Automatic Dependent Surveillance Broadcast:
ADS-B Sense-and-Avoid System

Ricardo Arteaga

NASA Armstrong Flight Research Center

AIAA, June 13-17

Washington DC

AVIATION 2016

Introduction to ADS-B

Automatic Dependent Surveillance Broadcast

- Replacing radar for tracking aircraft worldwide
  - Prevent collisions
- Sharing position, altitude, velocity, etc. with air traffic control and other aircraft
  - ADS-B Out = Transmit
  - ADS-B In = Receive
- **FAA-mandate**
  by Jan. 1, 2020

Operational View

AVIATION 2016

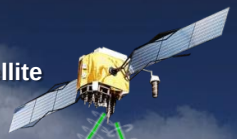
National Aeronautics and Space Administration

NASA

LEGEND
- Sense and Avoid (SAA Technologies)
- Air Traffic Services
- ADS-B Ground Stations and Network
- Legacy Command and Control (C2) Links

ACRONYMS
ADS–B: Automatic Dependent Surveillance—Broadcast
SAA: Sense and Avoid
NAS: National Air Space

Communications satellite



Cooperative aircraft

ADS–B

Sense and Avoid

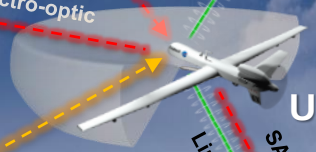
Radar and electro-optic

Non cooperative aircraft

Beyond line-of-site link

ADS–B

UAS Civil



Unmanned aircraft

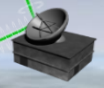
Manned aircraft

Line-of-site link

SAA Datalink

Air traffic services (en route)

Command and Control



Human Systems Integration

ADS-B ground stations

FAA ITT Network

Communications

Air traffic controller interaction

UAS ground control station

Research ground control station

Air traffic services (terminal)

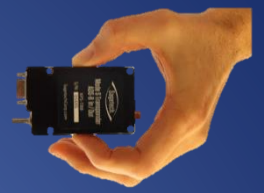
Small UAS (sUAS) Mini-ADS-B Technologies

Commercial UAS operations

UAS Restricted-Use Certification

Precision agriculture

Operational Use Cases



- Urgent need to safely integrate UAS into the National Air Space (NAS)
  - First responders and firefighters
  - Search-and-rescue missions
  - Monitoring and/or fighting forest fires
  - Package delivery (Amazon®, Domino's®, FedEx®)
  - Surveying farmland, borders, pipelines
- Consumer/Commercial demand for UAS likely to explode in the next decade
  - 30,000 drones operating by 2020 *(FAA)* [1]
- **Market opportunity by 2020 for ADS-B equipped Unmanned Aircrafts: from $240 to $360 million.**

[1] http://www.washingtontimes.com/news/2012/feb/7/coming-to-a-sky-near-you/?page=all, accessed on October 15, 2104

UNMANNED ADS-B AIRCRAFT SYSTEMS

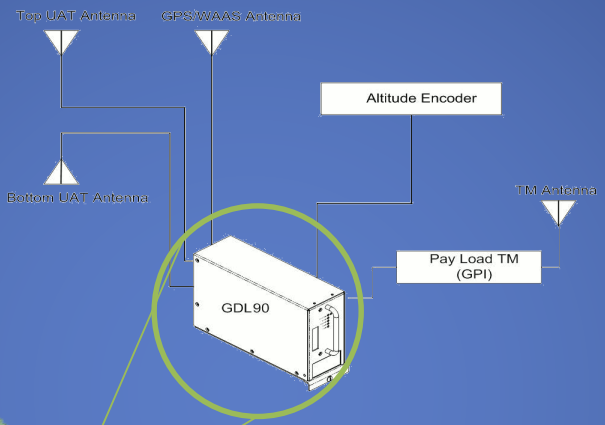
National Aeronautics and Space Administration

New Technology

- ADS-B OUT
- ADS-B IN
- ADS-B Sense and Avoid

- ADS-B system coupled to an unmanned aerial vehicle for increased situational awareness and self-separation assurance

GPS



C-BAND

LOS Datalink

978 MHz

978 MHz

1090 MHz

GCS

ADS-B Ground Station

NASA Patent Pending 13/785,661

NASA Results and Benefits

Results

ADS-B flight tests on Ikhana UAS

- ADS-B Out: March 2012
  - First time a UAS as large as the MQ-9 had flown equipped with ADS-B
- ADS-B In: May 2012
  - 2 Flight Tests at Dryden with successful traffic surveillance

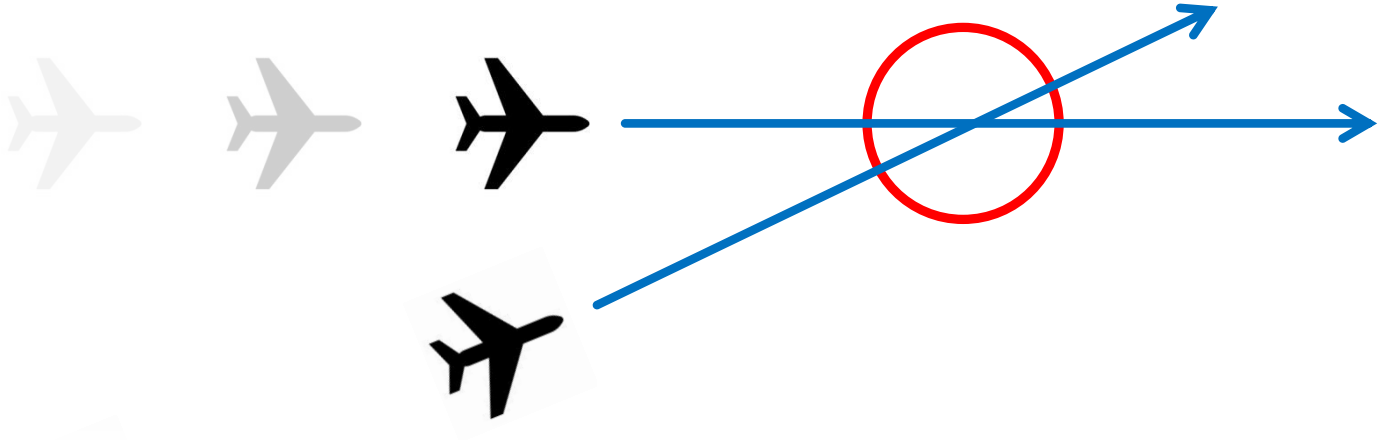
Benefits

- **Complies with FAA certification for ADS-B Out** (5.7 feet position accuracy, FAA independent analysis)
- **Provides backbone** technology for NextGen
- **Increases safety** by ensuring safe separation
- **Increases pilot awareness,** situational and traffic
- Other technical benefits
  - Provides 3D synthetic views
  - Loss link of UAS telemetry uses FAA Tech Center ADS-B data for redundancy

NASA Patent Pending 13/785,661

Advanced sense-and-avoid algorithm

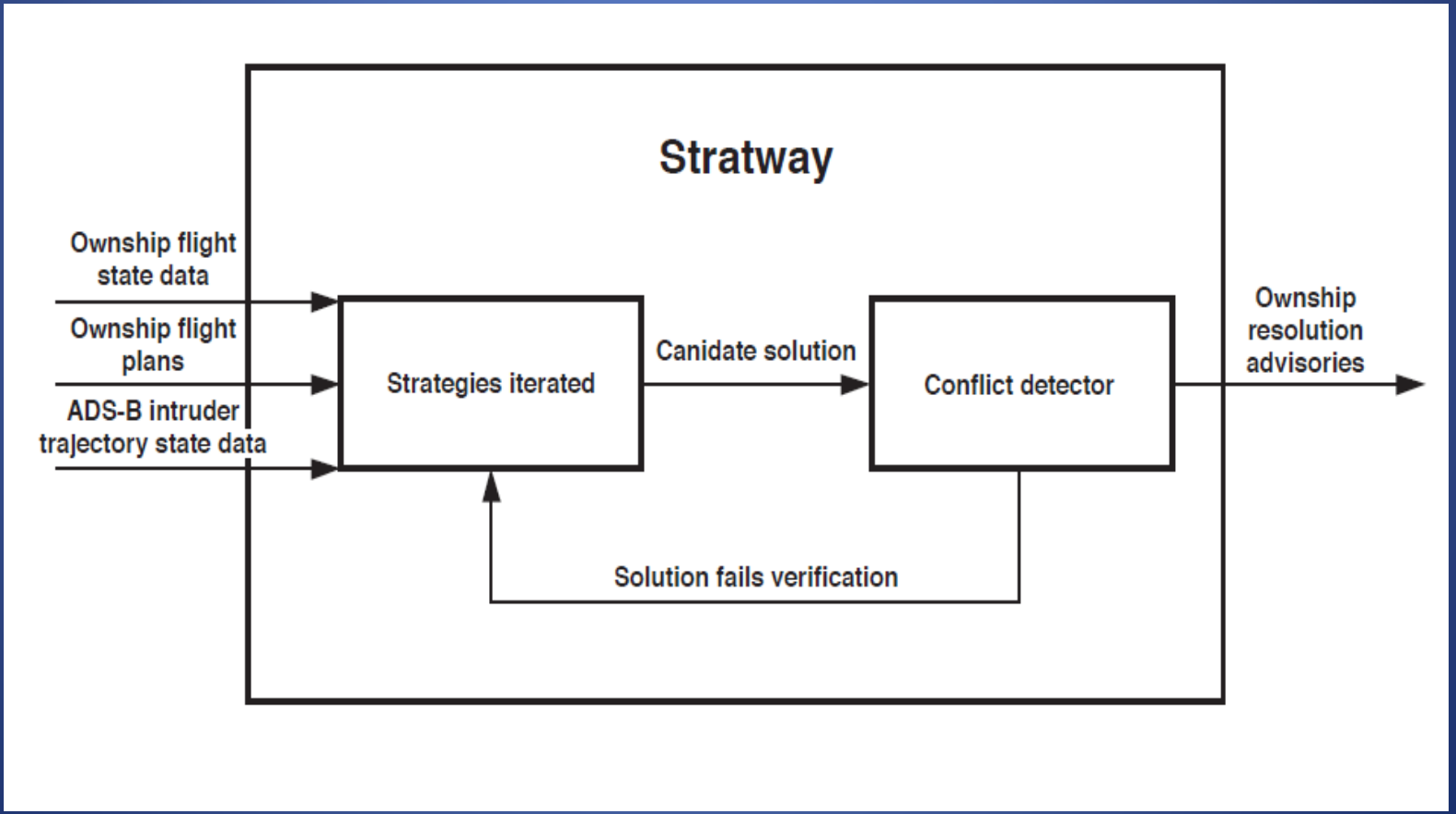
- Software uses ADS-B broadcast information to construct aircraft trajectories, and predict future loss of separation.



Collision possible: 33s

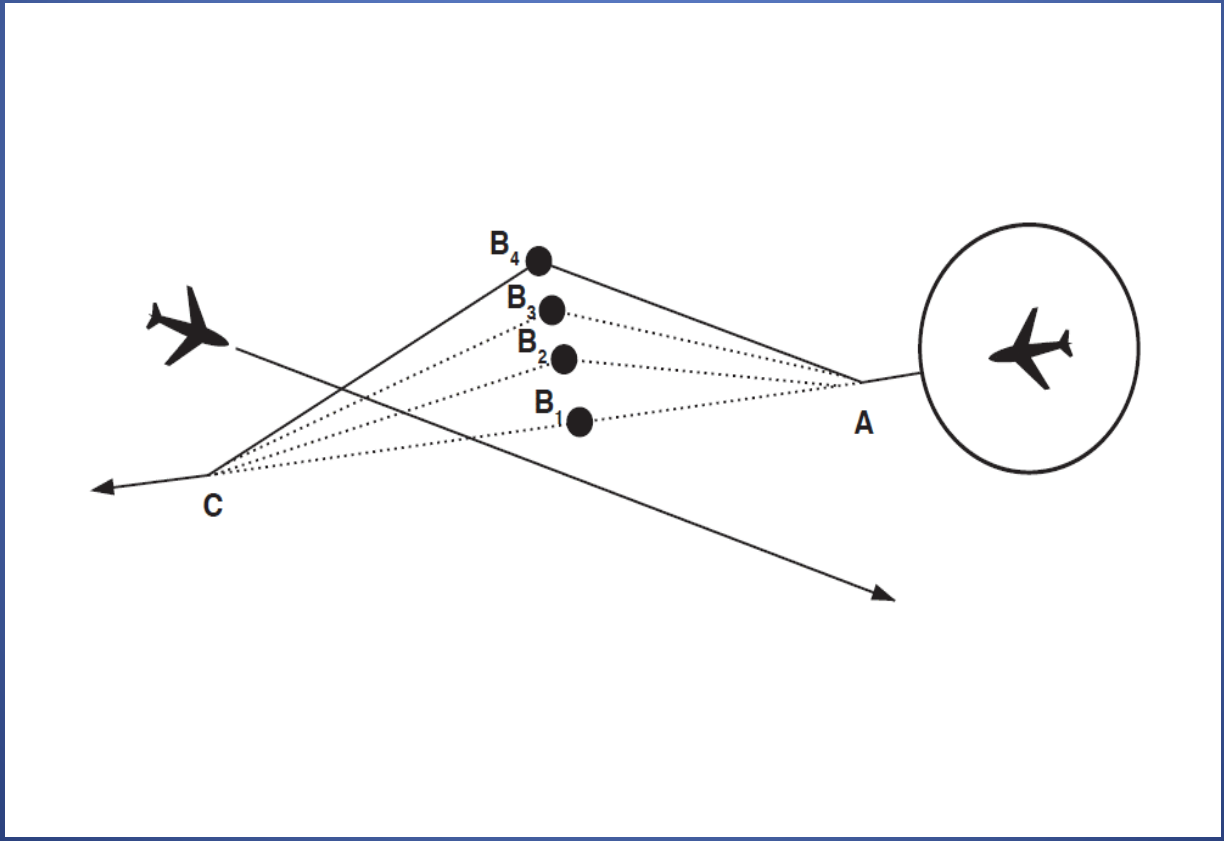
ADS-B sense-and-avoid algorithm

Stratway – a modular approach to safe conflict resolutions.



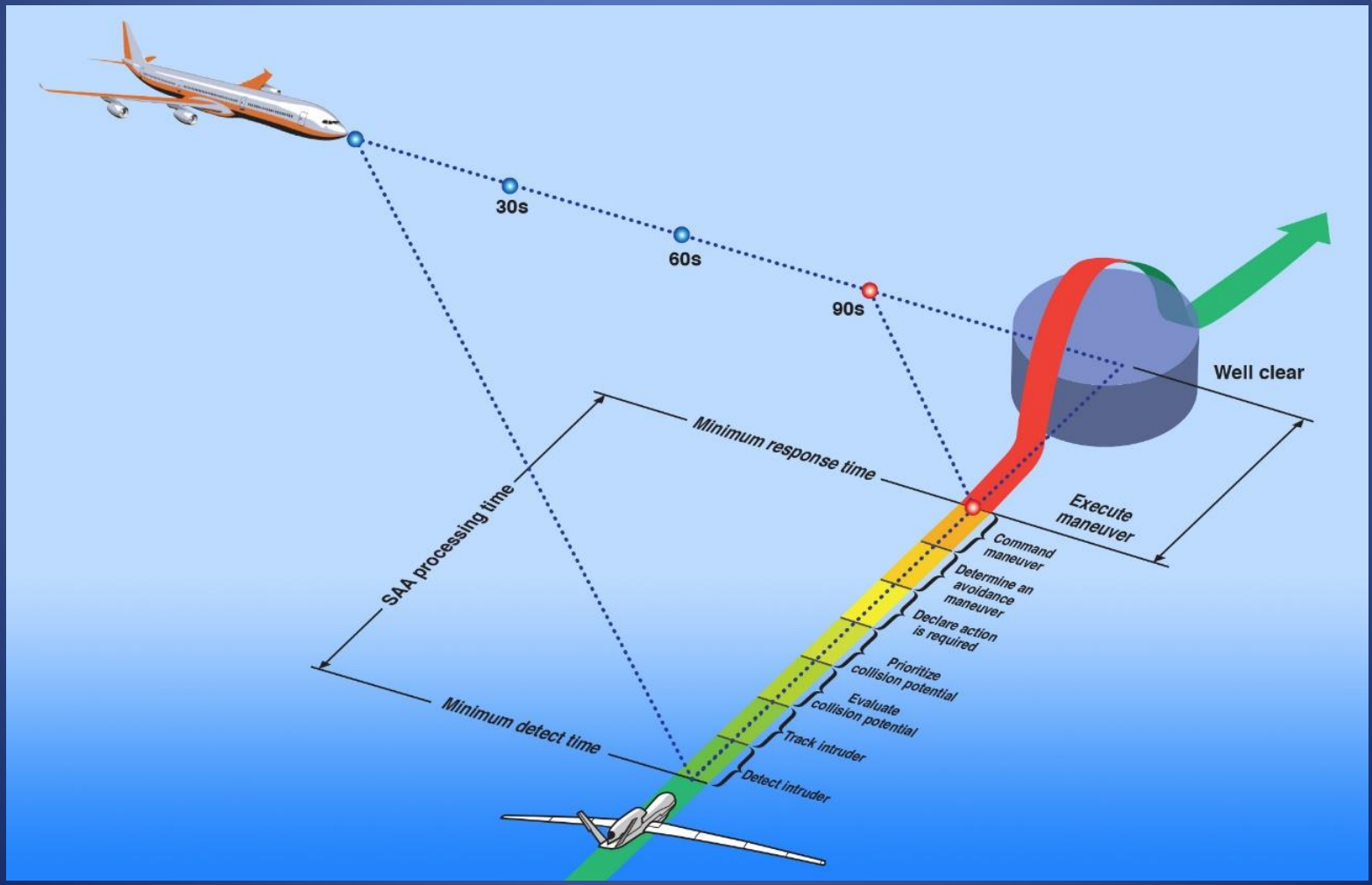
Stratway conflict resolution algorithm

Stratway – strategies are iterated.



Sense-and-Avoid sub-functions

NASA Sense and Avoid unique capabilities provided by the Stratway code.



NASA ADS-B SAA Display

LEGEND

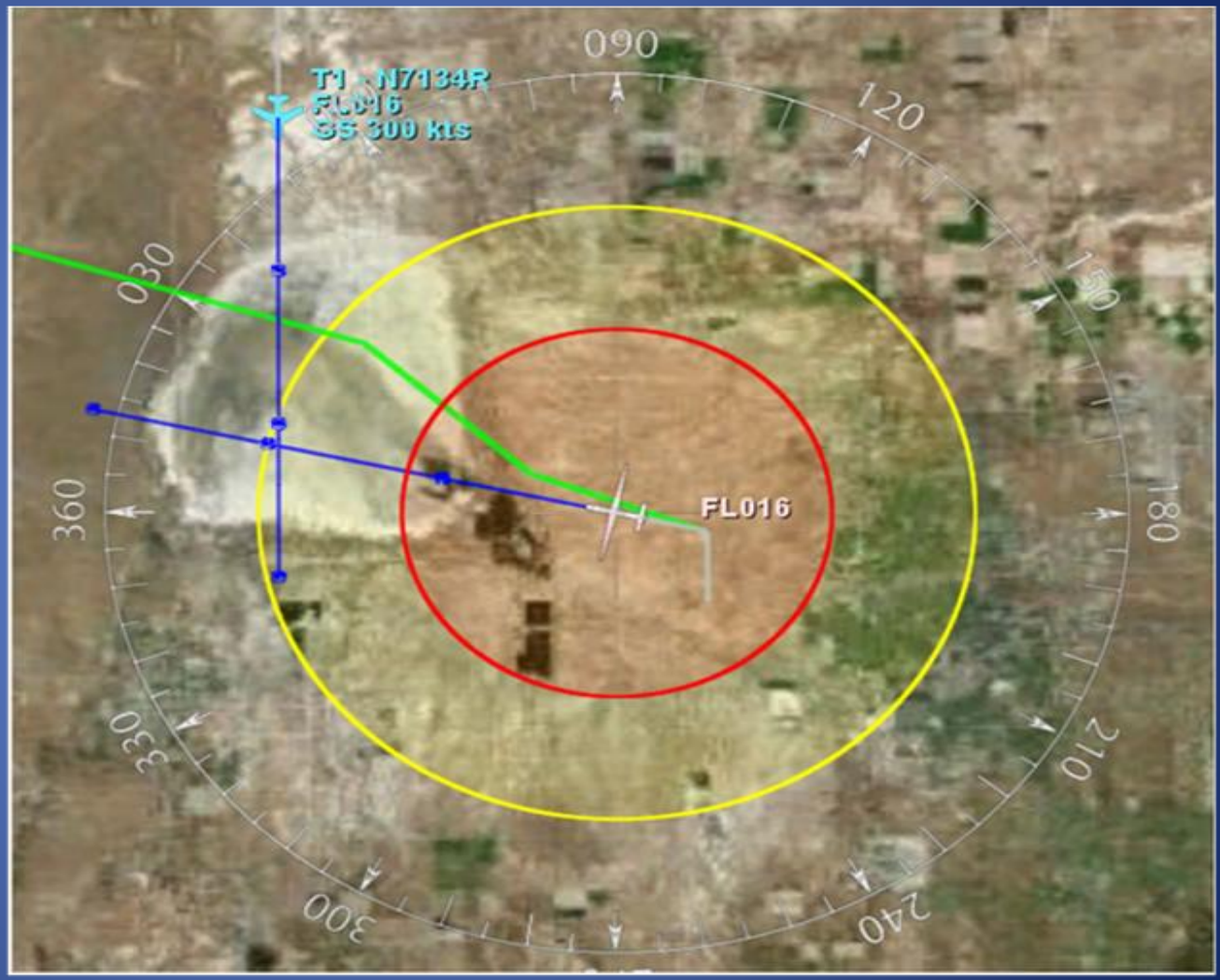
Target aircraft transmitting ADS-B

Ownship's resolution advisory

Aircraft's nominal trajectory

Traffic alert advisory

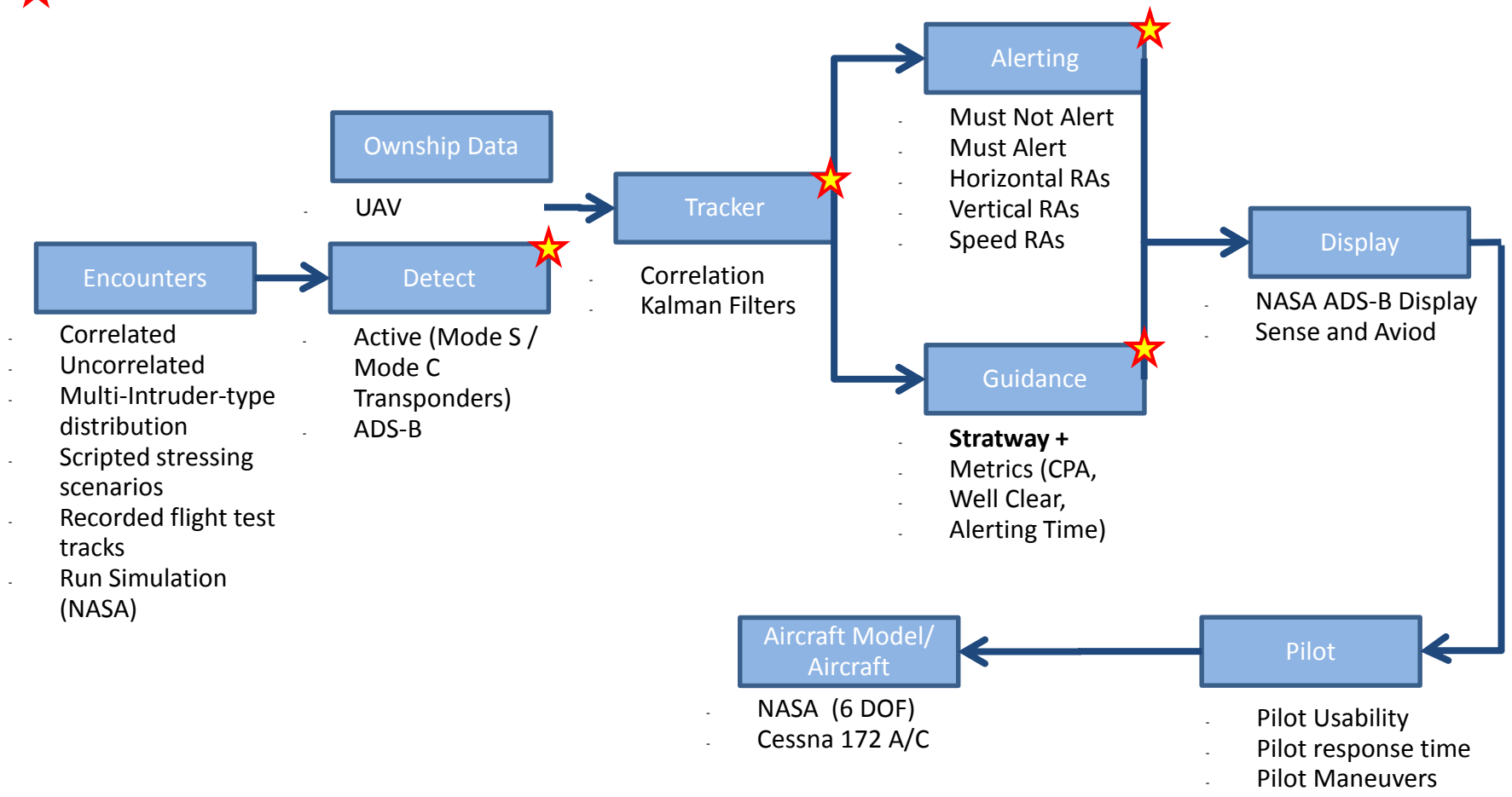
Traffic threat advisory



NASA Patent Pending 13/785,661

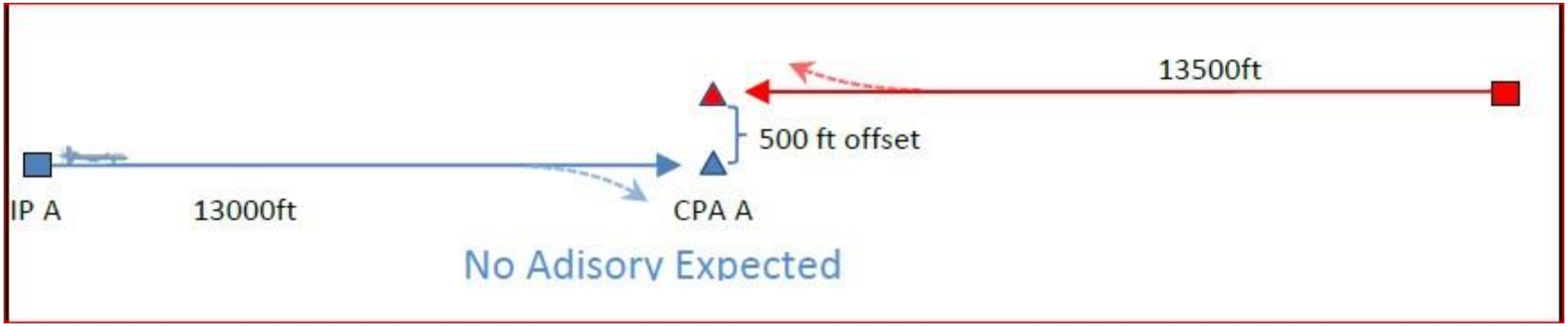
Model Elements Used To Develop and Validate Requirements

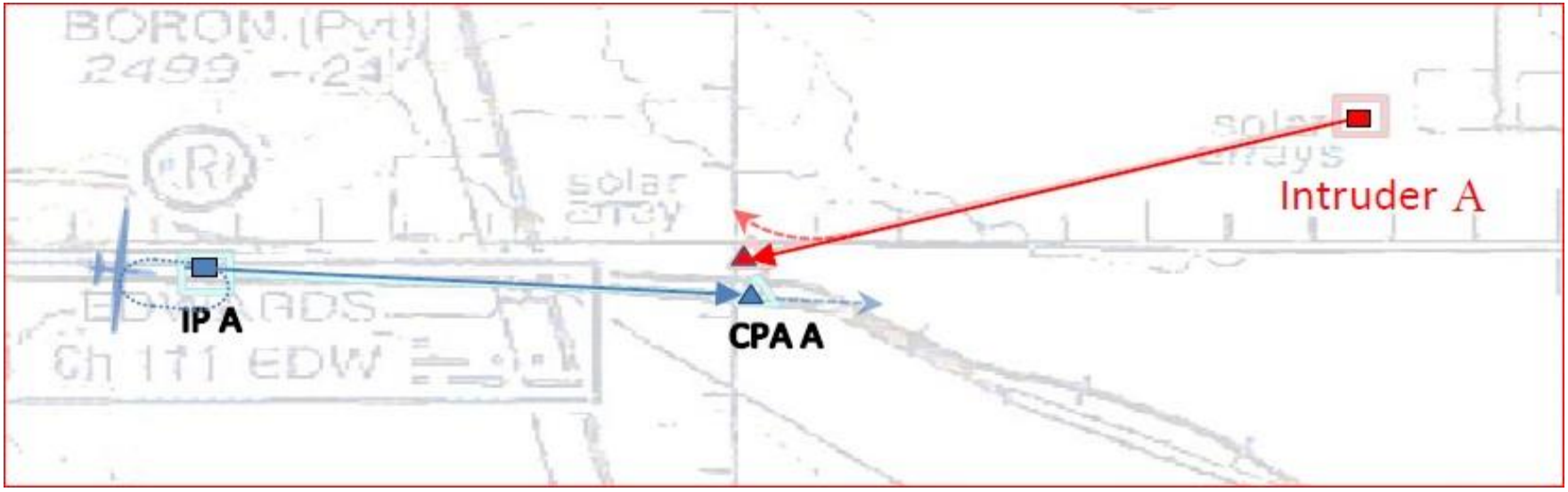
SAA Requirements



Encounters Geometries Used To Develop and Validate Requirements

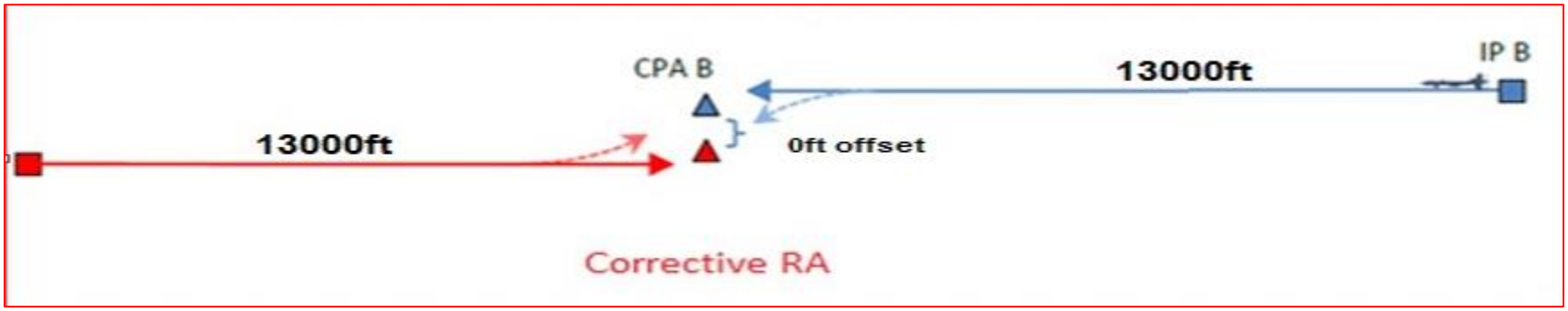
- Horizontal & Vertical Encounters
- 500, 200, 0, -200, -500 feet offsets
- Head On, Crossing, 45, 90, 180 degree.

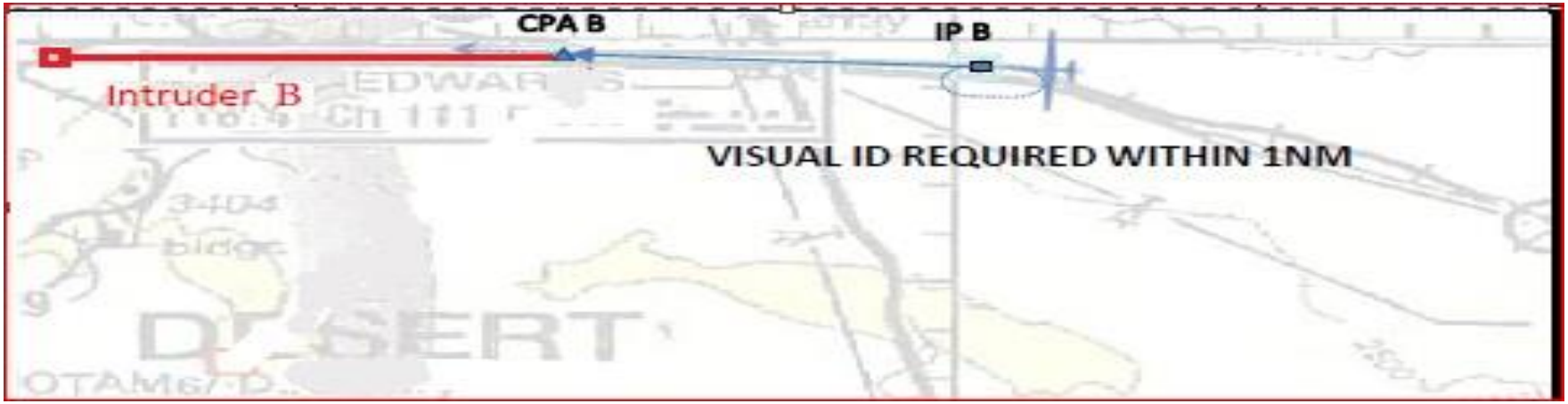




Encounters Geometries Used To Develop and Validate Requirements

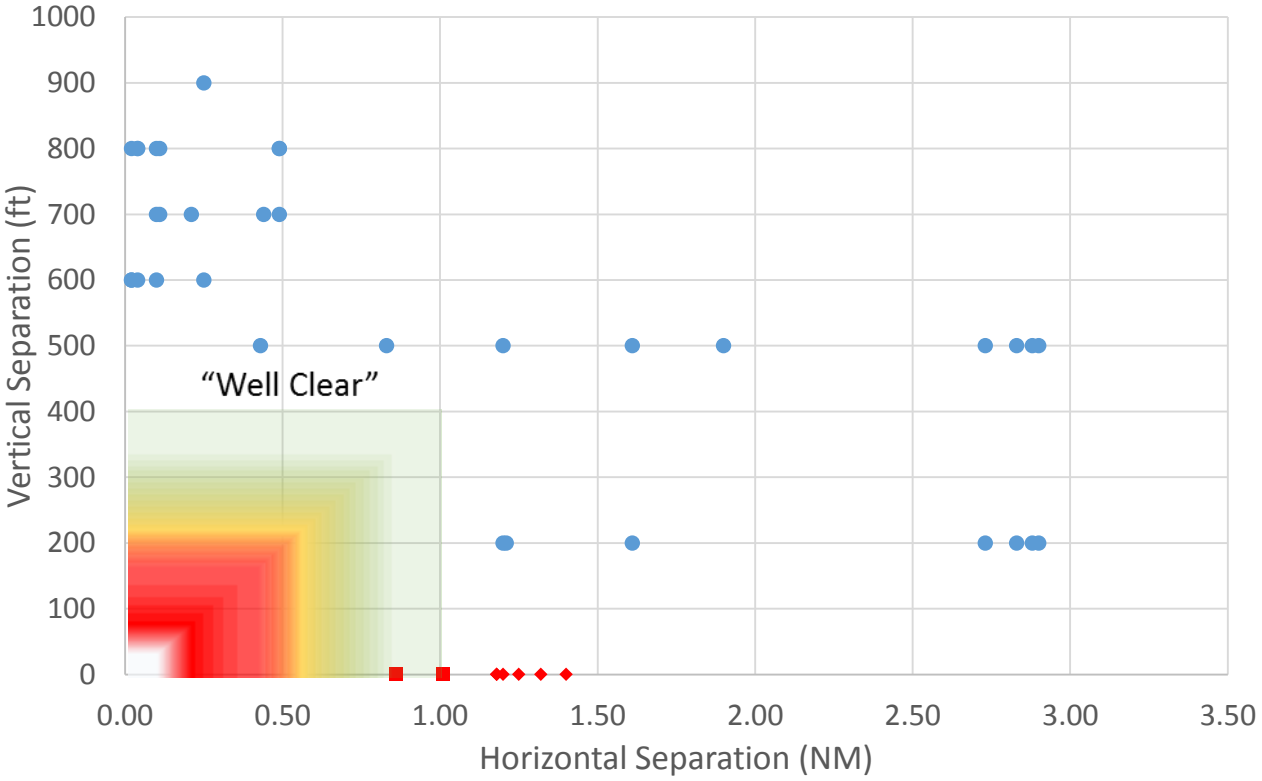
- Horizontal & Vertical Encounters
- 500, 200, 0, -200, -500 feet offsets
- Head On, Crossing, 45, 90 degree.



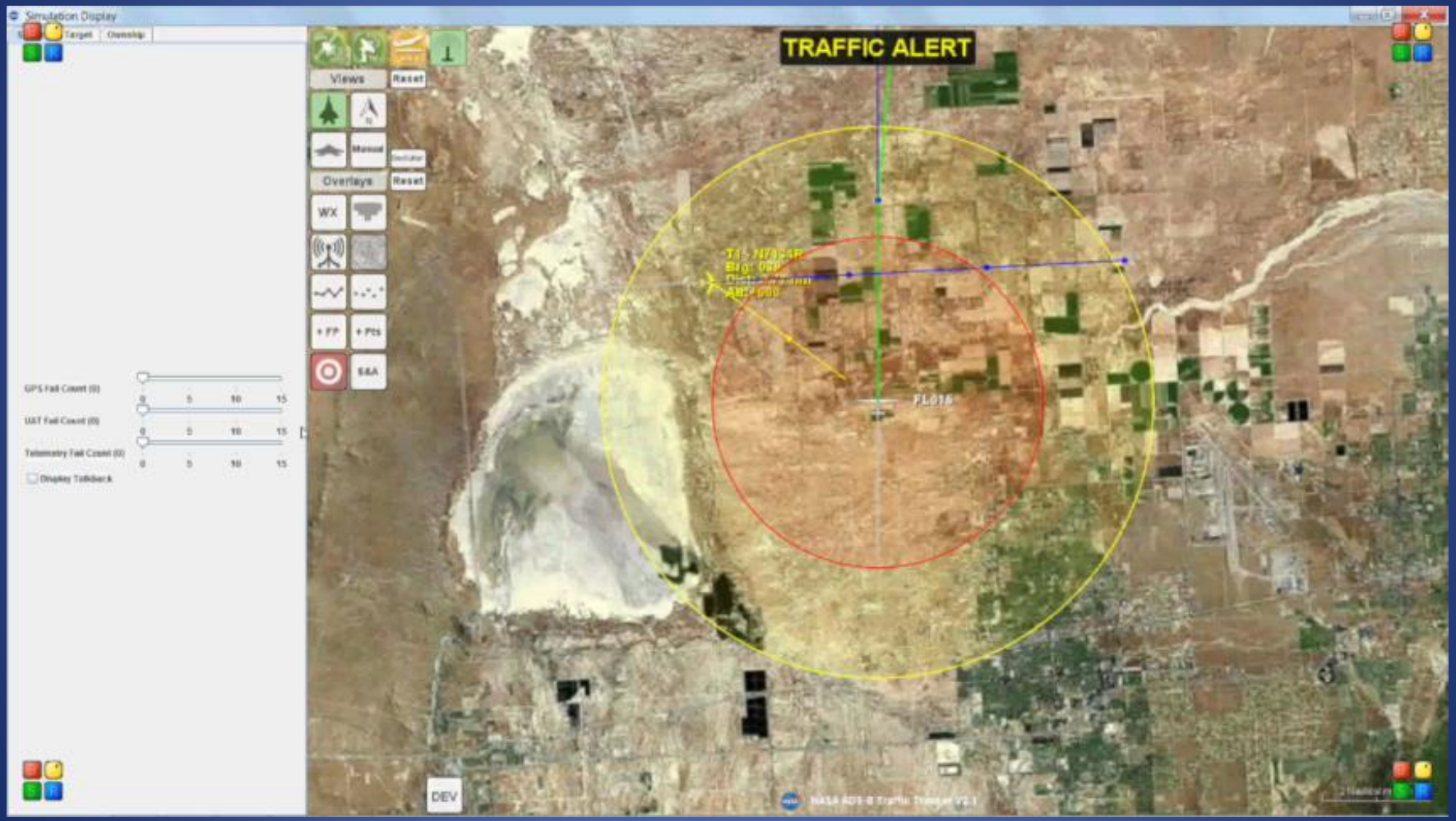


SAA Algorithm Performance

- Vertical Encounters
- Horizontal Encounters
- Multiple Intruders Scenario



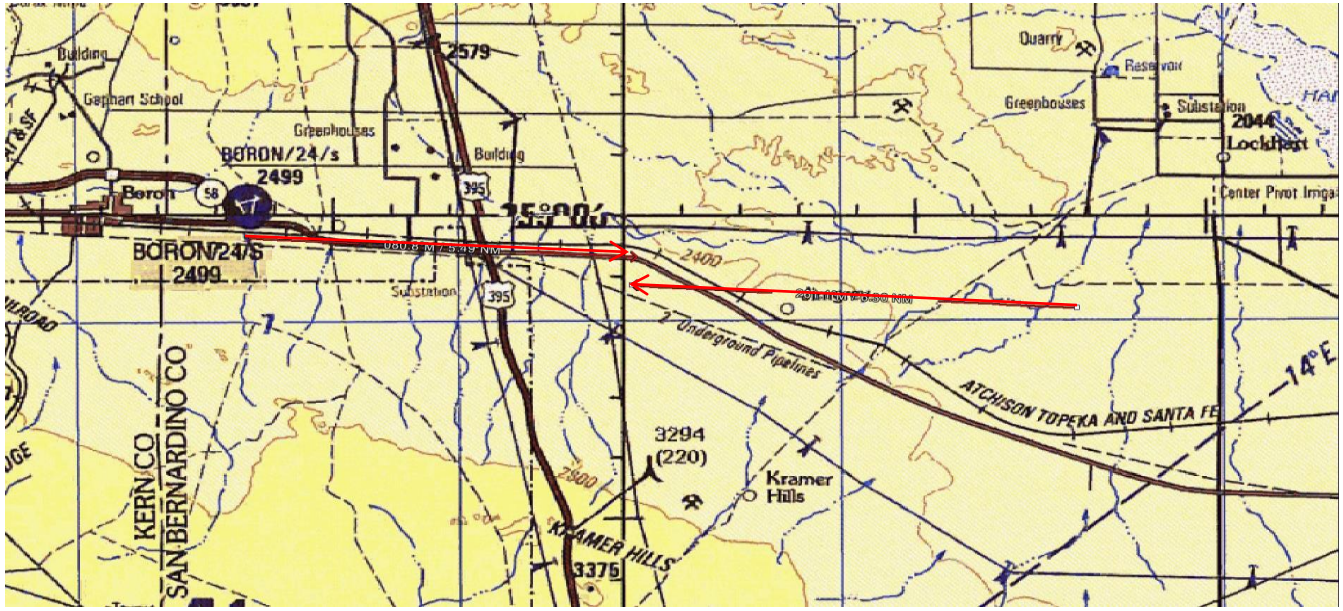
ADS-B Sense and Avoid Simulation



Manned Flight Tests ADS-B SAA

- Test Aircraft (Ownship)

- Intruder



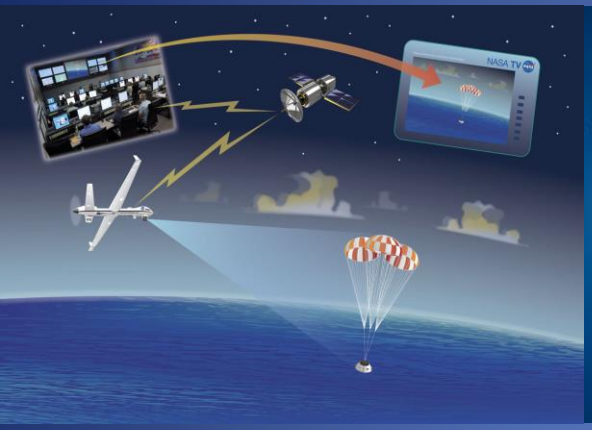
Flight Test Validation

Flight Test Lessons Learned

- Simplify, simplify, simplify, don't try to get it totally right the first time.
- Incrementally integrate the ADS-B Out and ADS-B In capability.
- Pilot Useabilty tests are critical for design of man-machine interface
- Flight tests can be used to validate simulations

Future Applications and Benefits

ADS-B on Space Craft Vehicles



- Complies with FAA certification for ADS-B Out
- ADS-B represents the backbone technology for NextGen.
- Provides re-entry tracking from ground station/UAS for space vehicle recovery

*Commercial Applications both inside and outside NASA: Long Endurance 5 years Commercial space vehicles with ADS-B Systems (*will likely emerge in the next decade).

NASA is a world class leader in cutting edge astronautics technology.

Conclusion

- Research presented demonstrates the ADS-B SAA performance for conflict detection and conflict resolutions for unmanned and manned general aviation using accurate ADS-B velocity state information.
- Vigilant Aerospace Systems, Inc has successfully licensed the NASA ADS-B SAA technology
- NASA will conduct research on a miniaturized radar for detecting uncooperative targets and/or objects.

ADS-B Sense and Avoid System Video

http://www.youtube.com/watch?v=7vUV2VqFw5E&feature=youtu.be

Questions?

Backup Slides

NASA's Successful Flight Tests

- **Various sizes:** Ikhana, DROID, Towed Glider
- **Performance:** 5.7 ft. accuracy (304 ft. mandate)
- **Traffic surveillance:** Up to 17 real-time tracks
- **Record-setting:** First time large UAS had flown with ADS-B

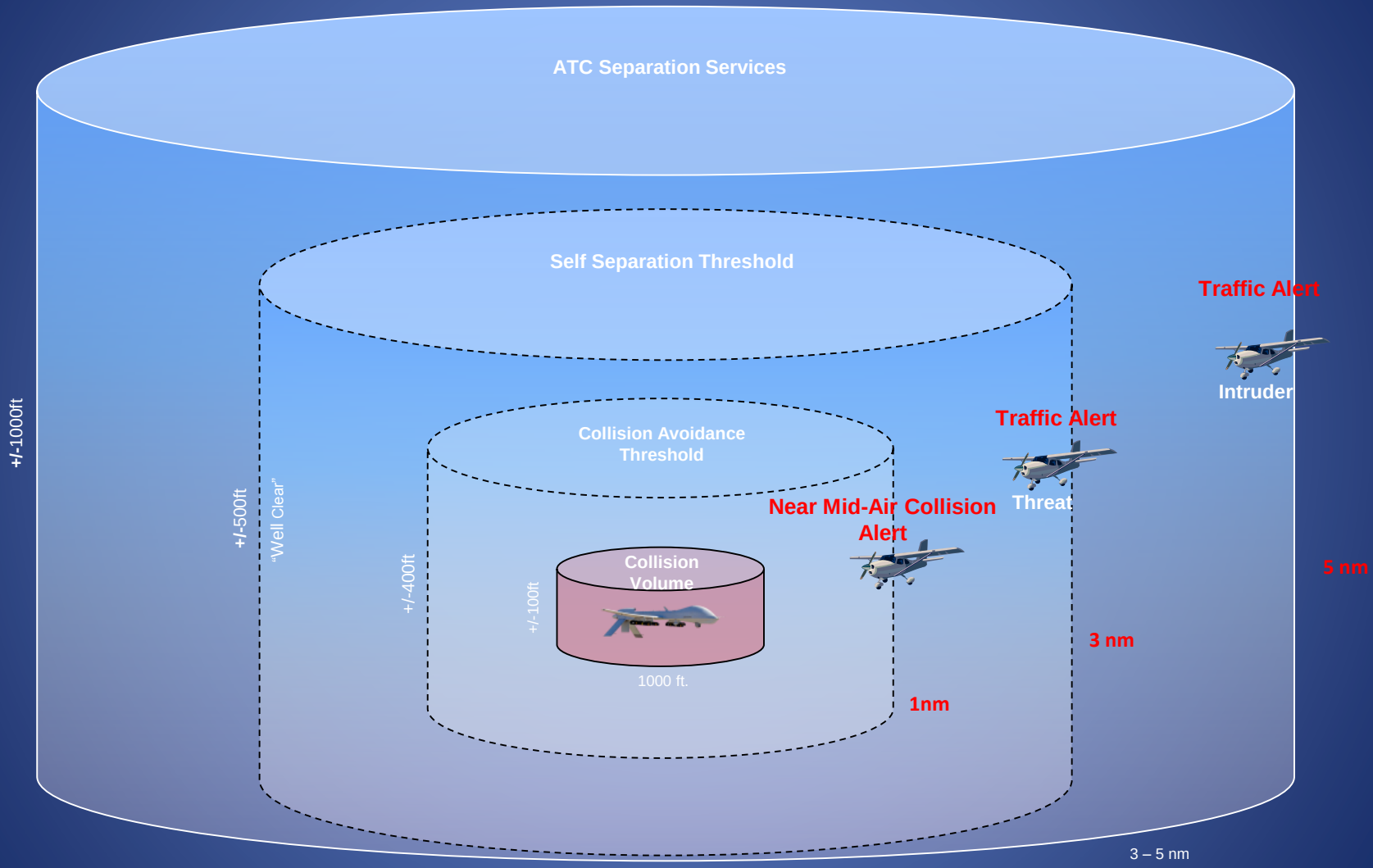
Ikhana

Dryden Remotely Operated Integrated Drone (DROID)

Towed glider

http://www.nasa.gov/centers/armstrong/Features/armstrong_engineers_honored.html, accessed on October 15, 2104

Alerting Logic
RISK Collision Volumes



New Technology

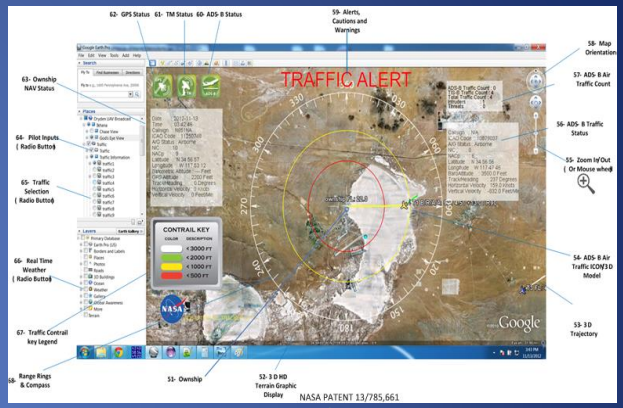
MANNED AIRCRAFT SYSTEMS

National Aeronautics and Space Administration

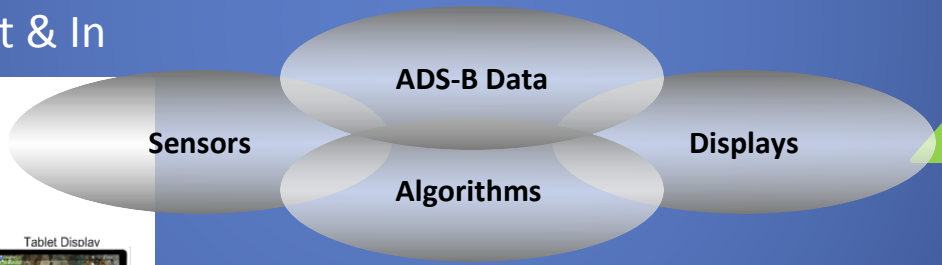
Aircraft

- **Traffic Conflict Detection**
- **Integrated 2D/3D Weather**
- **Integrated 3D Terrain**
- **NASA Dryden developed capability**
- **ADS-B Sense and Avoid**

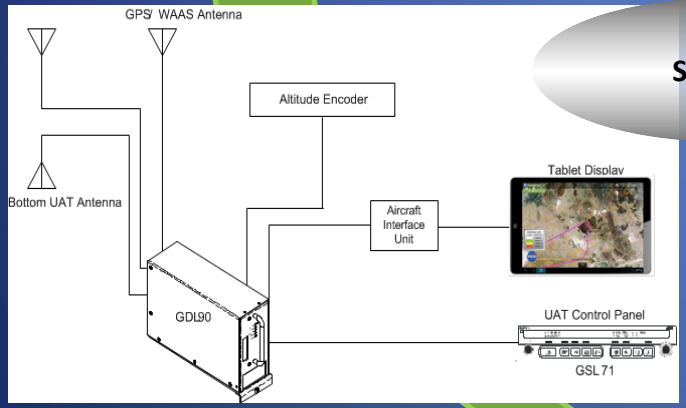
Tablet User Interface



Architecture

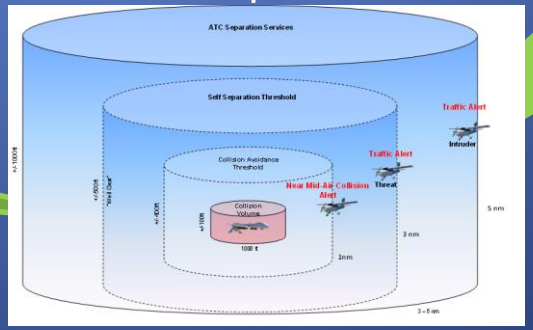


ADS-B Out & In



- ADS-B Out Broadcasts Ownship
- ADS-B In reception of air-to-air ADS-B messages from proximate aircraft and ADS-B In traffic information.

Sense and Avoid Self-Separation



- **Detects intruding aircraft in terms of increasing threat risk**
- **Alerts pilots of potential collisions and provides resolution advisories**

Simulation Scenario Demo

NASA Armstrong Flight Research Center

Small UAS ADS-B Sense and Avoid System for the DROID and Towed Glider

BACKGROUND

Urgent need to **safely** integrate UAS into the National Air Space (NAS), as these systems are less expensive alternatives for:

- Search and rescue missions
- Monitoring forest fires
- Package delivery
- Surveying farmland, borders, and pipelines
- Fire Fighting missions

Dryden
Remotely
Operated
Integrated
Drone

What is ADS-B?

- **ADS-B Out** is the *broadcast* of position information to other aircraft and ground stations.
- **ADS-B In** is the ability to *receive* ADS-B Out transmissions.

Why use ADS-B?

- By 2020, all aircraft flying in transponder airspaces will be required to have ADS-B.
- Provides more reliable tracking of aerial vehicles and increases safety.

OBJECTIVE

- Evaluate SAA Algorithm performance with small and mid-sized UAVs

Towed glider

SYSTEM

ADS-B Hardware

ADS-B Out transponder from Sagetech Corporation

- 3.5 x 1.8 x 0.7 inches
- 100 grams (3.5 ounces)

Sense & Avoid Software and Algorithms

The software package is entirely developed by NASA

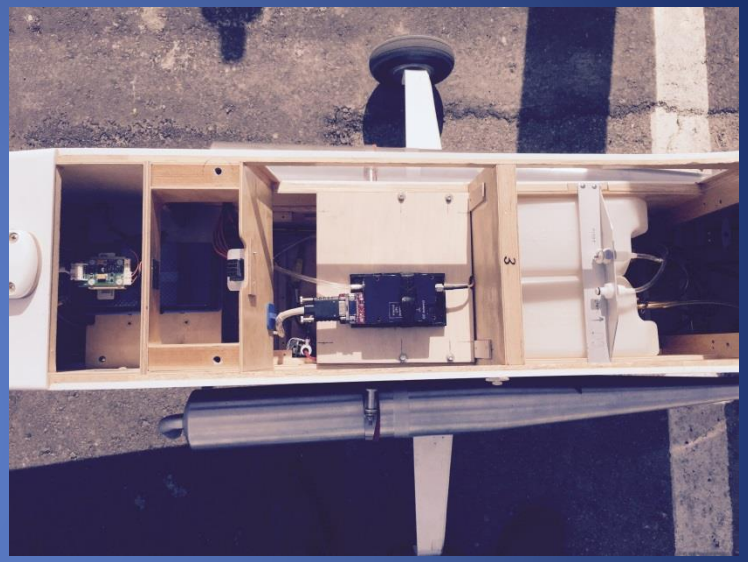
- **World Wind – 3D** Geobrowser
- **Stratway** - Strategic resolutions for aircraft conflicts
- **Sense & Avoid**–Alerts pilot of potential collisions to avoid accidents

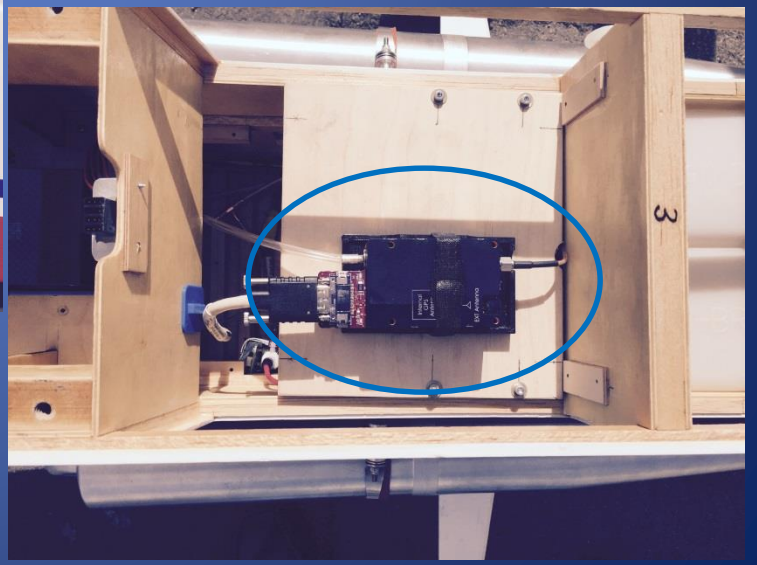
SYNOPSIS

- **Advanced system will be needed to keep drones from colliding with manned aircraft vehicles.**
- Validating the software algorithms with flight experiments to improve safety.
- **This ADS-B Sense and Avoid product is key to safety.**

http://www.nasa.gov/centers/armstrong/Features/armstrong_engineers_honored.html, accessed on October 15, 2104

ADS-B Equipped DRIOD





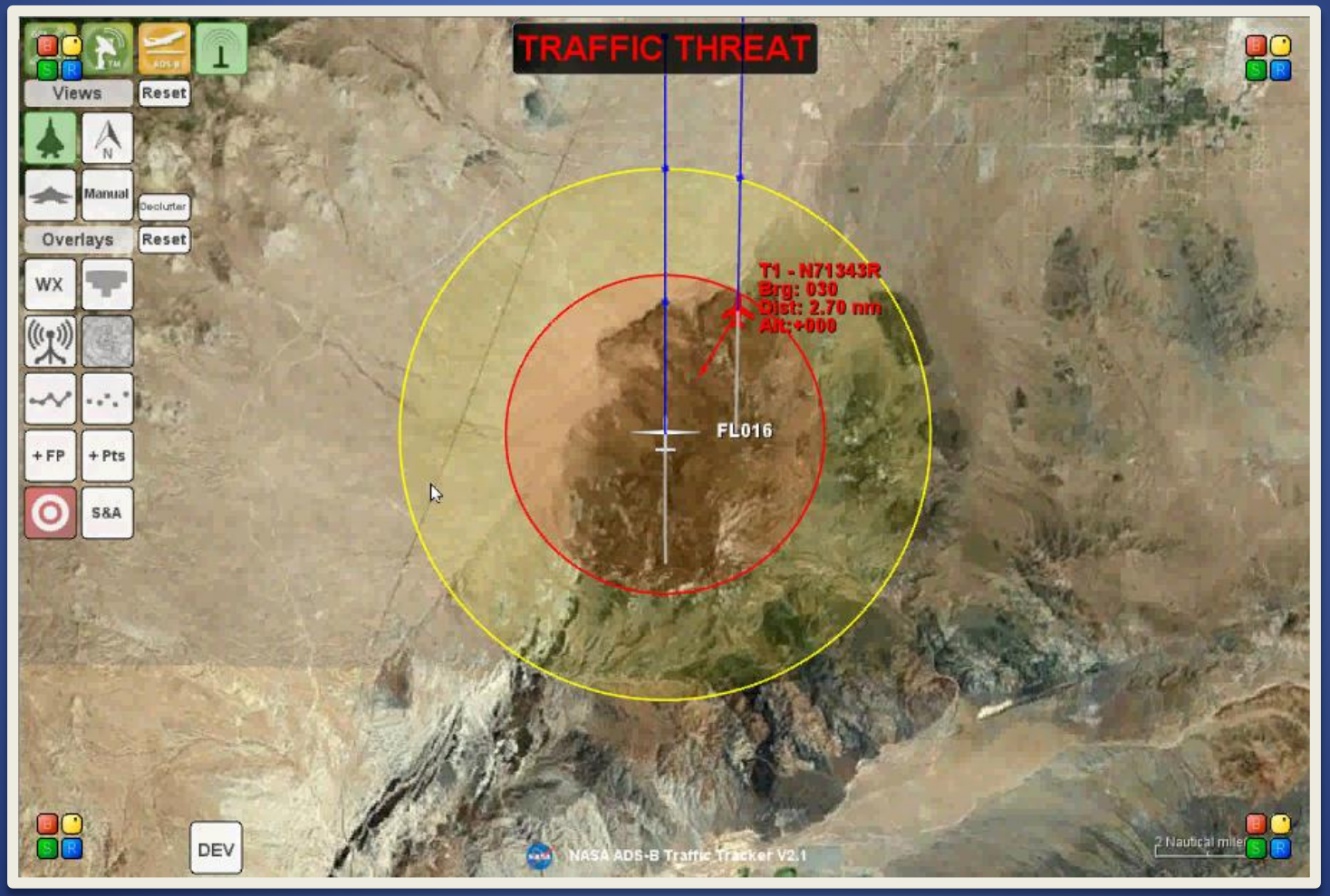
Benefits of NASA's ADS-B Technology

- **Complies with FAA** certification for ADS-B Out
- **Provides backbone** technology for NextGen
  - Tracking UAVs and other aircraft on tablets
- **Increases safety** by ensuring safe separation
  - ADS-B sense-and-avoid capability
- **Increases awareness**, situational and traffic
  - Preeminent attribute for successful UAS operations
- Other technical benefits
  - Provides 3D synthetic views of the UAS
  - Loss link of UAS telemetry uses FAA Tech Center ADS-B data for redundancy

NASA Patent Pending 13/785,661

National Aeronautics and Space Administration

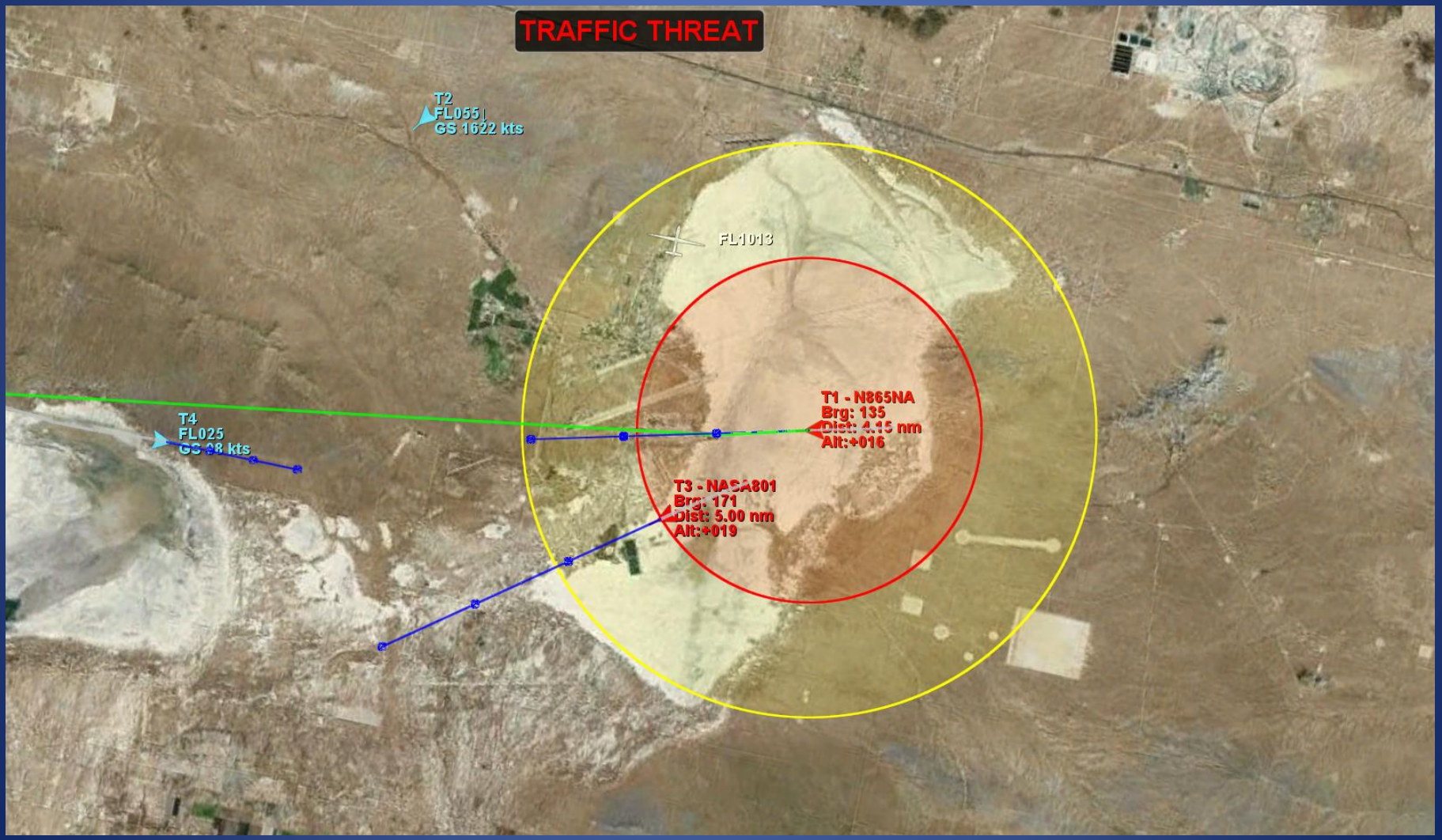
ADS-B SAA Display
Traffic Advisory



National Aeronautics and Space Administration

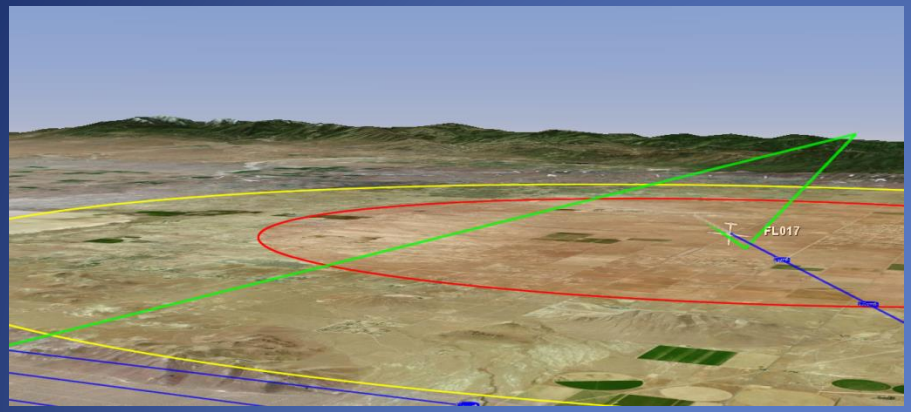
Flight Tests ADS-B Sense and Avoid

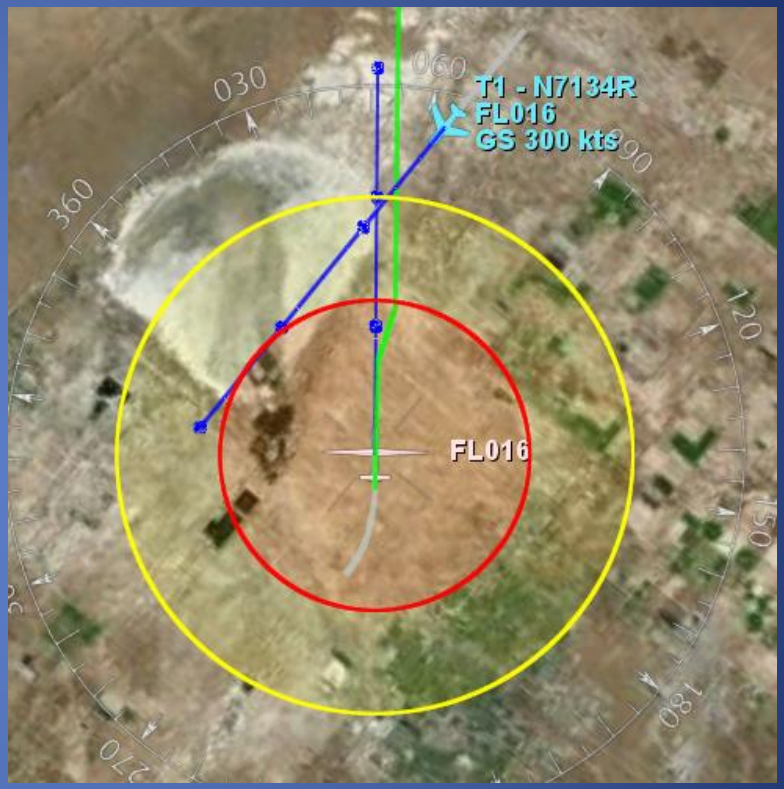
(Green Resolution Advisory)

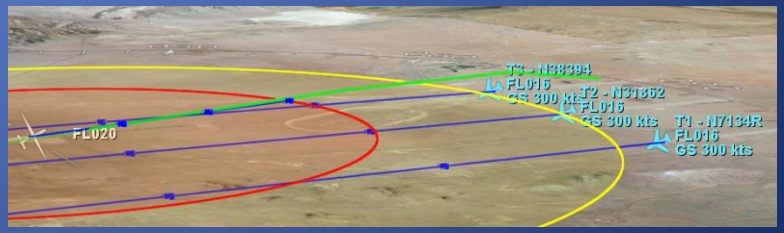


Conflict Detection Resolution Advisory

National Aeronautics and Space Administration

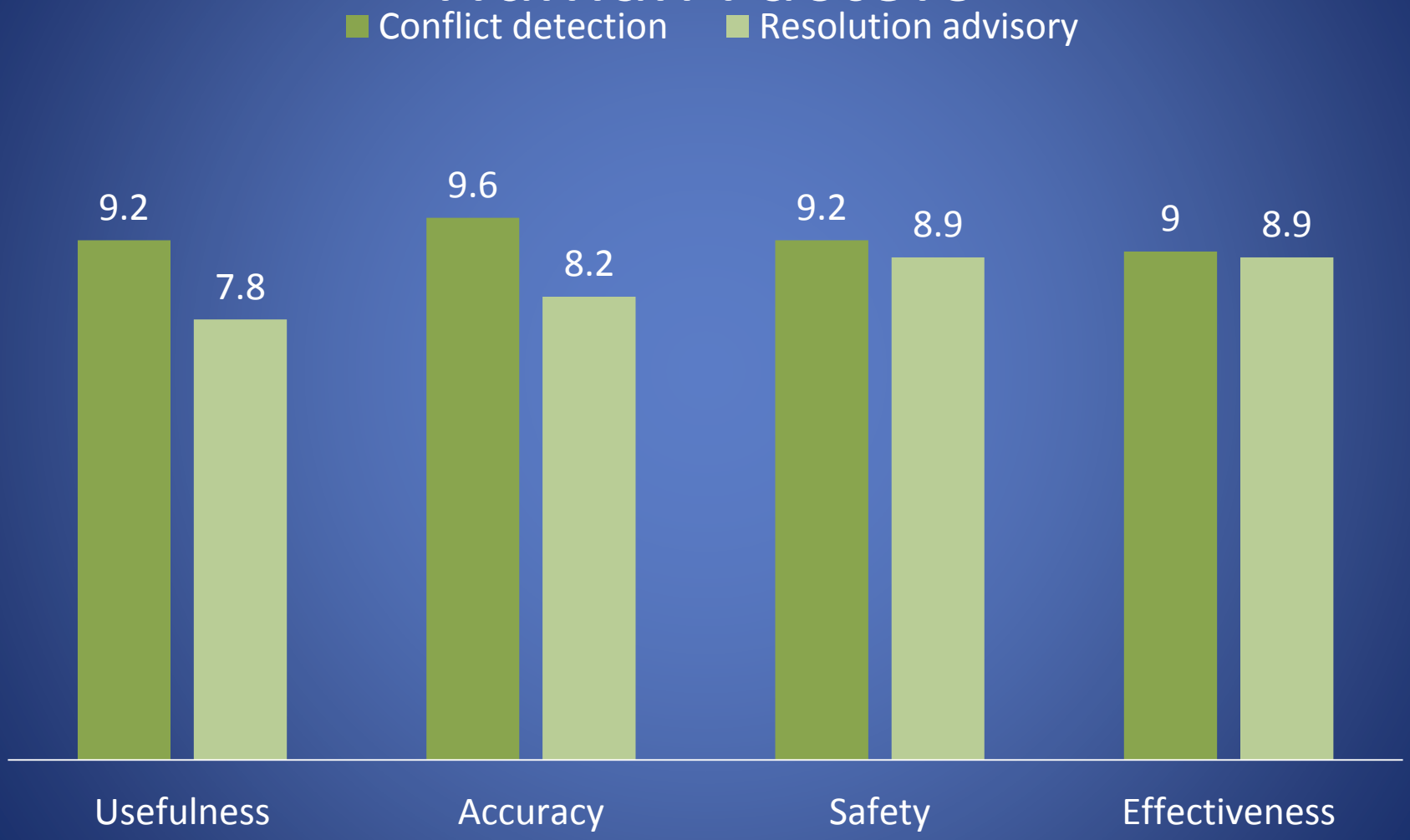






National Aeronautics and Space Administration

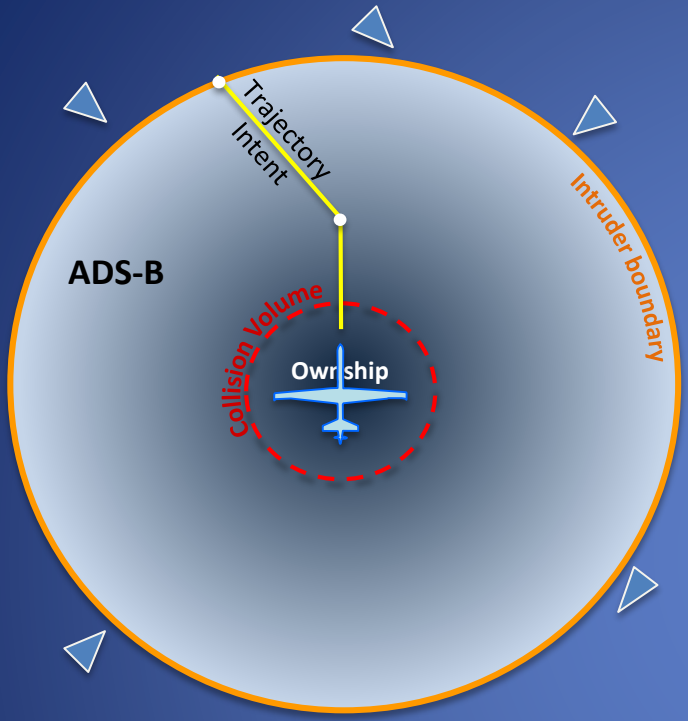
NASA Pilot Usability Tests Human Factors



ADS-B Situational Display
Traffic Alerting

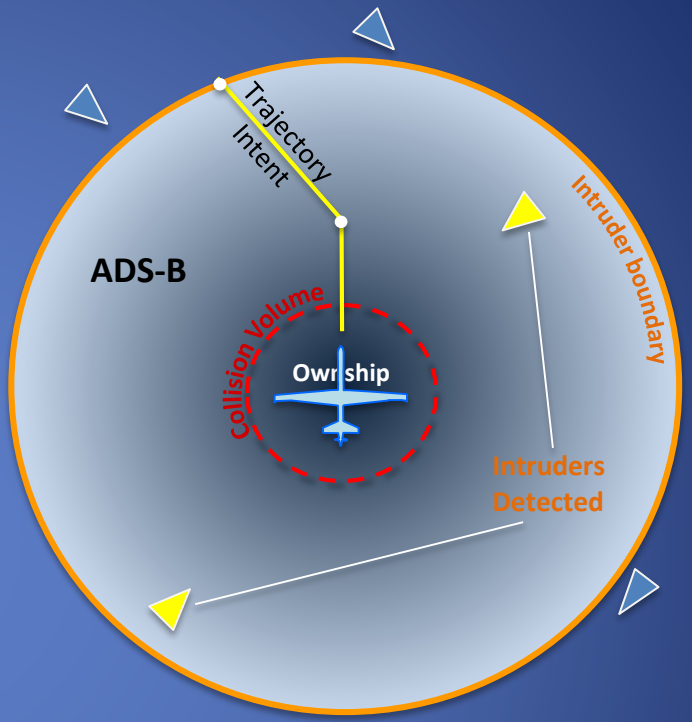
TRAFFIC THREAT INDICATORS

ADS-B Mission Scenarios



"**Baseline" case**: **No intruders**, **conflicts or collisions** detected.

- Nominal UAS Operations

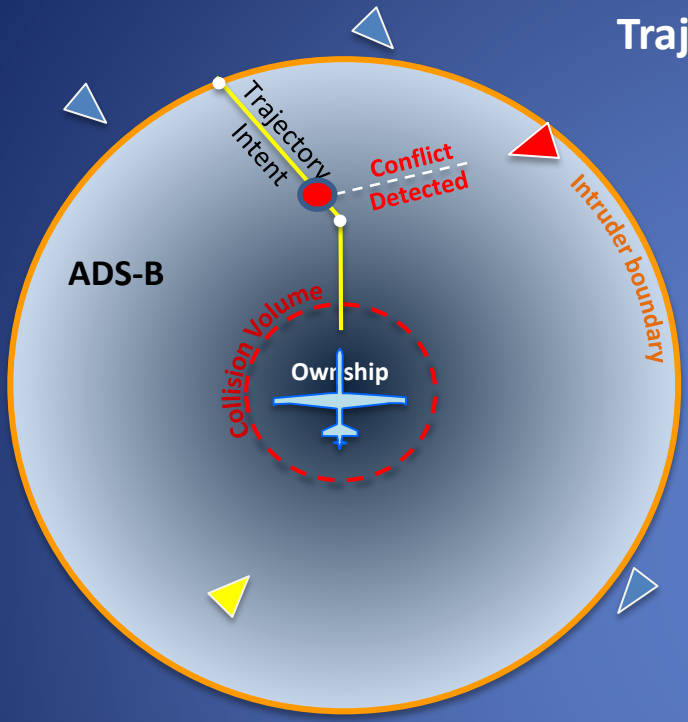


"**Intruder" case**: Traffic A/C crosses **intruder** boundary Traffic Alert

- Loss of Separation

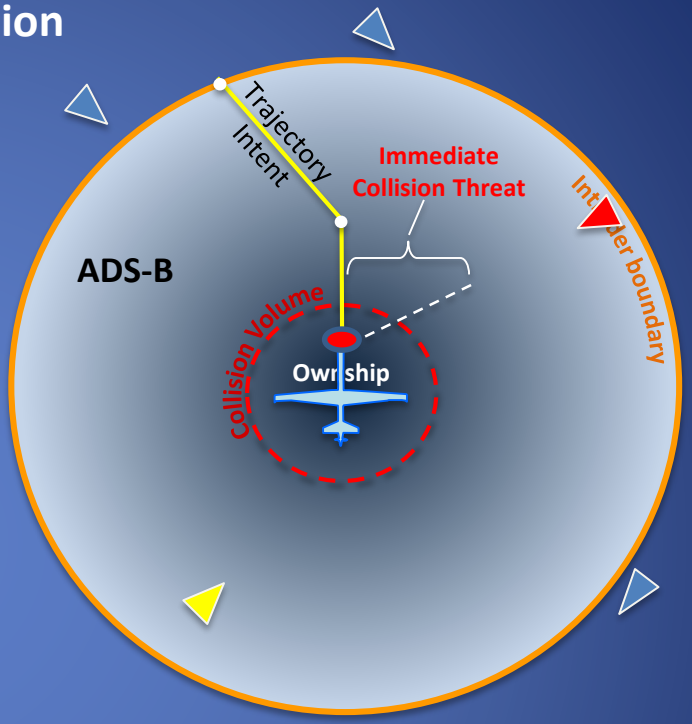
ADS-B Mission Scenarios

Trajectory Estimation



"Conflict" case: Traffic A/C Conflict threat detected.

- Conflict Threat Detection
- Resolution Advisory
- Time to CPA appears at top of the display



"Collision" case: Traffic A/C Collision threat detected.

- Collision Threat Detection
- & Resolution Advisory