2011

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Collision avoidance on large transport aircraft involves many components: Air Traffic Control (ATC), the pilot, and the Traffic alert and Collision Avoidance System (TCAS). This research explores pilots' interactions with ATC, the environment, and TCAS. Collision avoidance reports from NASA's Aviation Safety Reporting System (ASRS) were used to examine the encounter conditions surrounding collision avoidance incidents, including airspace, environment, and type of aircraft involved as well as pilot perceptions of the event. A coding scheme, developed in the early stages of this research, captured details regarding the traffic encounter, the role that ATC and TCAS played within the encounter, and the flight crew's response. This analysis spanned TCAS-related ASRS incident reports from 2008 to 2010. The results illustrate that the availability and presentation of traffic information impact pilot agreement (and disagreement) as well as their compliance (and noncompliance) with ATC and TCAS issue maneuvers.

The Traffic alert and Collision Avoidance System (TCAS) delivers a two-stage advisory and avoidance maneuver to the pilot when it predicts loss of aircraft separation. The first stage, "Traffic Advisory" (TA), advises the pilot to a situation, but does not command (or authorize) an avoidance maneuver. The second stage, "Resolution Advisory" (RA), delivers a vertical avoidance maneuver (or limits on vertical speed) as required to maintain separation. These stages are supported by the TCAS traffic situation display (TSD), which provides a horizontal spatial presentation of nearby traffic as an aid to visual acquisition.

When a pilot encounters a TCAS advisory, he or she has seconds to decide how to respond. The Federal Aviation Administration (FAA) Advisory Circular 120-55B mandates that the pilot in command should maneuver as a TCAS RA directs unless the maneuver would endanger safe flight operations. It is important to note that pilots generally receive these RAs in high-density air traffic environments, and thus the time period leading up to, and spanning, a TCAS RA may also include many other events. For instance, a pilot may visually acquire another aircraft, which may or may not be the advised traffic, or a pilot may receive a traffic call-out from the controller. In the same instance, the pilot may overhear other communications on the 'party-line' or incur non-collision avoidance related events and alerts. The pilot also may receive air traffic instructions, which may be perceived as creating or resolving the traffic situation. Still, the Federal Aviation Regulation (FAR) 91.3 explains that a pilot in command has the ultimate authority and responsibility for the safe flight of the aircraft. Therefore, to extensively examine pilot interactions with TCAS, it is critical to examine not only the interactions themselves, but also the context of the air traffic environment in which pilots may be influenced by multiple, sometimes-competing factors.

To explore the collision avoidance environment in context, reports from NASA's Aviation Safety Reporting System (ASRS) were examined. The ASRS is a database containing voluntarily submitted reports filed by any personnel (including pilots) to describe incidents relating to potential aviation safety concerns. This database provides a unique method of observation and analysis regarding the perceptions of pilots during events involving TCAS. Earlier studies, which examined pilot reported use of TCAS via ASRS reports, identified an unexpected degree of reported noncompliance to TCAS RAs, a wide range of roles that the pilots attributed to TCAS, and potential reliance on the TCAS traffic situation display beyond its intended role as an aid to visual acquisition (Mellone, 1993; Pritchett, 2001; Rantanen, 2003).

The purpose of this study is to provide a current review of ASRS reports with a more detailed analysis of the reported factors affecting a pilot's response to TCAS RAs and ATC instructions. This paper summarizes a broad analysis of cases where pilots report agreement (or disagreement) and compliance (or noncompliance) with TCAS and ATC instructions. While the narratives provide a window into pilots' perceptions of the events, it is important to note that the reports may reflect incomplete or inaccurate assessments of the events. Thus, the emphasis of this paper is on factors perceived by pilots and reported by pilots as influencing their responses.

Method

The ASRS database was accessed on July 20th, 2010, and relevant reports from January 2008 - April 2010 were selected using a pre-defined list of collision avoidance-related search terms: TCAS, ACAS, collision avoidance, traffic advisory, resolution advisory, avoid a collision, evasive action, and mid-air collision. An example is shown in Figure 1.

> "I was crewing as [Second-In-Command] of an aircraft cruising at [Flight Level] 190. There was a traffic alert on TCAS. The alert was an amber target at +3,300, twelve o'clock and descending rapidly. Both pilots' eyes [were] on the situation. We noticed the aircraft moved in a zigzag. [We] received an RA to descend on TCAS. Noticed the aircraft was at +300 feet. Reported to ATC immediately that we had an RA and were descending. At the same time of reporting to ATC, I looked out for traffic and spotted a B-52 at our two o'clock position and less than one mile horizontal. Looks like if we hadn't taken evasive action there could have been a collision. We descended until the TCAS advised us that we were clear of conflict. We descended to 18,300. Once clear of traffic we climbed back to assigned altitude of [Flight Level] 190. I listened to ATC tell the other aircraft he should have been at block altitude of 22,000 to 20,000 feet, thank goodness for TCAS."
> *(ACN: 879699, 2010)*

Figure 1. The narrative is an example of an ASRS report found in the July 20th, 2010 search, describing a pilot's interactions with TCAS.

A coding scheme was developed and tailored to the analysis of collision avoidance events involving TCAS from a preliminary analysis of reports from 2009 and 2010. The coding scheme is comprised of four dimensions. The first, *Encounter Conditions,* identifies the weather conditions, the airport, the types of aircraft involved and their respective flight paths. *Incident Description* and *Traffic Situation Awareness* record which type of advisory (TA, RA or both) that the pilot reports acting upon, whether the pilot was impacted by the possible visual acquisition of another aircraft, 'party-line' communications, and/or air traffic controller call-outs of traffic, as well as the response of the pilot to the advisory. Finally, *Perceptions of the Reporting Individual* captures descriptions framing important factors as positive or negative, perceived communication breakdowns, and recommendations related to TCAS or collision avoidance (as shown in Table 1).

Table 1.

Coding Example of ACN: 879699, 2010

Statement	Incident Description	Traffic Situation Awareness	Perceptions
There was a traffic alert on TCAS.	TA		
The alert was an amber target at +3,300, twelve o'clock and descending rapidly		Traffic Situation Display	
[We] received an RA to descend on TCAS	Descend RA		
Reported to ATC immediately that we had an RA and were descending.	Complied with RA		
At the same time of reporting to ATC, I looked out for traffic and spotted a B-52 at our two o'clock position and less than one mile horizontal.		After RA	
I listened to ATC tell the other aircraft he should have been at block altitude of 22,000 to 20,000 feet, thank goodness for TCAS.			Positive Perception of TCAS

Note: The dimensions of incident description, visual acquisition and perceptions were used to code the narrative itself, while encounter conditions were used to code information not included in the narrative.

Two coders independently coded the 278 ASRS reports with an inter-rater reliability goal of 80 percent. Using Cohen's kappa test, the resulting kappa value indicated 96% agreement, and coding disagreements between the raters were discussed until a consensus was reached. Subsequently, cases reporting noncompliance to instructions issued by TCAS or ATC were re-examined for common themes.

Results

As shown in Table 2 and Table 3, the reported incidents occurred in a variety of conditions and had a variety of outcomes in terms of reported compliance to TCAS RAs and ATC instructions. These categorizations were formed from the reports provided by the pilot, which in some cases were incomplete or may have been based on a biased perception of the situation.

Table 2.

Encounter conditions of the reported incidents

Year (n=278)			**Respondent Aircraft Type (n=278)**		
2008	109	39.20%	Commercial Jet	28	10.10%
2009	128	46.00%	Commercial Fixed Wing	35	12.60%
2010 (January – April)	41	14.80%	Commercial Jet Low Range	31	11.20%
Time of Day (n=262)			Commercial Jet Medium & Short Range	96	34.50%
Early Morning (12:01am – 6:00am)	20	7.60%			
Morning (6:01am – 12:00pm)	60	22.90%	Corporate Jet	51	18.40%
Mid-Day (12:01pm to 6:00pm)	131	50.00%	Military Aircraft	3	1.10%
Evening (6:01pm to 12:00am)	51	19.50%	Regional Jet	26	9.40%
Weather (n=226)			Small Personal Aircraft	8	2.90%
IMC	31	13.70%	**Other Aircraft Type (n=183)**		
Mixed	16	7.10%	Commercial Jet	44	24.10%
VMC	179	79.20%	Corporate Jet	6	3.30%
Phase of Flight (n=292, allowing for multiple flight phases per report)			Helicopter	6	3.30%
			Military Aircraft	9	4.90%
Climb	73	25.00%	Regional Jet	3	1.60%
Cruise	46	15.80%	Small Personal Aircraft	50	27.30%
Descent	44	15.10%	Visual Flight Rules Aircraft	18	9.80%
Approach	129	44.20%	Unknown Aircraft	47	25.70%

Table 3.

Reported compliance to TCAS RAs and ATC instructions

Reported Compliance to RA (n=248)		
Compliance	192	77.40%
Partial Compliance	25	10.10%
Noncompliance	19	7.70%
Unspecified	12	4.80%
Reported Compliance to ATC Instructions (n=78)		
Compliance	43	55.10%
Partial Compliance	15	19.20%
Noncompliance	20	25.60%

Of the reported RA encounters, 77% (n=192) of pilots reported complying with the TCAS instructions, while reported noncompliance to an RA occurred in less than 8% of the reports (n=19). Statistical analysis revealed no statistically significant relationships between the conditions described in Table 2 (year, time of day, weather, respondent aircraft, other aircraft, and phase of flight) and reported compliance to either TCAS RAs or ATC instructions, described in Table 3. Examining compliance in more detail, many pilots reported being already clear of the conflict when the RA was delivered, and thus did not comply with its instructions. For example, one pilot noted, "*I noticed that the TCAS depicted traffic was slightly behind us and to our left on my NAV display. The Captain immediately called something to the effect of, I've still got him, we're clear*" (ACN: 841821, 2009). Others reported using visual acquisition as justification for reported RA noncompliance: "*I elected, with the Captain's concurrence, to keep the descent so as to keep the MD80 in sight*" (ACN: 838285, 2009). In a few cases (15% of reported RA noncompliance, n=3) pilots viewed the TCAS instruction as directing them into traffic. "*Just then our TCAS gave an RA, 'Descend, crossing, descend.' The Captain said something to the effect of, 'I'm not doing that. He's descending, we'll descend right into him" and did not follow the TCAS RA*" (ACN: 854982, 2009). In 10% (n=25) of the analyzed reports, pilots conveyed partially complying with an RA. For these cases, pilots typically performed the vertical maneuver instructed by a TCAS RA, but added a horizontal component. These narratives suggest that the pilots believed their response was appropriate, and it followed standard procedure: "*As the Pilot Flying, the First Officer appropriately initiated a descending left-hand turn away from target per the aural and visual guidance from the TCAS*" (ACN: 802766, 2008).

Chi-square tests revealed that the relationship between reported compliance to TCAS RAs and any awareness of the location of other aircraft (i.e., from either the TCAS traffic situation display or visually out the window) is statistically significant, ($\chi^2(2, N = 233) = 10.990, p < 0.01$). Additionally, there exists a relationship between reported compliance and visual acquisition, without mention of the TCAS traffic situation display ($\chi^2(2, N = 233) = 7.291, p < 0.05$). As shown in Table 4, pilots reported 31 instances of maneuvering after receiving the precautionary TCAS TA and before receiving the RA. In these cases, pilots reported disconnecting the autopilot, performing a horizontal maneuver, or performing a vertical maneuver. For example, "*Pilot not flying reduced the scale of our TCAS display, and seeing traffic below, we reduced our descent rate to 300 FPM*" (ACN: 834304, 2009). During these maneuvers, pilots reported having awareness of the other aircraft 84% of the time. The relationship between a pilot's decision to maneuver on a TCAS TA and their reported awareness of the other aircraft, on the traffic situation display or visually is significant, ($\chi^2(1, N = 278) = 6.952, p < 0.01$). In the situation where a pilot reported maneuvering on a TCAS TA, it is likely he or she reported having awareness of the location of another aircraft.

Table 4.

Pilot reported response correlated to when a TCAS advisory was received

Reported Timing of Pilot Response to an Event (n=230)		
Pilot Maneuvered Before a TCAS Advisory	23	10.00%
Pilot Maneuvered After a TA and Before an RA	31	13.48%
Pilot Maneuvered After an RA	176	75.22%

In 78 of the narratives, pilots reported receiving collision avoidance instructions from ATC and in 26% of these reports (n = 20) pilots reported not complying with those instructions (shown in Table 3). Many pilots explained that they chose to follow a TCAS RA, which conflicted with air traffic instructions, and expressed a belief that the air traffic instructions would not resolve the traffic situation. For example, "*After we began the climb, ATC said to increase descent. Had we followed his instructions versus the TCAS RA, it would have ended in a midair collision*" (ACN: 852998, 2009). In some cases, pilots described relying on their awareness of other aircraft, based on the TCAS traffic situation display or visual acquisition. "*Traffic was depicted on TCAS, as we were converging traffic continued to head directly towards us and climbing up to our altitude. ATC issued a turning and climbing clearance to avoid conflicting traffic. I refused that clearance as I felt that would have caused a near midair or worse*" (ACN: 862593, 2009). Cases of "partial compliance" to air traffic instructions were also noted when pilots began to follow air traffic instructions but then received and complied with a TCAS RA(19%, n = 15). In several

cases, the pilot chose to continue an ATC commanded turn while also following the RA vertical command. "*About 30 seconds went by before ATC told us to turn a heading of 270. I started the turn and the TCAS gave an RA to descend at a rate of 1500-2000 FPM. I turned off the autopilot, pulled the power levers to idle, and descended at a rate of 2000 FPM while continuing the turn*" (ACN: 849888, 2009).

As previously stated, collision avoidance cannot be examined by considering only the TCAS advisories and instructions or ATC traffic call outs and instructions. Throughout a collision avoidance situation, a pilot may receive and interpret the information presented (from their environment, by ATC advisories, or by TCAS advisories) and from that information, he or she may determine an avoidance maneuver is necessary. In the cases where a pilot chose to maneuver prior to receiving an RA or instructions from the controller, there is a high likelihood that the pilot had previously established awareness of another aircraft via the traffic situation display ($\chi 2(2, N = 221) = 7.657$, $p < 0.03$ and ($\chi 2(2, N = 256) = 10.403$, $p < 0.01$). For the instances when a pilot receives an RA, statistical analysis suggests, he or she will be more likely to comply with the TCAS instructions if he or she was first notified of the potential collision by TCAS, through either the RA itself or a TA ($\chi 2(4, N = 229) = 14.059$, $p < 0.01$). Finally, if a pilot is directed to a traffic situation by either ATC or TCAS, they will most likely delay any response until prompted by an RA or ATC instructions ($\chi^2(4, N = 227) = 22.739$, $p < 0.01$ and $\chi^2(2, N = 267) = 9.266$, $p < 0.01$).

Pilots also frequently provided their assessments of the performance of TCAS and ATC (43%, n = 120), as shown in Table 5. In the case of TCAS, pilots focused their negative comments on the traffic situation display and their assumption of an error in the TCAS logic. For instance, one pilot explained that "*it was very hard to see [the other aircraft's] altitude as it was all cluttered together [on the traffic situation display]*" (ACN: 840426, 2009). Another pilot described his experience with TCAS, "*Descending into an airplane that is clearly descending? TCAS software clearly did not give appropriate guidance, nor did it self-correct when the initial guidance was so clearly wrong*" (ACN: 854982, 2009). Other pilots discussed feeling "overloaded" by the TCAS warnings. "*It was hard to hear instructions from ATC from the numerous RA callouts of the airplane and TA callouts which were shouting quite loud in our headsets – which made it difficult to understand the instructions given*" (ACN: 773537, 2008). Conversely, many narratives cited TCAS as the system that saved the day. "*The TCAS was what prevented this from being a potential midair*" (ACN: 802820, 2008).

Table 5.

Pilot perceptions of air traffic and TCAS performance

Perceptions of the Collision Avoidance System (N=278)			
Element	**Type of Perception**	**Sub Category**	**% of Sample**
ATC	**Positive (1.08% of all reports, n=3)**		
		Credit for save	100%
	Negative (35.25% of all reports, n=98)		
		Controller Assigned Collision Course	19.39%
		Lack of Traffic Call	16.33%
		Controller Error	12.24%
		Disinterest by the Controller	15.31%
		Lack of Situational Awareness	19.39%
		Other	17.35%
TCAS	**Positive (8.63% of reports, n=24)**		
		Credit for save	100%
	Negative (7.91% of all reports, n=22)		
		Unclear Information on TSD	13.64%
		TCAS Assigned Collision Course	50.00%
		Pilot was Overloaded	9.09%
		Other	27.27%

The overall perception of ATC as described in these ASRS reports was comparatively negative. Thirty-five percent of the analyzed reports included negative comments from the pilots regarding his or her interactions with the controller. Within these responses, pilots reported perceiving that the instructions provided by the air traffic controller, if complied with, would have resulted in a mid-air collision. These comments were common among the reports also describing noncompliance to air traffic instructions. Other pilots discussed the failure of the controller to provide traffic call-outs prior to the incident. "*I called the Tower after landing and told them it would have been helpful to get an advisory upon initial contact so we could have been more prepared. TCAS system was the only alert we had as Tower told us of traffic after the traffic had passed*" (ACN: 861931, 2009). Additionally, pilots noted instances where the air traffic controller appeared disinterested, unaware or not concerned about the traffic situation. "*It did not seem that the Tower Controller was very concerned about the event*" (ACN: 862312, 2009). Only three reports included positive comments, with one report stating "*THANK THE CONTROLLER and see if it could be counted as a 'save'*" (ACN: 858151, 2009).

Conclusions

The purpose of this study was to begin to explore the factors which affect pilots' agreement (or disagreement) and compliance (or noncompliance) with collision avoidance instructions. In an analysis of ASRS reports relating to collision avoidance and TCAS, pilots most often reported compliance with ATC and TCAS instructions. However, there were still many reports of noncompliance and partial compliance. In a large number of these cases, pilots perceived his or her actions as appropriate and aligned with standard procedure. Through further examination of these instances, the qualitative and quantitative findings indicate that pilots may perceive TCAS and ATC issued collision avoidance maneuvers as placing their flight into a near miss situation. Pilots also criticized ATC for not issuing traffic call-outs in a timely manner. In addition, the results suggest the information on the traffic situation display may be misleading. For instance, pilots' awareness of a second aircraft on the traffic situation display impacted their response to the potential collision. The information presented to a pilot about a collision avoidance situation is especially crucial in their decision making process. Both visual awareness and whether the pilot was directed to the potential incident by ATC, TCAS, or their environment were found to have a direct effect on a pilot's decision to maneuver.

In the complex environment which surrounds the collision avoidance system, it is necessary to understand the factors which affect a pilot's response to collision avoidance advisories and instructions. This study focuses on encounter conditions, traffic situation awareness, and other factors to begin to characterize patterns within pilots' interactions with TCAS and ATC. Future work in this area should consider a wider range of first-hand narratives, including those from the National Transportation Safety Board. Additionally, the results presented suggest further research is needed to determine different methods for presenting information in this dynamic and time-sensitive collision avoidance system.

Acknowledgements

This material is based upon work supported by a Cooperative Agreement (DTFAWA-10-C-00084) with the Federal Aviation Administration (FAA) Human Factors Research and Engineering Group, with Tom McCloy acting as technical manager.

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