International Civil Aviation Organization
Asia and Pacific Office

GUIDANCE MATERIAL
ON ISSUES TO BE CONSIDERED IN
ATC MULTI-SENSOR FUSION PROCESSING
INCLUDING THE INTEGRATION OF ADS-B DATA

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1 Introduction

Modern air traffic control systems use multi-sensor fusion processes to improve the quality of surveillance track data provided to air traffic controllers. This is the latest step in a series of evolutionary improvements to ATC surveillance systems, each offering performance benefits over previous systems.

The original surveillance systems presentations were limited to only displaying a single radar per controller's screen.

Radar mosaic displays provided the first advance on single radar displays. The coverage presented to a controller was divided into "sort boxes", and data from one radar could be displayed in some areas ("boxes"), and data from other radars displayed in other areas, each radar selected for best detection in a given area. Mosaic display systems are generally limited to displaying data from a single "preferred" radar per "sort box".

Multi-radar fusion processing provides an advance on mosaic processing by fusing the detections of multiple radars in areas of overlapping coverage, improving the probability of detection and the tracking of manoeuvring aircraft. Multi-radar fusion processing is a well established process, but is usually limited to integrating the outputs from similar radars that have overlapping coverage.

Multi-sensor fusion provides a further advance on multi-radar fusion by integrating data from a multiplicity of sensors to form a single track for each aircraft. A multi-sensor fusion processor may form a surveillance track using inputs from any or all of the following sensors:

- Primary radars
- Mode A/C SSRs using sliding window processing
- Mode A/C SSRs using monopulse processing
- Mode S SSRs
- Mode S SSRs with DAPS (downlinks of aircraft parameters)
- Wide Area Multilateration systems
- ADS-B receivers

Each of these sensors has different attributes, and a well designed multi-sensor fusion processor will take advantage of the strengths of each sensor, and use these to compensate where possible for the weaknesses of other sensors. It is important to note that some of the measures taken to mitigate the weaknesses of traditional radar sensors should not be applied to data from newer data sources (such as ADS-B) if those weaknesses are no longer a characteristic of the new data. Rather, the processing of each type of data in a multi-sensor fusion algorithm should be adapted to make best use of the actual performance of each of the data sources. Factors to be considered include accuracy, update rates, integrity (probability of false data), and amount of data provided (ie in addition to position, other aircraft information such as aircraft address, flight ID, vertical and horizontal velocities, bank angle, on ground or not, cleared flight level entered into the aircraft FMS, etc may be provided by some sensors, and these items should be used where they can improve performance).

2. Characteristics of Different Sensors

A high level summary of some of the key characteristics of the different sensor types listed above is provided at Attachment 1. The following figures provide examples of accuracy and update characteristics from different sources, and the impact they can have on multi-sensor fusion tracking.

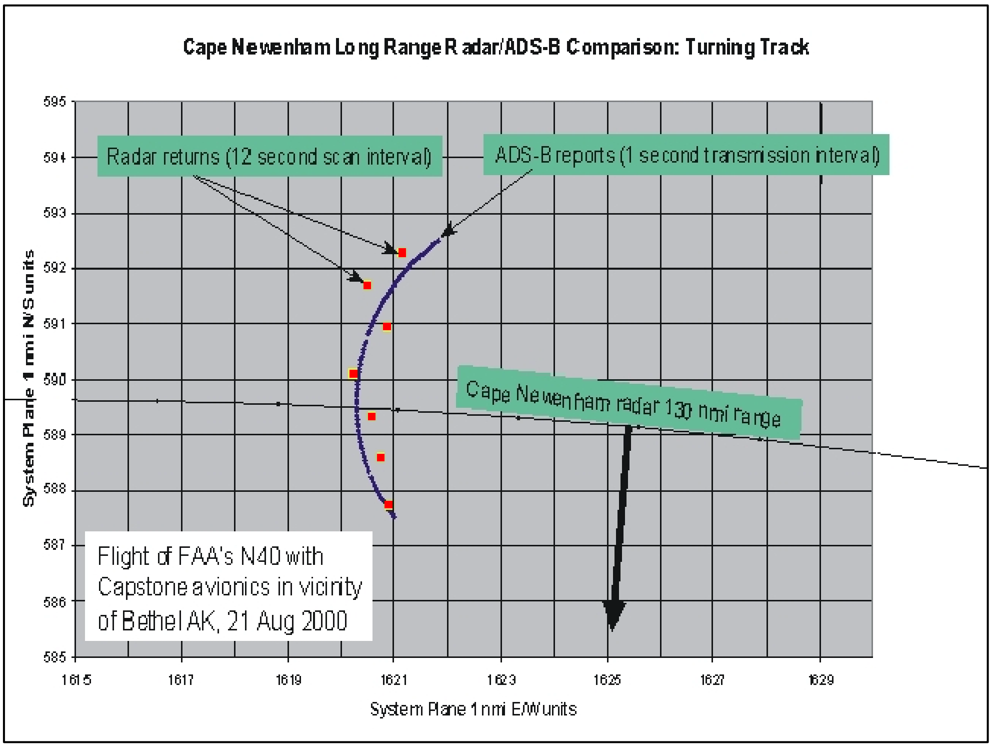

Figure 1 – Alaska: ADS-B and Radar position reports *(FAA)*

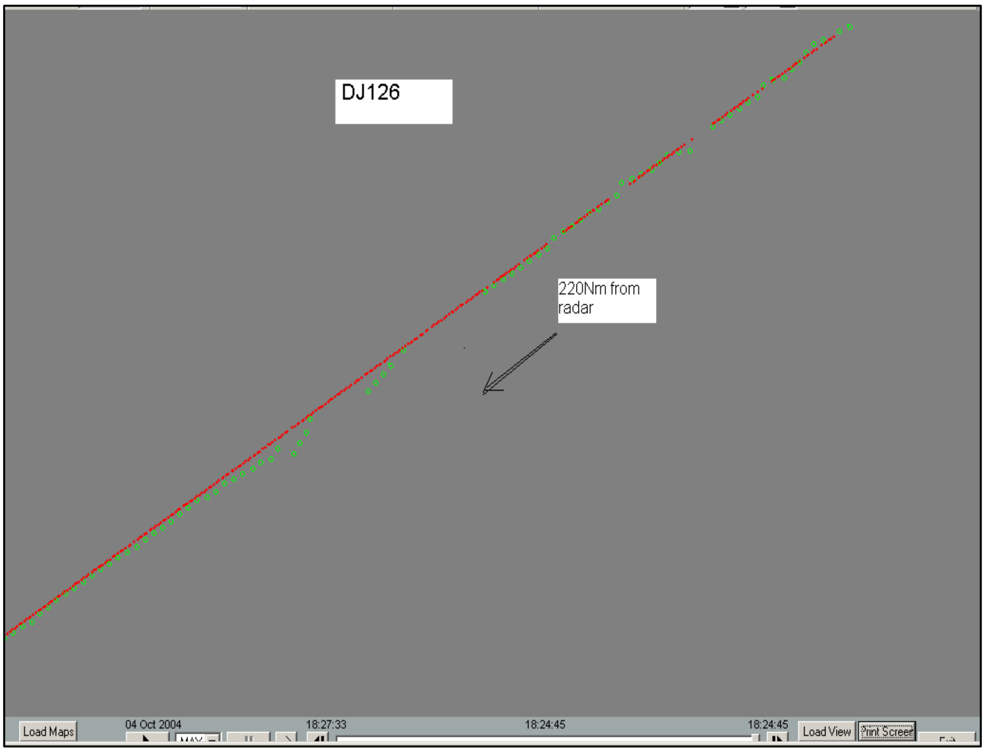

Figure 2 – Australia: ADS-B (red) and Monopulse SSR (green) *(Airservices Australia)*

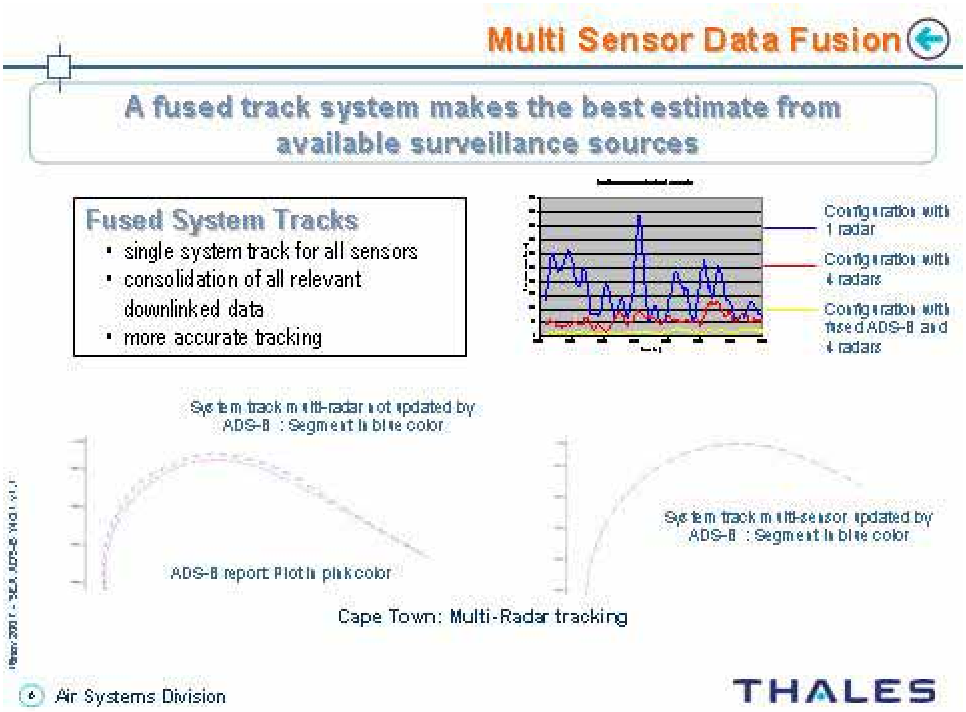

Figure 3 – Analysis of Multisensor Data Fusion with ADS-B *(Thales ATM)*

Figures 1 and 2 provide examples where the position accuracy of ADS-B is clearly much better than that of the radars at the radar ranges indicated. In addition, the update rate of the ADS-B data is much higher (once per second compared to once every 5 or 12 seconds). Both of these factors contribute to improved performance. Radar measurements that exhibit high position noise must be damped to mitigate against false couplings with position reports from other aircraft, and to achieve moderate stability of velocity vectors. While this damping improves tracking for straight line flights, the penalty of damping is overshoot position errors during manoeuvres. The improved accuracy of ADS-B data means there is little if any need for damping. Furthermore, for a given level of damping the overshoot errors tend to increase as the square of the time between updates, and so the higher update rate of ADS-B data significantly reduces the impact of any small amounts of damping that may be applied to this data. In Figure 3 the red line on the graph also shows the improvement from fusion of data from four overlapping radars, which the effect of increasing the average update rate for radar data, but the yellow line shows that the integration of ADS-B data further reduces position errors by a significant amount.

3 Issues to be considered in ATC multi-sensor fusion processing

Many different approaches are possible in the design of multi-sensor fusion surveillance systems suitable for air traffic control. The following paragraphs describe some of the issues to be considered when designing such a system, and the performance that can be expected from ADS-B in these areas.

3.1 Filtering of anomalous data

All of the sensor types listed above have the potential to generate anomalous reports, and the processing system needs to have the capability to filter out this data. Often this is undertaken in a two step process, with a first pre-processing filter at the sensor processing level, and a second filtering at the multi-sensor processing level.

Primary radars detect many objects which are not aircraft, such as road vehicles, weather cells, ground clutter and birds. If the radar is a combined primary and SSR system, then those primary radar detections that correlate in position with an SSR report can be given added credence in a sensor pre-processing filtering process. At this level some form of scan to scan surveillance processing or track formation is carried out, to filter out reports that do not show a scan to scan position movement consistent with aircraft performance parameters. However, even after pre-processing at the sensor, primary radars will output reports that are not from aircraft.

SSR systems require a transponder on each aircraft, and therefore do not generate the sort of anomalous reports that can occur with primary radars. However, SSR systems generate other forms of anomalous reports, such as those caused by reflections, mutual interference (garbling) and poor signal to noise ratios. SSR signals may be reflected off structures such as hangars and terminal buildings to create erroneous reports with incorrect azimuth and range. Some form of surveillance processing at the sensor is normally applied to try to filter out SSR reflection plots, but this is not always totally successful. Garbling occurs when the signals from two or more aircraft interfere with each other in the receiver. Garbling can cause loss of detection, corrupted Mode A (identity) and Mode C (pressure altitude) data, and azimuth shifts. SSR Mode A/C systems that use monopulse signal processing are less prone to losses of detection and azimuth shifts when replies from two aircraft partially overlap in azimuth. Weak signals (usually at longer ranges) can also lead to corrupted Mode A and C data, where receiver noise can corrupt the data detection process. Data from a Mode A/C SSR system does not have any form of error checking, making corrupted data difficult to detect.

SSR Mode S was developed to overcome the SSR garbling problem. Each aircraft is allocated a unique 24 bit address, which is used to selectively interrogate that aircraft. Only the aircraft with the specified address reply, eliminating garbling. False plots due to reflections are largely eliminated also, because on acquisition the Mode S ground station has to work out which replies are the correct ones, and thereafter it will only schedule selective interrogations on that azimuth, and not on the false reflective path azimuths. Incorrect decoding of data by a receiver is still possible when signal to noise ratios are poor, but SSR Mode S data includes a rigorous error detection and correction check sum generated in the aircraft that not detects virtually all errors, but also allows many to be corrected. In general the amount of anomalous data from SSR Mode S sensors is much reduced compared to previous SSR systems. SSR Mode S also allows an aircraft to downlink a number of aircraft parameters (referred to as DAPS), and this data can be used to improve the multi-sensor processing.

A Wide Area Multilateration (WAM) system requires transmissions from an aircraft to be received at a number of geographically dispersed receiving sites. The position accuracy of WAM reports is highly dependent on the geometry of the receiving sites relative to the position of the aircraft (meaning that accuracy for an aircraft in one position may be quite different to that for an aircraft in another position). It is important that the accuracy of WAM data is known to any multi-sensor fusion process. Wide Area Multilateration can operate by processing squitter signals from SSR Mode transponders (including Mode S Extended Squitter ADS-B signals), or by processing reply signals generated from any transponders in response to interrogations from other sources (TCAS on other aircraft, or ground based interrogators). In general, when processing signals from Mode A/C transponders a WAM system can suffer from garbling similar to SSR, but when processing signals from Mode S transponders the improvements in data integrity of SSR Mode S are obtained.

ADS-B data uses the SSR Mode S error detecting and correcting communication protocols to ensure that the data received from an aircraft has not been corrupted. Occasional garbling of ADS-B signals can occur if signals from two aircraft arrive at a receiver at the same time, but this is infrequent due to the pseudo random timing of ADS-B transmissions. It may result in the loss of one report, but is extremely unlikely to create an erroneous report. Given the high rate of transmissions, a new report is likely within a second, making the occasional loss of a report much less significant to the multi-sensor fusion process than the loss of a report from any of the radar sensors. Position determination is carried out by the aircraft avionics system, and the accuracy and integrity of this position determination is included in the data transmitted by the aircraft (parameters such as NUC for equipment certified to DO260, and NIC, NAC and SIL for equipment certified to DO260A). **It is critically important that this aircraft generated position accuracy and integrity information is taken into account when integrating ADS-B data into an ATC multi-sensor processing system.** For example, reports with low NUC values (such as 0,1,2 or 3) will often be discarded as inadequate to support an ATC application. For an airport surface surveillance separation application the threshold is likely to be set much higher whereas for an airport surface surveillance advisory service it may be less stringent. There is a possibility that faulty position determining equipment on an aircraft could generate anomalous position reports but mark these as high accuracy and integrity, although the probability of this occurring is considered extremely low. To detect and eliminate these spurious reports, some form of basic surveillance processing is recommended, such as a ‘reasonableness check’ on distance traveled between subsequent reports. For example, it is not ‘reasonable’ for an aircraft to appear to have travelled 25 miles in the half or one second interval between two ADS-B messages.

3.2 Integrating Data from Different Sensors in the Multi- Sensor Fusion Process

The multi-sensor fusion process needs to be adapted to make best use of the performance characteristics of each of the contributing sensor systems.

Mapping to common datum, the process which converts the various sensor reports to a common datum. Uncertainties can be created in conversion of radar data (based on slant range measurements) to a geographic reference without accurate altitude information. Consideration of processing requirements when there is poor altitude data needs to be considered.

Correlation, the process of deciding which sensor reports are updates to the track of a given aircraft, is a critical part of the fusion process. ADS-B, SSR Mode S and some WAM reports will include the unique 24 bit aircraft address of the aircraft, and this provides a very high confidence indicator that should be used for correlating new reports with an existing multi-sensor track. These reports may also include the aircraft Flight Identification, which is also a good indicator. For SSR Mode A/C systems, the Mode A code is a reasonable measure for correlation, but as explained above it is subject to corruption in garbling situations, and cannot be used with the same confidence as an aircraft address. (Label swaps in garbling situations are not unknown in Mode A/C multi-radar fusion systems). The position data in a report is also a factor in correlating a new report with an existing fused track – the change in position since the last update should be within the bounds of an airplanes' aerodynamics. For correlating primary radar only reports, position correlation is the only measure that can be used.

Position Estimation in a multi-sensor fusion process should to take full advantage of the characteristics of each contributing sensor system – items such as position accuracy, resolution, integrity and update rates differ from sensor to sensor, and the contribution that each makes to the multi-sensor fusion process should be weighted accordingly. **Update rate** is particularly important in tracking the position of a manoeuvring aircraft, and ADS-B and WAM, with typically an update every second, can provide large performance benefits over the typical five, ten or twelve second updates provided by radars. **Position accuracy and integrity** of the data from each sensor type should also influence the weighting given in estimating the multi-sensor track position (and position noise) at each update. For ADS-B the NUC (or DO260A equivalent) should be taken into account in some way – for example, discarding reports with NUC below some threshold, and then perhaps assigning higher weights to higher NUC value reports. High NUC value reports are likely to be the most accurate of all sensors.

The accuracy of WAM position reports are dependent on the geometry of the ground receivers and the aircraft, and it is important that the multi-sensor fusion process is provided with information on WAM position accuracy – for example, all reports are better than a specified accuracy threshold (other reports having been discarded in pre-processing), or each report is accompanied by a "Figure of Merit" based on the geometry of the received signals.
For all types of radar sensors, the accuracy is likely to be constant in range from the sensor, but will decrease in azimuth with increasing range. Less weight should be given in the position estimation process to the azimuth component of radar reports as range increases. It is also necessary to protect against biases in the data from different sensor types.

Bias: ADS-B data is all based on WGS-84 latitude and longitude, and for all values of NUC likely to be used operationally, will be derived from GNSS. ADS-B bias can be assumed to be zero. WAM bias should also be low, but is dependent on the accuracy of survey of ground sites and the time tagging of receptions. Radar bias is mainly a factor of how accurately the north mark encoding of antenna position has been aligned on each radars, combined with the accuracy of survey of the sites. These are both manual processes, and significant errors are not unknown.

Velocity and Acceleration Estimation is important for a number of purposes, including presentation to the controller, safety net functions (such as STCA) and for predicting the multi-sensor track position as part of the correlation process for deciding which new reports should be correlated with which multi-sensor tracks. There are several ways of estimating velocity and acceleration. The traditional approach in multi-radar fusion processes was to look backwards at the last few position reports and calculate a direction, speed and sometimes an indication of whether the aircraft appeared to be turning or travelling straight. This use of historical data works moderately well in constant speed straight flight with accurate position data, but always lags when the aircraft accelerates (including in turns). If the position data is noisy and needs to be damped, this lag increases. The lag can be reduced by more frequent position updates. New sensors offer other ways of determining velocity and acceleration. For example, SSR Mode S with DAPS includes the capability to extract from an aircraft FMS parameters such as ground speed and bank angle, while each ADS-B report includes a velocity value that has been calculated by the position determining equipment (GPS) on board the aircraft. These sources can provide data that is superior to that estimated from an analysis of the historical position reports from the aircraft, and should be used to improve the multi-sensor fusion velocity and acceleration estimation process.

Collection, validation and reporting of downlink data is also to be considered. Downlink data includes barometric altitude, geometric altitude, selected flight level, Flight ID, 4 digit octal code etc. Rules and processes are required to treat these appropriately from each data source. In some cases it may be appropriate to cross check this data with the track trajectory Eg: velocity vector. In other cases the downlinked data may actually support the tracking itself.

4 Performance Requirements

There are no publicly available performance specifications for multisensor fusion processing systems. However an example specification for multiradar tracking is Eurocontrol Standard Document for Radar Surveillance in Enroute Airspace and Major Terminal Areas SUR.ET1.ST01.1000-STD-01-01. This is available on the Eurocontrol Web site.

The performance requirements of a multisensor fusion process will typically include the following:

a) for defined aircraft manoeuvres and defined sensor performance (eg defined radar systematic and random errors):

- Accuracy in straight line flight including position error, speed error, and heading error; and
- Accuracy in manoeuvres of defined characteristics (.5 g , 2 g turns etc)

b) Track initiation delay;
c) False track probability;
d) Track continuity;
e) Tracker processing capability taking into account the relevant sensors, reporting rates and sensor overlap;
f) Anomaly rates such as split tracks, track swap rate, ghost track rate; and
g) Latency – defined as appropriate with the system track display methodology.

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ATTACHMENT 1

Some Typical Performance Characteristics of Surveillance Sensor Systems

Performance Characteristic	**Primary Radar (PSR)**	**SSR Mode A/C sliding window**	**SSR Mode A/C monopulse**	**SSR Mode S**	**SSR Mode S withs DAPs**	**Wide Area Multilateration**	**ADS-B**
Position Accuracy	Decreases with range	Decreases with range	Better than PSR and sliding window SSR – decreases with range	Similar to monopulse SSR	Similar to monopulse SSR	Depends on Rx geometry – can vary from better than radar to worse than radar	GPS – reported by avionics (NUC /NIC, NAC, SIL).
Position updating rate (typical)	5 to 12 seconds	5 to 12 seconds	5 to 12 seconds	5 to 12 seconds	5 to 12 seconds	1 second	1 second
Anomalous position reports	Yes (weather, road vehicles etc)	Yes (multipath reflections)	Yes (multipath reflections	Low probability	Low probability	Low probability	Low probability (NUC/NIC, NAC, SIL protection)
24 bit Airframe Address	No	No	No	Yes (if Mode S avionics)	Yes (if Mode S avionics)	Yes (if Mode S avionics)	Yes
Flight Identification	No	No	No	Yes (if Mode S avionics)	Yes (if Mode S avionics)	Yes (if Mode S avionics)	Yes
Identity code (Mode A)	No	Yes	Yes	Yes	Yes	Yes	No
Altitude (LSB)	No	Yes (100’)	Yes (100’)	Yes (25’ if Mode S avionics))	Yes (25’ if Mode S avionics))	Yes (25’ if Mode S avionics))	Yes (25’)
Susceptibility to garbling	Not applicable	High	Moderate	Eliminated	Eliminated	Low	Low
Data error check/correct	Not applicable	No	No	Yes	Yes	Yes (if Mode S avionics)	Yes
Velocity	No	No	No	No	Yes (DAPS)	No	Yes (GPS)