Small UAV Command, Control and Communication Issues

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Above: the **EADS DRAC UAV** developed for the French military services

Talk outline

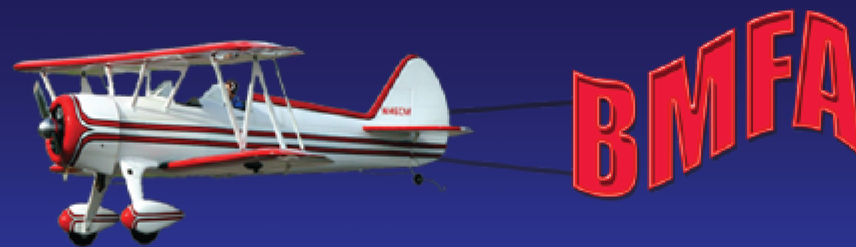
- Aircraft categories
- Command issues: the downlink
- Command issues: the uplink
- STANAG 4586
- UA communications
- Wireless LAN 802.11
- COFDM video transmission
- Potential frequencies
- Air Traffic Control voice relay
- Satellite Comms frequencies
- Frequencies used by some UAVs
- Mini-UAV data link
- Predator UAV data link
- Global Hawk communications links
- Ground Control Stations
- Conclusion

Right: EADS DRAC UAV “Ground Control Station”

Model aircraft categories

from Graham Lynn's presentation: "UAS's are not model aircraft" at UAV 2007 Conference in Paris.

EUROPEAIRSPORTS



Regulation

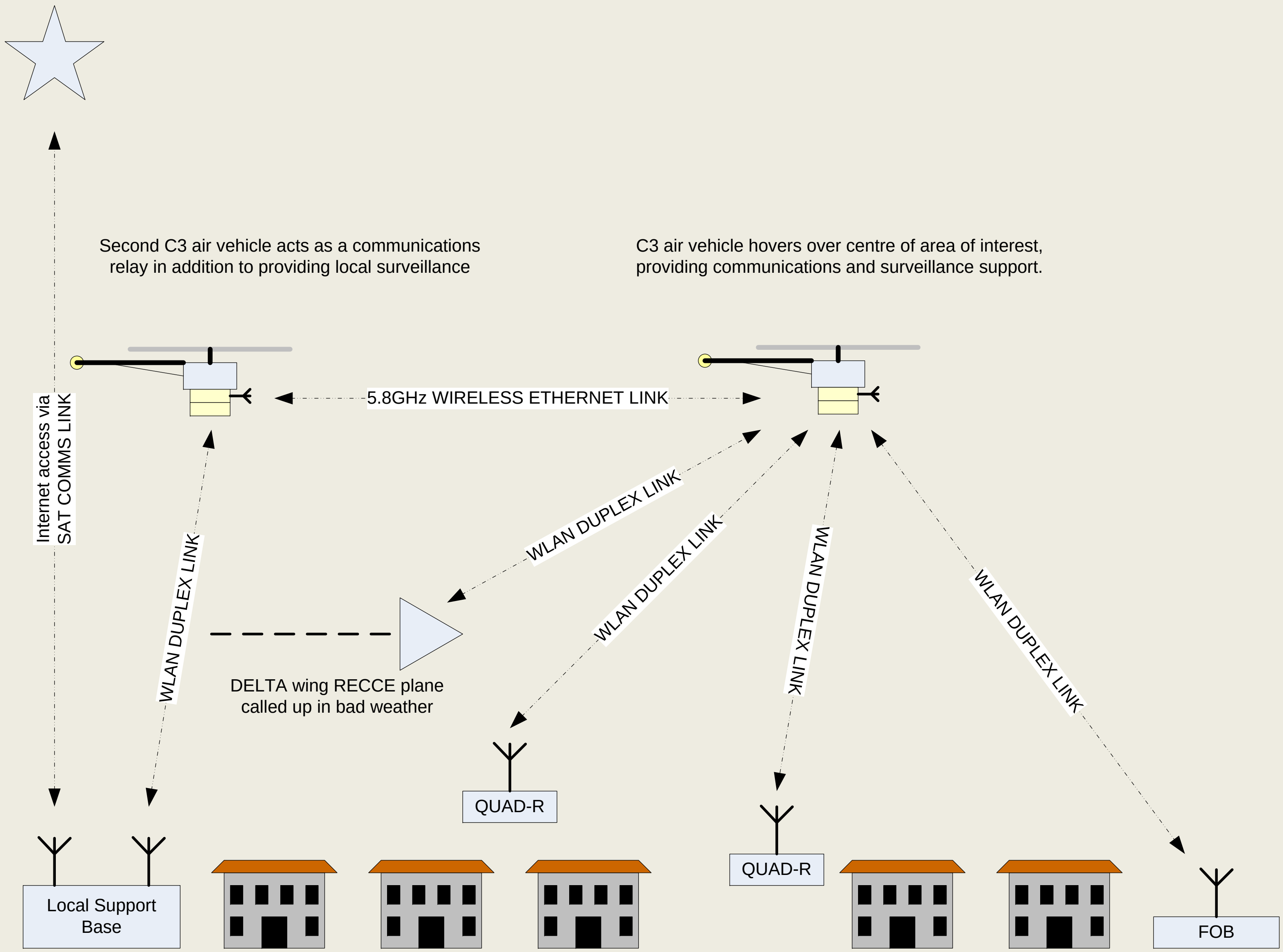
Radio controlled model flying is split into 3 categories in the UK and similar arrangements are in place in most of the European countries;

- Under 7 kgs — The majority of models
- 7kgs to 20kgs (25Kgs) — More specialist models
- 20kgs to 150kgs — Small Aircraft Class

Model flyers have developed very effective procedures for monitoring the build and test flying of the Small aircraft class of models - but more of this later

Regulation for all the categories up to 150kgs remains at a National level

UAV command issues



UA command issues: downlink

On one mission, might have, for example:

- 1 command and control UA (helicopter)
- 1 "investigator" UA (helicopter)
- 9 survey UA (delta wing)

Each Unmanned Aircraft has around 80 parameters to report on (see right hand side) depending on the number of engines and control surfaces (flaps) and other things to be controlled.

A typical UA status message size is 3,569 characters (bytes):

- Header
- Inertial Measurement Unit
- Flight Control Unit
- power
- warnings
- communications
- payload
- GPS
- sense (as in "sense and avoid")


```
BEGIN HEADER
        time 16:35:23.100
        date 20071114
        ua_id GB_123_ABC
        msg_num 133
        msg_version 1.21
END HEADER
BEGIN IMU
        gyro_x 23.105
        gyro_y 13.243
        gyro_z 12.596
        accel_x 3.933
        accel_y 0.022
        accel_z 0.223
        mag_x 15.877
        mag_y 225.112
        mag_z 8.254
        inclin_y 1.989
        inclin_z 3.850
        temp 11.213
END IMU
BEGIN FCU
        BEGIN engine
                id 1
                set_speed 13000
                actual_speed 14321
                carb_setting 12.3
                carb_actual 13.3
                temp 105.2
                fuel_flow_rate 23.23
                vibration 12.22
                cum_hours 128.77
        END engine
        BEGIN engine
                id 2
                set_speed 13000
                actual_speed 11321
                carb_setting 11.7
                carb_actual 10.3
                temp 125.2
```

UA command issues: downlink

Status message frequency:

▪ During possible collision, system problems	4 “mini-messages” per second
▪ On take-off and landing:	1 message per second (GPS synchronised)
▪ during mission	1 message every 10 seconds

Peak bandwidth required: downlink

- Message size = 3,569 Bytes
- Message format: ASCII text (not in reduced size binary format)
- Message rate = 1 full length message per second
- Message bit rate prior to coding = 3,569 x 8 = 28,552 bits / second
- 128 bit AES encryption is optional: no increase in bits per message
- With Reed-Solomon (255,223) coding to enable the detection and correction of transmission errors, the message size increases to 32,650 bits

A typical GPRS modem capable of operating at 900 MHz or at 1,800 MHz can support a data rate of up to 56 kbps and can thus adequately support the downlink telemetry.

A satellite communications modem can also readily support a bit rate of 56 kbps.

UA command issues: uplink

The uplink is used to change the flight plan, and needs to be protected from unauthorised use.

A flight plan is usually more than 1,000 Bytes in size, and varies greatly with mission complexity.

There is no regular flight plan update message rate, although there are often small GPS correction update messages broadcast from once a second to every ten seconds.

Due to the sensitivity of the uplink messages, they are typically :

- Encrypted using 128 bit AES encryption
- Forward Error Correction coded using Reed-Solomon (255,223) coding, or similar, to both detect errors and increase decryption complexity
- transmitted using a Spread Spectrum transmitter where the bandwidth is increased at least ten fold (from 10 to 50 times bandwidth increase)

```
BEGIN MISSION
    BEGIN SETUP
            MobileTelemetry 442083410566
            TEST MT_LINK
            WLAN CH6
            TEST WLAN
            TEST FUEL
            TEST FLAPS
            TEST BATTERY
    END SETUP
    BEGIN WAYPOINT 0
            GPS 12.12.123N 23.14.345W 100
            AGL 120
    END WAYPOINT 0
    BEGIN LEG 0_1
            duration 0.3.00
            BEGIN camera
                    type SONY_W200_1
                    compass 90
                    angle 270
                    MultiShot 100
            END camera
    END LEG 0_1
    BEGIN WAYPOINT 1
            GPS 12.15.123N 23.14.345W 100
            ALTIMETER 150
            SEND TELEMETRY
    END WAYPOINT 1
    BEGIN LEG 1_2
            duration 00:09.00
            MaxFuelEfficiency
            BEGIN Camera
                    type Nikon_D40X_2
                    zoom 100
                    compass 90
                    angle 270
                    SingleShot
            END Camera
    END LEG 1_2
```

The **Nato Standard Agreement ("STANAG") 4586** defines many of the command and control protocols used in military UAVs... but the document is very hard to get hold of!

NATO UNCLASSIFIED STANAG 4586 Ed. 2.5
Feb 2007

NORTH ATLANTIC TREATY ORGANISATION
(NATO)

NATO Standardisation Agency (NSA)

STANDARDISATION AGREEMENT
(STANAG)

SUBJECT: Standard Interfaces of UAV Control System
(UCS) for NATO UAV Interoperability

Example of message definition in STANAG 4586

4.1.9.3 Message #1600: IFF Status Report.

This message shall be used to report the IFF status to the CUCS.

Unique ID	Field	Data Element Name & Description	Type	Units	Range
1600.01	1	Time Stamp	Double	Seconds	See Section 1.7.2
1600.02	2	Vehicle ID	Integer 4	None	See Section 1.7.5
1600.03	3	CUCS ID	Integer 4	None	See Section 1.7.5
1600.04	4	Mode 1 Code	Integer 1	Units	First Digit 0..7 2^{nd} Digit 0..3, Transmitted As Decimal
1600.05	5	Mode 1 Enabled	Unsigned 1	Enumerated	0 = Off 1 = On
1600.06	6	Mode 2 Enabled	Unsigned 1	Enumerated	0 = Off 1 = On
1600.07	7	Mode 3/A Code	Integer 2	None	Octal 0000 to 7777, Transmitted As Decimal
1600.08	8	Mode 3/A Enabled	Unsigned 1	Enumerated	0 = Off 1 = On
1600.09	9	Mode C Enabled	Unsigned 1	Enumerated	0 = Off 1 = On
1600.10	10	Mode 4 Enable	Unsigned 1	Enumerated	0 = Off 1 = On
1600.11	11	Mode 4 A/B	Unsigned 1	Enumerated	A = 0 B = 1
1600.12	12	Mode 4 Hold	Unsigned 1	Enumerated	1 = Hold 0 = Normal
1600.13	13	Mode	Unsigned 1	Enumerated	0 = Off 1 = Standby 2 = Normal 3 = Emergency

Table B1 - 90: Message #1600: IFF Status Report

STANAG 4586

Unmanned Aircraft control and status messages fall into three general categories:

- Initialization, configuration, and mission upload messages exchanged pre-flight or infrequently during flight as necessary if the operating mode or configuration of the aircraft is changed.

- Control messages sent to control the aircraft and its engines at a frequency highly related to the level of autonomy characterizing the aircraft.

- Status messages sent by the aircraft

- These report dynamic changes in aircraft movements, direction, orientation, engine operation, etc. These messages can be sent very frequently.

- Typical update rates range from 1 to 20 times per second for critical parameters according to UAS manufacturers, where 1/sec. would be appropriate for a fully autonomous aircraft, and 20/sec. would apply to a hand flown UA.

- These updates rates are the major drivers in determination of aggregate aircraft to ground data-rate, and hence bandwidth.

Unmanned Aircraft communications

Telemetry and command bandwidth is considered separate from payload (such as video camera and photography) bandwidth.

Telemetry and command bandwidth can be accommodated by a 56 kbit/sec link:

- GPRS modem
- satellite communications link

Payload bandwidth is usually much larger: up to 8 Mbit/sec for a high quality video link using COFDM modulation technique. Finding and using this bandwidth is considered a “commercial” issue:

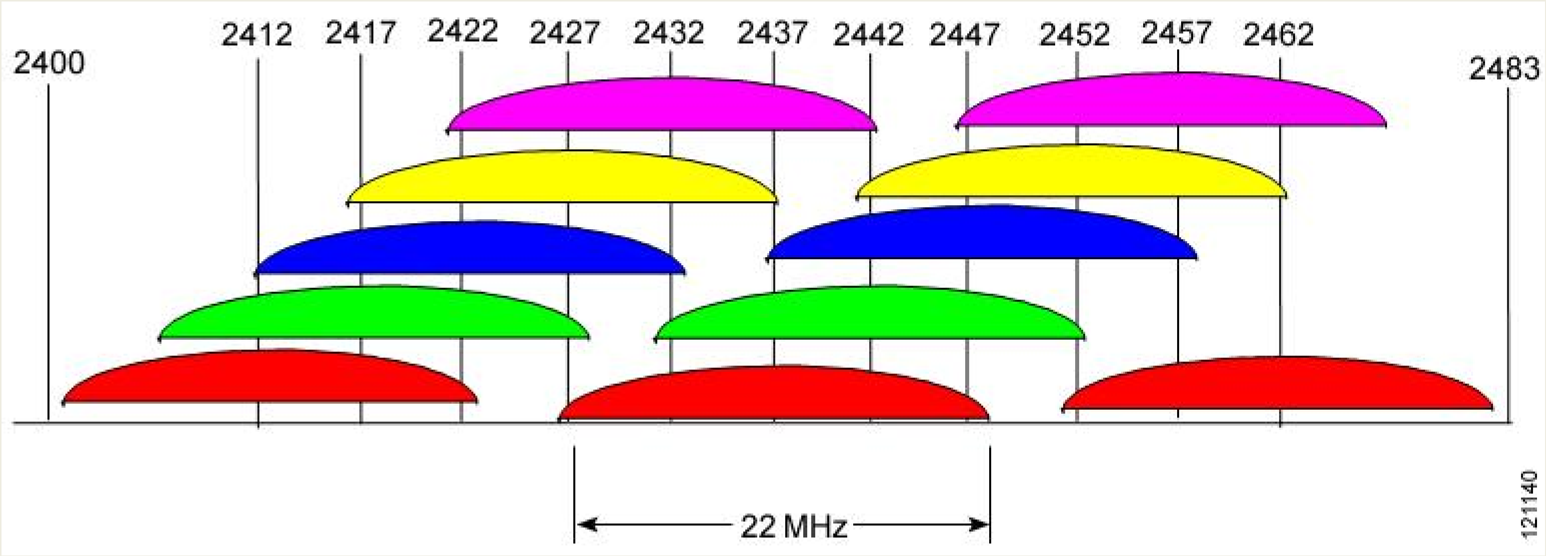
- Wireless Local Area Network (WLAN) based around 2.4 GHz band

- Coded Orthogonal Frequency Division Multiplexing (“COFDM”) based from 5 to 24 GHz. However, this system is degraded by Doppler frequency shift effects associated with UAV motion, so there is a limit on the UAV speed.

- Othogonal QPSK if COFDM cannot be used due to the Doppler shift problem

Wireless LAN 802.11 channel deployment scheme

from **Cisco Aironet 1200 Series**
Channel Deployment Issues for 2.4-GHz 802.11 WLANs



The highest bandwidth variant of the WLAN 802.11 family is the new 802.11n (DRAFT) variant. Switches supporting this draft standard are commercially available. For small Unmanned Aircraft, the use of WLAN 802.11 is popular for short range (less than 1 km) payload data links.

COFDM transmission of video information from a beyond line-of-sight UAV

Coded Orthogonal Frequency Division Multiplexing (COFDM) techniques are increasingly being used to transmit video payload data from a UAV to a receiving antenna on the ground, or to a relay UAV. The attributes of these links are as follows:

•tolerant of multi-path interference

•efficient modulation schemes: QPSK, 16 QAM or 64 QAM

•the Digital Video Broadcast – Terrestrial (DVB-T) standard suggests the use of 2,000 orthogonal sub-carriers in an 8 MHz bandwidth, with the frequencies of the sub-carriers carefully selected to ensure orthogonality Bandwidth of 6 and 7 MHz are realised by scaling the frequencies of all the sub-carriers.

•Forward Error Correction is applied (the “Coded” or “C” part of OFDM) to enable the measurement of the bit error ratio for each sub-carrier signal

•AES encryption, typically 64 bit or 128 bit, can optionally be applied

Bandwidth specifically for UAV telemetry and command uses

This and next two slides from presentation by Axel Klaeyle at UAV 2007 Conference in Paris

Federal Network Agency

UAS at WRC-07 : a preliminary but insufficient approach

Agence Nationale des Fréquences

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WRC-07 will likely make decisions on generic aeronautical items

- Agenda Item 1.5 : Aeronautical telemetry and associated telecommand for flight testing and UAV between 3 and 30 GHz
  - Preparatory process concentrated on the Aeronautical telemetry used for flight tests
  - Only limited effort was given to UAV operation due to lack of participation of UAV interested parties
  - No further decision on UAV operation
- Agenda Item 1.6 : Additional ATM spectrum between 108MHz and 6GHz
  - New allocations at VHF, L-band and 5 GHz band for ICAO systems

But WRC-07 will not make decisions on UAS specific requirements

- Worldwide harmonization of UAS frequencies
- Frequencies for Satcom component
- Frequencies in relation to the seamless integration of UAV in non segregated airspaces : ATC relay, Sense & avoid… as required
- Longer term considerations

Federal Network Agency

Time to start ITU-R studies

Agence Nationale des Fréquences

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WRC-07 decision to start studies

↓

Preparatory studies at national, regional and ITU level

↓

WRC-11 decision on harmonized international regulations

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RR modification applicable as of 01/01/2012
Applicable national/international spectrum regulations

↓

UAS take-off by 2015

↓

UAS users & manufacturers should raise support from their respective administrations as soon as WRC-07

List of potential frequency bands

from “EUROCAE WG 73 UAS spectrum vers 0.4.doc” by Christian Pelmoine

- 108-112MHz – ILS-LOC
- 112-118MHz. – VOR, GBAS
- 118-137 MHz – AM(R)S
- 138-144 MHz
- 960-1164 MHz – DME / TACAN / Transponders
- 1.8 GHz
- 2.3 – 2.4 GHz
- 2.7-3.1 GHz – Radio-location, Radio-navigation
- 5.0 – 5.15 GHz – Radio-navigation, mobile, .

Air Traffic Control voice relay

UAV manufacturers and operators hope this requirement "will somehow just go away"...
Air Traffic Controllers are adamant this requirement is cast in concrete.

UAVs need to be treated no differently from manned aircraft, from an Air Traffic perspective.

The UAV must respond to a voice command from an Air Traffic Control station, such as an Airport Control Tower, and acknowledge the command, from the ATC station, such as:

"Flight UAV123 descend to Flight Level 130"

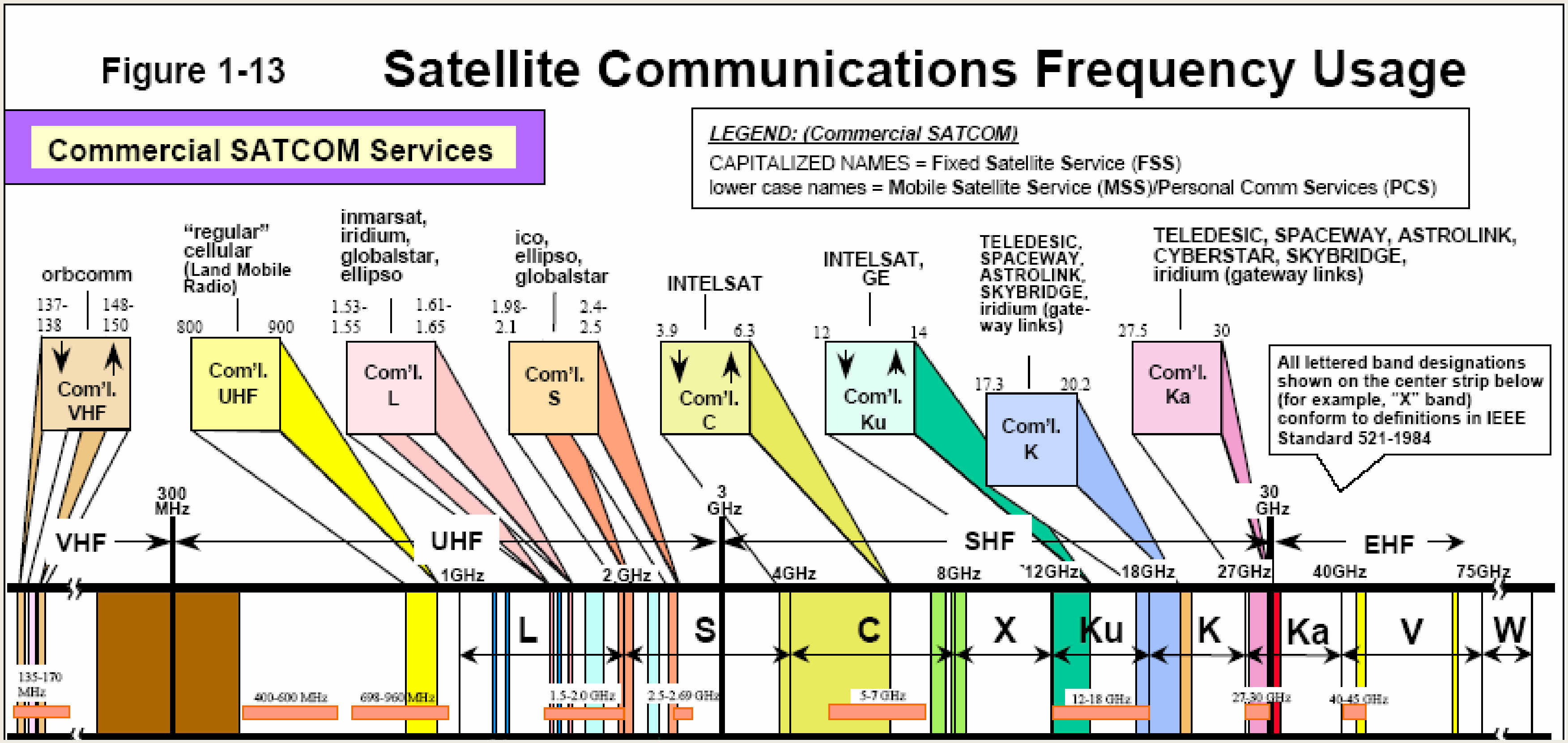
with: "Flight UAV123 descending to Flight Level 130"

One solution for the situation in which the UAV Ground Control Station is remote from the UAV and the Air Traffic Control station is to relay the digitised voice via satellite. The problem is the latency in satellite communications, which in tests using the Intelsat system have been found to be as much as 25 seconds. One suggestion is to use voice recognition software...

Domain	Threshold	Objective
En Route	3.0 sec	1.5 sec
Tower	3.0 sec	1.5 sec
Terminal	3.0 sec	1.5 sec

Satellite communications frequencies

from “EUROCAE WG 73 UAS spectrum vers 0.4.doc” by Christian Pelmoine



Frequencies used by some current Unmanned Aircraft

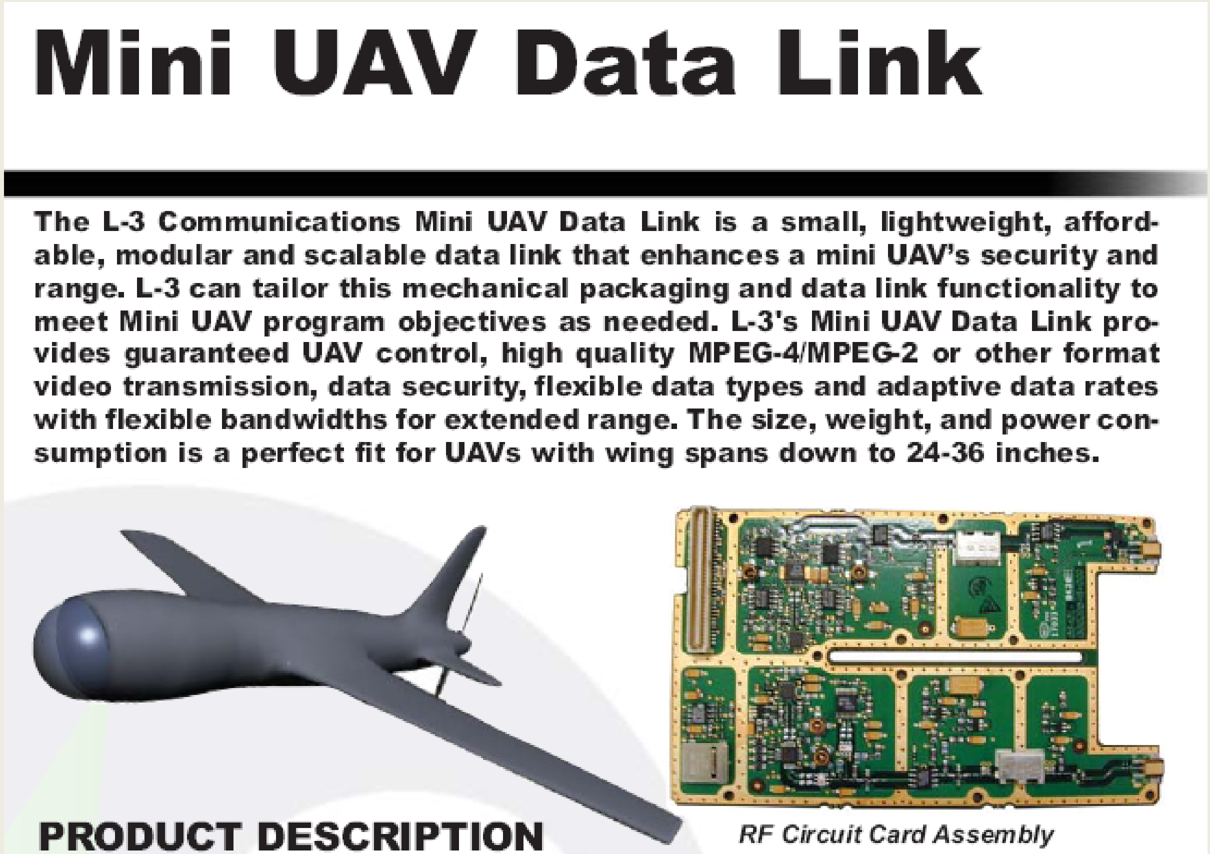
from UAV Frequency Management Concerns presentation by Mikel Ryan at UAV 2007

						Stand-By				
Airborne	BatIII	CamCopter	Dakota	Dragon Eye	Fire Scout	Hunter	Pointer	Raven	Rmax	Scan Eagle
BatIII	72,902,2472	7	9						7	6
CamCopter	7	2450,4620,72	7						7	
Dakota	9	7	72,902,2400						7	6
Dragon Eye				394.95, 1790	1		3	2		
Fire Scout				1	396.8,428,2210,2286		4	2		
Hunter						4415,4755				
Pointer				3	4		433.8,1787.5	3		
Raven				2	2		3	395,1787.5		
Rmax	7	7	7						2493,1281,73	
Scan Eagle	6		6							902-928
Sentry HP	6		6		8					6
Tern XPV-1				3	4		3,4			

Yellow	Use caution, adjacent channeling
Green	Good to go
Red	NO Go!

(Go/No Go Chart for UAV Exposition at Webster Field MD)

1. FIRE SCOUT's uplink is on 396.8 MHz, DRAGON EYE is less then 2 MHz below him.
2. RAVEN's uplink is on 395 MHz, DRAGON EYE is on either 394.95, 395.0, 395.05, or 395.10 MHz.
3. POINTER and RAVEN are using the same downlink 1787.5 MHz. And TERN, DRAGON EYE are co-located within the 1740-1860 MHz band.
4. POINTER and TERN and FIRE SCOUT are co-located in the same band (420-450 MHz) although conflict is a possibility it is not probable.
5. The RMAX downlink is on 2493 MHz, the CAM COPTER uplink is 2450 and DAKOTA downlink is on 2400 MHz.
6. The BATIII has TM in the 902-928 MHz band, DAKOTA is using a VACS link, SENTRY is around 900 MHz and SCAN EAGLE uses it for uplink and downlink.
7. The RMAX, CAM COPTER, BATIII and DAKOTA use 72-73 MHz.
8. SENTRY is co-located with with FIRE SCOUT's downlink.
9. BATIII, CAM COPTER, DAKOTA all use 72, 902 and 2400 MHz equipment.



Mini UAV Data Link

The L-3 Communications Mini UAV Data Link is a small, lightweight, affordable, modular and scalable data link that enhances a mini UAV's security and range. L-3 can tailor this mechanical packaging and data link functionality to meet Mini UAV program objectives as needed. L-3's Mini UAV Data Link provides guaranteed UAV control, high quality MPEG-4/MPEG-2 or other format video transmission, data security, flexible data types and adaptive data rates with flexible bandwidths for extended range. The size, weight, and power consumption is a perfect fit for UAVs with wing spans down to 24-36 inches.

PRODUCT DESCRIPTION

RF Circuit Card Assembly

from www.L-3com.com/csw brochure

The above link for small UAVs from L3 operates from 1,755 MHz to 1,850 MHz with a power output up to 10 Watts and a data rate up to 10.7 Mbps. There is a general trend for the smaller UAVs to operate their beyond-line-of-sight communications links at the lower frequencies, typically from 900 MHz (GSM modem) to the ISM band at 5.8 GHz.

Ku-band SATCOM Data Link (KuSDL) Predator (MAE-UAV)

Reconnaissance System(Block 1 Upgrade in Process, circa 2001

The KuSDL utilizes commercial, geostationary satellites to effect full duplex SATCOM linking the Predator UAV to a remote control'explorita-tion complex. The command link provides real-time control and data while the return link transfers real-time EO, IR or SAR motion video (VQ compressed) to the exploitation facilities.

II) Transponder lease(s) on appropriately posi-tioned commercial, Ku-band geosynchronous satellites. Lease, rev-enue arrangements and spot beam locations all established long before mission initiation.

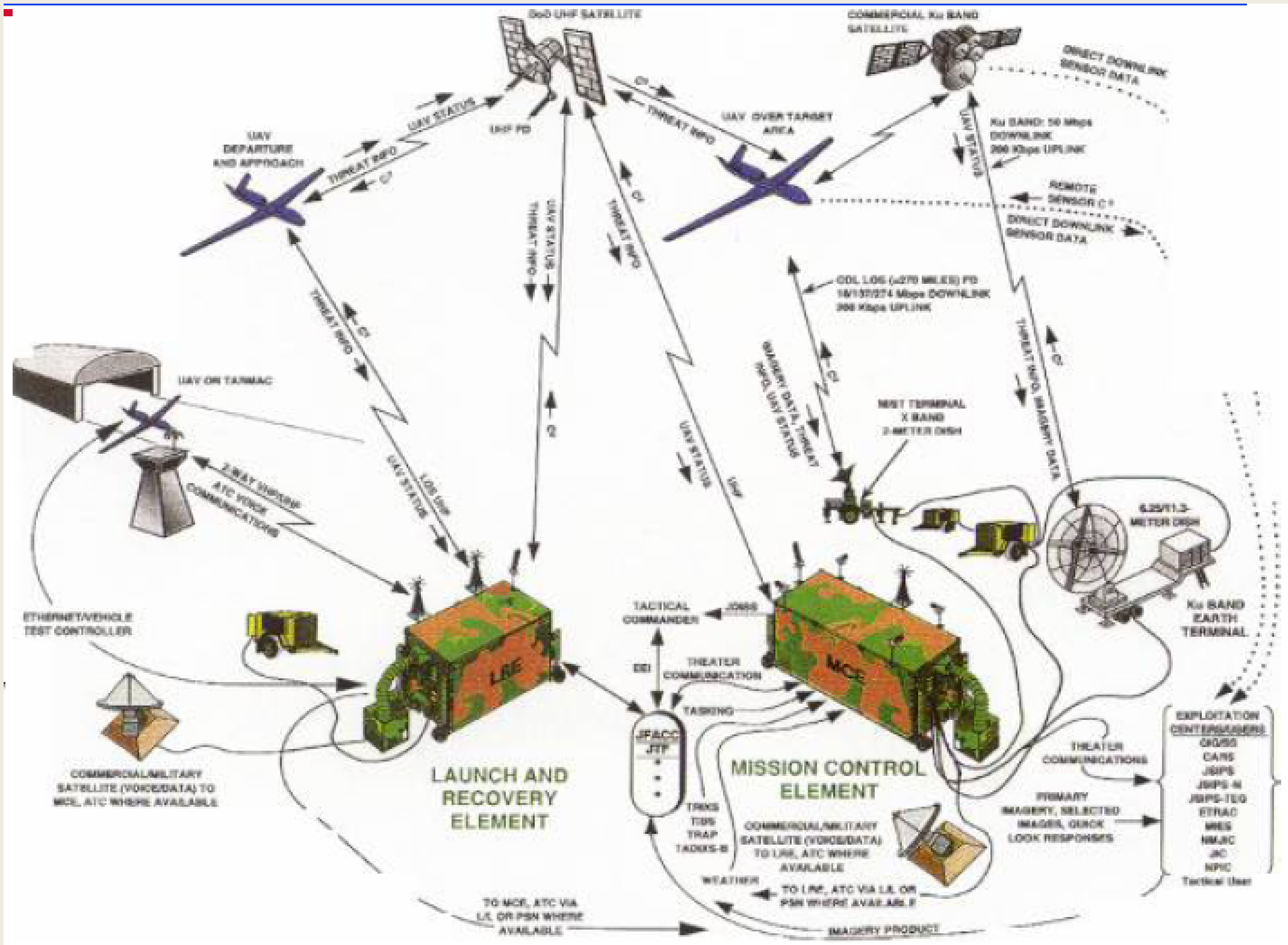
By contrast, the communications link for the relatively large Predator Unmanned Air Vehicle consists of:

an on-board receiver operating in the frequency range from 10.95 GHz to 12.75 GHz

and a 50 Watt transmitter operating in the frequency range from 14.0 GHz to 14.5 GHz.

Example: Global Hawk communications requirements in 2007

from UAV Frequency Management Concerns presentation by Mikel Ryan at UAV 2007



Global Hawk spectrum systems

from UAV Frequency Management Concerns presentation by Mikel Ryan at UAV 2007

- Ku-Band SATCOM
- Synthetic Aperture Radar
- Common Data Link
- GPS
- UHF Data Link (Line Of Sight)
- Radar Altimeter
- IFF
- G-Band Tracking (Flight Test Only)
- Differential GPS
- VHF Voice
- UHF SATCOM
- UHF Line of Sight
- MINI-CDL (DS Only)
- INMARSAT
- UHF Voice
- Instrumentation Elementary (Flight Test Only)

Global Hawk frequency bands used

from UAV Frequency Management Concerns presentation by Mikel Ryan at UAV 2007

- 112.7 - 117.9 MHz
- 118 - 136 MHz
- 225 - 400 MHz
- 1030 - 1090 MHz
- 1217 - 1235 MHz (L2)
- 1530 - 1559 MHz
- 1565 - 1585 MHz (L1)
- 1626 – 1660.5 MHz

- 2.3 - 2.4 GHz
- 4.2 - 4.4 GHz
- 5.4 - 5.9 GHz
- 8.4 - 9.0 GHz
- 9.75 - 9.95 GHz
- 10.015 – 10.425 GHz
- 10.95 – 12.75 GHz
- 14.0 - 14.5 GHz

Example of a complex Ground Control Station, here for the RUAG Ranger UAV

Example of a complex Ground Control Station, here for the Predator UAV

Conclusion

▪ The telemetry and command link must be considered separately to the payload link.

▪The command downlink of UA status information is relatively simple, and can be managed using a 56 kbps GPRS modem or a satellite communications link.

▪ The command and control uplink to the Unmanned Aircraft needs to take into account the need to prevent unauthorised use of the uplink, so this data path must be robust and encrypted. Although the actual information bit rate is relatively low, the transmission bandwidth used in the uplink can be comparable to the downlink bandwidth due to the use of Spread Spectrum modulation.

▪ The World Radio Conference may assign a bandwidth specifically for UAS command and telemetry use... by 2015.

▪ The payload link typically requires a much higher bandwidth than the telemetry and command link, typical values being 8 MHz for a COFDM video link. This bandwidth is not readily available for UAV use, so use is often made of the Industrial, Scientific and Medical (ISM) bands at 2.4 GHz (WLAN 802.11), 5.8 GHz, 20 GHz and so on.

▪ Air Traffic Control voice relay must be supported: the problem at present concerns the latency often experienced with satellite communications: a case for voice recognition software?