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A Study on Mode C Transponder Operation To Improve Aviation Safety in the San Francisco North Bay

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To Improve Aviation Safety in the San Francisco North Bay

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Abstract

The purpose of this study is to determine if Mode C transponder operation by all aircraft in flight would improve aviation safety in the San Francisco North Bay. With air travel expected to increase annually for the foreseeable future, it is critical that aircraft operating requirements provide a high level of safety. Current aviation regulations require aircraft to operate Mode C transponders in congested airspace and at high altitude, but do not require use in other airspace, where many aircraft operate unmonitored in the vicinity of commercial aircraft. This situation can create a potential hazard to flight safety and could result in a catastrophic midair collision. This study combines data gathered from pilot and controller surveys, a case study on flight incident reports, and a series of expert interviews to help establish whether or not Mode C transponders should be operated by all aircraft to preserve aviation safety.

Author

Clifford D. Cochran is a third generation pilot, registered aircraft owner, and former Air Force air traffic control specialist. He has been flying for over ten years, and served as an air traffic controller in five facilities. In 2011, he facilitated the Travis Air Force Base Cooperative Research and Development Agreement, which set industry standards for surveillance radar operations near a wind farm. He holds a B.S. in Aviation Technology from the University of Alaska Anchorage (2007) and an MBA from Sonoma State University (2013).

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I. Introduction

On August 31, 1986, Aeroméxico Flight 498 departed Tijuana for Los Angeles, with 58 passengers and six crewmembers on board. The DC-9 aircraft was under the command of Captain Antonio Valdez Prom, a seasoned airline pilot with over 10,000 hours of flight experience. Weather conditions were excellent, with clear skies and good visibility, as Captain Prom prepared to descend into the Los Angeles Terminal Control Area (TCA). At nearby Torrance Airport, William Kramer and two passengers boarded his Piper aircraft and departed to Big Bear City. Kramer was a relatively inexperienced pilot, with 231 hours of flight time, but conditions indicated the flight would be smooth.

At 11:47 a.m., the Los Angeles arrival controller established contact with Flight 498 and issued descent instructions in preparation for landing. Moments later, the controller turned his attention to a Grumman Tiger airplane departing from Fullerton, which requested air traffic control services. The pilot failed to properly set his transponder, and began climbing directly through the TCA. This alarmed the controller, who told the Grumman pilot that in the future he should look at his flight charts, because he very nearly collided with another aircraft.

Distracted by the airspace violation, the controller did not observe Kramer's Piper inadvertently enter the TCA. The Piper was not equipped with a transponder, making it nearly impossible to see on the radar scope. At 11:52 a.m., the Piper's engine collided with the tail of the Flight 498, shearing off the top of the Piper's cockpit and decapitating its occupants. The heavily damaged Piper fell onto an empty playground at Cerritos Elementary School. With most of its tail section torn off, the DC-9 inverted and dived into a residential neighborhood in Cerritos, exploding upon impact and killing all 64 on board. The explosion destroyed five homes, damaged seven others, and killed 15 people on the ground. In the subsequent accident investigation, it was determined that proper Mode C transponder use could have prevented this shocking disaster (National Transportation Safety Board, 1987).

The Cerritos midair collision provides one of the most compelling examples for the importance of Mode C transponder use in the aviation industry. Transponders, short for transmitter-responder, are devices installed in aircraft that produce an electronic response upon receiving a radio-frequency interrogation. Mode C is the type of transponder that provides altitude information to air traffic control, in addition to aircraft identification and airspeed. Air traffic control systems rely heavily on signals from Mode C transponders to monitor and direct traffic over a large area (Spitzer, 2007). In addition, aircraft collision avoidance systems have been developed to use transponder transmissions as a means of detecting aircraft at risk of collision. These systems, known as TCAS, are only effective if both aircraft are operating a properly functioning transponder (Peppler, 1996).

The first aircraft transponders were developed by the British military during World War II, in order to distinguish the difference between friendly and enemy aircraft on radar. Wide scale use of transponders in commercial aviation began during the 1960s, when the technology was deemed necessary for aircraft flying in specific areas (Bartsch, 2012). In 1988, the federal government established the first legal requirement for Mode C transponder use by aircraft operating within certain airspace (Mode C Rule, 1988). In September 1993, the United States adopted the international method of classifying airspace, based on air traffic operations. This provided a more precise method of regulating Mode C transponder use, which was mandated for aircraft operating in Class A, B, and C airspace, as well as Class E airspace above 10,000 feet MSL. For Class B airspace, Mode C transponder use is required within 30 nautical miles of the busiest airports in the United States, and for Class C airspace, Mode C transponder use is required within 10 nautical miles of other large airports (Airspace Reclassification, 1991). However, the remaining airspace classes, D through G, account for the majority of navigable airspace in the United States. This includes hundreds of low-altitude airways, where many aircraft operate on a regular basis (Nolan, 2011).

There have been no significant changes to Mode C transponder operational requirements in controlled airspace since airspace reclassification in 1993 (Airports/Locations: Special Operating Restrictions, 2014). In the last 20 years, air travel has nearly doubled, with annual passenger enplanements in the United States increasing from 468.3 million to 740.2 million (FAA.gov, 2014), commanding a review of the current policies. The purpose of this study is to determine if Mode C transponder operation by all aircraft in flight would improve aviation safety in the San Francisco North Bay. The hypothesis for this dissertation states that Mode C transponder use by all aircraft would improve aviation safety. The research question inquires if Mode C transponder use is required for all aircraft in flight above the San Francisco North Bay, would there be an improvement in aviation safety?

This thesis combines three methods of data collection to address the hypothesis and answer the research question. Surveys were released to pilots and air traffic controllers in the San Francisco North Bay to obtain general statistical data on Mode C transponder use. Next, a case study on flight incident reports in the San Francisco North Bay for a period of two years was completed to obtain additional evidence. And finally, interviews were conducted with experts in the professional piloting, air traffic control, and aviation administration communities to supplement the evidence gathered with experience. Data from the survey, case study, and expert interviews was used to evaluate whether or not requiring Mode C transponder use for all aircraft in flight would improve aviation safety in the San Francisco North Bay.

II. Literature Review

The review of literature seeks to address all significant published information on the subject of transponder use in aircraft. First, an examination of federal rulemaking on transponder use was completed to obtain information on previous changes to legal operational requirements. Next, an analysis of transponder use in air traffic control operations and application to anti-collision technology in aircraft was completed. Additionally, the impact of transponder use on national security was investigated. Finally, this review concludes with consideration of other technologies and potential replacements for transponders.

Government regulation of aircraft transponder use in the United States began in December 1985, when the Federal Aviation Administration issued the Transponder-On Rule. This required any pilot operating an aircraft equipped with an operable transponder to have that transponder turned on while flying in controlled airspace. The rule was intended to enhance flight safety by providing an increased degree of aircraft target visibility to radar controllers in air traffic control facilities (Transponder-On Rule, 1985).

The 1986 midair collision over Cerritos brought public attention to the issue of Mode C transponder use in congested airspace. Since the private aircraft involved in the collision was not equipped with a transponder, it flew undetected by air traffic control as it inadvertently entered the Los Angeles Terminal Control Area (Block, pp. 87-88). In response to public fears about aviation safety, including people on the ground, Congress passed The Airport and Airway Safety and Capacity Expansion Act of 1987. This new legislation mandated the FAA require pilots to use transponders with altitude encoding equipment, called Mode C, in designated airspace where radar service was provided for separation of aircraft (Weiner, p. 14).

In February 1988, the FAA published a new proposal to mandate Mode C transponder use in all airspace within 40 nautical miles of airports where terminal radar approach control service had been established. The proposal also sought to require Mode C transponder use in controlled airspace above 6,000 feet AGL or 12,500 feet MSL, whichever was lower (Mode C Rule, 1988). However, due to the great expansion in airspace restrictions, the proposal was dubbed the Valentine's Day Massacre by pilots, because it was released on February 12. An extensive lobbying campaign by the Experimental Aircraft Association and the Aircraft Owners and Pilots Association resulted in a flurry of 65,000 letters sent to FAA headquarters, opposing the proposal. The FAA reported it was one of the highest responses to a rulemaking proposal ever (Weiner, p. 14). Many of the respondents, including members of Congress, suggested the FAA exceeded the requirements for the legislation passed in 1986 (Mode C Rule, 1988). Faced with intensive opposition, the FAA relented and reduced Mode C transponder requirements to within 30 nautical miles of large hub airports and above 10,000 feet MSL (Weiner, p. 14).

Since the initial proposal to expand Mode C transponder use met such fierce opposition, the FAA has been cautious with aircraft transponder requirements. When the FAA published wide scale changes to airspace design with airspace reclassification in September 1993, they did not change transponder requirements (Airspace Reclassification, 1991). Even after the terrorist attacks in September 2001, when hijackers turned off transponders in three of the four aircraft, the FAA did not change transponder requirements for airspace classes (National Commission on Terrorist Attacks, p. 22). In the two decades since airspace reclassification, there have been no changes to transponder requirements for any class of airspace, and it might take another accident to sway public opinion in favor of any changes.

The second focus for the literature review examined the impact of Mode C transponder use on air traffic control operations and aircraft anti-collision technology. Published works introduced the topic by discussing the two types of radar systems, primary and secondary. Primary radar systems, which do not use aircraft transponder information, are said to have limited usefulness. They cannot identify individual aircraft directly, and are often affected by clutter, such as signals reflected from the ground or precipitation. Secondary radars, which incorporate electronic data received from transponders, are considered to be tremendously beneficial to air traffic control, because every aircraft can be easily identified by controllers. Non-pertinent aircraft and other phenomena observed by the radar may be filtered and easily ignored. If the equipment is functioning properly, aircraft identity and altitude can be constantly displayed on the radar screen, relieving air traffic controllers of mentally trying to keep each radar target properly identified (Hewish, p. 567).

Additional benefits of transponder use with secondary radar include modifications to radar software, which performs additional tasks to assist the air traffic controller. Aircraft with an assigned transponder code are tracked by the radar software and may be automatically handed off to other controllers in adjacent sectors, alleviating a great volume of workload. Secondary radars maintain aircraft track data, allowing future position of aircraft to be projected, preventing conflicts with other aircraft and terrain. *Conflict alert* provides controllers with warnings for aircraft-aircraft conflicts, while *minimum safe altitude warning* alerts controllers for aircraft-terrain conflicts. These warning systems have decreased the number of near-misses between aircraft in controlled airspace (Nolan, pp. 368-369).

Although transponder use with secondary radar has provided many benefits to air traffic control, there are some challenges as well. Skies are becoming increasingly crowded, and the increase in transponder signals produces an effect known as *garbling*. The train of pulses emitted by an aircraft transponder cover a three-kilometer area, and if there are more than one aircraft in that area, the radar can become confused and cause the signals to overlap. An additional problem lies in the fact that when two secondary radars interrogate the same aircraft, the transponder cannot reply to both, and the signal is sometimes dropped. Furthermore, aircraft transponders send replies in all directions, so ground stations often pick up unwanted signals, sometimes causing ghost aircraft to appear (McClellan, 1991, p. 98). Another disadvantage with secondary radar is how conflict alerts and minimum safe altitude warnings are provided. The system provides a visual and aural warning for each, but does not provide the controller with any possible remediation for the impending problem. The solution may be simple, but in the case of rapidly maneuvering aircraft, it could be greatly difficult. However, advances in technology are addressing these issues, and the benefits of transponder use with secondary radar far outweigh the negatives (Wise, Hopkin, & Garland, 2009).

Another benefit aircraft transponders provide is in their application to anti-collision technology. Traffic Collision Avoidance Systems (TCAS) provide independent backup of the air traffic control system, and greatly assists pilots in their responsibility to see and avoid other aircraft. TCAS systems are effective in warning pilots of other aircraft that are on a potential collision course, but only if the other aircraft is operating a transponder (McClellan, 1987, pp. 82-84). In wake of the Cerritos midair collision, TCAS became considered critical to flight safety, compelling Congress to pass legislation requiring its operation in all commercial aircraft the following year (TCAS Rule, 1989).

Pilot and airline operator response to the TCAS Rule was slow and met with resistance. In December 1989, the airlines pressured the FAA to extend the deadline for installation of TCAS in their fleets for two years. When that deadline was not met, the FAA extended TCAS requirement an additional year. In October 1992, the Regional Airline Association petitioned for an exemption to the rule and urged the FAA to extend the deadline again. Because of delays in equipment development and testing, complexity of the equipment, and requirements for supplemental type certification, the FAA extended the compliance date for installing TCAS to December 1995 (Collision Avoidance Systems, 1994).

While the FAA actively pursued installation of TCAS in commercial airline fleets, it avoided private aircraft owners altogether. The high cost of TCAS equipment, above $100,000 per unit, made it nearly impossible to push on private pilots (Ashley, p. 80). This lack of equipment has made it understood that private aircraft operating without transponders can be a problem for commercial aircraft. The FAA has made their best attempt to separate these aircraft from commercial airlines, through the operational requirements of airspace in terminal areas. However, even with these new regulations in place, a small plane operating without a transponder could still enter terminal airspace with radar coverage and be virtually undetected (U.S. Congress, Office of Technology Assessment, pp. 147-148).

Since the advent of TCAS, commercial pilots have grown accustomed to the protection it provides. While almost no small aircraft have TCAS, they often operate transponders, which provide data to TCAS, and enables commercial aircraft to avoid a potential collision. This added level of safety provided by TCAS made one airline captain say that he felt exposed without it (Ashley, p. 80).

A third consideration regarding transponder use is a relatively new concept, only since the terrorist attacks on 9/11. Before the events of September 2001, a flight crew would have responded appropriately to an airborne hijack situation by meeting hijacker demands, flying the aircraft to the instructed destination, and allowing the appropriate authorities to resolve the situation. Due to the violent nature of the 9/11 hijackings, none of the four flight crews were able to switch their transponders to the designated hijack alert code. This delaying air traffic control awareness of the unfolding situation and prevented military intervention (FAA Issues Security Guidance for Aircraft Transponders, 2003).

In wake of the 9/11 hijackings, the United States federal government established a task force to develop transponder modifications. Transponders were not designed well in the case of a hijacking, and the hijack code itself, *7500,* is widely published. A hijacker could simply reset or turn off the transponder, preventing air traffic control from intervening. Within one year of the 9/11 attacks, recommendations on transponder use were made to the FAA, which began an evaluation of transponder operations (National Commission on Terrorist Attacks, p. 16-17).

In January 2003, the FAA issued a notice of proposed rulemaking to improve safety through transponder operations in the event of a hijacking. Under the proposal, passenger and cargo airlines would have to modify transponders so that pilots or copilots could activate the hijack code in a single, simple action. Upon activation, the transponder would continuously broadcast the hijack code, thwarting attempts to change the code, deactivate the transponder, or cut off its power. Transponders would need to be activated using a device protected against unintentional activation, such as lifting a guarded switch or breaking a frangible wire. The flight crew would get visual confirmation of activation, a requirement arising from an incident in which an aircraft began a flight with the hijack alert code inadvertently activated by ground personnel. That aircraft was challenged by air traffic control and sent back to the departure airport, with a two-fighter aircraft escort (Bond, p. 47). However, despite significant changes being required for transponder equipment, no changes were made to transponder operational requirements in the different classes of airspace, indicating the FAA is reluctant to make such changes (National Commission on Terrorist Attacks, 2011).

A final consideration to review when examining possible increases to Mode C transponder use requirements is the impending advent of the United States Next Generation Air Transportation System (NextGen) and Automatic Dependent Surveillance Broadcast (ADS-B). This new system provides cooperative surveillance technology in which aircraft positions are determined via satellite and provided to air traffic control, enabling controllers to efficiently track aircraft. The information can be received by air traffic control ground stations as a replacement for secondary radar or by other aircraft to provide self separation. Unlike transponders, ADS-B is automatic in that it requires no pilot or external input (Government Accountability Office, pp. 23-24).

In 2008, the FAA announced that ADS-B would become the cornerstone for the NextGen air traffic control system. The FAA subsequently issued notice mandating that by 2020, all airplanes operating in Class A, B, and C airspace, along with Class E airspace above 10,000 feet, must be equipped for ADS-B. The Mode C transponder requirement within 30 miles of Class B airports would be replaced by the same requirement with ADS-B (Benenson, p. 83).

ADS-B presents a unique consideration when evaluating the need to mandate Mode C transponder use by all aircraft in flight. The problem of aircraft flying undetected without a transponder would be mitigated by ADS-B, which the FAA maintains will be fully operational by 2020 (Federal Aviation Administration, 2013). However, the FAA has historically expected more than the aviation industry is willing to provide, with initial TCAS compliance taking three times longer than expected (Collision Avoidance Systems, 1994). With air traffic expected to continue to increase each year, transponder operation may be necessary until ADS-B becomes operational (Federal Aviation Administration, 2013).

After completing a review on the different aspects regarding Mode C transponder use, it appears there are acceptable reasons to support and refute required operation by all aircraft. To summarize the literature review, greater situational awareness for air traffic control and the increased safety provided through the application of TCAS are reasons to support mandatory Mode C transponder use, while excessive costs and restrictions placed on pilots, as well as the impending onset of ADS-B are primary reasons against it.

III. Methodology

In the previous chapter, the effects of Mode C transponder use on air traffic control and pilot operations are discussed in detail. From those insights, parameters for designing research materials to obtain qualitative and quantitative results were devised. It was determined that a survey, case study, and expert interviews were the most appropriate research methods. This research methodology is discussed in four parts. Research design provides general information about the study, while sample, instrumentation, and data collection provide detailed description of the research process.

Research Design

In order to address threats to reliability and validity, triangulation of data sources was determined to provide the most effective solution (McMurray, p. 263). Triangulation in this study was accomplished through the use of a survey, case study, and expert interviews. In the survey, the opinions of pilots and controllers in the San Francisco North Bay provide information for primarily quantitative analysis, but also for qualitative study. In the case study, two years of flight safety incident reports from the San Francisco North Bay were examined, adding secondary data to the primary from the surveys. Lastly, subject matter expert interviews were conducted to provide professional insights to the subject. The interviews enhance both the data gathered from the surveys and the case study.

This research seeks to determine that if Mode C transponder use is required for all aircraft in flight above the San Francisco North Bay (independent variable), there would be an improvement in aviation safety (dependent variable). Since the public expects perfection in safety for the aviation industry (Birkland, p. 277), any improvement in safety would be considered significant. Terms requiring operational definitions are Mode C transponder use, aircraft, San Francisco North Bay, and aviation safety. *Mode C transponder use* is defined as the operation of an electronic device by aircraft that transmits identification, altitude, and airspeed information to air traffic control facilities, enabling them to provide accurate separation services and advisories. *Aircraft* is defined as a vehicle used for flight in the air, including all fixed-wing airplanes and rotor-wing helicopters (Aeronautical Information Manual, 2014). For the purposes of this study, *San Francisco North Bay* is defined as the counties of Marin, Sonoma, Napa, and Solano, located in the state of California, from which the data was gathered. *Aviation safety* is defined as the preservation of lives, property, and the environment by taking preventive measures to preclude aircraft accidents.

Sample

For the survey portion of this study, a stratified random sample of pilots and air traffic controllers from the San Francisco North Bay was identified as the best method for data collection. Random sampling offers the single best way to obtain a representative sample. No technique guarantees a representative sample, but the probability is higher for this procedure than for any other (Gay, p. 104). Surveys were provided to pilots and controllers of varying licensing and experience, generating the best possible results for the overall population.

In preparation for the case study, Oakland Air Route Traffic Control Center and Travis Radar Approach Control were identified as the only air traffic control facilities responsible for radar-controlled airspace in the San Francisco North Bay. Oakland Center did not respond to requests to provide data for this study, but Travis Approach permitted declassified data to be available for examination.

For the interview component of the study, aviation experts with at least ten years of experience, and at least three years of experience in the San Francisco North Bay were pursued. Interview participants were chosen from three categories, in order to gain a diverse perspective and wide range of knowledge to study. Interviews were conducted with experts in the professional piloting, air traffic control, and aviation administration communities, with experience in the San Francisco North Bay.

Instrumentation

The survey instrument (Appendix A) was administered using SurveyGizmo.com and included demographics and a questionnaire. The survey began with an introduction, explaining that no responses were considered correct, and that its purpose was to gather opinions on transponder operations. A disclaimer was provided, stating responses would remain confidential and used solely for statistical analysis, in order to encourage more candid participation.

The first section, items 1-11, gathered demographic information on respondents. Item 1 required each respondent to identify themselves as a pilot, controller, or both, which directed them to the appropriate set of demographic questions. Items 2-4 gathered necessary demographic information on pilots, including license, possession of an instrument rating, and hours of experience. These metrics were chosen because they best describe the experience and knowledge level of a pilot on this subject. An instrument rating is the only pilot rating directly related to operations in a radar air traffic control environment, so it was the only rating requested. Items 5-6 gathered demographic information on air traffic controller participants, including type of air traffic control facility ratings held and years of air traffic control experience. These metrics were chosen because they best describe the experience and knowledge level of a controller on this subject. Items 7-11 provided identical demographic questions from the previous five items, combined for respondents with both a pilot license and air traffic control rating. Information on respondent location was collected automatically by SurveyGizmo.com, and was not requested in any of the demographic sections.

The second section of the survey, items 12-17, gathered data in the form of a questionnaire. Items 12-13 utilized Likert scales to obtain opinions on the importance of Mode

C transponder use under instrument flight rules (IFR) and visual flight rules (VFR). Items 14-15 utilized Likert scales to obtain opinions on the importance of Mode C transponder use in terminal and controlled airspaces. The purpose of these questions was to contrast pilot and controller opinions on the use of Mode C transponders when legally required and when suggested (Aeronautics and Space, 2014). A high number of low importance responses from pilots for items 13 and 15 compared to items 12 and 14 could indicate low Mode C transponder use in conditions of flight when it may be necessary to preserve aviation safety. Item 16 requested respondents to identify their level of agreement with a statement that Mode C transponder use should be mandatory for all aircraft in flight. Item 17 gathered opinions on the reasons pilots sometimes do not operate transponders, with the option to write-in responses. The survey then concluded with a brief message thanking participants for their time and contributions.

After receiving completed surveys from over 100 pilots and air traffic controllers in the San Francisco North Bay, a qualitative interview was designed to supplement those responses. Since the research topic is narrow and key informants selected are professionals with very little spare time, it was determined that standardized open-ended interviewing was best for this study. The standardized open-ended interview is based on open-ended questions and results in qualitative data. At the same time, neither the wording, nor the sequence of the questions of the interview protocol is varied, so the presentation is constant across participants (Patton, p. 445). For each interview, the research question for the study would be presented, and each interviewee would be requested to share their personal opinion on the matter, including examples from experiences (Appendix B).

Data Collection

The survey questionnaire from SurveyGizmo.com was opened to respondents on January 20, 2015. E-mails containing a request for pilot participation and a link to the survey (Appendix C) were sent to the Gnoss Field Community Association (Novato), Petaluma Area Pilots Association, Napa Airport Pilots Association, Solano Pilots Association (Vacaville), and Travis Aero Club (Rio Vista) on January 20, 2015. There are approximately 300 pilots in these organizations, which are all located in the San Francisco North Bay. Similar e-mails containing a request for air traffic controller participation (Appendix C) were sent to Travis Radar Approach Control and Oakland Air Route Traffic Control Center. Both facilities were unable to disseminate the survey request, due to access permissions on government computers, but some 30 controllers were contacted through personal e-mail and social media.

Initial pilot responses to the survey were rapid, with 53 respondents submitting completed surveys in the first 24 hours, while controller participation started slow, with just 10 responses during the first week. Pilot responses gradually decreased after the first two days until the fourth day, when no surveys were completed. Automated statistical data indicated most survey responses were from Napa, so a second series of e-mails was released to Marin, Sonoma, and Solano county pilot organizations on January 26, 2015. Within 24 hours of this second campaign, 16 pilot responses were completed.

After being denied dissemination of the survey to controllers in air traffic control facilities in the San Francisco North Bay, a robust campaign was launched using social media on January 30, 2015. Rather than contacting groups of controllers, individuals of varying levels of experience were contacted independently and requested to participate. In all, 46 controllers were contacted directly in the second attempt to gather survey data. This proved successful, with 22 controllers completing the survey within 48 hours. However, after the third round of survey dissemination, responses began to slow within three days, and stopped altogether on February 3, 2015. Periodic analysis of the responses revealed only slight changes throughout the two weeks, so with 156 surveys completed, it was determined to close the survey and evaluate the data.

Potential shortfalls from survey participation were addressed by gathering data from additional sources, in an effort to boost validity. Airfield Operations Board (AOB) minutes from Travis Air Force Base were examined, from calendar years 2009 and 2010, with Hazardous Air Traffic Reports (HATRs) extracted and declassified. HATRs provide narratives of unsafe air traffic control events, including near midair collisions between the Travis turbojets and private aircraft. This secondary data provides qualitative information that adds weight to the primary data collected.

Requests to interview aviation experts with experience in the San Francisco North Bay were disseminated through e-mail on February 12, 2015. Three specific groups were targeted, in order to provide the greatest range of experience and most comprehensive data set. Interview requests were sent to three pilots, three air traffic controllers, and three aviation administration experts. Each of the pilots and controllers possessed at least 10 years of experience, with at least three years of experience in the San Francisco North Bay. The aviation administration experts possessed over 20 years of experience each, specializing in air traffic, surveillance radar, and airspace regulation. With experience in the San Francisco North Bay, these experts provide the required knowledge to address the hypothesis and research question. However, due to the contentious nature of the research question, three interview requests were declined, leaving six experts willing to have their comments published.

IV. Results and Findings

In this chapter, the results of the data collection are presented and analyzed. The data was collected to determine an answer to the research question of this study, specifically if Mode C transponder use was required for all aircraft in flight above the San Francisco North Bay, would there be an improvement in aviation safety? Findings were then examined to provide material evidence that either supported or refuted the hypothesis, that Mode C transponder use by all aircraft would improve aviation safety. Two fundamental goals drove the collection of data and subsequent analysis. Those goals were to develop a base of knowledge about the perceived importance of Mode C transponder use in various conditions, and to determine if current perception and utilization are consistent with requirements to maintain appropriate levels of aviation safety. Sufficient primary and secondary data was collected to answer the research question and confirm the hypothesis.

Response Rate

The survey questionnaire was released to points of contact in five pilot organizations and two air traffic control facilities in the San Francisco North Bay. These points of contact forwarded the survey to their members, with approximately 300 pilots and 70 air traffic controllers receiving the questionnaire. In all, 166 surveys were started, but 10 were not completed, resulting in 156 surveys considered legitimate for this study. The survey was completed by 122 pilots and 34 air traffic controllers, including eight who possessed both a pilot license and air traffic control experience. The estimated response rate for pilots was 40.7% and the estimated response rate for controllers was 48.6%. Web-based modes of survey collection often achieve low response rates, but it is understood that a response rate above 40% is considered acceptable (Bethlehem & Biffignandi, p. 244).

Initial examination of pilot survey responses revealed a strong correlation between the licensing of survey participants and pilot licensing in the United States. Although the survey was released to 300 pilots at random, Table 1 shows participation by each pilot license was highly consistent with national figures. The standard deviation for this data set is 3.14%, which indicates pilot participation in the survey closely matches overall pilot demographics in the San Francisco North Bay.

Table 1

	Survey		**United States**		
Licenses	**Pilots**	**Percent**	**Pilots**	**Percent**	**Difference**
Sport/Recreational	3	2.5%	5,062	1.1%	+1.4%
Private	56	45.9%	180,214	40.7%	+5.2%
Commercial	26	21.3%	108,206	24.4%	-3.1%
Airline Transport	37	30.3%	149,824	33.8%	-3.5%

Source: U.S. Civil Airmen Statistics, FAA.gov

The FAA does not release certification information on air traffic controllers, therefore demographic data from the survey could not be compared with actual controller demographics. However, Table 2 indicates the air traffic controllers who participated in the survey possessed a wide range of facility ratings, providing diverse experience to support the resulting data.

Table 2

	Experience (years)						
Facility Ratings	**1-5**	**6-10**	**11-15**	**16-20**	**21-25**	**26-30**	**Total**
Control Tower	3	7	3	1	6	2	**22**
Radar Approach	6	9	5	1	6	3	**30**
Enroute Center	1	3	1	0	2	1	**8**
Total	**10**	**19**	**9**	**2**	**14**	**6**	**60**

Data Analysis

The survey questionnaire featured six questions, intended to determine pilot and controller opinions on the importance of Mode C transponder use in different conditions of flight and types of airspace. The first four questions gathered responses on transponder use when currently considered necessary and when currently suggested. This provided a baseline, then data to evaluate the potential need to increase transponder requirements.

The first survey question after demographics, Question 12, asked participants, “How important is Mode C transponder use for IFR aircraft in flight?” Respondents identified their opinion on a Likert scale, ranging from “Very Important” to “Not Important”. Table 3 presents the data gathered from responses.

Table 3

Certifications	**Very Important**		**Fairly Important**		**Somewhat Important**		**Slightly Important**		**Not Important**	
Sport/Recreational	2	66.7%	0	—	0	—	0	—	1	33.3%
Private	52	92.9%	1	1.8%	0	—	1	1.8%	2	3.6%
Commercial	26	100%	0	—	0	—	0	—	0	—
Airline Transport	35	94.6%	2	5.4%	0	—	0	—	0	—
Pilot Total	**115**	**94.3%**	**3**	**2.5%**	**0**	**—**	**1**	**0.8%**	**3**	**2.5%**
Tower Only	2	100%	0	—	0	—	0	—	0	—
Radar Only	8	66.7%	3	25.0%	1	8.3%	0	—	0	—
Tower & Radar	20	100%	0	—	0	—	0	—	0	—
Controller Total	**30**	**88.2%**	**3**	**8.8%**	**1**	**2.9%**	**0**	**—**	**0**	**—**
Grand Total	**145**	**92.9%**	**6**	**3.8%**	**1**	**0.6%**	**1**	**0.6%**	**3**	**1.9%**

Data from Question 12 demonstrates the importance of Mode C transponder use in IFR flight, with 93% of both pilots and controllers selecting “Very important.” Federal Aviation Regulations do not require Mode C transponder use for IFR, but data gathered in this question indicates it is considered necessary to ensure aviation safety. Question 12 also provides insight on the issue of pilots deliberately not operating their transponder. Even though an overwhelming majority considered Mode C transponder use necessary, three pilots chose “Not Important.” Further evaluation of these surveys revealed one was probably the result of error, since the respondent chose “Very Important” on the following two questions, and “Strongly Agree” to the proposal for required Mode C transponder use. However, two pilots clearly identified Mode C transponder use to be “Not Important” in a condition of flight where the clear majority deems it necessary. This holds consistent with comments in the last question, where two pilots stated transponder use is certainly not required to ensure safety.

Question 13 asked participants, “How important is Mode C transponder use for VFR aircraft in flight?” Respondents identified their opinion on a scale, identical to Question 12. Table 4 presents the data gathered from responses.

Table 4

Certifications	Very Important		Fairly Important		Somewhat Important		Slightly Important		Not Important	
Sport/Recreational	2	66.7%	1	33.3%	0	—	0	—	0	—
Private	28	50.0%	13	23.2%	10	17.9%	4	7.1%	1	1.8%
Commercial	12	46.2%	7	26.9%	7	26.9%	0	—	0	—
Airline Transport	22	59.5%	10	27.0%	2	5.4%	1	2.7%	2	5.4%
Pilot Total	**64**	**52.5%**	**31**	**25.4%**	**19**	**15.6%**	**5**	**4.1%**	**3**	**2.5%**
Tower Only	0	—	1	50.0%	1	50.0%	0	—	0	—
Radar Only	2	16.7%	8	66.7%	2	16.7%	0	—	0	—
Tower & Radar	4	20.0%	11	55.0%	5	25.0%	0	—	0	—
Controller Total	**6**	**17.6%**	**20**	**58.8%**	**8**	**23.5%**	**0**	**—**	**0**	**—**
Grand Total	**70**	**44.9%**	**51**	**32.7%**	**27**	**17.3%**	**5**	**3.2%**	**3**	**1.9%**

Data from Question 13 indicates the perceived need for Mode C transponder use declines when the burden of flight safety is placed entirely on the pilot. However, the majority of pilot respondents still selected “Very Important” for transponder use in VFR flight, and 93% chose at least “Somewhat Important.” With air traffic control relieved of separation services under VFR, controller responses showed a sharp change in the perceived importance of transponder use. Only about one in six controllers surveyed found Mode C transponder use to be “Very Important” for VFR flights. This discrepancy reveals that even under VFR, when pilots are responsible for separation from other aircraft, they believe air traffic control still has responsibility for their safety, since controllers use Mode C transponder signals for separation, not pilots.

Question 14 asked respondents, “How greatly does Mode C transponder use impact flight safety in terminal airspace (Class B, C, D)?” Respondents identified their opinion on a scale, identical to previous questioning. Table 5 presents the data gathered from responses.

Table 5

Certifications	**Very Important**		**Fairly Important**		**Somewhat Important**		**Slightly Important**		**Not Important**	
Sport/Recreational	2	66.7%	1	33.3%	0	—	0	—	0	—
Private	47	83.9%	6	10.7%	2	3.6%	1	1.8%	0	—
Commercial	23	88.5%	2	7.7%	1	3.8%	0	—	0	—
Airline Transport	31	83.8%	4	10.8%	2	5.4%	0	—	0	—
Pilot Total	**103**	**84.4%**	**13**	**9.8%**	**5**	**4.1%**	**1**	**0.8%**	**0**	**—**
Tower Only	2	100%	0	—	0	—	0	—	0	—
Radar Only	7	58.3%	4	33.3%	1	8.3%	0	—	0	—
Tower & Radar	19	95.0%	1	5.0%	0	—	0	—	0	—
Controller Total	**28**	**82.4%**	**5**	**14.7%**	**1**	**2.9%**	**0**	**—**	**0**	**—**
Grand Total	**131**	**84.0%**	**18**	**11.5%**	**6**	**3.8%**	**1**	**0.6%**	**0**	**—**

Data from Question 14 demonstrates the importance of Mode C transponder use in busy airspace, with 84% of pilots and controllers selecting "Very Important." This shows a small decrease from Question 12, where 93% of both groups selected "Very Important" for transponder use in IFR flight. However, Federal Aviation Regulations require Mode C transponder use in busy terminal airspace, but not for IFR flight. This reveals both pilots and controllers believe Mode C transponder use is more important in a condition where it is not required, IFR flight, than conditions where it is legally required, such as Class B airspace. This further supports the theory that current transponder use requirements are somewhat arbitrary.

Question 15 asked respondents, "How greatly does Mode C transponder use impact flight safety in controlled airspace (Class E)?" Respondents identified their opinion on a scale, identical to previous questioning. Table 6 presents the data gathered from responses.

Table 6

Certifications	**Very Important**		**Fairly Important**		**Somewhat Important**		**Slightly Important**		**Not Important**	
Sport/Recreational	1	33.3%	1	33.3%	1	33.3%	0	—	0	—
Private	18	32.1%	14	25.0%	12	21.4%	7	12.5%	5	8.9%
Commercial	6	23.1%	5	19.2%	11	42.3%	3	11.5%	1	3.8%
Airline Transport	17	45.9%	12	32.4%	6	16.2%	1	2.7%	1	2.7%
Pilot Total	**42**	**34.4%**	**32**	**26.2%**	**30**	**24.6%**	**11**	**9.0%**	**7**	**5.7%**
Tower Only	0	—	1	50.0%	1	50.0%	0	—	0	—
Radar Only	3	25.0%	5	41.7%	3	25.0%	1	8.3%	0	—
Tower & Radar	6	30.0%	9	45.0%	4	20.0%	0	—	1	5.0%
Controller Total	**9**	**26.5%**	**15**	**44.1%**	**8**	**23.5%**	**1**	**2.9%**	**1**	**2.9%**
Grand Total	**51**	**32.7%**	**47**	**30.1%**	**38**	**24.4%**	**12**	**7.7%**	**8**	**5.1%**

Data from Question 15 clearly shows that Mode C transponder use is thought to be less important in less busy airspace, with a 51% drop in "Very Important" responses. With the lowest indicated level of importance in the survey, this question suggests pilots flying through Class E controlled airspace do not believe Mode C transponder use impacts their safety. This may cause some pilots to consider turning off their transponder, as they weigh the perceived low impact of safety with the greater risk of policing from air traffic control. Similar to Question 14, current Federal Aviation Regulations require pilots operate Mode C transponders, if equipped, in controlled airspace, but do not require use for IFR flights. However, the survey reported a much higher positive response for IFR than Class E airspace, once again indicating current transponder use requirements may not have been properly assigned.

Question 16 made the statement, “Mode C transponder use should be mandatory for all aircraft in flight.” Respondents identified their opinion on a Likert scale, ranging from “Strongly Agree” to “Strongly Disagree”. Table 7 presents the data gathered from responses.

Table 7

Certifications	**Strongly Agree**		**Agree**		**Undecided**		**Disagree**		**Strongly Disagree**	
Sport/Recreational	2	66.7%	0	—	0	—	1	33.3%	0	—
Private	11	19.6%	14	25.0%	11	19.6%	12	21.4%	8	14.3%
Commercial	8	30.8%	5	19.2%	2	7.7%	7	26.9%	4	15.4%
Airline Transport	8	21.6%	8	21.6%	3	8.1%	14	37.8%	4	10.8%
Pilot Total	**29**	**23.8%**	**27**	**22.1%**	**16**	**13.1%**	**34**	**27.9%**	**16**	**13.1%**
Tower Only	1	50.0%	0	—	1	50.0%	0	—	0	—
Radar Only	5	41.7%	3	25.0%	3	25.0%	0	—	1	8.3%
Tower & Radar	6	30.0%	7	35.0%	2	10.0%	5	25.0%	0	—
Controller Total	**12**	**35.3%**	**10**	**29.4%**	**6**	**17.6%**	**5**	**14.7%**	**1**	**2.9%**
Grand Total	**41**	**26.3%**	**37**	**23.7%**	**22**	**14.1%**	**39**	**25.0%**	**17**	**10.9%**

After pilots and controllers weighed the effects of Mode C transponder use on aviation safety in various conditions of flight, Question 16 sought to directly address the main purpose of this thesis. However, rather than conclusively supporting or refuting the hypothesis, this question provided the greatest range of responses. In fact, with the first 100 completed surveys, 50 respondents agreed that Mode C transponder use should be mandatory for all aircraft in flight and 50 did not agree. With survey collection complete, pilots responded 46% in favor of mandatory Mode C transponder use and 41% against, with 13% undecided. Air traffic controllers responded 65% in favor of mandatory use, with 17% against and 18% undecided. These numbers suggest that air traffic control operations would be improved if all aircraft operated Mode C transponders, but pilots are hesitant to increase requirements.

A more thorough examination of the data collected from Question 16 reveals that although the overall results are somewhat inconclusive, certain demographic groups maintain very strong opinions. The most polarizing attribute among pilot respondents was whether or not they possessed an instrument rating. Instrument rated pilots responded 49% in favor of mandatory Mode C transponder use, with 43% against and 8% undecided. Pilots without an instrument rating responded only 34% in favor of mandatory use, with 40% against and 26% undecided. This disparity indicates that pilots using Mode C transponders for navigation consider them more important than pilots who do not.

Flight hours of experience provided a second distinguishing factor among pilots. Pilots with less than 1,000 hours of flying experience offered the most support for mandatory Mode C transponder use, with 47% in favor, 30% against, and 23% undecided. Pilots with between 1,000 and 10,000 hours of flight experience responded 46% in favor of mandatory Mode C transponder use, 46% against, and 8% undecided. Pilots with more than 10,000 hours of flight experience offered the most opposition, responding 35% in favor of mandatory Mode C transponder use, 45% against, and 20% undecided. The decline in support for transponder use as flight experience increases could be the result of these pilots completing most of their flight hours before Mode C transponder use was regulated.

While increase of experience resulted in decrease of support for transponder use among pilots, the inverse proved true for air traffic controllers. Controllers with 1-10 years of experience offered the least support for mandatory Mode C transponder use, with 55% in favor, 27% against, and 18% undecided. Controllers with 11-20 years experience offered 5% more support, while controllers with over 21 years experience responded 78% in favor, 11% against, and 11% undecided. This trend illustrates that more experienced controllers believe Mode C transponder use is important to maintain aviation safety.

Three additional air traffic control demographics provided increased support for mandatory Mode C transponder use, specifically radar controllers, dual-rated controllers, and controllers with a pilot license. These groups are considered better informed on transponder use than tower or less experienced controllers, and their inputs should be considered accordingly. Radar controllers supported mandatory Mode C transponder use, with 68% in favor, 20% against, and 12% undecided. Dual rated controllers, meaning controllers with ratings in tower and radar, responded 73% in favor of mandatory Mode C transponder use, 18% against, and 9% undecided. Controllers who possess a pilot license, probably the most informed group in this study, responded 63% in favor of mandatory Mode C transponder use, 12% against, and 25% undecided. These numbers suggest that the most informed air traffic controllers are highly in favor of mandatory Mode C transponder use.

Question 17 asked participants, “Identify the greatest reason(s) you think some pilots avoid Mode C transponder use.” This question was only available to pilots, who could choose any of the three common reasons provided, and an “other” choice for custom responses. Table 8 provides an overview of the data gathered from this question.

Table 8

Licenses	Equipment Cost		Flight Privacy		Pilot Error		Other	
Sport/Recreational	1	25.0%	2	50.0%	1	25.0%	0	—
Private	30	38.5%	23	29.5%	9	11.5%	16	20.5%
Commercial	12	38.7%	12	38.7%	2	6.5%	5	16.1%
Airline Transport	23	50.0%	11	23.9%	4	8.7%	8	17.4%
Total	**66**	**41.5%**	**48**	**30.2%**	**16**	**10.1%**	**29**	**18.2%**

Data from Question 17 identified the primary reasons pilots do not operate a Mode C transponders in flight. Most respondents indicated transponder equipment is too expensive, and therefore some aircraft owners do not install the equipment in their aircraft. Several responses from the "other" category should be added to this category. Six respondents wrote that some older aircraft lack an electrical system, making transponder installation highly expensive. Along the same lines, two respondents indicated their gliders were not equipped because of the potential added weight. The second most selected reason for pilots to avoid Mode C transponder use is to ensure flight privacy. In addition to 30% of responses selecting flight privacy, five written responses also identified this concept. The high response rate for privacy indicates a number of pilots deliberately choose to avoid transponder operation in order to ensure their activities are not followed by air traffic control. The third reason for transponder disuse, pilot error, received the fewest responses. However, six written responses also addressed pilot error. The primary reason chosen under the "other" category was that since Mode C transponder use is not mandatory in certain airspace, transponders are not necessary. This indicates some pilots consider transponder regulations more important than actual safety implications. Other reasons some pilots avoid transponder use varied widely from "They are too stupid" to "Just not needed for the flight. Like a seat belt on a farm tractor."

In order to provide additional support for findings in the survey, a case study on air traffic incidents in the San Francisco North Bay was performed. HATRs from Travis Airfield Operations Board minutes, from January 1, 2009 to December 31, 2010, were examined in order to determine if Mode C transponder use was involved in any flight safety incidents. There were no reports involving aircraft without a transponder, but at least six near-miss collisions were prevented by TCAS, which depends on aircraft operating a transponder.

On August 6, 2009, a KC-10 entered the Travis radar pattern from the south, and began a descent to their assigned altitude of 4,000 feet. During the descent, the approach controller alerted the KC-10 to VFR traffic five miles away at their 10 o'clock position. As the KC-10 crew searched for that traffic, the approach controller turned them onto the radar downwind to runway 21L. At that point, the controller called out additional VFR traffic at the 12 o'clock position and four miles. Shortly thereafter, the KC-10 crew received a TCAS resolution advisory (RA) and responded to it with an immediate descent. A near-miss ensued, as the VFR aircraft passed off the KC-10's left wing with approximate vertical separation of 400 feet and lateral separation of one mile. The subsequent safety investigation determined the approach controller acted in accordance with protocol, but there were simply too many aircraft in the area (Lloyd, 2009). If the KC-10 crew had not received the TCAS RA off the VFR aircraft's transponder, a midair collision could have occurred, since the aircraft were within nine seconds of impacting each other.

On November 18, 2009, an incident occurred between a C-5 and a small VFR aircraft operating a transponder. Prior to the incident, the C-5 was cleared by Travis radar approach to descend to 2,000 feet towards Travis AFB from the north. During descent, an unknown VFR aircraft departing from Yolo County Airport began to climb into the C-5's flight path. The C-5 attempted to contact Travis arrival control, but that position was not open due to low traffic volume. The C-5 returned to the Travis approach frequency and was immediately advised to stop descent at 4,000 feet for the VFR traffic, but the aircraft targets continued to merge. The C-5 responded to a TCAS RA and initiated an immediate climb of 1,000 feet to avoid the climbing VFR aircraft. The two aircraft came within about one mile and 300 feet (Lloyd, 2010). In this case, if the C-5 crew had not responded to the TCAS RA off the VFR aircraft's transponder, a midair collision could have occurred within eight seconds. Since both aircraft were transitioning altitudes, it is possible that without the TCAS RA, the aircrews may not have seen each other until impact.

On February 11, 2010, a KC-10 departing from Travis AFB was alerted to a VFR aircraft crossing the departure corridor by the tower. Upon switching to departure frequency, they were given an initial vector to the west. After beginning a 20-degree turn to the right, the KC-10 was cleared direct to Manteca, at which point they continued the right turn. The controller anticipated a left turn for the KC-10, and upon noticing the continuation of the right turn, directed them to turn left due to the VFR traffic. After beginning the left turn, the KC-10 received a TCAS RA, which was complied with by a 2,000 foot-per-minute descent. At this point, the KC-10 crew visually acquired the VFR traffic and maneuvered appropriately to avoid a conflict. Air traffic control was found to be non-causal in this incident and again Mode C transponder operation by the small VFR aircraft prevented a collision (Lloyd, 2010).

On May 6, 2010, a C-5 on descent into Travis AFB was given traffic advisories on two VFR aircraft, but was only able to identify one. Travis approach control vectored the C-5 south to achieve lateral separation, and then turned the aircraft back towards Travis, as soon as separation was achieved. Suddenly, one of the VFR aircraft unexpectedly turned towards the descending C-5, causing the C-5 to receive a TCAS RA. The C-5 complied with the RA, acquired the aircraft visually, and resumed altitude clearance once clear of the conflict (Lloyd, 2010). This incident provides another example of Mode C transponder use preventing a midair collision. In the two years of data that were analyzed, Mode C transponder use prevented six potential midair collisions. With aircraft traveling towards each other at a closing speed over 400 miles per hour, eight seconds of reaction time pushes the limits of aviation safety.

With the survey and case study complete, interviews with subject matter experts provided additional evidence to address the hypothesis and research question. Though coming from different specialties in aviation, interviewees were asked the exact same question to ensure reliability and validity with responses. The standardized open-ended interview asked one question, “If Mode C transponder operation was required for all aircraft in flight, would there be an improvement in aviation safety?”

On February 15, 2015, aviation administration expert John D. Collins provided some remarks on Mode C transponder use. Collins is a multiengine instructor pilot with 44 years flying experience. He is one of the most active writers in the aviation industry, providing scholarly articles for a number of aviation magazines and publications. Over the past 14 years, he has served as a consultant for ADS-B development and actively participated in aviation safety rulemaking.

Collins stated that a Mode C transponder is still “essential” to preserve aviation safety, because it is used by TCAS and secondary radar services outside the areas it is mandated. Transponders with Mode C are also required to be on if the system is installed and working any time pilots operate in Class E airspace, even though it may not be mandated to be installed. For aircraft equipped with ADS-B, a target aircraft without ADS-B, but with a Mode C transponder, will still be displayed as a conflict, if one exists. If an aircraft operator installed an ADS-B system to satisfy the 2020 mandate and retained their Mode C transponder, they could utilize the anonymous feature anytime they do not receive air traffic services and squawk VFR.

Collins addressed several key issues regarding Mode C transponder use. He confirmed that use is essential within Class E controlled airspace, even though it is not required, and outside controlled airspace, because of its function with TCAS. He also mentioned that the system is compatible with ADS-B for additional traffic alerts. Finally, he explained how pilots may achieve anonymity using Mode C transponders, but also to retain aviation safety.

On February 24, 2015, air traffic expert Ronald E. Morgan shared his knowledge on Mode C transponder use. Morgan has 39 years experience in ATC operations, global air traffic management, and national airspace system modernization. He served as Director of Air Traffic Services for the FAA from 1996 to 2001. Since 2008, he has been a consultant for enXco, developing green energy in the San Francisco North Bay, while preserving flight safety.

Morgan stated that he believes the FAA has emphasized the importance of transponder usage, with Mode C veils placed around major airports for safety. In those areas, the FAA wants to make sure aircraft not equipped stay out, and those that are operate their Mode C transponders. This enables air traffic controllers to issue traffic alerts, while providing knowledge and situational awareness of non-participating aircraft versus those being worked. With the requirements for transponder use in Class B, Class C, and Class E above 10,000 feet, the FAA has acknowledged that transponder use in areas with certain volumes of aircraft provide additional safety above and beyond aircraft not transponder equipped.

Morgan recalled that during his time with the FAA, there was discussion about requiring transponder to equipage down to 6,000 feet. This altitude was selected because 6,000 feet is where most aircraft obtain en route radar service throughout the United States. With en route air traffic control systems, it’s very difficult for controllers to provide primary radar service without a Mode C transponder. It takes a lot of workload time for controllers, who often decide not to work with non-transponder equipped aircraft. In the en route environment, if a non-transponder equipped aircraft requests ATC services, and it's VFR, most controllers will not provide advisories, if it's IFR, they will not give a clearance. So Mode C transponders give pilots the capability of obtaining services they wouldn't obtain if they didn't have a transponder.

Morgan explained that in Europe, countries are creating new transponder mandatory zones. In the past, transponder required areas have always been related to volume of aircraft, but within the last six months, they've instituted a transponder mandatory zone for wind turbine fields. The UK instituted a transponder mandatory zone for a wind turbine field over water, since it was an area that aircraft used to transit back-and-forth. If someone wanted flight services in that area, they needed to have a transponder, because ATC could not see primary targets as a result of the wind turbine field. However, if someone did not have a transponder, they had the opportunity to go around the mandatory zone. Morgan added that he is hoping this becomes a model for the United States, with the FAA deciding their public policy regarding transponder usage, and regulating it appropriately. If a policy is only going to impact a very small percentage of people to provide aviation safety for a large majority, the government should consider it.

On February 23, 2015, retired Air Force airfield operations commander Major Monty L. Harshner provided his observations on Mode C transponder operations. Harshner is a former head of the Air Force air traffic control school, and with 25 years of experience, has served as commander of ATC facilities at three Air Force bases. He last served in this capacity at Travis AFB in San Francisco North Bay from 2008 to 2011.

Harshner agreed that requiring Mode C transponder use for all aircraft would improve aviation safety, but with a note of trepidation. He said that with proper Mode C transponder use in aircraft, comes information. The more information an air traffic controller has about aircraft in flight, the better they can provide separation and safety services. Altitude information is critical to all aircraft, even those non-participating aircraft controllers are required to provide traffic advisories and information on. There is prescribed air traffic control phraseology for aircraft without Mode C that controllers provide this service for and to, but it includes the phrase “altitude unknown.” If Mode C transponder operation was required, controllers would have positive assurance, or at least reasonable assurance, about the altitude of the aircraft. However, non-participating aircraft without a validated Mode C would still be described as “altitude indicates.” With non-participating aircraft, air traffic control does not have the opportunity to validate the Mode C information. Therefore, controllers do not have absolute certainty on the altitude presented by the aircraft’s transponder signal. Still, in consideration of flight safety, “altitude indicates” is more useful than “altitude unknown.”

Harshner continued, stating that there is still the right to fly and be free in airspace. The more regulations we impose upon pilots, the more we trade freedom for safety. There are probably a certain percentage of people that would incur the cost of upgrading their aircraft and equipment should a Mode C requirement be put into the FARs. Harshner concluded, saying that his perception as an air traffic controller, where safety is paramount, is that mandatory Mode C transponder use would lead to greater safety and awareness.

On February 19, 2015, air traffic control specialist Karlton D. Bagby provided his thoughts on Mode C transponder operations. Bagby has 27 years of radar air traffic experience, including nine years in the San Francisco North Bay. He formerly served as chief controller for the Travis AFB Radar Approach Control from 2010 to 2011.

Bagby stated that there would be many benefits for all aircraft flying within the ATC system to have an operating Mode C transponder. Transponders aid controllers in identifying, tagging, and tracking aircraft through the national airspace system. Transponders greatly reduce a controller’s workload by helping them maintain the identity of many aircraft at once. If the primary target of an aircraft is lost, the secondary target from the transponder is usually still displayed and tracked. Radar systems also have a much longer range in detecting secondary targets from transponders than primary targets from the actual aircraft. Transponders also provide altitude and ground speed information, which is useful to controllers issuing traffic calls and vectoring aircraft.

Bagby also stated that air traffic controller radar screens use information from Mode C transponders to alert controllers to conflicting traffic situations. Radar systems also use an aircraft's transponder altitude information to alert a controller when an aircraft is in close proximity to terrain. Since TCAS systems use transponder information to alert pilots to a traffic conflict, this would be greatly enhanced if all aircraft flying within the ATC system had transponders. Once ADS systems come online in the next few years, it will be even more important for aircraft to have transponders, since this will greatly enhance the ATC system's ability to track and monitor an aircraft's route of flight.

On February 26, 2015, airline transport pilot and radar safety expert Biren Oberoi shared his insights on Mode C transponder use. Oberoi has over 3,000 hours of military and 200 hours of general aviation flying experience, with extensive knowledge of flight operations in the San Francisco North Bay. In 2010, he was selected by Travis AFB leadership to oversee military components of the Travis Cooperative Research and Development Agreement with wind farm developers to optimize Travis ATC radar.

Oberoi stated that from his experiences, in both military and general aviation, he believes that equipping all aircraft with Mode C transponders is step in the right direction. He added that an even more important concern is that pilots operate their transponders when they fly. Mode C transponders have protected his flights many times, in uncontrolled and tactical airspaces, over the United States and combat zones overseas. After flying through the San Francisco Bay Area to a small FBO, Oberoi strongly believes Mode C transponder use ensured his aircraft and others in the sky were safe. It also enabled air traffic controllers to assist him in remaining outside San Francisco Class B airspace and safely navigate to his destination.

Oberoi noted there is a sentiment among general aviation pilots, that they do not want the government watching over them. He added that American pilots have been given near limitless freedom to be able to fly relatively unimpeded through the national airspace system, but with freedom comes responsibilities. With experience flying and worked closely with aviation authorities in other countries, he strongly believes the freedoms afforded to pilots in the United States are benchmark. All pilots should continue to preserve those freedoms by being responsible aviators. As general aviation airspace continues to become further congested, with not only manned, but also unmanned aircraft, it is imperative for aviators to use the tools, such as Mode C transponders, to keep themselves safe and preserve their freedom as aviators.

On February 15, 2015, Air Force safety pilot Nathan A. Schauermann provided his experience with Mode C transponder operations. Schauermann is a C-5 pilot with 13 years of flying experience. He has served in the flight safety offices for Air Force bases in the United States and overseas, including a tour at Travis AFB in the San Francisco North Bay.

Schauermann stated that mandatory Mode C transponder use appears to be a “no-brainer” in the interest of safety, but there is a lot of resistance to a requirement for Mode C in every aircraft. Many aircraft owners are totally opposed to the idea of any transponder requirements. There are two main reasons for resistance from some aviators. First, they don’t understand why they are in danger, as long as they keep their eyes outside and operate under “see and avoid” rules. Second, they balk at any requirements that cost them money. Aircraft parts are expensive and the aircraft manufacturing industry thrives on government required equipment. If a component is required, then the price goes up due to a false demand, so aircraft owners lose out, while the manufacturers benefit.

Schauermann said he believed a Mode C transponder requirement would make flying safer. Anything that gives professional pilots and controllers more information with which to make decisions makes the national airspace system a safer place. However, he added that Mode C transponders should not be forced on the aviation enthusiast who flies for pleasure. Instead, there are several other ways to improve aviation safety. One method to ensure safe flight is to remove offending pilots from the sky. If a pilot violates controlled airspace, they have no right to fly in general. Safety is an attitude, and as much as the government tries to regulate, it all comes down to the attitude and mindset of the operators. Pilots who resist talking to air traffic control, or don't operate their transponder unless required, or meander through approach corridors are the biggest threats to aviation safety. An additional method to preserve flight safety would be through the use of GPS airways as a navigation source. The FAA should establish required routes of flight near heavily controlled airspaces that are outside Class A, B, and C. This would enhance "see and avoid" and potentially reduce situations where radar controlled aircraft and non-controlled aircraft are a conflict. Those routes could be easily depicted on sectional charts.

Analysis of the interviews identified several common understandings among aviation experts. All agree that Mode C transponder use is an important tool to maintain aviation safety. Pilots consider transponders provide a major enhancement to safety with TCAS, which adds another layer of protection from midair collisions. Air traffic controllers believe the information provided from Mode C transponders greatly reduces workload and significantly improves safety. When radar returns for aircraft drop from the scopes, the signal from transponders often remain, ensuring the controller is able to continue safely separating air traffic. Even with more advanced technologies considered, such as GPS and ADS-B, safety experts agree that Mode C transponder use is still essential, and that transponders should be operated by all pilots flying aircraft that are equipped.

However, aviators agree that transponder operations should not be forced upon all pilots in every condition of flight. While this may increase safety, the disadvantages outweigh the advantages, such as increased cost to pilots for equipment from opportune manufacturers. Also, there needs to be a balance between mandatory transponder zones and airspace where they are not required. The national airspace system of the United States offers many freedoms to pilots in comparison to other countries, and the experts agree that American aviators need to be proactive in aviation safety, including proper use of Mode C transponders.

Significant Findings

An exhaustive examination of data from surveys, the case study, and expert interviews revealed four significant findings. First, a discrepancy was identified between Federal Aviation Regulations and the general consensus on Mode C transponder requirement for IFR flight. Second, Mode C transponder use in Class D and E airspace was considered essential, a much greater degree than regulations prescribe. Third, significant support exists for increased Mode C transponder use requirements in both pilot and controller communities. And fourth, acceptable reasons remain to ensure aircraft not equipped with a Mode C transponder are able to fly.

Federal Aviation Regulations require Mode C transponder use in busy terminal airspaces, specifically Class B and Class C, but not for IFR flight. However, both pilots and air traffic controllers offered compelling support, the greatest of any condition of flight, for transponder use with IFR flights. Pilots and controllers provided much less support for Mode C transponder use in busy terminal airspace, where federal regulations require use. This disconnect indicates that current regulations were assigned arbitrarily, without sufficient research, and need to be updated to conform to actual aviation safety needs.

Current regulations suggest Mode C transponder use for Class D and E airspace, but data from this study revealed use in those areas is essential. With exception of pilots hoping to maintain anonymity, every other demographic offered strong support to regulated transponder use in Class D and E airspace. Controllers strongly supported mandatory Mode C transponder use in these airspaces, where they are required to provide separation services with aircraft often not visible to them in the immediate vicinity. Support was offered in non-controlled airspace as well, due to the application of transponder use with TCAS.

Significant support for increased Mode C transponder requirements was identified in both pilot and controller communities. Aviation safety experts provided strong support for increased transponder regulation. Previous attempts to increase transponder use requirements were met with rigorous opposition from pilots, but this study demonstrated pilot attitudes may be changing. This study also revealed controllers strongly support an increase in Mode C transponder requirements.

Even with robust support for mandatory Mode C transponder use, significant reasons exist to ensure aircraft not equipped are able to fly. This study acknowledged that transponder installation is not practical for certain types of aircraft. Some older aircraft lack electrical systems, while some gliders cannot accept the added weight of transponder equipment. Also, transponder equipment is expensive and requiring it for all aircraft most significantly benefits the manufacturing companies, not the pilots. These reasons dictate some aircraft must be allowed to fly without a Mode C transponder.

V. Conclusion

This study was conducted to determine if Mode C transponder operation by all aircraft in flight would improve aviation safety in the San Francisco North Bay. With air travel expected to increase annually for the foreseeable future, it is critical that aircraft operating requirements provide a high level of safety. Current aviation regulations require aircraft to operate Mode C transponders in congested airspace and at high altitude, but do not require use in other airspace where many aircraft operate unmonitored in the vicinity of commercial aircraft. This situation can create a potential hazard to flight safety and could result in a catastrophic midair collision.

With support from 156 surveys completed by pilots and controllers, two years of flight safety incident reports, and six expert interviews, considerable data was gathered to provide an answer to the research question and confirm the hypothesis. The significant findings of this study have confirmed that if Mode C transponder use is required for all aircraft in flight above the San Francisco North Bay, there would be an improvement in aviation safety. However, due to the operational constraints of some aircraft, it is not considered permissible to enforce this conclusion through regulation. This study has determined acceptable reasons exist to allow aircraft not equipped with a Mode C transponder to remain airworthy.

Recommendations

In order to address the significant findings of this study, two recommendations are provided. First, it is recommended that the federal government amend current regulations to require Mode C transponder operation in all IFR aircraft. Second, it is recommended that the federal government establish a new requirement for Mode C transponder operation around military and certain commercial Class D airports. Both recommendations would follow the federal rulemaking process, and could be put into effect in 2016.

The first recommendation, a requirement for all IFR aircraft to operate Mode C transponders in all classes of airspace, received overwhelming support in this study. Pilots and controllers both responded 97% in favor of this requirement, while interview experts suggested IFR flight without transponder use is not practical, commanding a change to the current regulations. This requirement would not only reduce air traffic controller workload, but would not impact VFR flying procedures, allowing pilots without transponders to continue their flights.

The second recommendation, a requirement for all aircraft to operate Mode C transponders around military and certain commercial Class D airports, also received strong support in this study. Pilots responded 95% in favor of this requirement, while controllers responded 97% in favor of this requirement. Additionally, case study data indicated most incidents occurred during descent into Class D airspace, creating the need for added protection in this transition. The recommended requirement would adopt the Mode C rule for Class C airports, which dictates aircraft must operate a Mode C transponder within a 10-nautical-mile radius of the primary airport (Aeronautics and Space, 2014). It would protect the transition of large and fast moving military and commercial aircraft from 10,000 feet MSL, above which Mode C transponder use is required, to the airport.

In the San Francisco North Bay, the requirement for Mode C transponder use with Class D airports would be applied to Sonoma County Airport (STS) and Travis Air Force Base (SUU). This recommendation affects only two of the 12 general aviation airports in the San Francisco North Bay, and allows aircraft not equipped with a transponder to circumnavigate protected areas. Aircraft not equipped with a Mode C transponder based at the affected airports could be granted a waiver to ensure they remain airworthy. Pilots of these aircraft would then be required to file a VFR flight plan with air traffic control prior to entering Mode C transponder airspace.

This would allow them to fly, while enabling air traffic control to safely separate their traffic from the aircraft without a transponder.

Future Study

The main complication with recommendations from this study is the application of local data to federal regulations. The San Francisco North Bay is one of the more congested airspaces in the United States, with the majority of pilots accustomed to operating Mode C transponders on a regular basis. If this study were conducted in a more rural setting, the results could be significantly different. It is suggested this study be replicated at another location in the United States to provide more complete data to support the findings and recommendations.

Another suggested area for future study could be an analysis on the opinions of commercial passengers. While the general public often does not understand what is required to maintain flight safety, public opinion has been critical in establishing new regulations following serious aviation accidents. The debate on whether or not Mode C transponders should be required, and to what extent, will continue between pilots and controllers. However, public opinion could break the deadlock and result in the best possible solution to this unique and highly disputed issue.

References

Aeronautics and Space, 14 C.F.R. § 91.215 (2014).

Aircraft. (2014). In *Aeronautical Information Manual* (4/3/14 ed.). Washington, DC: U.S. Government Printing Office.

Airports/Locations: Special Operating Restrictions; 79 Fed. Reg. 57431 (September 25, 2014) (to be codified at 14 C.F.R. pt. 91).

Airspace Reclassification; 56 Fed. Reg. 65638 (December 17, 1991) (to be codified at 14 C.F.R. pt. 91).

Ashley, S. (1988, August). TCAS: Can it stop midair collisions? *Popular Science*, 233 (2).

Bartsch, R. (2012). *International Aviation Law: A Practical Guide*. Burlington, VT: Ashgate Publishing Company.

Benenson, T. (2008, October). Airwork. *Flying*, 135 (10).

Bethlehem, J. & Biffignandi, S. (2011). *Handbook of Web Surveys*. Hoboken, NJ: John Wiley & Sons.

Birkland, T. (2014). *An Introduction to the Policy Process: Theories, Concepts and Models of Public Policy Making* (3rd ed.). New York: Routledge.

Block, T. (2002, September). Collisions, Part II. *Flying*, 129 (9).

Bond, D. (2003, January). FAA Launches Rulemaking on Transponder Hijack Mode. *Aviation Week & Space Technology*, 158 (4).

Collision Avoidance Systems; 59 Fed. Reg. 67584 (December 29, 1994) (to be codified at 14 C.F.R. pt. 91).

FAA Issues Security Guidance for Aircraft Transponders (2003, January). *The Weekly of Business Aviation*, 76 (4).

FAA.gov (2014). *Passenger Boarding (Enplanement) for U.S. Airports*. Retrieved from http://www.faa.gov/airports/planning_capacity/passenger_allcargo_stats/passenger/.

Federal Aviation Administration. (2013). *NextGen Implementation Plan*. Washington, DC: U.S. Government Printing Office.

Gay, L. (1987). *Educational Research: Competencies for Analysis and Application* (3rd ed.). Columbus, OH: Merrill Publishing Company.

Government Accountability Office. (2006). *Next Generation Air Transportation System*. (GAO Publication No. 07-25). Washington, DC: U.S. Government Printing Office.

Hewish, M. (1980, November). Air-Traffic Police Steer A New Approach. *New Scientist, 88*, 566-568.

Lloyd, M. (2009, October). *Airfield Operations Board Minutes*. Fairfield, CA: Travis AFB.

Lloyd, M. (2010, January). *Airfield Operations Board Minutes*. Fairfield, CA: Travis AFB.

Lloyd, M. (2010, April). *Airfield Operations Board Minutes*. Fairfield, CA: Travis AFB.

Lloyd, M. (2010, July). *Airfield Operations Board Minutes*. Fairfield, CA: Travis AFB.

McClellan, J. (1991, October). Eyeball Separation. *Flying*, 118 (10).

McClellan, J. (1987, June). TCAS. *Flying*, 114 (6).

McMurray, A. (2004). *Research: A Commonsense Approach.* Victoria, Australia: Thomson Social Science Press.

Mode C Rule; 53 Fed. Reg. 23356 (June 21, 1988) (to be codified at 14 C.F.R. pt. 91).

National Commission on Terrorist Attacks. (2011). *The 9/11 Commission Report: The Attack from Planning to Aftermath.* New York: W. W. Norton & Company.

National Transportation Safety Board. (1987). *Aircraft Accident Report: Collision of Aeronaves de Mexico, S.A. McDonnell Douglas DC-9-32, XA-JED and Piper PA-28-181, N4891F,* *Cerritos, California, August 31, 1986*. Washington, DC: U.S. Government Printing Office.

Nolan, M. (2011). *Fundamentals of Air Traffic Control* (5th ed.). Clifton Park, NY: Delmar.

Patton, M. (2002). *Qualitative Research and Evaluation Methods.* Thousand Oaks, CA: Sage.

Peppler, I. (1996). *From The Ground Up* (27th ed.). Ottawa, Ontario: Aviation Publishers.

Spitzer, C. (2007). *Avionics: Elements, Software and Functions* (2nd ed.). Boca Raton, FL: CRC Press.

Traffic Alert and Collision Avoidance System (TCAS) Rule; 54 Fed. Reg. 940 (January 5, 1989) (to be codified at 14 C.F.R. pt. 91)

Transponder-On Rule; 50 Fed. Reg. 45599 (December 2, 1985) (to be codified at 14 C.F.R. pt. 91).

U.S. Congress, Office of Technology Assessment (1988). *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment*. Washington, DC: U.S. Government Printing Office.

Weiner, E. (1988, September). Reporting Points. *Flying*, 115 (9).

Wise, J., Hopkin, V., Garland, D. (2009). *Handbook of Aviation Human Factors* (2nd ed.). Boca Raton, FL: CRC Press.

Appendix A

Aircraft Transponder Use Survey

Thank you for participating in this survey. There are no correct answers and the purpose is to gather your opinions. Your responses are confidential and used solely for statistical analysis.

1. Please select one:
   - ○ Pilot
   - ○ Controller
   - ○ Both

Pilot Demographics

2. Please select your current pilot license:

Sport/Recreational	Private	Commercial	Airline Transport

3. Are you an instrument rated pilot?
   - ○ Yes
   - ○ No

4. Please select hours of flight experience:

   0 ———————————————— 20,000

Controller Demographics

5. Please select ATC facilities you have worked:
   - □ Control Tower
   - □ Radar Approach
   - □ Enroute Center
   - □ Flight Service

6. Please select years of ATC experience:

   0 ———————————————— 30

Both Demographics

7. Please select your current pilot license:

Sport/Recreational	Private	Commercial	Airline Transport

8. Are you an instrument rated pilot?
   - ○ Yes
   - ○ No

9. Please select hours of flight experience:

   0 ———————————————— 20,000

10. Please select ATC facilities you have worked:
    - □ Control Tower
    - □ Radar Approach
    - □ Enroute Center
    - □ Flight Service

11. Please select years of ATC experience:

    0 ———————————————— 30

Questionnaire

12. How important is Mode C transponder use for IFR aircraft in flight?

Very Important	Fairly Important	Somewhat Important	Slightly Important	Not Important
○	○	○	○	○

13. How important is Mode C transponder use for VFR aircraft in flight?

Very Important	Fairly Important	Somewhat Important	Slightly Important	Not Important
○	○	○	○	○

14. How greatly does Mode C transponder use impact flight safety in terminal airspace (Class B, C, D)?

Very Important	Fairly Important	Somewhat Important	Slightly Important	Not Important
○	○	○	○	○

15. How greatly does Mode C transponder use impact flight safety in controlled airspace (Class E)?

Very Important	Fairly Important	Somewhat Important	Slightly Important	Not Important
○	○	○	○	○

16. Mode C transponder use should be mandatory for all aircraft in flight.

Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
○	○	○	○	○

17. Identify the greatest reason(s) you think some pilots avoid Mode C transponder use.

- ☐ Equipment Cost
- ☐ Flight Privacy
- ☐ Skipped Checklist
- ☐ Other ______

Thank You

Thank you for completing the survey. Your response is much appreciated.

Appendix B

Sample Interview Request

Greetings,

This is Cliff Cochran, formerly Captain Cochran from Travis Air Force Base. I'm a graduate student at Golden Gate University and working on my thesis, which proposes:

If Mode C transponder operation was required for all aircraft in flight, there would be an improvement in aviation safety.

If you have time, I would greatly appreciate if you would share your thoughts on whether or not you agree with the statement above and why. If possible, please include personal experiences to support your reasoning. Your response will be included in a document published by Golden Gate University, but if you do not wish to comment, or do not have time, I understand.

Thank you for taking the time to read my request and I look forward to hearing from you.

Sincerely,
Cliff

Appendix C

Sample Survey Request

Greetings,

My name is Cliff Cochran, former Airfield Operations Officer at Travis Air Force Base and currently a graduate student at Golden Gate University. I am completing my master's degree in public administration, and as part of my thesis, request members of your organization participate in a brief survey to obtain their opinions on aircraft transponder use.

The survey will take about three minutes to complete and is accessed with the following link: www.surveygizmo.com/s3/1966121/Aircraft-Transponder-Use. General demographic information is requested, but responses will be kept confidential and used solely for statistical analysis. Would you be so kind to forward this survey to your members? Thank you.

Sincerely,
Cliff