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Technology Workshop
ICAO RPAS MANUAL
C2 Link and Communications

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Functions Supported by the C2 Link

• **Control**
  – Provides function for PIC to modify the behavior of the RPA
    • Control Flight of RPA – Aerodynamics, Propulsion, Landing Gear etc.
    • Control Detect and Avoid system on RPA – Transponder, ADS-B, Radar etc.
    • Support RPA/RPS handover, Flight Data Recording etc.
  – Provides function for RPA to indicate its state to the PIC
    • RPA health and status - Speed, Attitude, Warnings etc.
    • Monitor Detect and Avoid system on RPA – Target tracks, Advisories etc.
    • Support RPA/RPS handover, Flight Data Recording etc.

• **Communications**
  – Provides function for voice and/or data communications between PIC and ATC and other pilots
  – Some RPA may relay voice and/or data through the RPA
C2 Link Terminology

- RPA DATA LINK
- RPA C2 LINK#
- RPA PAYLOAD LINK
  - WILL NOT BE COVERED IN SARPS
  - PILOT ATC RELAY COMMUNICATIONS LINK*
  - CONTROL LINK
    - TELECOMMAND LINK
    - TELEMETRY LINK

# RTCA and ITU-R call this the Control and Non-Payload Communications (CNPC) Link

* This link provides a means for the pilot to exchange voice or data with the VHF radio on the RPA to allow the pilot to communicate with ATC and other pilots
C2 Link Control Architectures

• Radio Line Of Sight – RLOS
  – RPA and ground radio (collocated with PIC) directly communicate with each other
  – A ground radio can be separated from the PIC so long as the additional signal delay is small
  – Often used for takeoff and landing even if BRLOS used enroute

• Beyond Radio Line Of Sight – BRLOS
  – RPA and PIC cannot directly communicate because the distance between them is very large compared to the curvature of the earth
  – Signal delay is significantly longer than for RLOS
  – Satellites can be used to support the C2 Link
  – An extensive network of RLOS ground radios can be used to support the C2 Link
C2 Link Communications Architectures

- **Relay through the RPA**
  - RPA appears just like a manned aircraft to ATC. Uses standard VHF ATC equipment on the RPA. No change to ATC procedures or infrastructure
  - RLOS Relay through the RPA
    - C2 link degrades Communications Performance. May or may not be significant

- **BRLOS Relay through the RPA**
  - Adds approximately 0.5 second one-way latency to Communications path
  - C2 Link degrades Communications Performance. May or may not be significant
C2 Link Communications Architectures

- **Non-Relay through the RPA**
  - Does not provide “Party Line” to other pilots
  - VHF Radio to VHF Radio
    - Uses standard VHF ATC equipment in RPS. No change to ATC infrastructure or procedures.
    - Limited Range

- **Ground to Ground Link**
  - Wired network provides lower latency than BRLOS Relay and higher reliability than all radio based connections
  - Requires new network to connect PICs with ATC
  - International/oceanic operation may need special considerations
C2 Link Characteristics

• **The C2 Link supports Safety Critical functions**
  – Requires adequate performance to ensure a reliable connection between the PIC and the RPA
    • Data Rates
    • Link Budgets
  – Requires protection from harmful interference
    • Security Measures
    • Appropriate Frequency Spectrum
  – Requires an Appropriate Certification and Operational Approval

• **Loss of the C2 Link must not cause an RPAS to become unsafe**
  – Lost C2 Link Procedures
C2 Link Performance

• The C2 Link must have adequate performance to support the services it carries
  – RCP (voice/data, if relayed through the RPA), RNP (navigation), RSP (surveillance), Detect and Avoid and Collision Avoidance.

• Currently no C2 Link Performance has been derived for safely controlling the RPA

• Required C2 Link Performance will depend on
  – Levels of RPA automatic operation versus Pilot in the Loop functionality
  – Operating environment and Class of Aircraft

• A wide range of possible RPAS configurations exists so one set of C2 Link RCP will not be applicable for them all
C2 Link Performance

• **Data Rates are not expected to be high (>50kbps)**
  – Low data rates make higher performance C2 Links easier to achieve
  – Not enough spectrum for every aircraft to use high data rate situational awareness enhancing video

• **Operational considerations**
  – RLOS links suffer from large signal fades especially when the RPA is close to the ground
  – BRLOS (satellite links) can suffer from weather related signal fading
  – Signal path obstruction by the RPA airframe can cause signal fading

• **Mitigations**
  – Use multiple antennas on the RPA and on the ground
  – Use frequency diversity
  – Use multiple C2 Links and choose “best” link
C2 Link Security

• Security requirements need to be internationally harmonized

• Security is a multi-level consideration
  – Many aspects similar to manned aviation e.g. Physical security
  – RPA are different e.g. C2 Link message security, C2 Link RF Signal security

• C2 Link message security
  – Authentication, Integrity, Confidentiality
  – End to End Encryption can provide adequate protection
    • Key management logistics need to be considered

• C2 Link RF Security
  – Impractical to completely protect C2 Link RF signal
  – RPA have natural defence to RF Interference
    • Lost C2 Link procedure
    • ATC procedures will be required to handle Lost C2 Link
C2 Link Spectrum

• C2 Link plays a major role in maintaining the safety and efficiency of RPA flight

• International Telecommunications Union allocates spectrum to a variety of services
  – Protection from harmful interference is a key ITU-R consideration
  – Aeronautical Mobile Route Service (AM(R)S) spectrum is reserved for communications relating to safety and regularity of flight

• In 2012 ITU-R identified a number of bands as suitable for RPA C2 Links, the following are receiving the most interest
  – Terrestrial - 960-1164MHz, 5030-5091MHz
  – Satellite – 1545-1555/1645.5-1656.5MHz and 1610-1626.5MHz as well as 5030-5091MHz
C2 Link Spectrum

- ITU-R determined that there was not enough capacity in the AMS(R)S bands to meet the anticipated number of RPA flights
- ITU-R is currently considering the technical and regulatory aspects of how non Route service Satellite bands can be used
  - ICAO ACP WG-F is supporting ITU-R in their studies to determine if
    - Safety of life concerns can be sufficiently addressed
    - There are no undue implications for other aeronautical systems
    - No precedent will be set to risk other aeronautical safety services
    - The satellite bands for RPA can be clearly identified in the ITU Radio Regulations
    - The frequency assignments recognize that safety services require special measures (ITU-R RR 4.10) to ensure freedom from harmful interference
- Then ICAO will support use of non AMS(R)S bands for RPA
  - ICAO will include additional conditions in SARPS to meet the technical and operational aspects of RPA when using non AMS(R)S satellites
C2 Link Certification

- C2 Link Certification is an Airworthiness and Operational topic not a technical topic
- Regulatory oversight of the C2 Link performance will be required to verify minimum standards are maintained
  - CAA certifies C2 Link if all components are under direct control of TC holder
- If part of the C2 Link is provided by a third party Communications Service Provider (e.g. satellite or terrestrial network operator)
  - CAA can directly oversee third party Communications Service Provider
  - CAA can indirectly oversee third party CSP as part of the RPAS operators Safety Management System
- CSP will provide service in accordance with TC’d RPAS design
- Final responsibility and liability for the proper design and operation of the RPAS (including third party CSP) lies with the RPAS design organization, production organization and operator
Lost C2 Link

- Lost C2 Links can be caused by equipment failure, human error, interference etc.

- Lost C2 Links can also be caused by RF propagation related conditions
  - Atmosphere/weather, reflection of signals from terrain, buildings and airframe cause received RF signal level to vary with time (fade)
  - True for both terrestrial and satellite C2 Links with different fade depths, durations and periodicities for each
    - Fade depths up to 30dB (1000x)
    - Fade times 10’s msec – 100’s secs
      - Longer times less likely
    - Terrestrial typically deeper fades
    - Satellite typically longer durations
    - Tools available to predict statistics
  - Fades cause temporary, self-repairing, link outages

Minimum Required Signal Level at Receiver

Received Signal Level versus Time

- Short outage
- Longer outage
Lost C2 Link

• **Nominal State**
  – C2 Link is available and the pilot is able to actively manage the flight

• **Lost C2 Link State**
  – C2 Link is unavailable and the pilot is “unable to intervene in the management of the flight”
  – But the aircraft is performing a flight plan that was pre-programmed by the pilot following TBD ICAO procedures so is safe
    • Recommend states harmonize the Lost C2 Link procedures for pilots and ATC
    • Continue flight plan, climb to regain C2 Link, or land at alternate aerodromes?

• **Lost C2 Link Decision State**
  – C2 Link is unavailable but RPS has not yet declared a Lost C2 Link
    • Short decision time causes “nuisance” Lost C2 Link declarations
    • Long decision time could lead to an unsafe condition
    • Decision times depend on Class of RPA and operating region
Future C2 Link SARPS - Overview

- **General Provisions and Supported Functions**
- **C2 Link Establishment, Termination and Coverage**
  - Handovers (pilot and RPS) and transfers between CSPs
- **Contingency and Emergency**
  - Lost C2 Link
- **Security**
  - Authentication, Integrity, Confidentiality
- **Link status Monitoring, Logging and data Recording**
- **RF Parameters**
  - General characteristics, compatibility not interoperability requirements
- **C2 Link Message Priority**
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