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

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AIAA, June 13-17
Washington DC
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 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.

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

UNMANNED ADS-B AIRCRAFT SYSTEMS

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

GPS
C-BAND
LOS Datalink

NASA Patent Pending 13/785,661
Results

ADS-B flight tests on Ikhana UAS

• ADS-B Out: March 2012
  o First time a UAS as large as the MQ-9 had flown equipped with ADS-B

• ADS-B In: May 2012
  o 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
  o Provides 3D synthetic views
  o Loss link of UAS telemetry uses FAA Tech Center ADS-B data for redundancy
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**

- **T1 FL100**
  - Target aircraft transmitting ADS-B

- **Ownship’s resolution advisory**

- **Aircraft’s nominal trajectory**

- **Traffic alert advisory**

- **Traffic threat advisory**
Model Elements Used To Develop and Validate Requirements

- Encounters
  - Correlated
  - Uncorrelated
  - Multi-Intruder-type distribution
  - Scripted stressing scenarios
  - Recorded flight test tracks
  - Run Simulation (NASA)

- Detect
  - Active (Mode S / Mode C Transponders)
  - ADS-B

- Ownship Data
  - UAV

- Tracker
  - Correlation Kalman Filters

- Alerting
  - Must Not Alert
  - Must Alert
  - Horizontal RAs
  - Vertical RAs
  - Speed RAs

- Guidance
  - Stratway +
  - Metrics (CPA, Well Clear, Alerting Time)

- Display
  - NASA ADS-B Display
  - Sense and Avoid

- Aircraft Model/Aircraft
  - NASA (6 DOF)
  - Cessna 172 A/C

- Pilot
  - Pilot Usability
  - Pilot response time
  - Pilot Maneuvers
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

"Well Clear"
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 Useability 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

- 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.

- 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
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

- **ATC Separation Services**
- **Self Separation Threshold**
- **Collision Avoidance Threshold**
- **Collision Volume**
- **Near Mid-Air Collision Alert**

- **Traffic Alert**
- **Intruder**
- **Threat**

- +/-1000 ft
- +/-500 ft
- "Well Clear"
- +/-100 ft
- 1000 ft
- 1 nm
- 3 nm
- 3 – 5 nm
MANNED AIRCRAFT SYSTEMS

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

New Technology

Aircraft

Tablet User Interface

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

ADS-B Data

Sensors

Algorithms

Displays

Sense and Avoid Self-Separation

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.
Simulation Scenario Demo
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

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

Towed glider

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

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.
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
ADS-B SAA Display
Traffic Advisory
Flight Tests ADS-B Sense and Avoid (Green Resolution Advisory)
Conflict Detection
Resolution Advisory
NASA Pilot Usability Tests

**Human Factors**

- **Conflict detection**
- **Resolution advisory**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Conflict Detection</th>
<th>Resolution Advisory</th>
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<tbody>
<tr>
<td>Usefulness</td>
<td>9.2</td>
<td>7.8</td>
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<tr>
<td>Accuracy</td>
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<tr>
<td>Effectiveness</td>
<td>9</td>
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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 Threat Detection
- Resolution Advisory
- Time to CPA appears at top of the display

- **Conflict** case: Traffic A/C Conflict threat detected.

- **Collision** case: Traffic A/C Collision threat detected.

- Collision Threat Detection
- & Resolution Advisory