Addressing the Operational and Technical UAS Airspace Integration Challenges

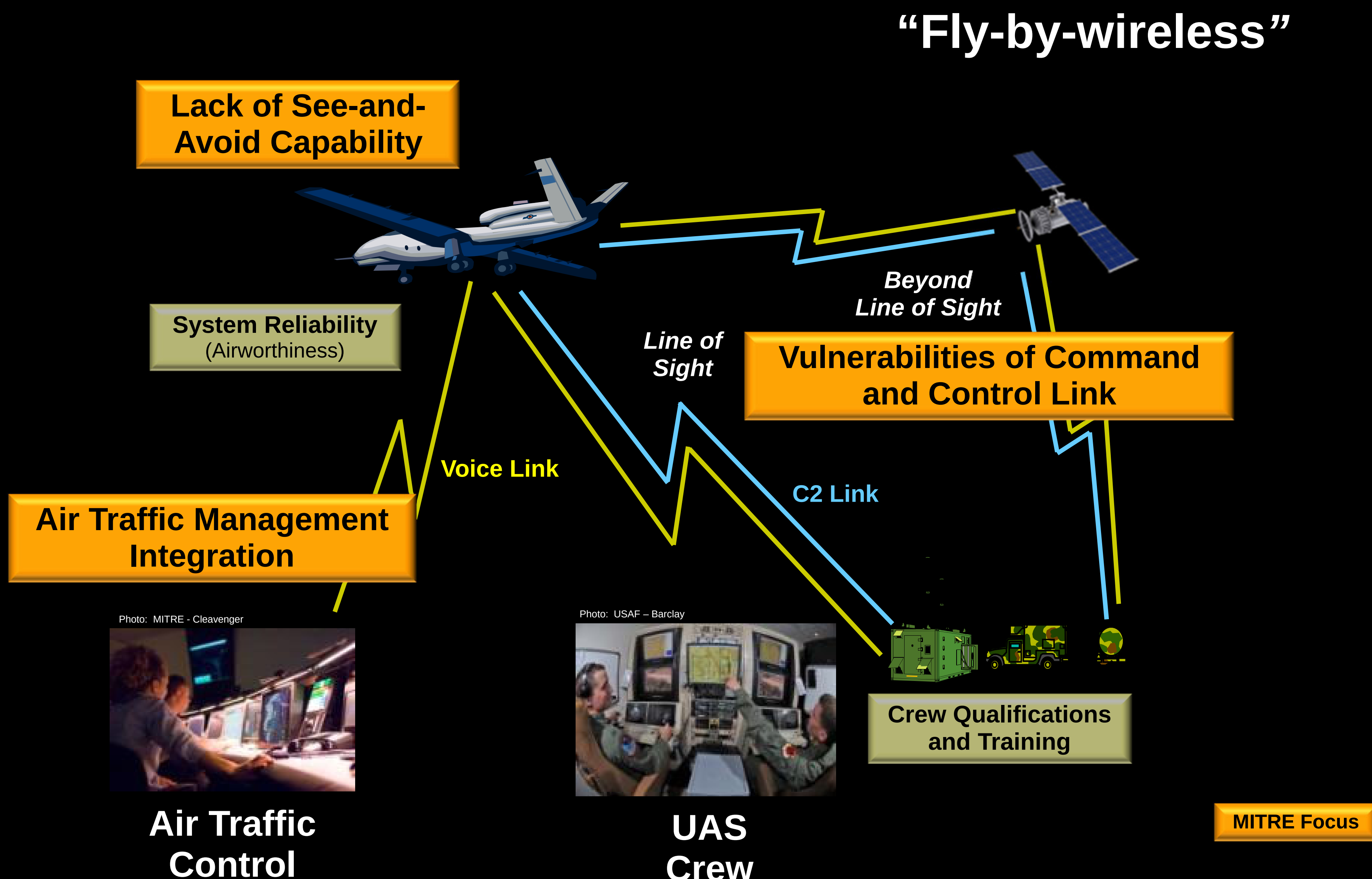
Andrew Lacher

January 2013

Presented at Transportation Research Board Annual Meeting

MITRE

Key UAS Integration Challenges



The Aviation Community Knows How to Certify Airframes

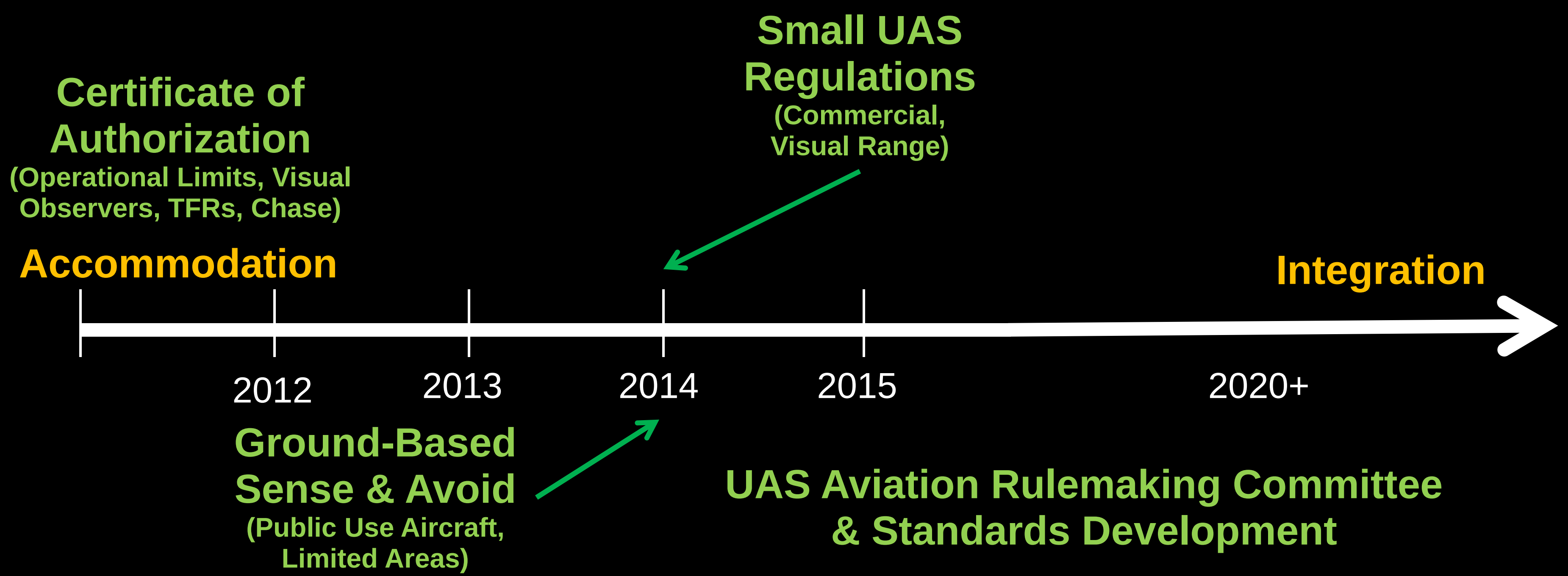
To Be Developed

<u>UAS</u> Standards & Regulations

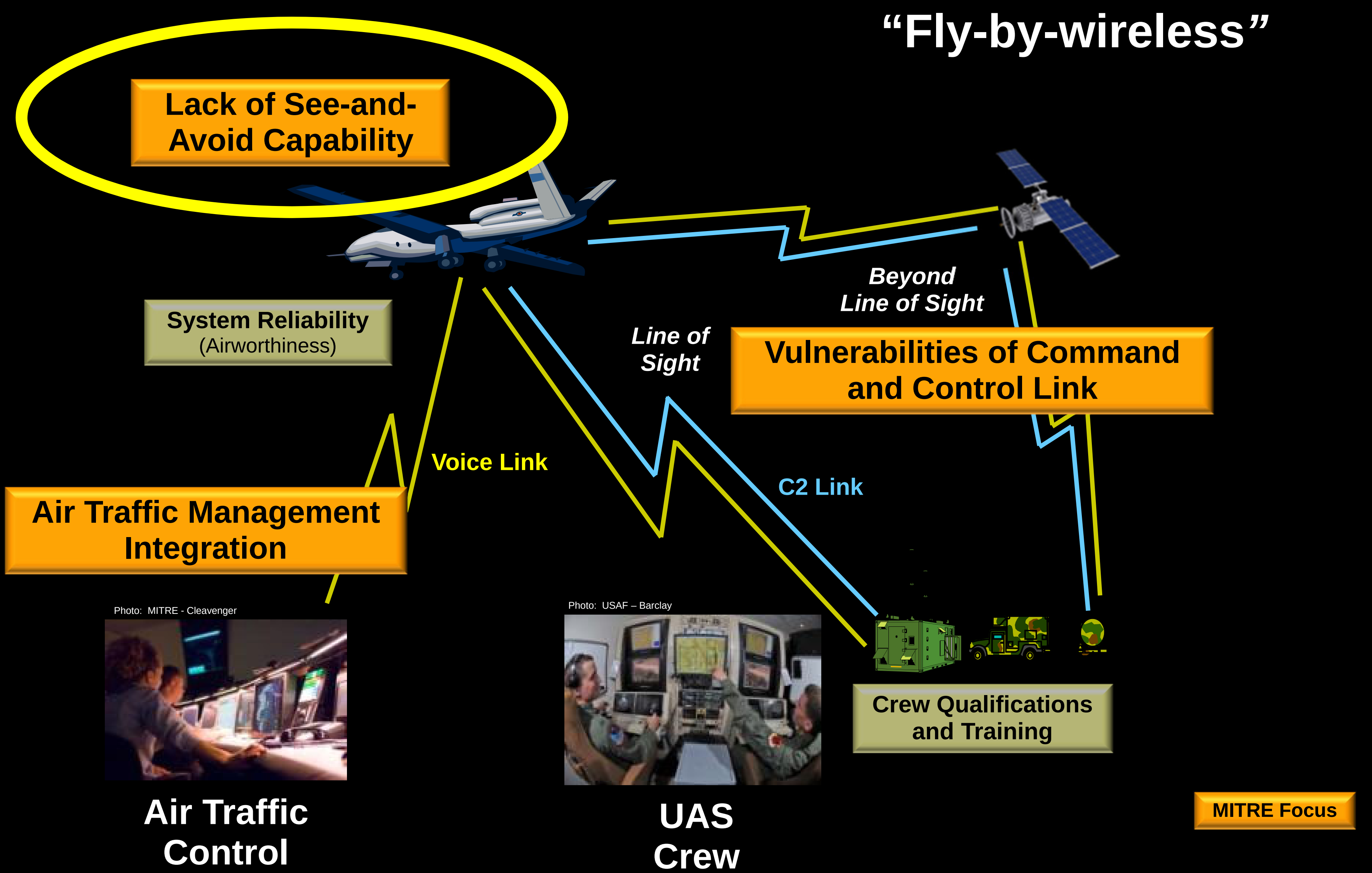
- ***Control Station***
- ***C2 Link***
- ***Launch & Recovery Equipment***
- ***Sense and Avoid***

UAS Airspace Integration Vision

- **UAS regularly operate in non-segregated civil airspace**
  - Without degrading the safety of the aviation system
  - Without disrupting manned aircraft



Key UAS Integration Challenges



See and Avoid Requirement

Sense and Avoid

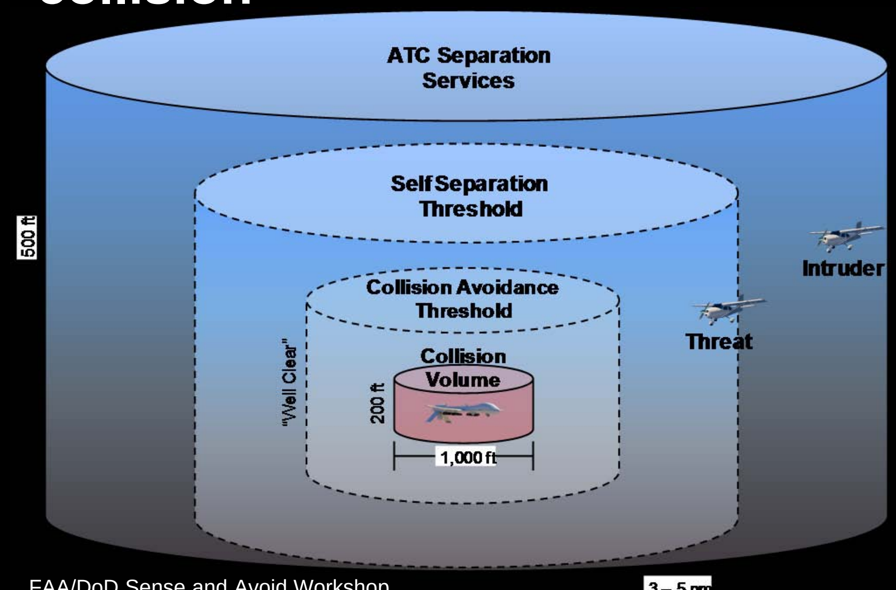
14 Code of Federal Regulations

§91.111 …No person may operate an aircraft so close to another aircraft as to create a collision hazard…

§91.113 …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 <u>see and avoid other aircraft</u>

Major challenge in Class E & G (uncontrolled) airspace

- **Self-Separation**
  Reduce probability of a collision by remaining "well clear"
- **Collision Avoidance**
  Last-ditch maneuver to prevent collision



FAA/DoD Sense and Avoid Workshop

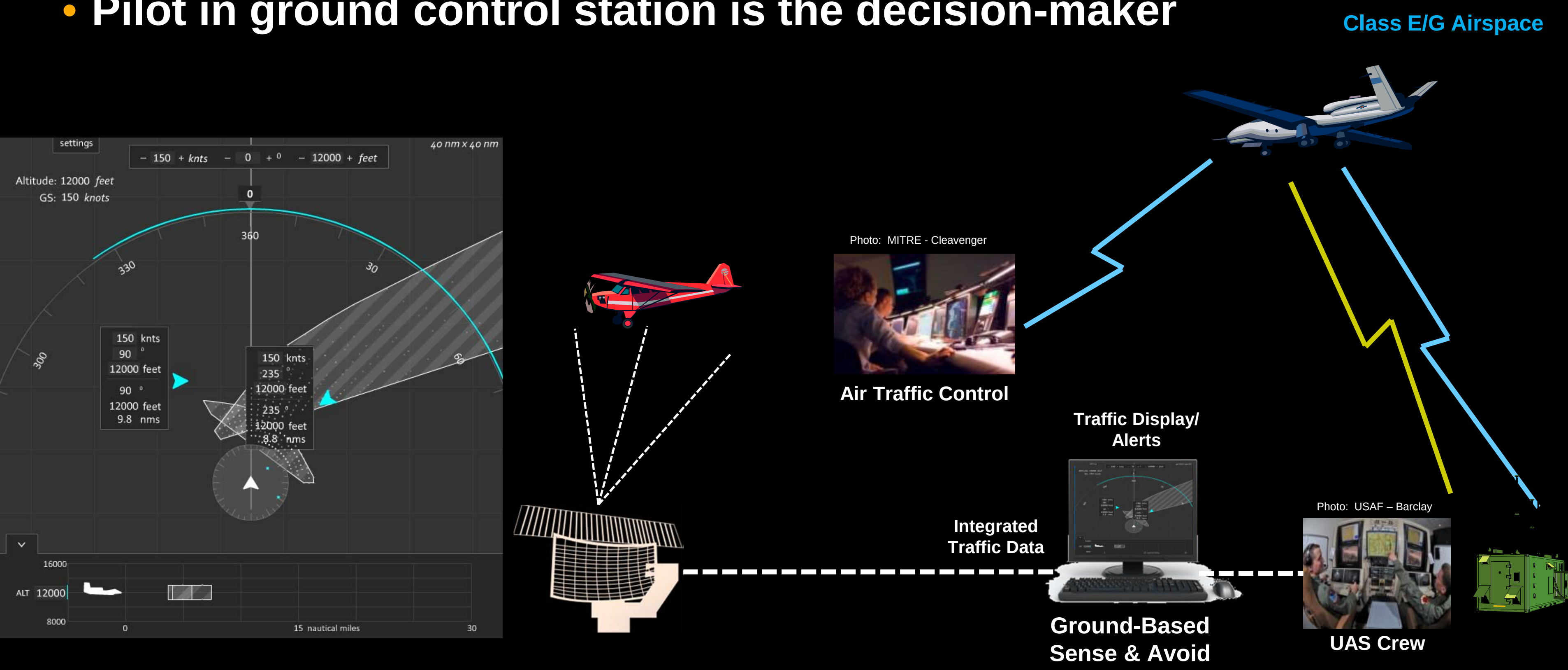
Two Major Mitigations

- **Ground-based Sense and Avoid**

- **Automatic Sense and Avoid**

Ground-Based Sense and Avoid

- Sensors used for traffic situation awareness
  - Focus is upon ATC and COTS ground radars
  - Additional surveillance sources add robustness/improve data
- Remain well-clear of potential conflicts of non-cooperative traffic
- Pilot in ground control station is the decision-maker



Approved for Public Release – Distribution Unlimited - Case: 13-0022

Automatic Sense and Avoid?

Self-Separation

Collision Avoidance

Human-*in*-the-loop

Ground-based Sense and Avoid (GBSAA)

Human-*on*-the-loop

Automatic Sense and Avoid

- Works *without* pilot action
- Without connection to the ground → i.e., Airborne
- Predetermined action
- Control Theory – Sense/Act
- Avoids conflicts (self-separation)
- Prevents collisions (collision avoidance)

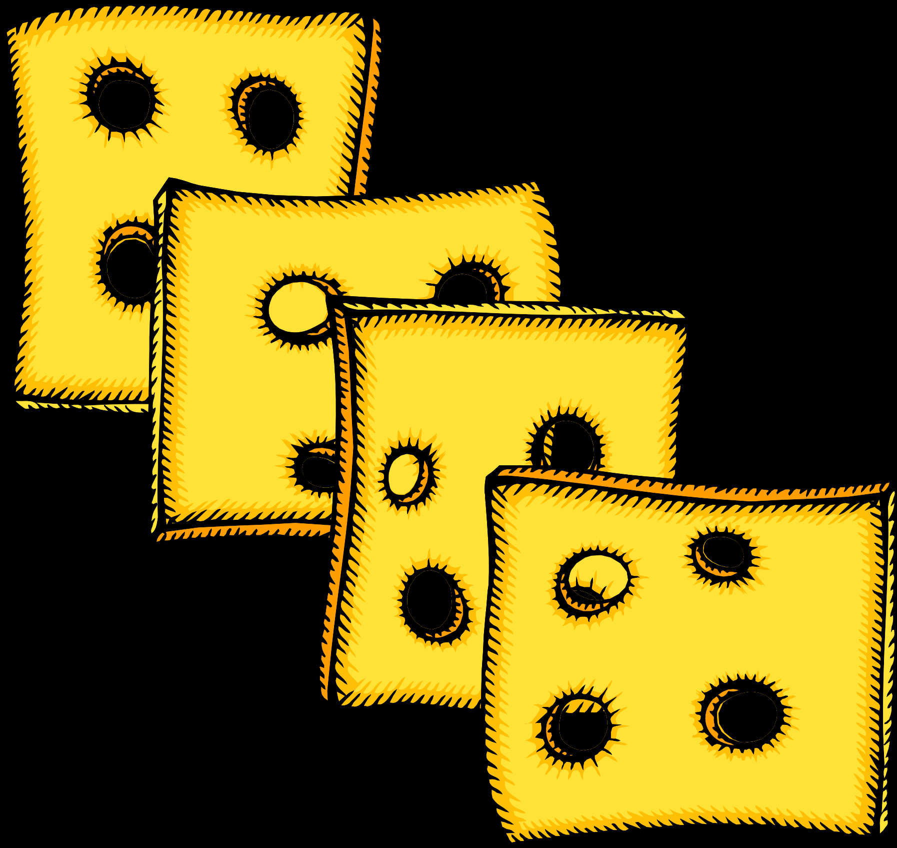
Airborne-based Sense and Avoid (ABSAA)

Chasm

Human — Supervisory Control — Automatic — Autonomous

Reason's *Swiss Cheese* Model of Aviation Safety

- Layered approach
- Individual layers have holes
- In combination, holes don't align
- Potential to reach Target Level of Safety



James Reason, *Achieving a safe culture: theory and practice,* Work and Stress, VOL. 12, NO. 3 293-306, European Academy of Occupational Health Psychology 1998.

Layered Approach to Avoiding Collision

Manned Flights

- Big Sky
- Radar Separation Services
- TCAS/CDTI
- See and Avoid

Lost UAS Control Link

Unmanned Flights

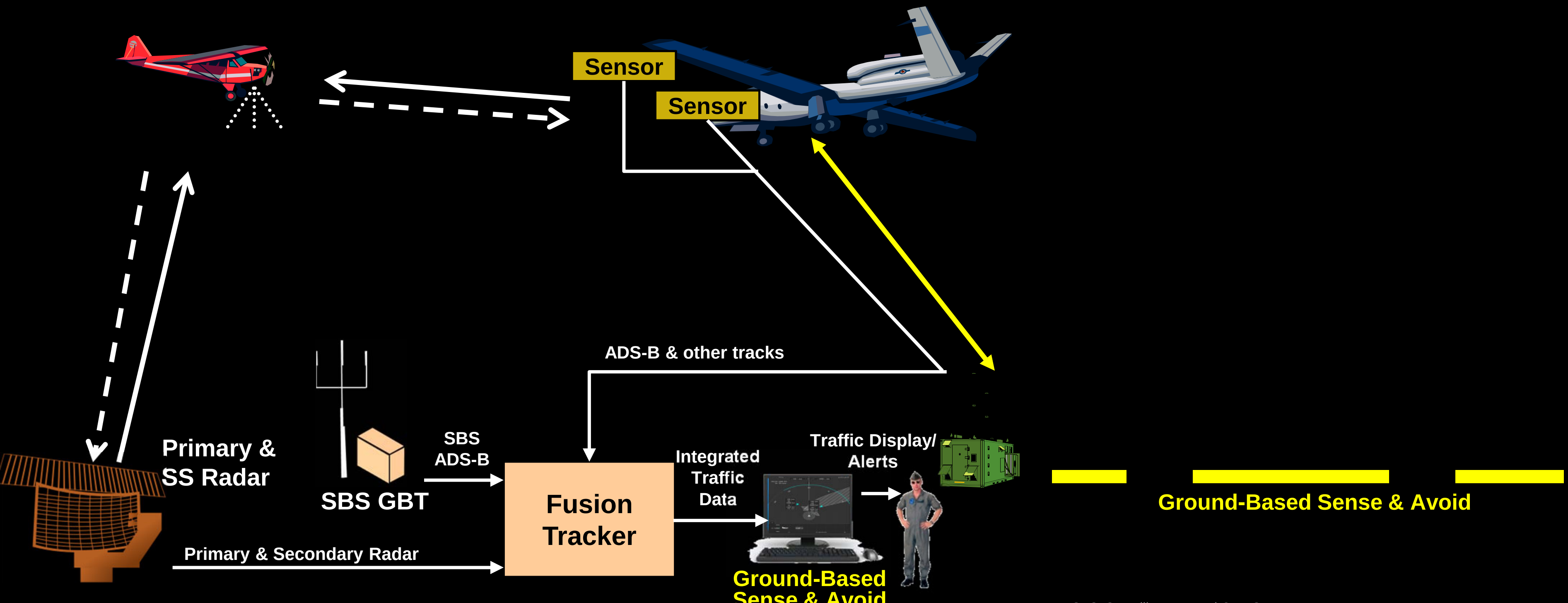
- Big Sky
- Radar Separation Services
- ? Self-Separation
- ? Collision Avoidance

Acceptable Collision Risk Level

One Potential Integrated Approach

Notional

- **Ground-Based Sense and Avoid**
  - Pilot in ground control station is the decision-maker
- **Additional surveillance sources adds robustness/improves data quality**

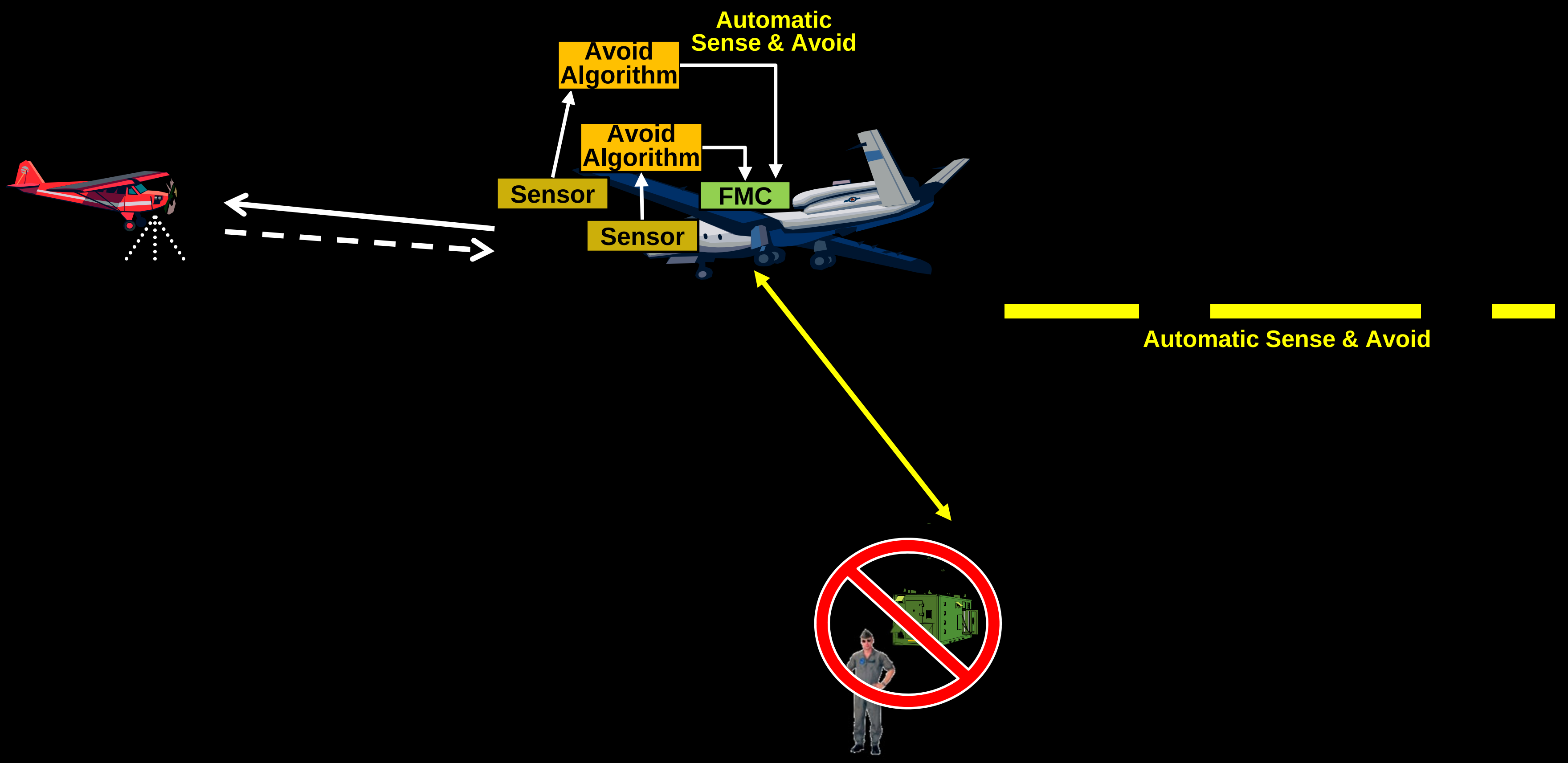


SBS: Surveillance Broad Cast System
GBT: Ground-based Transceiver

One Potential Integrated Approach

Notional

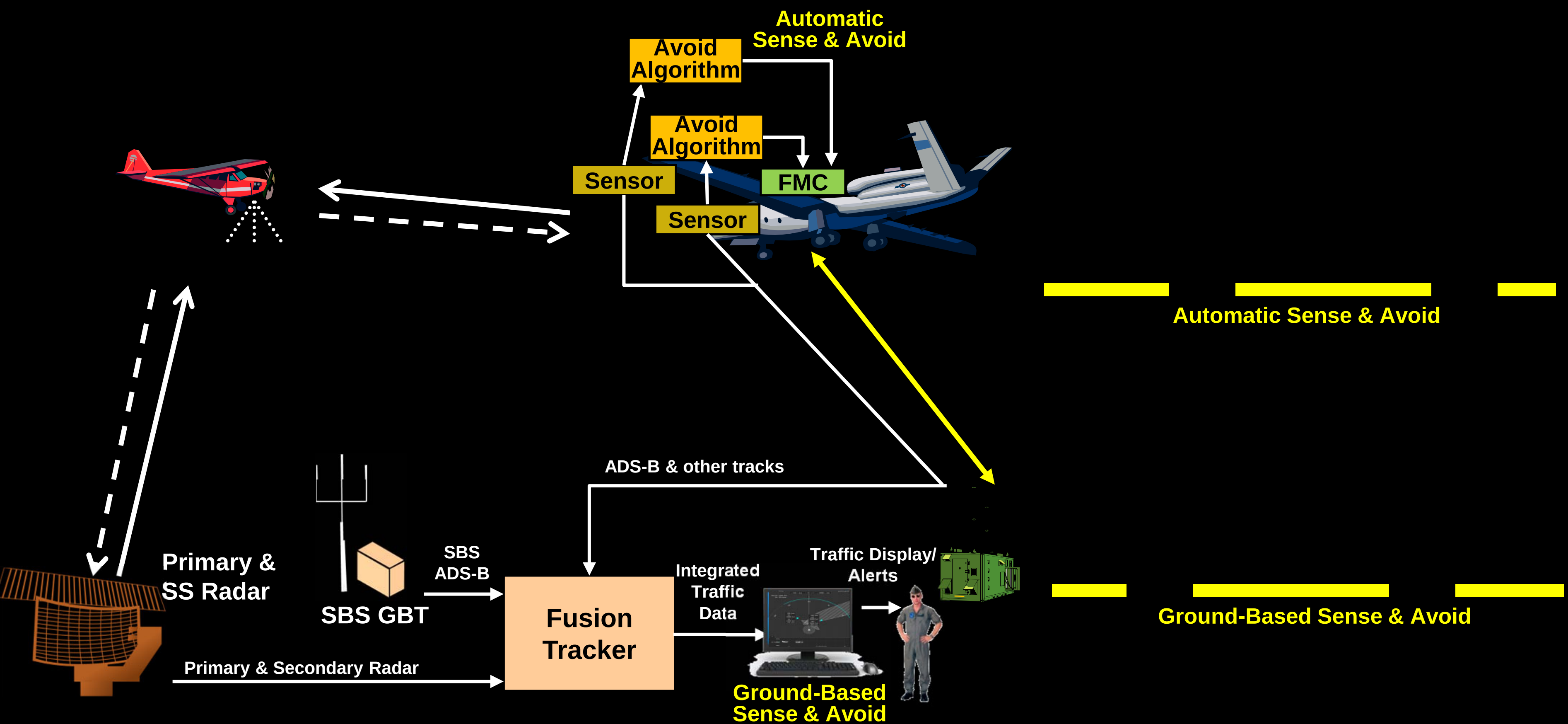
- **Automatic Sense and Avoid**
  - Automation on board aircraft is the decision-maker



One Potential Integrated Approach

Notional

- **Leverages multiple surveillance sources as well as Pilot-in-the-loop with automatic response in event of failures**
- **Mitigates common failure modes**



Approved for Public Release – Distribution Unlimited - Case: 13-0022

Research on Multiple Sensor Modalities*

Operational, Technical, and Policy Components

MITRE Exploring the Viability of Cooperative Automatic Sense and Avoid

Cooperative

requires intruder aircraft to be appropriately equipped

Non-Cooperative

does not require intruder aircraft to participate

Passive

Cooperative

Automatic Dependent Surveillance – Broadcast (ADS-B)

FreeFlight Systems RANGR

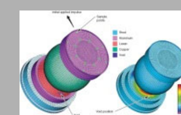
Garmin GDL-90

Non-Cooperative

Electro-Optic

Photo: US Army Research Lab Web-site

Acoustic



Drawing: Lawrence Livermore National Lab Web-site

Bistatic Radar

MITRE Feasibility Of Sensor Modality

Active

Cooperative

SSR/Mode C/S

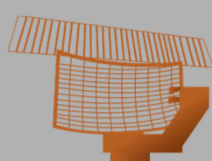
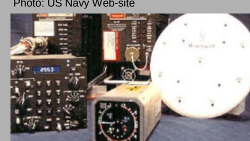


Photo: US Navy Web-site



TCAS Interrogator/ Mode C/S Transponder

Non-Cooperative

Primary Radar

LIDAR

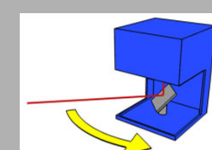


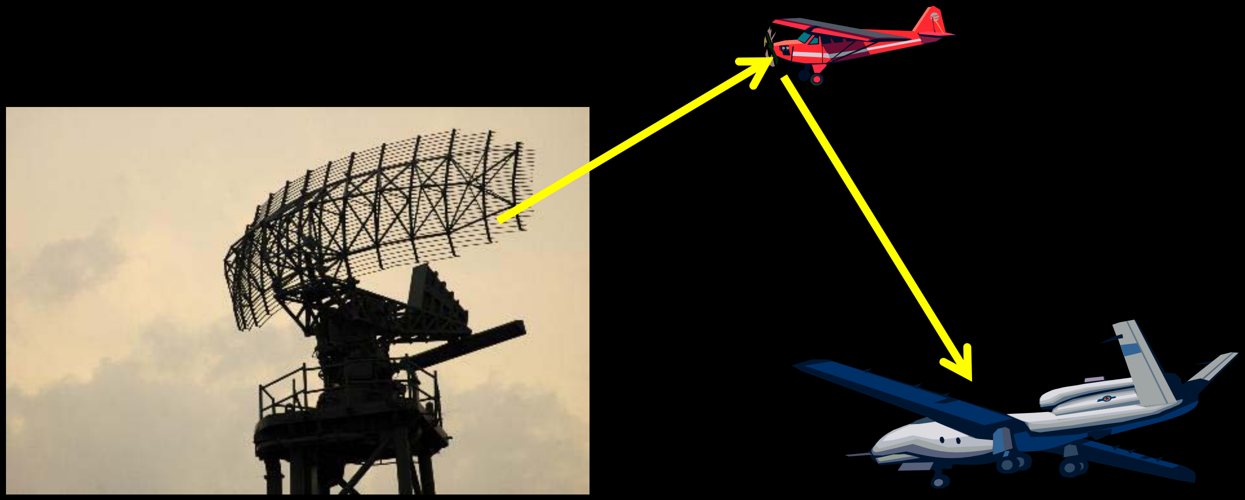
Photo: Wikipedia, Used w/ Permission

Not meant to be all inclusive

Bistatic Radar

- **Non-cooperative sensor**
- **Focus is on 'sense' part of the problem**
- **Uses small, lightweight, inexpensive components**
- **Leverages advanced signal processing developed for a fielded ISR system**

Bistatic radar: **Transmitter and receiver are not collocated**

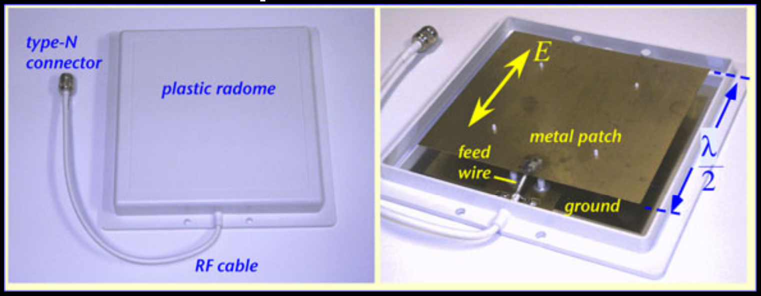


iStockphoto.com

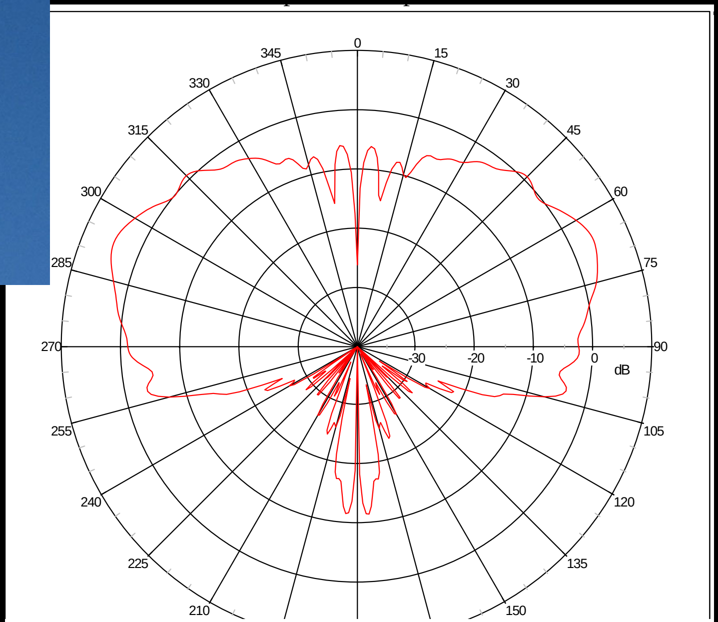
Bistatic Radar Antenna Hardware

- **Examining multiple antenna options**
  - Simple antennas (e.g. omni's)
  - Small arrays (e.g. patch antennas)
  - Considering SWaP implications

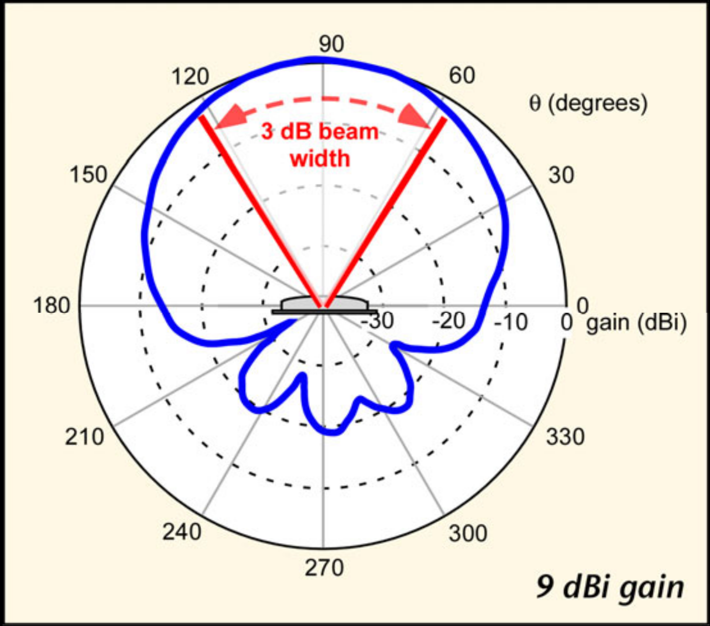
Sample Patch Antenna



Omni-Directional Antenna



Antenna Pattern (10 GHz)



Approved for Public Release – Distribution Unlimited - Case: 13-0022

Automatic Sense and Avoid: Why use at ADS-B in Research?

ADS-B vs. Non-Cooperative (e.g., radar, electro-optic)

ADS-B

- Available proven technology
- Minimizes Size, Weight, & Power (SWAP)
- Accuracy & integrity known
- Simplifies algorithms
- Reduces development & certification risks

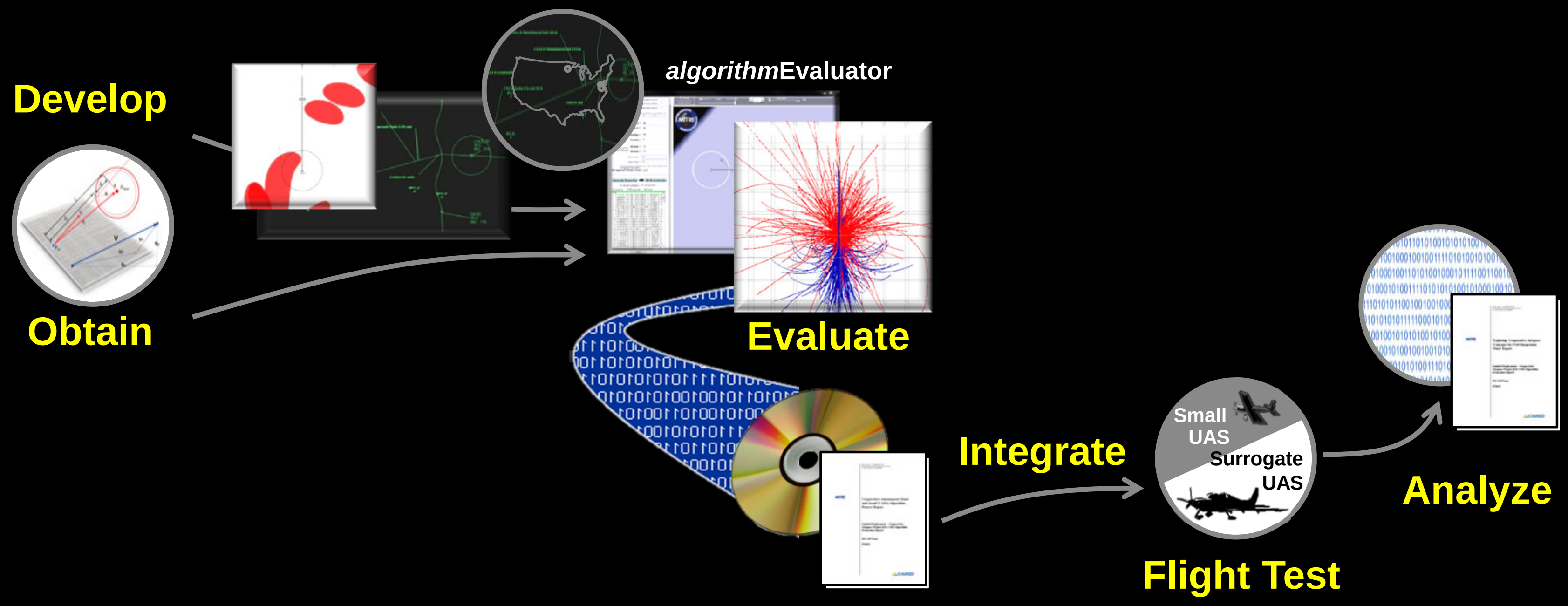
Non-Cooperative (e.g., radar, electro-optic)

- Independent of intruder equipage
- Requires ***no*** change in policy

ADS-B may not be suitable as a *sole* means

No other sensor is likely to have better accuracy and integrity

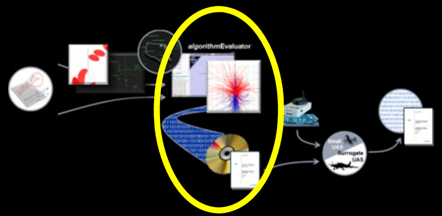
Automatic Sense and Avoid: Development, Test, and Evaluation (DT&E)

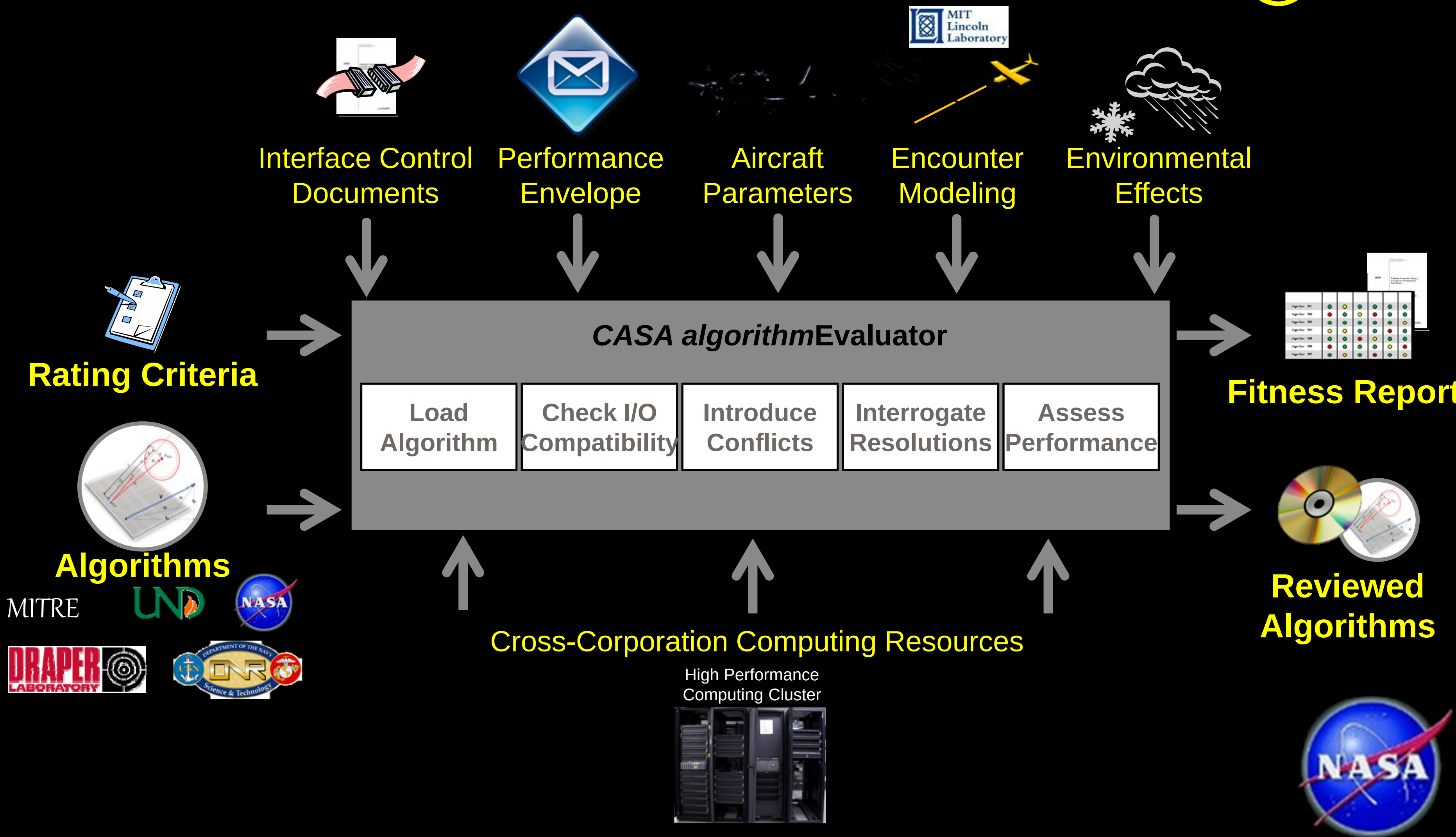


Acquire Algorithm(s)	▶	Evaluate Algorithms	▶	Determine Flight Suitability	▶	Integrate	▶	Execute Flight Tests	▶	Analyze Flight Data

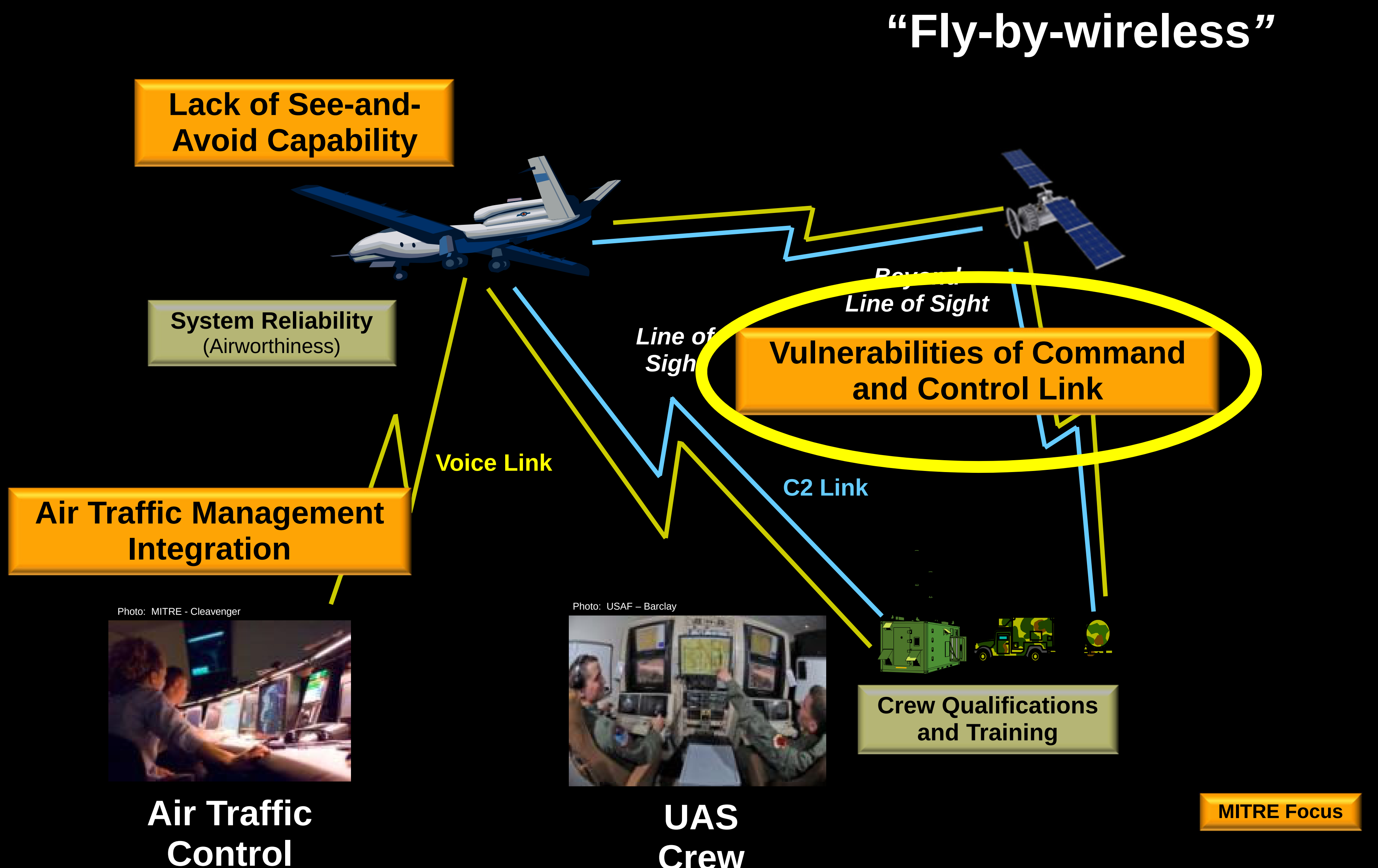
Approved for Public Release – Distribution Unlimited - Case: 13-0022

Automatic Sense and Avoid: MITRE’s *algorithm*Evaluator





Key UAS Integration Challenges



Command & Control Link Vulnerabilities

Fly-by-wireless will likely never be as robust as mechanical or fly-by-wire linkages

Factors contributing to C2 link vulnerabilities

- **Operational**
  - **Radio spectrum interference**
  - **Maneuvering/tracking failures**
  - **Multi-hop delays**
  - **Crosstalk**
- **Deliberate acts**
  - **Interception/spoofing**
  - **Jamming**
- **Failures (On-board, Control Station, Satellite or other multi-hop)**
  - **Radio**
  - **Software**
  - **Power**

Mini lost link events (<1 sec) to extended outages

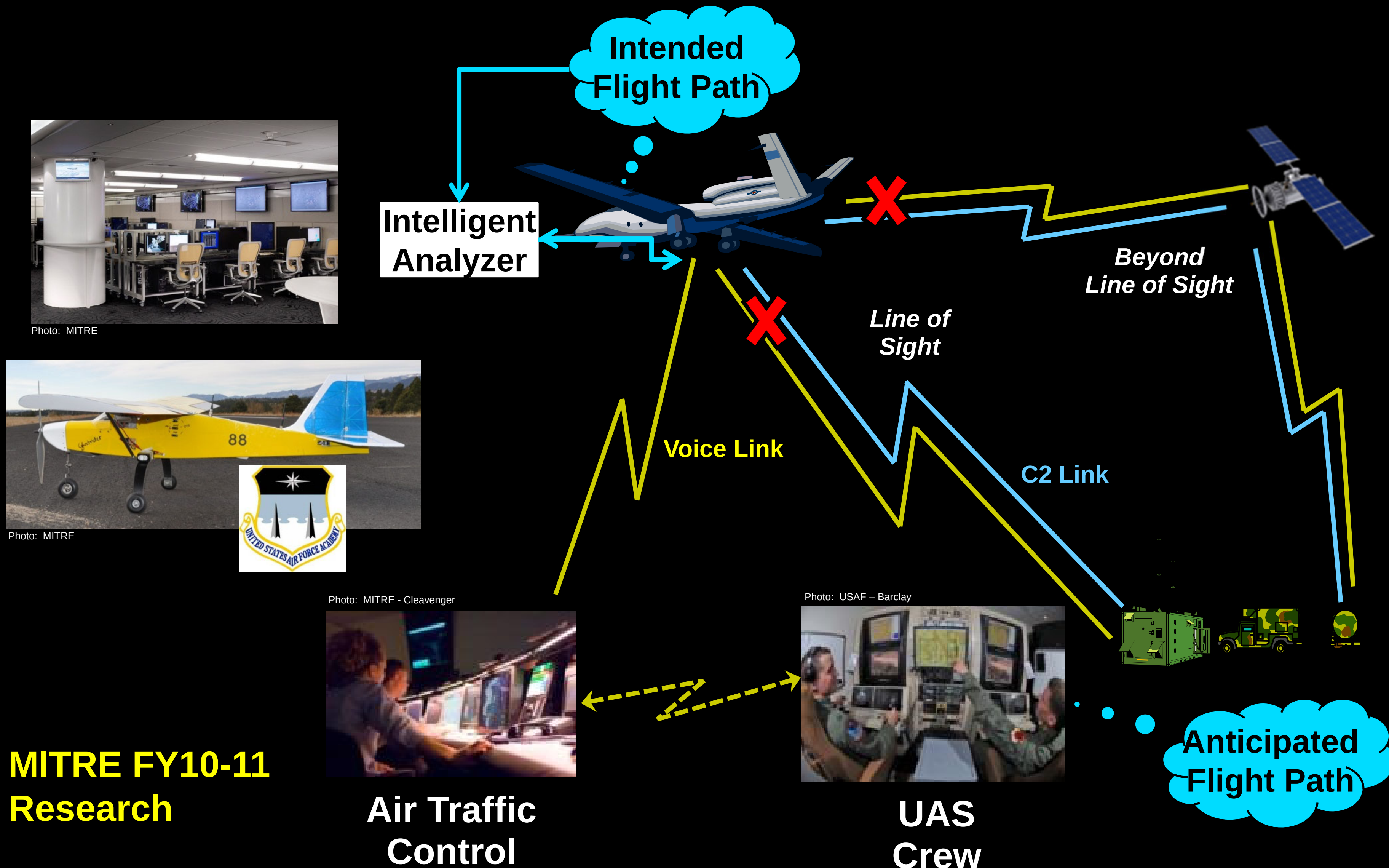
Lost C2 Link

- Pilot no longer has operational control of the aircraft
- Aircraft is flying automatically
  - Course set prior to loss of link (often prior to take-off)
- ATC can not affect the flight's path
- ATC must clear airspace
  - Needs to know where the aircraft is going
- Aircraft may not maintain its clearance

Lost C2 Link Mitigations

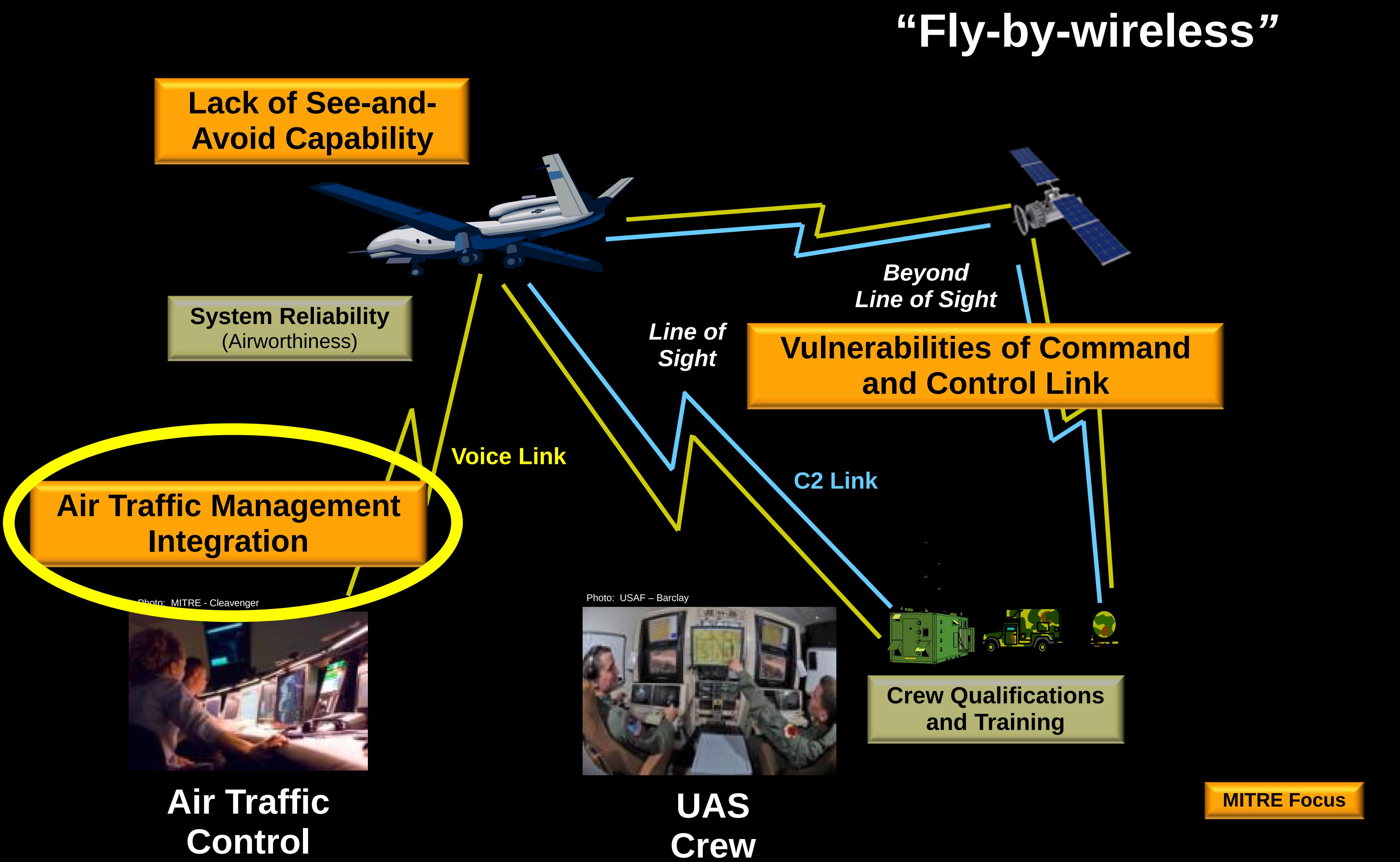
- Technical
  - Redundant links
  - Encrypted/proprietary links
  - Validated handoffs
  - Protected spectrum
  - System certification
  - Ground-to-ground communications (pilot to ATC)
- Operational/Procedural
  - Standardized lost link procedures / special purpose beacon code
  - Separation standards

Intelligent UAS Situation Awareness and Information Delivery



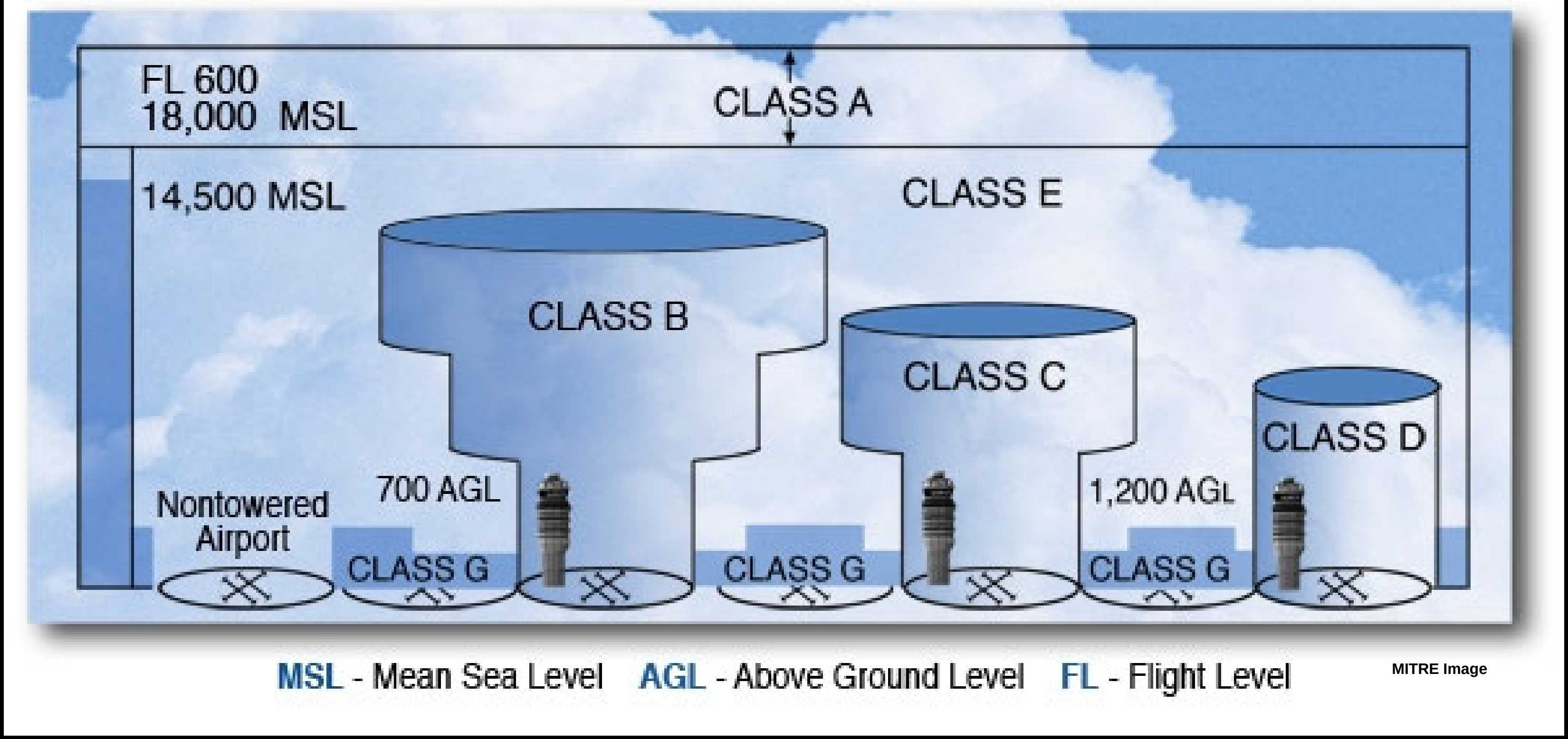
MITRE FY10-11 Research

Key UAS Integration Challenges



Airspace Classes

- Each class of airspace has different requirements and different operating procedures
- Class A, B, C, & D require contact w/ ATC
- Aircraft in Class A, B, & C are transponding



MITRE Image

Sullivan Test – With Apologies to Alan Turing*

"You know you have integrated UAS when a controller can't distinguish between an unmanned and a manned aircraft"

– Patrick Sullivan, Manager of Airspace and Procedures Minneapolis Center

*** Turing test is a test of a machine's ability to exhibit intelligent behavior. If a human texting can't tell whether they are texting with a computer or a human**
- Alan Turing, "Computing Machinery and Intelligence", *Mind*, 1950.

Some ATM Integration Challenges

- Diverse performance characteristics (operating altitude, cruise speeds, and climb/descent rates)
- Not necessarily point-to-point routes
- Communications latency
  - Read-back and step-on issues
- Potential for Lost Link
  - No standardized lost link procedures
  - No special purpose transponder beacon code for lost link
- ATM Automation Challenges
  - Non-traditional flight plans (e.g., > 24 hrs, loiter patterns)
  - Missing adaptation data
  - No contingency routes
- UAS GCS Challenges
  - No FMS with navigation database

Summary

- Three key challenges
  - Lack of See-and-Avoid capability
  - Vulnerability of command and control link
  - Air Traffic Management integration
- Technical, operational and policy aspects
- To achieve target level of safety for Sense and Avoid a layered approach will likely be necessary
  - Requires independence among layers
    - Sensors and Algorithms
    - GBSAA and ABSAA
    - Self-separation and Collision Avoidance

Thank You

Photo: DHS Custom and Border Protection

Backups

?

USAF Photo by Lt. Col. Leslie Pratt))

MITRE UAS Airspace Integration Work Program

Safety Case Approach

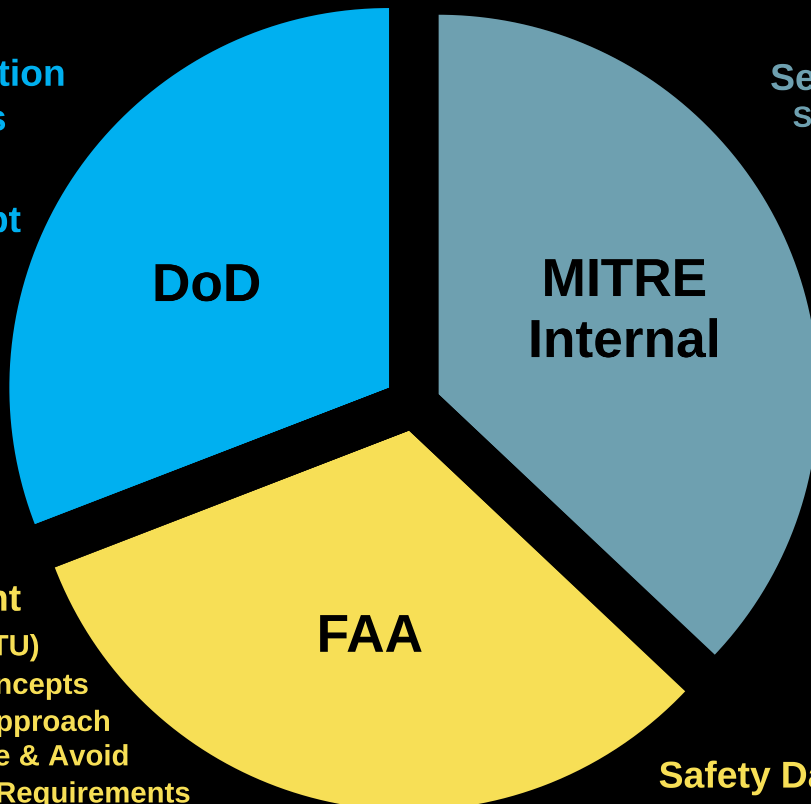
OSD: Analytic Contributions to Airspace Integration IPT

Sense & Avoid Research Panel

US Navy: BAMS Integration Concepts & Analysis

USNORTHCOM: Concept Test & Evaluation

USAF: GBSAA Implementation



Sense and Avoid Technologies:
Sensors, Algorithms, and Evaluation Methods

- Electro Optic
- ADS-B
- Bi-Static Radar

ATM Integration: Lost Link Contingencies, Automation, & Datalink

Standards Development & Analysis (RTCASC-203, ITU)

System Concepts

Safety Case Approach

Sense & Avoid

C2 Link Spectrum Requirements and Architecture Analysis

UAS ARC

Small UAS Operational Safety and Risk Analysis

Airspace Impacts

Safety Data Analysis

Future ConOps Development

DHS – CBP, USCG

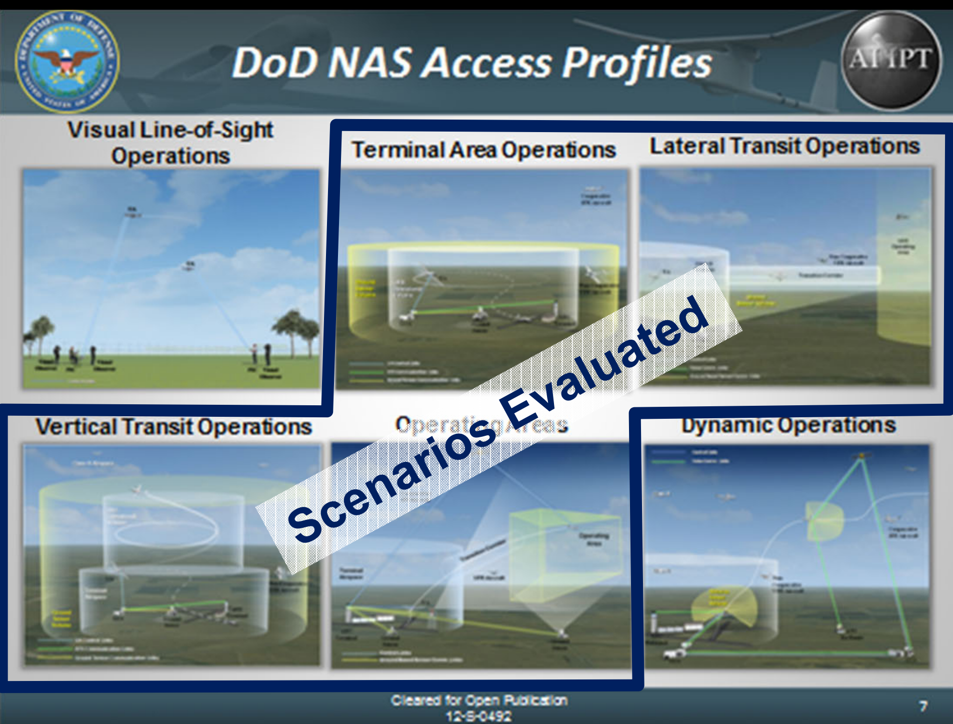
Regular TEMs

sUAS T&E Advisory Committee

UAS Airspace Integration ConOp Quick Reaction Test (QRT) – June 2012

Distributed simulation conducted in MITRE Labs

- Military Controller & UAS Pilot participants
- FAA, DHS, NASA observers



UAS AI CONOP QRT Recap

Problem: The Services and combatant commands do not have standardized and tested UAS flight NAS access procedures, which limits efficient ops, training, and support missions. Validated *UAS AI CONOP* flight profiles provide DoD a steppingstone to increased NAS access

Purpose: Evaluate *UAS AI CONOP* flight profiles (Terminal Area, Operating Area, Lateral Transit, & Vertical Transit) in a simulated environment

Objectives: Conduct, record, and analyze the impact of CONOP procedures on ATC and flight operations and identify initial CONOP issues and gaps

Results: Participants from all services conducted the test on 18-21 June 2012. 142 total runs were executed under 59 test configurations. Initial results were favorable. Comprehensive data analysis is ongoing.

Next Steps: Completed data analysis. Final report is due to sponsor on 1 Aug. QRT results will be used to support the Joint Test nomination.

POC: LTC Patrick Davis, john.davis@northcom.mil or Tony Militello, amilitello@mitre.org

1

Overview of Unmanned Aircraft Systems

Andrew Lacher

January 2013

Presented at Transportation Research Board Annual Meeting

MITRE

MITRE Manages 6 FFRDCs

(Federally Funded Research and Development Centers)

NSEC

DoD's National Security Engineering Center

Established 1958

CAASD

FAA's Center for Advanced Aviation System Development

Established 1990

CEM

IRS' and VA's Center for Enterprise Modernization

Established 1998

HS SEDI

DHS' Homeland Security - Systems Engineering and Development Institute

Established 2009

JEMC

Federal Judiciary's Judiciary Engineering and Modernization Center

Established 2010

CNHT

Center for National Health Transformation

Established 2012

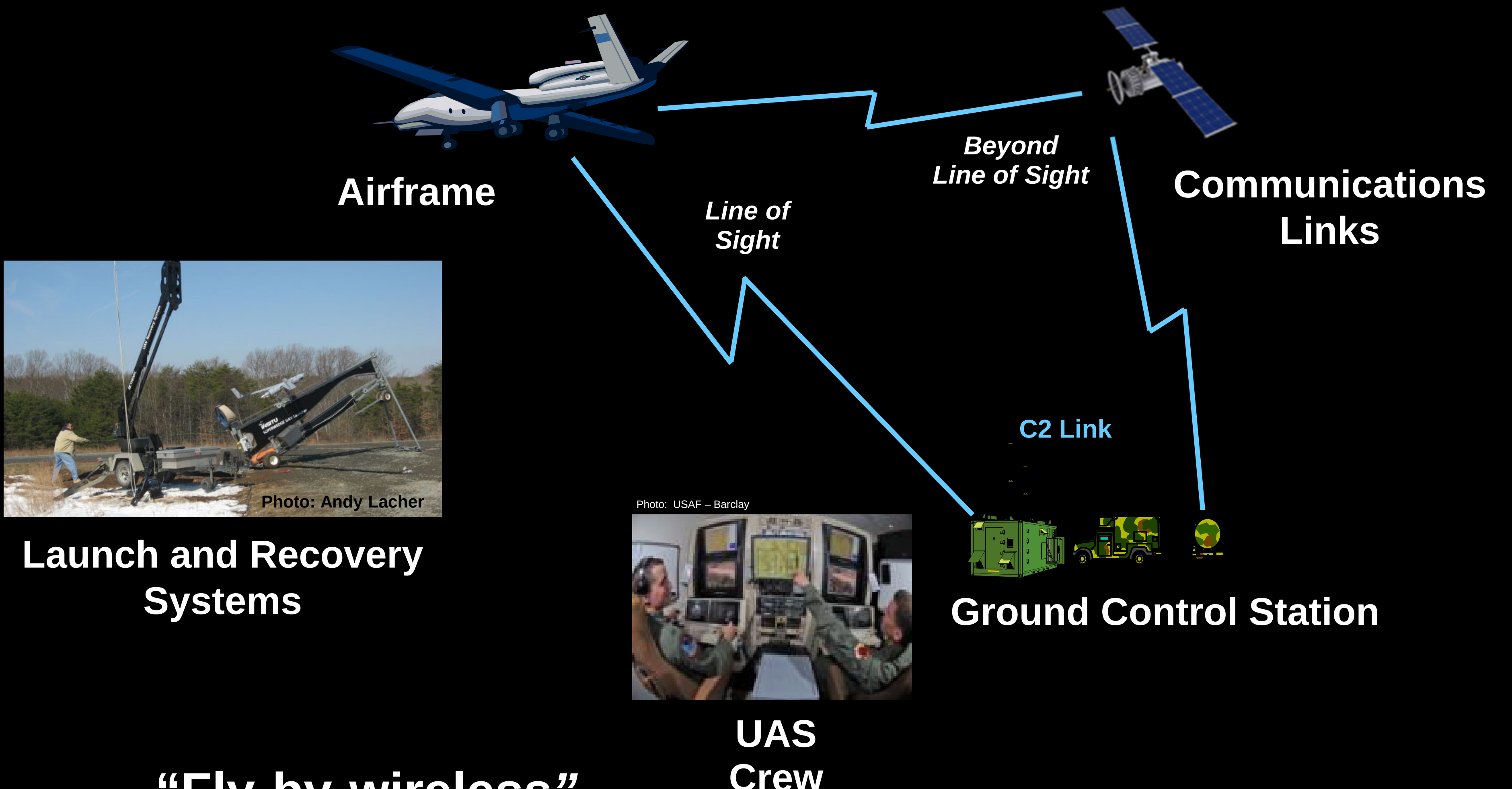
Applying Systems Engineering and Advanced Technology to Critical National Problems

What is in a Name?

- Unmanned Aircraft Systems (UAS) — FAA, RTCA Military Services
- Unmanned Airspace System (UAS)
- Unmanned Aerial Systems (UAS)
- Uninhabited Aircraft System (UAS)
- Remotely Piloted Aircraft (RPA) — USAF
- Remotely Piloted Aircraft System (RPAS) — ICAO
- Unmanned Aerial Vehicle (UAV) — Legacy Term
- Drones — Uninformed Media

What is an Unmanned Aircraft System?

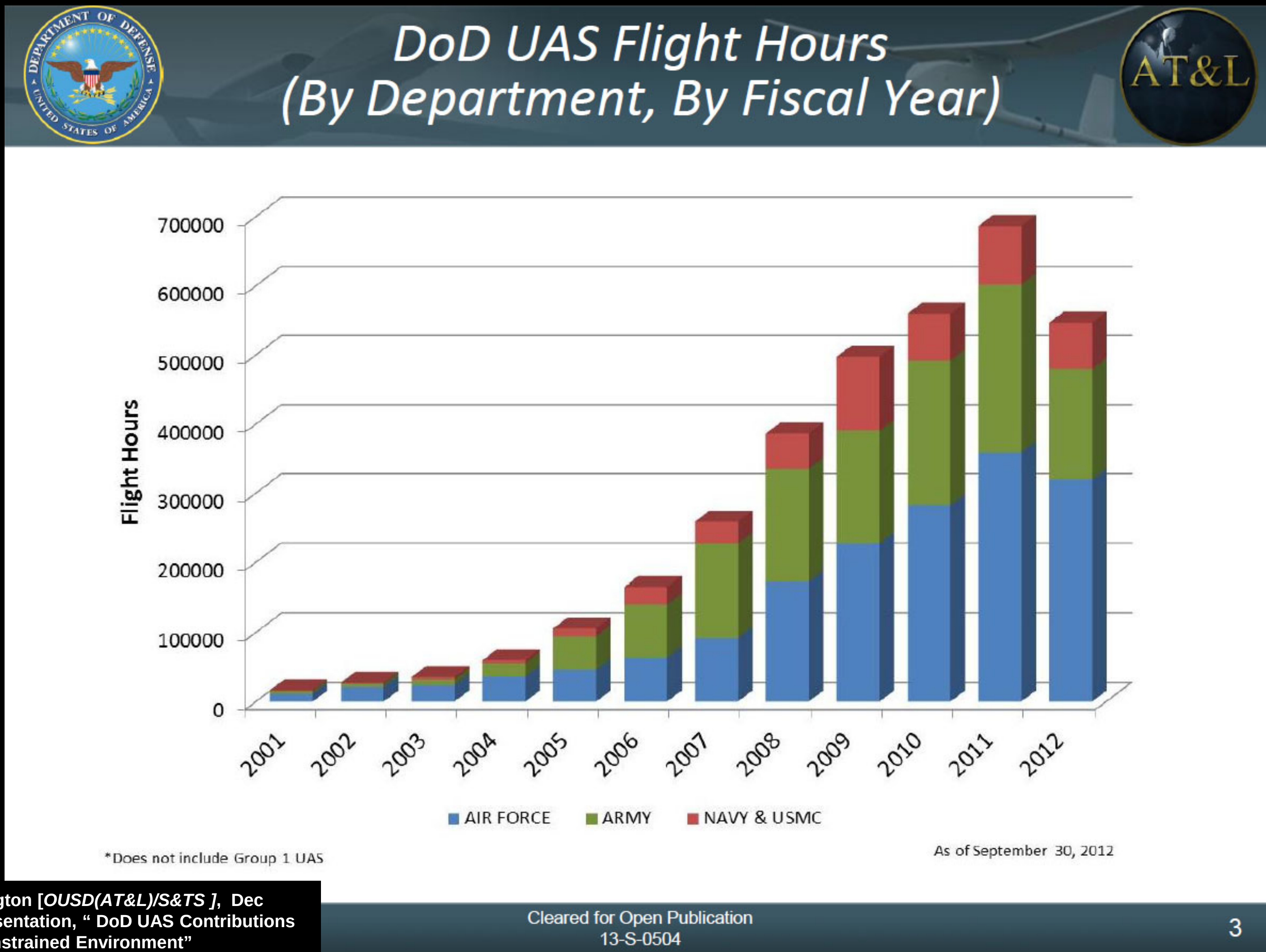
Unmanned Aircraft System: An aircraft operated without the possibility of direct human intervention from within or on the aircraft and its associated elements required for operation – RTCA UAS OSED
Remotely-piloted aircraft (RPA): An unmanned aircraft which is piloted from a remote pilot station. - International Civil Aviation Organization (ICAO)



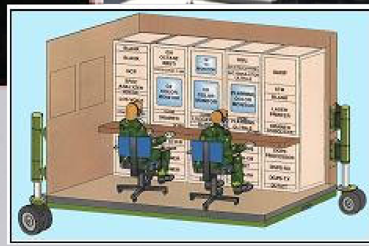
“Fly-by-wireless”

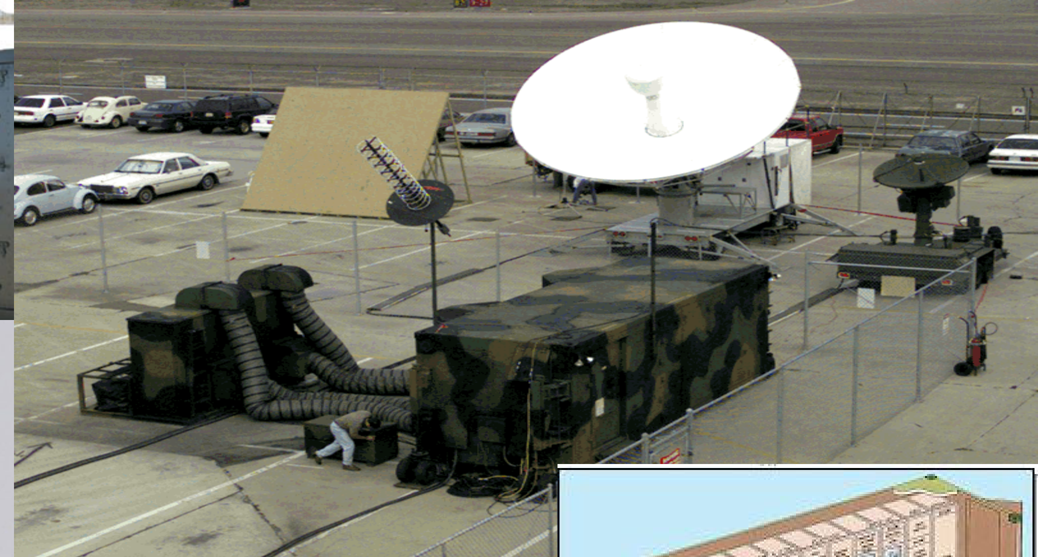
Historical Retrospective

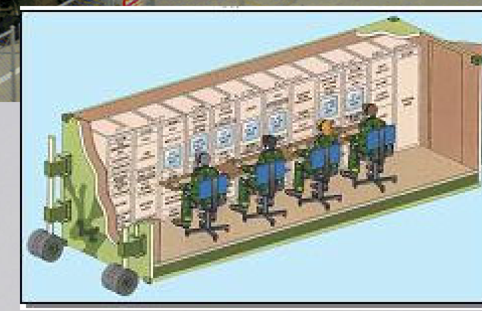
UAS Are Transforming the Military



Dyke Weatherington [*OUSD(AT&L)/S&TS*], Dec 2012, TAAC Presentation, " DoD UAS Contributions in a Fiscally Constrained Environment"



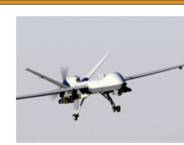




Photos: US Military

DoD Photo
Cpl Robert S. Morgan USMC

US Department of Defense
UAS Groups

UAS Category	Maximum Weight (lbs)	Ops Alt (ft)	Speed (KIAS)	Current Representative UAS
Group 1	0-20	<1200 AGL	<250	 Raven  T-Hawk
Group 2	21-55	<3500 AGL		 ScanEagle
Group 3	<1320	< FL180		 Shadow
Group 4	>1320		n/a	  Predator/Grey Eagle, Firescout
Group 5		≥ FL180		  Global Hawk / Triton, Reaper/Pred 'B'

•Hand Launched
•Short Duration (<1 hr)
•Mostly Line-of-sight (LOS)
•Auto flight stabilized

•Unique Launch & Recovery systems
•Several Hours → 1 day
•Beyond LOS
•Waypoint-to-waypoint
•Auto Recovery

•Unique Launch systems
•Runway Landing
•Several Hours
•Beyond LOS

•Sized like a manned aircraft
•USAF: Remote Split Ops
•Long Endurance - >12 hrs
•Autonomy varies

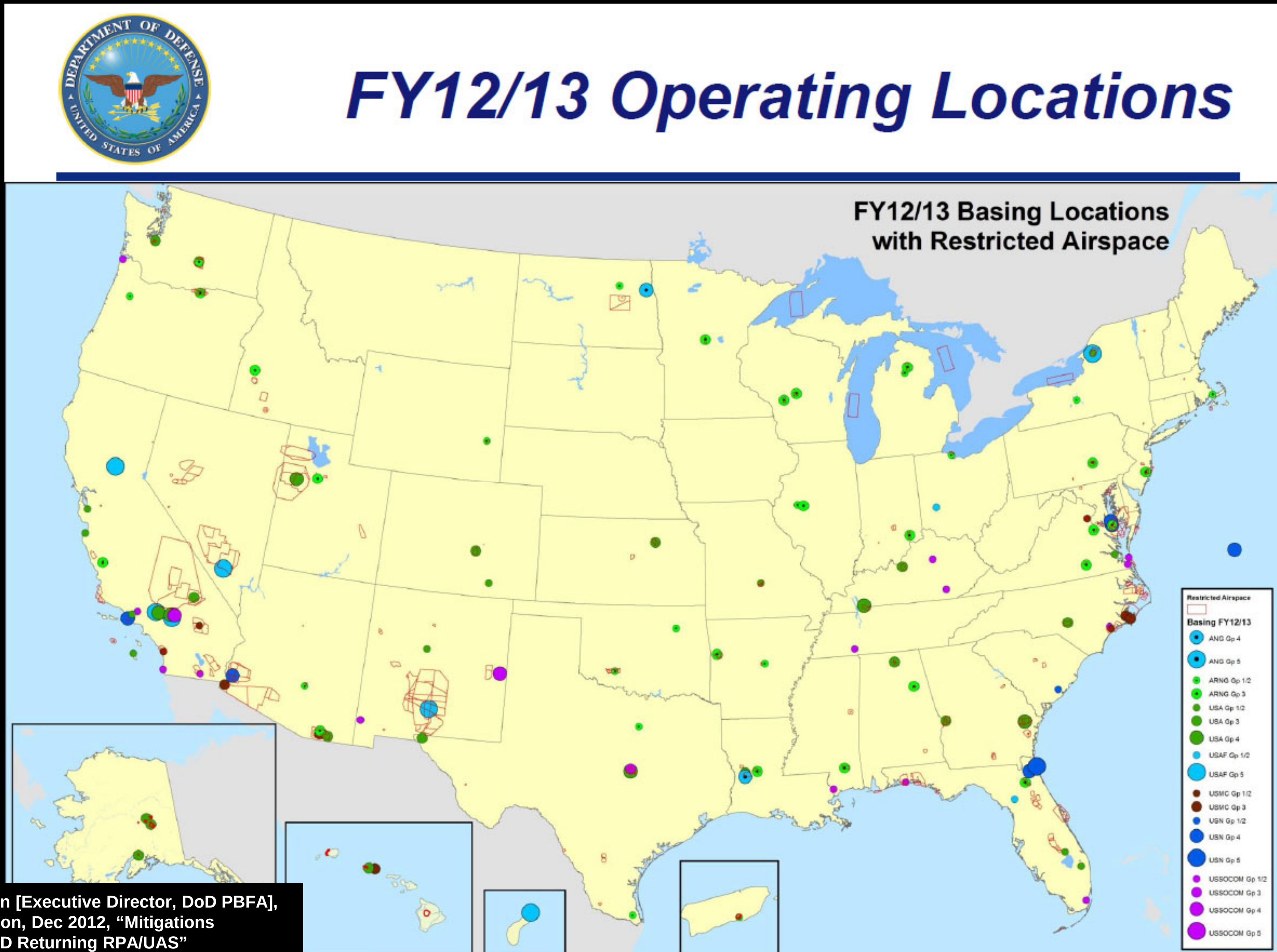
•Sized like a manned aircraft
•Includes turbo jets
•Long Endurance
•Larger Payloads

MITRE

Approved for Public Release – Distribution Unlimited - Case: 13-0021

Images: US Military Services

Restricted Airspace – Not Sufficient



Steve Pennington [Executive Director, DoD PBFA], TAAC Presentation, Dec 2012, "Mitigations Required For DoD Returning RPA/UAS"

Military Not the Only Ones Using UAS

USCG Photo
http://www.uscg.mil/comdt/blog/2009/12/maritime-predator-acceptance-ceremony.asp

Lacher Photo

Lacher Photo

US Custom and Border Protection

NASA Photo
www.nasa.gov

Custom and Border Protection Routine Use

MG (ret) Michael Kostelnik [Assistant Commissioner, Air & Marine Ops], TAAC Presentation, Dec 2012, "Air and Marine Operations on Leading Edge in Border Security"

Potential Commercial & Research Apps

- **Scientific**
  - Natural hazards research/monitoring
  - Environmental monitoring/ mapping
  - In-situ atmospheric monitoring
  - Wildlife observation
  - Technology experimentation

- **Commercial**
  - Surveying/mapping/imaging
  - Aerial photography / Surveys
  - Agricultural application
  - Crop monitoring
  - Motion picture
  - High altitude imaging
  - Communications relay
  - Utility/Pipeline patrol
  - Traffic monitoring
  - News/media
  - Aerial advertising
  - Fish spotting
  - Cargo
  - Infrastructure Protection

Yamaha RMAX

- Available commercially
- Designed for agriculture sprayi
- Flies autonomously
- Automatic stabilization
- 1000s operating in Japan
- ~$86k Agriculture Model

Business Case will Start with Small UAS

Law Enforcement Application

How do UAS Differ From Legacy Aircraft?

- No pilot on-board – *Fly-by wireless*
  - Situation awareness reduction
  - Command and control link vulnerabilities


Istockphoto.com


MITRE Photo

- Can be smaller

- Often not designed or constructed to established aircraft standards

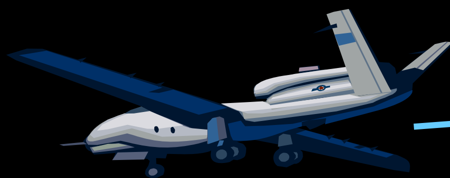

NASA Photo

- Different flight performance and mission profiles


USAF Photo

What is an Unmanned Aircraft System?

Unmanned Aircraft System: An aircraft operated without the possibility of direct human intervention from within or on the aircraft and its associated elements required for operation – RTCA UAS OSED
Remotely-piloted aircraft (RPA): An unmanned aircraft which is piloted from a remote pilot station. - International Civil Aviation Organization (ICAO)



Airframe

Beyond Line of Sight

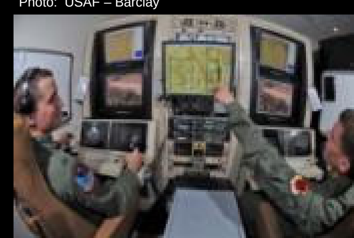
Communications Links

Line of Sight

C2 Link

Launch and Recovery Systems

Photo: USAF – Barclay



UAS Crew

Ground Control Station

"Fly-by-wireless"

Ground Control Stations Vary…

Photo: USAF

Photo: US Army

Draganflyer X6 Photo: www.PRWeb.com

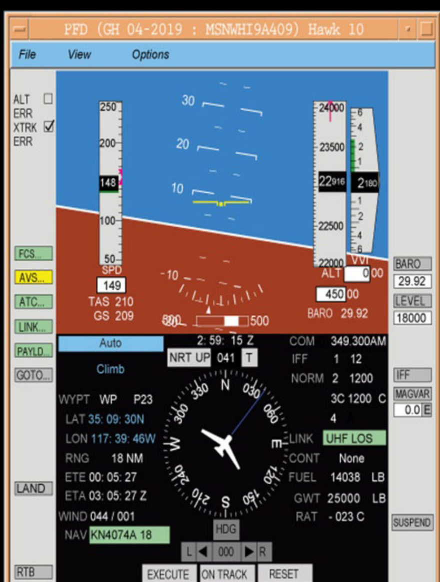


Photo: USAF

U.S. Air Force photo by Airman 1st Class Michael Shoemaker

Photo: USCG

Degree of Control


Photo: US Army

Photo: USAF

Direct Control
- Pilot continuously controls pitch, bank, yaw, and power

Direct Guidance
- Pilot controls heading, speed, and altitude
- Auto-stablized

Pilot-Managed Automatic
- Pilot Manages Flight
- Auto T/O Land
- Waypoint-to-Waypoint
- Auto Taxi

Fully Automatic
- Pilot Manages Flight
- Can operate w/o pilot-in-the-loop
- Auto T/O Land
- Waypoint-to-Waypoint
- Auto Taxi

Autonomous
- Software using perception and judgment to make decisions
- Operates w/o pilot-in-the-loop

Take-Off Variations

- Runway

Runway Independent

- Vertical
- Hand-launched
- Launcher

Photo by 1st Sgt. Vaughn R. Larson, Wisconsin National Gua

Recovery Variations

- Runway – Traditional
- Runway – Arrested

Runway Independent

- Vertical
- Snagged
- Deep-stall

Some Observations

- **Wide variety of UAS**
  - Size, Performance, Mission, Degree of Autonomy
  - All UAS are not the same → we can't think about them as a single group → no one size fits all solution
- **"Unmanned" is a misnomer**
  - Human operators are directly involved – e.g., remote pilots
  - In some cases in large numbers
  - UAS are not necessarily cheaper to operate than manned
  - Will continue to have challenges with human factors
- **Military is not the only UAS user**
  - Other public entities (Border Security, Science, Law Enforcement, etc.)
  - Commercial Emerging – Especially small UAS

Summary

UAS – RPAS – RPA

- Have a number of military, security, and commercial applications
- Are varied in size and flight characteristics
- Are not really unmanned
- *Are an important part of the future of flight*

U.S. Navy photo