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

Ricardo Arteaga
NASA Armstrong Flight Research Center
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 View

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

Small UAS (sUAS) Mini-ADS-B Technologies

Mini-ADS-B Technologies

Human Systems Integration

Precision agriculture

Commercial UAS operations

Precision agriculture

UAS Restricted-Use Certification

Sense and Avoid

Communications satellite

Unmanned aircraft

Manned aircraft

Cooperative aircraft

Non cooperative aircraft

Communications

Air traffic services (en route)

Command and Control

Beyond line-of-sight link

Line-of-sight link

UAS ground control station

Research ground control station

FAA ITT Network

Air traffic services (terminal)

Small UAS (sUAS)

UAS Civil
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

C-BAND

LOS Datalink

GPS

GCS

ADS-B Ground Station

NASA Patent Pending 13/785,661
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**
**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**
  - Ownship Data
    - UAV
  - Active (Mode S /
    Mode C
    Transponders)
  - ADS-B

- **Tracker**
  - Correlation
Kalman Filters

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

- **Display**
  - NASA ADS-B Display
  Sense and Aviod

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

- **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

COLLISION POSSIBLE 10s

NASA ADS-B Traffic Tracker V2.1
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
ADS-B on Space Craft Vehicles

Future Applications and Benefits

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.
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

http://www.nasa.gov/centers/armstrong/Features/armstrong_engineers_honored.html, accessed on October 15, 2104
Alerting Logic
RISK Collision Volumes

- **Collision Avoidance Threshold**: +/- 1000 ft
- **Self Separation Threshold**: +/- 500 ft
- **ATC Separation Services**: "Well Clear"
- **Traffic Alert Near Mid-Air Collision Alert**: +/- 500 ft, +/- 400 ft
- **Collision Volume**: 1000 ft
- **Near Mid-Air Collision Alert**: 1 nm
- **Traffic Alert**: 3 nm
- **Intruder**: 3 - 5 nm

[Diagram showing various alerting thresholds and volumes with aircraft symbols]
MANNED AIRCRAFT SYSTEMS

Tablet User Interface

New Technology
Aircraft

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

ADS-B Out & In

Architecture

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

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
- Surveying farmland, borders, and pipelines
- Fire Fighting missions

**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

**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
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

<table>
<thead>
<tr>
<th></th>
<th>Conflict detection</th>
<th>Resolution advisory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usefulness</td>
<td>9.2</td>
<td>7.8</td>
</tr>
<tr>
<td>Accuracy</td>
<td>9.6</td>
<td>8.2</td>
</tr>
<tr>
<td>Safety</td>
<td>9.2</td>
<td>8.9</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>9</td>
<td>8.9</td>
</tr>
</tbody>
</table>
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
“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