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ADS-B Communication Interference in Air Traffic Management

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Automated Dependent Surveillance Broadcast (ADS-B) is avionic equipment that will be essential for safe flight operations in the Next Generation (NextGen) Air Transportation System (ATS) infrastructure of the United States and the corresponding modernization efforts in China and the European Union (ICAO, 2016; PMV, 2020). It is part of the networks that share data with flight crews, other aircraft, and the Air Traffic Control (ATC) system. Surveillance of aircraft position, altitude, velocity, and other flight attributes is an essential aspect of managing a safe airspace. ADS-B is an attractive alternative to the current radar surveillance system, which is having difficulty handling the increasing needs of airspace management (Wang et al., 2020). It is noted for its positional accuracy and data sharing capabilities. With ADS-B, each aircraft broadcasts its positional and state information on the 1090MHz frequency. ADS-B will be used for maintaining safe separation distances between aircraft (Federal Aviation Administration [FAA], 2019; Honeywell, 2018; FAA 2009; Kirkman, 2003).

There is a risk that transponders sharing the same frequency will interfere with each other's signals (CISA, 2020). The National Spectrum Managers Association (1987) warns that radio systems sharing the same frequency risk interfering with each other's signals, a condition known as co-channel interference. This interference can cause bit errors and the effects are more severe for complex systems. Likewise, the Cybersecurity and Infrastructure Security Agency (2020) notes that co-channel interference is caused by more than one transmitter sharing the same frequency, the situation with ADS-B today as each plane transmits on the same frequency.

ADS-B transponders use Mode S-Extended Squitter, also known as 1090-ES, as the data link protocol. Mode S mitigates overloading that occurred in the original ATC Radar Beacon Systems (ATCRBS). Mode S-ES extends Mode S by increasing the packet length from 56-bits to 112-bits to allow for inclusion of Global Navigation Satellite System (GNSS) information in the messages (Burfeind, 2020).

In its 11th Annual Air Navigation Conference, held September to October 2003, the International Civil Aviation Organization (ICAO) made the decision to standardize on Mode S as the link service for ADS-B, while the United States had standardized on Mode-S in 2002 (ICAO, 2003b). Data link services transfer data between nodes in a network. In its conference report, the ICAO rejected an alternative to Mode S, the VDL Mode 4, because of cost and integration issues. VDL 4 uses Self-organized Time Division Multiple Access technology to avoid interference among multiple aircraft transponders. China began testing ADS-B on certain routes in 2003 (ICAO, 2003a).

The ICAO (2003b) also reported that Mode S would not be capable of supporting air traffic management in the future, and it would need to be replaced or augmented in the near term. Given the many variables that impact the decision to do this replacement, the ICAO would not give a precise timeframe. In 2002, The European Organisation for the Safety of Air Navigation (EUROCONTROL) commissioned a study to provide information on ADS-B link performance (National Air Traffic Services, 2002). In its report, National Air Traffic Services (2002) noted that VDL 4 did not experience any issues with interference or lost messages during the test, while Mode S did encounter lost messages from interference.

Valovage (2009) noted that the 1090 MHz surveillance band was expected to reach critical interference levels in the near term as well. Information loss from overlapping messages and garbling would become unacceptable as message densities increased. He concluded that the models and simulations used to analyse this problem need field measurements to verify the models. FRUIT (False Replies Uncorrelated In Time) is an industry acronym referring to this co-channel interference that degrades 1090 MHz communications.

Garcia (2015) developed an ADS-B co-channel interference model and ran a simulation of its performance. His research investigated the feasibility of space-based ADS-B surveillance. Naganawa et al. (2017) collected data from four experimental ground stations in Tokyo and developed a model to predict the probability of correct reception of ADS-B messages considering the potential for co-channel interference. Their ground stations provided log-video amplitude that they converted to signal power. They used signal power in their prediction of message detection.

Chiocchio et al. (2020) reported on methods for decoding ADS-B messages in high interference environments. They modelled a variety of possible events regarding ADS-B interference using data generated from a simulation environment. They concluded that improved methods are needed for ADS-B to perform safely in an era of increased air traffic and reliance on ADS-B for air space management.

The European Union has mandated ADS-B in its airspace since 2020 (PMV, 2020). China plans to phase in a complete operational ADS-B system for aircraft surveillance by 2025 (ICAO, 2016). The transition in the United States to its NextGen system, with a heavy reliance on ADS-B, is due for completion in 2030 (FAA, 2023).

By providing accurate location and flight path information, the ADS-B/Mode S system can improve flight paths and reduce costs. Air Traffic Management improves because it can more effectively collect and organize altitude, heading, and speed of aircraft in its traffic space for conflict detection and resolution. ADS-B integrates GNSS position information with onboard avionic systems to broadcast its messages about the aircraft and its spatial attributes (Ronen & Ben-Moshe, 2021).

As reviewed above, several papers have addressed the issue of ADS-B co-channel interference from different perspectives. The research behind these papers developed models or simulations on this issue to predict points when garbling becomes unacceptable. The contribution of this paper is a methodology to capture empirical data to monitor the extent of ADS-B degradation from actual ADS-B transmissions and analyse that data using straight-forward relational database aggregations. The research was conducted in an area that included Dulles International Airport, a military air base, and regional airports. The approach can be easily setup at any location that has significant air traffic.

Material and Methods

Research Hypothesis

This research collects ADS-B message traffic and generates a statistic from that data to test its hypothesis. The hypothesis is that ADS-B transponders using the Mode S data link service interfere with one another in the National Air Space (NAS). The statistic chosen is ADS-B message rate per aircraft correlated with the number of concurrent aircraft. The author collected the data running an RTL-SDR transponder from a ground station near Dulles International Airport. The collected data was organized into relational database tables.

The message rate per aircraft statistic is appropriate. If ADS-B transponders do interfere with each other, we would expect to see a corresponding drop in the message rate received at the ground station from each aircraft as the number of concurrent aircraft increases in the traffic space. If the statistic has a strong negative correlation to the number of concurrent aircraft that is support for the hypothesis that the transponders interfere with each other. On the other hand, if the findings show that the statistic has weak negative or a positive correlation, then that does not support the hypothesis that there is interference caused by other ADS-B transponders in the traffic space.

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Gather Data

The author chose to collect data in the northwest region of Dulles International Airport. This location also includes several regional airports and the 167th Airlift Wing of the WV Air National Guard. MRB Aviation in Martinsburg is also a reliever airport for the Baltimore-Washington corridor.

To derive the statistic, we need time of message broadcast, aircraft identifier, position, and status information. A rate implies time periods and counts. There is no timestamp information in ADS-B messages (Stroman, 2021; Sun, 2021), so time of message receipt (TOMR) was used in its place. Mode S Extended Squitter has various downlink formats, codes that indicate the type and purpose of the transmission. Not all these transmissions are ADS-B and an important consideration is the Mode S downlink format to use. There are three Mode S downlink formats for ADS-B transmissions: 1) DF 17 for ADS-B messages coming from a transponder that can be interrogated by the ATC system; 2) DF 18 for ADS-B messages coming from a system that cannot be interrogated; and 3) DF 19 for military avionics (Sun, 2021; FAA, 2016). This research is focused on DF 17 and 18 messages.

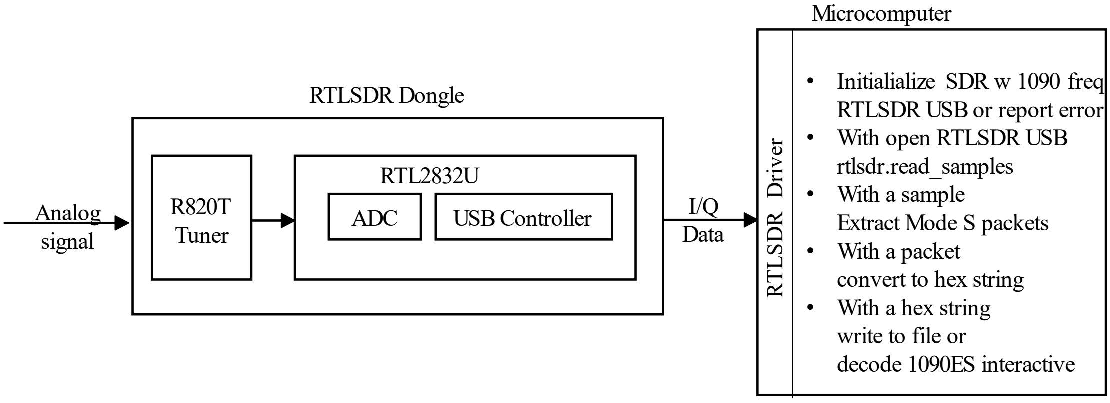
Using RTL-SDR to Receive ADS-B 1090ES Transmissions

The ever-increasing capability of microcomputers has given them the capability to decode and process radio signals that until recently could only be handled by dedicated analogue circuitry. Today, the calculations needed to process radio signals can be accomplished fast enough in microcomputer software. Moreover, the RTL2832U transponder chip was transformed into a wideband, general purpose radio receiver for microcomputers when Linux engineers developed drivers for it (Laufer, 2014).

The research for this paper uses an RTL2832U based transponder that attaches to a microcomputer via the USB interface to collect data. The receiver end of the transponder connects to a single pole antenna through a coax cable. The microcomputer operating system communicates with the transponder through software drivers as shown in Figure 1. Our software then reads 1090MHz signals to capture ADS-B messages.

Figure 1

Software Defined Radio as used in this Research



The core of the RTL2832U transponder is an analogue-to-digital converter that samples the radio waves and digitizes those samples (Laufer, 2014; Lichtman, 2023). The USB controller on the RTL2832U then makes the resulting I/Q data, In-Phase and Quadrature, available to the software driver on the microcomputer. The I/Q data is processed into Mode S messages.

Theory and Calculation

Organize the Data

A Python program collected raw data provided by the RTL-SDR driver over the period of a week, from April 1, 2023, 10:28pm to April 9, 2023, 2:20am. Over 42,808,866 Mode S messages were received and saved to disk files. These files were filtered to select only DF 17 and 18 messages, the civilian ADS-B traffic, which were then cleaned, transformed, and loaded into a relational database. There are 14,414,774 ADS-B messages in the relational database.

At different times, there will be different number of concurrent aircraft in the air space covered by the ground station we established. The number of concurrent aircraft is a discrete random variable; so, at any given time, an integer number of aircraft will be detected by this system. The range of this random variable in the collected data was a minimum of one aircraft and a maximum of 28 concurrent aircraft. Multiple times during the week, there will be the same number of concurrent aircraft. In other words, at various, different times during the week there will be one aircraft, other various times, 7 and so on for the other counts of concurrent aircraft. We will use the average message counts from those different times as the expected message count for a level of concurrent aircraft.

Process the Data

The raw ADS-B data is a hexadecimal set of codes that must be translated into meaningful position and state information. In addition, individual ADS-B broadcasts are partial pieces of a complete aircraft position, direction, and status record. These partial pieces are given an ADS-B type code to indicate the information they provide. For example, ADS-B type code 19 is for the velocity piece of the complete set of information, while type code 9 provides the position piece of the complete set. Each message has a unique aircraft identifier, the ICAO code, assigned to its ADS-B transponder.

Each record in the database table, named adsb, is the capture of an ADS-B transmission. Working backward, respice finem, we need the average or expected message rate associated with the number of concurrent aircraft. Message rate means we need time period and message count, which we can get from the adsb table. Concurrent aircraft implies we need aircraft identifiers and time period, again that we have.

ADS-B transponders broadcast velocity messages approximately two times per second, with some variation (Kim et al., 2017; Ronen & Ben-Moshe, 2021). Likewise, for position messages, with the rate for both position and velocity varying from one message every .4 to one every .6 seconds. There is also an operational status message every 1.7 seconds. By grouping the messages into one-half second intervals, we expect the number of messages per plane to be in the following range: On the high end, (1/.4+1/.4+1/1.7)/2 or 2.7 and on the low end (1/0.6 + 1/0.6 + 1/1.7)/2 or 1.9. This range is under optimal conditions. As a reasonableness check, message rates calculated in this research should be close to this range. If the message rates processed from the data are significantly outside this range, the processing method must be reexamined.

Grouping by TOMR and then binning into half-second blocks, message rate per half-second is obtained with a count (*) and the number of concurrent aircraft for that half-second as count (distinct ICAO). Given the end goal, these two intermediate calculations are needed in order to investigate the hypothesis that message rate per aircraft declines across the number of concurrent aircraft, and that more aircraft transmitting on 1090 MHz do interfere with each other, resulting in a declining average message rate.
The necessary calculations are a series of aggregation operations on the data, primarily done with SQL. The series of operations done to get the statistics necessary to test our hypothesis are listed in Table 1.

Table 1
SQL Aggregation Operation

Step 1	A Python program reads table *adsb* and creates a new table *times* that has the ICAO and timePeriod. timePeriod is a sequence of the half-second time intervals starting at period 1 and ending at period 911,403. Half-second was chosen for purpose of number of concurrent aircraft since Mode S transponders send two messages approximately every half second.
Step 2	*CREATE TABLE countBy* as *SELECT* count(*) as *Msg_Count*, count(distinct *ICAO*) as *Concurrent* *FROM times* *GROUP BY* timePeriod;
Step 3	*CREATE TABLE* Rt as *SELECT* Concurrent, avg(*Msg_Count*) as *Msg_Rate* *FROM countBy* *GROUP BY Concurrent*;
Step 4	*CREATE TABLE* Rp as *SELECT* Concurrent, Msg_Rate/Concurrent *FROM* Rt;

The database table countBy (Step 2) contains a list of ICAOs of the messages and the half-second time periods when those messages were broadcast. In that table, the message count for a specific number of concurrent aircraft is had by counting the time periods with that number of concurrent aircraft. In other words, of the hundreds of thousands of time periods, many will have that number of concurrent aircraft. Grouping by number of concurrent aircraft (Step 3), collects together all the records for the different time periods that have the same number of concurrent aircraft. Next, average the count and we are left with each specific number of concurrent aircraft associated with a statistic representing its distribution of message counts across all its time periods. This is the relation R_t.

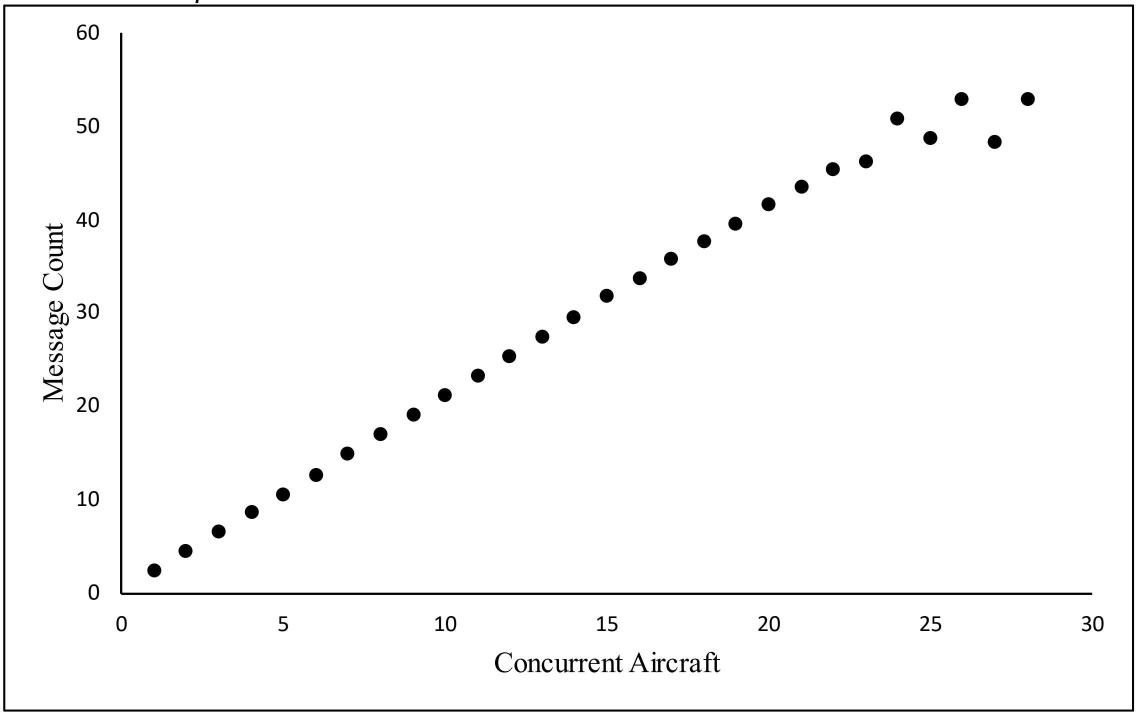
For Rt, each record is the number of aircraft along with the expected number of messages that many aircraft will broadcast. From R_t, an aggregation calculates an average per aircraft (Step 4) and results in a set of records: number of concurrent aircraft and average message rate per aircraft for that number of concurrent aircraft. This is the relation R_p. Finally, the correlation is calculated with a Spearman Rank correlation on that data.

Results and Discussion

Relation R_t had 28 records for the 28 unique levels of concurrent aircraft. For each unique level there is associated an average message count across all time periods for that level. As expected, the message count for all concurrent aircraft per time period is higher for those time periods that have more concurrent aircraft. This is reflected in the visualization of the relation, see Figure 2, as a scatter chart between concurrent aircraft in time periods and message count for those time periods.

Figure 2

Visualization of Relation Rt

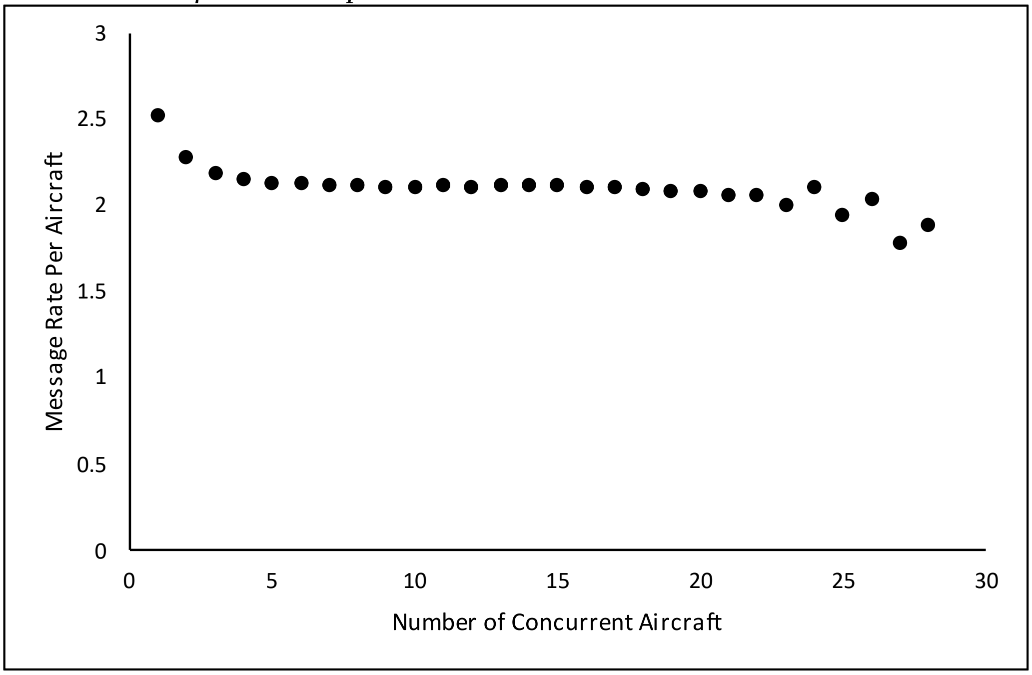


In relation R_p, the message count per time period in R_t is divided by the number of aircraft in that time period, to get the average message rate per aircraft associated with the number of concurrent aircraft. The visualization of this relationship is shown in Figure 3 below. To determine the correlation and corresponding p-value, the Python scipy.stats.spearmanr() function is applied to the data of relation R_p. The calculated correlation is -0.93 and the associated p-value is 7.58e-13. Since the p-value of the correlation is less than 0.05, the correlation is statistically significant.

There is a strong negative corelation between message-rate-per-aircraft and number-of-concurrent-aircraft. The statistic processed in this research supports the hypothesis that message rate per aircraft declines as concurrent aircraft increases. Furthermore, this supports the concern that ADS-B transponders do interfere with each other in the traffic space of a specific ground station. Also noteworthy is that the message rate per plane across all levels of concurrent aircraft is within the expected range of 1.9 to 2.7 messages per half second interval, as calculated in an earlier section, except that the message rate for higher levels of concurrent aircraft fell slightly below the lower bound of the range.

Figure 3

Visualization of Relation Rp



Conclusion

In conclusion, this research examined over 14 million ADS-B communication transmissions and calculated the correlation between message-rate-per-plane and number-of-concurrent-aircraft. The findings showed a negative correlation between message rate and concurrent aircraft, which supports the hypothesis that ADS-B transponders do interfere with one another. As more aircraft are in the traffic space, there are more transponders broadcasting on the same 1090 MHz frequency, providing more potential for interference. This is an important finding for airspace management, as the next generation air traffic management systems are being phased into operation and as those systems will rely more on ADS-B for management and less on surveillance radars.

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