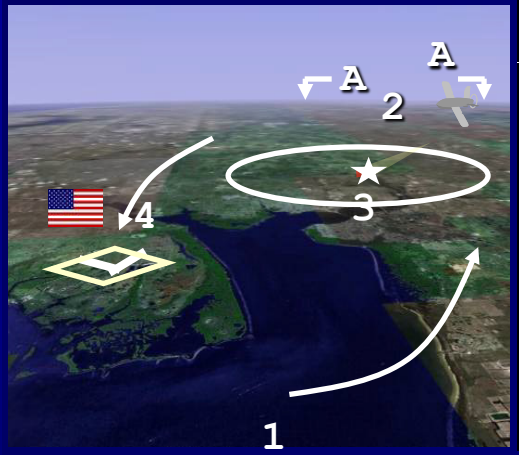
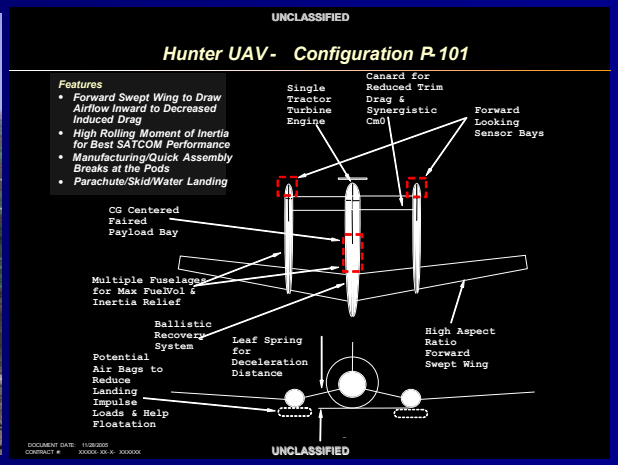
Tier II UAS RF Communication Study

Advanced Tech Engineering
Where Technical Performance & Integrity Matters

Tomorrow's Technology To The Warfighter Today

December 2008





Frank Lucchesi
(952) 435-5805 (Office)
(952) 465-6009 (Mobile)
AdvancedTechEgrg@comcast.net

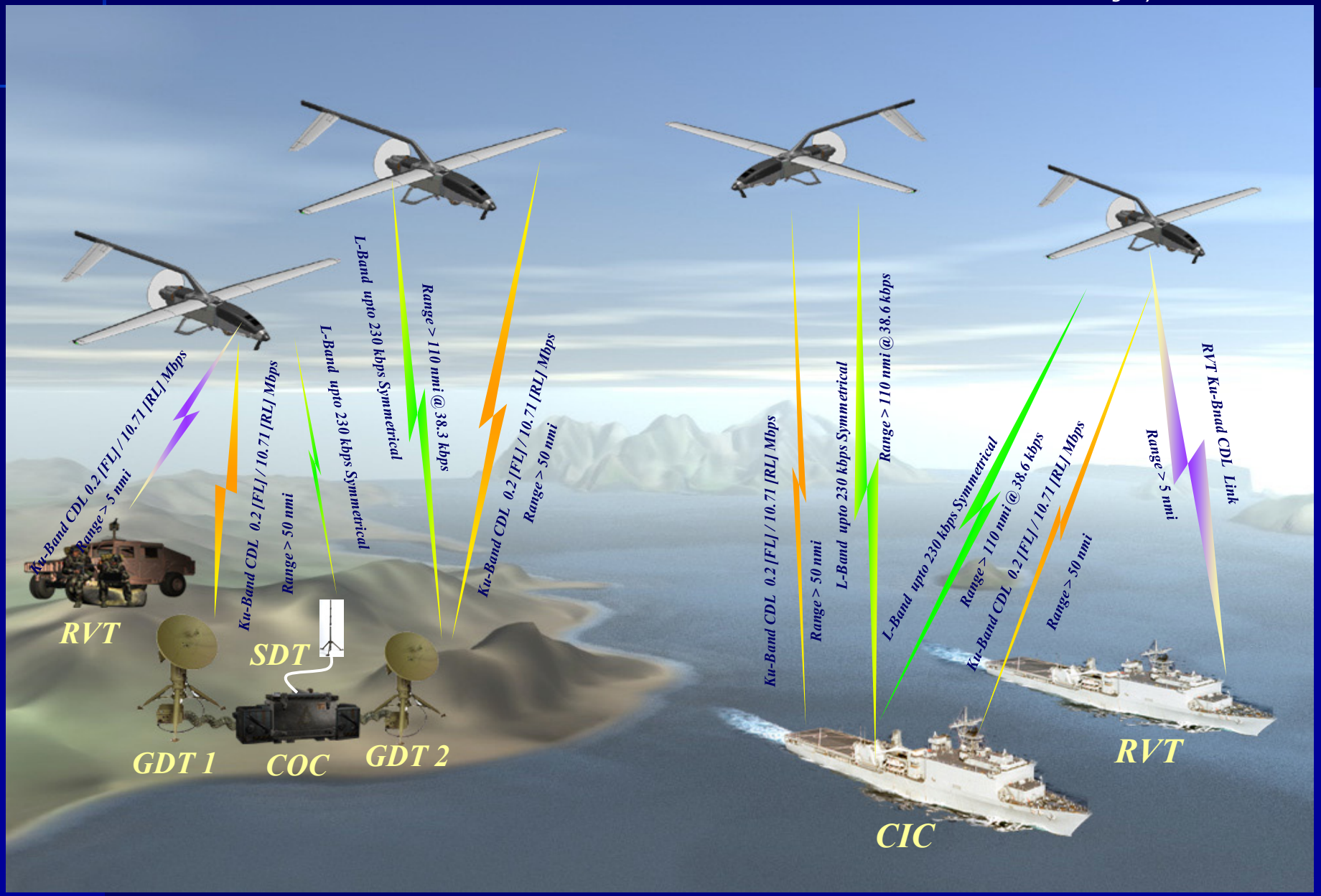
CDD Requirements

- Key System Requirements
  - Persistent surveillance is defined as a combination of AV endurance and system reliability capable of sustained 12 hour per day operations for 30 days, and one surge capability of 24 hours per day for a 10 day period during any 30 day cycle.
  - The GCS shall be capable of controlling and monitoring two air vehicles simultaneously (T).
  - Air Vehicle Operator (AVO) should be able to switch instantaneously between AVs with control measures in place to ensure that safety of flight of both AVs is maintained

- Payload Requirements
  - Full Motion Video (FMV, EO/IR)
  - Communication Relay (CRP)
  - Automatic Identification System (AIS)
  - AV Control Link Relay (Data Relay)

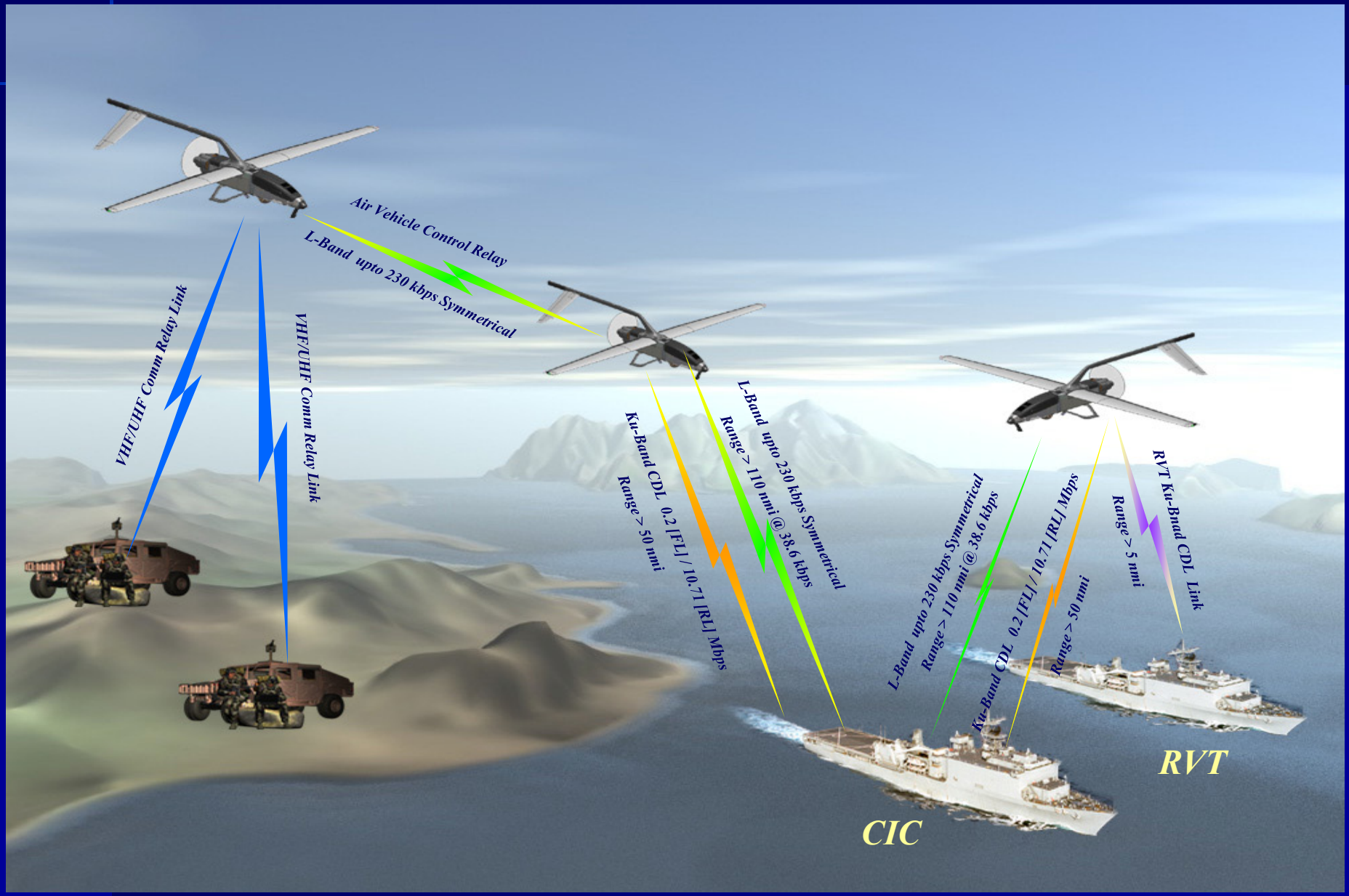
OV1 - CDL as integrated C2, ISR and RVT links

Advanced Tech Engineering
Where Technical Performance & Integrity Matters



OV2 - UAV Control & UHV/VHF Comms Relay links

Advanced Tech Engineering
Where Technical Performance & Integrity Matters



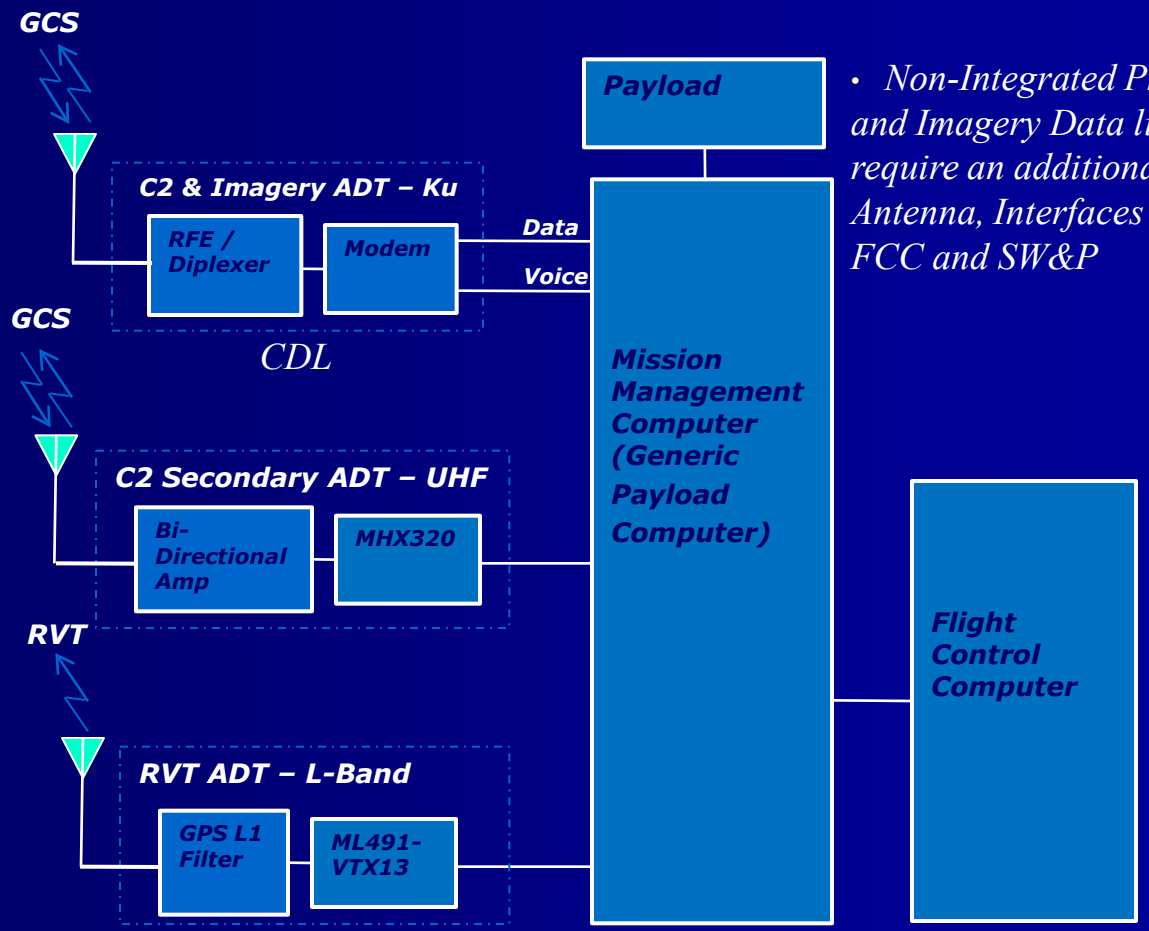
CDL as integrated C2 & Imagery links

- Recommendation
  - ATEI evaluated various UAV C2 Primary, C2 Secondary, Imagery and RVT data link options
  - ATEI recommends using CDL as the integrated primary C2 and Imagery data link baseline; Eliminates one antenna and reduces associated co-site interference contribution
  - Key discriminators:
    - Provides the lowest SW&P impact of all alternatives
    - Lowest NRE cost approach of all alternatives
    - Greatest technical compliance of all alternatives
    - Lowest technical risk of all alternatives
      - Non-proprietary interfaces & waveforms controlled by specification, currently at Rev H
      - Mature technology
        - Spiral 1 units demonstrated on Tier II and other platforms
        - Completed second spiral of three 1 month ahead of schedule
        - Commenced third spiral August 08
    - Will results in the lowest proposed data link cost
  - ATEI has concluded the associated risk is based on unfounded perception of non-mature technology. TRL assessment completed 9/05

CDL incorporates mature, proven technology and provides the best technical and cost effective solution for Tier II platforms

Recommended Comms Baseline DT/OT System

Integrated Primary C2 and Imagery ADT: CDL
Secondary C2 ADT: UHF
RVT ADT: L-Band



- *Non-Integrated Primary C2 and Imagery Data link will require an additional C2 ADT, Antenna, Interfaces to MMC / FCC and SW&P*

Tier II CDL Key Features

- Bi-directional Ku-band
- Full-duplex; Symmetrical, if required
- 200 kbps , 2 Mbps & 10.71 Mbps (Symmetrical) data bandwidth
- Provides one analog voice channel that will provide AVO or MPO to tactical user capability with CRP
- 1, 2 (recommended) , 4 Watt Transmitter Options
- Aperture gain: 4 dBi (Omni); 7.5 dBi (directional);
- Aperture polarization: RHCP (negligible roll-loss)
- SW&P: 3.14”x5.1”x0.72”(Modem); < 2.0 lbs; ~ 35 W
- Flight tested on two tier II platforms in 2007
- Payload Imagery data link data bandwidth drives the ADT power-aperture to meet the 50 nmi air-to-ground link requirement (T)
- Requires directional GDT antenna ~ 40 dBi to close the link @ 50 nmi
- Command and Status Interface (CSI)
  - Open and distributed: AAI; STANAG 4586

Notional System Requirements

General			Demonstration Hardware
Characteristic	**Threshold**	**Objective**	
Example SUAS	KillerBee KB-2 GoldenEye -50	Aerosonde MK4 ScanEagle	ACR Manta, Swift KillerBee, Insitu ScanEagle
Weight[1]	2 Lbs. or less	1 Lb. or less	2 Lb. goal
Volume[2]	20 Cu. In. or less	10 Cu. In. or less	20 Cu. In. goal
Power	20 Watts or less	10 Watts or less	20 Watt goal
CDL and Additional Data Rates[3]	Non-Spread: BR-0.2, BR-0.4, BR-2.0, BR- 10.71A, BR-10.71B; Spread: BR-0.2, BR-0.4, BR-2.0		Forward BR-0.2 spread, Return BR-10.71A
Supported Orthogonal Spreading Codes	4	16	1
IPv4 and IPv6 compatibile	Yes		IPv4
Supported Layer 2 Inputs[4]	2	4	2 Ethernet
Operating Frequency[3]	14.5-15.35 GHz		14.5-15.35 GHz
Encryption	KGV-135A Interoperable		Bypass Mode
Cost per Unit	<$10,000 in lots of 100	<$5,000 in lots of 100	

Notes:
1. All components, including power/control/data interface connectors to the platform, Modem, RF up/down converters, Diplexer, Power Amplifier, Antenna, and cables.
2. System less antenna and cables from terminal to antenna.
3. As defined in Common Data Link Specification, Revision F, Change 1. All rates shall be supported in both the forward and return links.
4. For example Ethernet 10/100, USB II, or other appropriate layer 2 interfaces for multi-sensor operation.

Link Analysis Overview

- *Output Power (Watts)*
- *VSWR Mismatch Loss*

- *Cable loss*
- *Antenna gain relative to isotropic for linear polarization*

- *Freespace propagation as function of range and freq*
- *Environmental noise as a function of freq*
- *Fading margin (fast and slow fades)*

- *Cable loss*
- *Antenna gain relative to isotropic*
- *Polarization Loss*
- *VSWR Mismatch*

- *Receive Noise figure at thread input*
- *Required carrier to noise density to close link*
- *Link margin allocation*

Link Analysis Calculation Overview

Pc = Transmitter Carrier Power (W)

α_T = VSWR mismatch at TX output

Lct = TX Cable Loss

G_T = Transmit antenna gain relative to isotropic

L_{FS} = Freespace path loss

Lf = Fading loss

T_{EXT} = External noise temperature (Deg K)

G_R = Receive antenna gain relative to isotropic

L_{CKT} = Receive antenna circuit loss

Ta = Actual antenna temp (Deg K)

α_R = VSWR mismatch at TX output

Lcr = RX Cable Loss

Tcr = Actual cable temperature

Fr = Receive thread noise figure

$$C/No = \{Pc * \alpha_t * Lct * G_T * L_{FS} * Lf * G_R * \alpha_R\}/\{k * [T_{EXT} + (L_{CKT} - 1) * Ta + (Lcr - 1) * L_{CKT} * Tcr + (Fr - 1) * Lcr * L_{CKT} * To]\}$$

where $k = 1.38*10^{-23}$ and To = 290 Deg K and C/No is computed at the output of a lossless receive antenna

System Margin = 10*log(C/No) –10*log(C/No Required) – Implementation Loss Allowance (dB)

System Noise Temperature Simplifications for Omni Antennas

$C/No = \{Pc * \alpha_t * Lct * G_T * L_{FS} * Lf * G_R * \alpha_R\}/\{k * [T_{EXT} + (L_{CKT} -1)*Ta + (Lcr-1)* L_{CKT} *Tcr + (Fr-1)*Lcr* L_{CKT} *To]\}$

Note that

$T_{EXT} + (L_{CKT} -1)*Ta + (Lcr-1)* L_{CKT} *Tcr + (Fr-1)*Lcr* L_{CKT} *To$

can be simplified if we assume $Ta = Tcr = To$ *to*

$T_{EXT} + To * (Fr*Lcr* L_{CKT} - 1)$

If we combine the antenna circuit loss terms into single antenna temperature that is estimated to be 290 Deg K in the absence other

external noise factors then a simplified expression is just

$T_{ANT} + To * (Fr*Lcr-1)$

where T_{ANT} *is the max(*T_{EXT}*, To) and C/No is referenced to the output of the lossy antenna and the antenna gain includes the losses of the antenna matching network or other ohmic losses*

Resulting expression for C/No is

$C/No = \{Pc * \alpha_t * Lct * G_T * L_{FS} * Lf * G_R * \alpha_R\}/\{k * [T_{ANT} + To * *(Fr*Lcr-1)]\}$

where T_{ANT} *is estimated to be the external noise terms plus circuit noise that will set a floor of at least 290 Deg K*

Preliminary Link Analysis – Primary C2 and Imagery Data Link (Mini –TCDL)

CDL Link Analysis

Example using LinkBudget 98

```
-------------------------------------------------------------
File Name   = C:\Users\Frank\Documents\STUAS\Link Analysis\
              STUAS Mini-TCDL.lb8
Date        = 09/07/08  20:37:03
Title       = STUAS Mini-TCDL Link Analysis
================ Link Information ================================
    Frequency                                 = 14.6          GHz
    Data Rate                                 = 2000          kb/s
    Modulation Type                           = QPSK
    Forward Error Correction Decoder          = VA 1/2
    Bit Error Rate (BER)                      = 1.0E-08
    Transmitter Altitude                      = 9000          ft
    Receiver Altitude                         = 10            ft
    Receiver Elevation Angle                  = 1.38          degree
    Slant Range                               = 50            nm
    Earth Radius Factor                       = 1.333

================ Link Budget ====================================
    Saturated Power                           = 2             W
    Output Backoff (OBO)                      = 0.00          dB
    Losses to Antenna Feed                    = 1.50          dB

    Tx Antenna Gain                           = 4.00          dB
    Net EIRP (includes all losses)            = 5.51          dBW

    ECM Path (95.00% availability)
        Fading                                = 4.95          dB
        Scintillation                         = 4.59          dB
        Atmospheric Loss                      = 1.60          dB
        Cloud Loss                            = 1.67          dB
        Rain Loss                             = 4.62          dB
    Combined Attenuation                      = 9.87          dB

    Free Space Loss                           = 155.07        dB

    Rx Antenna Gain                           = 40.00         dB
    Polarization Mismatch Loss                = 0.35          dB
    Tracking (pointing) Loss                  = 0.75          dB
    Received Power                            = -120.53       dBW

    Rx Noise Power Density                    = -203.98       dBW/Hz
    Rx System Feed-Line Losses                = 0.50          dB
    Receiver Noise Figure                     = 3.00          dB
    Effective System Temperature              = 28.12         dBK
    Boltzman's Constant                       = -228.60       dBW/Hz-K
    Link Carrier to Noise (C/No)              = 79.94         dB-Hz

    Theoretical Eb/No Required                = 5.89          dB
    Implementation Loss                       = 1.00          dB
    Eb/No Required                            = 6.89          dB
    Eb/No Available                           = 16.93         dB
    Link Margin                               = 10.05         dB
```

Preliminary Link Analysis – CDL Primary C2 and Imagery Data Link Summary

Link Analysis Summary

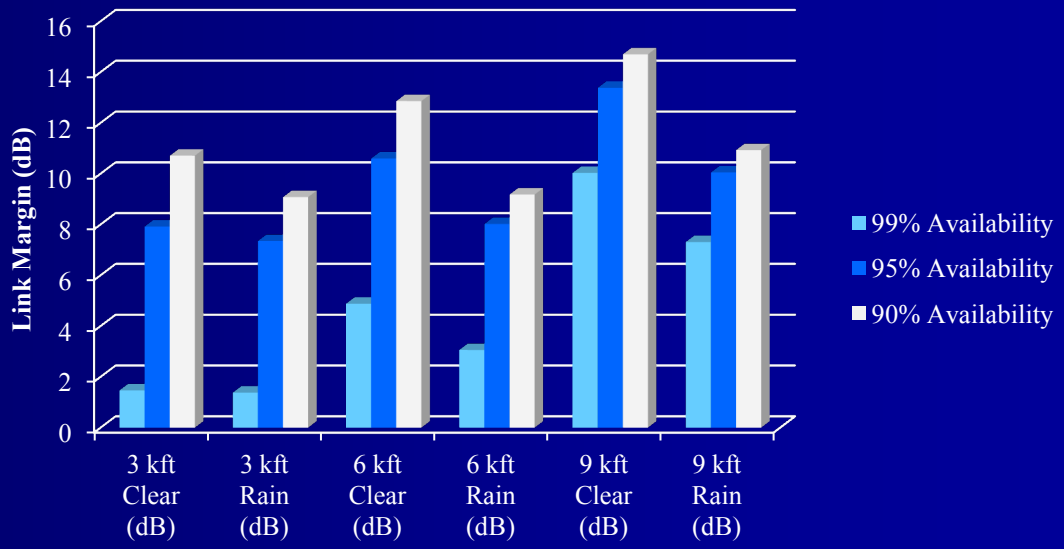
- *Preliminary link analysis shows link closure at 50nmi @ 2 Mbps (optional waveform) in the clear and specified rain conditions for 90%, 95% and 99% availability*
- *This case represents the nominal case since the max data rate corresponding to compressed MPEG2 video ~ 1.4 Mbps*
- *Antenna gain over specified coverage volume under normal roll/pitch condition and co-site degradation has not been considered*

Note: Link availability has not yet been specified in the system specification

	UAV Height / Conditions					
Availability	**3 kft Clear (dB)**	**3 kft Rain (dB)**	**6 kft Clear (dB)**	**6 kft Rain (dB)**	**9 kft Clear (dB)**	**9 kft Rain (dB)**
99%	1.47	1.38	4.88	3.06	10.03	7.31
95%	7.92	7.35	10.6	8.02	13.38	10.05
90%	10.71	9.08	12.86	9.18	14.7	10.93

Data BW: 2.0 Mbps
Rain Rate - 2.5 mm /hr
UAV Pt = 2W; Gt = 4.0 dBi
Modulation.: QPSK; FEC 1/2 Viterbi; BER 1E10(-8)

CDL Link Margin (50 nmi @ 2.0 Mbps without Co-site degradation)



Preliminary Link Analysis – CDL Primary C2 and Imagery Data Link Summary

Link Analysis Summary

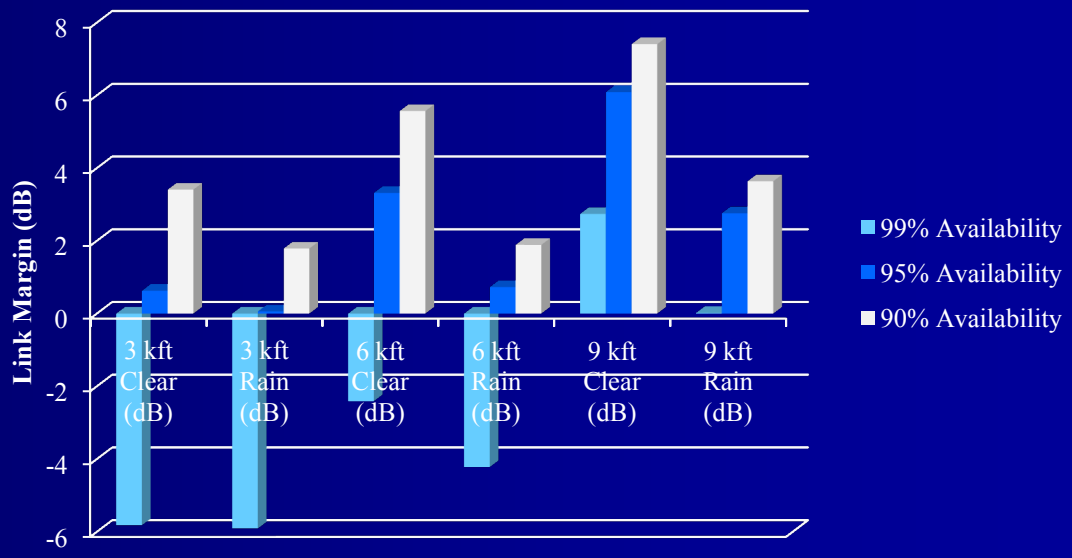
- *Preliminary link analysis shows link closure at 50nmi @ 10.71 Mbps (mandatory waveform) in the clear and specified rain conditions for 90%, 95% availability, and in the clear and rain conditions at 9 kft relative UAV altitude*
- *This case does not represent the nominal case since the required max data BW ~ 1.4 Mbps*
- *Antenna gain over specified coverage volume under normal roll/pitch condition and co-site degradation has not been considered*

Note: Link availability has not yet been specified in the system specification

	UAV Height / Conditions					
Availability	**3 kft Clear (dB)**	**3 kft Rain (dB)**	**6 kft Clear (dB)**	**6 kft Rain (dB)**	**9 kft Clear (dB)**	**9 kft Rain (dB)**
99%	-5.82	-5.91	-2.41	-4.22	2.74	0.02
95%	0.63	0.06	3.32	0.73	6.09	2.76
90%	3.41	1.79	5.57	1.89	7.41	3.64

Data BW: 10.71 Mbps
Rain Rate - 2.5 mm /hr
UAV Pt = 2W; Gt = 4.0 dBi
Modulation.: QPSK; FEC 1/2 Viterbi; BER 1E10(-8)

CDL Link Margin (50 nmi @ 10.71 Mbps without Co-site degradation)



Preliminary Link Analysis – RVT Link @ Ku-Band

Link Analysis Summary

- *Preliminary link analysis shows that the RVT link does not close at Ku-Band due low RVT antenna gain, 3.5 dBi.*
- *Antenna gain over specified coverage volume under normal roll/pitch condition and co-site degradation has not been considered*

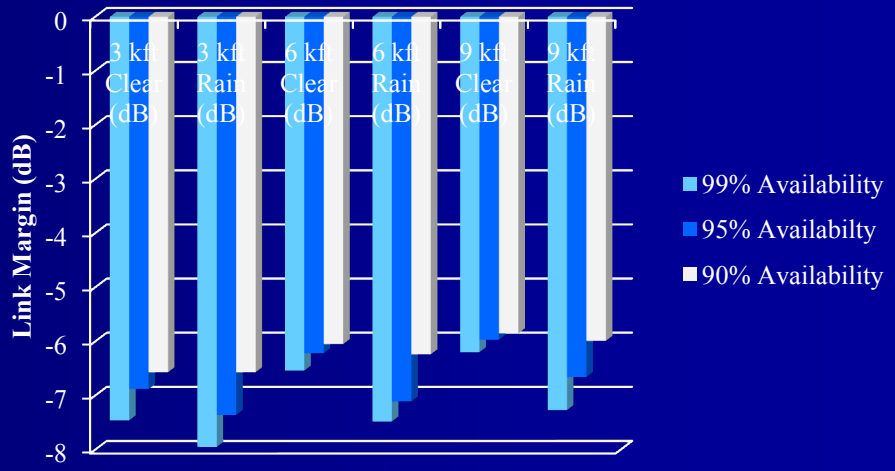
Note: Link availability has not yet been specified in the system specification

- *Recommend using L-band analog RF link for RVT*

	UAV Height / Conditions					
Availability	**3 kft Clear (dB)**	**3 kft Rain (dB)**	**6 kft Clear (dB)**	**6 kft Rain (dB)**	**9 kft Clear (dB)**	**9 kft Rain (dB)**
99%	-7.46	-7.95	-6.54	-7.48	-6.2	-7.27
95%**	-6.88	-7.36	-6.22	-7.11	-5.97	-6.66
90%*	-6.57	-6.57	-6.05	-6.24	-5.85	-5.99

Data BW: 10.71 Mbps
Rain Rate < 1.8 mm /hr
UAV Pt = 2W; Gt = 4.0 dBi
RVT Gt = 3.5 dBi
Modulatio.: QPSK; FEC 1/2 Viterbi; BER 1E10(-8)
*** No rain available in model at this availability**
**** Rate rate < 1.8 mm / hr**

CDL RVT Link Margin (5 nmi @ 10.71 Mbps without Co-site degradation)



Preliminary Link Analysis – RVT Link @ L-Band

Link Analysis Summary

- *Preliminary link analysis shows RVT link closure at 5nmi, RF analog video, L-Band with minimal design margin assuming 10W PA*
- *Short term fades range over about 13 dB between the 10 and 90 percentile levels*
- *Antenna gain over specified coverage volume under normal roll/pitch condition and co-site degradation has not been considered*

Note: Link availability has not been specified in the system specification

	Video Link Budget for Downlink Air-> Gnd	Low- Ch	Mid-Ch	High- Ch	
	Link Frequency of Operation (MHz)	1710	1780	1850	Comments
Item	Transmit Power				
1	PA output power (Watts)	10	10	10	Min carrier power per L3 spec
2	Video Transmit power (dBm)	40.0	40.0	40.0	10*log(Item1) + 30
3	VSWR mismatch loss (dB)	0.7	0.7	0.7	Transmit module into cable plus notch/antenna. Assumes Measured Aperture VSWR
4	Cable loss (dB)	0.5	0.5	0.5	Verify Cable Assy Loss
5	Notch Filter Loss (dB)	0.75	0.75	0.75	Estimate for In-line filter(s) to reduce GPS L1 and Uplink Rx interference
6	Antenna peak gain (dBi)	2	2	2	Assume perfect isotropic aperature. Gain relative to isotropic for LP
7	**Effective radiated power (dBm)**	**40.1**	**40.1**	**40.1**	PT+GT-L
	Channel Loss				
8	**Link range (KM)**	**9.26**	**9.26**	**9.26**	Line of sight path length (1.852 km = 1 nmi)
	Calculated nmi	**5.0**	**5**	**5**	
9	Excess path loss	0	0	0	multipath fading
10	Absorption Loss (Clear/ Rain)	0.06	0.06	0.06	One -way Loss; L-band
11	Polarization Efficiency Loss (dB)	1	1	1	Vert LP-> Vert LP Aperture. Assume 1.5 dB efficiency loss for non co-linear. Will lose efficiency when turning/banking loss
12	Avg. Beamshape Loss	0	0	0	Omni-directional L-Band or S-Band Gnd Antenna
13	**Channel Path Loss (dB)**	**117.5**	**117.8**	**118.2**	Fading_Loss + 37.8 + 20*log(FreqMHz) + 20*Log(R_KM)
	System Noise Power = KTBF				
14	Antenna temperature (Deg K)	290	290	290	
15	Cable loss (dB)	0.5	0.5	0.5	Validate cable type/loss at frequency; 3 Cable Assy and Bulkhead connector
16	In-Line HPF or BPF Loss	0.0	0.0	0.0	Lorch Microwave Spec
17	Receiver Module noise figure (dB)	6	6	6	Sensitivity Improvement 2 dB Per L3 Comm PO (e.g. -87 dBm)
18	Channel noise figure at antenna output (dB)	6.5	6.5	6.5	Composite noise figure referenced to antenna output
19	Noise Bandwidth (MHz)	22.0	22.0	22.0	IF BW per L3 Spec
20	Receive noise power (dBm)	**-94.1**	**-94.1**	**-94.1**	30+ 10*LOG10(1.38E-23)+ 10*LOG10(T)+ 10*log10(B*1e6) + NF
21	Co-Site Degradation	0.00	0.00	0.00	Degradation from co-site Interference (Spurs, Harmonis, Broadband Noise)
22	**Noise Power w/Degradation (dBm)**	**-94.1**	**-94.1**	**-94.1**	
	Received Carrier Power to Noise Ratio (CNR)				C/N
23	Receive antennna peak gain (dBiL)	0	0	0	Gain relative to isotropic for Linear Vertical Pol. Spec Values
24	VSWR Mismatch (dB)	0.0	0.0	0.0	Antenna into cable to Rx module (assume considered in erover Sensitivity)
25	Received Carrier Power (dBm)	**-77.4**	**-77.8**	**-78.1**	EIRP-Path_Loss+Gr-Mismatch
26	Noise Power w/Degradation (dBm)	-94.1	-94.1	-94.1	From Item 19
27	**C/N (dB)**	**16.6**	**16.3**	**15.9**	Item 20-21. Assumes no degradation due to co-site interference
	Link Margin				
28	Required C/N	12	12	12	From back calc from L3 spec data. Corresponds to C/No = 58.5 dBm for FM Channel
30	Excess C/N (dB)	4.6	4.3	3.9	Items 27-28-29
31	**Zero Margin Link Range (KM)**	**15.7**	**15.1**	**14.6**	Range increase or reduction at 0 margin
32	**Zero Margin Link Range (nmi)**	**8.5**	**8.2**	**7.9**	Range increase or reduction at 0 margin

CDL Task Order 2 Design Capabilities

Functionality	**Task Order 1**	**Task Order 2**
Power out of PA	0.8 watts	1 to 2 watts
Ant Gain	0 dBi	3dB Omni, 6-8 dBi Directional
Data Rates	.2/2/10.71A Mbps	.2/.4/2/10.71A&B/21/45 Mbps *2.0/4.0 Mbps
Interfaces	Ethernet	Ethernet/Serial
MPEG2	External	Internal to Modem
Encryption	None	NSA Type 1 partitioning
Gender Agnostic	No	Yes
Nav Data Channel	No	Yes
Power Draw	<20 watts	<40 watts