Optical RF Communications Adjunct (ORCA)

Program and BAA Overview

11 July 2007

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Note: Any government solicitation information takes precedence over the information contained in this presentation.

Optical RF Communications Adjunct (ORCA)

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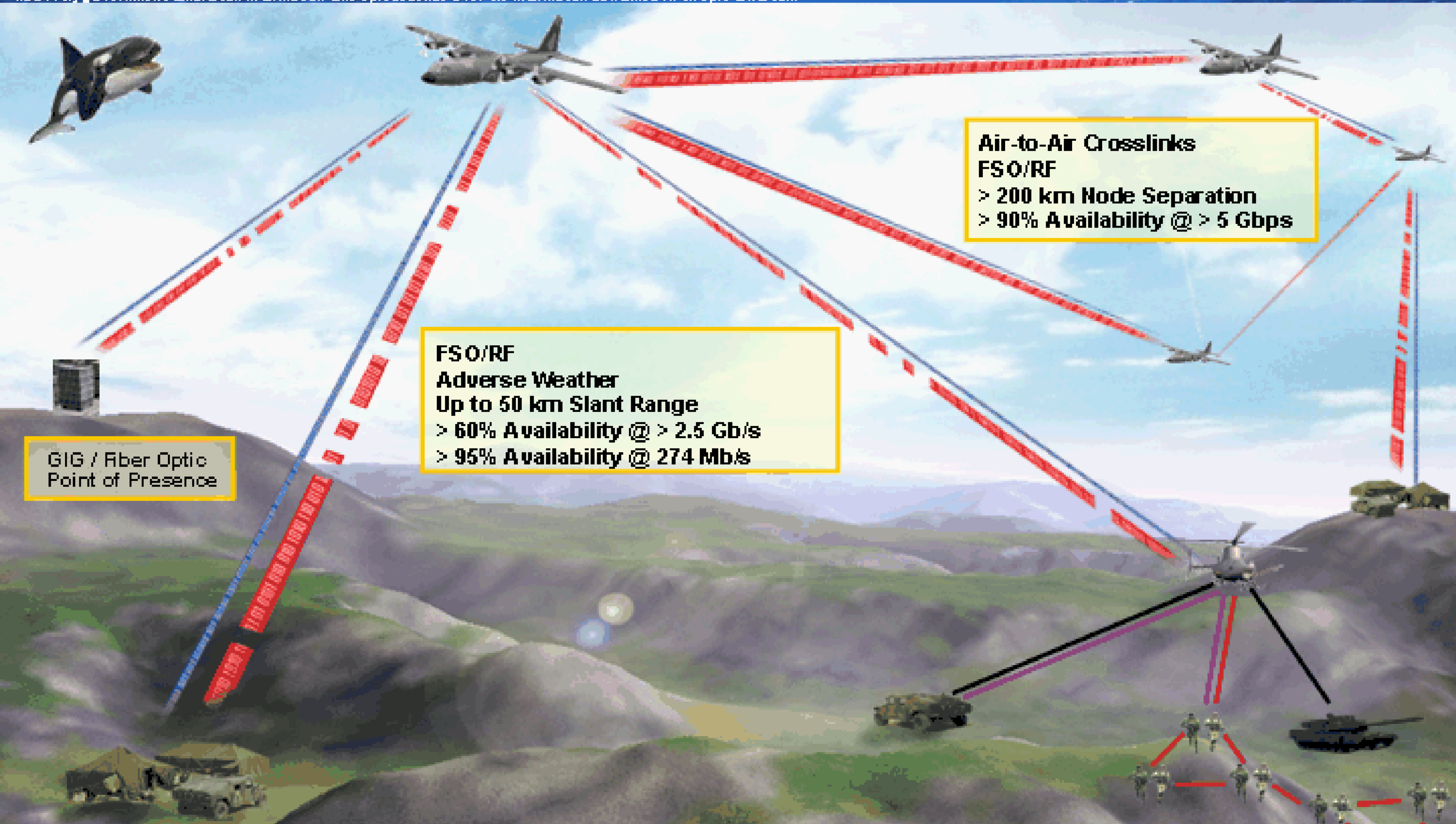
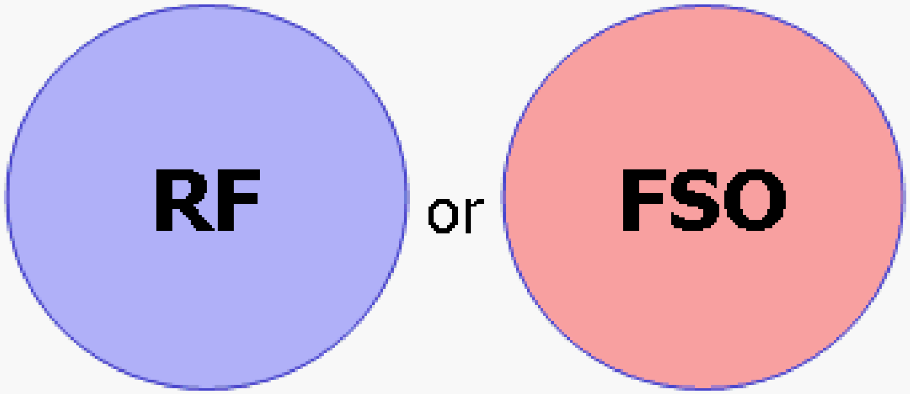


Develop & Demonstrate a Leave-Behind, High Reliability, High Data Rate TRL 6 Tactical Communication Network

Technical Approach Paradigm Shift
Hybrid Optical-RF Communications Systems

Strategic Technology Office

Today's Commercial Approach Building to Building



RF

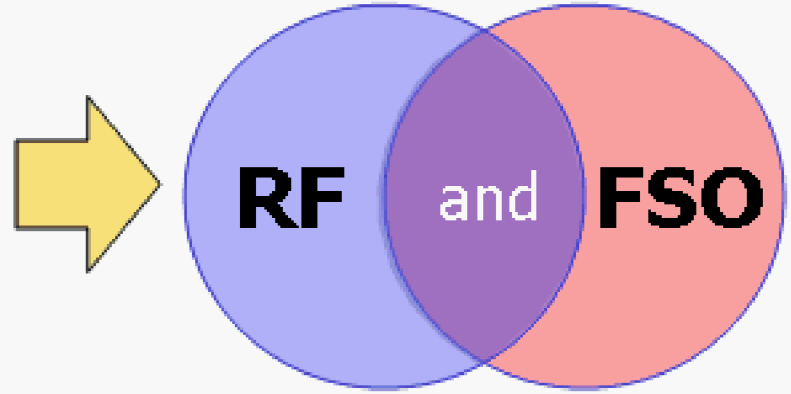
– Low Data Rate
– Stable Channel
– Relatively immune to cloud blocking
– Sometime affected by rain

FSO

– High Data Rate
– Bursty Channel
– Must have clear / haze conditions
– Less degradation than RF in Rain

Generally complementary channel characteristics

ORCA Approach to Mobile Free Space Communications with High Availability and High Average Data Rate



- Enables Free Space Optical (FSO) Communications bandwidth without giving up RF reliability and "adverse-weather" performance
- Improves network availability Quality of Service (QoS)
- More options for adapting to weather
  - Common atmospheric path effects and compensation (directional links)
  - Physical Layer diversity improves Jam Resistance
- Size, Weight and Power (SWaP) Focus
  - Leverages common Power, Stabilization, etc.
  - Economical use of platform volume
- Enables seamless transition of free space optical communications into RF Environment

Notional ORCA Air Terminal

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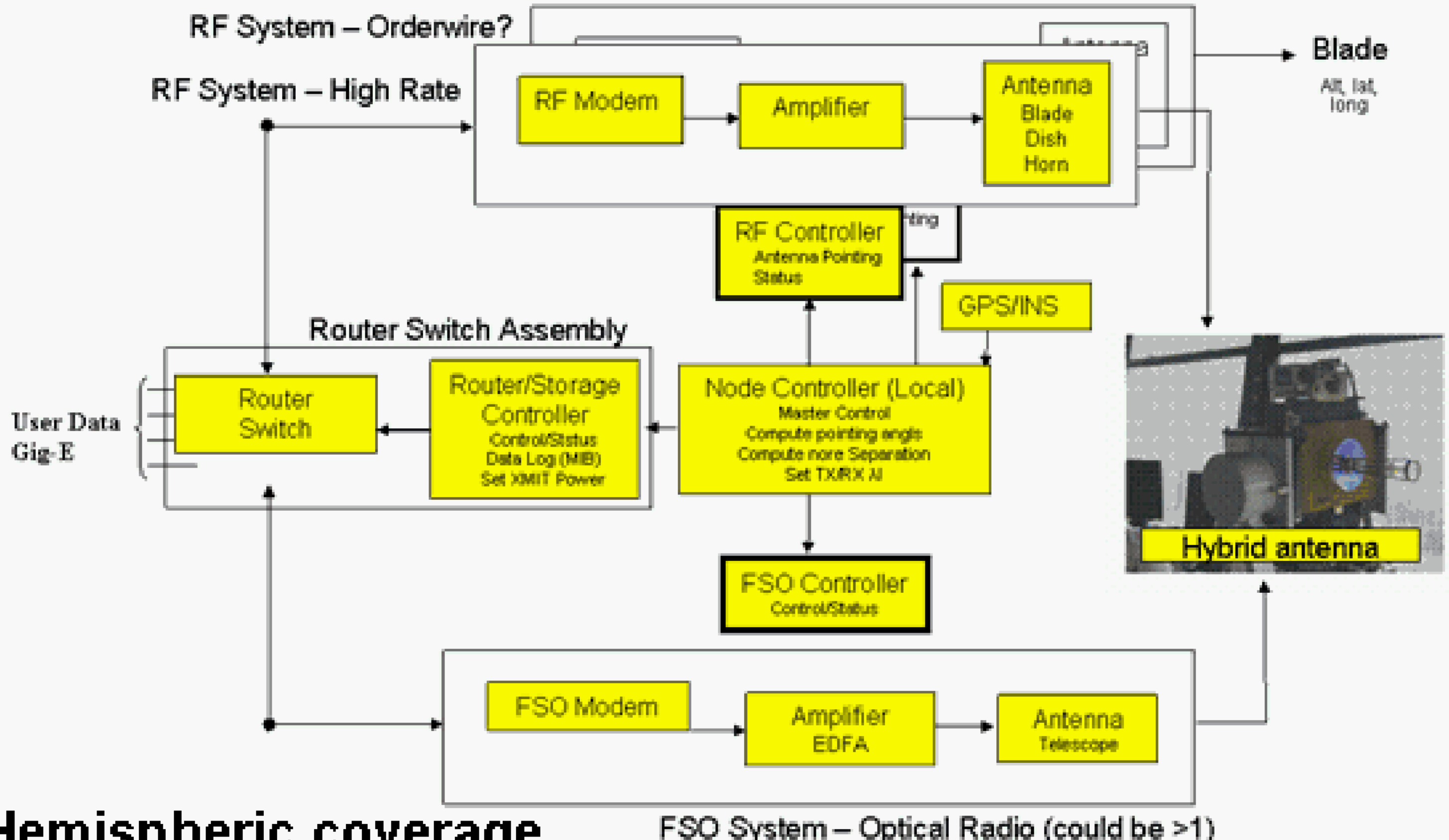


- Hemispheric coverage
- Non-cooperative link acquisition
- Optical Radome and/or Turret
- RF Radome and/or Blade
- Pod or integrated into airframe

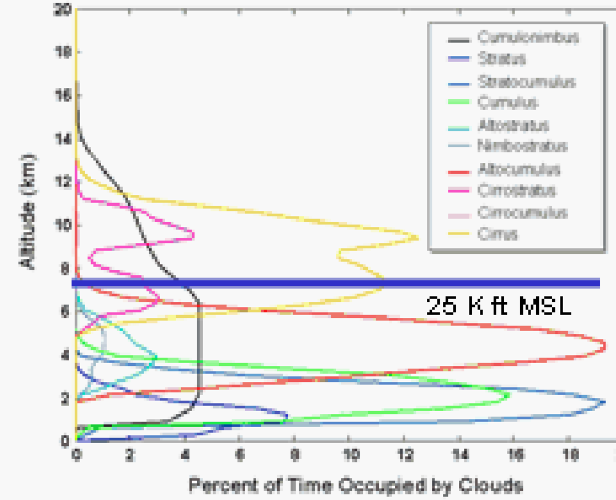
ORCA Technical Challenges

- **Physical Links**
  - **> 5 Gb/s FSO Link: Power*Aperture product conducive to Link Margin and SWaP**
    - FSO Data Rate > 2.5 Gb/s, Air-to-Ground / Ground-to-Air
    - FSO Data Rate > 5 Gb/s, Air-to-Air
  - **274 Mb/s RF Link: Power*Aperture product conducive to Link Margin and SWaP**
    - Spectrum efficiency in available bands enabling Gb/s at military ranges >200Km
  - **Nominal 40-50 dB variation because of atmospheric turbulence (i.e., scintillation)**
  - **Link Availability because of limited Power*Aperture product**
  - **Aero-Optic effects in airborne platforms**
  - **Affordable Pointing, Acquisition, Tracking**
  - **Obscurants (clouds, haze, rain, snow)**
  - **Receiver Performance vs Complexity (e.g., APD, PIN, PMT)**
- **Network**
  - **Network traffic:**
    - Characteristics of data sources. (Volume, Burst, Stream)
  - **Traffic demand. (Consumers, Diversity)**
    - Network element capability:
    - Mobility, altitude, orbital pattern.
    - Link or port density.
  - **Survivability**
    - Tolerance of network to node or link outage.
  - **Reliability with limited redundancy, intermittent, directional links**
  - **5+ Gb/s encryption of a highly mobile transitory node network**
  - **Dynamic QOS to provide 'Dial Tone' i.e. >95% network availability**
    - Traffic prioritization, dynamic link allocation, buffering routers
- **Platform**
  - **Air Segment**
    - Minimizing SWaP and Mold Line impacts to vehicle (drag & weight = fuel)
  - **Ground Segment**
    - Mobile ground optical terminal

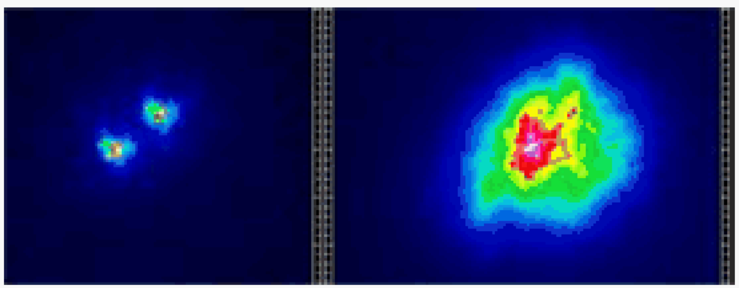
Red = key challenges

FSO Performance Challenges

- **Reliable High Data Rate**
  - FSO high but *unreliable* data rate
  - RF lower, but *reliable*

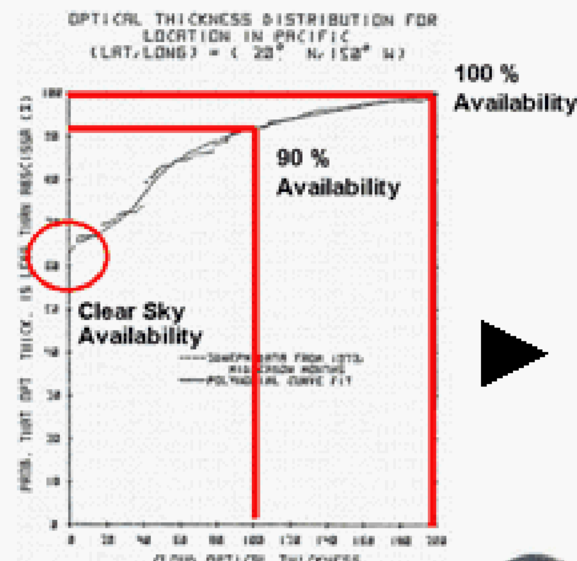


- **Operating In the Lowest 10 km of atmosphere**
  - Weather limitations (Most clouds located at lower altitudes)
  - Stochastic channel degradation (e.g., turbulence-induced fading)



Two Imaged Stars:

- **Without Turbulence (left)**
- **With Turbulence (right)**



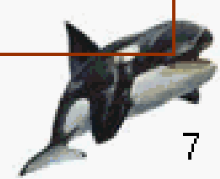
- **High System Availability in Adverse Weather Conditions**
  - FSO performance strongly tied to Cloud Characteristics and Cloud Free Line of Sight (CFLOS) Statistics
    - In most locations, Clear Days are on the order of 60-70%
  - RF relatively immune to most channel characteristics, not all

Challenge is High Data Rate at a Relatively High System Availability

Optical Atmospheric Propagation Effects

- **Absorption & Scattering (extinction)**
  - Attenuation of optical wave
  - Reduces received power
  - Limits optical channel availability in the presence of fog or clouds
- **Fluctuations in Index of Refraction**
  - Small temperature fluctuations cause refractive-index fluctuations known as *optical turbulence*
  - Cause intensity and phase fluctuations on propagating beam
- **Atmospheric Links**
  - Extended path turbulence between Transmitter and Receiver (Tx & Rx)
    - Uplink/downlink to/from air
    - Aircraft to aircraft
  - Aero-optic effect around aircraft, especially with external dome
    - Modeled as thin turbulent layer (phase screen) near Tx/Rx

- **Propagation Effects on Beam**
  - Larger beam spot size at receiver
    - Leads to additional power loss in signal
  - Beam wander
    - Caused by turbulent eddies near Tx
    - Contributes to long-term spot size
    - Can contribute to scintillation
  - Scintillation (intensity fluctuations)
    - Reduces signal-to-noise ratio (SNR)
    - Leads to signal fades
  - Phase fluctuations
    - Angle-of-arrival fluctuations (causes beam jitter on detector)
    - Reduces spatial coherence of beam (determines speckle size at Rx)
    - Limits heterodyne efficiency in coherent detection
    - Limits "effective" Rx aperture size for improved SNR to size of r_0



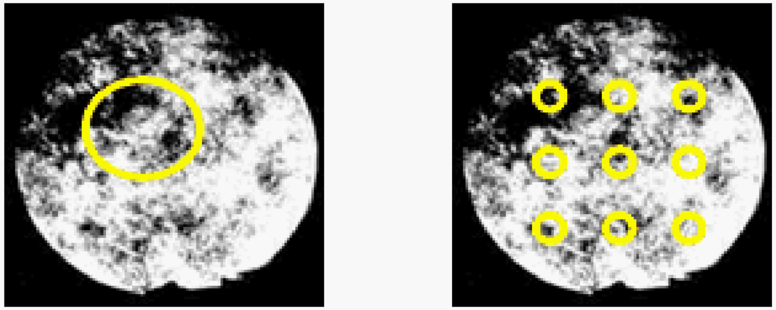
Mitigation of Atmospheric Effects

- **Transmitter System Architecture**
  - ***Increase transmitted power***
    - Improve SNR at Rx
  - ***Multiple beams***
    - Sufficiently separated to ensure statistical independence at Rx
    - Produces aperture averaging of scintillation (similar to receiver array)
  - ***Multiple wavelengths***
    - RF and optical
  - ***Adaptive optics***
    - Corrects phase distortions caused by optical turbulence

- **Receiver System Architecture**
  - *Incoherent (direct) detection*
    - intensity modulation
    - large aperture receiver (improve reliability)
    - array receivers (improve reliability)
  - *Coherent (heterodyne) detection*
    - intensity and phase modulation
    - large aperture receiver
    - array receivers

Intensity cross-section of beam after propagating thru extended turbulence. Dark patches denote a signal fade and yellow circle(s) depict (*a*) a large Rx aperture or (*b*) an array of small Rx apertures.

(*a*) (*b*)



What Was Demonstrated by the Network Centric Radio System (NCRS) Demonstration

Note: Any government collaboration information takes precedence over the information contained in this presentation.

1. **Raytheon Network Centric Radio In Operations**
   - Operates Like WNW would In Network Centric Operations at Tier 1 & Tier 2
   - SCA Compliant, Non-Proprietary Software
     - Raytheon Will supply FCS C Waveform Given to JTRS Library as above
   - High data rate LOS (including LOS airborne extensions to BLOS) networked radio system
     - >100 km Non-LOS Ranges Achievable with Airborne Relays
     - Automatic Adaptation to Lower Data Rates for Increased Range
   - Automated "configuration" and Network Management

2. **Heterogeneous MANET Gateway Architecture Implemented In TCA Structure**
   - Operates with High Packet Loss and Latency
   - Accommodates both Proprietary and Non-Proprietary Radios
   - Gateways linked end-users via Sample WAN technologies
     - FCS-NC, Ku SATCOM, Inmarsat, Iridium, GlobalStar
   - Gateways linked end-users via Tactical Data Radios (IP Capable)
     - EPLRS, EPLRS micro-Lite, Soldier Radio Waveform (SRW), SECNET 11
   - Gateways linked end-users via Tactical Voice Radios
     - PRC 117, PRC 119, PRC 150

3. **Complete Soldier Operation In Simulated Missions**
   - Initial Training in NOV/DEC 2005 at Fayetteville, TN
   - Heterogeneous Gateway Operations as well as Surrogate UAV Placement for Optimum Connectivity

Demonstrated MANET GATEWAY Capability for Brigade and Below

FCS-C Network Centricity Demonstration

Network Connectivity without FCS MANET Gateway

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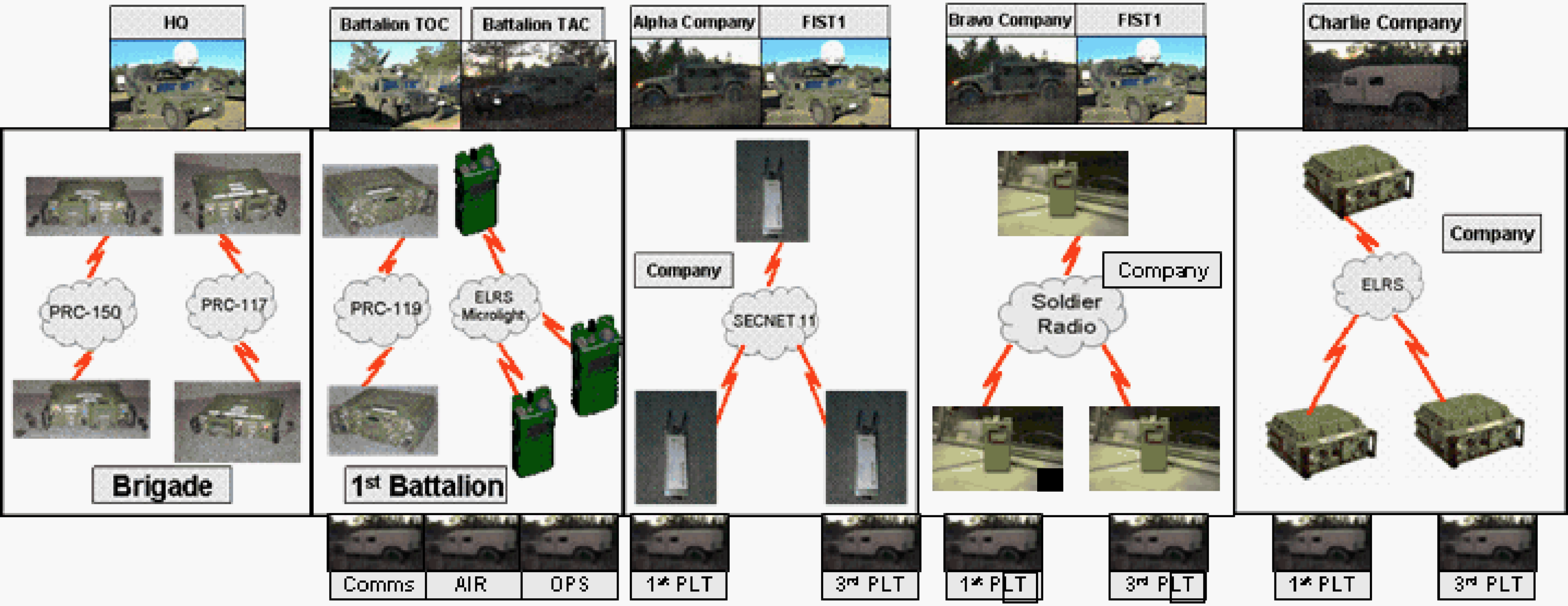
- ***Individual units***
  - ***Different radio systems***
    - ***Can only communicate within the group***



FCS-C Network Centricity Demonstration

Network Connectivity with FCS MANET Gateway

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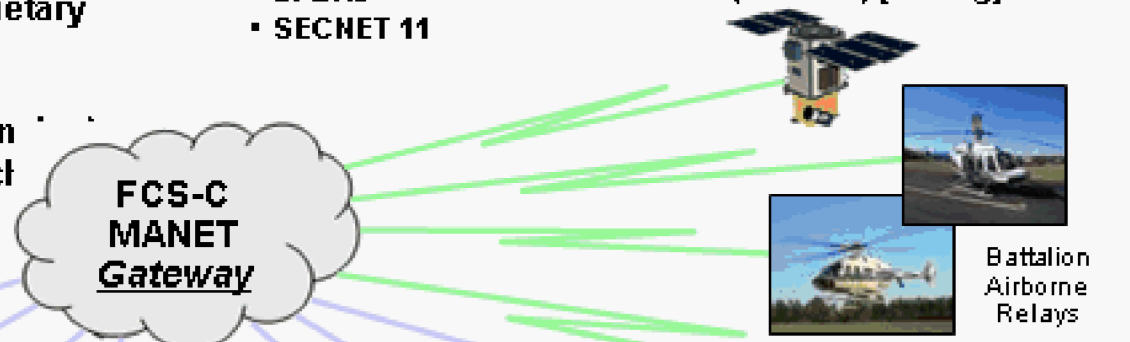
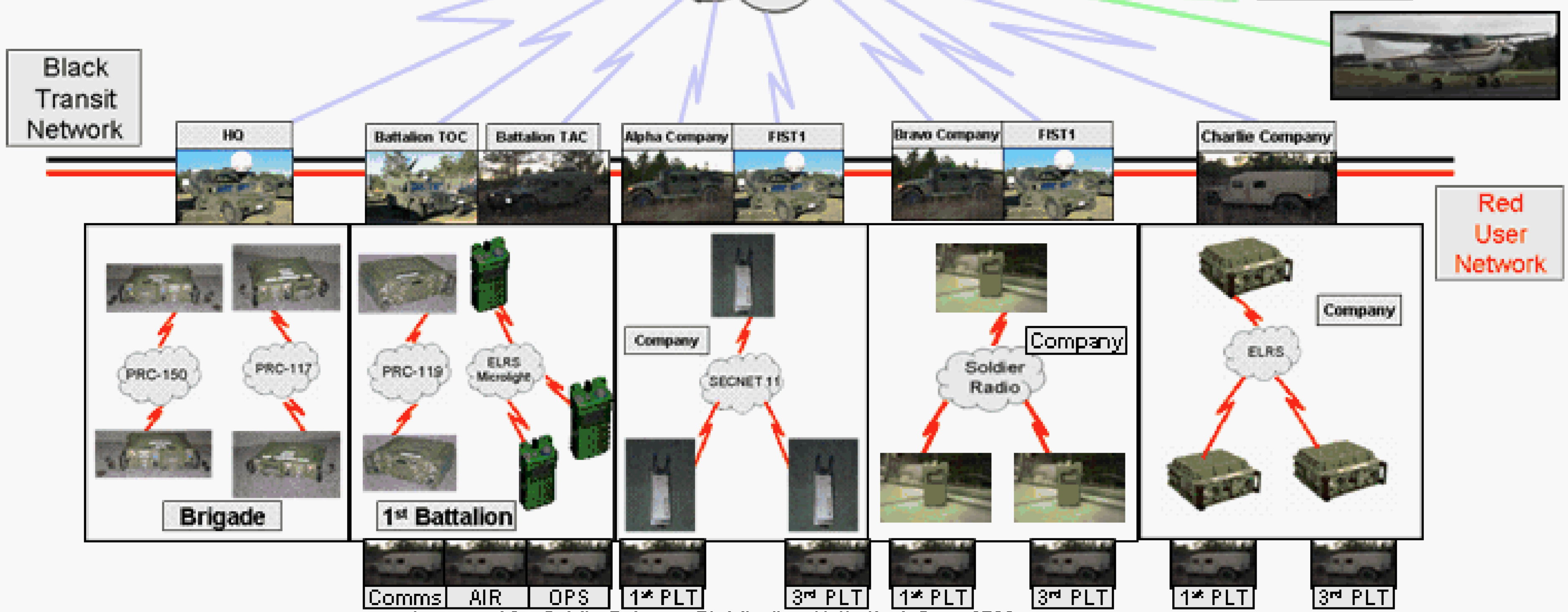
- Heterogeneous MANET Gateway Nodes
  - High Packet Loss (5-40%)
  - Latency (e.g., 5-10 seconds typical A/G-G/A)
  - Works with proprietary and non-proprietary radios
- Complete Soldier Operation
  - FCS Signal Soldiers (Ft Gordon, Ft Ben...
  - USA Soldier Battle Lab (Futures Branch McKenna Urban Ops)
  - FCS Contractors (Raytheon, CenGen)

Interoperable Communications Demonstrated:

- CPOF's & Cisco VoIP
- ITT Soldier Radio
- EPLRS
- SECNET 11
- HAVEQUICK I/II (PRC-117)
- SINCGARS (PRC-119)
- HFMR (PRC-150) [Analog]





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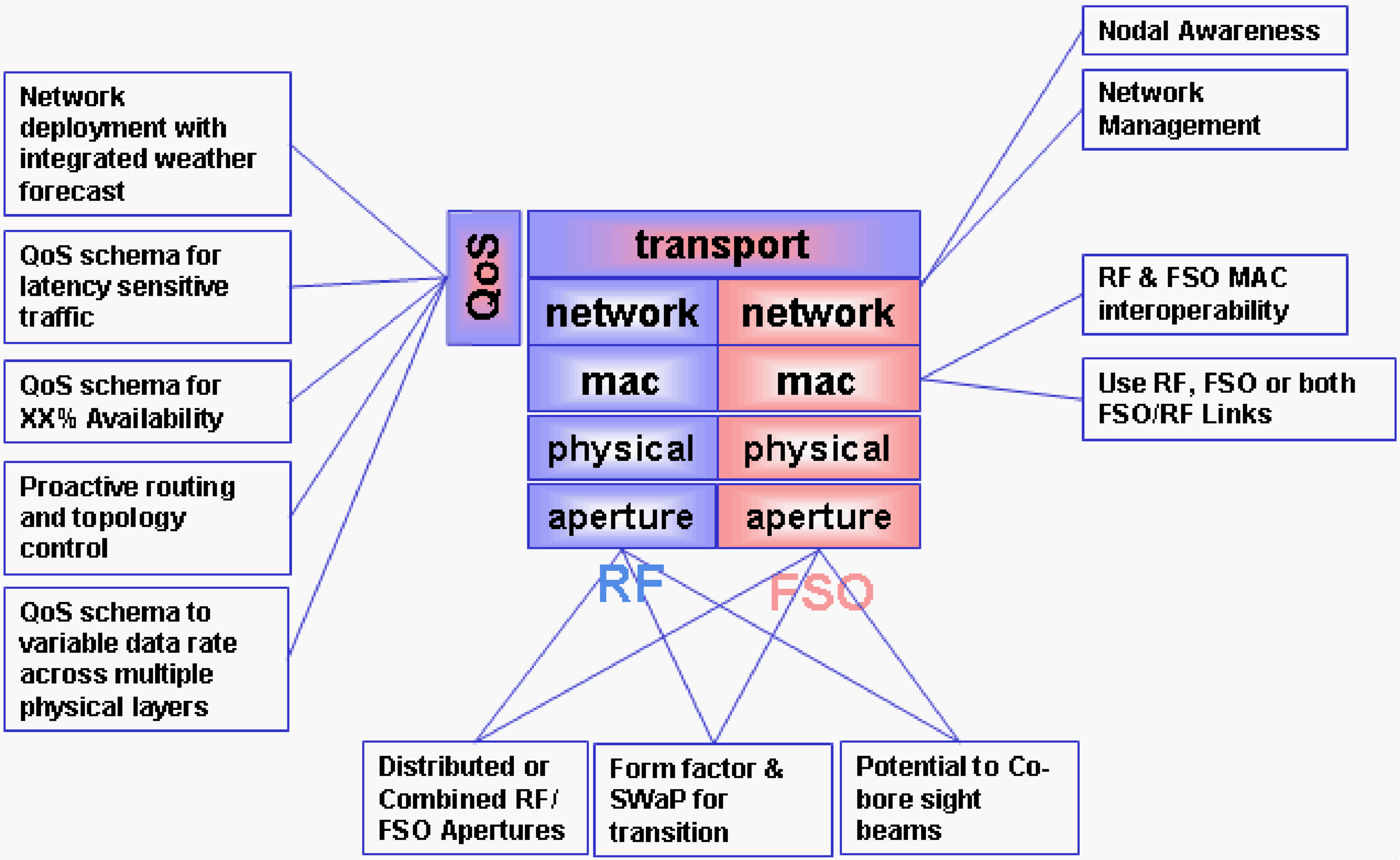
Hybrid System Considerations



ORCA Networking

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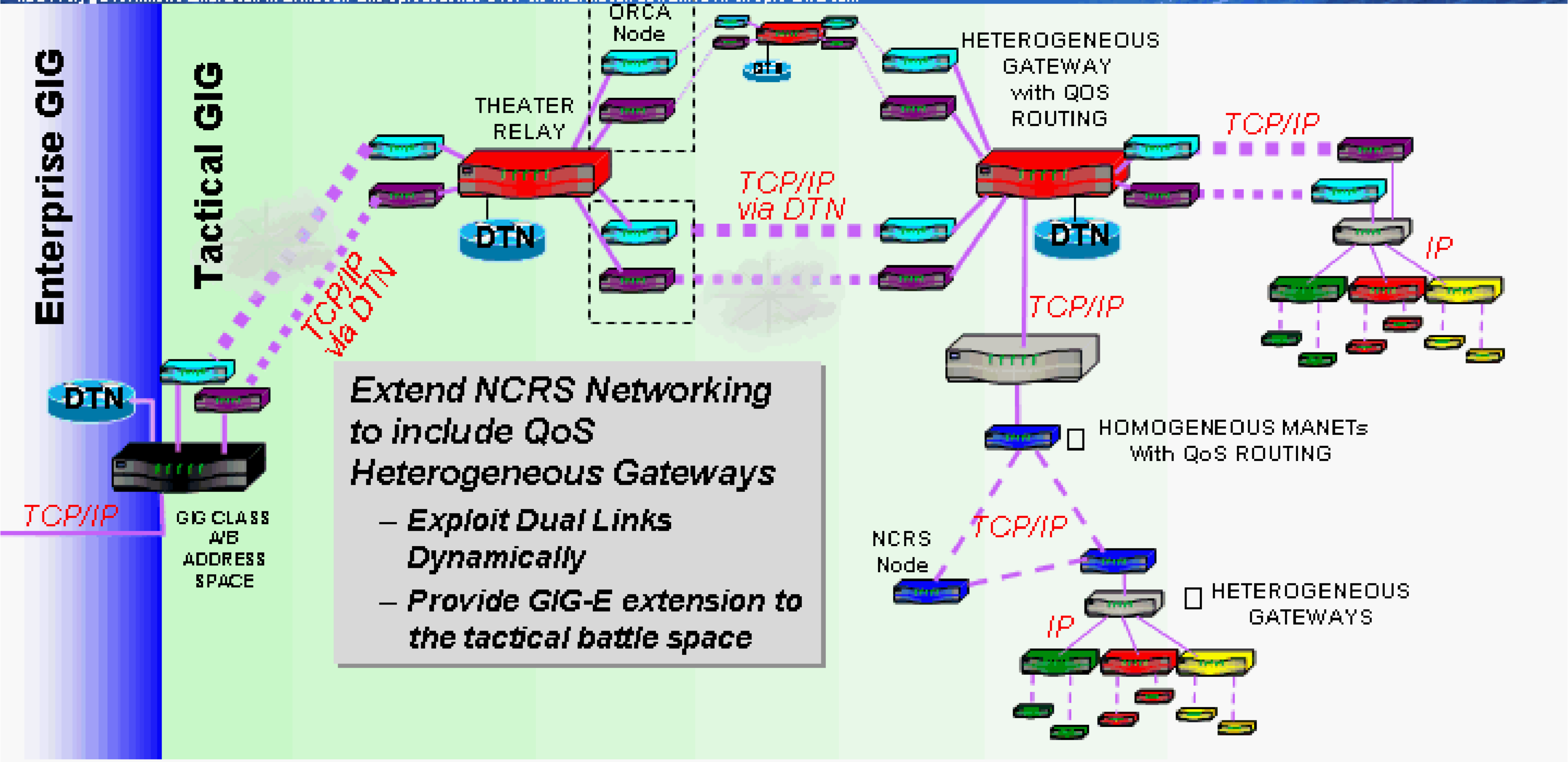

Networking Challenges:

- Extending NCRS: Provide QoS at gigabit rates across heterogeneous nodes with data aggregation
- Architecture to include handoff between TCP/IP, TCP/IP with DTN, and IP-only segments.
- Dynamics: Soft handoffs between dual links due to connectivity degradations
- Security: Provide gigabit rate IPSEC for tactical nodes

NCRS Networking Extensions

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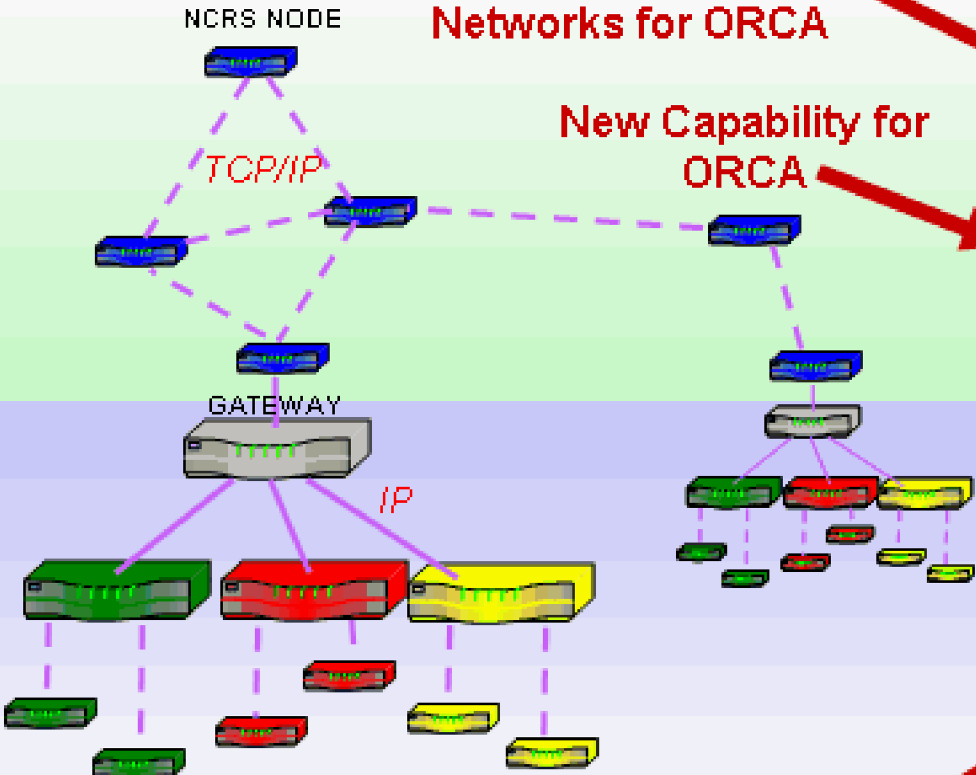

Extend to Heterogeneous Networks for ORCA

- **Node Activated Multiple Access (NAMA) Scheduler**
  - Dynamic TDMA effected by QoS Queue Characterization
- **Efficient Routing**
  - Unicast Routing via Scoped Link State Routing (SLSR)
  - Lower Overhead Receiver Oriented Multicast Routing (ROM)

New Capability for ORCA

- **Disruption Tolerant Networking to address temporary link outages due to movement and occlusions**

FSO/RF Network becomes the new backbone in ORCA

- **IP Gateway for Interoperability**
  - **Conversion of analog signals into digital streams**
  - **Treat Legacy Radios as feeder stub networks**
  - **Route into NCRS backbone network**

The Network has been Proven and is Extensible to ORCA

ORCA BAA Details

Acquisition Approach

- 3 Phases, with downselect at Preliminary Design Review (PDR)
  - Maybe, Second Downselect at CDR if Service Partner co-funds Phase 2 as well as Phase 3
  - PDR and CDR will occur after significant field demonstrations
- BAA
  - Detailed objectives
  - Specific definition of performance models to be used for evaluation
- Emphasis on past performance and maturity of system
  - Entrance TRL Level to Phase 1: TRL 5 Brassboard / TRL 6 Components
    - Verified by technology demonstrations and/or simulations
  - Orals at Contractor facilities
- Final demonstration will be in operationally representative conditions and scenario with User oversight and evaluation
  - Leave behind system expected

ORCA Range Testing

- Phase 1 (PDR) in Hawaii--Mauna Loa to Haleakala
  - Progressive Increasing Capability and Complexity
  - Test-Fix-Test Development Process
    - Contractor run, with On-site Government observers
  - Stressing but repeatable conditions
    - Hawaii provides very predictable weather, including clouds, regularly present
    - Test-Fix-Test Process
  - Mountaintop-mountaintop: Approx 150 km
  - Air-Mountain: Approx 200 km (nominal 10Kft & 25Kft MSL aircraft altitudes)
  - Mountaintop-ground: Approx 50 km
- Phase 2 (CDR) in Hawaii--Mauna Loa to Haleakala to aircraft/ground & aircraft to aircraft
  - Same Philosophy as Phase 1
  - Repeat Phase 1 tests, plus air-to-air communications and mutliple node networking:
    - Air-Air: Approx 200 km (nominal 10K ft & 25kft MSL aircraft altitudes)
    - Mountaintop-mountaintop: Approx 150 km
    - Air-Mountain: Approx 200 km
    - Mountaintop-ground: Approx 50 km
- Phase 3
  - Demo in Operational Setting— i. e. Ft Bragg
    - Air-Air: Approx 200 km
    - Air-Ground / Ground to Air: Approx 50 Km
    - Operational environment
    - Limited user testing
      - Government observers
    - Ground-Air-Air-Ground, with Multiple Ground & Airborne Nodes
    - System Leave Behind capable

Phase 1 Metrics

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PERFORMANCE	GO-NO GO METRICS	MEASUREMENT CONDITIONS
1. FSOC Airborne Cross Links		
Overall Data Rate	≥ 5 Gb/s	Flight Altitude ~ 10 & 25 kft MSL
Overall Information Rate	≥ 2.25 Gb/s	Range ~150 km; Rate 1/2 coding + 10% protocol overhead
FSOC Link Availability	≥ 95 %	Node-to-node
Bit Error Rate	≤ 1E-06 (uncorrected)	Various Times of Day & Night
	≤ 1E-8 (corrected)	Availability tests over 2 hours period
		Full-Duplex
		Air to Mountain (~11 kft)
		Aircraft Speed = 200-250 kts IAS
2. FSOC MTN-to-MTN Cross Link		
Overall Data Rate	≥ 5 Gb/s	MTN Altitude ~ 11 kft MSL nominal
Overall Information Rate	≥ 2.25 Gb/s	Range ~150 km; Rate 1/2 coding + 10% protocol overhead
FSOC Link Availability	≥ 90 %	Node-to-node
Bit Error Rate	≤ 1E-06 (uncorrected)	Various Times of Day & Night
	≤ 1E-8 (corrected)	Availability tests over 10 hours period
		Full-Duplex
3. FSOC MTN/GND Uplink/Downlink		
Overall Data Rate	2.5 Gb/s	MTN Altitude ~ 11 kft MSL nominal
Overall Information Rate	> 1.7 Gb/s	GND Altitude ~ 0 MSL nominal; Rate 3/4 coding + 10 % protocol overhead
FSOC Link Availability	≥ 60 %	Range ≤ 50 km
Bit Error Rate	≤ 4 E-06 (uncorrected)	Node-to-node
	≤ 4 E-8 (corrected)	Various Times of Day & Night
		Availability tests over 10 hours period
		Full-Duplex
		GND Transceiver Speed = 0-65 mph

Phase 1 Metrics (cont)

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4. RF Airborne Cross Links		
Overall Data Rate	274 Mb/s	Flight Altitude ~ 25 kft & 10 kft MSL
Overall Information Rate	>112 Mb/s	Range ~200 km; Rate 1/2 coding + 10% protocol overhead
RF Link Availability	≥ 95 %	Node-to-node
Bit Error Rate	≤ 4 E-05 (uncorrected)	Various Times of Day & Night
	≤ 4 E-07 (corrected)	Availability tests over 2 hours period
		Full-Duplex
		Air-to-Air, Air-to-MTN (~11 kft) &
		Aircraft Speed = 200-250 kts IAS
5. RF MTN-to-MTN Cross Link		
Overall Data Rate	274 Mb/s	MTN Altitude ~ 11 kft MSL nominal
Overall Information Rate	>112 Mb/s	protocol overhead
RF Link Availability	≥ 95 %	Node-to-node
Bit Error Rate	≤ 4 E-05 (uncorrected)	Various Times of Day & Night
	≤ 4 E-07 (corrected)	Availability tests over 10 hours period
		Full-Duplex
6. RF MTN/GND Uplink/Downlink		
Overall Data Rate	274 Mb/s	MTN Altitude ~ 11 kft MSL nominal
Overall Information Rate	>185 Mb/s	GND Altitude ~ 0 MSL nominal; Rate 3/4 coding + 10% protocol overhead
RF Link Availability	≥ 95 %	Range ≤ 50 km
Bit Error Rate	≤ 4 E-05 (uncorrected)	Node-to-node
	≤ 4 E-07 (corrected)	Various Times of Day & Night
		Availability tests over 10 hours period
		Full-Duplex
		GND Transceiver Speed = 0-65 mph

Phase 1 Metrics (cont)

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		Air-to-Air, Air-to-MTN (~11 kft) &
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Bit Error Rate	≤ 4 E-05 (uncorrected)	Node-to-node
	≤ 4 E-07 (corrected)	Various Times of Day & Night
		Availability tests over 10 hours period
		Full-Duplex
		GND Transceiver Speed = 0-65 mph
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7. NETWORKING	*System networking architecture includes:*	Italic Items are primary Metric; Un-italic items are Sub-metrics to primary Metric
	Ground node that with a direct interface to the GIG, ground node with a direct interface to tactical network gateway, airborne networking segment that provides connectivity between ground GIG node and tactical network gateway node;	
	Conformity to IPv6 protocol standard IPv6 inclusive of link/network security	
	Inclusion of link disruption mitigation protocols	
	Support to all DoD QoS services defined by ASD NII	
	Airborne networking segment that supports ≥ 4 platforms with multiple networking nodes;	
	End-to-end network configuration with minimum support to: one ground GIG node, four airborne platforms each with multiple nodes for mesh and/or mobile ad hoc networking support, and two ground tactical network nodes each with up to 64 IP addressable tactical communications nodes	
	Secure communications capability (i.e. HAIPE) for end-to-end secure transport that is permissible by the source and destination pair	
	Traffic shaping/prioritization to allow resource management between high priority, low latency internal ORCA network traffic and lower priority, latency tolerant external ORCA network traffic.	
	Successful Laboratory demonstration of the core technologies used in the system networking architecture	

Phase 1 Metrics (cont)

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ENVIRONMENTAL	GO-NO METRIC	REMARKS
Laser Safety	ANSI Z136.1 (2000), "Safe Use of Lasers"	Perform to Standard
	ANSI Z136.6 (2000), "Safe Use of Lasers Outdoors"	Perform to Standard
Antenna Testing	IEEE Standard 149-1979, "Standard Test Procedures for Antennas"	Perform to Standard
	IEEE Standard 1100-1999,"Recommened Practice for Powering and Grounding Electronic Equipment"	Perform to Standard
Marking Requirements	MIL-STD-27733, "Modification and Marking Requirements for Test Equipment in Aerospace Vehicles and Related Support Equipment"	Perform to Standard
EMI/EMC	Mil-Std-461 (EMI/EMC electrical interference testing and isolation techniques)	Perform to Standard
PROGRAMMATIC	GO-NO METRIC	REMARKS
Test Sites	All Tests will be performed in Hawaii	MTN-MTN tests will be between Mauna Loa to Haelakala
Ground Platform	Contractor Vehicle	
Air Platform for Design	Contractor Aircraft	
Metrological Ground Truthing	Contractor Supplied/Government Approved	To Ground Truth Theoretical Predictions and Sensitivity Analyses

Phase 2 Metrics

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PERFORMANCE	GO-NO GO METRICS	MEASUREMENT CONDITIONS
1. FSOC Airborne Cross Links		
Overall Data Rate	≥ 5 Gb/s	Altitude ~ 10 & 25 kft MSL nominal
Overall Information Rate	≥ 2.25 Gb/s	Range ~150 km; Rate 1/2 coding + 10% protocol overhead
FSOC Link Availability	≥ 95%	Node-to-node
Bit Error Rate	≤ 1E-06 (uncorrected)	Various Times of Day & Night
	≤ 1E-8 (corrected)	Availability tests over 2 hours period
		Full-Duplex
		Transceiver Coverage = 4π
		Air-to-Air & Air-to-MTN (~11 kft)
		Aircraft Speed = 200-250 kts IAS
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3. FSOC MTN/GND Uplink/Downlink		
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		Full-Duplex
		Transceiver Coverage = 4π
		GND Transceiver Coverage = 2π
		GND Transceiver Speed = 0-65 mph

4. FSOC AIR/GND Uplink/Downlink		
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		Full-Duplex
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		Aircraft Speed = 200-250 kts IAS
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	≤ 4 E-07 (corrected)	Availability tests over 10 hours period
		Full-Duplex
		Transceiver Coverage = 4π

Phase 2 Metrics (cont)

Note: Any government collaboration information takes precedence over the information contained in this presentation.

7. RF MTN/GND Uplink/Downlink		
Overall Data Rate	274 Mb/s	MTN Altitude ~ 11 kft MSL nominal
Overall Information Rate	>185 Mb/s	GND Altitude ~ 0 MSL nominal; Rate 3/4 coding + 10% protocol overhead
RF Link Availability	≥ 95%	Range ≤ 50 km
Bit Error Rate	≤ 4 E-05 (uncorrected)	Node-to-node
	≤ 4 E-07 (corrected)	Various Times of Day & Night
		Availability tests over 10 hours period
		Full-Duplex
		Transceiver Coverage = 4π
		GND Transceiver Coverage = 2π
		GND Transceiver Speed = 0-65 mph
8. RF AIR/GND Uplink/Downlink		
Overall Data Rate	274 Mb/s	AIR Altitude ~ 25 kft & 10 kft MSL
Overall Information Rate	>185 Mb/s	GND Altitude ~ 0 MSL nominal; Rate 3/4 coding + 10% protocol overhead
RF Link Availability	≥ 95%	Range ≤ 50 km
Bit Error Rate	≤ 4 E-05 (uncorrected)	Node-to-node
	≤ 4 E-07 (corrected)	Various Times of Day & Night
		Availability tests over 2 hours period
		Full-Duplex
		Transceiver Coverage = 4π
		GND Transceiver Coverage = 2π
		GND Transceiver Speed = 0-65 mph
		Aircraft Speed = 200-250 kts IAS

Phase 2 Metrics (cont)

9. NETWORKING	*protocol standard IPv6 inclusive of link/network security*	Italic Items are primary Metric; Un-italic items are Sub-metrics to primary Metric
	Demonstration of Network Connectivity to GIG and tactical gateway (defined by gov't)	
	Field demonstration of airborne segment networking supporting two air platforms and two mountains, with multiple networking	
	Maintain end-to-end connectivity of airborne segment of >99% reliability with 75% of end-to-end disruptions <5 sec	
	Secure communications capability (i.e. HAIPE) for end-to-end secure transport that is permissible by the source and destination pair;	
	Laboratory demonstration end-to-end network performance utilizing four airborne nodes and two ground nodes	
	Demo of link disruption mitigation protocols to link disruptions of >5 sec without connection loss	
	Network simulations of multiple nodes to reach 90% system availability of 250 Mbps data rate	
	Support of up to two stub networks, each with 64 IP-addressable nodes;	
	Laboratory demonstration of traffic shaping/prioritization to allow resource management between high priority, low latency internal ORCA network traffic and lower priority, latency tolerant external ORCA network traffic.	

Phase 2 Metrics (cont)

PHYSICAL	GO-NO METRIC	REMARKS
Size	≤ 13 cubic feet	Credible Design, with supporting Documentation
Weight	600lbs (including cabling, radome)	Credible Design, with supporting Documentation
Power	<4000 Watts (max)	Credible Design, with supporting Documentation
Aircraft Power	400 Hz AC	Credible Design, with supporting Documentation
ENVIRONMENTAL	COMPONENTS/SUBSYSTEMS GO-NO METRIC	REMARKS
Laser Safety	ANSI Z136.1 (2000), "Safe Use of Lasers"	Perform to Standard
	ANSI Z136.6 (2000), "Safe Use of Lasers Outdoors"	Perform to Standard
Antenna Testing	IEEE Standard 149-1979, "Standard Test Procedures for Antennas"	Perform to Standard
	IEEE Standard 1100-1999,"Recommened Practice for Powering and Grounding Electronic Equipment"	Perform to Standard
Marking Requirements	MIL-STD-27733, "Modification and Marking Requirements for Test Equipment in Aerospace Vehicles and Related Support Equipment"	Perform to Standard
EMI/EMC	Mil-Std-461 (EMI/EMC electrical interference testing and isolation techniques)	Perform to Standard

Phase 2 Metrics (cont)

Note: Any government collaboration information takes precedence over the information contained in this presentation.

Electronic Component Testing	Mil-Std-202 (electronic component testing)	Perform to Standard
Environmental Testing	MIL-STD-810F "Environmental Engineering Considerations and Laboratory Tests." Part II, Laboratory Test Methods,	Perform to Standard
		Temperature range: -56.5 (36 kft) to 130 Degrees C
		Method 509.4 - Salt Fog
		Method 520.2 - Temperature, Humidity, Vibration, and Altitude
		MIL-HDBK-1568 - MATERIAL AND PROCESSES FOR CORROSION PREVENTION AND CONTROL IN AEROSPACE WEAPONS SYSTEMS
		MIL-HDBK-1250A - CORROSION PREVENTION AND DETERIORATION CONTROL IN ELECTRONIC COMPONENTS AND ASSEMBLIES
		Air Platform PSD = C-130
		Ground Platform PSD = HUMVEE
PROGRAMMATIC	GO-NO METRIC	REMARKS
Test Sites	All Tests will be performed in Hawaii	MTN-MTN tests will be between Mauna Loa to Haelakala
Ground Platform	Contractor Vehicle	
Air Platform for Design	Contractor Aircraft	
Metrological Ground Truthing		To Ground Truth Theoretical Predictions and Sensitivity Analyses

Phase 3 Metrics

Note: Any government collaboration information takes precedence over the information contained in this presentation.

PERFORMANCE	GO-NO GO METRICS	MEASUREMENT CONDITIONS
1. FSOC Airborne Cross Links		
Overall Data Rate	≥ 5 Gb/s	Altitude ~ 10 & 25 kft MSL nominal
Overall Information Rate	≥ 2.25 Gb/s	Range ~150 km; Rate 1/2 coding + 10% protocol overhead
FSOC Link Availability	≥ 95%	Node-to-node
Bit Error Rate	≤ 1E-06 (uncorrected)	Various Times of Day & Night
	≤ 1E-8 (corrected)	Availability tests over 2 hours period
		Full-Duplex
		Transceiver Coverage = 4π
		Aircraft Speed = 200-250 kts IAS
2. FSOC AIR/GND Uplink/Downlink		
Overall Data Rate	2.5 Gb/s	AIR Altitude ~ 25 kft & 10 kft MSL
Overall Information Rate	> 1.7 Gb/s	GND Altitude ~ 0 MSL nominal; Rate 3/4 coding + 10% protocol overhead
FSOC Link Availability	≥ 60%	Range ≤ 50 km
Bit Error Rate	≤ 4 E-06 (uncorrected)	Node-to-node
	≤ 4 E-8 (corrected)	Various Times of Day & Night
		Availability tests over 2 hours period
		Full-Duplex
		Transceiver Coverage = 4π
		GND Transceiver Coverage = 2π
		GND Transceiver Speed = 0-65 mph
		Aircraft Speed = 200-250 kts IAS
3. RF Airborne Cross Links		
Overall Data Rate	274 Mb/s	Flight Altitude ~ 25 kft & 10 kft MSL
Overall Information Rate	>112 Mb/s	Range ~200 km; Rate 1/2 coding + 10% protocol overhead
RF Link Availability	≥ 95%	Node-to-node
Bit Error Rate	≤ 4 E-05 (uncorrected)	Various Times of Day & Night
	≤ 4 E-07 (corrected)	Availability tests over 2 hours period
		Full-Duplex
		Transceiver Coverage = 4π
		Aircraft Speed = 200-250 kts IAS

Phase 3 Metrics (cont)

Note: Any government collaboration information takes precedence over the information contained in this presentation.

4. RF AIR/GND Uplink/Downlink		
Overall Data Rate	274 Mb/s	AIR Altitude ~ 25 kft & 10 kft MSL
Overall Information Rate	>185 Mb/s	GND Altitude ~ 0 MSL nominal; Rate 3/4 coding + 10% protocol overhead
RF Link Availability	$\geq$ 95%	Range $\leq$ 50 km
Bit Error Rate	$\leq$ 4 E-05 (uncorrected)	Node-to-node
	$\leq$ 4 E-07 (corrected)	Various Times of Day & Night
		Availability tests over 2 hours period
		Full-Duplex
		Transceiver Coverage = 4π
		GND Transceiver Coverage = 2π
		GND Transceiver Speed = 0-65 mph
		Aircraft Speed = 200-250 kts IAS
5. NETWORKING	*Field demonstration of airborne segment networking supporting three platforms, a ground node with direct interface to the GIG, and two ground nodes with an interface to a tactical gateway supporting up to 64 IP-addressable nodes*	Italic Items are primary Metric; Un-italic items are Sub-metrics to primary Metric
	Demonstrate end-to-end connectivity (between GIG and tactical gateway) of >95% reliability with 75% of end-to-end disruptions <5 sec;	
	Secure communications capability (i.e. HAIPE) for end-to-end secure transport that is permissible by the source and destination pair;	
	Demonstrate the implementation of a packet prioritization mechanism between external ORCA and internal ORCA network traffic	
	Demonstrate multiple service capabilities: Voice Interactive data Video Bulk data transfer Real-time video	

Phase 3 Metrics (cont)

Note: Any government collaboration information takes precedence over the information contained in this presentation.

PHYSICAL	GO-NO METRIC	REMARKS
Size	≤ 13 cubic feet	
Weight	600lbs (including cabling, radome)	
Power	<4000 Watts (max)	
Aircraft Power	400 Hz AC and 28VDC	If other voltage sources are available the contractor can use any available extra power as agreed to by the owner.
Ground Power	120V 60Hz AC and 12VDC	
ENVIRONMENTAL	COMPONENTS/SUBSYSTEMS/SYSTEMS GO-NO METRIC	REMARKS
Laser Safety	ANSI Z136.1 (2000), "Safe Use of Lasers"	Perform to Standard
	ANSI Z136.6 (2000), "Safe Use of Lasers Outdoors"	Perform to Standard
Antenna Testing	IEEE Standard 149-1979, "Standard Test Procedures for Antennas"	Perform to Standard
	IEEE Standard 1100-1999, "Recommened Practice for Powering and Grounding Electronic Equipment"	Perform to Standard
Marking Requirements	MIL-STD-27733, "Modification and Marking Requirements for Test Equipment in Aerospace Vehicles and Related Support Equipment"	Perform to Standard
EMI/EMC	Mil-Std-461 (EMI/EMC electrical interference testing and isolation techniques)	Perform to Standard
Electronic Component Testing	Mil-Std-202 (electronic component testing)	Perform to Standard

Phase 3 Metrics (cont)

Note: Any government calibration information takes precedence over the information contained in this presentation.

Environmental Testing	MIL-STD-810F "Environmental Engineering Considerations and Laboratory Tests." Part II, Laboratory Test Methods,	Perform to Standard
		Temperature range: -56.5 (36 kft) to 130 Degrees C
		Method 509.4 - Salt Fog
		Method 520.2 - Temperature, Humidity, Vibration, and Altitude
		MIL-HDBK-1568 - MATERIAL AND PROCESSES FOR CORROSION PREVENTION AND CONTROL IN AEROSPACE WEAPONS SYSTEMS
		MIL-HDBK-1250A - CORROSION PREVENTION AND DETERIORATION CONTROL IN ELECTRONIC COMPONENTS AND ASSEMBLIES
		Air Platform PSD = C130
		Ground Platform PSD = HUMVEE
PROGRAMMATIC	GO-NO METRIC	REMARKS
Test Sites	FT Bragg	Subject to change by Government
Ground Platform	M998 High Mobility Multipurpose Wheeled Vehicle (HMMWV or Humvee)	
Air Platform for Design	C-130s and Contractor Aircraft	Subject to change by Government
Metrological Ground Truthing		Equipment necessary to validate and predict systems performance and sensitivity

Performer TRL 5 Entry Criteria

- Must demonstrate, or have demonstrated, ~TRL 6 components and subsystems, which will integrate into a TRL 5 system, for ORCA Phase 1 and 2
- Document achievements in proposals and supportive background
- Must allow evaluation team to see high fidelity laboratory component integration and test in simulated environments.
  - Proposers will be encouraged to use outside ranges or demonstration sites when able to show ability to operate in relevant environments
    - Must show ability to deliver RF at 274-548 Mb/s – scaleable to 1 Gb/s
    - Must show ability to deliver FSO at 2.5 Gb/s – scaleable to 5-10 Gb/s
    - Must show network capability
- Program Entry Criteria: Prove equipment, algorithm, network, etc is mature enough to enter this program

The 5000.2 Model Explained

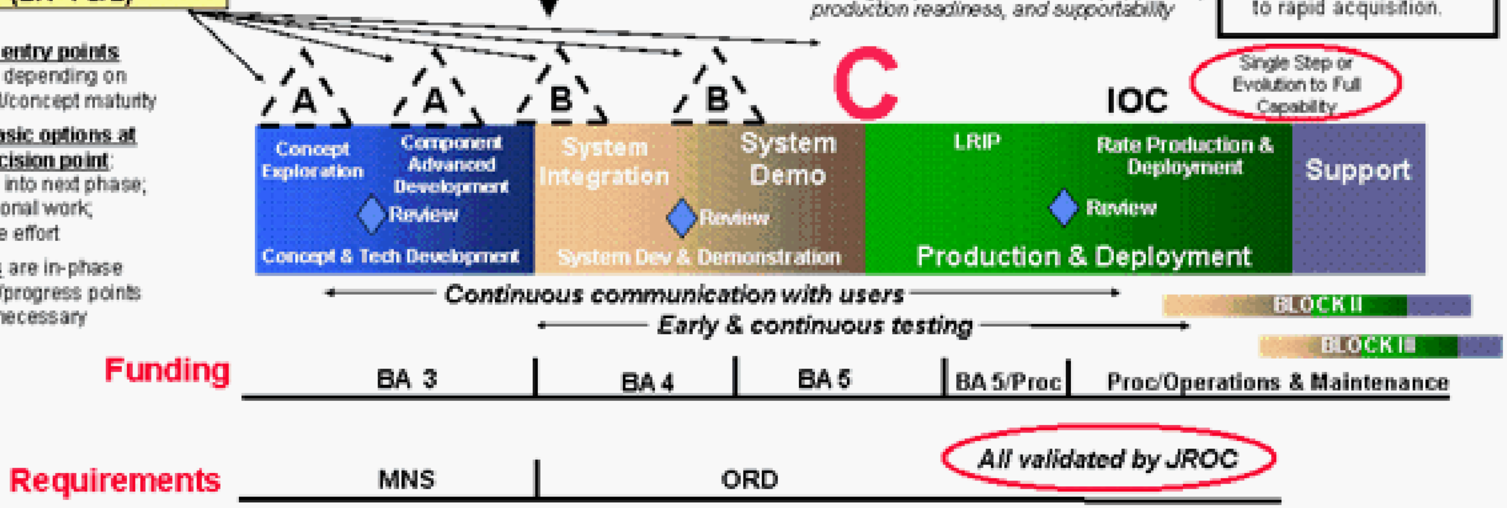
Technology Opportunities & User Needs
(BA 1 & 2)

Program Outyear Funding

MS C EXIT CRITERIA
- ☑ *Demonstrated system*
- ☑ *Approved ORD & assured interoperability*
- ☑ *Affordability assessment*
- ☑ *Strategy in place for evolutionary approach, production readiness, and supportability*

- MS A: Analyze concepts
- MS B: Begin development
- MS C: ***Commitment*** to rapid acquisition.

- **Multiple entry points** possible depending on technical/concept maturity
- **Three basic options at each decision point**: Proceed into next phase; do additional work; terminate effort
- **Reviews** are in-phase decision/progress points held as necessary



Concept Exploration
- Paper studies of alternative concepts for meeting a mission
- Exit criteria: Specific concept to be pursued & technology exists.

Component Advanced Development
- Development of subsystems/components that must be demonstrated before integration into a system
- Concept/tech demonstration of new system concepts
- Exit criteria: System architecture & technology mature.

System Integration
- System integration of demonstrated subsystems and components
- Reduction of integration risk
- Exit criterion: System demonstration in a relevant environment (e.g., first flight).

System Demonstration
- Complete development
- Demo engineering development models
- Combined DT/OT
- Exit criterion: System demonstration in an operational environment.

LRIP
- IOT&E, LFT&E of prod-rep articles
- Create manufacturing capability
- LRIP
- Exit criterion: B-LRIP report.

Rate Prod & Deployment
- Full rate production
- Deployment of system

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

Technology Readiness Levels

Note: Any government collaboration information takes precedence over the information contained in this presentation.

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
1	Basic Principles observed and reported	**Basic research** – Invention of Gas Laser
2	Technology concept and/or application formulated.	**Basic research** – Invention of Ring Laser. Theoretical description of Ring Laser Gyro
3	Analytical and experimental critical function and/or characteristic proof of concept.	**Applied research** – Demonstration of Ring Laser as a rate sensor
4	Component and/or breadboard validation in laboratory environment.	**Applied research** – Demonstration of Ring Laser Gyro (RLG)-based Inertial Measurement Unit (IMU) operation under temperature, shock, vibration, and g-loading
5	Component and/or breadboard validation in relevant environment.	**Advanced Technology Demonstration** – Demonstration of HG1700-based guidance set components (IMU, GPS receiver, control system, flight computer) in a high-fidelity hardware-in-the-loop facility
6	System/subsystem model or prototype demonstrated in a relevant environment.	**Advanced Technology Demonstration** – Demonstration of actual flight-ready HG1700-based guidance set in a high-fidelity hardware-in-the-loop facility and under expected levels of shock, vibration, altitude and temperature
7	System prototype demonstrated in an operational environment.	**System Design and Development** – Demonstration of actual Guided MLRS missile in a flight test sequence from an operational launcher. Successful operation in multiple flight demonstrations
8	Actual system completed and "flight qualified" through test and demonstration.	**Low Rate Initial Production** – Developmental Test and Evaluation of GMLRS in its final form under mission conditions.
9	Actual system "flight proven" through successful mission operations.	**Production** – Operational Test and Evaluation of GMLRS by the soldier, airman, or seaman.

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

Technology Readiness Example

Note: Any government collaboration information takes precedence over the information contained in this presentation.

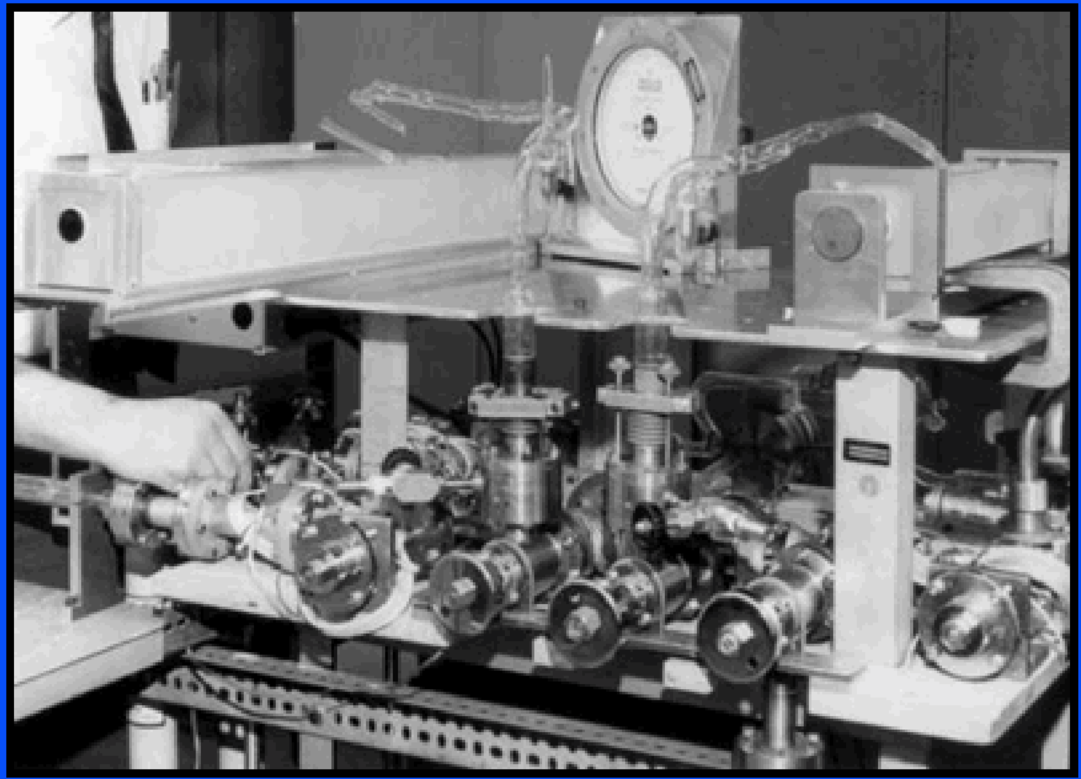
Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
1	Basic Principles observed and reported	**Basic research** – Invention of Gas Laser
2	Technology concept and/or application formulated.	**Basic research** – Invention of Ring Laser. Theoretical description of Ring Laser Gyro

Laser

Research

Facility

circa 1960

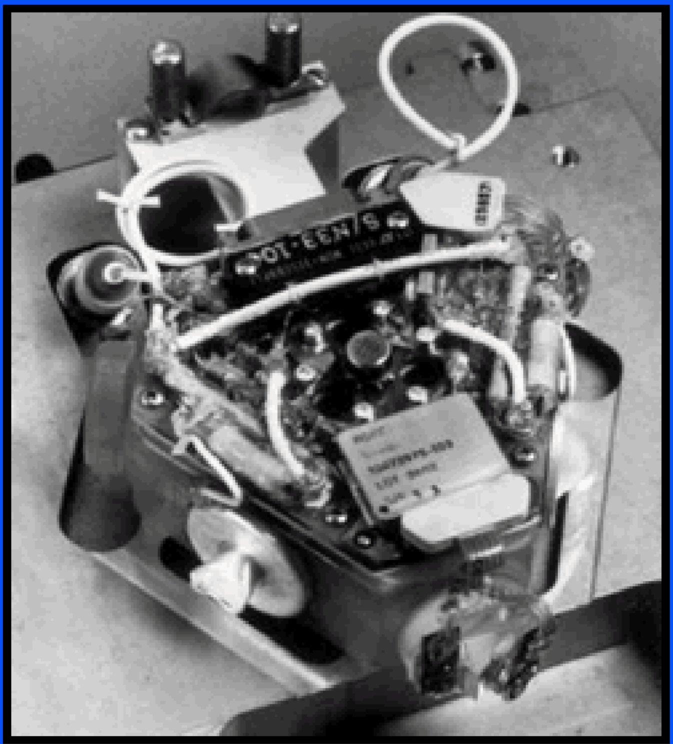


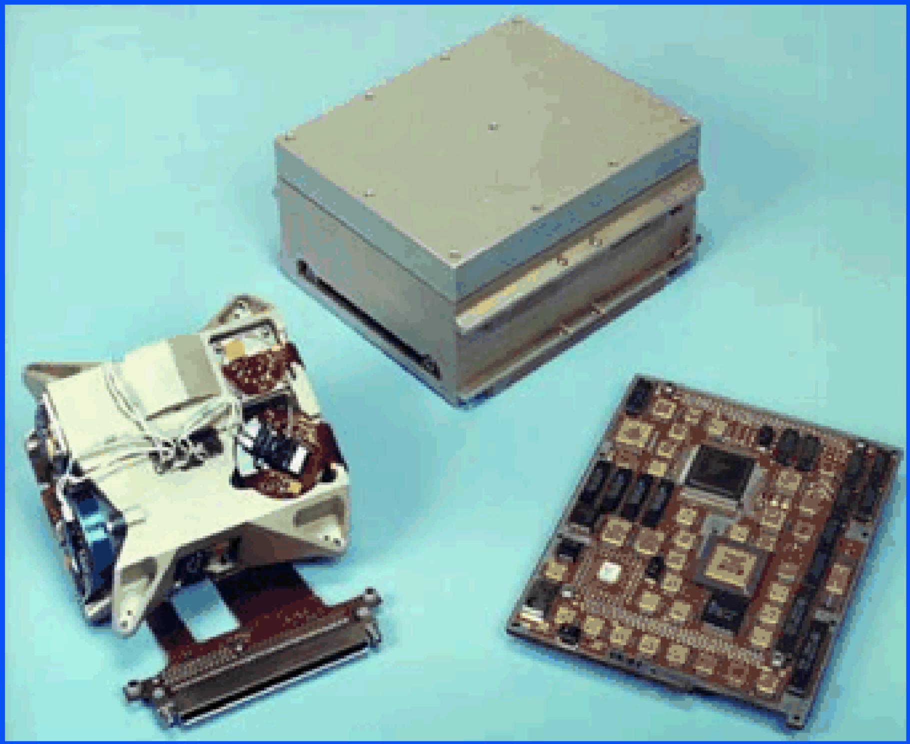
Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
3	Analytical and experimental critical function and/or characteristic proof of concept.	**Applied research** – Demonstration of Ring Laser as a rate sensor

Ring Laser Gyro circa 1975





HG1108 Inertial Measurement Unit circa 1990

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

Technology Readiness Example

Note: Any government collaboration information takes precedence over the information contained in this presentation.

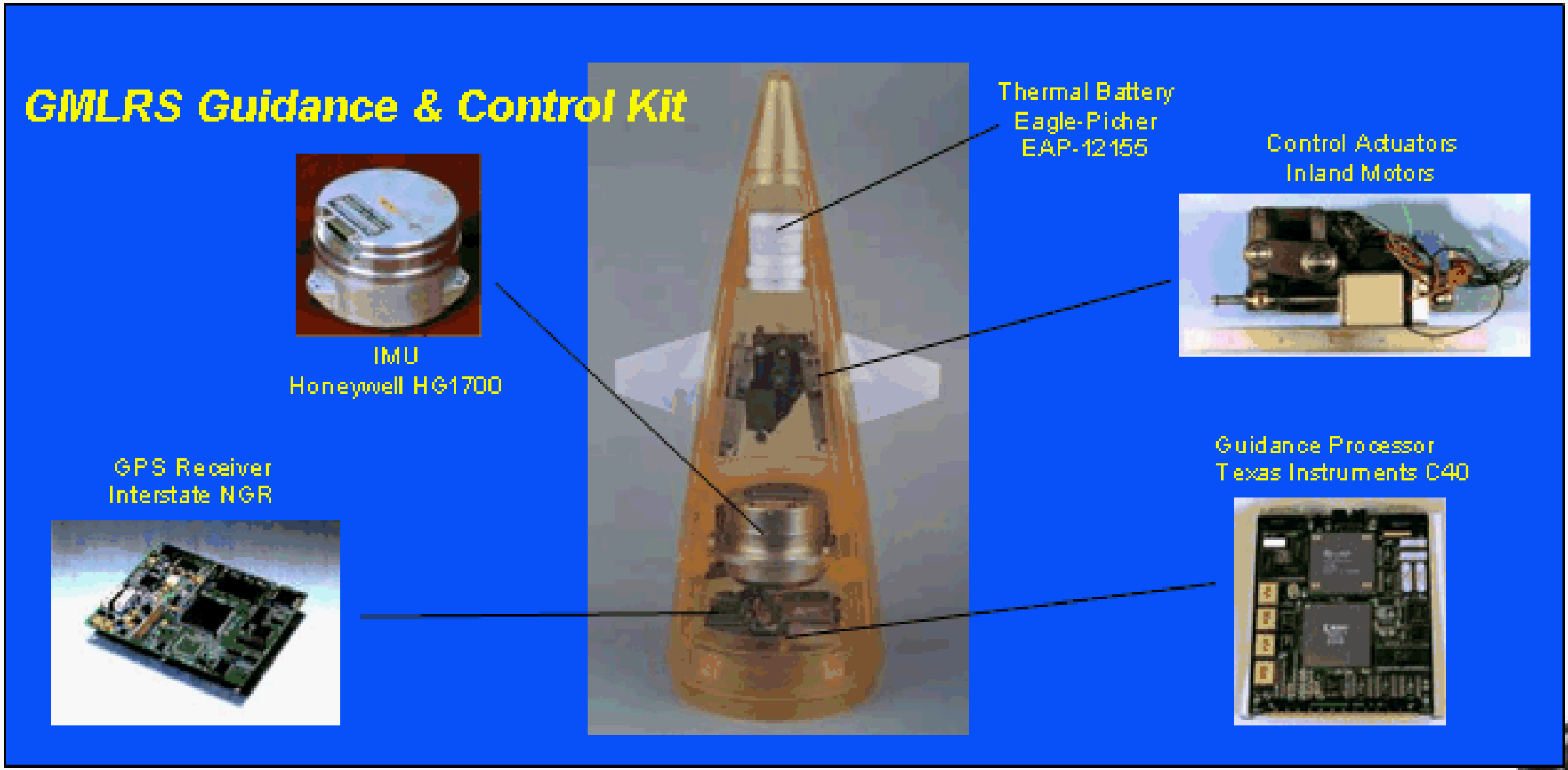
Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
4	Component and/or breadboard validation in laboratory environment.	**Applied research** – Demonstration of Ring Laser Gyro (RLG)-based Inertial Measurement Unit (IMU) operation under temperature, shock, vibration, and g-loading

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

Technology Readiness Example

Note: Any government collaboration information takes precedence over the information contained in this presentation.

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
5	Component and/or breadboard validation in relevant environment.	**Advanced Technology Demonstration** – Demonstration of HG1700-based guidance set components (IMU, GPS receiver, control system, flight computer) in a high-fidelity hardware-in-the-loop facility



Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

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Technology Readiness Example

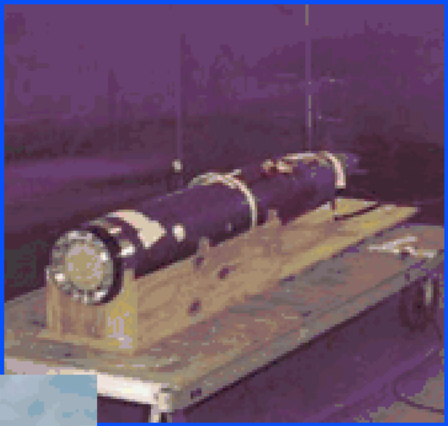
Note: Any government collaboration information takes precedence over the information contained in this presentation.

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
6	System/subsystem model or prototype demonstrated in a relevant environment.	**Advanced Technology Demonstration** – Demonstration of actual flight-ready HG1700-based guidance set in a high-fidelity hardware-in-the-loop facility and under expected levels of shock, vibration, altitude and temperature

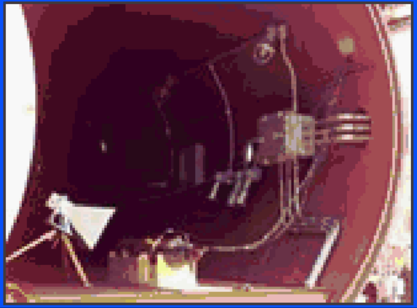
Advanced Technology Demonstration


Hardware-in-the-loop


Live-sky Testing


Temperature Test

Vibration Test



Altitude Test

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
7	System prototype demonstrated in an operational environment.	**System Design and Demonstration** – Demonstration of actual Guided MLRS missile in a flight test sequence from an operational launcher. Successful operation in multiple flight demonstrations

Advanced Concept Technology Demonstration

GPS-aided IMU Flight
(2m miss at 49 km range)

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

Technology Readiness Example

Level	Technology Readiness	Example – HG1700 Inertial Measurement Unit Guided Multiple Launch Rocket System (GMLRS)
8	Actual system completed and "flight qualified" through test and demonstration.	**Low Rate Initial Production** – Developmental Test and Evaluation of GMLRS in its final form under mission conditions.
9	Actual system "flight proven" through successful mission operations.	**Production** – Operational Test and Evaluation of GMLRS by the soldier, airman, or seaman.

Low Rate of Initial Production

Production

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

Specification Definition

The contractor shall perform a system design to achieve the ORCA metrics using the GFI and other guidance provided in the solicitation/contract. Included in this design will be a definition of the quantitative specification for each major component and subsystem comprising the overall system, a sensitivity analysis related to the design's robustness and ALL underlining assumptions in the design. Major categories in each specification, from the system down to the components, should include at the minimum: (1) Performance (e.g., for an inertial sensor, bias stability, drift rate, scale factor, accelerometer dynamic range); (2) physical (e.g., size, weight, volume, required electrical power); (3) environmental (e.g., temperature range, vibration/power spectrum density; shock; humidity range; waterproof; immersion depth); and (4) programmatic (e.g., test/measurement environment, affordability). Qualitative metrics are not acceptable. It will be complete and unambiguous, using accepted industry standard definitions as available. The specification for the components, subsystem and systems will be the measurement metrics for the associated Technology Readiness Assessment.

TRL 5 Assessment

Strategic Technology Office

Note: Any government collaboration information takes precedence over the information contained in this presentation.

The definition of TRL 5 is "component and/or breadboard validation in relevant environment." Its description is that the "basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment." Examples include "high-fidelity" laboratory integration of components. Table gives the example that the components of the HG 1700 like the IMU, GPS receiver, control system and flight computer were exercised and evaluated in a high-fidelity "hardware in the loop" facility.

In simple terms, the contractor will be expected to test the components, subsystems and/or systems in the laboratory under some simulated, expected operational conditions, but the breadboard is not expected to meet the full packaging, complete environmental and programmatic specifications. For example, the device will be shown to meet the performance specification while simultaneously experiencing vibration from a vibration table or temperature cycling in a temperature chamber or both. The parts that compose the entity also may not be packaged in its final form as well.

The entity must meet, or exceeds, 100% of the performance, but will not be expected to be tested under all specified ranges because of cost, equipment limitations, or some other reasonable consideration. However, the test must be comprehensive enough (>70% of the range, centered between the two extremes) to give the government the confidence that the any performance variation is not trending towards future catastrophic failure modes at this stage of development. Some statistical testing of the components, subsystems and system ($3 < X < 10$) is expected; greater confidence will be given to more samples being used.

Critical to this assessment is a clear, detailed definition of the tests and procedures that were used. This definition must be documented with the analyzed test results for review by the government and non-government Subject Matter Experts (SMEs).

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

TRL 6 Assessment

Note: Any government collaboration information takes precedence over the information contained in this presentation.

The definition of TRL 6 is “System/subsystem model or prototype demonstration in a relevant environment.” Its description is that the “representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment.” It represents a major step up in a technology’s demonstrated readiness and the S&T entrance criteria for a Milestone B Decision. This is normally the assessment that comes after the Component Technology Development (Exit Criteria). Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment” Table gives the example that the demonstration of a flight-ready HG-1700-based guidance set, exercised and evaluated in a high-fidelity “hardware in the loop” facility under expected vibration, shock, altitude and temperature.

In simple terms, the contractor will be expected to test the subsystems, system and/or prototype in the laboratory under full simulated, expected operational conditions. Unlike TRL 5, the subsystems, system and/or prototype is expected to meet all the specification, including the full packaging, complete environmental and programmatic specifications. It will be not be evaluated under the full formal testing outlined by Acquisition and IOT&E policies, requiring a statistical Test and Evaluation Master Plan (TEMP) and formal documentation, but enough testing is expected to provide the government with confidence that it would pass the formal process. In other words, sufficient statistical testing must be exercised to ensure that a zero/minimal set of unknown unknowns will occur in future development, if it occurs. The entity must meet, or exceeds, 100% of the complete specification.

Critical to this assessment is a clear, detailed definition of the tests and procedures. This definition must be reviewed and approved by the government before execution. In addition, all tests will be observed by a government official or representative. These requirements are mandated to ensure government expectations are met. As stated above, this TRA could provide a Technology Maturity Assessment for a future Program of Record at the Milestone B stage, hence the reason for the extra scrutiny.

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

TRL 6 Assessment (cont)

Note: Any government collaboration information takes precedence over the information contained in this presentation.

Based on the customers' desire before the end of Phase 2, a Technical Maturity Assessment may be formally signed between the DARPA Director and the receiving Program Executive Officer or appropriate Acquisition Executive, and the aforementioned contractor derived specification will be replaced with a set of Key Performance Parameters (KPPs), defined solely by the customer. This set of KPPs will be in accordance with the customer's Operational Requirement Document (ORD) or equivalent documentation. In this assessment, all testing will performed independent of contractor testing, either by representatives from the government, an independent, disinterested contractor/ FFRDC, or a combination of the aforementioned. To ensure operational utility, some Limited User Testing (LUTs) be done as part of this assessment as well.

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

TRL 7 Assessment

The definition of TRL 7 is "System prototype demonstration in an operational environment." Its description is that Prototype near, or at, planned operational system represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft." This is normally the assessment that comes after the System Integration portion of System Development and Demonstration (Exit Criteria; see figure 1). Table gives the example of actual demonstration of a GMLRS flight test from an operational launcher. It requires successful operations in multiple flight operations.

TRL 7 testing (aka Developmental Testing, or DT) requires formal documentation like a TEMP developed by representatives from the Service and OSD testing communities. All documentation is reviewed by numerous groups and organizations, and approved by the pertinent Acquisition Executive before execution. All testing is done independently by the government, and periodic reports come out outlining test results and analyses.

This type of assessment is beyond what is required by ORCA, and DARPA, in general, and is provided for informational purposes only.

Reference: DDR&E, DoD Technology Readiness Assessment (TRA) Desk Book, September 2003

SWaP Metrics and Other Guidance

Note: Any government collaboration information takes precedence over the information contained in this presentation.

SWaP for Each Complete ORCA System Node

- Size: ≤ 13 cubic feet
- Weight: ≤ 600lbs (including cabling, radome)
- Power: <4000 Watts (max)
- Aircraft Power: 400 Hz AC

Other Objectives

- Prefer co-aperture
- Operation Duration: 24 hours
- Integrate Disruptive Tolerance Network Equipment into TCP/IP-based ORCA Network to minimize network inefficiencies
- Adverse Weather
- TRL 6 System Prototype Delivery at end of Phase 2, one cycle less to TRL-7 (Developmental Testing level)
- Solar rejection at disk

REFERENCE DOCUMENTATION

Note: Any government collaboration information takes precedence over the information contained in this presentation.

- Technology Readiness Assessment Handbook
- ANSI Z136.1 (2000), "Safe Use of Lasers"
- ANSI Z136.6 (2000), "Safe Use of Lasers Outdoors"
- IEEE Standard 149-1979, "Standard Test Procedures for Antennas"
- IEEE Standard 1100-1999,"Recommened Practice for Powering and Grounding Electronic Equipment"
- MIL-STD-27733, "Modification and Marking Requirements for Test Equipment in Aerospace Vehicles and Related Support Equipment"
- Mil-STD-810 (physical standard containing shock, vibration, humidity test procedures etc.)
- Mil-Std-202 (electronic component testing)
- Mil-Std-461 (EMI/EMC electrical interference testing and isolation techniques)

Integrated M&S A Discerning Factor for Success

Note: Any government collaboration information takes precedence over the information contained in this presentation.

- Communications & Link Models (RF & Optical)
- Atmospheric Propagation (e.g. modtran, PLEXUS)
- Control System Models (RF/Optical e.g. MATLAB)
- Network Models (e.g. OPNET)
- Utility Models (e.g. EADSIM)
- Optical System Models (e.g. WAVETRAIN, OSLO)
- Solids Models

GFE Information
Reference Models and Standards

Note: Any government collaboration information takes precedence over the information contained in this presentation.

- WGS-84
- 1976 Atmosphere
- Crane Region D3
- 5 X Hufnagel-Valley 5/7
  - Wind 20fps
  - Ground C_n^2 (T) = 1.0e-13
- Cloud Free Line of Sight Probability
  - Korea-June
- Visibility
  - Korea-April
- Optical Propagation: Beam Type

QUESTIONS?

Optical RF Communications Adjunct (ORCA)