REMOTELY PILOTED AIRCRAFT SYSTEMS SYMPOSIUM
23-25 March 2015

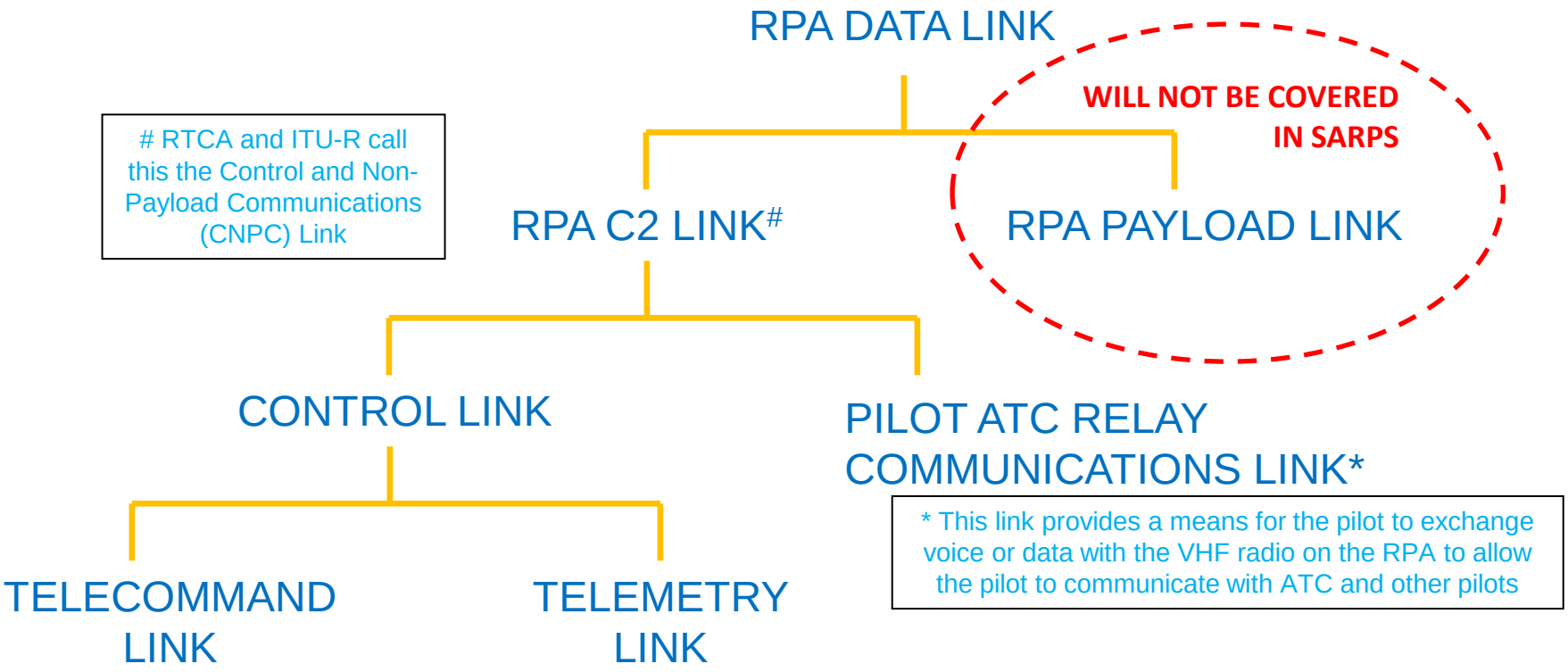
Technology Workshop
ICAO RPAS MANUAL
C2 Link and Communications

Michael Neale and Dominique Colin
C2 Link Rapporteurs

Functions Supported by the C2 Link

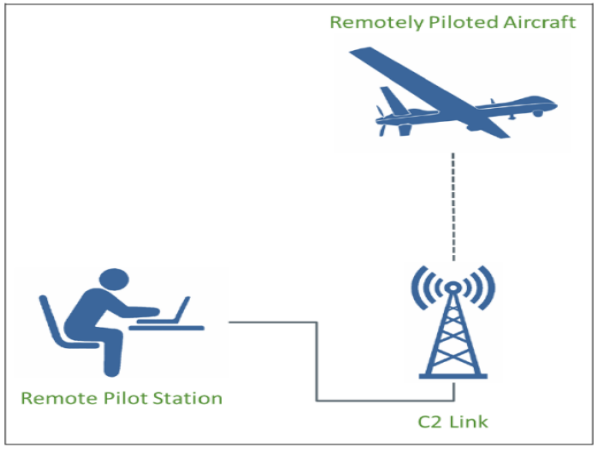
- **Control**
  - Provides function for PIC to modify the behavior of the RPA
    - Control Flight of RPA – Aerodynamics, Propulsion, Landing Gear etc.
    - Control Detect and Avoid system on RPA – Transponder, ADS-B, Radar etc.
    - Support RPA/RPS handover, Flight Data Recording etc.
  - Provides 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

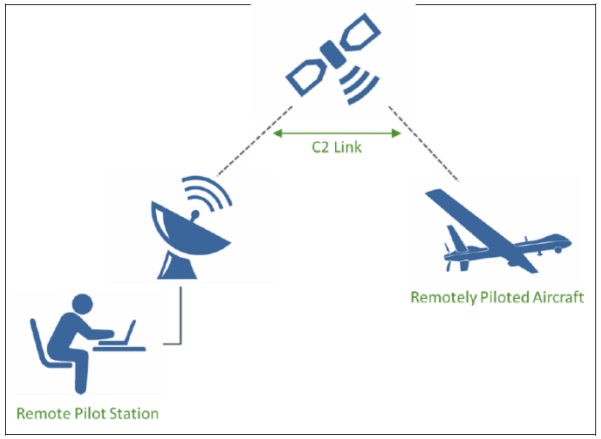


C2 Link Control Architectures

- **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

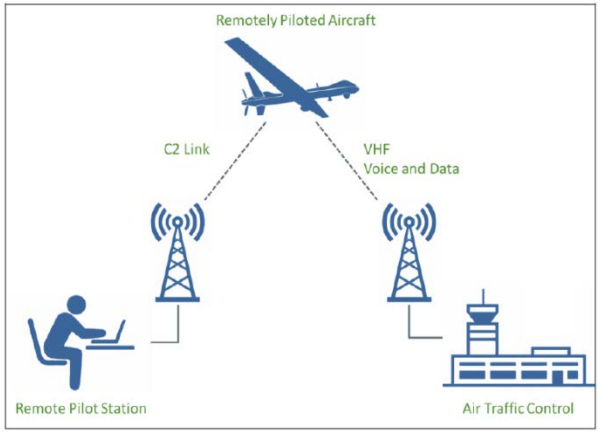


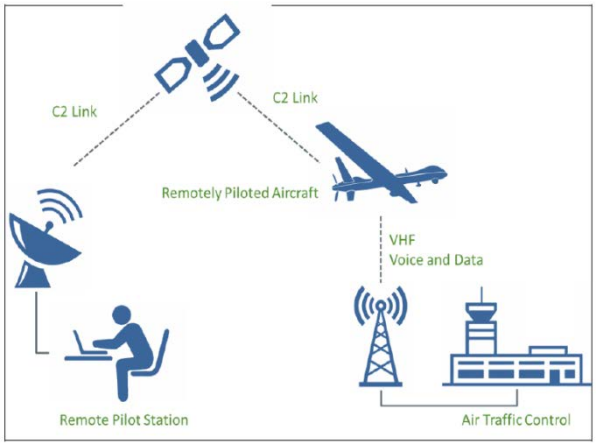
- **Beyond Radio Line Of Sight – BRLOS**
  - RPA and PIC cannot directly communicate because the distance between them is very large compared to the curvature of the earth
  - Signal delay is significantly longer than for RLOS
  - Satellites can be used to support the C2 Link
  - An extensive network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



C2 Link Communications Architectures

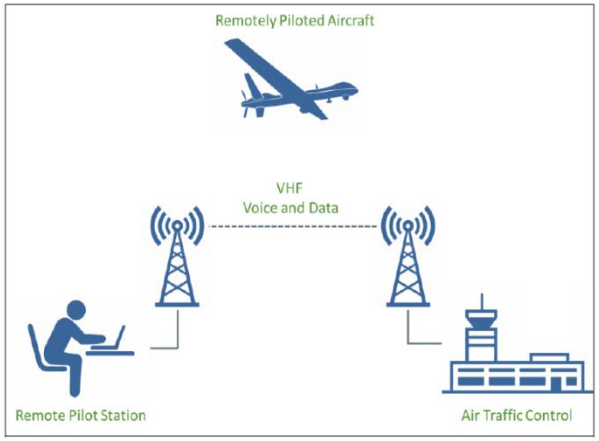
- **Relay through the RPA**
  - RPA appears just like a manned aircraft to ATC. Uses standard VHF ATC equipment on the RPA. No change to ATC procedures or infrastructure
  - RLOS Relay through the RPA
    - C2 link degrades Communications Performance. May or may not be significant
  - BRLOS Relay through the RPA
    - Adds approximately 0.5 second one-way latency to Communications path
    - C2 Link degrades Communications Performance. May or may not be significant



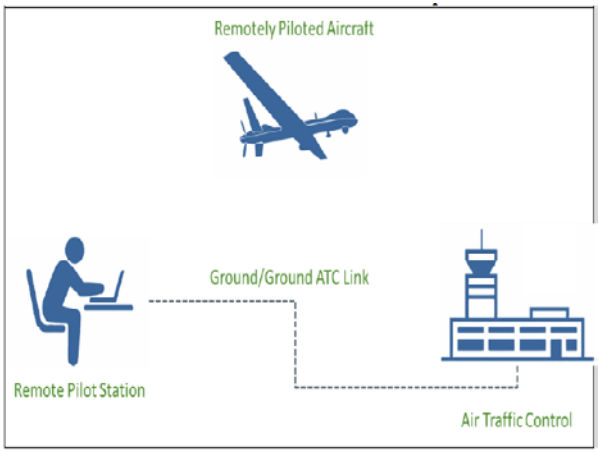


C2 Link Communications Architectures

- **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

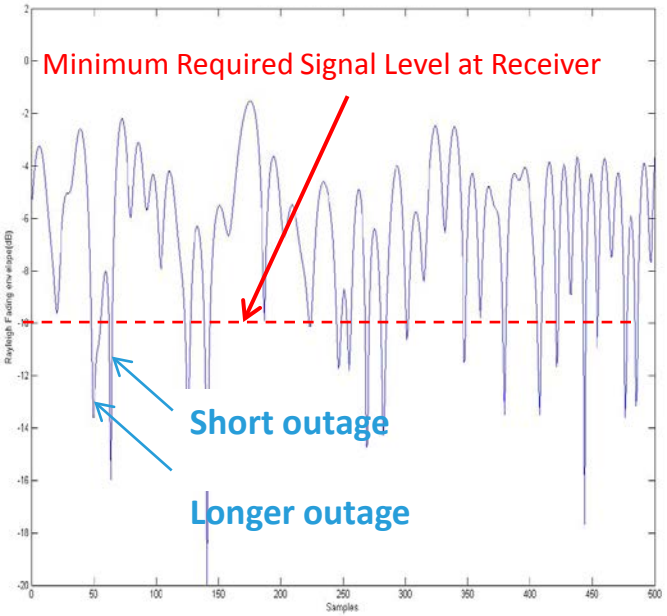
- **ITU-R determined that there was not enough capacity in the AMS(R)S bands to meet the anticipated number of RPA flights**
- **ITU-R is currently considering the technical and regulatory aspects of how non Route service Satellite bands can be used**
  - ICAO ACP WG-F is supporting ITU-R in their studies 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**



Received Signal Level versus Time

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**

- Michael Neale
- General Atomics Aeronautical Systems, Inc.
- michael.neale@uav.com
- 001 858 312 3617

ICAO

THANK YOU