

# Aircraft Automatic Dependent Surveillance – Broadcast (ADS-B) Verification and Validation

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## I. Extended Abstract

AIRCRAFT-based Automatic Dependent Surveillance – Broadcast (ADS-B) promises to provide significant operational enhancements to military and civilian applications: a greater degree of surveillance accuracy, improved situational awareness, shared separation responsibility (at far greater range than Traffic Alert and Collision Avoidance System (TCAS)), more accurate parallel landings, and better surface surveillance – these ultimately will lead to increased safety and capacity in the National Airspace System (NAS).

However, as currently designed, ADS-B will not necessarily provide guaranteed, uninterrupted state and intent data from aircraft equipped with ADS-B transponders. Data dropouts, erroneous inputs, and even deception (spoofing and potential terrorist corruption) may degrade data integrity. In civilian applications, traditional Secondary Surveillance Radar (SSR) obtains aircraft information through a rotating radar that interrogates aircraft transponders. In the terminal area around an airport, update rates of once per four to five seconds are typical, and in en route airspace the update rate is once per twelve seconds. However, not all airspace in the NAS is covered by SSR. Mountainous regions and remote regions (e.g., Alaska) are not well covered, and in these areas, ADS-B will likely be the sole source of surveillance information. Thus, we cannot assume that SSR will always be available to verify ADS-B signals. This paper investigates a verification technique which is intended for airborne use and is independent of a secondary source of tracking information.

The first part of the ADS-B Verification and Validation (V&V) is to receive ADS-B data and process the aircraft state variables into continuous real-time signals that describe the motion of the aircraft. This involves several steps:

- Unwrapping Data – Certain ADS-B data elements will make discontinuous jumps. For instance, headings that instantaneously change from 0 to 360 degrees.
- Units Conversions – ADS-B data is converted to a consistent set of units for reasoning about all the state and intent variables as a set of logically related variables.
- Bad Data Flagging – A flag is set for data that exceeds a bound on the state or derivative of a variable. If the state value or derivative value exceeds the bounds, the flag is set and the data will be ignored by Kalman filters.
- Missing Data Identification – Data dropouts, regardless of cause, are identified when the time stamp on ADS-B inputs do not follow the nominal one second update.

ADS-B signal receiver antenna attributes are then compared to the ADS-B datagram Kalman Filter results to validate that the antenna data matches the ADS-B datagram content. Only the true ADS-B signal will have ADS-B antenna properties that match the ADS-B Target State (TS) Report content. To make the comparison, a bearing only tracking system processes the ADS-B antenna signal properties. This tracker takes into account any motion of the ADS-B sender and ADS-B receiver (e.g., airborne vs. ground-based receiver). These results are compared to the Kalman filter tracking results based on the ADS-B TS Report content. If there is a match, then we validate the signal, with certain levels of confidence that are a function of the match. Note: Even if the ADS-B TS Report has bad data points, we can perform this validation function based on Kalman Filter estimates of the current aircraft state data given the historical data collected for the aircraft being tracked.

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The intent of the aircraft is revealed in the ADS-B Trajectory Change (TC) Report. The Trajectory Change Point (TCP) is described in terms of horizontal, vertical, and speed (time) dimensions. The purpose of Intent Verification is to determine if the aircraft is flying to the TCP within the Required Navigation Performance (RNP). To perform Intent Verification, we define correlation functions as mathematical tools. Then, Geometric Conformance (the aircraft is geometrically within the RNP) and Intent Conformance (the aircraft exhibits the intent to achieve the TCP) are introduced to perform Intent Verification utilizing the correlation functions.

A novel part of this new technology is a theory for Intent Inference which attempts to explain why the aircraft may be outside the RNP but potentially following the appropriate intent. Intent inference is used to validate the ADS-B TC Report intent information. To accomplish this task, several intent models are explored in conjunction with test Scenarios. The following intent models have been developed:

- Verify that the pilot is flying the filed flight plan horizontal profile, vertical profile, and speed profile (TCPs in the ADS-B data)

And if the verification fails, our algorithms try to explain why; our intent inference algorithms:

- Hypothesize and verify if the pilot is apparently skipping one or more TCPs (e.g., a direct-to)
- Hypothesize and verify if the pilot is flying directly towards an airport (destination, alternate, or nearest airport from an airport database)
- Hypothesize and verify if the pilot is avoiding a known SUA or deviating around a weather cell - requires access to an SUA database or weather data input (e.g., Flight Information Service (FIS) or onboard weather radar)
- Hypothesize and verify if the pilot is avoiding a conflict with a second aircraft
- Hypothesize and verify if the pilot is blundering

The end result of the intent inference process is a confidence value in the geometric conformance and intent conformance of the aircraft. The algorithm reasons about how long the pilot has been consistently following the same intent, and if that intent is has been consistently validated. The confidence builds up monotonically as the total number of consistently validated ADS-B broadcasts grow. Further research is currently being performed to establish how to combine the geometric conformance and intent conformance into a final V&V “certification” for an ADS-B signal.

## II. Biographies

**Jimmy Krozel** is the Chief Scientist in the Research and Development Division at Metron Aviation. Jimmy Krozel received an AS (1984, Computer Science), BS (1985, Aeronautical Engineering), MS (1988, Aeronautical Engineering), and Ph.D. (1992, Aeronautical Engineering) from Purdue University. Krozel was a Howard Hughes Doctoral Fellow (1987-1992) while at the Hughes Research Labs (1987-1992). Dr. Krozel has over 40 technical publications, and is the winner of two AIAA best paper awards. His research interests include computational geometry, computer graphics, visualization, air traffic management, air traffic control, intelligent path prediction, intent inference, and autonomous vehicles. Dr. Krozel is an Associate fellow of the AIAA.

**Dominick Andrisani, II** is an Associate Professor in the School of Aeronautics and Astronautics at Purdue University. Dominick Andrisani received a B.S. (Aeronautical Engineering, 1970) from Rensselaer Polytechnic Institute, M.S. (Electrical Engineering, 1975) State University of New York at Buffalo, and Ph.D. (Electrical Engineering, 1979) State University of New York at Buffalo. Dr. Andrisani has worked at NASA Langley Research Center (1970-1972) and at Calspan Advanced Technology Center (1972-1980). He has been at Purdue University since 1980. His technical specialization is in the area of flight dynamics and control of aircraft, including estimation and prediction of aircraft trajectories. He current research interests include targeting and navigation systems for un-piloted aerial vehicles, the use of Kalman filtering to construct integrated aircraft navigation systems using both inertial instruments and GPS satellites, and intelligent tracking systems – systems that include vision and/or domain knowledge to improve tracking performance. He is an expert in the fields of modern state estimation and system identification. Prof. Andrisani is a member of the AIAA.

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