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Applying the ADS-B Out to Facilitate Flight Data Analysis for General Aviation

Chenyu Huang
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APPLYING THE ADS-B OUT TO FACILITATE FLIGHT DATA
ANALYSIS FOR GENERAL AVIATION

by

Chenyu Huang

A Dissertation

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In Partial Fulfillment of the Requirements for the degree of

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THE PURDUE UNIVERSITY GRADUATE SCHOOL
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Special thanks to my family who are thousands of miles away for your endless support, encouragement, and endless love throughout these years. To another half of my life – Ciying Yang, thanks to your strong and steadfast support. To my family in the U.S. – Uncle Lou and Aunt Tracy, thanks to your constant support and caring.

Without your unconditional love, I would never accomplish this monumental goal. I love you all forever.
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and the School of Aviation and Transportation Technology provided cost-share supporting this research. The views presented in this dissertation are mine and do not reflect those of the FAA. The information in this research does not constitute FAA Flight Standards or FAA Aircraft Certification policy.
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LIST OF ABBREVIATIONS

ADS-B Out-Automatic Dependent Surveillance-Broadcast Out
CASA-Civil Aviation Safety Authority
EASA-European Aviation Safety Agency
FAA-Federal Aviation Administration
FDM-Flight Data Monitoring
FDR-Flight Data Recorder
FOQA-Flight Operational Quality Assurance
GA-General Aviation
GAJSC-General Aviation Joint Steering Committee
GAMA-General Aviation Manufacturers Association
ICAO-International Civil Aviation Organization
NTSB-National Transportation Safety Board
RTCA-Radio Technical Commission for Aeronautics
U.K. CAA-U.K. Civil Aviation Authority
U.S. GAO-U.S. Government Accountability Office
ABSTRACT

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Major Professor: Mary E. Johnson.

The International Civil Aviation Organization (ICAO) and major airlines believe that flight data analysis is an effective approach to mitigate the risk of aviation accidents (International Civil Aviation Organization, 2010; International Air Transport Association, 2016). In the United States, flight data analysis is encouraged by the Federal Aviation Administration (FAA) through the flight operational quality assurance (FOQA) program. Among all aviation activities, general aviation (GA) has the highest accident rate (National Transportation Safety Board, 2014). However, implementation of flight data analysis for GA not only requires expensive investment on flight data recording devices, but also increases long-term labor cost due to regular data collection and data analysis. Automatic Dependent Surveillance Broadcast Out (ADS-B Out) is a precise satellite-based surveillance system that periodically broadcasts flight data retrieved from satellites and onboard avionics of the ADS-B Out capable aircraft. Based on the standard technical provisions of the ADS-B Out, the use of ADS-B data is expected to be a possible approach to facilitate the flight data analysis for general aviation. This research explored the use of ADS-B data to facilitate flight data analysis for general aviation.

Researchers started the current study phase from analyzing the structure and content of the ADS-B message by referring to the ICAO technical provisions (2008) and the operational performance standard of ADS-B from the Radio Technical Commission for Aeronautics (RTCA) (2009). Based upon the findings of the ADS-B data structure and content, a set of retrievable aircraft
parameters was identified, and additional aircraft parameters were derived from the basic ADS-B information. Furthermore, sets of flight metrics were developed using the aircraft parameters broadcasted by ADS-B Out. The development of flight metrics was expected to be essential for measuring flight operational performance to support flight data analysis. In addition, exceedance detection was adopted to analyze the flight metrics in flight data analysis. ADS-B data were collected using an ADS-B receiver, and 40 sets of ADS-B data were selected to detect five operational exceedances of the Cirrus SR-20 aircraft of the Purdue Fleet. Exceedances were detected from the 40 sets of data. However, researchers noticed that the sparse ADS-B data caused by the low reception rate might affect the exceedance detection. Therefore, a preliminary analysis was conducted to investigate the difference of exceedance detection using ADS-B data with different reception rates. The results of analysis indicated that sparse ADS-B data could affect the detection of exceedances, but some exceedances might be less sensitive to the sparse data. Based on the findings of this research, recommendations were proposed for future studies.
CHAPTER 1. INTRODUCTION

This chapter presents an introduction to this research. The statement of problem, research questions, scope, and significance are introduced. Assumption, limitations, delimitations, and key definitions are also listed.

1.1 Statement of the Problem

Aviation safety is essential for the economic and sustainable development of the air transportation industry. Aviation safety enhancement has been one of the fundamental objectives of the International Civil Aviation Organization (ICAO) and of the Federal Aviation Administration (FAA). A variety of safety enhancement strategies have been widely investigated to address possible issues risking aviation safety. With continuous efforts and cooperation from aviation stakeholders, the total number of aviation accidents and the accident rates have decreased over the last ten years. According to the ICAO Safety Report 2017, the number of accidents worldwide, as defined in ICAO Annex 13, decreased by 18 percent to 75 in 2016 compared to 2015, and the global accident rates involving scheduled commercial operations decreased by 25 percent to 2.1 accidents per million departures in 2016 compared to 2015 (ICAO, 2017). In Destination 2025, the FAA made reducing the general aviation accident rate one of its top priorities and set a goal of “no more than 1 fatal accident per 100,000 hours of flight by 2018” (FAA, n.d., p. 4).

The International Civil Aviation Organization (ICAO) believes that flight data monitoring is one of the most effective approaches to improve flight safety and operational efficiency by detecting unsafe events and anomalies. Airlines are highly encouraged by ICAO to implement a
Flight Data Monitoring (FDM) program, the U.S. commercial airlines are now applying corresponding FDM programs in routine operations in accordance with Advisory Circular 120-82 of the Federal Aviation Administration (FAA) (ICAO, 2010; FAA, 2004). The implementation of FDM programs depends on the availability of data from flight data recording devices.

General aviation (GA), as a key component of the civil aviation sector, flies more than 362,000 general aviation aircraft worldwide, of which over 204,000 aircraft are based in the U.S. (GAMA, 2016). In the U.S., GA flies more than 23 million flight hours annually across more than 5,000 U.S. public airports (GAMA, 2016). However, GA has the highest accident rate among all aeronautical activities (NTSB, 2017). Unlike commercial flights, GA operations are typically resource-constrained, and airline-based FDM programs are less affordable to GA owners and operators. Accordingly, operators and analysts are much less capable of collecting and analyzing GA flight data due to the low availability of data or the high expense of the flight data monitoring equipment.

To be effective January 1, 2020, the FAA requires all aircraft operating in most controlled airspace to equip with Automatic Dependent Surveillance-Broadcast Out (ADS-B Out) (14 C.F.R. § 91.225, 2011; 14 C.F.R. § 91.227, 2014). By then, most aircraft operating in the U.S. will have to be ADS-B Out capable. That includes GA aircraft, most of which do not currently have ADS-B Out. Certain types of flight data can be acquired by listening to the ADS-B messages broadcasted by aircraft. In addition, receiving ADS-B messages is inexpensive compared to the use of flight data recording systems. Therefore, the aspect of ADS-B data analysis is expected to be a practical approach to understanding GA operations and improving GA safety.
The purpose of this study is to explore ADS-B data to facilitate flight data analysis for general aviation.

1.2 Research Questions

This study has one primary research question and three sub-questions. The primary research question is: How can ADS-B data be applied to flight data analysis in general aviation?

Sub-questions are:
1. What flight data metrics can be developed from ADS-B data?
2. How can the developed flight metrics be used to identify flight operational exceedances?
3. What are the differences in exceedance detection with varying reception rates of ADS-B data?

1.3 Scope

Civil aviation aircraft operations can be categorized by scheduled flights, non-scheduled flights, and general aviation activities (ICAO, 2009). This study concentrates on applying ADS-B data to flight data analysis for GA operations.

Flight data analysis involves the regular collection of flight operational data, and analysis of flight data to provide objective information regarding the performance of flights (FAA, 2004). In order to effectively apply ADS-B data in flight data analysis for GA, flight data metrics were developed using the flight parameters of GA aircraft that an ADS-B Out system can transmit to ground-based receiving stations. Flight exceedance detection is one of the most effective techniques in flight data analysis; methods were developed to analyze the developed flight
metrics for the purpose of detecting flight operational exceedances. In addition, the frequency of receiving ADS-B data is affected by many factors, such as the performance of the ADS-B receiver, and the location where the ADS-B receiver is deployed. Therefore, the differences of exceedance detection were examined by varying ADS-B data reception rates.

1.4 Significance

According to the records of the National Transportation Safety Board (NTSB), general aviation has the highest accident rate among all aviation activities (NTSB, 2017). However, because of limited resources, GA has fewer practical solutions and affordable technologies to enhance safety, as compared to commercial air transport services. Therefore, developing a practical and affordable solution specifically for GA is urgent and significant for improving the safety of GA operations.

Flight data analysis is one of the effective approaches to proactively mitigate aviation accidents. However, the airline-based flight data analysis programs are complicated and resource consuming; most GA operators can hardly afford the human resources and technology to implement such programs that are designed for commercial airlines. The FAA requires all aircraft flying in most controlled airspace of the U.S. National Airspace System to be equipped with FAA certified ADS-B Out avionics, beginning in January 2020 (14 C.F.R. § 91.225, 2011; 14 C.F.R. § 91.227, 2014). Receiving standardized flight parameters from an ADS-B Out system is relatively inexpensive. Therefore, applying an ADS-B Out system for GA flight data analysis might be an appropriate approach given the constraint of low-cost operations in GA activities.
Based on the findings of this research, the use of ADS-B data might be an affordable and effective approach to support flight data analysis of general aviation, and eventually enhance the safety of GA operations.

1.5 Assumptions

This research was conducted based on the following assumptions:

1. There are demands to explore an affordable and effective strategy to facilitate flight data analysis for general aviation.

2. The ADS-B receiver used for this study functions reliably to receive and store flight data broadcast by onboard ADS-B Out systems.

3. The flight data broadcasted by the ADS-B receiver for this study accurately reflected actual aircraft operational status.

4. The amount of flight data acquired for this study was sufficient to represent the operational features of general aviation.

5. The research methods selected were appropriate to explore answers to the proposed research questions.

1.6 Limitations

This study was conducted based on the following limitations to the pursuit of answering research questions:

1. This study was limited to the quantity and quality of flight data received by ADS-B receiver on 1090 MHz.

2. This study was limited to the number of the ADS-B Out capable GA aircraft based at the
Purdue University Airport.

3. This study was limited by the performance of the Mode S ES transponder equipped on the GA aircraft based at the Purdue University Airport.

4. This study was limited by the performance of a non-commercial ADS-B receiver.

5. One practical approach to analyze the effect that the reception rates of ADS-B Out have on the exceedances detection is to use sets of ADS-B data with different reception rates. However, it is impractical to collect ADS-B data with different reception rates in this study. Therefore, ADS-B data with different reception rates were emulated using Flight Data Recorder (FDR) data which was a rich flight operational data source.

### 1.7 Delimitations

The following delimitations might help to identify the scope and limitations of this research:

1. This study only focused on the ADS-B data broadcasted by the 1090 MHz Extended Squitter.

2. The flight data used in this study were collected randomly from October 2016 to May 2017. The data collection process was affected by weather conditions.

3. The actual implementation of the FAA mandate for equipping ADS-B Out was outside the scope of this study.

### 1.8 Definitions of Key Terms

Automatic Dependent Surveillance – Broadcast Out (ADS-B Out) – “A function on an aircraft or vehicle that periodically broadcasts its state vector (position and velocity) and other
information derived from on-board systems in a format suitable for ADS-B In capable receivers” (ICAO, 2008, p. ix).

Automatic Dependent Surveillance – Broadcast In (ADS-B In) – “A function that receives surveillance data from ADS-B data sources” (ICAO, 2008, p. ix).

Broadcast – “the protocol within the Mode S system that permits uplink messages to be sent to all aircraft in the coverage area, and downlink messages to be made available to all interrogators that have the aircraft wishing to send the message under surveillance” (ICAO, 2008, p. ix).

Commercial air transport operation – “an aircraft operation involving the transport of passengers, cargo or mail for remuneration or hire” (ICAO, 2010, p. 1-3).

Exceedance detection – exceedance detection looks for deviation from flight manual limits and standard operating procedures (CASA, 2011, p. 3).

Flight data analysis – “a process of analysing recorded flight data in order to improve the safety of flight operations” (ICAO, 2010, p. 1-4).

Flight Operational Quality Assurance (FOQA) – “a voluntary safety program that is designed to make commercial aviation safer by allowing commercial airlines and pilots to share de-identified aggregate information with the FAA so that the FAA can monitor national trends in aircraft operations and target its resources to address operational risk issues” (FAA, 2004, p. 1).

General aviation – “is defined, for statistical purpose, as all civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire. For ICAO statistical purposes the general aviation activities are classified into
instructional flying, business flying, pleasure flying, aerial work and other flying” (ICAO, 2009, p. b-3).

Squitter – “by definition, the word ‘squitter’ refers to a periodic burst or broadcast of aircraft tracking data that is transmitted periodically by a Mode S transponder without interrogation from controller’s radar” (Garmin, 2017, p. 8).

1.9 Summary

Flight data analysis, as one of the key components of the Flight Data Monitoring (FDM) programs is expected to be an effective approach to address flight risks by routinely collecting and analyzing flight operational data. However, the implementation of flight data analysis needs a large investment in flight data recording devices and labor resources for analytic work. General Aviation (GA) is typically operating with more undesirable resource constraints, and thus cannot afford a FDM program. ADS-B Out broadcasts certain types of flight operational data in real time, and receiving ADS-B data is relatively inexpensive. This project studies the use of ADS-B data to facilitate flight data analysis for GA.
CHAPTER 2. REVIEW OF LITERATURE

With the impressive progress of aviation technology during the last decades, the public has benefited from more convenient and safer air transportation services and recreational aviation activities. However, maintaining safe air travel requires continuous effort and daily attention from scientists, engineers, legislators, front-line operators, passengers and other related participants. Unlike commercial aviation, general aviation (GA) is typically resource constrained, and is operating without an effective flight safety assurance. Additionally, GA has a wide range of aircraft types and utilities. Those features of GA contribute to a higher accident rate than commercial air transport services.

This chapter provides an overview of the literature on improving flight safety by implementing flight data analysis. First, recent flight safety facts that highlight GA accident rates are introduced. Next, relevant safety enhancement strategies are reviewed, including the flight operational quality assurance in commercial aviation, and safety enhancement approaches in general aviation. In the following sections, this chapter reviews prevalent data analysis techniques for aviation data in general, and flight data analysis of GA in particular. Finally, the application of automatic dependent surveillance – broadcast technology in general aviation are reviewed and discussed.

2.1 Flight Safety Facts Review

While commercial air transport services carry the most passengers and freight between major airports in the form of scheduled or non-scheduled flights, general aviation (GA) performs an important role in regional air transportation, recreation, agriculture, observation and patrol,
flight training, and other tasks that supplement common aerial work (ICAO, 2009). By 2015, there were over 362,000 GA aircraft worldwide, ranging from reciprocating engine aircraft and utility helicopters to intercontinental turbine engine aircraft (GAMA, 2016). In the United States, there were more than 204,000 registered GA aircraft, which are flying over 23 million hours yearly using almost 5,000 U.S. public airports (GAMA, 2016). Driven by a strong demand, especially from emerging markets, the number of general aviation aircraft is expected to reach 210,695 in the U.S. by 2036 with a growing number of turbine-powered aircraft and a shrinking number of fixed wing piston aircraft, which would consequently increase the hours flown by GA up to around 30,600 hours (FAA, 2016c).

Carrying more than 206 million passengers around the world, commercial carriers understand that safety must come before profit (FAA, 2016d). With the comprehensive development of relevant technologies and managerial strategies, commercial air carriers have exponentially improved flight safety and efficiency. From 2003 to 2015, the accident rate of commercial carriers in the U.S., regulated by 14 CFR Part 121, decreased by around 50 percent from 3.02 accidents per million flight hours to 1.55 accidents per million flight hours (NTSB, 2017). For non-scheduled flights in the U.S., regulated by 14 CFR Part 135, accident rates were fluctuating with an average accident rate of 13.36 accidents per million flight hours between 2003 and 2015, and most accidents were non-fatal (NTSB, 2017). However, for general aviation regulated by 14 CFR Part 91, accident rates slowly dropped to 58.5 accidents per million flight hours from 1996 to 2015, shown as Figure 2.1 (NTSB, 2017). Because of different operational features of general aviation, such as the wide range of aircraft and operations, and typical operations at low flight altitudes, GA is more vulnerable to more adverse influential factors than commercial flights.
2.2 Flight Data Monitoring

Currently, there are fewer aviation accidents with a few common causes (NTSB, 2015). It is challenging to improve flight safety by using traditional reactive approaches. As a result, government and the aviation industry have steered safety enhancement strategies from reactive approaches to proactive approaches (U.S. GAO, 2010).

The Flight Data Monitoring (FDM)/Flight Operational Quality (FOQA) program is “a voluntary program for the routine collection and analysis of flight operational data to provide more information about, and greater insight into, the total flight operations environment” (FAA, 2004, p. 1). Before official FAA guidance, the Flight Safety Foundation (FSF) published a comprehensive document on FDM, and adopted the name FOQA to better define its functions (FSF, 1998). Today, FDM is also known as flight data analysis or operational flight data.
monitoring (OFDM) under the framework of the ICAO and other civil aviation authorities, as shown in Figure 2.2 (ICAO, 2010).

![Figure 2.2 Procedure of Routine Flight Data Monitoring](image)

There are three primary components in the FDM system: airborne flight data recording devices, ground data replay and analysis system (GDRAS), and air/ground data migration (FAA, 2004). Airborne data recording devices include aircraft parameter input sources and the data recording equipment, which function to acquire and capture the necessary in-flight operational data. For instance, various onboard sensors serve as aircraft parameter input sources, whose data are transmitted via data buses, and stored in the Quick Access Recorder (QAR) (FAA, 2004).

According to the FAA Advisory Circular No. 120-82 (AC No. 120-82) (2004), GDRAS is typically a software program used to transform, process, visualize, analyze flight data, and eventually report useful flight information to users. Given the same types and the same amount of flight data, the capability of GDRAS most likely determines how much useful information one can derive from those flight data. The FAA AC No. 120-82 (2004) describes flight data exchange process of air/ground data migration, which is usually the most labor intensive and expensive
part of a FDM program. Air/ground data migration involves aircraft maintenance schedules and data migration between where the data are saved and where GDRAS is located. Therefore, a specific data collection process will be planned and conducted by assigned personnel based on the maintenance schedule and air/ground data exchange technology. Based on the collected flight data, aviation analysts can evaluate individual aircraft performance, identify safety events, pinpoint operational defects, and other safety related events. Consequently, FOQA can help operators promptly take corrective measures to mitigate operational risks (FAA, 2004).

Another value of implementing FDM is to share de-identified flight data among stakeholders and government agencies under a voluntary data sharing agreement (FAA, 2004). To better promote secure and effective flight data sharing, the FAA launched the Aviation Safety Information Analysis and Sharing (ASIAS) program in 2007 (FAA, 2014). With the ASIAS system, users are able to perform integrated queries across multiple databases to get desired safety data. Currently, the ASIAS involves almost the entire commercial aviation sector, and has greatly contributed to the reduction of commercial fatal accident rate.

Because of research and development on flight data analysis and sharing technology and procedures, flight data monitoring is expected to be one of the most powerful techniques to enhance aviation safety (ICAO, 2010, FAA, 2004, EASA, 2015).

However, the implementation of a FDM/FOQA program is expensive because of the significant investment in flight data recording devices, flight data processing and analyzing tools, as well as the long-term labor cost for data collection and analysis. The 2013 FAA Audit Report revealed that only 38 out of 88 Part 121 air carriers implemented a FOQA program, of which 22 were large carriers by fleet size, 11 were medium carriers, and 5 were small carriers, shown as Figure 2.3 and Table 2.1 (Federal Aviation Administration, 2013). The report indicates that “the
relative lack of progress at medium and smaller air carriers is also due in part to the fact that FAA lacks a focused strategy to assist small carriers, such as providing best practices and guidance in implementing voluntary safety program” (FAA, 2013, p. 7). The total number of FOQA implemented air carriers has recently grown to 46 in the U.S. (FAA, 2016e). As a result, exploring an inexpensive FDM strategy appears crucial to popularize the deployment of FDM/FOQA programs in small air carriers and general aviation. Lowering the cost of flight data collection is expected to be one of the breakthrough points to reduce the overall cost of routine flight data monitoring.

![Figure 2.3 Deployment of FOQA in Part 121 Carriers, adapted from FAA (2013)](image)

<table>
<thead>
<tr>
<th>Table 2.1 Carrier Classification by Fleet Size</th>
</tr>
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<tbody>
<tr>
<td><strong>Large Air Carriers</strong></td>
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<tr>
<td>Size of Fleet</td>
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*Note. Data are from the 2013 FAA Audit Report*
2.3 Improving General Aviation Safety

Apart from owning the largest commercial aviation fleet in the world, the United States has the largest and most diverse GA community in the world (FAA, 2016c). GA has the most diverse types of aircraft, flexible operational procedures, and complex operational environment; however, GA operators typically have comparatively limited resources. Reducing GA accident rates has been a challenge for many years. During the last decades, GA accident rates indicate a decreasing trend, but there were still 373 people killed by GA accidents in 2015 (NTSB, 2017). To improve the GA safety, implementation of the Safety Management System is recommended for GA, which should have the functions of identifying actual and potential safety hazards, assessing the associated risks, developing and implementing remedial action, as well as continuous monitoring and regular assessing the appropriateness and effectiveness of safety management activities (ICAO, 2013a). However, different from the operators under Part 121 who are required to develop and implement an SMS, the implementation of an SMS is a voluntary option for non-Part 121 operators, MROs, and training organizations (FAA, 2015b).

With a goal of reducing GA accident rates in the U.S. by 10 percent over the 10 years from 2009-2018 (FAA, 2017a), government and aviation industry have been working closely on various initiatives to enhance GA safety, through organizations such as the General Aviation Joint Steering Committee (GAJSC), the National Transportation Safety Board, the National Aeronautics and Space Administration (NASA), and the Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS). Other international agencies, such as the European Aviation Safety Agency (EASA), the European General Aviation Safety Team (EGAST), and the General Aviation Safety Council (GASC) are also working toward improved GA safety.
Like the approaches adopted by commercial aviation, aviation authorities and industry intend to develop and implement proactive data-driven, consensus-based approaches to identify and mitigate risks to GA operations. Launched in 1997, the GAJSC is a public–private partnership with the goal of improving GA safety through data-driven risk mitigation efforts based on education, training, and promoting new equipment in GA aircraft (GAJSC, 2016). Loss of Control (LOC) accidents are identified as one of the most important challenges for GA safety, because 40 percent of fixed wing GA fatal accidents have been designated as due to the loss of control (NTSB, 2015). In order to address the challenge of LOC, the GAJSC has concentrated on the study of Loss of Control with two specific work groups focusing on the phases of approach and landing, and other phases of flight respectively (CAJSC, 2016). By 2017, the GAJSC has accomplished more than 39 safety enhancements, covering the areas of procedures, technology, and training, to mitigate the risks of Loss of Control (FAA, 2017a). The angle of attack (AoA) system, aeronautical decision making (ADM), stabilized approach and landing, and airman certificate standards are examples of recent GAJSC accomplishments.

2.4 Prevalent Data Analysis Techniques for Aviation Data

Data analysis is a process of obtaining raw data, cleaning, transforming data, and modeling and converting data into useful information to support decision-making. In the field of aviation, data analysis is widely conducted for specific needs, stretching from the aspect of aviation safety enhancement, and airspace utility assessment, to the purpose of operational efficiency measuring. With different purposes, aviation data are collected, analyzed and interpreted from different perspectives with a variety of techniques. For example, data of air traffic volume are usually used for airspace management and airline network planning, passenger
load factors are used for an airline’s economic performance related analysis, and operational data from flight data recorders can be used for safety analysis. Currently, there are 81 categories of analysis techniques documented by the Federal Aviation Administration System Safety Handbook for specific tasks (FAA, 2000). For example, accident analysis, contingency analysis, operating and support hazard analysis, and task analysis are four of the 81 categories listed (FAA, 2000).

In aviation safety analysis, flight safety data mostly can be divided into three broad categories:

Reports of incidents, events or hazardous situations that occurred during routine operations and are generally submitted by operational personnel; detailed aircraft parameters about flight operational performance collected as part of a flight data monitoring (FDM) or flight operational quality assurance program; and the results of safety audits of organizational units or line operations undertaken by suitably trained and experienced personnel from within the airline or from outside agencies. (FSF, 2003, p.6).

To support aviation safety analysis, the US Government Accountability Office identified aviation databases and the responsible US governmental agencies, such as Aviation Safety Reporting System (ASRS) managed by NASA and Aviation Safety Action Program (ASAP) managed by the FAA that each collect data on aviation safety events (U.S.GAO, 2010). In addition, the report noted the FAA’s movement toward proactive, data-driven analysis approaches, such as precursor identification and system wide trends (U.S. GAO, 2010). Those database systems archive all types of safety events and in-flight operations in terms of narrative or quantitative data about aviation safety (U.S. GAO, 2010).
Among all available aviation data, flight operational data are widely used for aviation safety improvement because of the increasing recording capacity and capability of flight data recording devices. Compared to the first generation of analog FDRs which only record less than 10 parameters, the most recent solid-state digital FDR on Boeing 787 aircraft can continuously record more than 1000 aircraft parameters for at least 25 hours to support flight data analysis and accident/incident investigation (Campbell, 2007; Dodt, 2011). Table 2.3 shows FDR types. Recorded flight parameters are periodically downloaded for post-flight safety analysis when an aircraft arrives at a suitable station or maintenance center. By routinely analyzing and monitoring flight operational data, operators are able to obtain insight into the overall flight operational environment and proactively prevent safety related events from happening.

Currently, analysis of FDR data is conducted by using the ground data replay and analysis system (GDRAS), which is basically a group of software programs provided by different vendors specifically designed for flight data analysis. Most GDRAS users specify the thresholds for predetermined exceedances and then identify the occurrences where thresholds were exceeded in the data (FSF, 2003). In addition, GDRAS provides trend analysis of large amounts of data with data visualization functions (FSF, 2003). Although the features of individual programs may vary, most are developed with two primary approaches: The exceedance detection approach and the statistical analysis approach (FAA, 2004).

**Exceedance Detection.** Exceedance detection looks for deviations from flight manual limits and standard operating procedures (SOPs) (CASA, 2011). The exceedance detection approach identifies predefined undesired safety occurrences. It monitors interesting aircraft parameters and triggers warnings or draws the attention of safety specialists when parameters hit the preset limits or baselines under certain conditions. For instance, analytics can set the program
to detect the occurrence when the bank angle of an aircraft exceeds 45 degrees. Usually, the focus list of aircraft parameters coincides with the flight operations manual or operator’s standard operating procedures. The pitch at takeoff, the approach speed, and the climb speed are examples of parameters in the watch list (FAA, 2004). Based on the level of exceedance, corresponding corrective actions would be taken on the highest perceived risk area. For instance, a higher level of risk could be associated with an occurrence when the bank angle reached or exceeded 60 degrees (FAA, 2004). Typically, exceedance levels and thresholds are developed through integrated analyzing and assessment of the standard operations manual, risk evaluation processes, and training programs as part of the overall safety management program (FAA, 2004). In addition, operators need to well develop the thresholds of occurrences to support exceedance analysis. The results of risk assessment for particular events, carrier’s operations manuals, and training programs, collectively determine the sensitivity and effectiveness of the exceedance detection (FAA, 2004). On the other hand, the exceedance analysis is relatively easy to be automated in software programs, and flexible to be customized by users upon specific demand. Roughly, exceedance detection can use aircraft parameters and exceedance rules to identify over 60 basic types of events; e.g., pitch high at takeoff, excessive bank angle at takeoff, takeoff high speed, high descent rate, and other events could be developed for the carrier’s operations manual (FAA, 2004).

**Statistical Analysis.** A statistical analysis approach is used to create the flight profiles, plot the distributions and trends of certain types of flight parameters, or map flight track on geo-reference charts to examine particular operational features of flight. By using a statistical analysis approach, aviation operators not only obtain numeric features of flight operations, but also acquire a more comprehensive picture of the flight operations based on the distributions of
aggregated flight data (FAA, 2004). The tracks of the phase of approach is an example of a particularly interesting flight procedure, because nearly half of worldwide commercial jet aircraft accidents from 2004 through 2013 occurred during the final approach or landing phases of flight (FSF, 2014). Based on the distribution of all flight paths during the phase of approach, the operator can determine when a flight may result in an unstable approach or landing. Statistical analysis is a tool to investigate the overall performance and determine the critical safety concerns for an airline’s operation. In addition, both exceedance analysis and statistical analysis can dive into the data on a specific target, such as phases of flight, airports, or aircraft type.

Similar to the exceedance analysis approach, basic descriptive statistical analysis is another approach used in flight data analysis. Appropriate application of statistical analysis can assist in identifying trends, outliers, and signal changes in performance (FSF, 2003). The benefit of adopting statistical analysis is that the aggregated flight data could be used to identify the latent risk of operations independent from the predefined specific exceedances; in addition, the data distributions can be used to establish the baselines for the trend analysis and determine the critical safety concerns (FAA, 2004). Unlike the exceedance analysis that depends on predefined limits, statistical analysis can detect anomalies both in terms of user-defined limits and statistical significance versus randomness (U.K.CAA, 2013). In addition, statistical analysis can be deployed in conjunction with information management software programs to support routine data analysis and processing of large size of datasets.

In addition to the two prevalent FDR data analysis approaches used in current Flight Data Monitoring (FDM) programs for flight safety enhancement, many other data analysis techniques are being developed and used for more specific objectives. Because both Exceedance Detection and Statistical Analysis rely on predefined baselines of the interesting indicators, only known
issues can be detected, and latent risks remain out of scope; data mining techniques have been studied to analyze the increasing large amount of aviation data to identify interesting patterns and trends in the data (Gavrilovski et al., 2016). Many observations in aviation data are either spatially or temporally related; for instance, aircraft flight parameters captured by FDR, tracks from radar, and aircraft GPS position data, are all in the form of sequential observations. Given that characteristics of flight data, time-series data mining strategies have been investigated, and primarily focused on:

“Classification: Given an unlabeled time series, assign it to one of multiple predefined classes such as phases of flight

Clustering: Find natural groupings of the time series in database under similarity/dissimilarity measure

Indexing: Given a query time series and some similarity/dissimilarity measure, find the nearest matching time from a database

Segmentation: Given a time series containing n data points, construct a model from piecewise segments such that it closely approximates the time series” (Keogh & Kasetty, 2003, p. 350).

A broader and specific view on all kinds of data mining techniques for data streams was included in the publication of Gaber, Zaslavsky, and Krishnaswamy (2005). Despite the differences between time-series techniques, the basic concept is to measure the dissimilarity between time series, and identify outliers based on the dissimilarity (Li & Hansman, 2013).
2.5 Flight Data Analysis of General Aviation

Although different operational characteristics are commonly recognized between commercial aviation and general aviation, flight data monitoring is still regarded as a useful approach for safety management in those two types of aviation activities. The FAA and the GA community have been cooperating on applying de-identified GA operational data in the Aviation Safety Information Analysis and Sharing (ASIAS) program to identify risks before they cause accidents (FAA, 2017a). However, until the early 2000s, most GA aircraft operators did not have a feasible method to collect routine flight data except from high-end business jets which have data buses compatible with quick access recorders (QAR) onboard (Rosenkrans, 2015). To address that issue, the National General Aviation Flight Information Database was launched as a joint FAA-industry initiative designed to bring voluntary FDM to general aviation, and a datalink between ASIAS and the NGAFID was built by the University of North Dakota in 2013 (FAA, 2015a). Based on the successful experience of using ASIAS to reduce the commercial aviation accident rate, in 2014, GAJSC initiated a pilot project on FDM and started to expand ASIAS to the GA community (FAA, 2014).

During routine commercial aviation FDM operations, representatives from one U.S. air carrier claim that FOQA sometimes only captures a portion of flight data given lack of maintenance personnel available to collect FOQA data from aircraft (Perera, 2014). Therefore, it is not hard to see that the technology and labor cost of commercial aviation-deployed FOQA are beyond the affordability of general aviation operations. The high cost of commercial aviation FDM programs and the advantages of FDM for improving GA safety led Mitchell, Sholy, and Stolzer to direct their research toward a capable, yet affordable FOQA program for the GA industry, in 2006 (Mitchell, Sholy, & Stolzer, 2006). Their proposed concept would extend the
GPS data by adding sensors to measure more flight parameters; however, their concept depends on the active cooperation of aircraft pilots, so as to avoid the costly process of air/ground data transfers (Mitchell, Sholy, & Stolzer, 2006).

In addition to the issues of the air/ground data transfer, the de-identified flight recorder data usually present problems with data transmission and data integration caused by hardware or software issues during commercial aviation FDM operations (Perera, 2014). Collecting flight operational data of GA is more difficult in terms of technology than commercial aviation. Typically, GA operators could collect flight operational data from FDR/QAR capable avionics, if equipped onboard. Garmin G1000 and Avidyne series are examples of popular FDR/QAR capable avionics. However, there is still a considerable proportion of GA aircraft not equipped with modern integrated flight instruments, which invalidates this data collection approach for the GA aircraft with conventional instruments. To explore another data collection method, the MITRE Corporation released the General Aviation Airborne Recording Device (GAARD) application, which is a prototype designed to collect certain types of flight data by using the Global Positioning System (GPS) module embedded on a mobile device (MITRE, 2015). Still, flight data collected by GAARD are limited. Without any additional sensors attached, GAARD is mostly limited to the position data generated by the GPS. Above all, incorporating GAARD as a flight data collection method requires active cooperation from GA aircraft pilots.

Given all limitations of current FDM programs designed for general aviation, there is a necessity to explore a more practical and affordable flight data analysis solution for GA.
2.6 **Automatic Dependent Surveillance Broadcast**

The Automatic Dependent Surveillance Broadcast (ADS-B) is a precise satellite-based surveillance system, which retrieves an aircraft’s location, speed, altitude, and other data from the Global Positioning System (GPS) and broadcasts that information to ground stations and nearby aircraft, as shown in Figure 2.2 (FAA, 2016b).

![ADS-B Diagram](image)


ADS-B has two types of functions: ADS-B In and ADS-B Out. ADS-B Out periodically broadcasts encoded messages containing flight information; ADS-B In receives and decodes the messages broadcast by ADS-B Out from other aircraft. Theoretically, ADS-B In capable ground stations and aircraft are able to receive the aircraft information broadcast by all other ADS-B Out capable aircraft within the maximum range of the ADS-B Out signal, while communication
satellites provide a solution to extend the coverage of the ADS-B Out signal. With the upcoming ADS-B mandated implementation date of January 1, 2020, there will be more GA aircraft equipped with ADS-B Out. Therefore, study on ADS-B data analysis is expected to be necessary to promote flight data analysis in GA operations.

Basically, there are two types of FAA-compliant physical layers to support ADS-B Out – Mode S Extended Squitter (Mode S ES) working on 1090 MHz, and the Universal Access Transceiver (UAT) working on 978 MHz; the selection of solutions depends on the aircraft operation altitude in the U.S. (FAA, 2016b). In general, the advantages of Mode S ES is that it is regulated by an international technical standard; however, it operates on a congested frequency band. Compared to the Mode S ES, the UAT has high data bandwidth and fewer interferers, but there is not an international standard to regulate the operations with technical provisions (Chen, Lo, Enge, & Jan, 2014). In other words, the UAT can handle more data, so more aircraft in a concentrated area will work without overloading ground stations or other aircraft, but the Mode S transponders are already installed on most large commercial aircraft, which is believed to help minimize the expense of promoting ADS-B equipage (FAA, 2014). To comply with the 2020 mandate, aircraft operating in Class A airspace (from an altitude of 18000 feet above mean sea level (MSL) to and including 60000 feet MSL) must broadcast flight position data using the Mode S ES; aircraft operating in designated airspace exclusively below 18000 feet MSL can use either Mode S ES or UAT (14 C.F.R. § 91.225). Currently, there are many aircraft already being equipped with a corresponding type of ADS-B Out system, but most of them are based on Mode S ES.

As one of the core elements of the next generation air transportation system (NextGen), ADS-B is believed to be useful for aviation safety by enhancing pilots’ situational awareness in airspace without radar coverage (FAA, 2016b). Early in 2007, the FAA invested U.S. $1.8
billion to deploy the ADS-B ground infrastructure to initiate the ADS-B Out broadcasting services (FAA, 2017c). By finishing the deployment in April 2014, there were about 634 radio stations distributed in more than 300 service volumes in the U.S., the service volume is defined as the geographical area with ADS-B Out service (FAA, 2017c). In 2011, Zhang, Liu, and Zhu (2011) evaluated the performance of ADS-B in China by comparing the ADS-B data to radar. Their study concluded that the performance of ADS-B is better than radar data, because the received air traffic information could be projected on user-end display by processing the ADS-B data (Zhang, Liu, & Zhu, 2011). ADS-B is considered to be the NextGen successor to radar as a tool of air traffic control (FAA, 2016b). To better apply ADS-B as an ATC tool, Jeon, Eun, and Kim (2015) proposed a system for the estimation fusion of multiple heterogeneous sensors, which includes radar and ADS-B. Wang (2015) also investigated ADS-B used in improvement of air traffic control. What is more, other operational environment information and decision-making functions can also be achieved by using the ADS-B data. As early as 1998, Hicok and Lee (1998) published the testing results of applying ADS-B for airport surface surveillance. In 2014, Orefice, Vito, Corraro, Fasano, and Accardo (2014) explored an aircraft conflict detection method based on ADS-B input data.

Apart from the benefits that ADS-B brings to pilot and air traffic control, ADS-B Out could also function as a good flight data source for aviation safety analysts. According to the ICAO technical provisions, ADS-B messages transmitted from the ADS-B Out capable aircraft shall include position, aircraft identity, airborne velocity, periodic status and event driven information, including emergency/priority information. (ICAO, 2014). With those features, ADS-B data have the potential to be used for other purposes. In 2015, McNamara, Mott, and
Bullock presented their research on applying ADS-B data to fleet management and airport operations (McNamara, Mott, & Bullock, 2015).

Given the advantages of ADS-B, the FAA requires all aircraft operating in assigned airspace to equip with ADS-B Out after January 1, 2020, which is supposed to improve overall air traffic safety (14 C.F.R. § 91.225, 2011; 14 C.F.R. § 91.227, 2014). With the execution of the FAA requirement on ADS-B Out, most aircraft operating in the U.S. will have to be ADS-B Out capable, and general aviation aircraft are no exception. Considering the technical assets of ADS-B Out and the regulatory requirement from government, we reasonably believe that ADS-B Out could provide a new approach to facilitate flight data analysis and the development of other safety enhancement solutions for general aviation. As required by the FAA, all aircraft operating in the following airspace must be equipped with ADS-B Out:

1. Class A, B, and C airspace
2. Class E airspace areas at or above 10,000 feet Mean Sea Level (MSL) over the 48 states and D.C., excluding airspace at and below 2,500 feet above ground level (AGL)
3. Airspace within 30 nautical miles of certain busy airports, from the surface up to 10,000 feet MSL; airports listed in appendix D to Part 91
4. Above the ceiling and within the lateral boundaries of a Class B or Class C airspace area up to 10,000 feet MSL
5. Class E airspace over the Gulf of Mexico at and above 3,000 feet MSL within 12 nautical miles of the coastline of the United States (FAA, 2017b).

The ADS-B Out requirement can be visualized in the following flowchart, Figure 2.3, to determine if ADS-B Out is needed for compliance with the FAA regulations regarding ADS-B requirements.
Figure 2.5 Flowchart of Determining the Requirement of ADS-B Out, adapted from the FAA (2017b)

2.7 Summary

An overview of aviation safety facts and safety enhancement strategies was provided in this chapter. The reduction of the accident rate of general aviation is one of the major objectives of the aviation community. Flight data analysis is expected to be an effective method to proactively prevent aviation accidents. However, because of the high cost of routinely conducting flight data monitoring and analysis, it is necessary to develop more practical and affordable flight data analysis approaches for GA.

In this chapter, the development, and applications of ADS-B technology were reviewed. The technical assets of ADS-B Out and relevant government regulations suggest that ADS-B Out could be a feasible data source to support GA flight data analysis.
CHAPTER 3. FRAMEWORK AND METHODOLOGY

3.1 Research Approach

General aviation (GA) pilots continue to fly with higher accident rates than commercial aviation pilots because of the nature of GA operations. Flight data analysis has been recognized as one of the most effective strategies to proactively increase flight safety and has been gradually implemented by many commercial airlines. However, due to the limited resources that the GA community owns, the flight data analysis programs for commercial airlines have not been popular in the GA community. The purpose of the current research was based on the use of the Automatic Dependent Broadcast (ADS-B) data to facilitate flight data analysis for GA. In other words, this research explored how to apply ADS-B data for flight safety analysis of GA, which included two tiers of objectives:

1. Develop flight metrics that could be retrieved or derived from messages broadcasted by the ADS-B Out equipment.

2. Develop the methods to analyze the ADS-B flight metrics in flight safety analysis.

Based on the fundamental purpose and specific tasks of this research, the proposed methodology was developed based on the model of knowledge discovery in database proposed by Fayyad et al. (1996), as shown in Figure 3.1.
The first step was decoding the ADS-B messages transmitted by an aircraft equipped with an ADS-B Out capable transponder. The second was collecting readable ADS-B data and storing ADS-B data into a database. In the second step, a decoded ADS-B message contains the basic flight parameters required by the standard technical provisions (ICAO, 2008). Datasets with better data quality in terms of data integrity and completeness are selected. For example, a set of flight data broadcasted by an individual aircraft during a single flight mission may not be fully received or successfully decoded; there could be missing values randomly distributed in the data set. Therefore, datasets with a large portion of missing values were not selected. Data sampling was conducted from the selected datasets based on the adopted sampling strategy in this research, which was illustrated in the section on Data Collection. Data preprocessing included the derivation of additional flight parameters. In order to turn the ADS-B data into meaningful flight information, the preprocessed ADS-B data were transformed as a set of flight metrics for further analysis in step three. Unlike data analysis in other fields, descriptive data analysis and exceedance detection worked as the primary method in flight safety data analysis (U.K. CAA, 2013). Typically, interesting patterns, trends, deviations, and other features of flight
metrics were measured and compared to the flight operations manual limits of a specific type of aircraft.

Given the features of iterative process in the model, the output of each step was not only the input for the next step, but also gave feedback to the previous steps; thus, necessary corrective measures, such as adjusting the sample size and tuning the data collection instrument, were taken to better the entire process toward the desired outcomes.

The application of ADS-B data was expected to be a good approach to facilitate flight data analysis for GA operations; however, this concept would be technically achieved only if useful flight data could be obtained from an ADS-B Out message. Given that prerequisite, qualitative approaches were adopted to examine the first hypothesis:

1. Informative flight metrics can be retrieved or derived from ADS-B Out for the purpose of GA flight data analysis.

Enhancing flight safety was the primary motivation of flight data analysis, and exceedance analysis is one of the two major analysis techniques in flight data analysis (FAA, 2008). Therefore, exceedance detection was adopted as the flight data analysis technique in this study. However, exceedance detection could be practically conducted only if flight metrics could effectively measure flight operations and used to detect flight exceedances. The process of exceedance detection using ADS-B data was conducted on the second hypothesis:

2. Flight metrics developed based on ADS-B data can be used to detect flight operational exceedances in GA operations.

In addition, researcher believes that exceedance detection could be affected by many factors. In this study, the reception rate of ADS-B data was investigated as the influential factor affecting the exceedance detection, and analysis was conducted to verify the third hypothesis:
3. The reception rate of ADS-B data affects the exceedance detection.

Methods to detect flight exceedance were developed using the flight metrics developed upon ADS-B data; then, the differences in exceedance detection were compared by varying the reception rates of ADS-B data. The ADS-B data used in this comparison was emulated from the Flight Data Recorder (FDR) data, which was the richest flight data currently available.

To answer the research questions, this research was designed to be conducted with the following procedures:

*Step one:* Analyze the structure and content of ADS-B Out messages, identified flight parameters that could be retrieved from an ADS-B Out message.

*Step two:* Derive flight metrics based on the basic flight parameters identified in *Step one*.


*Step four:* Receive and decode ADS-B Out messages, and preprocess the decoded ADS-B data for the use of exceedance detection.

*Step five:* Detect the identified exceedances using the developed flight metrics or parameters.

*Step six:* Determine the reception rates of ADS-B Out messages, and emulate the ADS-B data with determined reception rates by manipulating the Garmin G1000 data files.

*Step seven:* Detect the same types of identified exceedances using the emulated ADS-B data, and analyze and compare the differences in exceedance detection by varying the reception rate of ADS-B data.

*Step eight:* Summarize the findings of this research.
3.2 Data Collection

In order to study the actual solution of using ADS-B data in flight data analysis for general aviation, experiments and analysis were based on real general aviation flight data collected with a ground-based ADS-B receiver. In this research, a portable ADS-B receiver was built and deployed at Purdue University Airport (KLAF) to collect flight data transmitted from KLAF based aircraft. Currently, there are 81 aircraft based at KLAF, including 71 single engine GA airplanes, 7 multi engine GA airplanes, 4 jet GA airplanes, and 1 helicopter (FAA, 2016a). However, because helicopters have different flight procedures and operational characteristics than fixed-wing aircraft, only fixed-wing aircraft data were used in this research.

3.2.1 Population and Sampling

In this research, the population was the ADS-B Out capable GA aircraft based at Purdue University Airport. Currently, 13 Cirrus SR20-G3 S and 3 Cirrus SR20-G2 GTS were ADS-B Out compliant with Mode S ES transponders based at Purdue University Airport (Purdue University, 2016). Flight data used in this research were collected from those 16 ADS-B Out compliant Cirrus reciprocating engine aircraft by using 1090 MHz ADS-B receiver(s). Typically, the sample size for quantitative analysis should be determined by using a target variance for an estimate to be derived from the sample. A target for the power of a statistical test, a confidence level, and other techniques can also be used to determine the sample size. In this research, the ADS-B data were analyzed qualitatively to evaluate the fitness for flight safety analysis. Therefore, the typical methods of determining sample size for quantitative research might not be applicable at this phase of study. Accordingly, sample size was determined with a method used for qualitative research, thus; the sample sizes should be large enough to attain information
saturation (Glaser & Strauss, 1967). Since there was not a standard of sample size to guarantee the attainment of saturation, a convenience sampling strategy was adopted for this research and a rule of thumb was adopted to determine the sample size: A set of flight data recorded in a single flight mission was considered as one unit; 40 sets of flight data were selected from the total data sets to be analyzed. The selection of sample considered the quality of flight data, such as the density of observations and data integrity.

3.2.2 Data Collection Approach

The Automatic Dependent Surveillance Broadcast (ADS-B) technology is a precise satellite-based surveillance system. ADS-B Out retrieves the aircraft’s location, speed, altitude, and other data from GPS and other sensors, and broadcasts that information to the ground receiver station and nearby ADS-B In capable aircraft (FAA, 2016b). Basically, there are two types of recognized ADS-B Out solutions available for aircraft to choose from, depending on the aircraft operation altitude in the U.S. – Mode S Extended Squitter (Mode S ES) working on 1090 MHz, and the Universal Access Transceiver (UAT) working on 978 MHz (FAA, 2016b).

Flight data used in this research came from the Cirrus SR-20 aircraft of Purdue University. For this research, 13 Cirrus SR20-G3 S and 3 Cirrus SR20-G2 GTS are ADS-B Out compliant with Mode S ES transponders (Purdue University, 2016). Flight data used in this research were collected from those 16 ADS-B Out compliant Cirrus reciprocating engine aircraft by using 1090 MHz ADS-B receiver(s). The data collection approach is demonstrated in Figure 3.2. The range of the ADS-B signal depends on antenna height, aircraft altitude and terrain. Theoretically, the range for air-to-ground transmitting is around 150 nautical miles (FAA, 2016b). Therefore, for a long-range cross-country flight that is farther than 150 nautical miles,
several ADS-B receivers must be set up along the flight route to collect more comprehensive flight data, as shown in Figure 3.3.

![Diagram](image)

**Figure 3.2 Flight Data Collection using the ADS-B Receiver**

![Diagram](image)

**Figure 3.3 Data Collection for Long Range Cross-Country Flight**

Theoretically, flight data are broadcast by the ADS-B Out capable Mode S transponder once per second, which contains the basic flight parameters, such as aircraft identity, surface position data, airborne position data, airborne velocity, and other operational data. The ADS-B receiver remained continuously operational to listen to the ADS-B message while collecting
data. When the receiver intercepted an ADS-B Out signal, a timestamp was attached to the data packet using the computer time. In the meantime, the ADS-B Out message was decoded and converted into readable flight parameters automatically by software programs on the computer. In fact, the ADS-B receiver used in this research integrated the ADS-B receiver and computer into one module, as introduced in the following paragraph. Different flight parameters were identified by checking the type code of an ADS-B Out message, and the source of flight data was identified by matching the aircraft identity. Therefore, the decoded ADS-B messages were organized with respective data fields, and the raw flight data were saved in a relational database for later analysis and further study.

3.2.3 Data Collection Tool

There are various models of ADS-B receivers and compatible software applications available on the market. However, building a customized ADS-B receiver was believed to be more flexible and extendable in general for further research and development. Therefore, an ADS-B receiver was built by the researcher to collect flight data.

Given the low-cost characteristics of general aviation, an affordable self-built ADS-B receiver was used as the instrument to collect flight data. After comparing the cost and technical specifications of possible solutions, an ADS-B receiver was built based on the platform of the Raspberry Pi 3 micro-computer. The first version of the ADS-B receiver was assembled and tested in October 2016, and is shown in Figure 3.4.
Based on the testing result of poor receiver sensitivity, this first version of the ADS-B receiver was modified by attaching a band-pass filter and a 1090MHz outdoor antenna to the architecture of the ADS-B receiver, shown as Figure 3.5 and Figure 3.6.
Figure 3.5 The Second Version ADS-B Receiver

Figure 3.6 Architecture of the ADS-B Receiver
This ADS-B receiver project was developed on the Raspberry Pi 3 computer, which decodes the ADS-B message received by a software-defined radio (SDR). SDR is a radio communication system embedded with radio signal processing software and radio frequency (RF) front end, such as antenna, RF radio, RF amplifier, local oscillator, and mixer. A vertically polarized antenna was attached to the SDR to receive the radio signal. The SDR module received the ADS-B radio signal broadcasted by the ADS-B Out capable aircraft, and output the binary flight information. The binary information was decoded on the Raspberry Pi 3 computer using a decoding software - Dump1090, which was released under the BSD three clause license on the Github (Sanfilippo, 2012). There were many other approaches to write the scripts to decode the binary flight information. However, all codes should be written based on the algorithms provided by the ADS-B technical standards (ICAO, 2008). The uncleansed flight data were output after being decoded on the Raspberry Pi 3. The decoded ADS-B data were written on the SD card and migrated to a relational database, which was implemented on another computer for preprocessing and analyses. The decoded ADS-B data could also be transmitted to the database through Wi-Fi in real-time.

The second version of receiver was deployed near Purdue University Airport to collect flight data, shown as Figure 3.7 (a) (b). The location was at the east side of the extended center line of Runway 23. This location is relatively higher than the surrounding area with a flat landscape. The clear sight without blocking is helpful for transmitting and receiving radio signals.
Figure 3.7 (a) Deployed ADS-B Receiver (b) Location of Deployment

3.2.4 Additional Data Sources

This research explored the use of the ADS-B data for flight data analysis in GA. In addition to the informative flight metrics and methods of using flight metrics, the reception rate of ADS-B data was another factor that may affect the exceedance detection in flight data analysis. However, it was impractical to control the reception rate through the ADS-B receiver; therefore, ADS-B data with different reception rates were emulated from the Flight Data Recorder (FDR) data. Currently, FDR data were the richest flight data available, and the
historical FDR data recorded by the Garmin G1000 system was used in this study as additional data. The FDR data used in this study were secured from the Purdue Cirrus SR20 fleet.

### 3.3 Data Analysis

The selection of appropriate data analysis techniques for this research was a crucial step to determine whether the research could proceed to unbiased findings. The selected data analysis techniques should perform well on aviation safety data analysis. Exceedance detection, as one of the most effective safety analysis techniques in flight data monitoring programs, was selected in this study as the flight data analysis technique (FAA, 2004; U. K. CAA, 2013; EASA, 2015).

Reviewing the research goal: Applying ADS-B data to facilitate flight data analysis in general aviation, the proposed research focused on investigating the feasibility of applying ADS-B data to support GA flight data analysis. Therefore, three aspects of ADS-B data were studied: 1) What flight metrics can be retrieved or derived from ADS-B data for flight data analysis in GA? 2) How can the flight metrics be used to detect the flight operational exceedances? And 3) What are the differences in exceedance detection with varying reception rates of ADS-B data?

In this research, the first task was to explore the capability of ADS-B data from the perspective of supporting flight data analysis. The structure and content of ADS-B data was analyzed; sets of flight metrics were retrieved or derived. In flight data analysis, statistical analysis and exceedance analysis were the two primary functions (FAA, 2004). In this study, the exceedance analysis was selected to analyze the developed flight metrics using the collected ADS-B data. Based on the developed flight metrics, five exceedance detection functions were selected, as introduced in Chapter 3.4, and were paired to corresponding flight metrics. However, many limitations were believed to exist with the results; for instance, the accuracy of exceedance
detection was not examined, the sample size of flight data was limited, and the ADS-B data quality was not assured. Given those limitations, the researcher determined that quantitative analysis would not reveal trustworthy findings. Therefore, a qualitative analysis strategy was adopted to extract information from the results of analysis concerning the possibility of applying ADS-B data in flight data analysis.

In addition to the identified limitations, the researcher noticed that there was a prominent influential factor, which might affect the flight exceedances detection – the reception rate of ADS-B data. However, many factors affect the reception rate of ADS-B data; including the performance of the ADS-B receiver, and the location where the ADS-B receiver was deployed. Therefore, to examine the influence of the ADS-B data reception rates on exceedances detection, the differences in exceedance detection were compared and analyzed by varying the ADS-B data reception rate. In this study, ADS-B data with different data reception rates were emulated and used in exceedance detection, and the results of exceedance detections were compared and discussed.

The first part of data analysis was based on basic physical rules and mathematical theories, such as the acceleration formula, and inverse trigonometric functions. In this study, 29 flight metrics were retrieved or derived from ADS-B data, as shown in Table 3.1, and were used to detect the five exceedances.
<table>
<thead>
<tr>
<th>Flight Metric</th>
<th>ADS-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Derive</td>
</tr>
<tr>
<td>Latitude</td>
<td>Retrieve</td>
</tr>
<tr>
<td>Longitude</td>
<td>Retrieve</td>
</tr>
<tr>
<td>Altitude (AGL)</td>
<td>Retrieve</td>
</tr>
<tr>
<td>Ground speed</td>
<td>Retrieve</td>
</tr>
<tr>
<td>Airspeed (IAS)</td>
<td>Retrieve</td>
</tr>
<tr>
<td>Heading</td>
<td>Retrieve</td>
</tr>
<tr>
<td>Vertical Rate</td>
<td>Retrieve</td>
</tr>
<tr>
<td>GPS Track</td>
<td>Derive</td>
</tr>
<tr>
<td>Glide Angle</td>
<td>Derive</td>
</tr>
<tr>
<td>Climb Angle</td>
<td>Derive</td>
</tr>
</tbody>
</table>

For the second part of the analysis, the exceedances of flight operations could be determined by many approaches, and are usually suggested in the Pilot Operating Manual (POH) of a specific type of aircraft. In this study, exceedances and corresponding thresholds were identified using the Cirrus SR20 Flight Operations Manual. Analysis of flight exceedance using the developed flight metrics were based on the procedure shown as Figure 3.8.
In this study, five exceedances were selected, based on the Cirrus SR20 Flight Operations Manual (Cirrus Aircraft, 2011):

1. No turn before reaching 400 feet above ground level (AGL) during the phase of takeoff.

2. Suggested climb angle during initial climb from 0 to 1000 feet AGL: 7 – 10 degrees.


5. Stabilized Approach: Constant glide angle established from 500 feet AGL to 0 feet AGL, for flight under visual flight rules (VFR).

The third task was to compare the differences in exceedance detection by varying the reception rates of ADS-B data, since the frequency of receiving ADS-B data would affect the exceedance detection. However, controlling the reception rate through the ADS-B receiver was impractical at the current phase of this research. In this research, ADS-B data with different reception rates were emulated from FDR data, because FDR data were the richest flight data
currently available with 60 records per minute for each flight parameter. Three reception rates: 4 records per minute for each parameter, 20 records per minute for each parameter, and 40 records per minute for each parameter, were emulated and used in the selected five exceedances detection, to compare the differences.

In addition, given the sparseness of the ADS-B data with low reception rate (approximately a 15-second interval between two datum points), simple straight-line connection between contiguous data points did not adequately reflect the actual flight history in the process of generating flight profiles, because a recording of flight operations should be a time series, and the flight attitude change is a gradual procedure; the simple connection between discrete data points could not reflect the nature of real flight operations. In an effort to roughly recover the flight history using the sparse ADS-B data, a smooth line was drawn through the observed data points. Given the sparse ADS-B data, a cubic spline was used to bridge the gap between observed adjacent data points while considering the trend of time series. The cubic spline uses the cubic function “\(S_i; i = 0,1,2 \ldots n - 1\) so as to piece together a curve with continuous first and second derivations” (Pollock, 1999, p. 2):

The cubic function \(S_i\) can be expressed as (Pollock, 1999, p. 3):

\[
S_i(x) = a_i(x - x_i)^3 + b_i(x - x_i)^2 + c_i(x - x_i) + d_i
\]

where \(x\) is from \(x_i\) to \(x_{i+1}\)

The first and second derivatives of this function can be expressed as (Pollock, 1999, p. 2):

\[
S'_i(x) = 3a_i(x - x_i)^2 + 2b_i + c_i
\]

\[
S''_i(x) = 6a_i(x - x_i) + 2b_i
\]

In addition, the condition that \(S_i\) and \(S_{i-1}\) meet at the point \((x_i, y_i)\) can be expressed as \(S_{i-1}(x_i) = S_i(x_i) = y_i\), also, the first and second derivatives should be equal (Pollock, 1999).
3.4 Summary

This chapter described the methodology used in this study. It listed the research approaches for each corresponding hypothesis, described the data collection method, and the data analysis techniques used in this research.
CHAPTER 4. RESULTS

The objective of this research was to identify the flight safety metrics from the ADS-B data to conduct exceedance detection using flight data broadcasted by ADS-B Out capable aircraft, focused on GA flight paths near an airport. The following research work has been done by the researcher to complete this study:

1. The structure and content of ADS-B Out messages were analyzed, based on the technical provision for mode S service and extended squitter (ICAO, 2008).
2. Based on the content of ADS-B messages, a set of flight metrics was developed from the standpoint of flight data analysts. Additional flight metrics were developed by incorporating relevant aeronautical information.
3. An ADS-B receiver was built and deployed at Purdue University Airport to collect ADS-B data.
4. Five exceedances were identified using the Cirrus SR-20 Pilot Operating Handbook (POH) to test and analyze the developed flight metrics using collected ADS-B data.
5. The results of exceedance detection were compared and analyzed by using emulated ADS-B data with different reception rates.

The results of the above research tasks are described in this Chapter¹.

4.1 Structure and Content of ADS-B Out Message

ADS-B uses the global positioning system (GPS) to determine an aircraft’s location and airspeed, derives other flight data from onboard avionics, and broadcasts all information

¹This chapter builds and expands on the work presented in Huang and Johnson (2017).
periodically over the 1090 MHz extended squitter (ICAO, 2008). The extended squitter is an extended portion of the mode S transponder’s transmission bandwidth, which contains the ADS-B information in the form of data packets. According to ICAO’s *Technical Provisions of Mode S Services and Extended Squitter* (ICAO, 2008), ADS-B data are structured with a standard format. An ADS-B message is 112 bits long encoded either in BIN format or HEX format, and the format is specified by the Radio Technical Commission for Aeronautics (RTCA) ADS-B Out minimum operational performance standards (2009) and the ICAO technical provisions (2008). The structure of ADS-B data in this research can be format as Table 4.1.

Table 4.1 *Structure of an ADS-B Message* (Huang & Johnson, 2017; ICAO, 2008; RTCA, 2009)

<table>
<thead>
<tr>
<th>Bit from</th>
<th>Bit to</th>
<th>Type of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>Downlink Format</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>Message Subtype</td>
</tr>
<tr>
<td>9</td>
<td>32</td>
<td>ICAO Aircraft Address</td>
</tr>
<tr>
<td>33</td>
<td>88</td>
<td>Data Frame</td>
</tr>
<tr>
<td>89</td>
<td>112</td>
<td>Parity Check</td>
</tr>
</tbody>
</table>

The content of an ADS-B message is encoded in different sections in the 112 bits of the message. Each type of data functions to convey the necessary information to transmit relevant aircraft data. For example, the Downlink Format (DF), from bit 1 to bit 5, is used to identify the type of message, the DF for ADS-B message is fixed as 17, or 10001 in binary format. The most aircraft information is contained in the Data Frame, from bit 33 to bit 88. In the Data Frame, the value of bit 33 to 37 encodes the Type of Code, which is used to indicate the specific aircraft information, shown as Table 4.2.
Table 4.2 *ADS-B Message Types* (Huang & Johnson, 2017; ICAO, 2008; RTCA, 2009)

<table>
<thead>
<tr>
<th>Type Code (TC)</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 4</td>
<td>Aircraft identity</td>
</tr>
<tr>
<td>5 to 8</td>
<td>Surface position</td>
</tr>
<tr>
<td>9 to 18</td>
<td>Airborne position (Barometric altitude)</td>
</tr>
<tr>
<td>19</td>
<td>Airborne velocities</td>
</tr>
<tr>
<td>20 to 22</td>
<td>Airborne position (GNSS height)</td>
</tr>
<tr>
<td>23</td>
<td>Test message</td>
</tr>
<tr>
<td>24</td>
<td>Surface system status</td>
</tr>
<tr>
<td>25 to 27</td>
<td>Reserved</td>
</tr>
<tr>
<td>28</td>
<td>Extended squitter AC status</td>
</tr>
<tr>
<td>29</td>
<td>Target state and status (V.2)</td>
</tr>
<tr>
<td>30</td>
<td>Reserved</td>
</tr>
<tr>
<td>31</td>
<td>Aircraft operation status</td>
</tr>
</tbody>
</table>

Based on the *ADS-B* message types shown as above, a series of 11 aircraft parameters can be encoded into *ADS-B* messages. In general, aircraft information that can be transmitted through *ADS-B* messages includes airborne position, airborne velocity, surface position, aircraft identification and emitter category, and event-driven protocols (ICAO, 2013b). A comprehensive list of aircraft parameters that could be transmitted through *ADS-B* messages can be found in the ICAO Doc 9871 - *Technical Provisions for Mode S Services and Extended Squitter* (ICAO, 2008). For each parameter, information is encoded in a specific data format in the *ADS-B* message. In this report, only a high-level *ADS-B* message structure was described considering the concentration is not on the decoding method of *ADS-B* Out messages. In this research, a set
of flight parameters that most likely could be decoded from ADS-B messages using an ordinary ADS-B receiver was summarized as Table 4.3.

The basic flight parameters that could be decoded from ADS-B messages include Aircraft Callsign, Latitude and Longitude of Aircraft Position, Barometric Altitude above mean sea level (MSL) or the Height of Aircraft above the Ellipsoid (HAE), Ground Speed, Ground Track, Airspeed, Heading, Vertical Speed, and other indicators of data integrity, accuracy, or uncertainties of the position measurement from GPS unit. However, based upon the actual received ADS-B data, only a few aircraft reported Heading and Airspeed.

Table 4.3 Basic Flight Information Contained in ADS-B Messages (Huang & Johnson, 2017)

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Primary</th>
<th>Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Timestamp of received frame</td>
<td>Timestamp of received frame</td>
</tr>
<tr>
<td>Aircraft Identification</td>
<td>ICAO ID/Callsign</td>
<td>ICAO ID/Callsign</td>
</tr>
<tr>
<td>Surface Position</td>
<td>Latitude</td>
<td>Latitude</td>
</tr>
<tr>
<td></td>
<td>Longitude</td>
<td>Longitude</td>
</tr>
<tr>
<td>Airborne Position</td>
<td>Altitude (Barometric Altitude)</td>
<td>Altitude (GNSS Height)</td>
</tr>
<tr>
<td></td>
<td>Ground Track</td>
<td>Heading</td>
</tr>
<tr>
<td>Velocities</td>
<td>Ground Speed</td>
<td>Airspeed</td>
</tr>
<tr>
<td></td>
<td>Vertical Speed</td>
<td>Vertical Speed</td>
</tr>
</tbody>
</table>

Note. The primary flight information is transmitted as default by ADS-B Out; alternative parameters are transmitted as optional or when the primary information is not available. Adapted from “Exploring ADS-B as an Alternative Data Source for Flight Data Monitoring of General Aviation” by C. Huang and M. E. Johnson, 2017, Collegiate Aviation Review – International, 2, p. 21. Copyright 2017 by the University Aviation Association. Adapted with permission.
4.2 Data Description

The portable ADS-B receiver was first deployed in October 2016 to collect flight data at Purdue University Airport (KLAF). A number of flight operations of the Purdue Cirrus SR20 fleet from October 2016 to May 2017 were collected. Thirty flight operations were selected for data analysis according to the data quality and flight operational characteristics. Given the ADS-B data from training flights, flights could be roughly categorized into cross country flights and local flights. However, because of the low-altitude operations of traffic pattern training, ADS-B data quality was greatly affected by surrounding obstacles blocking the ADS-B Out radio signal. In addition, flight maneuvers training resulted in a lack of regularity compared to cross-country flight training or traffic pattern training, shown in Figure 4.1. Therefore, the selected 40 sets of ADS-B data only reflected cross-country flights between KLAF and airports in the vicinity. The locations of airports near Purdue University Airport are shown in Figure 4.2.
Figure 4.1 Example of Performance Maneuvers Training

*Note.* The vertical bars represent the positions and altitudes of an aircraft’s movement plotted using ADS-B data.
Figure 4.2 Locations of Vicinity Airports Near Purdue (FAA, 2016a)

*Note.* Figure 4.2 is the obtained using a Google Earth add-on provided by the FAA.

As described in Chapter 3, ADS-B Out encoded relevant flight information and broadcasts to nearby receiving devices with analog signal via 1090MHz or 978MHz. In order to obtain analyzable flight data, the ADS-B Out signal was decoded using radio tuner and decoding software. More details can be found in Chapter 3. After data processing, an example of the decoded ADS-B data set is shown in Figure 4.3.
<table>
<thead>
<tr>
<th>Time (EST)</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Track</th>
<th>Ground Speed (KTS)</th>
<th>MSL (feet)</th>
<th>Vertical Rate (f/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun 13:43:53</td>
<td>40.3911</td>
<td>-86.9745</td>
<td>287°</td>
<td>106</td>
<td>1,300</td>
<td>0</td>
</tr>
<tr>
<td>Sun 13:44:08</td>
<td>40.3959</td>
<td>-86.9821</td>
<td>328°</td>
<td>104</td>
<td>1,500</td>
<td>706</td>
</tr>
<tr>
<td>Sun 13:44:27</td>
<td>40.4045</td>
<td>-86.9840</td>
<td>11°</td>
<td>107</td>
<td>1,700</td>
<td>769</td>
</tr>
<tr>
<td>Sun 13:44:47</td>
<td>40.4138</td>
<td>-86.9800</td>
<td>19°</td>
<td>104</td>
<td>2,000</td>
<td>686</td>
</tr>
<tr>
<td>Sun 13:45:02</td>
<td>40.4212</td>
<td>-86.9766</td>
<td>20°</td>
<td>109</td>
<td>2,100</td>
<td>600</td>
</tr>
<tr>
<td>Sun 13:45:17</td>
<td>40.4274</td>
<td>-86.9736</td>
<td>20°</td>
<td>109</td>
<td>2,300</td>
<td>800</td>
</tr>
<tr>
<td>Sun 13:45:32</td>
<td>40.4353</td>
<td>-86.9695</td>
<td>22°</td>
<td>113</td>
<td>2,500</td>
<td>600</td>
</tr>
<tr>
<td>Sun 13:45:47</td>
<td>40.4428</td>
<td>-86.9654</td>
<td>22°</td>
<td>112</td>
<td>2,600</td>
<td>800</td>
</tr>
<tr>
<td>Sun 13:46:02</td>
<td>40.4498</td>
<td>-86.9618</td>
<td>19°</td>
<td>100</td>
<td>2,900</td>
<td>857</td>
</tr>
<tr>
<td>Sun 13:46:43</td>
<td>40.4675</td>
<td>-86.9547</td>
<td>18°</td>
<td>93</td>
<td>3,400</td>
<td>750</td>
</tr>
<tr>
<td>Sun 13:46:58</td>
<td>40.4738</td>
<td>-86.9519</td>
<td>20°</td>
<td>95</td>
<td>3,600</td>
<td>800</td>
</tr>
<tr>
<td>Sun 13:47:13</td>
<td>40.4795</td>
<td>-86.9487</td>
<td>24°</td>
<td>100</td>
<td>3,800</td>
<td>600</td>
</tr>
<tr>
<td>Sun 13:47:28</td>
<td>40.4868</td>
<td>-86.9446</td>
<td>22°</td>
<td>103</td>
<td>3,900</td>
<td>581</td>
</tr>
<tr>
<td>Sun 13:47:44</td>
<td>40.4941</td>
<td>-86.9407</td>
<td>22°</td>
<td>105</td>
<td>4,100</td>
<td>750</td>
</tr>
<tr>
<td>Sun 13:48:00</td>
<td>40.5008</td>
<td>-86.9371</td>
<td>23°</td>
<td>103</td>
<td>4,300</td>
<td>714</td>
</tr>
<tr>
<td>Sun 13:48:26</td>
<td>40.5119</td>
<td>-86.9313</td>
<td>18°</td>
<td>98</td>
<td>4,600</td>
<td>732</td>
</tr>
</tbody>
</table>

Figure 4.3 Example of Decoded ADS-B Data

Note. Flight data were broadcasted by Purdue Cirrus SR20 aircraft; aircraft ID was intentionally removed for privacy protection.

To test the feasibility of developed flight metrics, a set of flight metrics was selected to be tested using collected ADS-B data. First, the flight profiles were visualized by using the aircraft 4-dimensional data to generally understand the flight features; an example is shown as Figure 4.4.
As shown in Figure 4.4, the general flight profile can be visualized; however, the poor integrity of received ADS-B data decreases the accuracy of the GPS track. For example, poor integrity was due to the relatively large amount of missing data for the phases of flight near the ground level, and the frequency of being able to receive ADS-B data was far lower than one time per second. Those issues were believed to result from the location where the ADS-B receiver was installed, and the capability of the receiver.

The basic flight parameters were demonstrated with the collected ADS-B data, shown in Figure 4.5. The operational features of flight could be roughly displayed, but better quality data would increase the accuracy of flight data analysis using ADS-B data.
a) Plot of Aircraft Altitude Above Mean Sea Level

![Altitude Above Mean Sea Level](image)

b) Plot of Aircraft Ground Speed

![Ground Speed in Knots](image)

Figure 4.5 Visualization of Basic Flight Parameters Using ADS-B Data
Figure 4.5 continued

(c) Plot of Aircraft Course Track

Figure 4.5 Visualization of Basic Flight Parameters Using ADS-B Data

d) Plot of Aircraft Vertical Rate
In addition, derived flight metrics were measured using collected ADS-B data. Climb/Glide angle is shown as an example here, in Figure 4.6. Empirically, constant climb/glide angle was highly related to safe takeoff and stable approach. Appropriate data analysis algorithms for Climb/Glide Angle were expected to be useful to identify the safety trend of takeoff and approach.

![Figure 4.6 Climb/Glide Angles Derived from ADS-B Data](image)

*Note.* Positive value indicates Climb Angle. Negative value indicates Glide Angle.

### 4.3 Answers to Research Questions

#### 4.3.1 Flight Metrics Developed from ADS-B Data

With the purpose of supporting flight data monitoring and flight operations analysis, an initial set of flight metrics related to exceedances, safety events, pilot performance, and fleet performance were developed using the flight data transmitted by ADS-B Out, shown as Table
4.3. This set of flight metrics was developed based upon identifying the types of metrics and measures that would help GA reduce risk of accidents. The initial set of basic flight metrics was either directly retrieved or derived from the flight parameters contained in the ADS-B Out messages. Those basic flight metrics were expected to provide primary information to describe the profile of flights, and prepare information for further flight data analysis for desired purposes.

Given the limited number of basic flight data broadcasted by ADS-B Out, the identified flight metrics were directly retrieved from ADS-B messages or derived with additional aeronautical and physics knowledge. For instance, the Glide Angle and Climb Angle were derived using Ground Speed, Vertical Speed, and Timestamp as shown in Figure 4.7.

\[
\alpha = \frac{1}{n} \sum_{i=0}^{n} \arctan \frac{V_{Si}}{G_{Si}}
\]


Similar to the Glide/Climb Angle, Flight Time was estimated using the ADS-B Out message timestamp; GPS Track was generated using aircraft Coordinates, Altitude and Timestamp; Vertical and Longitudinal g-force were calculated using corresponding instantaneous speed and timestamps, as shown in Figure 4.8.
\[ a_v = \frac{\Delta V_S}{\Delta t} = \frac{V_{S_{i+1}} - V_{S_i}}{t_{i+1} - t_i}, (i = 0, 1, 2 \ldots n) \]

\[ a_{lon} = \frac{\Delta G_S}{\Delta t} = \frac{G_{S_{i+1}} - G_{S_i}}{t_{i+1} - t_i}, (i = 0, 1, 2 \ldots n) \]

Figure 4.8 Calculation of the Vertical and Longitudinal G-force

Where \( a_v \) is the Vertical g-force, \( a_{lon} \) is the longitudinal g-force, \( V_{S_i} \) is the vertical speed at time \( i \), \( G_{S_i} \) is the ground speed at time \( i \).

Heading Change Rate was estimated using aircraft Heading/Track information and the corresponding Timestamp; Day/Night Operations were estimated by tracking the aircraft activities.

The specific flight metrics and the corresponding needed data for the use of deriving flight metrics were shown in Table 4.4.
Table 4.4 *Flight Metrics Identified Using Basic ADS-B Data* (Huang & Johnson, 2017)

<table>
<thead>
<tr>
<th>Flight Metric</th>
<th>ADS-B Data Needed</th>
<th>Flight Metric</th>
<th>ADS-B Data Needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight altitude</td>
<td>Altitude</td>
<td>Maximum altitude</td>
<td>Altitude</td>
</tr>
<tr>
<td>Ground speed</td>
<td>Ground speed</td>
<td>Airspeed</td>
<td>Airspeed</td>
</tr>
<tr>
<td>Vertical speed</td>
<td>Vertical speed</td>
<td>Vertical g-force</td>
<td>Vertical speed</td>
</tr>
<tr>
<td>Glide angle</td>
<td>Ground speed</td>
<td>Climb angle</td>
<td>Ground speed</td>
</tr>
<tr>
<td></td>
<td>Vertical speed</td>
<td></td>
<td>Vertical speed</td>
</tr>
<tr>
<td></td>
<td>Timestamp</td>
<td></td>
<td>Timestamp</td>
</tr>
<tr>
<td>Heading</td>
<td>Heading</td>
<td>Heading change rate</td>
<td>Heading</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flight time</td>
<td>Aircraft ID</td>
<td>Longitudinal</td>
<td>Airspeed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>acceleration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Timestamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS track</td>
<td>Latitude</td>
<td>Night time</td>
<td>Aircraft ID</td>
</tr>
<tr>
<td></td>
<td></td>
<td>operations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Altitude</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Timestamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daytime operations</td>
<td>Aircraft ID</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Timestamp</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GPS track</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Tables 4.3 and 4.4 show the initial and basic metrics; all of these metrics can be retrieved or derived by directly using corresponding ADS-B data. More metrics were expected to be developed based on the purposes of specific flight data analyses. The list of flight metrics was expected to be extendable to meet particular requests of flight analysts. For example, Flight Data Monitoring was used to detect flight operational exceedances, monitor pilot and fleet
performance, and identify safety-related occurrences. To demonstrate some of the flight metrics derivable from ADS-B messages, an additional set of flight metrics was developed by incorporating other common aeronautical information, shown as Table 4.5.
Table 4.5 *Flight Metrics Identified with Additional Aeronautical Information* (Huang, & Johnson, 2017)

<table>
<thead>
<tr>
<th>Additional Metric</th>
<th>Basic Metric</th>
<th>Aeronautical Information</th>
<th>Additional Metric</th>
<th>Basic Metric</th>
<th>Aeronautical Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessive longitudinal acceleration</td>
<td>Longitudinal acceleration</td>
<td>Exceedance information</td>
<td>Excessive vertical acceleration</td>
<td>Vertical g-force</td>
<td>Exceedance information</td>
</tr>
<tr>
<td>Loss of separation</td>
<td>GPS track</td>
<td>Separation standards</td>
<td>Altitude above ground level</td>
<td>Altitude</td>
<td>Ground level above MSL</td>
</tr>
<tr>
<td>Deviation from runway centerline</td>
<td>GPS track</td>
<td>Airport information</td>
<td>Altitude en-route minimum</td>
<td>Altitude</td>
<td>Flight plan</td>
</tr>
<tr>
<td>Undershoot/Overshoot</td>
<td>GPS track</td>
<td>Airport information</td>
<td>Runway excursion</td>
<td>GPS track</td>
<td>Airport information</td>
</tr>
<tr>
<td>Runway incursion</td>
<td>GPS track</td>
<td>Airport information</td>
<td>Estimated distance from reported weather hazards</td>
<td>GPS track</td>
<td>Weather information</td>
</tr>
<tr>
<td>Runway float time</td>
<td>GPS track</td>
<td>Airport information</td>
<td>Altitude in relation to low-altitude en-route chart minimum obstruction clearance altitude</td>
<td>Altitude</td>
<td>Low-altitude chart information</td>
</tr>
<tr>
<td>Altitude in relation to sectional chart maximum elevation</td>
<td>Altitude</td>
<td>Sectional chart information</td>
<td>Altitude in relation to low-altitude en-route chart minimum en-route altitude</td>
<td>Altitude</td>
<td>Low-altitude chart information</td>
</tr>
</tbody>
</table>

In addition, this preliminary study expected to extend the use of ADS-B data, and the above identified flight metrics could provide references for further extension of ADS-B data applications with additional data sources. Therefore, good understanding of the relationship between ADS-B data and other aeronautical information was crucial for further study. An exploration of the relationship diagram between ADS-B data and other relevant aeronautical data is shown in Figure 4.9.

![Diagram showing relationship between ADS-B data and other aeronautical data](image)

**Figure 4.9** Relationship between ADS-B Data and Other Aeronautical Data

Given the limitations of ADS-B data, especially the number of flight parameters that ADS-B Out broadcasts, it would be necessary to incorporate other available aeronautical data to achieve more robust functions of ADS-B data analysis. Figure 4.9 depicts the functional relationship between ADS-B data and other aeronautical information. For example, the aggregated ADS-B data were expected to be helpful in developing advanced statistical analysis of flight operations, the incorporation with FDR data could supplement the shortages of ADS-B data, and the integration of airport geographical and weather information would be supportive for more accurate and diverse analytical work.
4.3.2 Exceedance Detection

Exceedance detection is one of the standard flight data analysis methods used in airline operations (FAA, 2004; CASA, 2011). The second research question of this study was to explore the approach to conduct exceedance detection using the flight metrics developed in Chapter 4.3.1. Given the limitation that the collected ADS-B data were not well received and decoded due to the inadequate performance of ADS-B receiver and other influential factors, five exceedances, as introduced in Chapter 3.4, were identified from the Cirrus SR-20 Flight Operations Manual to demonstrate the potential of ADS-B data in general aviation flight data analysis. These five exceedances were (Cirrus Aircraft, 2011):

1. No turn before reaching 400 feet above the ground level (AGL) during the phase of takeoff.

2. Suggested climb angle during initial climb from 0 to 1000 feet AGL: 7 – 10 degrees.


5. Stabilized Approach: Constant glide angle established from 500 feet AGL to 0 feet AGL for flight under visual flight rules (VFR).

Based on the identified exceedances and the respective threshold, each exceedance was matched to the developed flight metrics before importing the collected ADS-B data for detection, shown as Table 4.6. All matched flight metrics were calculated using collected ADS-B data. However, the actual decoded ADS-B data in this study did not contain the airspeed information, though ADS-B Out was expected to broadcast airspeed alternatively when groundspeed was not available (ICAO, 2008). Given the fact that no airspeed data were available from ADS-B Out
messages broadcasted by Purdue Cirrus SR-20 aircraft, airspeed information was replaced using the airspeed data recorded by onboard avionics – Garmin G1000 system. Five exceedances were detected and analyzed using the matched flight metrics with a respective analytical process.

Table 4.6 The Relationship between Exceedances and Flight Metrics

<table>
<thead>
<tr>
<th>Exceedance</th>
<th>Flight Metrics Matched</th>
</tr>
</thead>
<tbody>
<tr>
<td>No turn before reaching 400 feet above the ground level (AGL) during the phase of takeoff</td>
<td>Flight altitude (MSL)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Airport elevation</td>
</tr>
<tr>
<td></td>
<td>Runway configuration</td>
</tr>
<tr>
<td></td>
<td>Track</td>
</tr>
<tr>
<td>Suggested climb angle during initial climb from 0 to 1000 feet AGL: 7 – 10 degrees</td>
<td>Flight altitude (MSL)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Airport elevation</td>
</tr>
<tr>
<td></td>
<td>Runway configuration</td>
</tr>
<tr>
<td></td>
<td>Track</td>
</tr>
<tr>
<td></td>
<td>Climb angle</td>
</tr>
<tr>
<td>Suggested Indicated Airspeed for Base: 90±5 knots</td>
<td>Knots Indicated Airspeed</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Track</td>
</tr>
<tr>
<td></td>
<td>Runway configuration</td>
</tr>
<tr>
<td>Suggested Indicated Airspeed for Final Approach: 78±5 knots</td>
<td>Knots Indicated Airspeed</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Track</td>
</tr>
<tr>
<td></td>
<td>Runway configuration</td>
</tr>
<tr>
<td>Stabilized Approach: Constant glide angle established from 500 feet AGL to 0 feet AGL for flight under visual flight rules (VFR)</td>
<td>Flight altitude (MSL)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Airport elevation</td>
</tr>
<tr>
<td></td>
<td>Runway configuration</td>
</tr>
<tr>
<td></td>
<td>Track</td>
</tr>
<tr>
<td></td>
<td>Glide angle</td>
</tr>
</tbody>
</table>

Note. Exceedance was developed based on the Cirrus SR20 Flight Operations Manual (Cirrus Aircraft, 2011)
According to the Flight Operations Manual (Cirrus Aircraft, 2011) and the collected ADS-B data, the high-level analytical process of analyzing the Indicated Airspeed related exceedances using the matched flight metrics in the traffic pattern is shown as Figure 4.10.

Figure 4.10 Analytical Process of the Indicated Airspeed Related Exceedances

The high-level analytical process demonstrated the logic and steps of analyzing the corresponding exceedance. First, the analytical process started from visualizing the flight GPS track in Google Earth to have an overview of the flight history. Second, specific airports used was identified from the GPS track, and corresponding airport information was obtained from the FAA Airport Diagrams database. The third step was to identify the desired flight data observations by matching the exceedance criteria. The next step was to analyze the identified flight data observations for the specific exceedance.
An additional two analytical processes of analyzing the Course Track related exceedances and the Glide/Climb Angle related exceedances are shown in Figure 4.11 and Figure 4.12, respectively.

Figure 4.11 Analytical Process of the Course Track Related Exceedances
Figure 4.12 Analytical Process of the Glide/Climb Angle Related Exceedances

The set of five exceedances was analyzed using the collected ADS-B data of the selected 40 flights. An analysis result with details is shown in Figure 4.13 as an example. This result was based on the same set of flight data used in Figure 4.10, Figure 4.11, and Figure 4.12.
Figure 4.13 Demonstration of Detecting Five Exceedances

Note. ADS-B Data for A, B, E, and F; FDR Data for C and D.

In this example, five exceedances were coded as A, B, C, D, E, respectively. According to the plots shown in Figure 4.13, ADS-B data indicated that there was no exceedance detected from this flight in terms of exceedance A, C, and D. However, exceedances were detected on the Climb Angle in the initial climb phase. In addition, constant Glide Angle was not established by the recommended 500ft AGL for a stabilized approach in the landing phase.

The results of analyzing the number of exceedances found in the 40 sets of ADS-B flight data are shown in Table 4.7. No exceedance was detected for the first type. Exceedances for the stabilized approach were detected most frequently.

However, given the imperfect ADS-B data collected, exceedance detection did not well represent the actual operations of flights. One of the primary factors that might affect the exceedance detection and flight metrics derivation was the reception rate of ADS-B data.
<table>
<thead>
<tr>
<th>Type of Exceedance</th>
<th>Number of Detected Exceedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>No turn before reaching 400 feet above the ground level (AGL) during the phase of takeoff</td>
<td>0</td>
</tr>
<tr>
<td>Suggested climb angle during initial climb from 0 to 1000 feet AGL: 7 – 10 degrees</td>
<td>3</td>
</tr>
<tr>
<td>Suggested Indicated Airspeed for Base: 90±5 knots</td>
<td>5</td>
</tr>
<tr>
<td>Suggested Indicated Airspeed for Final Approach: 78±5 knots</td>
<td>3</td>
</tr>
<tr>
<td>Stabilized Approach: Constant glide angle established from 500 feet AGL to 0 feet AGL for flight under visual flight rules (VFR)</td>
<td>17</td>
</tr>
</tbody>
</table>

4.3.3 The Impact of Reception Rates on Exceedances Detection

The ADS-B equipment is required to continuously broadcast aircraft information without input by a human operator. Under the final rule for ADS-B performance requirements, the total latency of transmitting ADS-B data cannot exceed 2 seconds (14 C.F.R. § 91.227, 2014). The 14 C.F.R. § 91.227 (2014) requires that “the ADS-B Out compliant aircraft must transmit its position and velocity at least once per second while airborne or while moving on the airport surface, or must transmit its position at least once every 5 seconds while stationary on the airport surface” (14 C.F.R. § 91.227, 2014, p. 743). However, the reception rate of ADS-B data depends on the performance of the ADS-B receiver. For example, how many data frames can the ADS-B receiver process over a certain time span? In this study, due to the resource limitations, the hardware used in the ground-based ADS-B receiver constrained the signal processing capability of the ADS-B receiver. The actual reception rate in this study was lower than the theoretical value, which was 60 data frames in one minute. The actual reception rate in this study was about 4 data frames per minute, shown as Figure 4.3 in Chapter 4.2. The low reception rate was
expected to be one of the major factors that impact flight metric derivation and exceedance detection.

To analyze the impact of the reception rate on exceedance detection, a set of ADS-B data was emulated from the actual flight data stored by the Flight Data Recorders (FDRs), by manipulating the reception rate. Four reception rates (4/60, 6/60, 12/60, and 60/60) were determined between the lowest and the highest reception rate for data emulation, meaning 4 data frames per 60 seconds, 6 data frames per 60 seconds, 12 data frames per 60 seconds, and 60 data frames per 60 seconds, respectively. Flight metrics were calculated using sets of emulated ADS-B data with different reception rates to repeat the procedure of detecting the identified five exceedances. In total, there were 10 sets of ADS-B data, which was emulated using FDR data, and a set of flight data was randomly selected to demonstrate the exceedance detection with four reception rates. The exceedance detection was performed for four emulated reception rates:

1. 60 data frames per 60 seconds, as shown in Figure 4.14
2. 12 data frames per 60 seconds, as shown in Figure 4.15
3. 6 data frames per 60 seconds, as shown in Figure 4.16
4. 4 data frames per 60 seconds, as shown in Figure 4.17.
Figure 4.14 Exceedance Detection using Emulated ADS-B Data (60/60)

Note. Exceedance detection using the emulated ADS-B data with the reception rate of 60 data frames per 60 seconds (60/60).
Figure 4.15 Exceedance Detection using Emulated ADS-B (12/60)

*Note.* Exceedance detection using the emulated ADS-B data with the reception rate of 12 data frames per 60 seconds (12/60).
Figure 4.16 Exceedance Detection using Emulated ADS-B Data (6/60)

Note. Exceedance detection using the emulated ADS-B data with the reception rate of 6 data frames per 60 seconds (6/60).
Figure 4.17 Exceedance Detection using Emulated ADS-B Data (4/60)

*Note.* Exceedance detection using the emulated ADS-B data with the reception rate of 4 data frames per 60 seconds (4/60).

For the same set of emulated ADS-B data, another set of plots was made to provide an image of the difference in exceedance detection with the four reception rates.

The Cubic spline smoothing was also used to extrapolate the missing flight data observations for the purpose of plotting the flight profiles in terms of five flight metrics.

Figure 4.18 – 4.22 graphically depict the difference of plotted flight profiles using ADS-B data with four reception rates.
Figure 4.18 Ground Track during the Initial Climb Plotted with Four Reception Rates

Figure 4.19 Climb Angle during the Initial Climb Plotted with Four Reception Rates
Figure 4.20 Indicated Airspeed during the Base Leg Plotted with Four Reception Rates

Figure 4.21 Indicated Airspeed during the Final Approach Plotted with Four Reception Rates
Figure 4.22 Glide Angle during the Final Approach Plotted with Four Reception Rates

Figure 4.18 – 4.22 depict the flight profiles for the detection of five flight exceedances using four ADS-B data reception rates. These plots provided a graphical comparison of the fit the real flight profiles (plotted with 60/60) versus the other three lower reception rates, and what the differences were found in exceedance detection using this data set. In general, the sparser the ADS-B data, the more flight information is missed. This phenomenon might result in missing detection of exceedance if the exceedance happened between the observed data points. However, considering the flight operational features in different phases, sparse data might induce different levels of impact on the specific exceedances. For the five exceedances studied in this research using this data, the reception rate didn’t show significant impact on detecting the first, the second, and the fourth exceedance (in the order of exceedances listed in Chapter 4.3.2). Meanwhile low reception rate demonstrated a higher chance to miss exceedances for the third and fifth events (in the order of exceedances listed in Chapter 4.3.2) using this data. Considering
the operational characteristics of GA piston-engine training aircraft, stabilized approach might be a challenge for flight students, especially those who are in the initial phase of training. Atmospheric turbulence could be one of many additional factors influencing the performance of flight students. Relatively more exceedances were detected in the form of non-constant glide angle during the final approach compared to the other four exceedances. Additionally, the durations of Base and Crosswind legs are relatively shorter than those of Downwind and Final. Fewer flight data were received during the Base and Crosswind. In that case, low reception rate resulted in even less data being received for those two phases, and therefore a large piece of flight information could be missed. Therefore, the limited number of data observations could hardly support accurate analysis.

In addition to the graphical analysis, the same five exceedances were analyzed using the emulated 10 sets of ADS-B data to compare the impact of different reception rates. The statistical summary of the exceedance detection result using the 10 sets of emulated ADS-B data is shown in Table 4.8. The first, second, and fourth exceedances had different results, with different reception rates; the third and fifth exceedances did not provide a different result due to the change of reception rate. In general, this preliminary analysis demonstrates that low reception shows different levels of impact on different exceedances; operational exceedances could be sensitive or robust to sparse data.
Table 4.8 Statistical Summary of Exceedance Detection using Emulated ADS-B Data

<table>
<thead>
<tr>
<th>Order</th>
<th>Type of Exceedance</th>
<th>Number of Detected Exceedance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>60/60</td>
</tr>
<tr>
<td>1</td>
<td>No turn before reaching 400 feet above the ground level (AGL) during the phase of</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>takeoff</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Suggested climb angle during initial climb from 0 to 1000 feet AGL: 7 – 10 degrees</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Suggested Indicated Airspeed for Base: 90±5 knots</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Suggested Indicated Airspeed for Final Approach: 78±5 knots</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Stabilized Approach: Constant glide angle established from 500 feet AGL to 0 feet</td>
<td>8</td>
</tr>
</tbody>
</table>

4.4 Summary

This chapter introduced the structure and content of the ADS-B message, and provided the study outcomes for three research questions. For the first research question, based upon the ICAO and FAA technical provisions for ADS-B services and the actual collected ADS-B data, a list of 15 initial flight metrics was developed using the flight parameters transmitted by ADS-B Out. By incorporating other aeronautical information, a list of 14 additional flight metrics was developed. The second research question explores the usage of the developed flight metrics. As one of the most widely-used methods in flight data analysis, exceedance detection was used to analyze the developed flight metrics using the collected ADS-B data. In this study, 40 sets of ADS-B data were selected from a pool of ADS-B data collected from November 2016 to May 2017 according to the data selection methods introduced in Chapter 4.2. The third research
question sought to analyze the results of exceedance detection under the impact of the reception rate, which was determined as one of the primary influential factors affecting the exceedance detection. The last part of this chapter provided a comparison of exceedance detection results with different ADS-B data reception rates.
CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

Chapter Four provided the research outcomes for three research questions. This chapter summarizes the study and discusses the findings. In addition, this chapter presents the limitations of this study and proposes recommendations for future research studies.

5.1 Summary of Study

General aviation (GA) is one of the key components of the civil aviation industry with more than 362,000 general aviation aircraft worldwide (GAMA, 2016). However, GA has the highest accident rate among all aeronautical activities (NTSB, 2017). Flight data analysis is believed to be one of the most effective strategies to improve flight safety and operational efficiency by detecting unsafe events and anomalies during flight operations (ICAO, 2010). In ICAO Annex 6 and the Federal Aviation Administration (FAA) Advisory Circular 120-82, the Flight Data Monitoring (FDM) program is highly encouraged to be implemented by all airlines (ICAO, 2010; FAA, 2004). However, the routine operation of FDM depends on the availability of flight data from flight data recording devices. Automatic Dependent Surveillance-Broadcast Out (ADS-B Out) will be required equipment for all aircraft operating in assigned airspace, after January 1, 2020 (14 C.F.R. § 91.225, 2011; 14 C.F.R. § 91.227, 2014). By then, most aircraft operating in the U.S. will have to be ADS-B Out capable, including GA aircraft. ADS-B Out equipment periodically broadcasts certain types of flight data. Those flight data can be received by all of ADS-B In capable equipment. Therefore, compared to the approach of downloading flight data from flight data recording devices, ADS-B Out provides another relatively inexpensive approach to obtain flight data by receiving and decoding the public ADS-B Out messages. Given
the situation that GA is usually resource constrained to implement flight data analysis using flight data recording systems, this study investigated ADS-B data to support GA flight data analysis as opposed to on-board flight data recording equipment used in the high-cost traditional Flight Data Monitoring programs.

The first part of this research answered the first research question: What flight data metrics can be developed from ADS-B data?

This phase of study was based on the requirements and specifications of ADS-B Out services stated in the ICAO Doc 9871 – *Technical Provisions for Mode S Services and Extended Squitter* (ICAO, 2008), and the RTCA/DO-260 – *Minimum Operational Performance Standards for 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services (TIS-B)* (RTCA, 2009). Based upon the analysis results of the structure and content of ADS-B Out messages, 11 aircraft parameters that could be obtained from ADS-B Out messages were identified. An initial set of 15 flight metrics was developed using the 11 identified parameters. In addition, to further extend the use of ADS-B data for GA flight data analysis, a set of 14 flight metrics was developed by incorporating additional aeronautical information for flight data analysis. Airport information and aircraft performance specifications are examples of relevant information that is necessary for flight data analysis.

The second phase of this research studied the second research question: How can the developed flight metrics be used to identify flight operational exceedances?

The purpose of this part of study was to analyze the practical use of the developed flight metrics using ADS-B data in flight data analysis. Exceedance detection is one of the most effective safety analysis techniques in flight data monitoring programs (FAA, 2004; U. K. CAA, 2013; European Authorities Coordination Group on Flight Data Monitoring, 2015). Therefore,
exceedance detection was selected as an example of flight data analysis tasks in this study to analyze the ADS-B data in flight data analysis. Given the flight metrics developed in the first phase of study, the second phase provided the results of exceedance detection using ADS-B data. In this research, an ADS-B receiver was built and deployed to collect actual flight data. After initial testing, the ADS-B receiver was first deployed at Purdue University Airport (KLAF) in November 2016 for data collection, and the data collection process ended by May 2017. Only the flight data broadcasted by the Purdue Cirrus SR-20 aircraft were processed and analyzed in this research. The Purdue Cirrus fleet is primarily used for flight training; only cross-country flights were included to better reflect non-training flight missions. Local traffic pattern training and performance maneuvers training are relatively irregular compared to cross-country flight, shown in Figure 4.1. In total, 40 sets of flight data were selected for exceedance detection. Five exceedances were identified, based on the Cirrus SR-20 Flight Operations Manual for analysis in this study. However, the reception rate of ADS-B data was lower than the theoretical rate in this study because of the limitation of the hardware in terms of data processing speed. The reception rate was defined as the number of ADS-B data received in a minute by the ADS-B receiver. The theoretical reception rate was expected to be around 60 data frames per minute; the actual reception rate in this study is around 4 data frames per minute. Intuitively, ADS-B data with high reception rates could better depict and reflect the characteristics of flight operations than sparse ADS-B data. Therefore, the low reception rate may have an impact on exceedance detection due to inadequate data observations.

The third phase of this study explored the third research question: What are the differences in exceedance detection with varying reception rates of ADS-B data?
In other words, this part of study investigated the differences in exceedance detection with varying reception rates of ADS-B data. It is impractical to control the ADS-B data reception rate from the ADS-B receiver used in this study. Given the fact that ADS-B data and the corresponding types of flight data recorded by flight data recording (FDR) devices are generated by GPS and the aircraft sensing systems, ADS-B data and FDR data share the same data sources on the same aircraft. Therefore, ADS-B data with different reception rates were emulated using the flight data recorded by the Garmin G1000 system – a type of avionics which supports flight data recording service. Emulation was achieved by selecting the same ADS-B data parameters from FDR data and manipulating the sampling rate. In this study, 10 sets of ADS-B data with four different reception rates were emulated for analysis.

The primary results produced from this research work are:

1. The current version 2 ADS-B Out service (version 2 is defined by DO-260B or DO-282B standards) broadcasts 11 basic aircraft parameters (FAA, 2017b). Those aircraft parameters can be obtained by receiving and decoding ADS-B Out messages broadcasted on 1090 MHz or 978 MHz.

2. An initial set of 15 flight metrics was developed using the basic ADS-B data; an additional set of 14 flight metrics was developed by incorporating basic ADS-B data and other relevant aeronautical information.

3. Methods of exceedance detection were studied based on the developed flight metrics. Forty sets of collected ADS-B data were used in exceedance detection based on the developed methods. The results of exceedance detection indicated that stabilized approach (constant glide angle established from 500 feet above the ground level to the surface) had the highest number of exceedances. Non-constant
glide angle was detected from 17 of the 40 flights. No exceedance was detected for the operational suggestion of no turn before reaching 400 feet above ground level during the takeoff phase.

4. Using the data in this study, the analysis of the different ADS-B data reception rates showed that exceedances might be missed using ADS-B data with low reception rates, especially the exceedances of suggested indicated airspeed for Base leg (90 ± 5 knots), and stabilized approach (constant glide angle established from 500 feet above ground level to the surface) were demonstrated to be more sensitive to the low reception rate.

5.2 Discussion of Results

The purpose of this study was to investigate ADS-B data to facilitate GA flight data analysis, as opposed to the high cost of traditional Flight Data Monitoring (FDM) programs that require on-board flight data recording equipment and post-flight analyses. The Automatic Dependent Surveillance Broadcast Out (ADS-B Out) is one of the major components of the next generation air transportation system required to be installed in all aircraft operating in most controlled airspace after January 1, 2020 in the U.S. (14 C.F.R. § 91.225, 2011; 14 C.F.R. § 91.227, 2014). This study assumed that most GA aircraft will be ADS-B Out capable from the effective date. By then, the outcomes of the current and future related studies are expected to provide GA aircraft with a low-cost approach for implementing flight data analysis to improve GA safety.
5.2.1 Flight Metrics Development

The first research question addressed flight performance measurement by developing flight metrics using ADS-B data. The results of the current study show that 11 basic aircraft parameters can be obtained from ADS-B data, and 29 flight metrics can be derived using the 11 broadcasted aircraft parameters. Availability of adequate aircraft parameters and flight metrics is essential for flight data analysis. However, traditional FDM programs can identify over 60 basic types of events related to flight safety, because current onboard flight data recording (FDR) systems are capable of providing many more aircraft parameters than ADS-B Out (FAA, 2004; Campbell, 2007). Compared to onboard FDR systems, the number of flight parameters included in ADS-B data is limited; particularly, current ADS-B Out service does not broadcast aircraft attitude information (roll, pitch, and yaw). The unavailability of aircraft attitude data restricts the use of ADS-B data in many flight data analysis tasks which require aircraft attitude information. Nevertheless, the ADS-B technology is rapidly evolving. Based on relevant literature, more flight data could be encoded into Mode S services in the future. For example, the Mode S Enhanced Surveillance (EHS) provides an additional eight downlinked aircraft parameters (DAPs): “Selected Altitude, Roll Angle, Track Angle Rate (if available), True Track Angle, Ground Speed, True Airspeed, Magnetic Heading, Indicated Airspeed/Mach number, and Vertical Rate (Barometric rate or baro-inertial)” (EUROCONTROL, 2017, p. 8). It is technically feasible and possible to broadcast more aircraft parameters via ADS-B Out in the future.

Therefore, in addition to the primary function of ADS-B as a traffic surveillance system, this study presented the preliminary results to support the use of ADS-B into the area of flight data monitoring for GA, and to serve as a reference for relevant future study. Based on the findings
and limitations of the current study phase, more useful flight metrics should be developed in further studies to further expand the functionality of ADS-B data.

5.2.2 Flight Operational Exceedance Detection

The second research question explored the usage of the ADS-B data in flight data analysis. Exceedance detection was adopted as an example of flight data analysis in this research. Five types of exceedances were identified from the Cirrus SR-20 Aircraft Operations Manual, which are typical exceedances in the Landing and Takeoff Cycle (LTO). These exceedances are:

- No turn before reaching 400 feet above the ground level (AGL) during the phase of takeoff,
- Suggested climb angle during initial climb from 0 to 1000 feet AGL: 7 – 10 degrees,
- Suggested Indicated Airspeed for Base leg: 90+5 knots,
- Suggested Indicated Airspeed for Final Approach: 78+5 knots,
- Constant glide angle established from 500 feet AGL to 0 feet AGL for flight under visual flight rules (VFR).

An ADS-B receiver was built and deployed to collect ADS-B data, and the exceedance detection was conducted using this ADS-B data. However, aircraft airspeed is not included in the ADS-B messages unless the ground speed is not available (ICAO, 2008). The researcher noticed that there was no aircraft airspeed information in the collected ADS-B data. Therefore, airspeed information was replaced using the corresponding airspeed information from FDR data. Exceedance detection using ADS-B data demonstrated a typical approach of flight data analysis for safety enhancement. Although exceedance detection provides information on operational exceedance during flight operations, those exceedances are pre-defined and depend on the well-defined thresholds specified by the aircraft manufacturers and operators. Special operations such as performance maneuvers practice, aerobatic flight, and initial flight training, could possibly require a different set of exceedance thresholds. Therefore, other flight data analysis techniques
are needed to supplement the shortages of exceedance detection in flight data analyses. In addition, the ADS-B data used in this study are very sparse due to the low reception rate. The quality and quantity of ADS-B data constrains the accuracy of exceedance detection. As a result, exceedance detection using ADS-B data in this study demonstrated a high-level strategy and overall procedures of using ADS-B data in flight data analysis. The accuracy of corresponding analytic results depends on further verification using better quality ADS-B data.

5.2.3 Impact of Reception Rate

In this study, the reception rate of ADS-B data was much lower than the maximum possible reception rate due to the limitations of the ADS-B receiver used. Potential reasons were investigated and identified. The hardware platform of the ADS-B receiver that was used to receive and decode ADS-B messages was not technologically capable to capture ADS-B messages with an ideal reception rate because the microcontroller used in the Programmable Integrated Circuit (PIC)-based decoder is not computationally robust to capture all ADS-B data frames, and the performance is also affected by the 1090 MHz interference (ICAO, 2008). Although collected ADS-B data are restricted by the limitation of the ADS-B receiver, all required aircraft by 14 Code of Federal Regulations, Part 91.225 (2011) and Part 91.227 (2014) must have installed certified ADS-B Out systems, which are compliant with the respective technical standards (14 C.F.R. § 91.225, 2011; 14 C.F.R. § 91.227, 2014; ICAO, 2008; RCTA, 2009). The flight metrics and methods developed in this study were based on ADS-B technical standards, and were not affected by the quality of collected ADS-B data. The reception rate of ADS-B data could be affected by many factors, such as the hardware and software used on the ADS-B receiver, the nearby air traffic density, obstacles between aircraft and the ADS-B receiver, and weather conditions. Therefore, technology is not the single influential factor, and
the reception rate is vulnerable to various influential factors even if a larger investment is spent on the ADS-B receiver. Analysis of the impact from the reception rate in exceedance detection is expected to provide a better idea of determining the anticipated reception rate for exceedance detection. The results indicate that the reception rate affects the exceedance detection in general. A lower reception rate has more impact on the exceedance detection in terms of missing potential exceedances. As shown in Figure 4.18 to Figure 4.22, the collected ADS-B data had missing portions of the flight profile, and illustrated the sparsity of data collected versus the specified broadcast rate. For the reception rate of 4/60, the interval between two data observations is about 15 seconds. Undesired flight attitude changes in 15 seconds could result in a serious accident or incident during critical phases of flight, such as the Final approach. In addition, the duration of the phase of Base leg is usually very short because it serves as the transition between the Downwind and the Final. ADS-B data with low a reception rate may not provide enough flight information to conduct exceedance detection or other flight data analyses.

5.3 Conclusions

In regard to the first research question, ADS-B technical standards were used to identify aircraft parameters that are broadcasted by the ADS-B Out. There are 14 basic aircraft parameters that can be obtained by receiving and decoding the ADS-B messages. An initial set of 15 flight metrics was developed using the 14 basic ADS-B data parameters. In addition, a set of 11 flight metrics was derived by incorporating relevant aeronautical information. Flight metrics play a fundamental role in flight data analyses by measuring the interesting flight operational features. Those flight metrics that can be measured using ADS-B data are necessary to extend the use of ADS-B into GA flight data analysis.
Exceedance detection and the analysis of the impact from the reception rate of ADS-B data demonstrated a high-level procedure of exceedance detection, and serves as a reference for future relevant studies. Ideally, a higher reception rate could better support exceedance detection. Considering the investment needed for better ADS-B data receiving and processing systems, and resource limitations with which GA operators are usually confronted, a tradeoff between investment and the desired ADS-B data quality should be achieved for the particular purposes of operators. In general, a low reception rate may have more impact on detecting or analyzing flight operations during some critical phases, such as the Final Approach, but may still well support the analysis of the overall flight operations.

5.4 Limitations of the Study

This phase of study had a few limitations, particularly the limitations of the performance of ADS-B Out capable avionics and the ADS-B data collection device used in this study. The FAA has certified two types of ADS-B compliant equipment – Mode S Extended Squitter (Mode S ES) transponder and the Universal Access Transceiver (UAT). After January 2020, aircraft must be equipped with a corresponding type of ADS-B Out capable avionics, depending on the type of airspace (14 C.F.R. § 91.225, 2011). As per the classification of airspace, the operators of most GA aircraft are expected to select the UAT to have the ADS-B Out capability. However, the ADS-B data collected and analyzed in this study were broadcasted by the Mode S ES. It is possible that the ADS-B data broadcasted by the UAT could be slightly different from the data broadcasted by the Mode S ES in terms of data quality.

The researcher believes that the significance of this study is to explore a low-cost flight data collection approach for GA operators, and further facilitate the routine flight data analysis to
improve GA flight safety. Therefore, a low-cost (approximately $200) ADS-B receiver was built to collect ADS-B data in this study. Given the limitations of the hardware of the receiver, this low-cost ADS-B receiver cannot receive and process the ADS-B messages quickly enough to capture all broadcasted flight data. As a result, the reception rate was much lower than the desired rate, and the flight profile was constructed with limited accuracy using the sparse ADS-B data. This study considered and analyzed the impact of the low reception rate of ADS-B data; however, better quality ADS-B data with a higher reception rate are desired to better reflect the characteristics of flight operations, and potentially improve the accuracy of data analysis.

In addition, this study was based on the current technical performance of the ADS-B technology, and the ADS-B technology is rapidly evolving. According to the recent updated research outcomes from industry and academia, more aircraft parameters and other information could be encoded into the ADS-B Out messages, and by then, the ADS-B data would be able to support a wider range of flight data analyses.

5.5 Recommendations for Future Research

As preliminary research exploring a low-cost approach for GA flight data analysis, the results of this study show the potential for using ADS-B data in GA flight data analysis and safety enhancement. However, there are many additional questions and challenges that should be addressed in future studies. The following are recommendations for future studies on this topic:

1. Upgrade an ADS-B receiver to improve reception rate of ADS-B data to support accurate data analysis tasks. This current phase of study demonstrated the feasibility of using ADS-B data in GA flight data analysis; however, the accuracy and reliability must be assured before applying this technology for actual flight operations.
2. Compared to flight data recording devices, ADS-B data show certain disadvantages to fully support some typical functions of flight data analysis, especially aircraft attitude-related analyses. In that case, studies on developing more flight metrics from ADS-B data would be essential to improve the value of ADS-B data in flight data analysis.

3. Exceedance detection was adopted to study the ADS-B data in flight data analysis. However, exceedance detection shows some disadvantages in flight data analysis, and is not an appropriate approach for some aspects of flight data analysis. For example, exceedance detection highly depends on the predetermined thresholds of exceedances. Other flight data analysis techniques should be studied to broaden various application scenarios for ADS-B data.

4. Given the limited resources that GA operators can invest and the nature of telecommunication technology, the researcher assumes that GA operators would meet the issue of low data reception rate. How to extrapolate the flight parameters to bridge the gap between adjacent data observations is another research area to explore. Accurate prediction of flight paths would have additional significance for flight data analysis, and flight accident investigation, as well as search and rescue.

5. In order to apply the research outcomes to actual GA operations, relevant studies should be conducted to verify and validate the actual performance of ADS-B data in flight data analysis.
APPENDIX A: List of Commercial Off-the-Shelf Items for the ADS-B Receiver

The ADS-B receiver used in this study was built using the following items. All are commercial off-the-shelf. The prices listed are approximations.

<table>
<thead>
<tr>
<th>Item</th>
<th>Number</th>
<th>Estimated Unit Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1090 MHz Antenna – 66cm/26in</td>
<td>1</td>
<td>U.S. $50</td>
</tr>
<tr>
<td>1090 MHz Band-pass SMA Filter</td>
<td>1</td>
<td>U.S. $25</td>
</tr>
<tr>
<td>RTL2832U &amp; R820T2 Radio Tuner</td>
<td>1</td>
<td>U.S. $25</td>
</tr>
<tr>
<td>5V 2.5A Raspberry Pi 3 Power Supply</td>
<td>1</td>
<td>U.S. $12</td>
</tr>
<tr>
<td>USA-CA RFC240N MALE to SMA MALE Coaxial RF Pigtail Cable</td>
<td>1</td>
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</tr>
<tr>
<td>High Speed HDMI 1.4 Cable</td>
<td>1</td>
<td>U.S. $5</td>
</tr>
<tr>
<td>16 GB MicroSD Card</td>
<td>1</td>
<td>U.S. $13</td>
</tr>
<tr>
<td>Raspberry Pi 3 Model B</td>
<td>1</td>
<td>U.S. $38</td>
</tr>
<tr>
<td>Raspberry Pi 3 Case</td>
<td>1</td>
<td>U.S. $10</td>
</tr>
<tr>
<td>Dump1090 (or other software)</td>
<td>1</td>
<td>Free</td>
</tr>
</tbody>
</table>
APPENDIX B: Summary of Selected Sets of ADS-B Data

This table describes the 40 sets of ADS-B data used for flight data analysis in this study. The 40 sets of data were randomly-selected from an ADS-B data pool, which was collected from October 2016 to May 2017 using an ADS-B receiver at Purdue University Airport. The duration of flight was estimated using the ADS-B data.

<table>
<thead>
<tr>
<th>Flight Time</th>
<th>Duration</th>
<th>Flight Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/21/2016</td>
<td>1h41m34s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>10/25/2016</td>
<td>1h00m19s</td>
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</tr>
<tr>
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<td>1h32m34s</td>
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<td>1h13m30s</td>
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<tr>
<td>11/04/2016</td>
<td>2h03m02s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>11/04/2016</td>
<td>1h34m32s</td>
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</tr>
<tr>
<td>11/05/2016</td>
<td>1h47m37s</td>
<td>Cross country flight</td>
</tr>
<tr>
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<td>Cross country flight</td>
</tr>
<tr>
<td>11/09/2016</td>
<td>2h04m30s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>11/20/2016</td>
<td>2h23m58s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>11/21/2016</td>
<td>2h34m22s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>12/14/2016</td>
<td>1h15m33s</td>
<td>Cross country flight</td>
</tr>
<tr>
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</tr>
<tr>
<td>01/13/2017</td>
<td>1h47m06s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>Date</td>
<td>Duration</td>
<td>Flight Type</td>
</tr>
<tr>
<td>------------</td>
<td>-----------</td>
<td>-------------------</td>
</tr>
<tr>
<td>01/13/2017</td>
<td>1h19m56s</td>
<td>Cross country flight</td>
</tr>
<tr>
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<td>Cross country flight</td>
</tr>
<tr>
<td>01/21/2017</td>
<td>1h03m46s</td>
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</tr>
<tr>
<td>01/30/2017</td>
<td>1h05m18s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>01/30/2017</td>
<td>1h03m00s</td>
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</tr>
<tr>
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</tr>
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</tr>
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<td>2h48m11s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>02/10/2017</td>
<td>2h19m57s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>02/16/2017</td>
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</tr>
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<td>03/04/2017</td>
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<tr>
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<td>3h48m48s</td>
<td>Cross country flight</td>
</tr>
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<tr>
<td>03/11/2017</td>
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</tr>
<tr>
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<td>Duration</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>--------------</td>
<td>-------------------</td>
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<tr>
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<tr>
<td>05/07/2017</td>
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<tr>
<td>05/07/2017</td>
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<tr>
<td>05/07/2017</td>
<td>2h04m20s</td>
<td>Cross country flight</td>
</tr>
<tr>
<td>05/08/2017</td>
<td>1h57m47s</td>
<td>Cross country flight</td>
</tr>
</tbody>
</table>

*Note.* Flight Time (month/day/year), Duration (hour/minute/second).
APPENDIX C: The Entity Relationship Diagram for ADS-B Data Storage

A relational database was used to store collected ADS-B data for convenient data processing. The Entity Relationship Diagram of the database is shown below. Tables of the diagram were deployed using the Microsoft SQL Server.
LIST OF REFERENCES

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VITA

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EDUCATION

Purdue University, West Lafayette, Indiana, USA
Ph.D., Technology December 2017
M.S., Aviation and Aerospace Management August 2015

Civil Aviation Flight University of China, Sichuan, China June 2014
M.S., Air Traffic Management and Planning

Southwest University of Science and Technology, Sichuan, China Jun 2012
Bachelor of Science, Electrical and Electronic Engineering

RESEARCH EXPERIENCE

Ph.D. Dissertation Project: Applying ADS-B Out to facilitate flight data analysis for general aviation.

- Extend the use of ADS-B technology to general aviation flight data analysis with the purpose of improving GA flight safety.

FAA-PEGASAS Project: Data collection/metrics for non-FDR equipped GA aircraft.

- Exploring alternative flight data source for flight data monitoring in GA operations.
FAA-PEGASAS Project: Weather Technology in the Cockpit - Weather Information Latency Demonstrator, 2017

- Demonstrated the research outcome of a FAA funded project – Weather Technology in the Cockpit; collected user feedback from nationwide certified flight instructors and GA pilots.

Purdue University Ross Fellowship Funded Project: General Aviation Exhaust Emissions Assessment, 2015-2016

- Developed an algorithm to accurately identify the phases of flight in GA landing and takeoff (LTO) cycle using data from flight data recorder; integrated algorithm with aircraft engine exhaust emission indices in each phase of flight.

Purdue Joint Project with United Airlines, 2015

- Collaborated with United Airlines (UAL) project team tasked with the development and implementation of Turn Manager, a new software aiming to unify and simplify work process for Zone Controllers at the Station Operations Center (SOC) of UAL; Supported UAL project team to assure successful implementation of Turn Manager at O’Hare SOC in June 2015.
- Investigated operational defects of United Airline’s SOC in ORD; standardized baggage service and gate management; built a process map for standard operating procedure.


- Tested a flight planning and safety management tool; developed an extended module to enhance the visualization.

Purdue University: Purdue Fleet Utilization Improvement, 2015

- Investigated Purdue’s fleet operational problems and evaluated Cirrus fleet utilization; modified operational procedures of each unit and enhance operation efficiency by integrated use of Purdue’s operations center.

Purdue University: Visual Electronic Cumulative Threat & Ops. Risk Manager, 2015

- Developed a prototype of real time hazard/threat alerting system for line maintenance & ramp operations for the Hangar of the Future at Purdue University Airport.

Civil Aviation Flight University of China Joint Project with Boeing Company: Research of the Ground Power Unit Utility at Hub Airports of China, 2014

- Investigated the utility of the ground power unit at hub airports of China; assessed the carbon emissions from commercial aviation in China; drafted a proposal of airport
ground power layout specification to Civil Aviation Administration of China.

**Civil Aviation Flight University of China Joint Project with Boeing Company:** An Innovative Method to Identify the Airport Hot-spot, 2012-2013
- Developed an airport hot-spot identification software based on the image recognition technology using the aircraft surface movement data from airport surveillance radar.

**Civil Aviation Administration of China Project:** Aviation Rescue Management System R&D Project, 2013
- Developed a prototype of emergency rescue management system achieving the functions of publishing disaster situation and coordinating rescue information.

**TEACHING EXPERIENCE**

**Graduate Teaching Assistant**
*Purdue University, West Lafayette, USA*
Lab Instructor in AT205 - Statics for Aero Structures
- Instruct labs; develop and grade lab assignments.

**Guest Lecturer**
*Purdue University, West Lafayette, USA*
Aviation Safety Problems (AT481)
- Gave lectures on the section of Runway Incursion Prevention and the section of Aviation Safety History.
Research Methods in Aviation (AT505)
- Gave lectures on the section of Inferential Statistics and the section of Measurement Reliability and Validity.
Managerial Economics in Aviation (AT421)
- Gave lectures on the section of General Aviation Operations Management.

**Undergraduate Research Mentoring**
*Civil Aviation Flight University of China*
- Mentored eight undergraduate students in air traffic control and flight dispatch majors to successfully complete their graduation thesis projects. All of them passed thesis defense at the first time.
Graduate Teaching Assistant, Spring & Fall 2013

Civil Aviation Flight University of China

Lab Instructor

- Instructed and supervised ATC Radar Control Simulation labs; evaluated students’ performance.
- Instructed and supervised ATC Procedure Control Simulation labs; evaluated students’ performance.

Teaching assistant in ATM automated system course

Gave lectures on the section of communication, navigation, and surveillance (CNS), graded assignment and exams, supervised exams.

OTHER PROFESSIONAL EXPERIENCE

Graduate Research Assistant, Fall, Spring 2017

Purdue University, West Lafayette, USA


Academic Paper Reviewer, October 2016

2017 American Society for Engineering Education (ASEE) Annual Conference & Exposition – Engineering Technology Division

- Reviewed three academic papers submitted for 2017 ASEE Annual Conference & Exposition.
  - “Implementing Hands-on Experiments in an Engineering Technology Introductory Course”
  - “Overhauling a Vehicle Design Program: Some Assembly Required”
  - “Use LEGO to Teach Practical Engineering”
**Intern Researcher**  
June 2016-August 2016  
*Jeppesen - a Boeing company, Denver, Colorado, USA*  
- Two patents upon the research outcome are being pursued by Boeing company.

**Intern Product Analyst Assistant**  
June 2012-August 2012  
*Wisesoft LLC. Sichuan, China*  
- Analyzed the technical requirements of flight simulator development project.  
- Tested a new type of ATC radar simulator and proposed modification suggestions.

**Quality Control Intern**  
June 2011-August 2011  
*ChangHong Co. Ltd, Sichuan, China*  
- Assisted quality manager on product quality inspection and customer service.

**PRESENTATIONS**

2017 UAA Annual Conference, Riverside, CA.  
- **Education Session**: ADS-B is Coming to an Airport Near You, Johnson, M.E., Huang, C., and Mott, J.  

2017 EAA AirVenture, Oshkosh, WI.  
- FAA PEGASAS Project Demonstration – Weather Technology in the Cockpit.

2017 FAA PEGASAS Annual Meeting, College Station, TX.  

2017 Purdue Road School Transportation Conference & Expo, West Lafayette, IN.  
- Applications of ADS-B in General Aviation, Huang, C., Johnson, M.E.  
2016 UAA Annual Conference, Omaha, NE.
- **Education Session:** Investing in the Business of Aviation: Increasing Aviation Sustainability, Johnson, M.E., Huang, C., Rudari, L., and Spence, T..

2016 International Conference on Technology Management, Chicago, IL.
- Exploring the Centralized Safety Management to Mitigate the Threats and Risks of Aircraft Maintenance, Huang, C..

2016 AIAA Aviation Forum, Washington, D.C.
- Fuel Flow Rate and Duration of General Aviation Landing and Takeoff Cycle, Huang, C..

2016 Purdue Road School Transportation Conference & Expo, West Lafayette, IN.

2015 AIAA Region III Student Conference, Dayton, OH.
- Challenges for Air Traffic Controllers Behind the Aviation Boom, Huang, C..

2010 Global Sustainable Leaders Forum, Beijing, China.
- College Education on Sustainability, Huang, C..

### HONORS/AWARDS/ACHIEVEMENTS
- FAA Center of Excellence Outstanding Student of the Year for Outstanding Achievement in Aviation Research, 2017
- The Ross Fellowship at Purdue University, 2015-2016
- 2014 China National Scholarship for Graduate Students, 2014
- Southwest University of Science and Technology Outstanding Undergraduate Student Scholarship, 2010, 2009

### PROFESSIONAL AFFILIATIONS
- **American Institute of Aeronautics and Astronautics**
  - Student Member
  - Active
- **Institute of Electrical and Electronics Engineers**
  - Student Member
  - Active
• University Aviation Association  
  Student Member

• Experimental Aircraft Association  
  Member

• Purdue University Aviation Graduate Council  
  Public Relation (2015, 2016), Secretary

• Civil Aviation Flight University of China Graduate Student Union  
  September 2012-June 2014
  Director

• Southwest University of Science and Technology English Association  
  March 2009-March 2010
  President

• 23rd China Control and Decision Conference Committee, Sichuan, China  
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