Lesson objective - *to discuss*

UAV Communications

including …

- RF Basics
- Communications Issues
- Sizing

Expectations - You will understand the basic issues associated with UAV communications and know how to define (size) a system to meet overall communication requirements

Week 4

- **Sortie rate estimates**
- **Requirements analysis**

Week 5

- **Communication considerations and sizing**

Week 6

- **Control station considerations and sizing**
- **Payload (EO/IR and radar) considerations and sizing**

Week 7

- **Reliability, maintenance, safety and support**
- **Life cycle cost**

Week 8

- **Mid term presentations**

- **Communications are a key element of the overall UAV system**

- **A UAV system cannot operate without secure and reliable communications**

  - unless it operates totally autonomously

    - *Only a few (generally older) UAVs operate this way*

- **A good definition (and understanding) of communications requirements is one of the most important products of the UAV concept design phase**

- **RF basics**
    - Data link types
    - Frequency bands
    - Antennae
    - Equations
- **Communications issues**
    - Architecture
    - Function
    - Coverage
    - Etc.
- **Sizing (air and ground)**
    - Range
    - Weight
    - Volume
    - Power
- **Example problem**

- Simplex - One way point-to-point
- Half duplex - Two way, sequential Tx/Rx
- Full duplex - Two way, continuous Tx/Rx
- Modem - Device that sends data sent over analog link
- Omni directional - Theoretically a transmission in all directions (4π steradian or antenna gain ≡ 0) but generally means 360 degree azimuth coverage
- Directional - Transmitted energy focused in one direction (receive antennae usually also directional)
  - *The more focused the antennae, the higher the gain*
- Up links - used to control the UAV and sensors
- Down links - carry information from the UAV (location, status, etc) and the on-board sensors

Frequency bands

Civil Radio **band designation**

1-10 kHz	VLF (very low frequency)
10-100 kHz	LF (low frequency)
100-1000 kHz	MF (medium frequency)
1-10 MHz	HF (high frequency)
10-100 MHz	VHF (very high frequency)
100-1000 MHz	UHF (ultra high frequency)
1-10 GHz	SHF (super high frequency)
10-100 GHz	EHF(extremely high frequency)

US Military and Radar **bands**

1-2 GHz	L	Band
2-4 GHz	S	Band
4-8 GHz	C	Band
8-12 GHz	X	Band
12-18 GHz	Ku	Band
18-27 GHz	K	Band
27-40 GHz	Ka	Band
40-75 GHz	V	Band
75-110 GHz	W	Band
110-300 GHz	mm	Band
300-3000 GHz	μmm	Band

NATO

D	Band
E/F	Band
G/H	Band
I	Band
J	Band
K	Band
K	Band
L	Band
M	Band

Note - NATO designations cover almost the same frequency ranges

Satellite **band designation**

S	Band	1700-3000 MHz
C	Band	3700-4200 MHz
Ku1	Band	10.9-11.75 GHz
Ku2	Band	11.75-12.5 GHz
Ku3	Band	12.5-12.75 GHz
Ka	Band	18.0-20.0 GHz

Military and civilian UAVs communicate over a range of frequencies

- An informal survey of over 40 UAVs (mostly military, a few civilian) from Janes UAVs and Targets shows:

Up links

Band	% using
VHF (RC)	13%
UHF	32%
D	6%
E/F	11%
G/H	21%
J	15%
Ku	2%

Down links

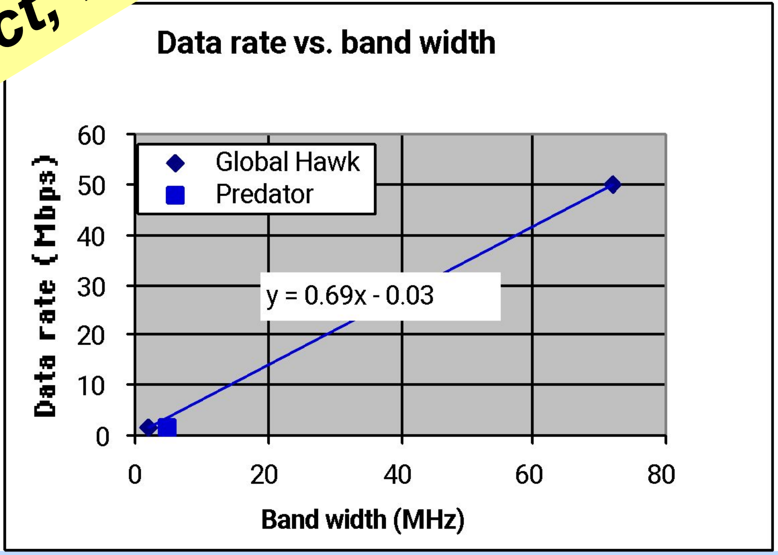
Band	% using
VHF	0%
UHF	17%
D	19%
E/F	13%
G/H	23%
J	17%
Ku	9%

Higher frequency down links provide more bandwidth

- **Carrier frequency**
  - The center frequency around which a message is sent
  - The actual communication or message is represented by a modulation (e.g. FM) about the carrier
- **Bandwidth**
  - The amount (bandwidth) of frequency (nominally centered on a carrier frequency) used to transmit a message
  - Not all of it is used to communicate
    - *Some amount is needed for interference protection*
  - Sometimes expressed in bauds or bits per second but this is really the data rate

- **How much real data can be sent (bits per second)**
  - A typical voice message uses a few Kbps ...d can be transmitted on a single frequency char...
    - *Real time video can require Mb... be transmitted across a range ...*
    - *Still images can be sent ... over time*
- **Sometimes describe... line notation**
    - T1 = 1.5 mbps; ... etc
- **Related to b... but not ...**
    - *- S... erro... and other facto... volved*
    - *- Limited data shows a 70% relationship*

Many people use band width and data rate as synonymous terms. Even though not rigorously correct, we will do likewise



- **The physical orientation of an RF signal**
  - Typically determined by the design of the antenna
  - But influenced by ground reflection
- **Two types of polarization, linear and circular**
  - Linear polarity is further characterized as horizontal ("h-pole") or vertical ("v-pole")
    - *A simple vertical antenna will transmit a vertically polarized signal. The receiving antenna should also be vertical*
    - *V-pole tends to be absorbed by the earth and has poor ground reflection (∴tracking radars are V-pole).*
    - *H-pole has good ground reflection which extends the effective range (∴ used for acquisition radars)*
  - Circular polarity typically comes from a spiral antenna
    - *EHF SatCom transmissions are usually circular*
    - *Polarization can be either right or left hand circular*

- **Antenna gain - a measure of antenna performance**
  - Typically defined in dBi = 10*log10(P/Pi)
    - *where P/Pi = ability of an antenna to focus power vs. theoretical isotropic (4π steradian) radiation*
    - *Example - an antenna that focuses 1 watt into a 3deg x 3 deg beam (aka "beam width") has a gain of*

*10*Log10(1/3^2/1/360^2) = 41.6 dB*

  - For many reasons (e.g., bit error rates) high gain antennae (>20dBi) are required for high bandwidth data

    Example - 10.5 Kbps Inmarsat Arero-H Antenna

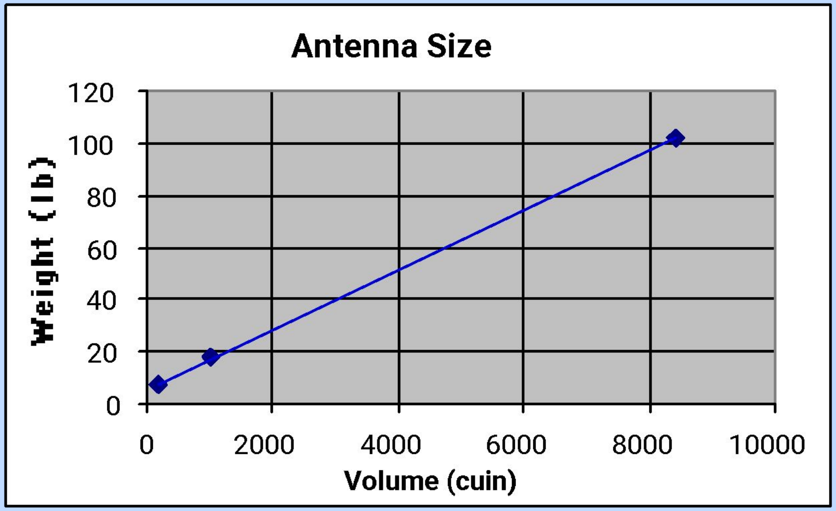
  - For small size and simplicity, low gain antenna (< 4 dBi) are used……….. for low bandwidth data

    Example - 600 bps Inmarsat Aero-L Antenna

Inmarsat L (600 bps)
Weight = 8 lb, ? dB

Inmarsat I (4.8 Kbps)
Weight = 18 lb, 6 dB

Inmarsat H (≈9.6 Kbps)
Weight = 102 lb, 12 dB



Data and pictures from http://www.tecom-ind.com/satcom.htm, weights = antenna + electronics

Free space loss

- The loss in signal strength due to range (R) $= (\lambda/4\pi R)^2$
- Example : 10 GHz (λ=0.03m) at 250 Km = 160.4 dBi

Atmospheric absorption

- Diatomic oxygen and water vapor absorb RF emissions
- Example : 0.01 radian path angle at 250 Km = 2.6 dB

Precipitation absorption

- Rain and snow absorb RF emissions
- Example : 80 Km light rain cell at 250 Km = 6.5 dB

Examples from "Data Link Basics: The Link Budget", L3 Communications Systems West

Architecture

- Military
- Commercial
- "Common"

Function

- Up link (control)
  - Launch and recovery
  - Enroute
  - On station
  - Payload control
- Down link (data)
  - Sensor
  - System status

Coverage

- Local area
- Line of sight
- Over the horizon

Other issues

- Time delay
- Survivability
  - Reliability
  - Redundancy
  - Probability of intercept
- Logistics

Military communications systems historically were quite different from their civilian counterparts

- With the exception of fixed base (home country infrastructure) installations, military communications systems are designed for operations in remote locations under extreme environmental conditions
- They are designed for transportability and modularity
  - Most are palletized and come with environmental shelters

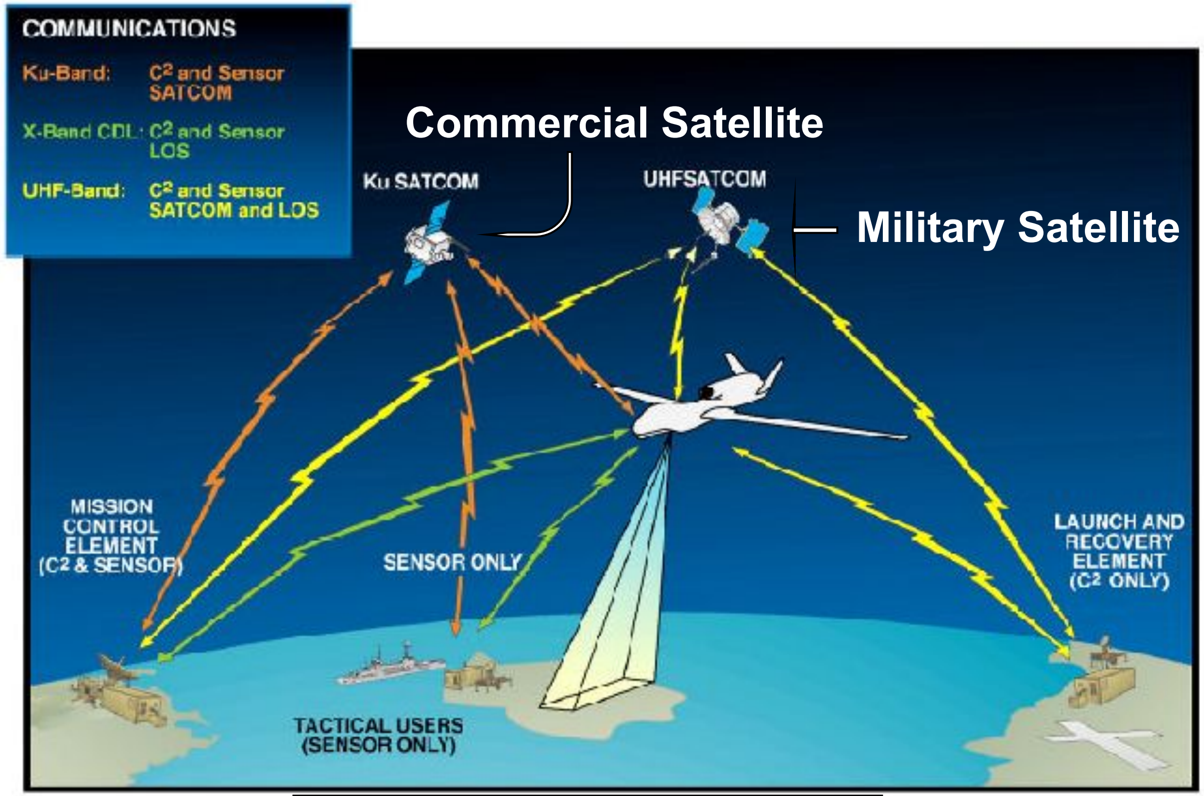
Civilian communications systems were (and generally still are) designed for operation from fixed bases

- Users are expected to provide an environmentally controlled building (temperature and humidity)

Now, however, the situation has changed

Military operators now depend on a mix of civilian and military communications services

- Cell phones and SatCom have joined the military

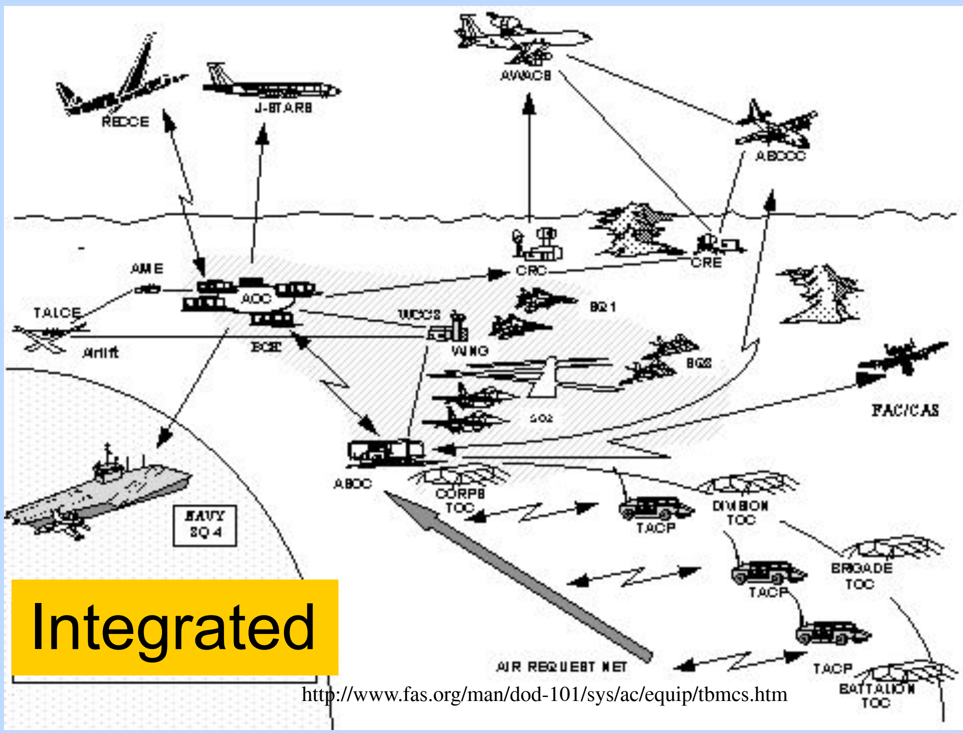


Global Hawk example

Approved for Public Release (Distribution Unlimited)

Military communications systems generally fall into one of two categories

- Integrated - multiple users, part of the communications infrastructure
- Dedicated - unique to a system



UAV communication systems are generally dedicated

- The systems may have other applications (e.g. used by manned and unmanned reconnaissance) but each UAV generally has its own communications system
  - *US military UAVs have an objective of common data link systems across all military UAVs (e.g.TCDL)*
  - *Multiple UAV types could be controlled*
- Frequencies or geographic areas are allocated to specific UAVs to prevent interference or "fratricide"

UAV communications equipment is generally integrated with the control station

- This is particularly true for small UAVs and control stations
- Larger UAVs can have separate communications pallets

US common data links

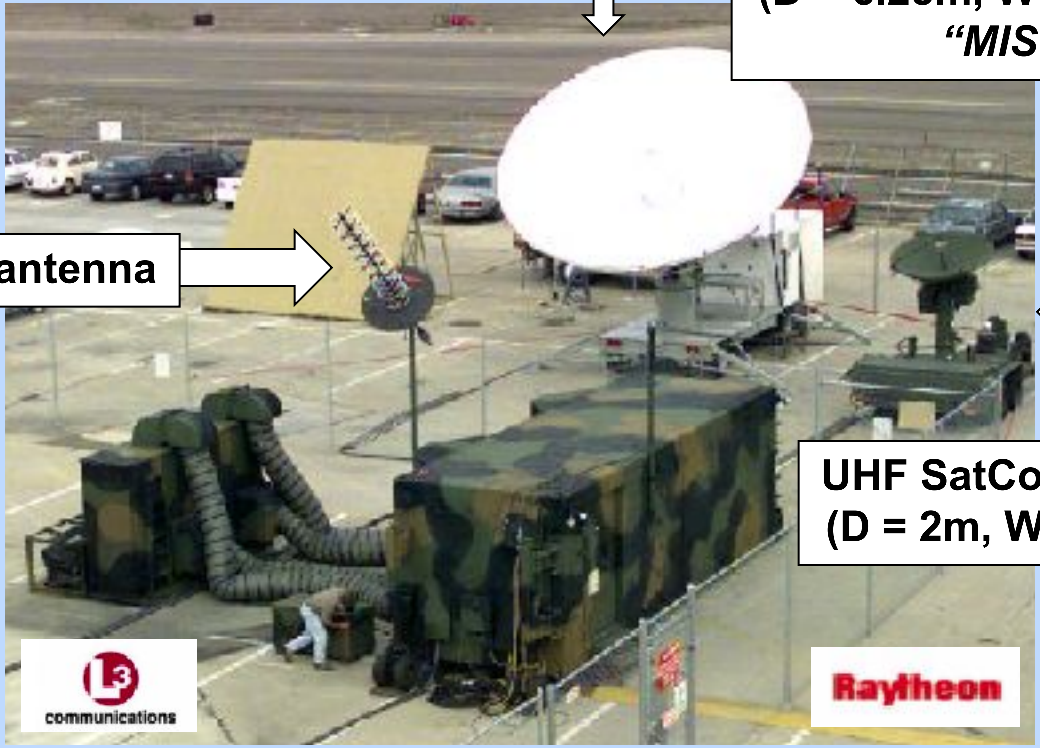
- *Excerpts from* - **Survey of Current Air Force Tactical Data Links and Policy,** ***Mark Minges, Information Directorate, ARFL. 13 June 2001***
  - A program which defines a set of common and interoperable waveform characteristics
  - A full duplex, jam resistant, point-to-point digital, wireless RF communication architecture
  - Used with intelligence, surveillance and reconnaissance (ISR) collection systems
- **Classes & tech base examples**
  - Class IV (SatCom) - DCGS (Distributed Common Ground System)
  - Class III (Multiple Access) - RIDEX (AFRL proposed)
  - Class II (Protected) - ABIT (Airborne Information transfer)
  - Class I (High Rate) - MIST (Meteorological info. std. terminal)
  - Class I (Low Rate) - TCDL (Tactical CDL)

Global Hawk GDT

GDT = Ground "data terminal"

Ku band SatCom terminal (D = 6.25m, W = 13950 lb) *"MIST"*

UHF LOS antenna



UHF SatCom terminal (D = 2m, W =6500 Lb)

Approved for Public Release (Distribution Unlimited)
August 12, 1999
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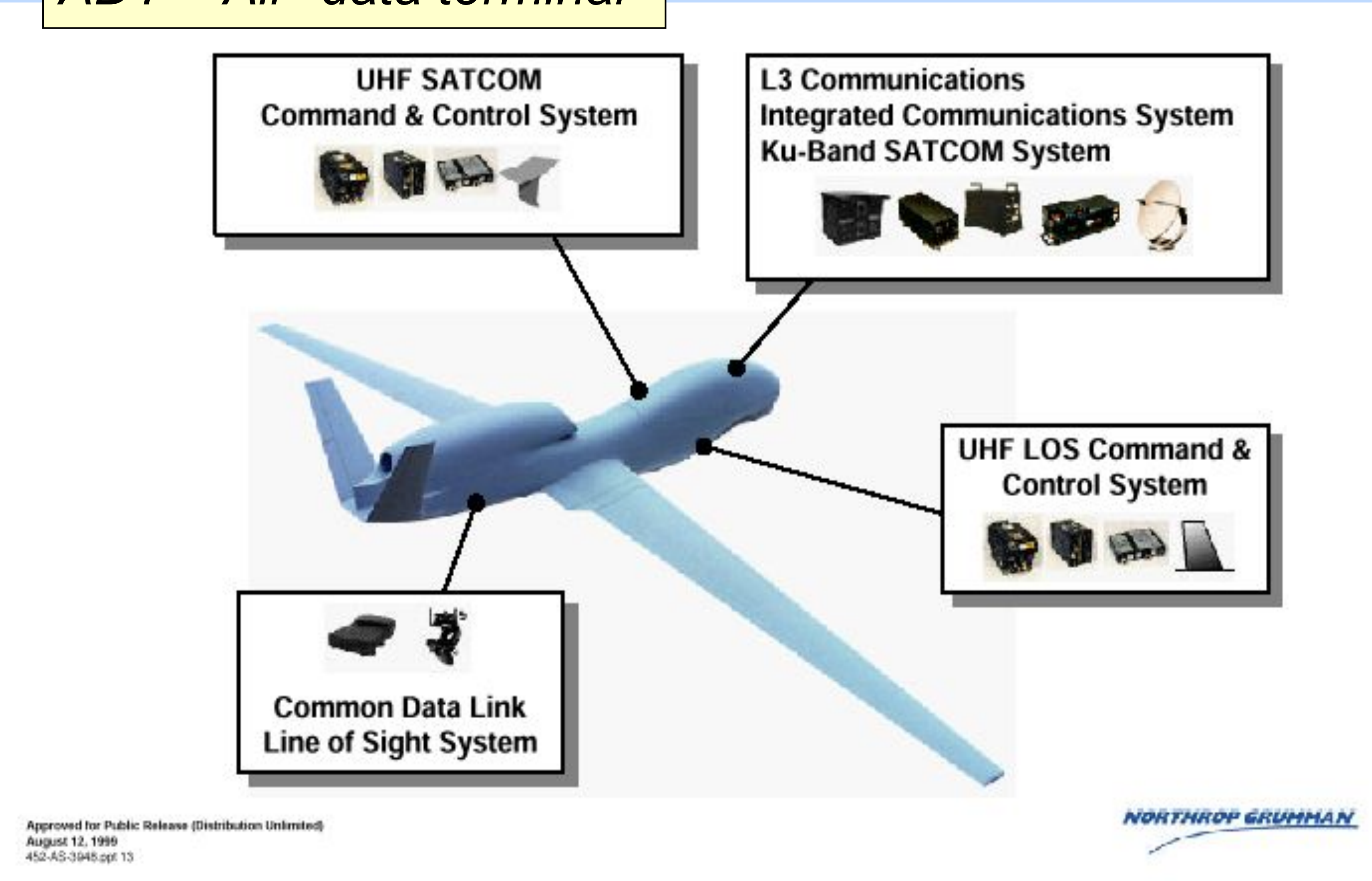
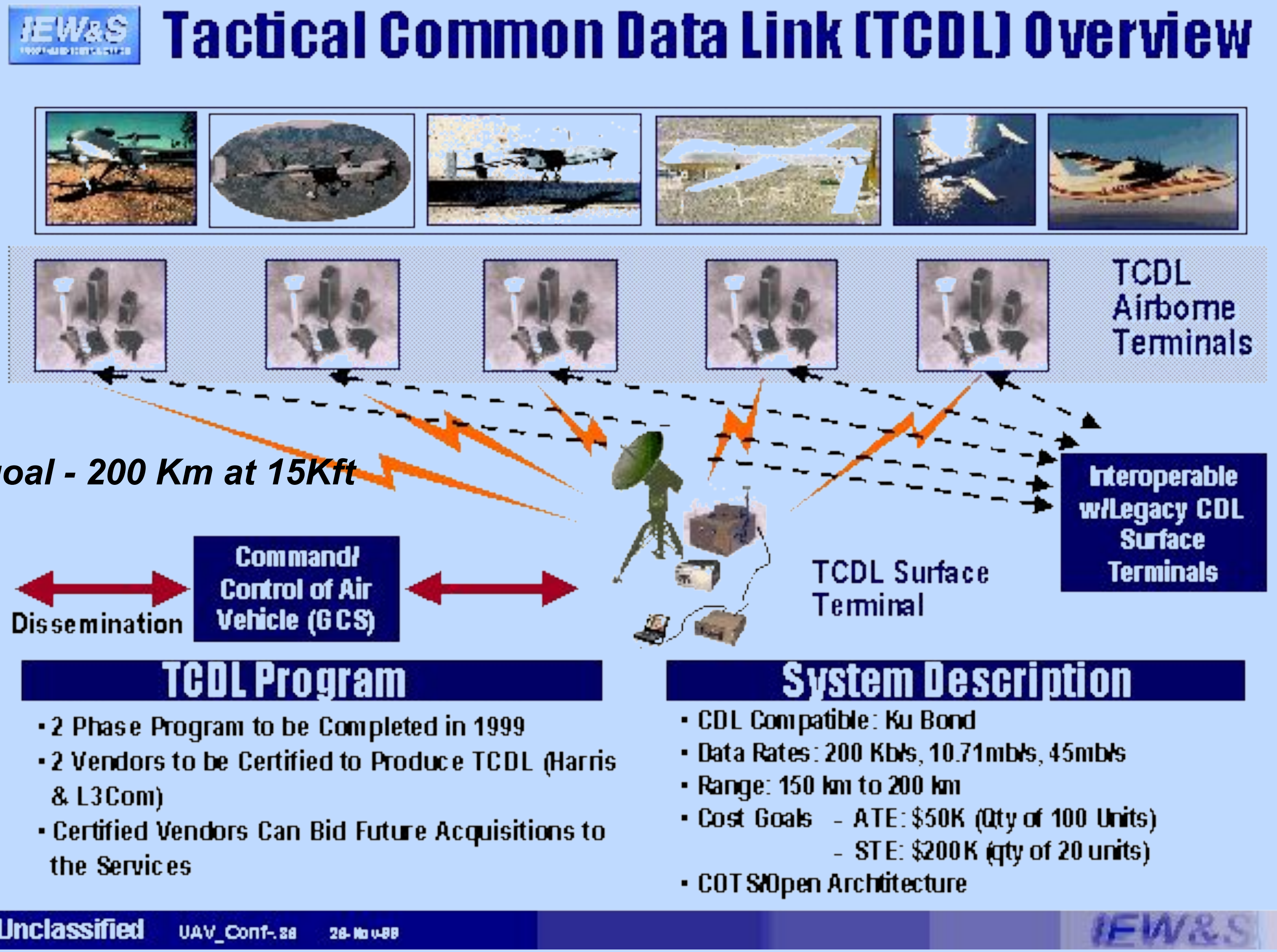
Global Hawk ADT

ADT = Air "data terminal"





Range goal - 200 Km at 15Kft

Next subject

Architecture

- Military
- Commercial
- "Common"

Function

- Up link (control)
  - Launch and recovery
  - Enroute
  - On station
  - Payload control
- Down link (data)
  - Sensor
  - System status

Coverage

- Local area
- Line of sight
- Over the horizon

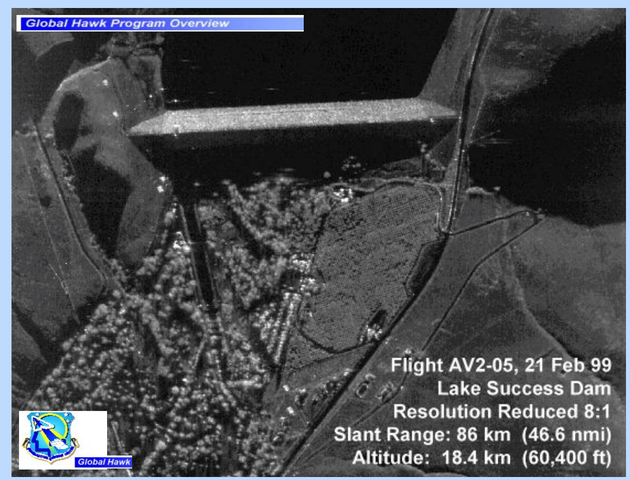
Other issues

- Time delay
- Survivability
  - Reliability
  - Redundancy
  - Probability of intercept
- Logistics

Launch and Recovery

Enroute

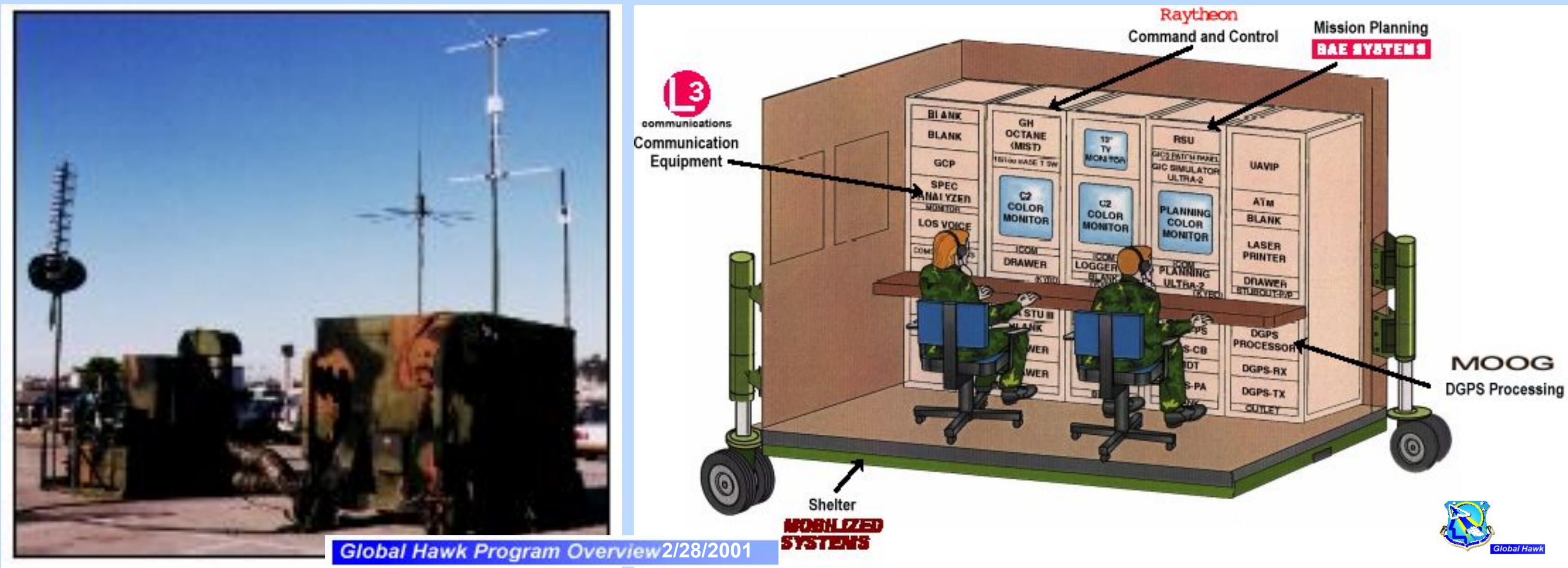
On station



Payload

Located at the operating base

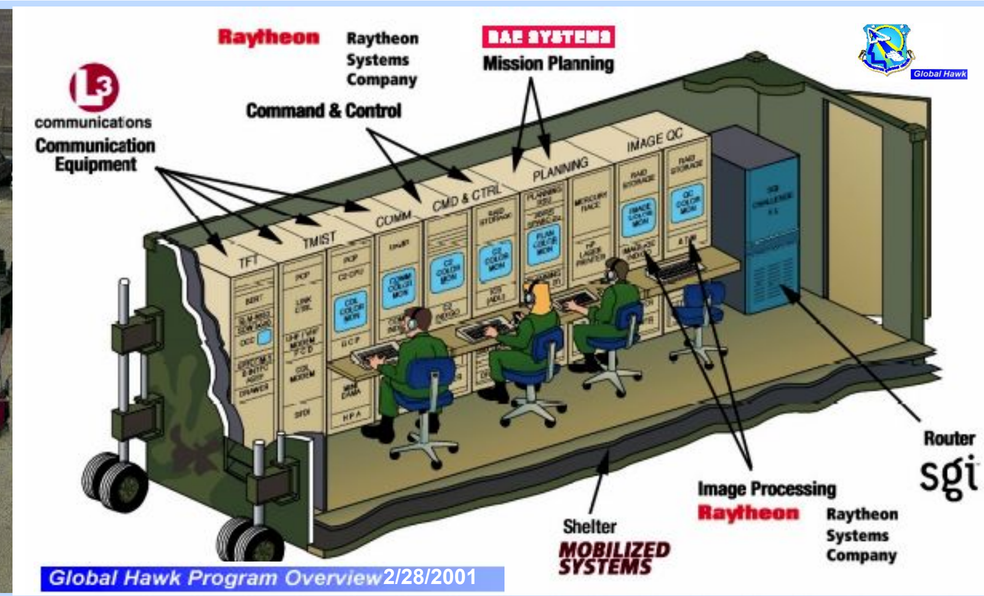
- Control the UAV from engine start through initial climb and departure….and approach through engine shut down
- Communications must be tied in with other base operations
  - Usually 2-way UHF/VHF (voice) and land line
- Also linked to Mission Control (may be 100s of miles away)



Global Hawk Launch Recovery Element

Launch and recovery <u>or</u> mission control responsibility

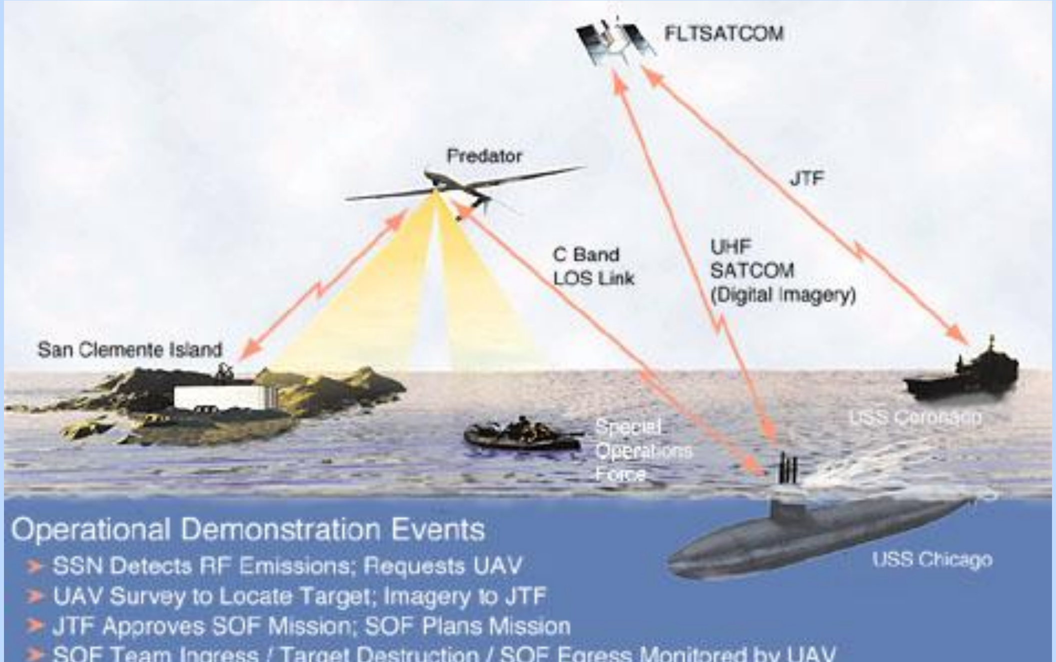
- Control the UAV through air traffic control (ATC) airspace
  - Usually 2-way UHF/VHF (voice)
- Primary responsibility is separation from other traffic - particularly manned aircraft (military and civil)
  - UAV control by line of sight, relay and/or SatCom data link



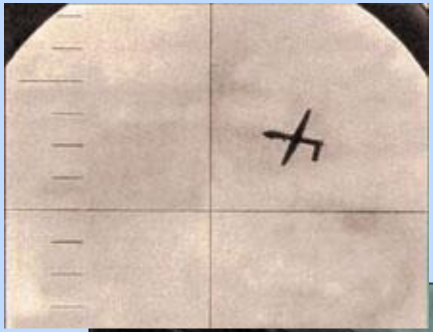
Global Hawk Mission Control Element

Primary mission control responsibility

- Control the UAV air vehicle in the target area using line of sight, relay and/or SatCom data link
  - Bandwidth requirements typically 10s-100s Kpbs
- Control sometimes handed off to other users
  - Mission control monitors the operation



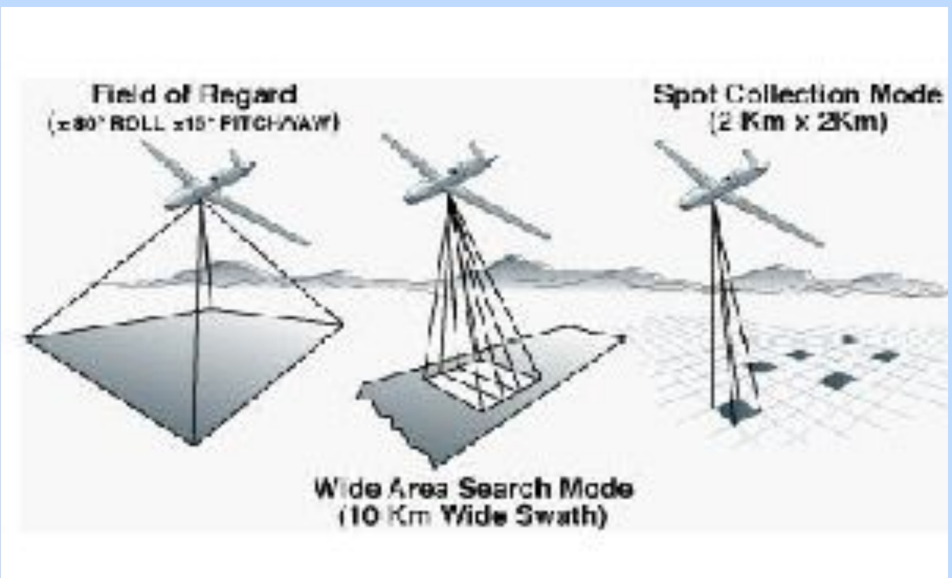
http://www.fas.org/irp/program/collect/predator.htm



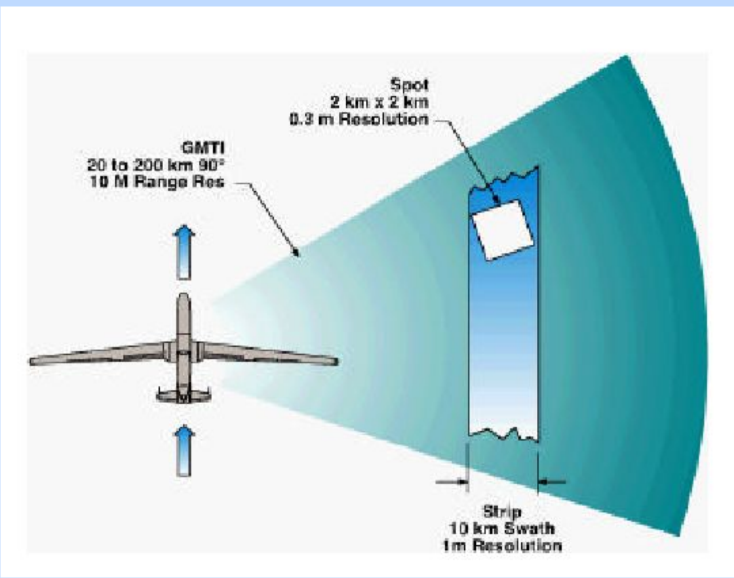
http://www.fas.org/irp/program/collect/predator.htm

Primary mission control responsibility

- Control the sensors in the target area using line of sight, relay and/or SatCom data links
  - Sensor control modes include search and spot
  - High bandwidth required (sensor control feedback)
- Sensor control sometimes handed off to other users



EO/IR sensor control



SAR radar control

Down links carry the most valuable product of a UAV mission

- UAV sensor and position information that is transmitted back for analysis and dissemination
  - *Exception, autonomous UAV with on board storage*
- Or UCAV targeting information that is transmitted back for operator confirmation

Real time search mode requirements typically define down link performance required

- *Non-real time "Images" can be sent back over time and reduce bandwidth requirements*

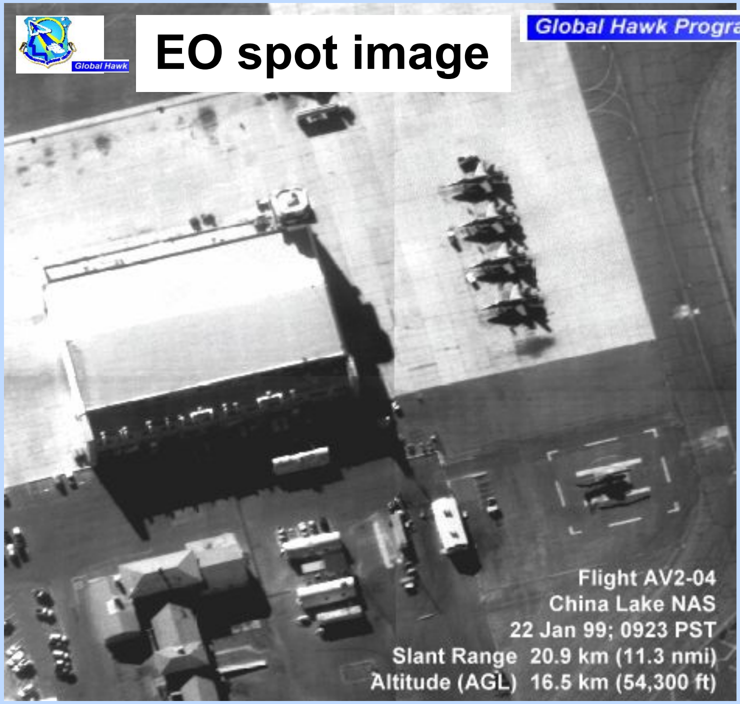
Line of sight down link requirements cover a range from a few Kbps to 100s of Mbps, SatCom down link requirements are substantially lower

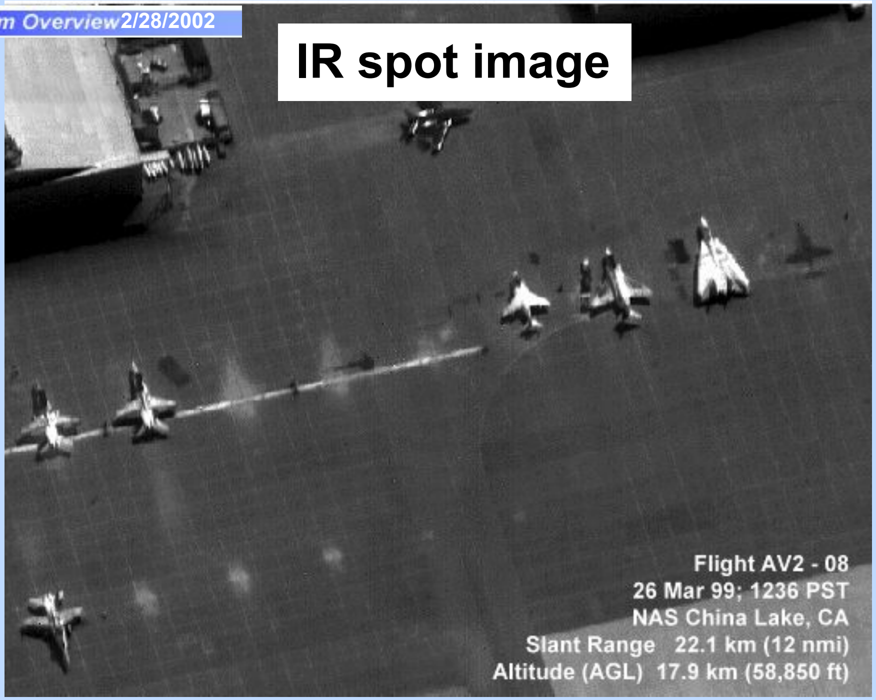
High resolution "imagery" (whether real or synthetic) establishes the down link bandwidth requirement

- Example - Global Hawk has 138,000 sqkm/day area search area at 1m resolution. Assuming 8 bits per pixel and 4:1 compression, the required data rate would be 3.2 Mbps to meet the SAR search requirements alone*
  - In addition to this, the data link has to support 1900, 0.3 m resolution 2 Km x 2 Km SAP spot images per day, an equivalent data rate of 2.0 Mbps
  - Finally there is a ground moving target indicator (GMTI) search rate of 15,000 sq. Km/min at 10 m resolution, an implied data rate of about 5Mbps
- Total SAR data rate requirement is about 10 Mbps

*See the payload lesson for how these requirements are calculated

EO/IR requirements are for comparable areas and resolution. After compression, Global Hawk EO/IR bandwidth requirements estimated at 42 Mbps*





This is why Global Hawk has a high bandwidth data link

* *Flight International, 30 January 2002*

Air vehicle system status requirements are small in comparison to sensors

- Fuel and electrical data can be reported with a few bits of data at relatively low rates (as long as nothing goes wrong - then higher rates required)
- Position, speed and attitude data files are also small, albeit higher rate
- Subsystem (propulsion, electrical, flight control, etc) and and avionics status reporting is probably the stressing requirement, particularly in emergencies

Although important, system status bandwidth requirements will not be design drivers

- A few Kbps should suffice

Once again, the sensors, not system status, will drive the overall data link requirement

Architecture

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- Commercial
- "Common"

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- Line of sight
- Over the horizon

Other issues

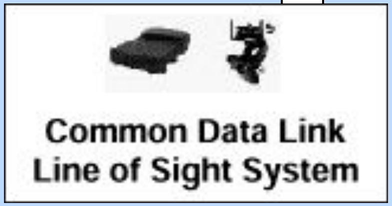
- Time delay
- Survivability
  - Reliability
  - Redundancy
  - Probability of intercept
- Logistics

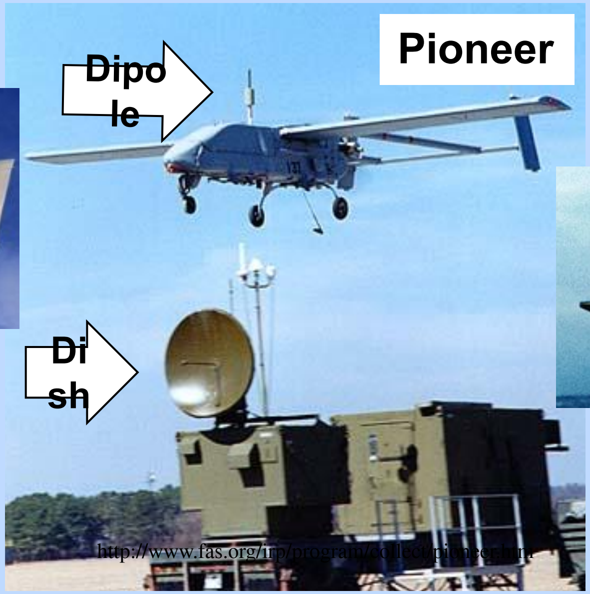
- Close range operations (e.g., launch and recovery) typically use omni-directional data links
  - *All azimuth, line of sight*
  - Air vehicle and ground station impact minimal
- Communications must be tied in with other base operations
  - Usually 2-way UHF/VHF (voice) and land line

Omni-directional antennae

Long range comms (LOS)

- **Typically require directional data links**
  - *RF focused on control station and/or air vehicle*
  - Impact on small air vehicles significant
  - Impact on larger air vehicles less significant
  - Significant control station impact
- Communications requirements include air traffic control
  - Usually 2-way UHF/VHF (voice)

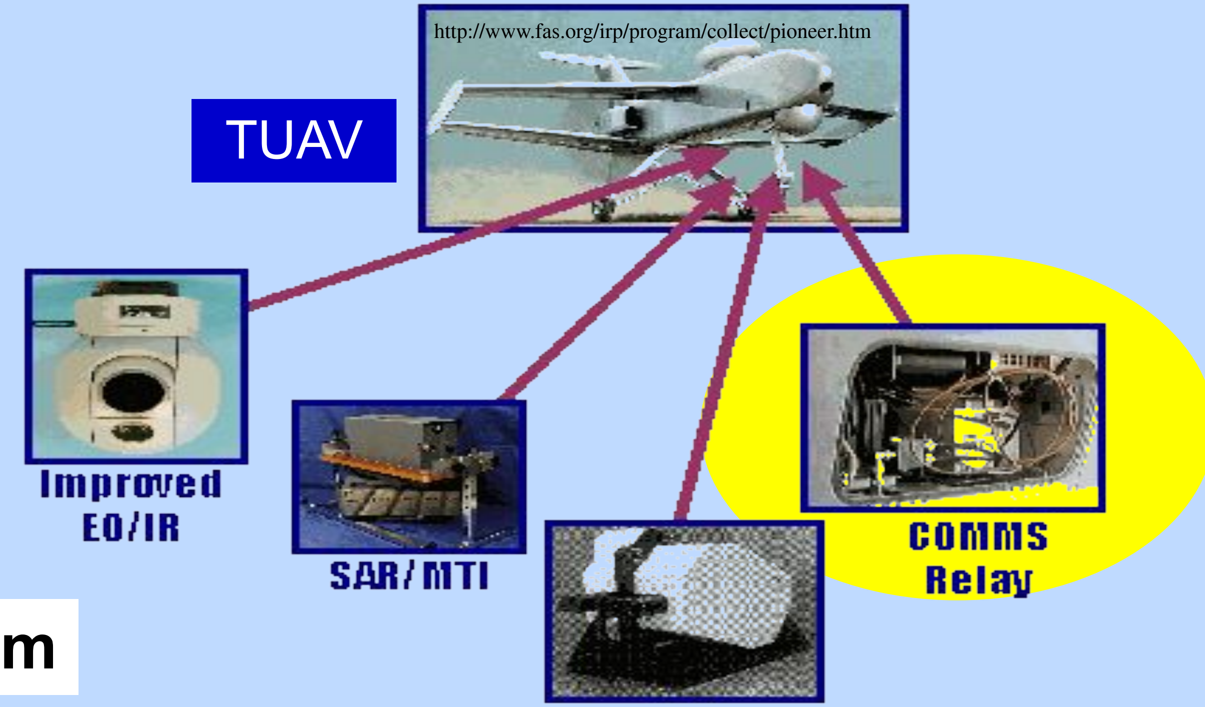




Over the horizon options

Relay aircraft - existing line of sight equipment

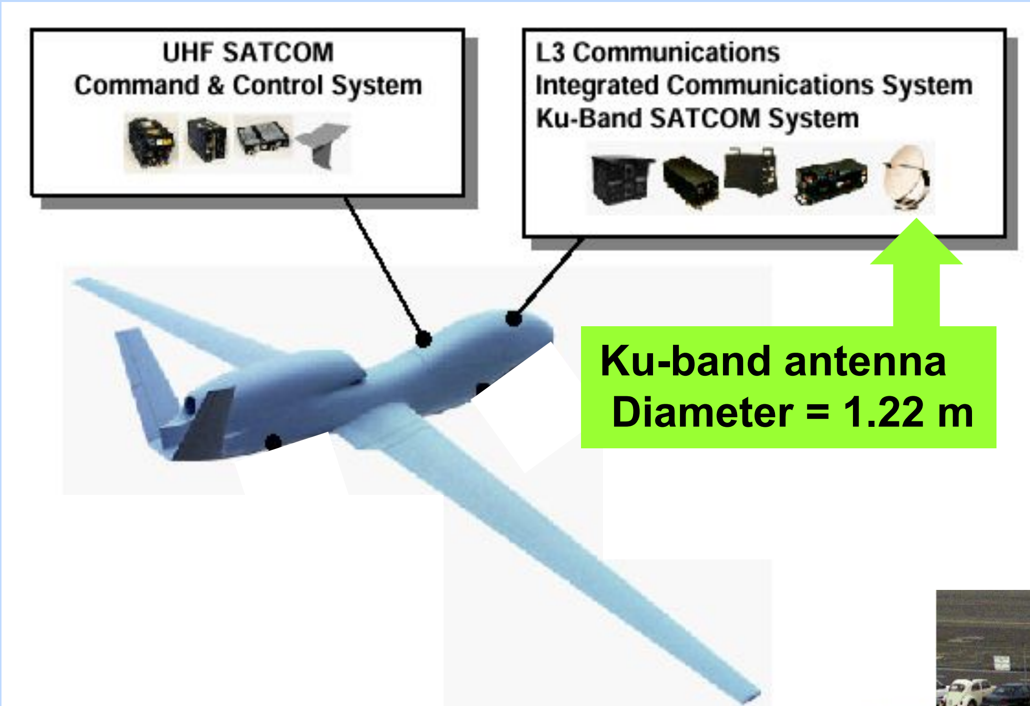
- *Minimal air vehicle design impact*
- *Major operational impact*



SatCom

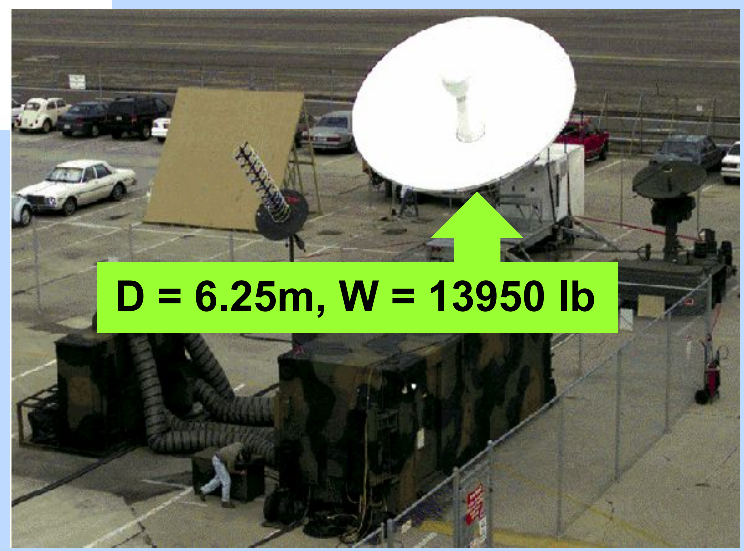
- Low bandwidth - minimal design impact, major operational
- High bandwidth - major impact (design *and* operational)

Global Hawk SatCom



Design issues

- Transmitter, receiver
  - Size
  - Weight
  - Location
- Antennae
  - Ditto
- Power and cooling
- Cost and complexity



Operational issues

- Link availability
- Bandwidth availability
- Logistics
  - *Transportability*
- Operations and support cost

Design of UAV Systems

Architecture

- Military
- Commercial
- UAV

Function

- Up link (control)
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Other issues

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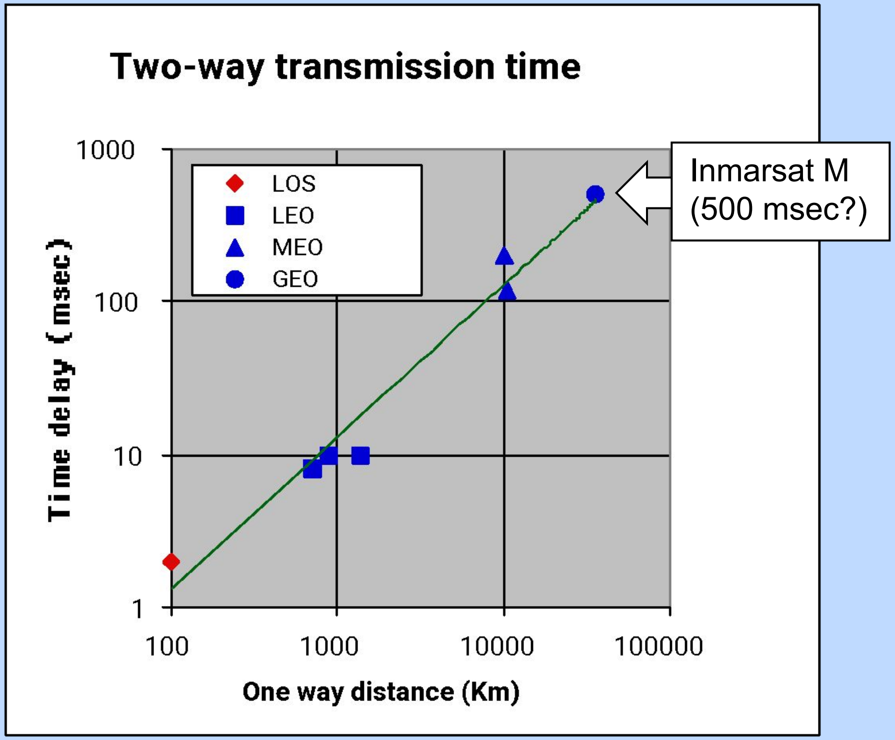
  - Probability of intercept
- Logistics

Other issues - time delay

- **The time required to transmit, execute and feed back a command (at the speed of light)**
  - ***- A SatCom problem***
- **Example:**
  - 200 Km LOS @ c = 3x10^5 Km/sec
    - Two way transmission time = 1.33 msec
  - Geo stationary Satcom at 35,900 Km
    - Two way transmission time = 240 msec



Raw data from, Automated Information Systems Design Guidance - Commercial Satellite Transmission, U.S. Army Information Systems Engineering Command (http://www.fas.org/spp/military/docops/army/index.html)

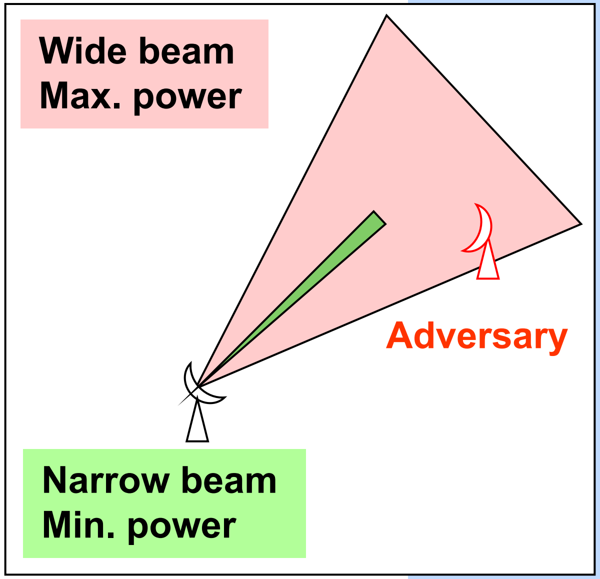
Time delays and UAVs

- **Also known as data "latency" or "lag"**
  - *Limited by speed of light and "clock speed"*
- **All systems have latency**
  - Human eye flicker detection - 30 Hz (33 msec delay)
  - Computer screen refresh rate - 75 Hz (13 msec)
  - Computer keyboard buffer latency - 10 to 20 msec
  - LOS communications - 2 msec
  - LEO SatCom - 10 msec
  - MEO Satcom - 100 msec
  - GEO Satcom - 200 to 300 msec
  - Typical human reaction - 150-250 msec
- **Acceptable overall system lag varies by task**
  - < 40 msec for PIO susceptible flight tasks (low L/D)
  - < 100 msec for "up and away" flight tasks (high L/D)
- **When OTH control latency > 40 msec, direct control of a UAV is high risk (except through an autopilot)**

Other issues - redundancy

- **The preferred reliability solution**
  - Separate back up data link(s)
- **Most modern UAVs have redundant data links**
  - Global Hawk has 4 (two per function)
    - UHF (LOS command and control)
    - UHF (SatCom command and control)
    - CDL (J-band LOS down link)
    - SHF (SatCom Ku band down link)
  - Dark Star also had four (4)
  - Predator, Shadow 200 have two (2)
- **Most UAVs also have pre-programmed lost link procedures**
    - If contact lost for TBD time period (or other criteria) return to pre-determined point (near recovery base)
      - *Loiter until contact re-established (or fuel reaches minimum levels then initiate self destruct)*

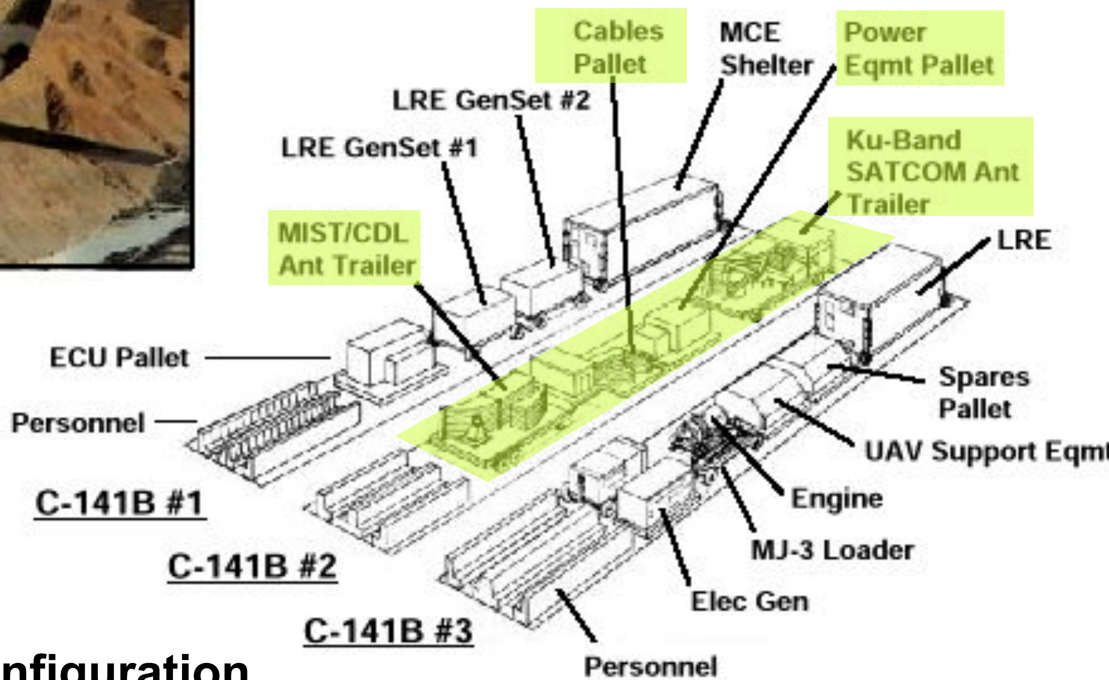
- **Probability that an adversary will be able to detect and intercept a data link and be able to**
  1. Establish track on the UAV position
  2. Interfere with (or spoof) commands
- **Purely a military UAV issue**
  - No known civil equivalent
- **Some well known techniques**
  - Spread spectrum
    - *Random frequency hopping*
  - Burst transmissions
    - Difficult to detect and track
  - Power management
    - *No more power than required to receive*
  - Narrow beam widths
    - *Difficult intercept geometry*



- **Power and cooling**

  - Communications equipment (especially transmitters) require significant power and cooling to meet steady state and peak requirements
    - At low altitudes, meeting these power and cooling requirements typically is not an issue
    - At high altitude, both are a problem since power and cooling required ≈ constant and ….
      - *Power available approximately proportional δ*
      - *Cooling air required(cfm) approximately proportional $1/\sigma$; one reason why high-altitude aircraft use fuel for cooling (also keeps the fuel from freezing!)*

A significant part of transport requirements are associated with communications equipment

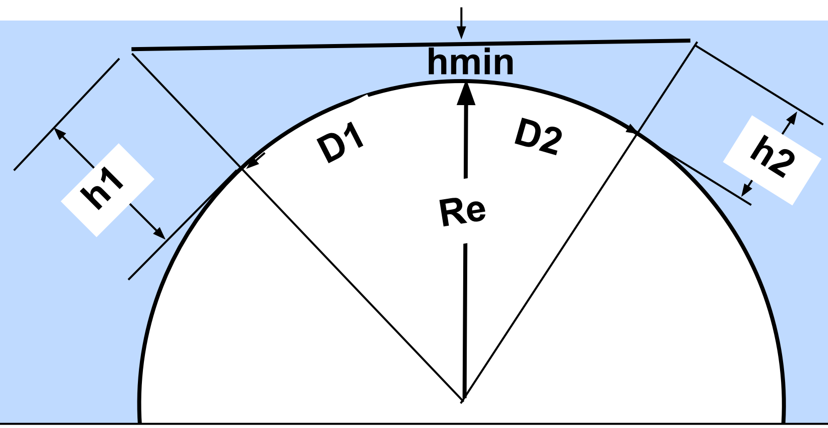


C-141B transport configuration

Next subject

- **RF basics**
  - Data link types
  - Frequency bands
  - Antennae
  - Equations
- **Communications issues**
  - Architecture
  - Function
  - Coverage
  - Etc.
- **Sizing (air and ground)**
  - Range
  - Weight
  - Volume
  - Power
- **Example problem**

- Given 2 platforms at distance (D1+D2) apart at altitudes h1 and h2 above the surface of the earth:



- From geometry

$$D1+D2 \equiv Re*\{ArcCos[(Re+hmin)/(Re+h2)]+ ArcCos[(Re+hmin)/(Re+h1)]\} \quad (9.1)$$

where

Re ≈ 6378 km (3444 nm)

hmin = intermediate terrain or weather avoidance altitude (≈ 20kft)*

and

ArcCos[ ] is measured in radians

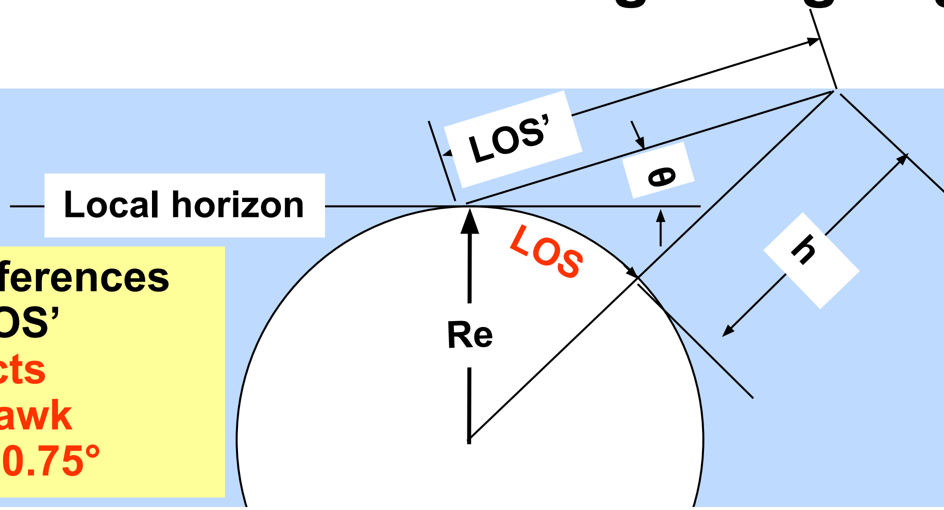
*not applicable if h1 and/or h2 lower than hmin

- **Due to earth curvature and atmospheric index of refraction, RF transmissions bend slightly and the RF line of sight (LOS) is > the geometric LOS by a factor ≈ $\sqrt{4/3}$** *(Skolnik, Radar Handbook, page 24-6)*
- **Another equation for communication LOS can be found using a simple radar horizon equation from Skolnik** (*page 24-8)* **where:**
  - LOS(statute miles) ≈ $\sqrt{2*h(ft)}$ (9.2)

or

  - LOS(nm) ≈ $0.869\sqrt{2*h(ft)}$ (9.3)
- **Note that the ratio of Eqs 9.1 and 9.3 for h1 = hmin = 0 and h2 = h is $\sqrt{4/3}$; e.g. LOS (Eq 9.1) = 184 nm @ h2 = 30Kft while LOS (Eq 9.3) = 213 nm**
  - We will assume that the $\sqrt{4/3}$ factor will correct any geometric LOS calculation including 9.4 when h1 and h2min ≠ 0

• Given a platform at altitude h at grazing angle θ above the horizon:



- **Ignore the small differences between LOS and LOS'**
- **The equation predicts published Global Hawk comm ranges at θ ≈ 0.75°**

• From geometry, the slant range (LOS') will be given by:

$$(Re+h)^2 = LOS'^2 + Re^2 - 2 \cdot LOS' \cdot Re \cdot \cos(\pi/2+\theta)$$

or

$$LOS'^2 - [2 \cdot Re \cdot \cos(\pi/2+\theta)] \cdot LOS' + [Re^2 - (Re+h)^2] = 0 \quad (9.4)$$

where LOS is the root of a quadratic equation of the form $a x^2+bx+c = 0$

or $x = [-b \pm \sqrt{b^2-4ac}]/2a$

which we then multiply by $\sqrt{4/3}$ to adjust for atmospheric effects

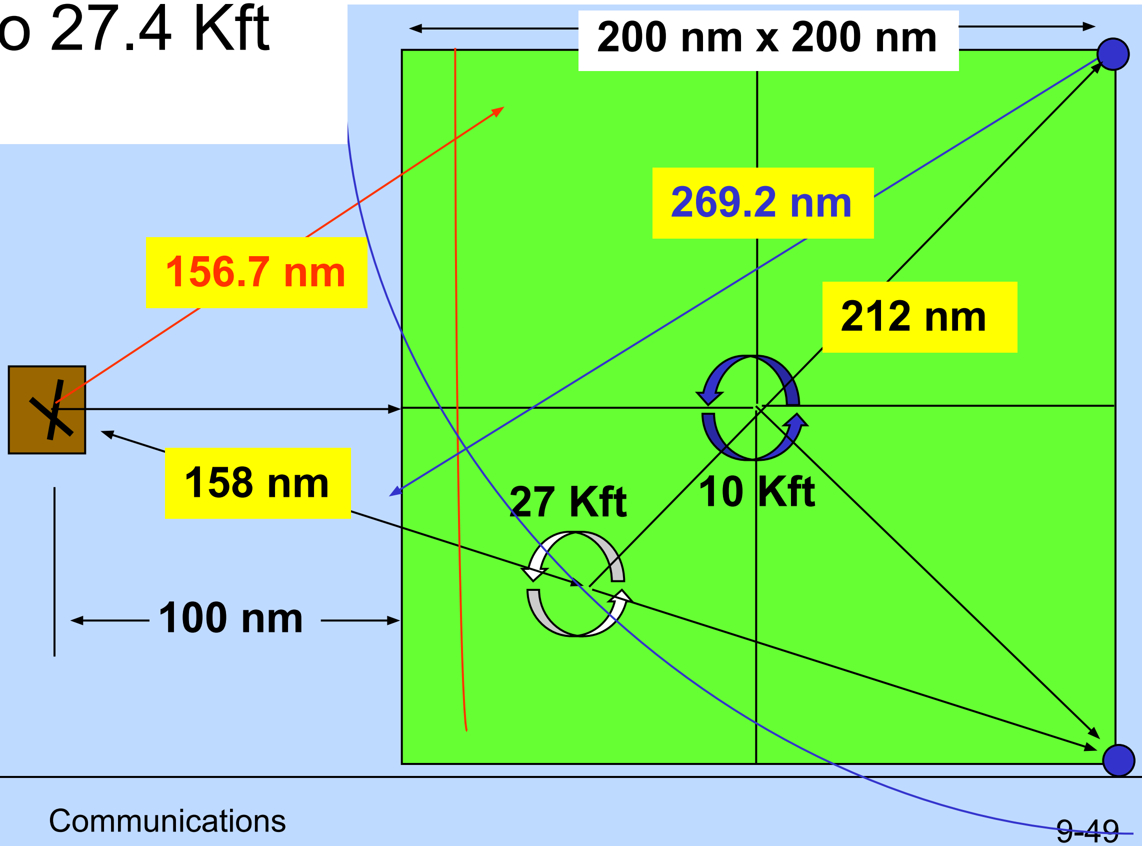
A system level solution for an organic over the horizon (OTH) UAV communications capability

- Requires that relay UAV(s) stay airborne at all times
  - *For extended range and/or redundancy*
- Also requires separate communication relay payload
  - *In addition to basic UAV communication payload*

But relay platform location is critical. Example:

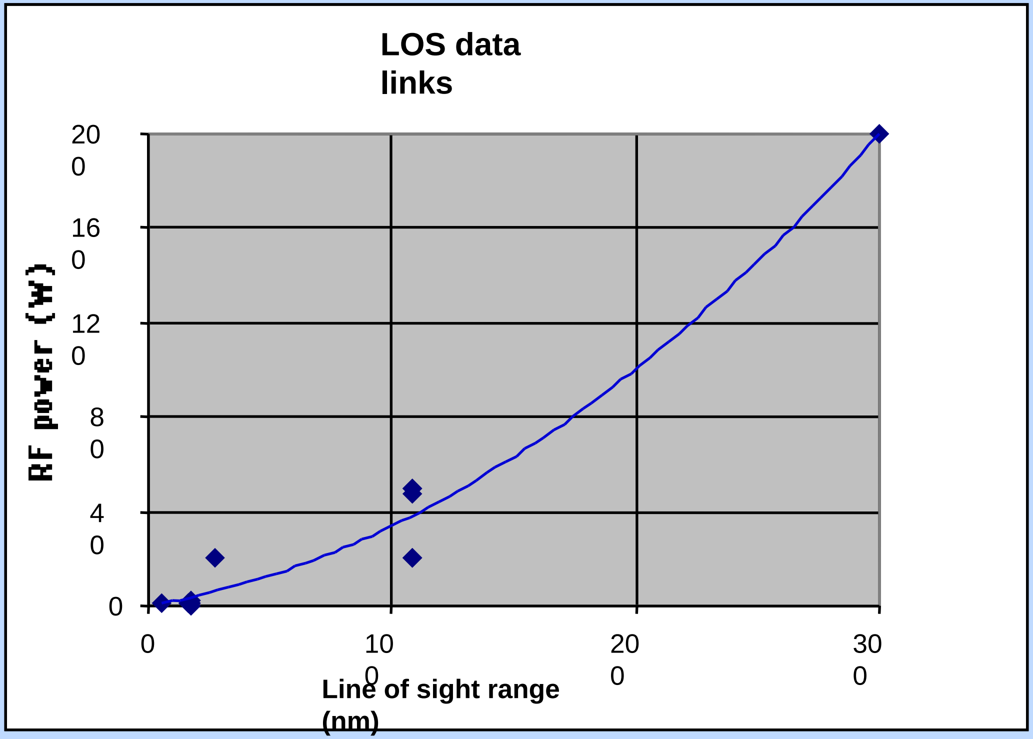
- Four (4) WAS UAVs loiter at 27 Kft and one (1) ID UAV loiter at 10 Kft over a 200 nm x 200 nm combat area located 100 nm from base
- Two (2) WAS UAVs closest to base function as communications relays for the three other UAVs
- Typical terrain altitude over the area is 5 Kft
- How would a WAS relay have to operate to provide LOS communications to the ID UAV at max range?

- **LOS defines max communication distance for relay**
  - At θ =0.75°, LOS from base = 156.7 nm vs. 158 nm req'd
  - At hmin = 5 kft, LOS from ID UAV at 10 Kft to WAS relay at 27 Kft = 269.2 nm vs. 212 nm req'd
- **WAS altitude inadequate to meet base relay requirement**
  - Altitude increase to 27.4 Kft required



Next - sizing data

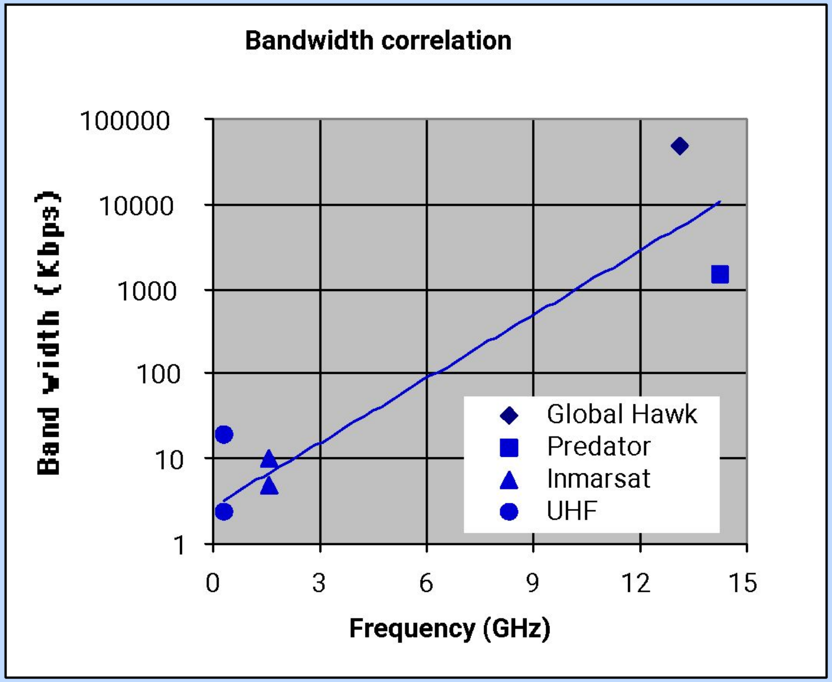
- **There is little public information available on UAV data links to use for initial sizing**
  - Including both air and ground data "terminals"
    *Short hand notation - **ADT** and **GDT***
- **Three sources**
  1. Janes UAVs and Targets, Issue 14, June 2000
     - *Mostly military UAV data links*
  2. Unpublished notebook data on aircraft communications equipment
     - *Both military and civil, not UAV unique*
  3. Wireless LAN data
     - *Collected from the internet, not aircraft qualified*
     - *Indicative of what could be done with advanced COTS technology*
- **For actual projects, use manufacturer supplied data**



Calculate LOS range

Equations 9.1-9.4

Estimate RF output power required



Select Bandwidth

Select frequency

Parametric data source

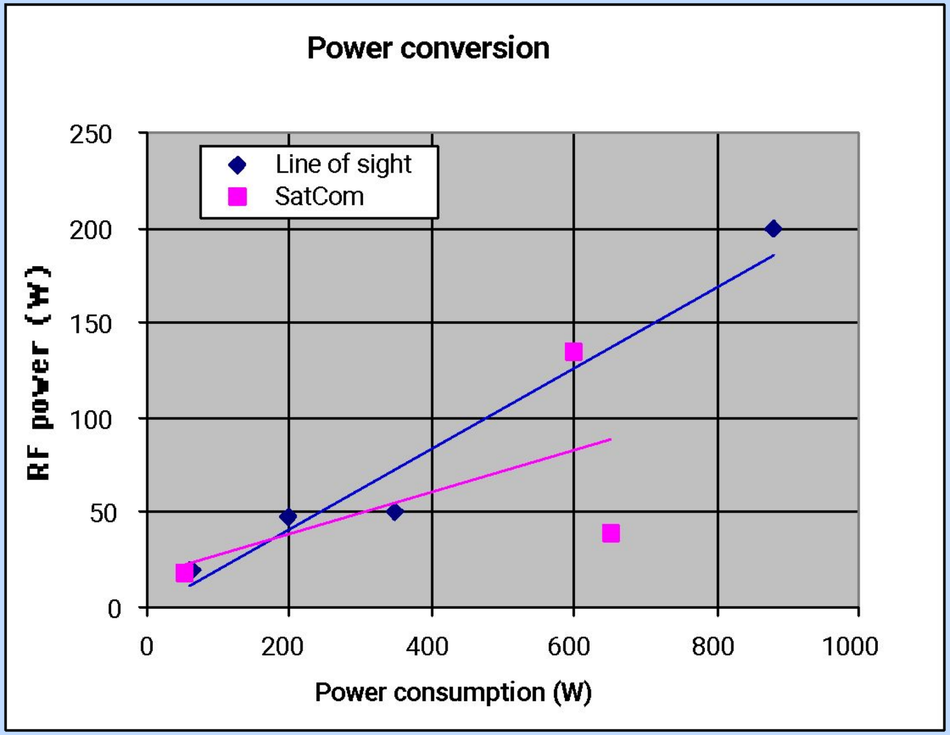
All Satcom data links
Frequency range 0.24 - 15 GHz
Bandwidth range 0.6 Kbps - 5.0 Mbs

Parametric correlation basis

Known correlation between band width or data rate and frequency

- **Bandwidth availability increases with frequency**

ADT power required

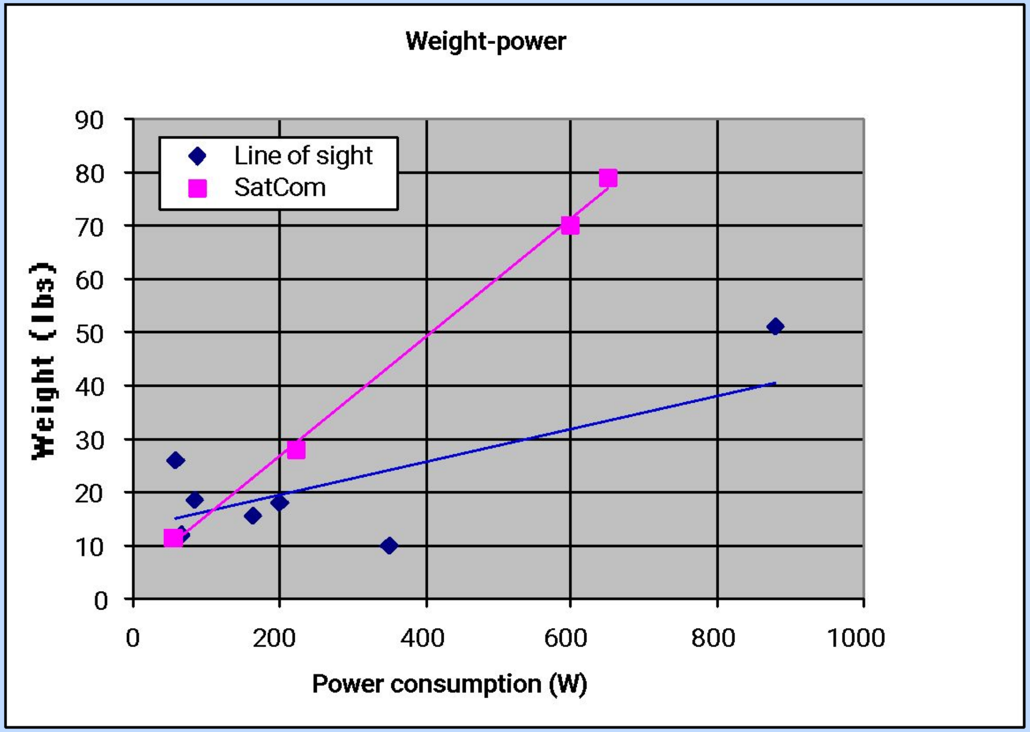


Estimate input power requirements

- LOS
- SatCom (GEO)

<u>Parametric data source</u>

Military line of sight data links
Frequency range 30 MHz - 15 GHz
Bandwidth range 0.01-5.0 Mbs



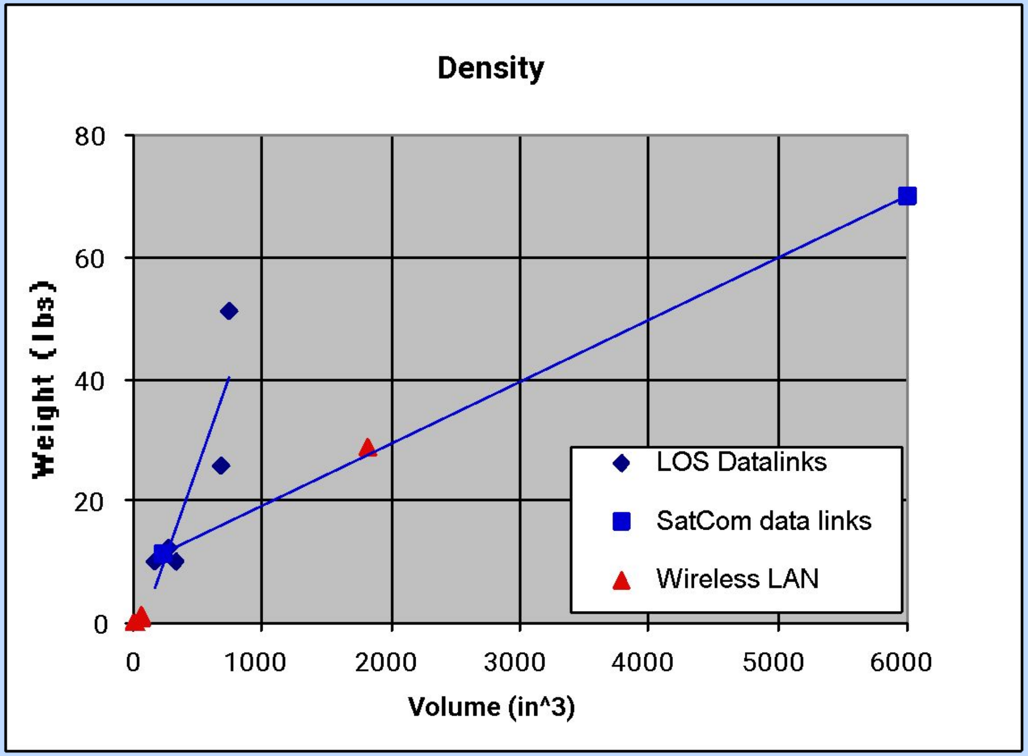
Estimate weight

- LOS
- SatCom (GEO)

Note - excludes antennae

<u>Parametric data source</u>

Janes and unpublished data
Frequency range 30 MHz - 15 GHz
Bandwidth range 0.01-5.0 Mbs



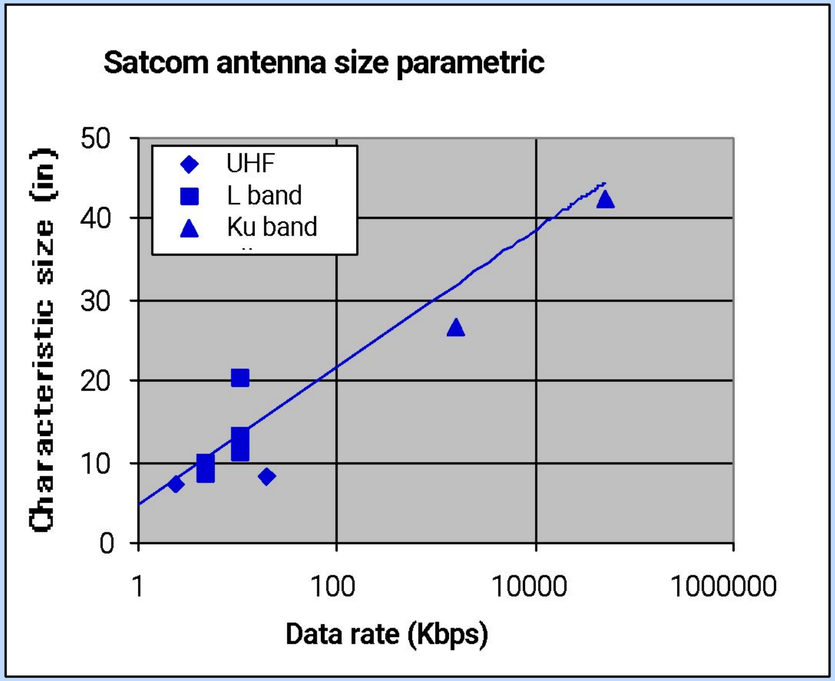
Estimate volume

- LOS
- SatCom (GEO)

<u>Parametric data source</u>

All LOS data links & modems
Frequency range 30 MHz - 15 GHz
Bandwidth range 0.01-5.0 Mbs

ADT Satcom antenna



Estimate antenna "size"

Calculate area, volume or length as appropriate

<u>Parametric data source</u>

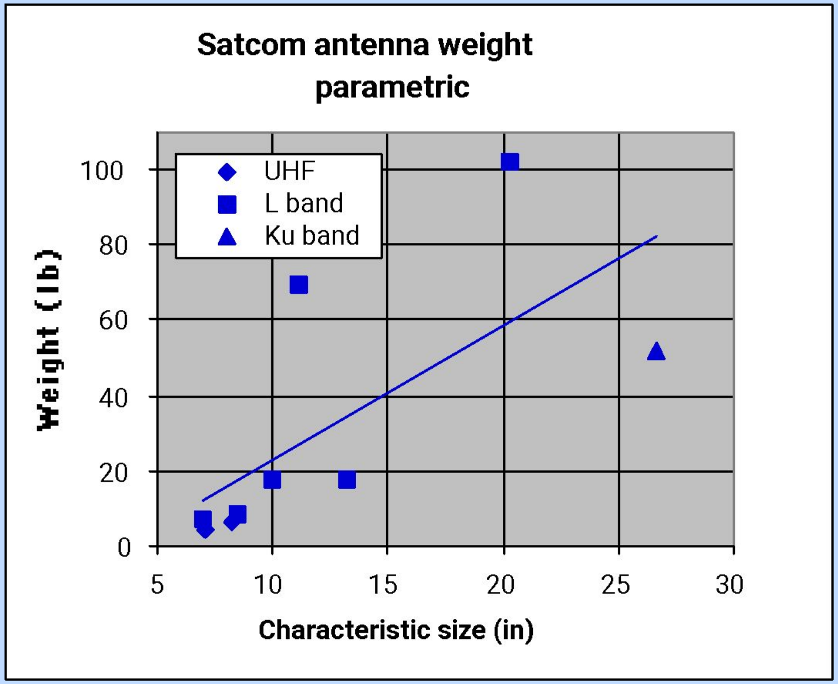
All Satcom data link antenna
Frequency range 0.24 - 15 GHz
Bandwidth range 0.6 Kbps - 5.0 Mbs

<u>Parametric correlation basis</u>

Known correlation between bandwidth required and size

Antenna characteristic "size" defined as following:

- **For EHF : square root of antenna area (when known) or cube root of installed volume**
- **For UHF : antenna length (blade) or diameter (patch)**

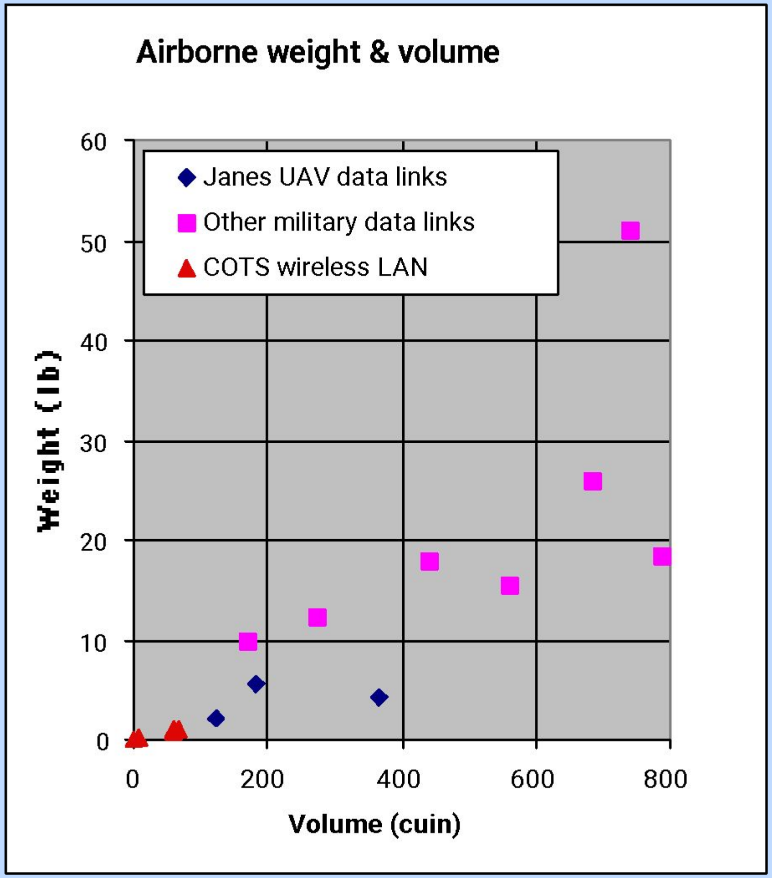


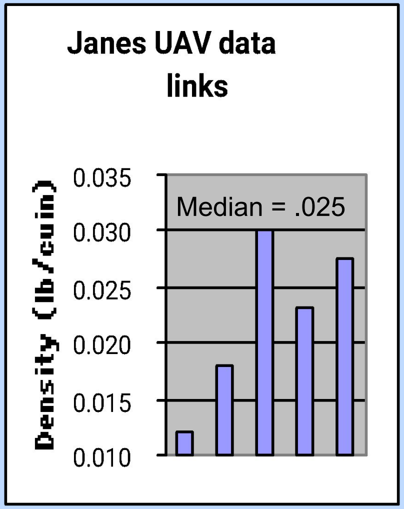
Estimate antenna weight

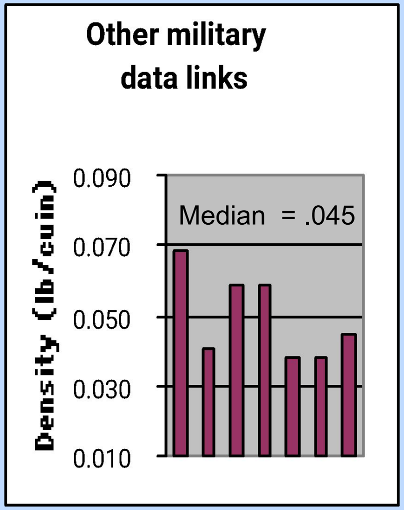
<u>Parametric data source</u>

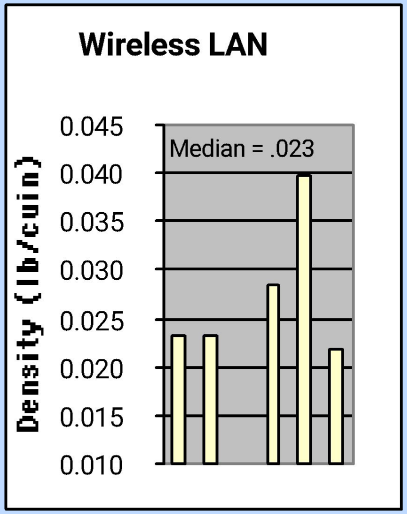
All Satcom data link antenna
Frequency range 0.24 - 15 GHz
Bandwidth range 0.6 Kbps - 5.0 Mbs

More ADT LOS data









<u>Parametric data source</u>

All LOS data links & modems
Frequency range 30 MHz - 15 GHz
Bandwidth range 0.01-5.0 Mbs

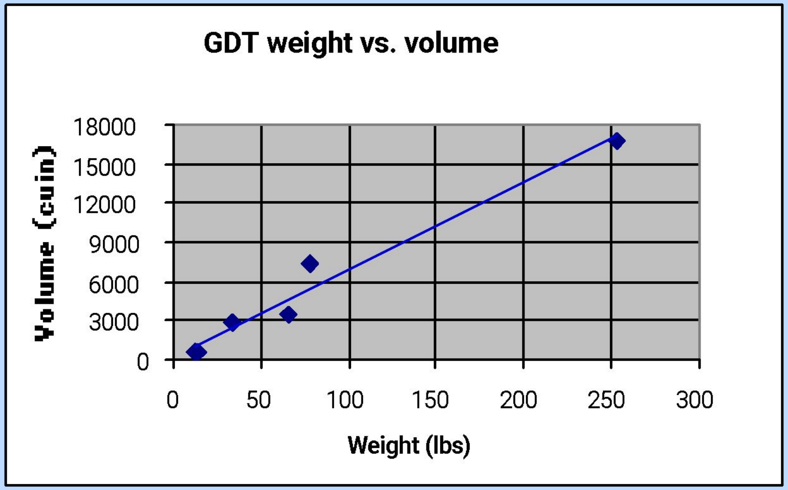
- **All systems on an air vehicle have an installation weight and volume penalty** (more in Lesson 19)
  - We will assume a typical installation at 130% of dry uninstalled weight
    - *We will make this assumption for all installed items (mechanical systems, avionics, engines, etc.)*
- **Installed volume is estimated by allowing space around periphery, assume 10% on each dimension**
  - Installed volume = 1.33 uninstalled volume
- **For frequently removed items or those requiring air cooling, we will add 25% to each dimension**
  - Installed volume = 1.95 uninstalled volume
  - Payloads and data links should be installed this way

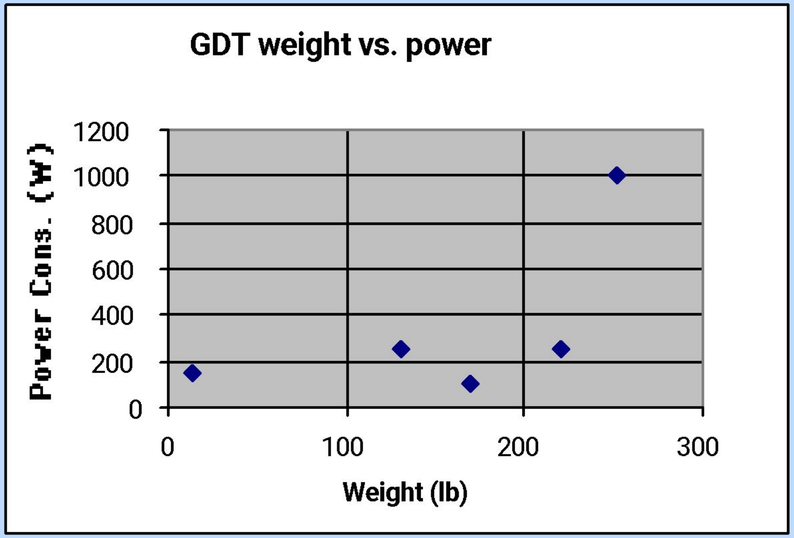
There are a few GDT system descriptions in Janes and on the internet for UAV applications.

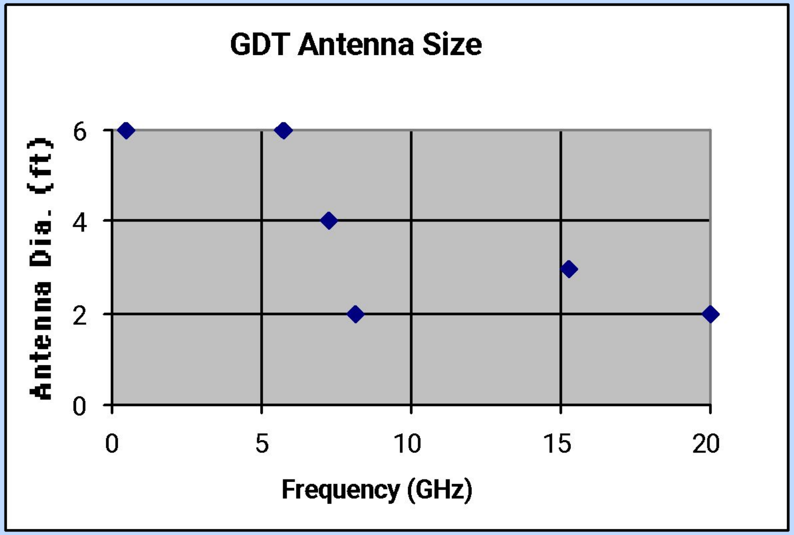
- Little technical data is provided but in general they are large
  - The CL-289 GDT is integrated into a truck mounted ground control station and includes a 12 meter hydraulic antenna mast
  - The Elta EL/K-1861 has G and I-band dish antennae (6 ft and 7ft diameter, respectively)
  - The AAI GDT appears to be about a 2 meter cube excluding the 1.83 m C-band antenna
- Smaller man portable systems are also described but little technical performance data is included

The following parametrics are very approximate and should be used only until you get better information from manufacturers

GDT parametrics







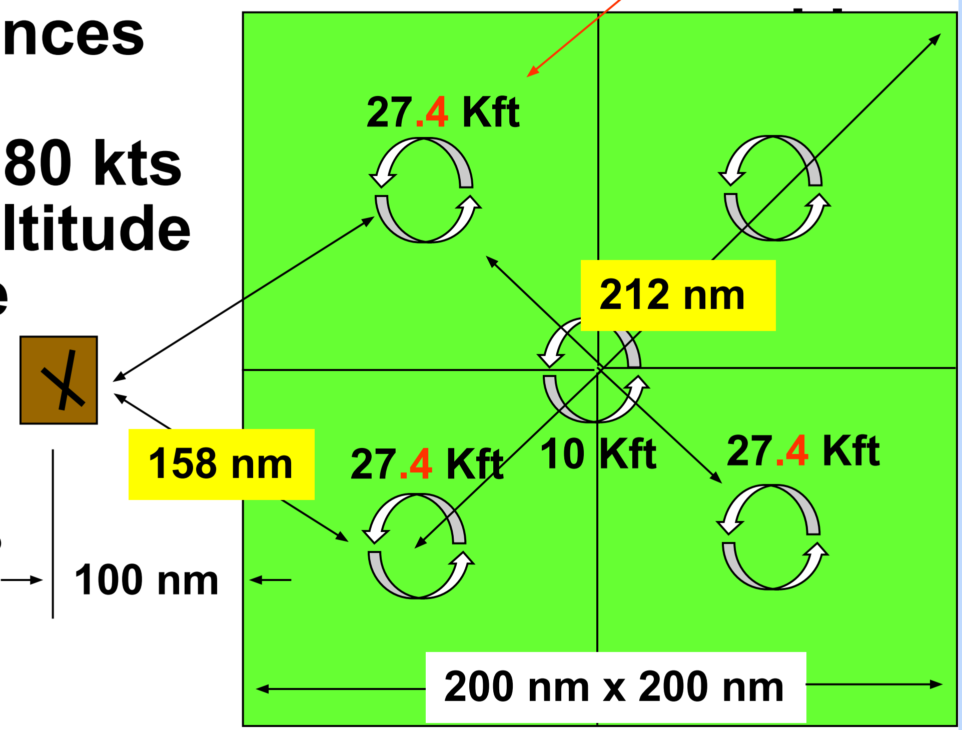
You should understand

- Communications fundamentals
- UAV unique communications issues
- How to calculate communication line of sight
- How to define (size) a system to meet overall communication requirements

- **RF basics**
  - Data link types
  - Frequency bands
  - Antennae
  - Equations
- **Communications issues**
  - Architecture
  - Function
  - Coverage
  - Etc.
- **Sizing (air and ground)**
  - Range
  - Weight
  - Volume
  - Power
- **Example problem**

- **Five medium UAVs, four provide wide area search, a fifth provides positive target identification**
  - -WAS range required (95km) not a challenge
- **Only one UAV responds to target ID requests**
  - No need to switch roles, simplifies ConOps
  - No need for frequent climbs and descents
- **Communications distances (158nm & 212 nm)**
- **Speed requirement = 280 kts**
- **Air vehicle operating altitude differences reasonable**
- **We will study other**
- **What is a reasonable communications**
- **How big are the parts?**

Altitude increase required to meet LOS relay requirement



- **Parametric data is used to size (1) a basic UAV data link and (2) a communications relay payload**
  - We assume both are identical and that all UAVs carry both, allowing any UAV to function as a relay
    - *Provides communication system redundancy*
- **Parametric sizing as follows (for each system)**
  - Max range = 212 nm ⇒ RF power = 110 W (Chart 51)
  - ⇒ Power consumption = 500 W (Chart 53)
  - ⇒ Weight = 27 lbm (Chart 54)
  - ⇒ Volume = 500 cuin (Chart 55)
- **We have no non-Satcom antenna parametric data and simply assume a 12 inch diameter dish, weighing 25 lbm with volume required = 2 cuft**
  - If you have no data, make an educated guess, document it and move on
    - *We will always check the effect later*
- **We include communications in our payload definition**

- **We have little GDT parametric sizing date and simply assume an ADT consistent input power requirement (500W) and use the chart 60 parametrics to estimate weight and volume**
  - 250 lbm and 9.5 cuft
- **Antenna size will be a function of frequency and bandwidth which we will select after assessing our payload down link requirements**

- **System element**
  - GDT weight/volume/power excluding antenna (each) = 205 lbm/9.5 cuft/500 W
  - GDT installations required = 2
- **Payload element**
  - Installed weight/volume/power = TBD
  - *WAS*
    - *Range/FOR /resolution/speed = 95 km/±45°/10m/2mps*
    - *Uninstalled weight/volume/power = TBD*
  - *ID*
    - *Type/range/resolution = TBD/TBD/0.5m*
    - *Uninstalled weight/volume/power = TBD*
  - *Communications*
    - *Range/type = 212nm/air vehicle and payload C2I*
      - *Uninstalled weight/volume/power ≤ 52 lbm/2.3 cuft/500 W*
    - *Range/type = 158nm/communication relay*
      - *Uninstalled weight/volume/power ≤ 52 lbm/2.3 cuft/500 W*

- **Air vehicle element**
  - *Cruise/loiter altitudes = 10 – 27.4Kft*

Assess communication requirements for your project and develop an architecture that you think will work

(1) Define a communications architecture that includes redundancy considerations

(2) Calculate LOS distances from base to vehicle(s) at the required operating altitudes.

- *Assume minimum grazing angle (θ) = 0.75°*

(3) If your architecture includes airborne relay, calculate the relay distances at your operating altitudes

- *Use the example problem as a guide*

(4) Determine the ADT weight, volume and power req'd

(5) Document your derived requirements

Submit your homework via Email to Egbert by COB next Thursday. Document all calculations