Challenges to using Ground Based Sense and Avoid (GBSAA) for UAS Operations

Federal Aviation Administration

Presented to: Digital Avionic Systems Conference

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Unmanned Aircraft Systems Integration Office

Date: October 16, 2012

Overview

- **What is Sense and Avoid (SAA)**
- **What is Ground Based Sense and Avoid (GBSAA)**
  - Intended Function
  - Where GBSAA may be useful
  - GBSAA Terminology
- **Display options and issues**
- **Sensors and Data Sources**
- **SAA Airworthiness**
- **Safety Assessment for SAA systems/equipment**
- **Discussion**
  - Army GBSAA Concept at El Mirage CA
  - USMC GBSAA Concept at Cherry Point NC

What is Sense and Avoid?

- **Intent is compliance to Title 14 Code of Federal Regulations, Part 91, §91.113(b), §91.111(a)**
  - § 91.113 (b) General. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft. When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and may not pass over, under, or ahead of it unless well clear.
  - § 91.111 (a) No person may operate an aircraft so close to another aircraft as to create a collision hazard.
- **Technology (Systems and Equipment) replacement for pilot's see and avoid responsibility.**
- **Systems and Equipment require specificity in intended function**

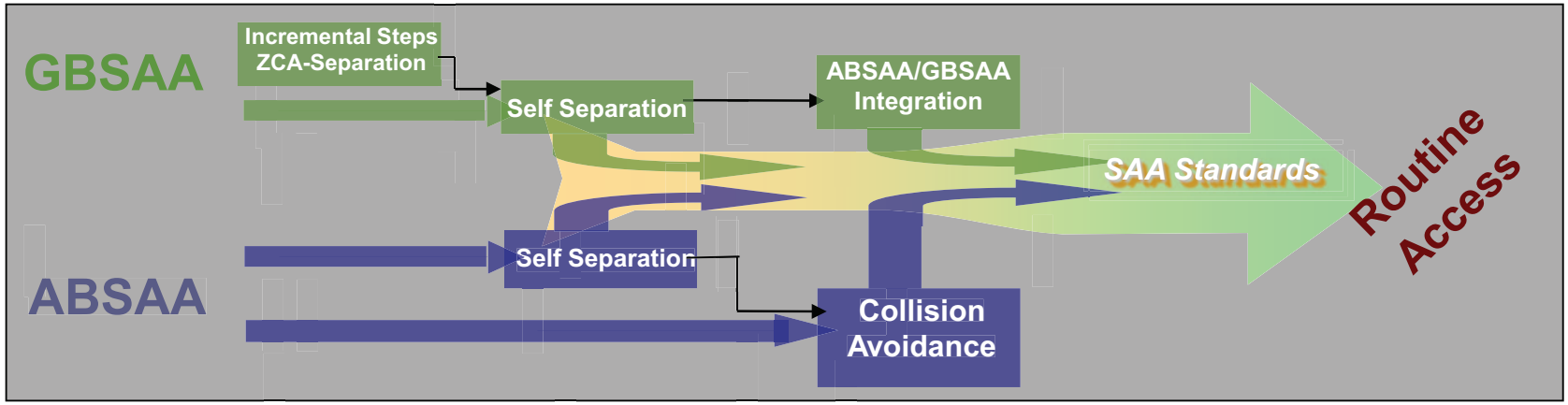
What is GBSAA?

- **GBSAA is just a label – the function is either to**
  - Provide a means to mitigate the inability for a UAS pilot to directly see and avoid other aircraft

    ~OR~
  - Provide a means of compliance to the operational rule (§91.113 and §91.111) to see and avoid
- **Declaration that a system is for "situational awareness" is vague and potentially misleading**
  - The decisions or actions that are dependent on that "awareness" must be clearly specified
  - The outcomes resulting from the decisions or actions should be specific and measurable

GBSAA Path Forward

- GBSAA Zero Conflict Airspace Separation
- GBSAA Self Separation
- Integration with Airborne Sense and Avoid and NextGen



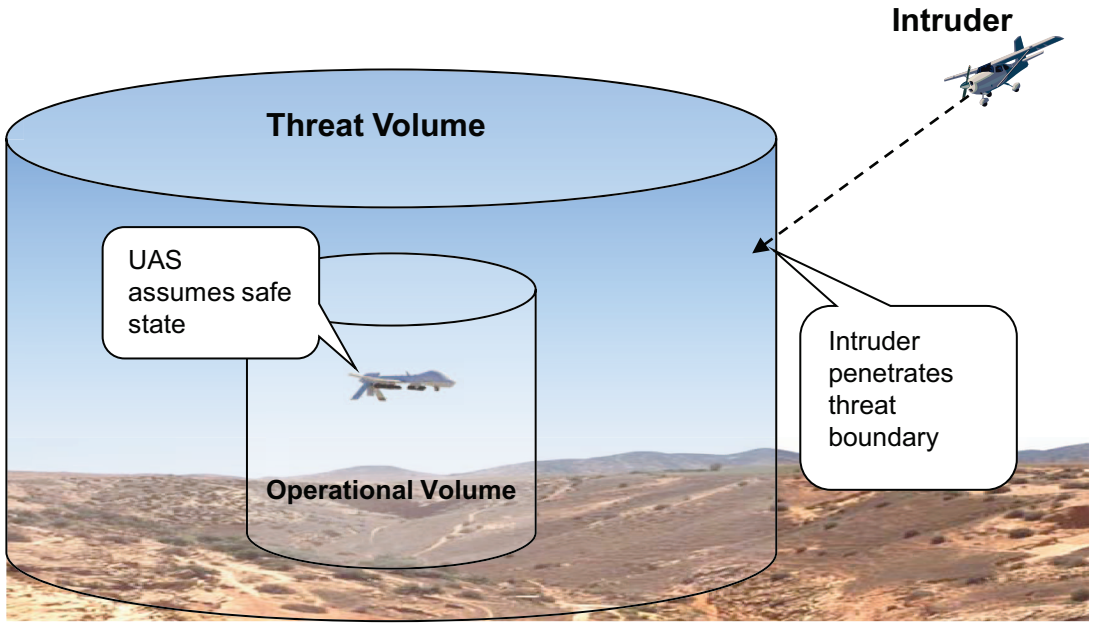
GBSAA Characteristics

- **Airspace of interest defined and fixed by geographic boundaries**
  - Surveillance Volume does not travel with the UA
  - Carefully placed sensors and validate system performance
- **Shapes and sizes of the operational volume and threat volume would vary**
  - Based on geography and specific UAS performance
  - Defined by operating objectives and environment
- **Any intruder within the threat volume is treated as collision threat**
- **Example operations**
  - Training operations in the traffic pattern
  - Transit operations into Restricted Airspace or Class A Airspace
  - Remote sensing operations within a pre-defined area

GBSAA Terminology

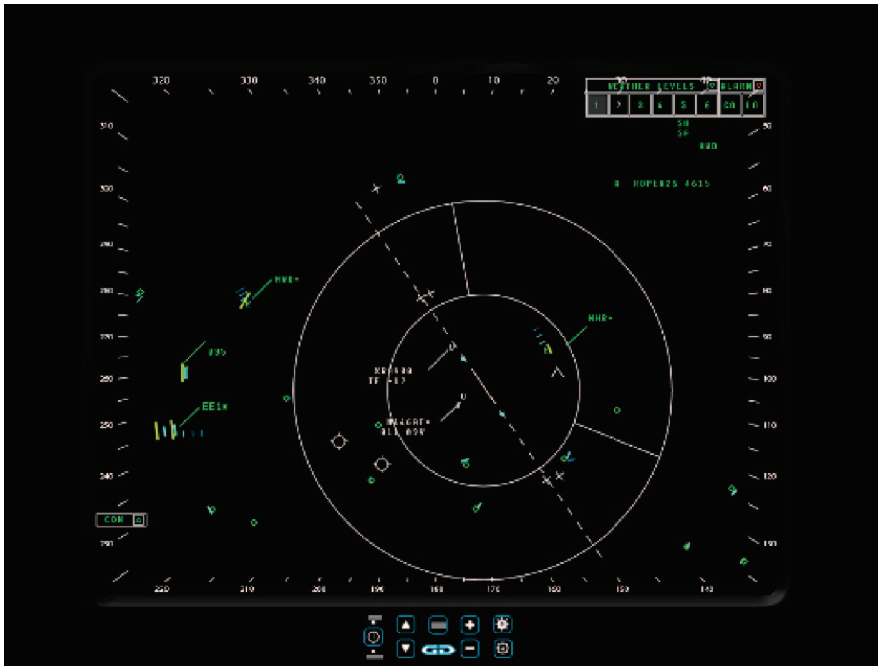
- Concept to provide traffic information and/or guidance to a UA Pilot using a ground surveillance system as a means to fulfill the “see and avoid” regulatory requirements.
  - **UA takes action to achieve a safe state upon detection of an intruder penetrating a geographically defined, fixed volume of airspace.**

- **Intruder** – Aircraft within the surveillance volume.
- **Threat** – Intruder determined to pose a potential collision risk.
- **Threat Volume** – the volume of airspace in which an intruder is considered a collision threat.
- **Operational Volume** – the volume of airspace in which the UAS is proposed to operate.
- **Surveillance Volume** – the volume that describes the effective limits (e.g. range) of the surveillance system. (Note: Surveillance Volume will be equal to or greater than Threat Volume.)



Traffic Display approach to SAA

- **Sensor/Algorithms/Displays**
  - Detect intruding aircraft
  - Display aircraft position
- **UAS Pilot/electronic observer**
  - Estimate state of intruders
  - (position, speed, acceleration)
  - Projection of future state
  - Declare threatening intruders
  - Determine maneuvering solution
  - Execute the maneuver
- **How is safety quantified**
- **in terms of collision risk?**
- **What about Training,**
- **Qualifications, Proficiency?**



Maneuvering Guidance Approach

- **Sensor/Algorithms/Displays**
  - Detect intruding aircraft
  - Estimates state of intruders (position, velocity, etc.)
  - Projection of future state
  - Declares threats
  - Determines maneuvering solution
  - Provides flight path guidance
    (turns, climbs/descents, speed changes)
- **Pilot follows flight path guidance**
  - Execute the maneuver
    (resolution advisory)

Surveillance Radar for GBSAA

- **FAA Surveillance Radar (Primary Surveillance Radar and Secondary Surveillance Radar) designed and developed to provide vertical and lateral safe separation distances between aircraft**
  - Airport Surveillance Radar (ASR)
  - Air Route Surveillance Radar (ARSR)
- **Separation distances (separation standards) based on multiple radar and human performance characteristics**
- **FAA Surveillance Radar could (potentially) be used as part of the design of a UAS separation and collision avoidance system if employed within the constraints of its design limitations**
  - This is not trivial.

Ground Tactical RADAR / LIDAR

- **Sensor systems can be designed to meet required performance**
  - 3D Position (Range, Azimuth, Elevation)
  - Position Accuracy
  - Probability of Detection
  - Update Rate
  - Multiple Sensors (Sensor Diversity, Location Diversity & Redundancy)
- **Separation distances and maneuver timeline are part of system design trade**
  - Allocation of performance requirements and safety requirements
- **The system's Intended Function(s) can be addressed early in the design**
  - Hazard Analysis should drive development assurance

Other Sensor / System* "Concepts"

- **ADS-B "in" - On the Ground**
  - Not all aircraft will be ADS-B "out" equipped
    - ADS-B "out" is only required where a transponder is required
  - UA may still need ADS-B "out" to be fully interoperable
  - May require both 1090ES and UAT
- **TIS-B**
  - Reported position may lag behind current position
  - Updates may be intermittent
  - Not all aircraft will be on TIS-B
- **TCAS – On the Ground**
  - Ground installation is not interoperable with TCAS
  - Intended to interoperate at close range
  - Not all aircraft require a transponder
- **FAA Telecommunication Infrastructure (FTI)**
  - May be difficult to get a "safety critical" tap for Civil operators
  - Not all aircraft surveillance data will be included

*Systems designed for a different "intended function"

GBSAA is an Aircraft System

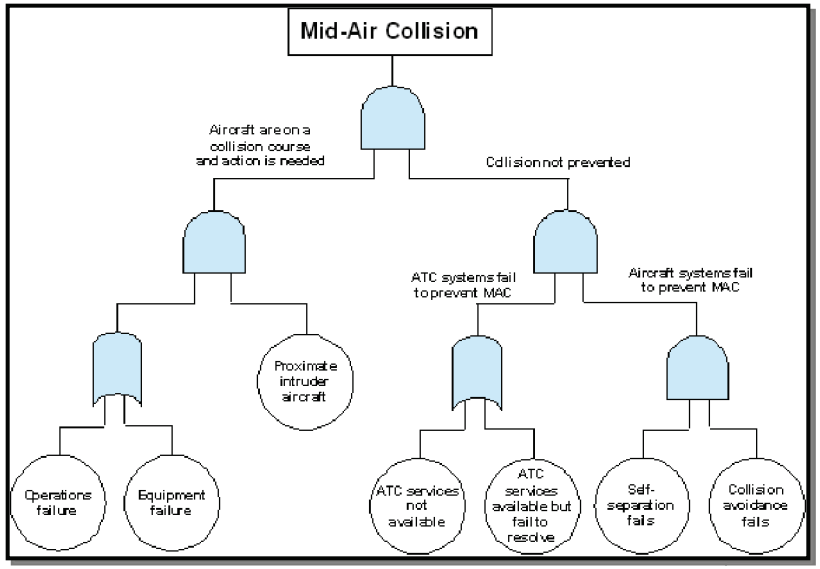
- **GBSAA Airworthiness**
  - Considered Aircraft systems subject to aircraft level (including control station) and system level safety substantiation.
    - SAE ARP 4761/4754, DO-178B, DO-254, DO-160
  - Must be demonstrated to perform its intended function under any foreseeable operating condition and include:
    - Possible modes of failure, including malfunctions and damage from external sources
    - The probability of multiple failures, and the probability of undetected faults.
- **Certified by an applicable airworthiness authority**
  - Following applicable process for determining Airworthiness
  - Public Operations and operating conditions may be unique
  - Issues Airworthiness Release (AWR) including operating limitations

SAA Safety Guidance

- ***Interim Operational Approval Guidance 08-01***
  - Applicants proposing “see and avoid” strategies in lieu of visual observers, need to support proposed mitigations with system safety studies which indicate the operations can be conducted safely.
  - Acceptable system safety studies must include a hazard analysis, risk assessment, and other appropriate documentation that support an ***“extremely improbable”*** determination.

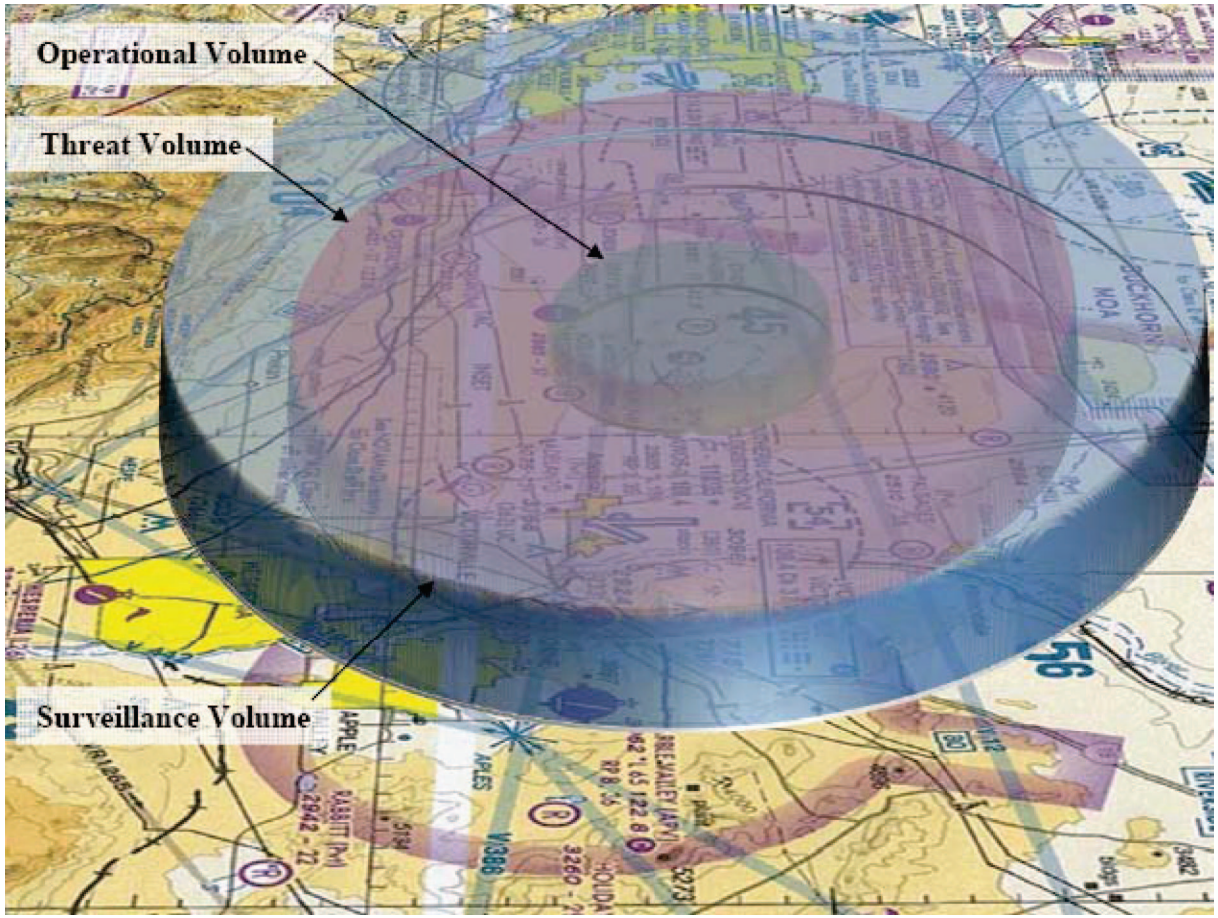
SAA Safety Assessment

- **Evaluation Techniques**
  - Safety Target (TLS)
  - Relative Risk (Risk Ratio)
  - Comparative Assessment
- **Safety Assessment Steps**
  - Develop a Safety Plan
  - Develop a System Description
  - Identify the Hazards
  - Conduct Risk Analysis for each Hazard
  - Identify Risk Mitigation Measures
  - Verify Risk Reduction
  - Track Hazards and Residual Risk.

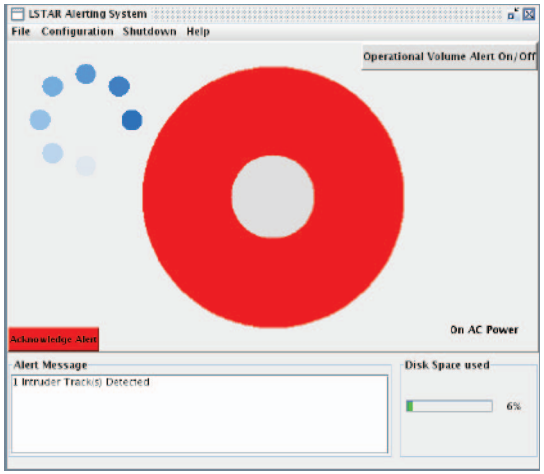


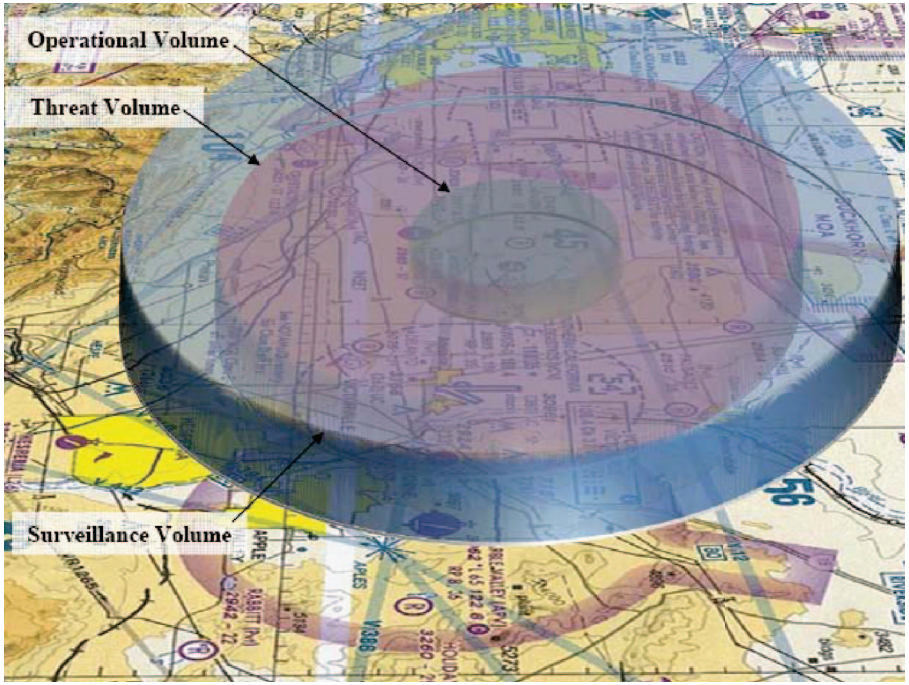
- **Safety Assessment Products**
  - Operational Safety Assessment
    - Operational Hazard Assessment
    - Allocation of Safety Objectives and Requirements
  - Functional Hazard Assessment
  - Preliminary System Safety Assessment
  - System Safety Assessments

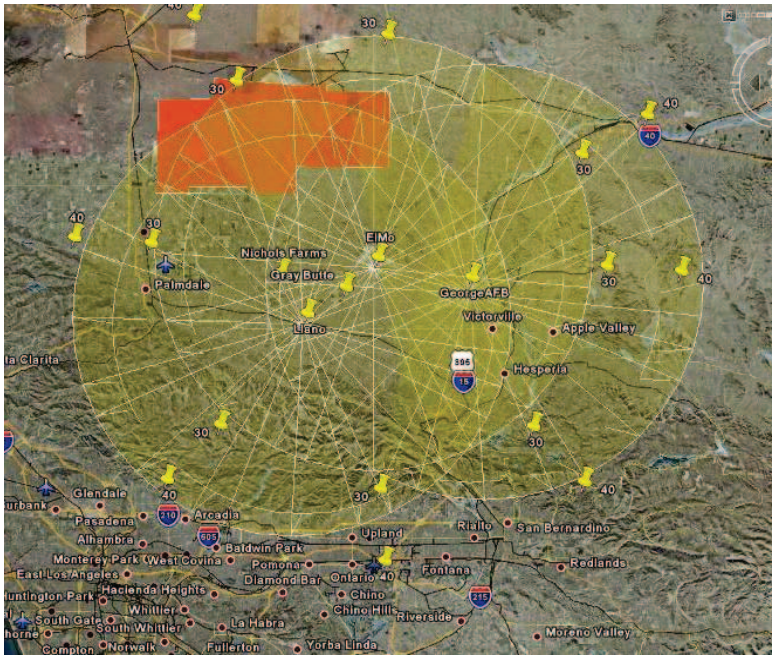
Army GBSAA Operations at El Mirage CA

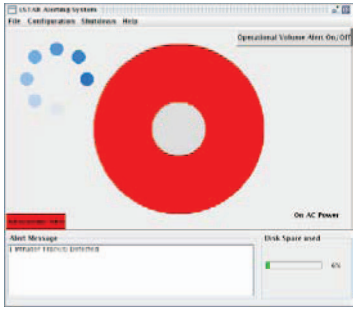


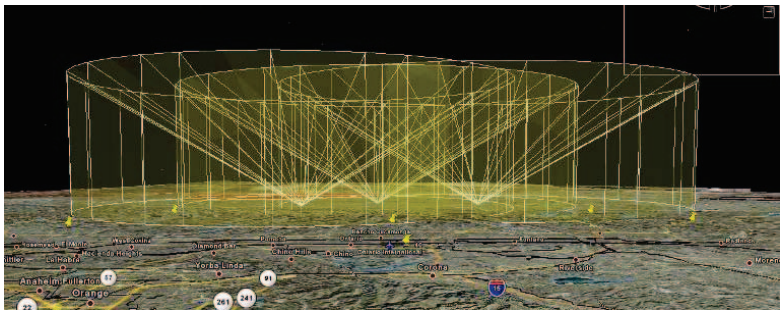
- UAS operates in the traffic pattern (operational volume).
- GBSAA system detects aircraft within the surveillance volume.
- Alerts when aircraft penetrating the threat volume.




Operational Volume
Threat Volume
Surveillance Volume


Nichols Farms
Gray Butte
Palmdale
EIMo
GeorgeAFB
Victorville
Apple Valley
Llano
Hesperia
Glendale
Pasadena
Arcadia
Alhambra
Baldwin Park
Upland
Rialto
San Bernardino
Monterey Park
West Covina
Pomona
Fontana
Redlands
East Los Angeles
Diamond Bar
Ontario
Chino
Hacienda Heights
Whittier
Chino Hills
Riverside
South Gate
South Whittier
La Habra
Moreno Valley
Compton
Norwalk
Fullerton
Yorba Linda

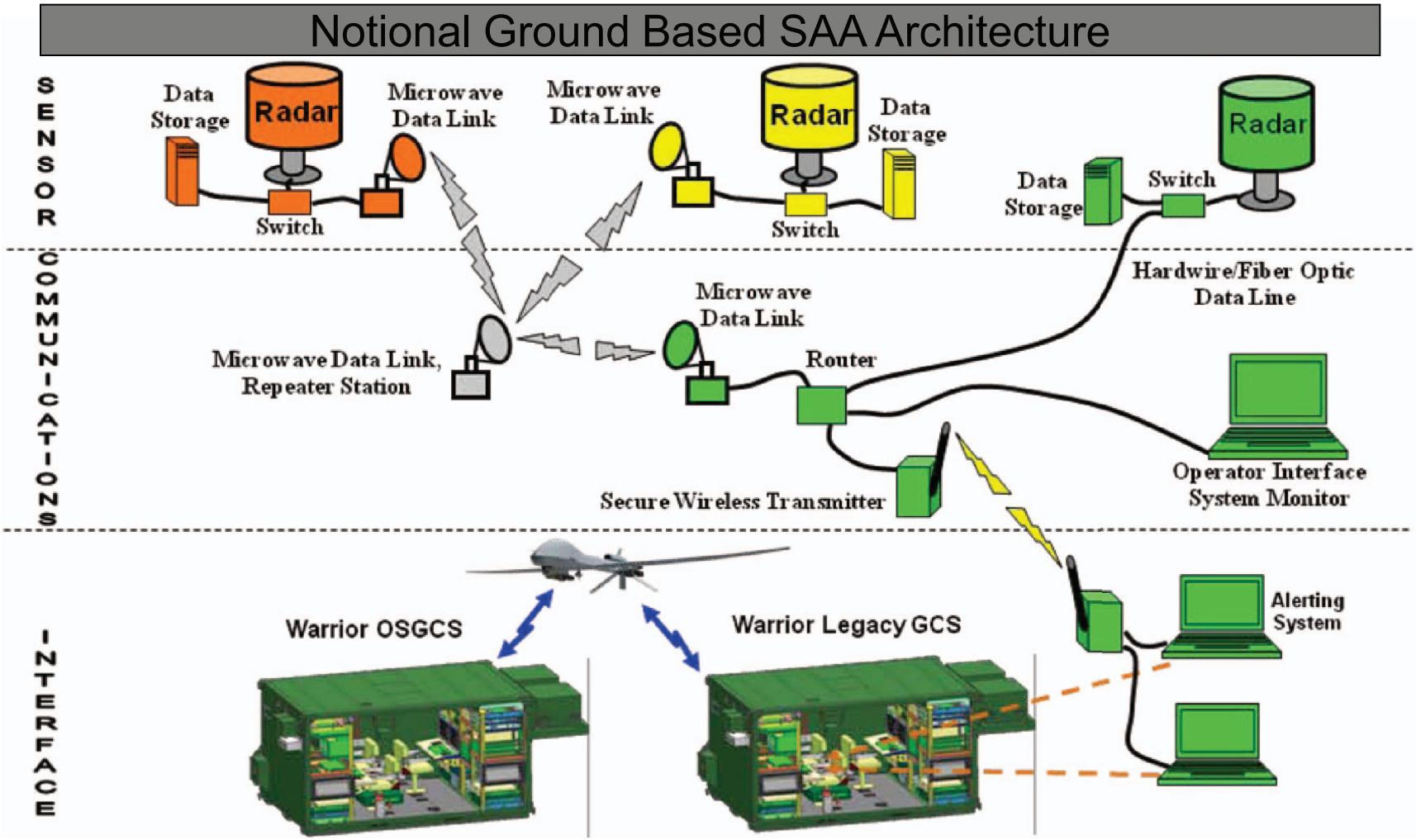




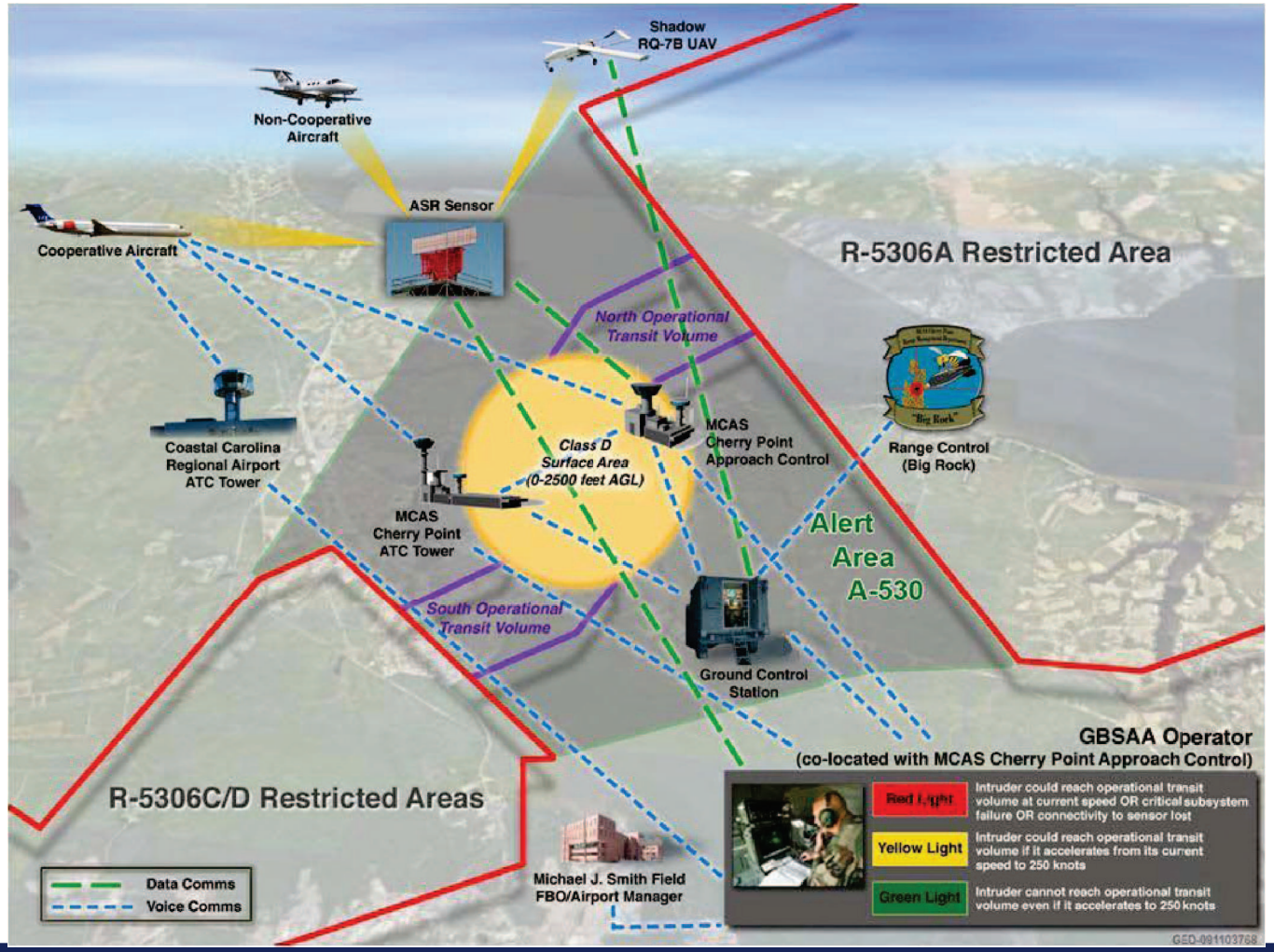
GBSAA Concept at El Mirage

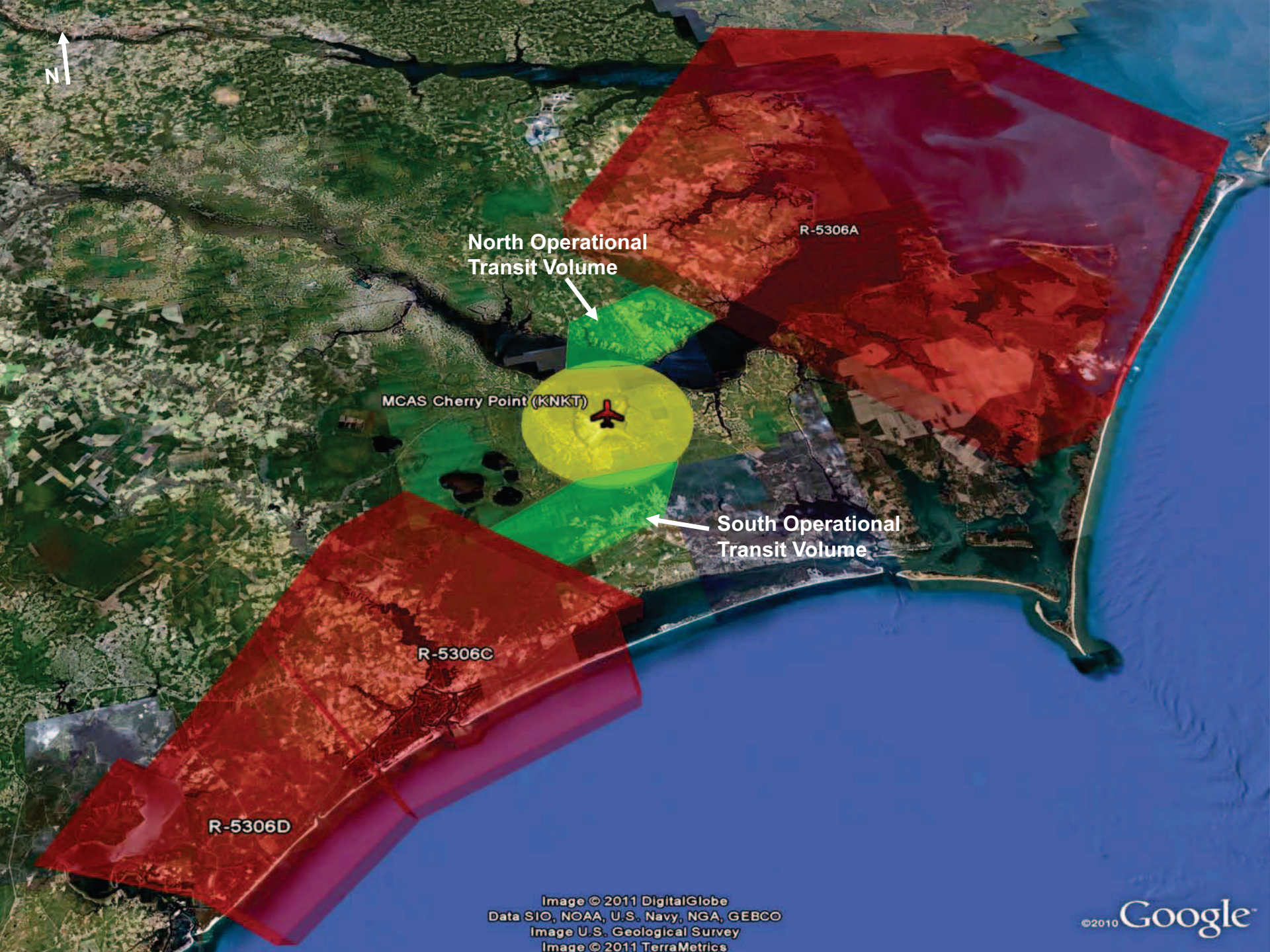
- **Operational Volume supports airport traffic pattern**
  - 2 nmi radius from ground to 1500 AGL Class G/E airspace
  - Budgeted time to land aircraft is about 3 minutes
  - UAS operating under Visual Flight Rules (VFR)
- **“Safe State” is “UAS on the ground”**
  - No visual observers required
- **GBSAA Alerting System Operation**
  - Alerting System evaluates threat aircraft within surveillance volume
  - GREEN status when no aircraft are in the threat volume
  - RED status when an aircraft enters the threat volume
  - UA will stay on the ground until the status turns GREEN
  - When airborne, the UA must land when the status turns RED
    - UA Pilot has 3 minutes to get the UA to the ground

Ground Based Sense and Avoid



USMC GBSAA Operations at Cherry Point NC




N
North Operational
Transit Volume
R-5306A
MCAS Cherry Point (KNKT)
South Operational
Transit Volume
R-5306C
R-5306D
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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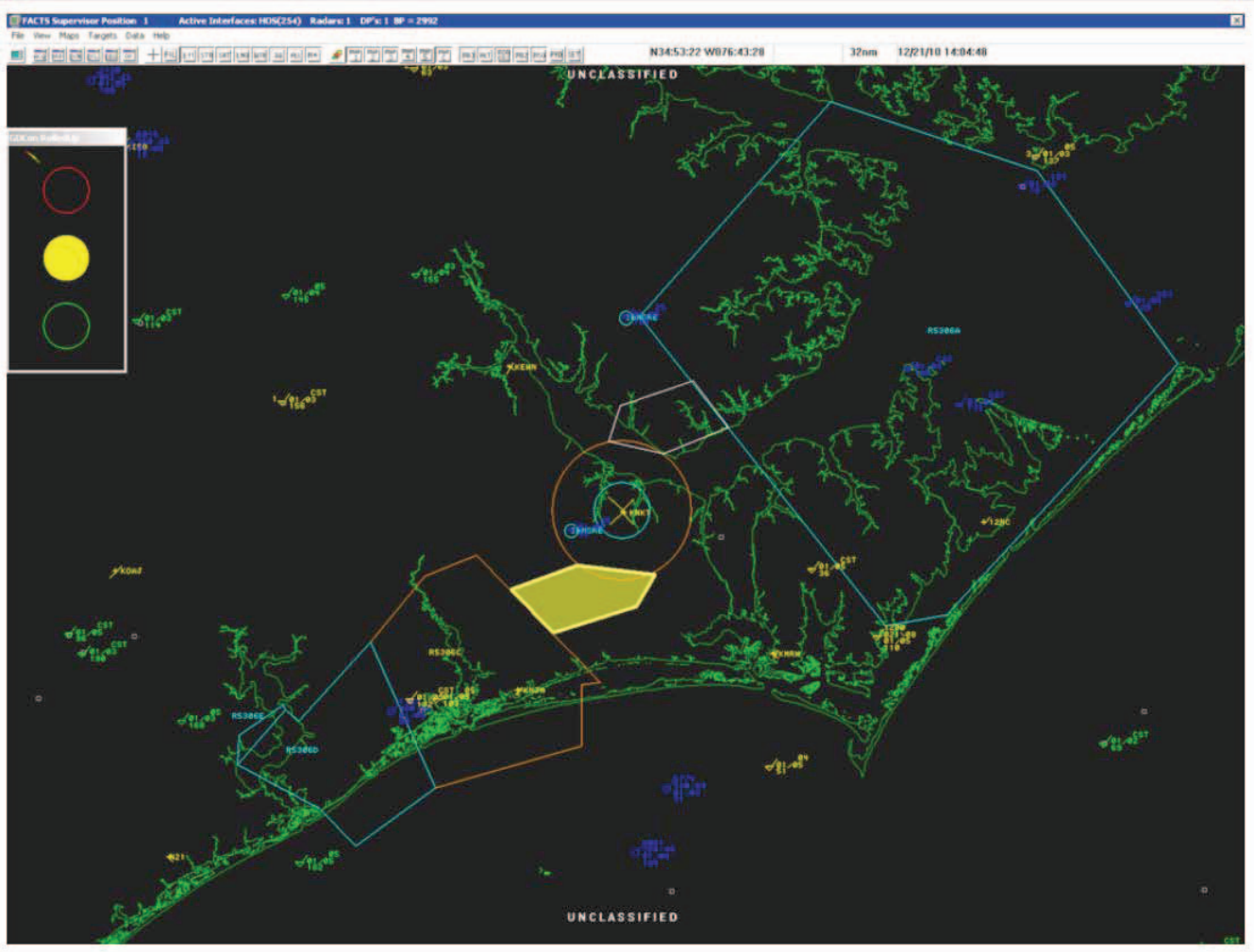
GBSAA Concept at Cherry Point

- **Operational Transit Volume (OTV) (Northern and Southern)**
  - 6 nmi at 3000 MSL through Class E airspace
  - Budgeted time to cross is about 5 minutes
  - UAS operating under Visual Flight Rules (VFR)
- **“Safe State” in Class D and Restricted airspace**
  - Visual Observers (Class D) and Range Control (Restricted)
- **GBSAA Operator Console**
  - GOCon evaluates threat aircraft within surveillance volume
  - Operator “downgrades” threat aircraft according to training & procedures – making inputs using GOCon
  - GOCon rolls up threat status RED, YELLOW, or GREEN
  - Scores “cooperative” aircraft differently from “uncooperative”
  - GBSAA Operator informs UA Commander of threat status
- **UA Commander makes determination to enter OTV when GREEN**

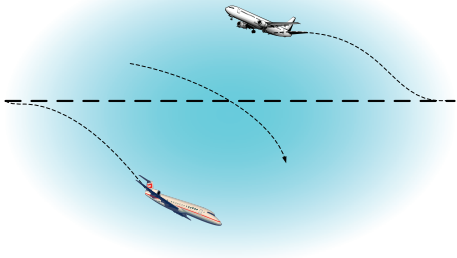

FACTS Supervisor Position 1
Active Interfaces: HDS(254) Radars: 1 DP's: 1 BP = 2992
N34:48:43 W077:11:56
16nm
05/11/11 00:57:09
UNCLASSIFIED
UNCLASSIFIED


FACTS Supervisor Position 1
Active Interfaces: HDS(254) Radars: 1 DP's: 1 BP = 2992
N34:53:22 W076:43:28
32nm
12/21/10 14:04:48
UNCLASSIFIED
UNCLASSIFIED

Lessons Learned

- **Design, architecture and low level requirements are essential in knowing (and proving) what you have**
- **Hazard assessment is not all SME opinion**
  - Consensus opinion on probability is difficult to substantiated
- **Prototype / Technology Demonstration**
  - It's an "Experiment" not a final system
  - Expect failures and accept as intent of the system
  - Manage expectations
- **Safety stand down criteria**
  - What constitutes conditions to suspend operations
- **Emotional attachments**
  - It's nobody's baby

Closing Summary



- **Sense and Avoid systems must be clearly defined in terms of expected intended function**
  - A well defined Concept of Operation is a good start
- **Ground Based Sense and Avoid systems may not support "collision avoidance"**
  - May not represent a complete solution
  - If there's a functional gap, what is the safety impact and what mitigates the issue… what operational limitations
- **Trade between Traffic Display and Maneuver Guidance**
  - Allocation of functionality to pilot or avionics
- **System Design, Sensors, Architecture**
  - Requirements should drive your design
- **Sense and Avoid systems are "Aircraft Systems" and subject to aircraft safety substantiation methods**
  - Quantitative safety analysis
  - Include the effects of Failures and False/Misleading information

Comments/Questions

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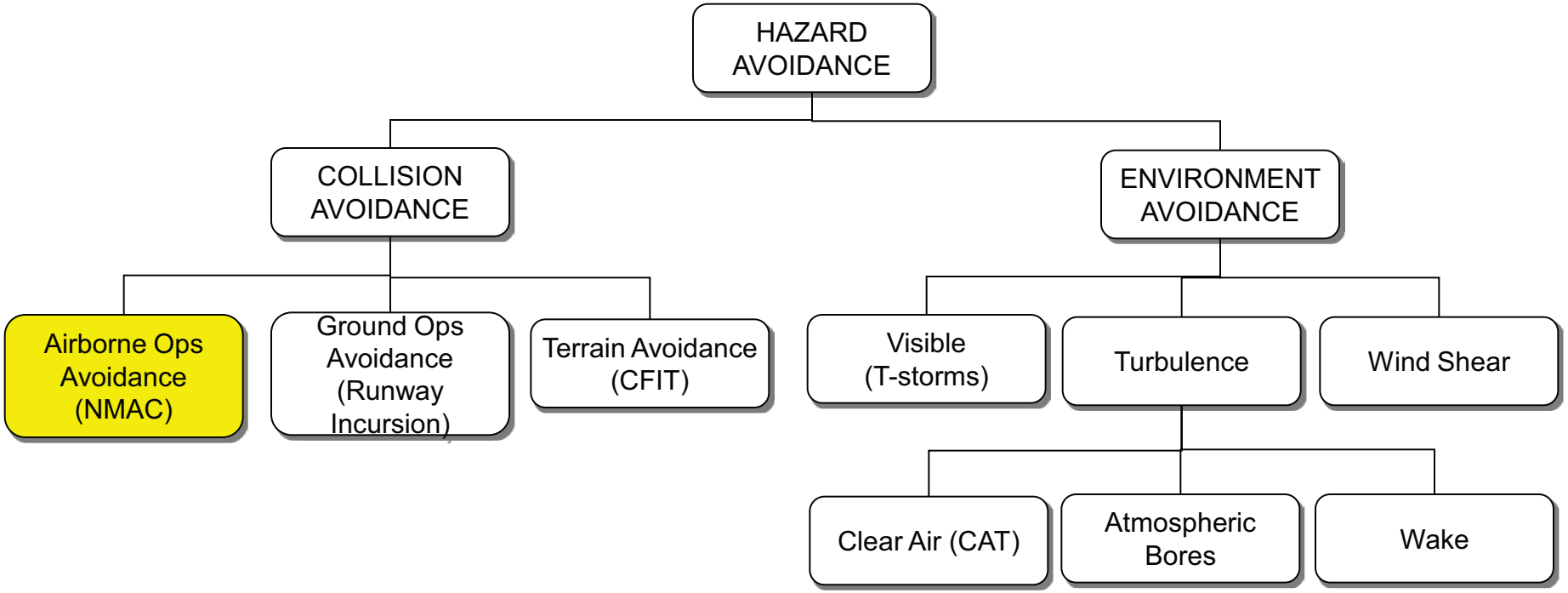
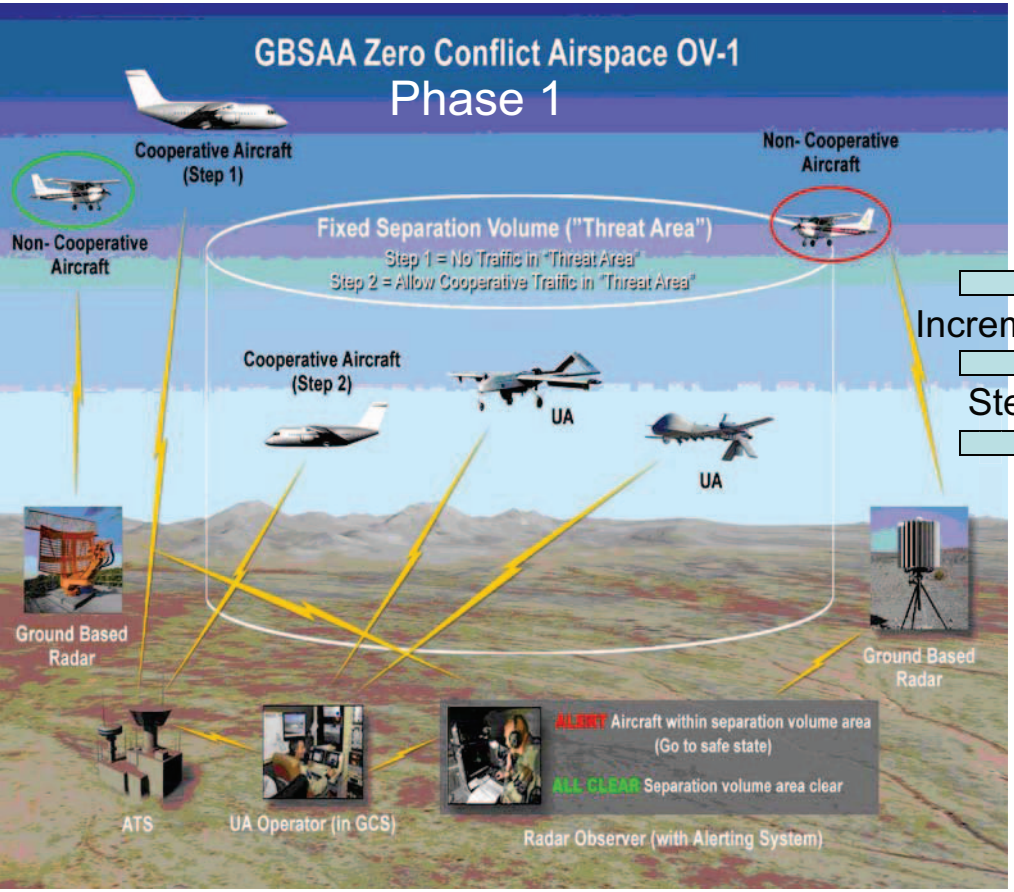
Backup Slides

Concepts Definitions

- **Cooperative Aircraft -** Aircraft that have an electronic means of identification (i.e., a transponder) aboard and operating.
- **Non-Cooperative aircraft -** Aircraft that do not have an electronic means of identification (i.e., a transponder) aboard or not operating such equipment due to malfunction or deliberate action.
- **Operational Volume** – The volume of airspace in which the UAS is proposed to operate, defined by points on the ground and altitudes.
- **Surveillance Volume –** That volume which describes the effective limits (e.g. range, elevation, azimuth) of the surveillance system.
- **Threat Volume –** The volume of airspace in which an intruder is considered a collision threat.
- **Intruder** – Aircraft within the surveillance volume.
- **Threat Aircraft –** An intruder determined to pose a potential collision risk (e.g. an intruder aircraft that has crossed the Self Separation Threshold.
- **Track** - One or more surveillance reports concerning the same intruder that supports estimation (e.g. current and/or future position) of its collision risk.
- **Safe State** – A state (e.g. position, velocity) in which the probability of mid-air collision is at a level acceptable to the regulator (or using agency for the airspace in which the UA is operating).

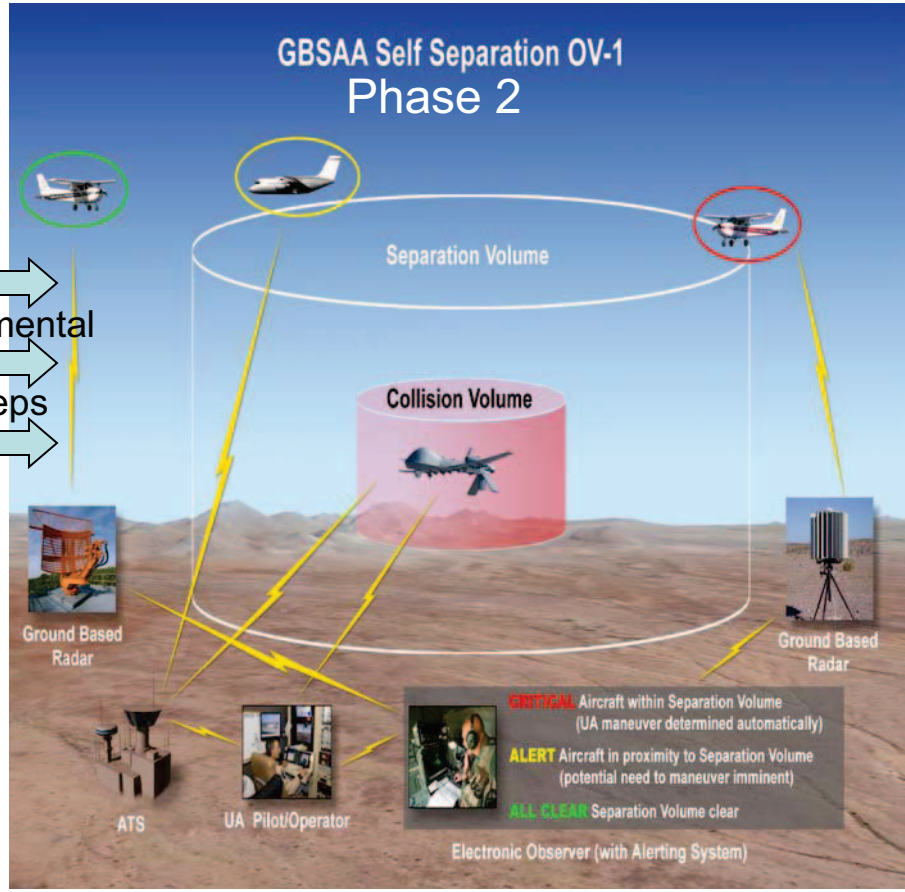
Scope: Hazard Avoidance



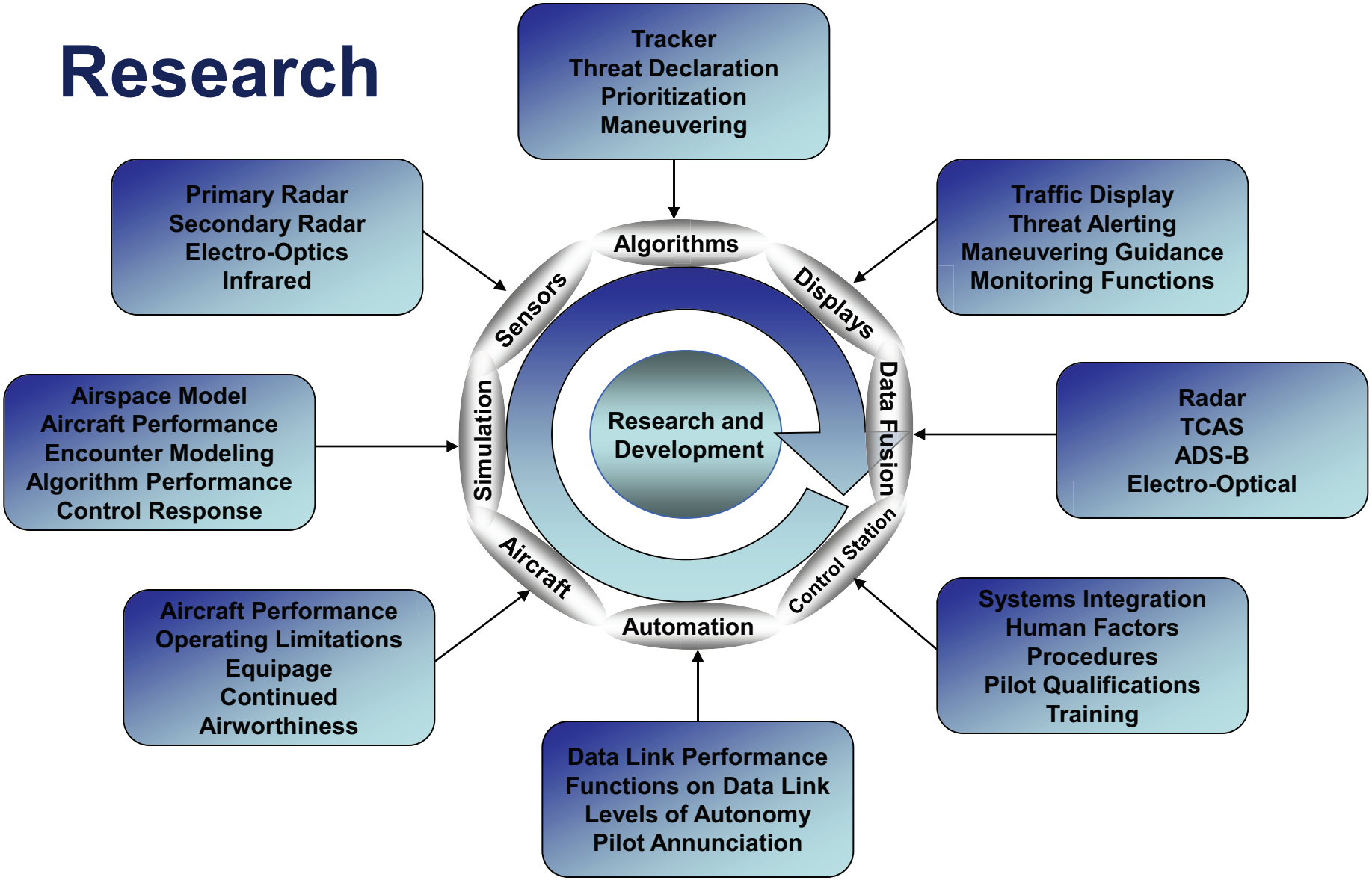


Incremental

Steps



Research


Tracker
Threat Declaration
Prioritization
Maneuvering
Primary Radar
Secondary Radar
Electro-Optics
Infrared
Traffic Display
Threat Alerting
Maneuvering Guidance
Monitoring Functions
Airspace Model
Aircraft Performance
Encounter Modeling
Algorithm Performance
Control Response
Radar
TCAS
ADS-B
Electro-Optical
Aircraft Performance
Operating Limitations
Equipage
Continued
Airworthiness
Systems Integration
Human Factors
Procedures
Pilot Qualifications
Training
Data Link Performance
Functions on Data Link
Levels of Autonomy
Pilot Annunciation
Algorithms
Sensors
Displays
Simulation
Data Fusion
Aircraft
Control Station
Automation
Research and Development