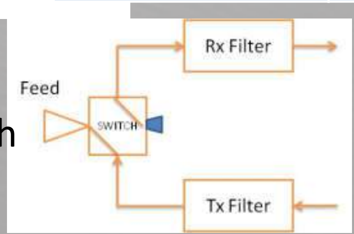


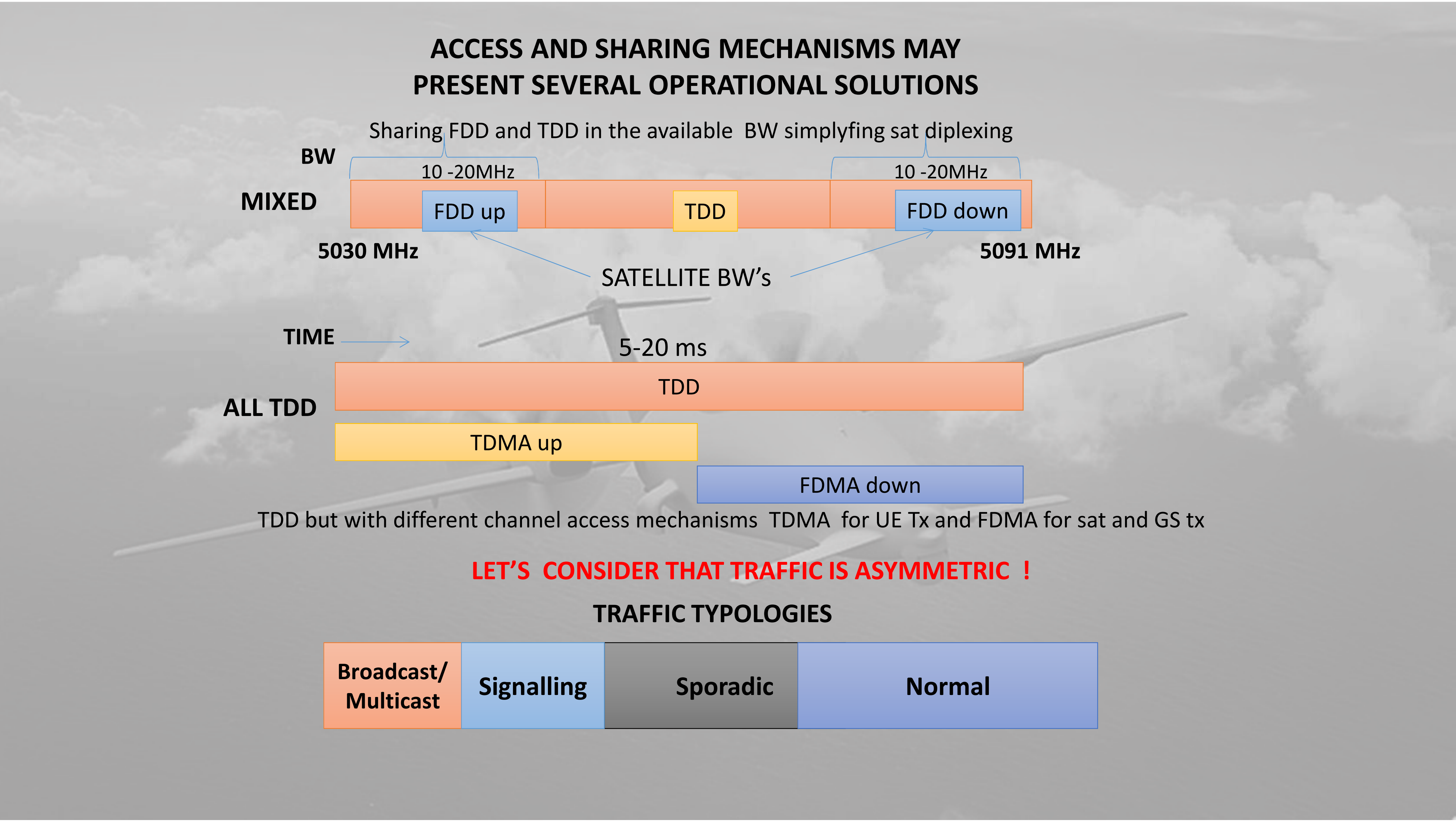
Satellite	Terminal
diplexer	diplexer
diplexer	switch
switch	switch

Diplexer



Switch




ACCESS AND SHARING MECHANISMS MAY PRESENT SEVERAL OPERATIONAL SOLUTIONS
Sharing FDD and TDD in the available BW simplyfing sat diplexing
BW
10 -20MHz
10 -20MHz
MIXED
FDD up
TDD
FDD down
5030 MHz
5091 MHz
SATELLITE BW's
TIME
5-20 ms
ALL TDD
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, miss-use 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 ASSIGMENT 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.

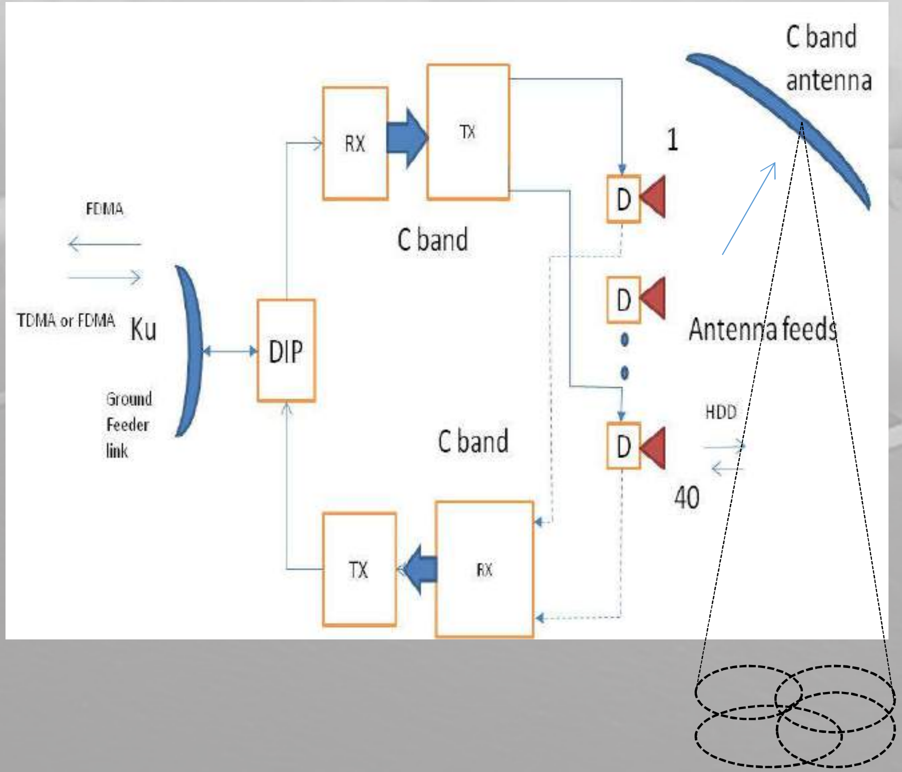
LINK LOSS and Operational Security

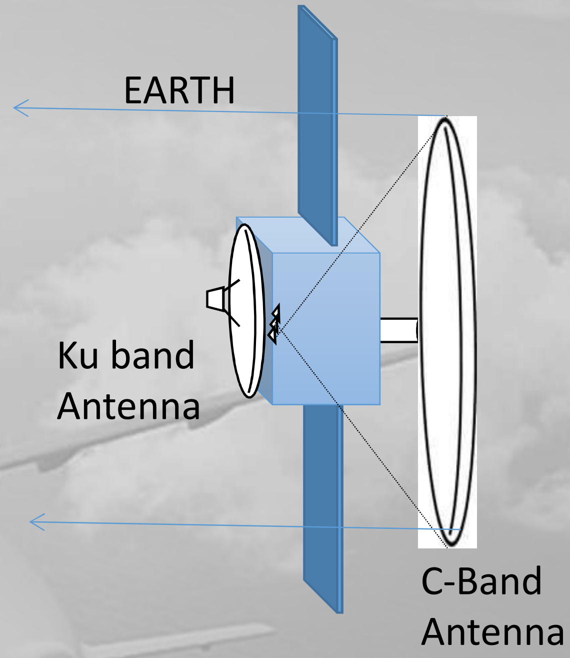
The loss of a data link must be addressed by a link-loss procedure. It is important that the aircraft always operates in a predictable manner. From the survey, it was revealed that the most common link-loss procedure is for the aircraft to fly to a predefined location. Once at the predefined location, 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.

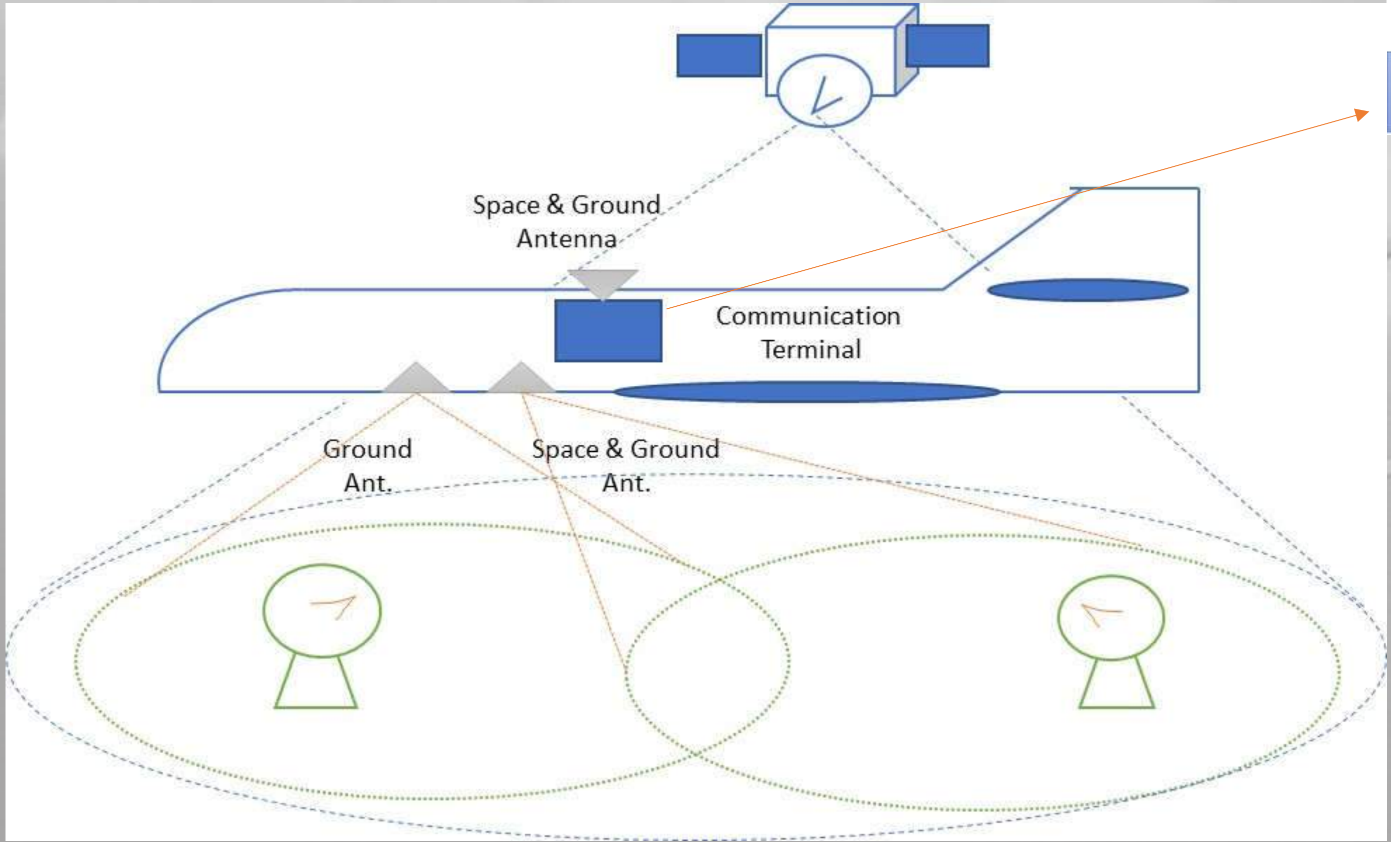
SATELLITE for C –Band communications

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



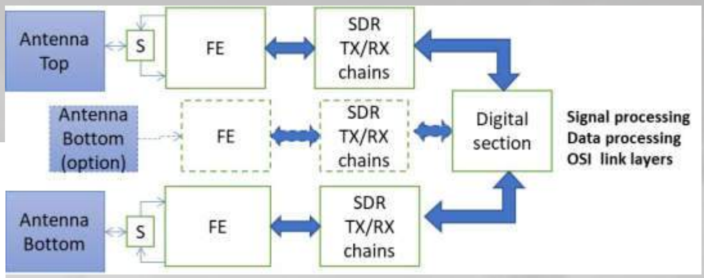


UAV TERMINAL CONFIGURATION



•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.