Reducing Aggressive Responses to TCAS: Evaluation of a TCAS Training Program

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The Traffic alert and Collision Avoidance System (TCAS) is an aircraft collision avoidance system designed to prevent mid-air collisions. While responding to a TCAS advisory is generally the safe course of action, instances of overly aggressive responses have resulted in injuries to crew members and passengers as well as disruptions in air traffic operations. However, current training standards do not address the need to mitigate overly aggressive responses. This paper details the design and evaluation of a training program for TCAS which incorporated a learning objective related to mitigating aggressive responses to advisories. The impact of the training program was evaluated by comparing the results of two flight simulator experiments. These experiments examined “trained” and “untrained” pilot responses to TCAS advisories in an integrated flight deck-Air Traffic Control simulator. Overall, the training program had a significant impact on the pilots’ behavior and aggressive responses to TCAS advisories were decreased.

The Traffic alert and Collision Avoidance System (TCAS) is an aircraft collision avoidance system designed to prevent mid-air collisions. TCAS delivers a two-stage advisory: the first stage, the ‘Traffic Advisory’ (TA), provides an initial alert to direct the pilot’s attention, while the second, the ‘Resolution Advisory’ (RA), displays a vertical advised collision avoidance maneuver. During an advisory, danger is imminent, and TCAS is assumed to have better, more up-to-date information than the ground operated air traffic control (ATC) facility. Thus, following a TCAS RA is generally the safe course of action.

To prepare pilots to respond to TCAS advisories, training standards for TCAS, as outlined in Federal Aviation Administration (FAA) Advisory Circular 120-55C, explicitly separate the training requirements into two segments: ground-based training requirements (e.g. classroom or computer training) and flight training requirements (e.g. simulator-based) (FAA, 2011a). This type of division is common in aviation training and aligns with training for other systems. The areas that must be covered in ground training are primarily related to general concepts of TCAS and its operation. These standards highlight the need for pilots to understand the types of advisories TCAS delivers as well as how those advisories are generated. While, TCAS flight training standards require that pilots be provided the opportunity to maneuver in response to a TCAS advisory at some point in their simulator training. Typically, TCAS flight training is integrated with line-oriented flight training (LOFT) and may be encountered within a sequence of other events.

One important concern not included in current (ground or flight) training requirements is overly aggressive pilot responses. Maneuvers in response to corrective TCAS RAs should be initiated with an acceleration (i.e. pull-up or push-down) of 0.25 g to then track the commanded vertical speed (FAA, 2011b). Responding to a corrective TCAS RA should typically cause an altitude deviation of no more than 300 to 500 feet with vertical speeds that are not excessive (FAA, 2011a). However, instances of overly aggressive responses to TCAS RA’s have resulted in injuries to crew members and passengers as well as disruptions in air traffic operations. One example of this is the response of Far Eastern Transport Flight EF306 in 2009 to a Descend RA. In this instance, the aircraft was maneuvered into a dive which at one point exceeded 12,000 feet per minute, resulting in the injury of twenty crew and passengers (Aviation Safety Council, 2007). Subsequently, a bulletin released by Eurocontrol in 2011 discussed the need for training objectives intended to prevent excessive responses (Eurocontrol, 2011).

Similarly, a human-in-the-loop study conducted by the Cognitive Engineering Center at Georgia Tech found pilots averaging an altitude deviation of approximately 750 feet for Climb RAs and approximately 1,200 feet for Descend and Crossing Descend RAs (Pritchett et al, 2012). Likewise, the TCAS Operational Performance Assessment (TOPA) program at MIT Lincoln Labs found similar pilot responses to TCAS advisories. TOPA monitored the occurrence of TCAS RA’s in the terminal area of eight major airports and found a maximum altitude deviation of 1,400 feet (Olszta et al, 2011). Altitude deviations of this magnitude could potentially disrupt air traffic operations, as another flight path may be located 1000 feet above or below the pilot’s cleared path.

This paper discusses the development and evaluation of a training program intended to train pilots to understand TCAS use for collision avoidance in the actual traffic and operational environment. Specifically, this paper evaluates the impact of this training on pilots’ aggressiveness in their responses to TCAS RAs.

Training Program Design

For initial knowledge training followed by task engagement, the complement of two training techniques was used for this TCAS training program: *Demonstration Based Training* (DBT) and *Event Based Training* (EBT). Additionally, this structure allowed an organization similar to that called for in FAA training guidelines with a division between ground-based (e.g. classroom or computer training) and flight training (e.g. simulator training). An added time constraint limited the combined program length to less than fifty minutes, reflecting the duration of time available in actual training programs to cover any one aircraft system.

DBT is a method of training through which the learner acquires knowledge, skills, and attitudes through various instructional features, including passive guidance and support as well as the observation of demonstrations of task performance (Rosen, et al., 2010). For the TCAS training program, DBT was implemented using a computer-based program designed in Microsoft PowerPoint and lasted approximately twenty-five minutes.

Also lasting approximately twenty-five minutes, the EBT segment was conducted using an aircraft simulator and presented traffic events to the pilot that created the requirement to act within a realistic environment. Feedback on pilot performance in each training event was facilitated by a researcher posing as the flight instructor and was based on pre-determined performance measures. If the pilot did not successfully meet any particular performance measure, the flight instructor reviewed the correct response for that scenario.

The traffic events were implemented within a two-crew flight deck based on the Boeing 747-400, emulated by the 'Reconfigurable Flight Simulator' (RFS) software (Ippolito & Pritchett, 2000). TCAS was emulated according to the standards required of the Minimum Operational Performance Standards (MOPS) for TCAS, including providing a TSD (RTCA, 1997). In each training and experimental scenario, the pilot participant acted as Captain and was assisted by a researcher posing as the First Officer (FO). The FO performed the duties of the 'Pilot Monitoring,' including communicating with ATC and reviewing standard checklists. Another researcher posed as the air traffic controller and provided commands to the participant via simulated radio for which the pilot wore a standard flight deck headset. The air traffic controller also communicated with other aircraft in the simulated airspace representing party-line information, created by a third researcher that the participant was able to overhear.

The training objectives for this TCAS training program follow FAA mandated training standards and also address common TCAS misunderstandings. Specifically, these objectives include general TCAS knowledge, TCAS advisory logic, the mental rules that should be invoked when responding to TCAS advisories, and the signs, signals, and symbols that the pilot can reference about the traffic to properly interact with TCAS. A training objective related to reducing aggressive response features was incorporated in both the DBT and EBT segments, however it is not included in FAA training standards. In DBT, a directed lesson was given about the need for compliance without excessive maneuvering as well as the potential consequences of excessive RA responses. In EBT, instructor feedback on pilot performance was related to both compliance and aggressiveness, including the need to reduce the aircraft's vertical rate with a weakening RA.

Simulator Study

The effectiveness of the TCAS training program was carefully evaluated through the duration of the DBT and EBT training phases as well as at the completion of the training program through pilot responses to six experimental (or 'data') flights. A prior study conducted in January 2012 serves as a baseline for comparison with the trained pilots in this study. Both the baseline and the trained pilots had been previously trained for TCAS by their carrier; the term 'trained pilots' is used here to denote pilots who completed the modified training program.

Sixteen pilots participated in the baseline study. All of the participants were male, ranging in age from their mid-20's to 59 years old. Eight held the rank of Captain in their airline, seven were ranked as First Officers, and one did not respond to the question (Pritchett et al., 2012). Eighteen pilots participated in the training study, recruited using a nearly identical recruiting protocol to the baseline study. All of the participants were male, ranging in age from their mid-20's to 59 years old. Four of the participants held the rank of Captain and fourteen were ranked as First Officers.

In both the baseline and training studies, the pilot's task was to fly a Standard Arrival Route (STAR) acting as the Captain. Typically, the flights began around an altitude of 10,000 to 20,000 feet and lasted fifteen minutes. The flights ended during the approach intercept, i.e. when the aircraft was within 'one dot' of the localizer beam indicating the approach course. The weather was calm with no wind. However, Instrument Meteorological Conditions (IMC) applied for the duration of the flight, as there were no out-the-window visuals; thus, the pilot could only reference a traffic situation display and air traffic communications for information about the traffic situation and could not visually acquire a target.

The pilots who participated in the training study flew six ‘data’ flights, with two traffic events in each flight. Some of events resulted in only TCAS TAs and required no maneuvering. The more severe events resulted in TCAS RAs. The run order of the scenarios was varied between pilots using a Latin Square design to compensate for possible run order effects. Three fixed variables defined each traffic event: the information provided to the pilot about traffic prior to the TCAS event (i.e., ATC Information), traffic density, and the TCAS advisory created by the target aircraft’s trajectory. The ATC information about the traffic was varied at three levels: Callout, Party-line, and Conflicting. For events with a traffic callout, the air traffic controller gave a call-out to the pilot about the other aircraft prior to the TCAS event. In events containing party-line information, the background radio chatter from other traffic contained relevant information about the target aircraft but may or may not have been recognized by the pilot. In those events with conflicting guidance, the air traffic controller instructed the pilots to “Descend for traffic” moments before the pilot received a TCAS advisory to Climb. The traffic density was varied at two levels: light and heavy. The density represented a subjective measure of how congested the airspace appeared and was simulated by ATC communications with other traffic occurring at a much higher rate in heavy traffic density, creating the appearance that the controller was extremely busy.

Of interest in this paper, the aggressiveness of pilot responses to TCAS RA’s can be evaluated using four measures of effectiveness: Altitude Deviation Over Duration of RA, the Average Vertical Rate Difference, the Maximum Vertical Rate Difference, and the Maximum Vertical Rate. After completing the training program, measures of aggressive RA responses are expected to decrease. Figure 1 depicts a graphical example of how the vertical rate measures can be viewed; the measure Altitude Deviation Over Duration of RA is the integral of the pilot’s vertical rate.

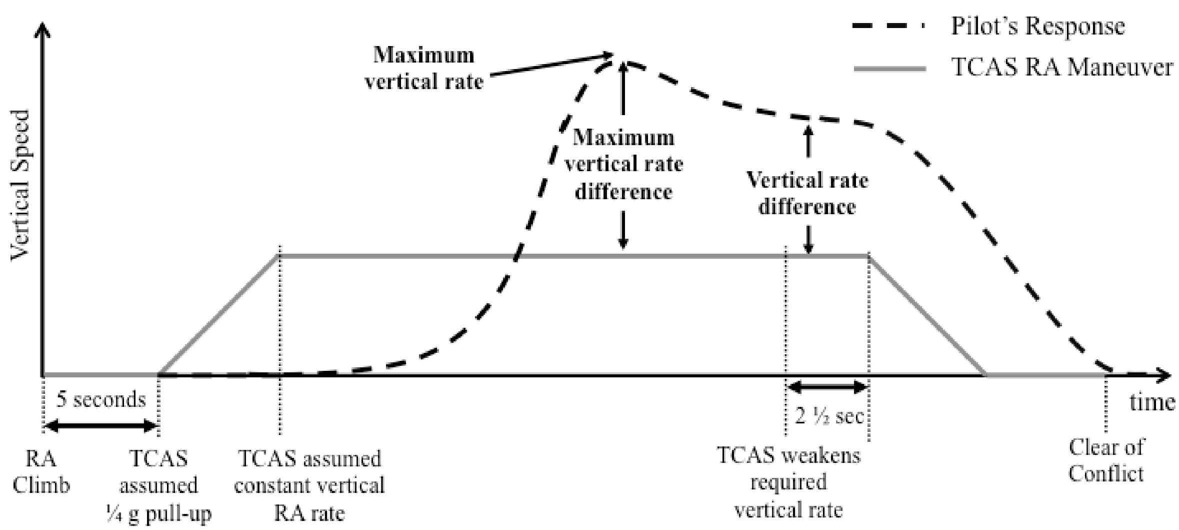

FIGURE 1. TCAS maneuver, pilot response, and corresponding measures of aggressiveness

Several other measures were also collected, including measures of compliance, recorded interaction with ATC, and pilot opinions gathered through questionnaires. However, their analysis is outside this paper’s focus on aggressive responses and will be documented elsewhere.

Results

Pre-Training Results

Before completing the training program, each pilot was asked to complete a brief ‘Pre-Training TCAS Quiz’ comprised of eleven multiple choice questions related to material taught by the training program. Pilot responses to the Pre-Training Quiz concluded that only two of the eighteen pilot participants (11%) correctly knew that an RA should typically cause less than 500 feet of altitude deviation.

During Training Results

In the training events, the pilots had significantly lower Altitude Deviation Over Duration of RA and the Average Vertical Rate Difference in two of the training events (Climb and Crossing RA's) compared to the baseline study, as shown in Figure 2. The pilots were also more consistent during the EBT in the Climb RA event in the measure Altitude Deviation Over Duration of RA and in the Conflicting Guidance event in the measure of the Average Vertical Rate Difference.

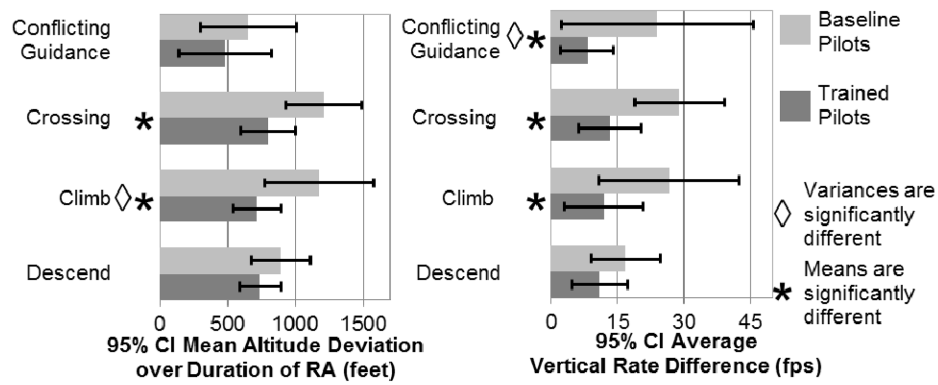

Figure 2. Mean and 95% confidence interval of the measure Altitude Deviation Over Duration of RA and Average Vertical Rate Difference within each EBT event, comparing pilot responses during training to prior baseline study

Post Training Results

Examining the measures taken in the experiment after the training, aggressive responses were reduced as indicated by nearly all measures for most events, when compared to the baseline study, as shown in Figure 3 and Figure 4. In many cases, the responses were also more consistent within the trained pilots compared to the baseline, i.e. the variance was also significantly lower.

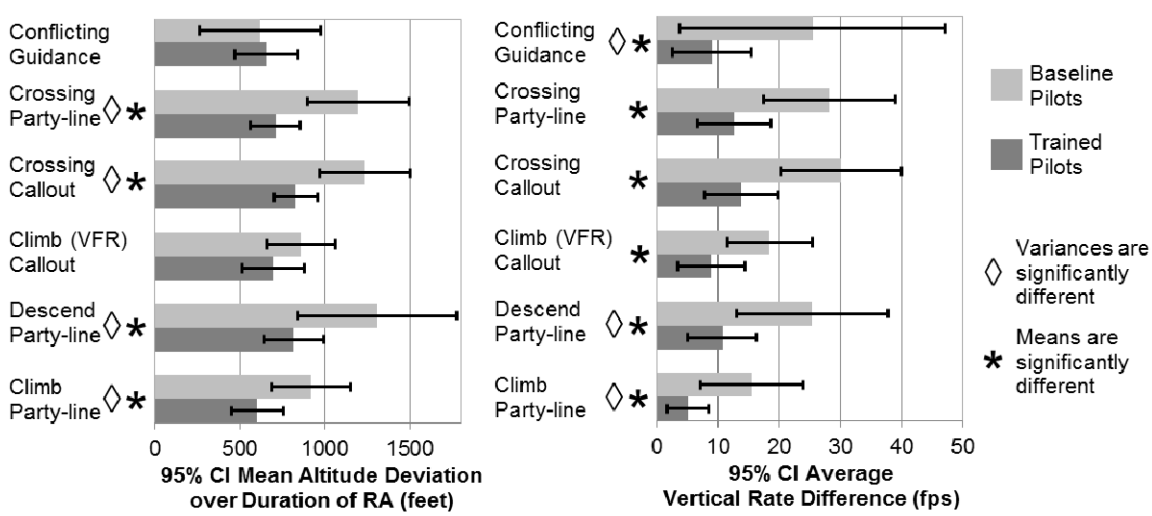

Figure 3. Mean and 95% confidence interval of the measure Altitude Deviation Over Duration of RA and Average Vertical Rate Difference within each experiment event, comparing trained pilot responses to prior baseline study

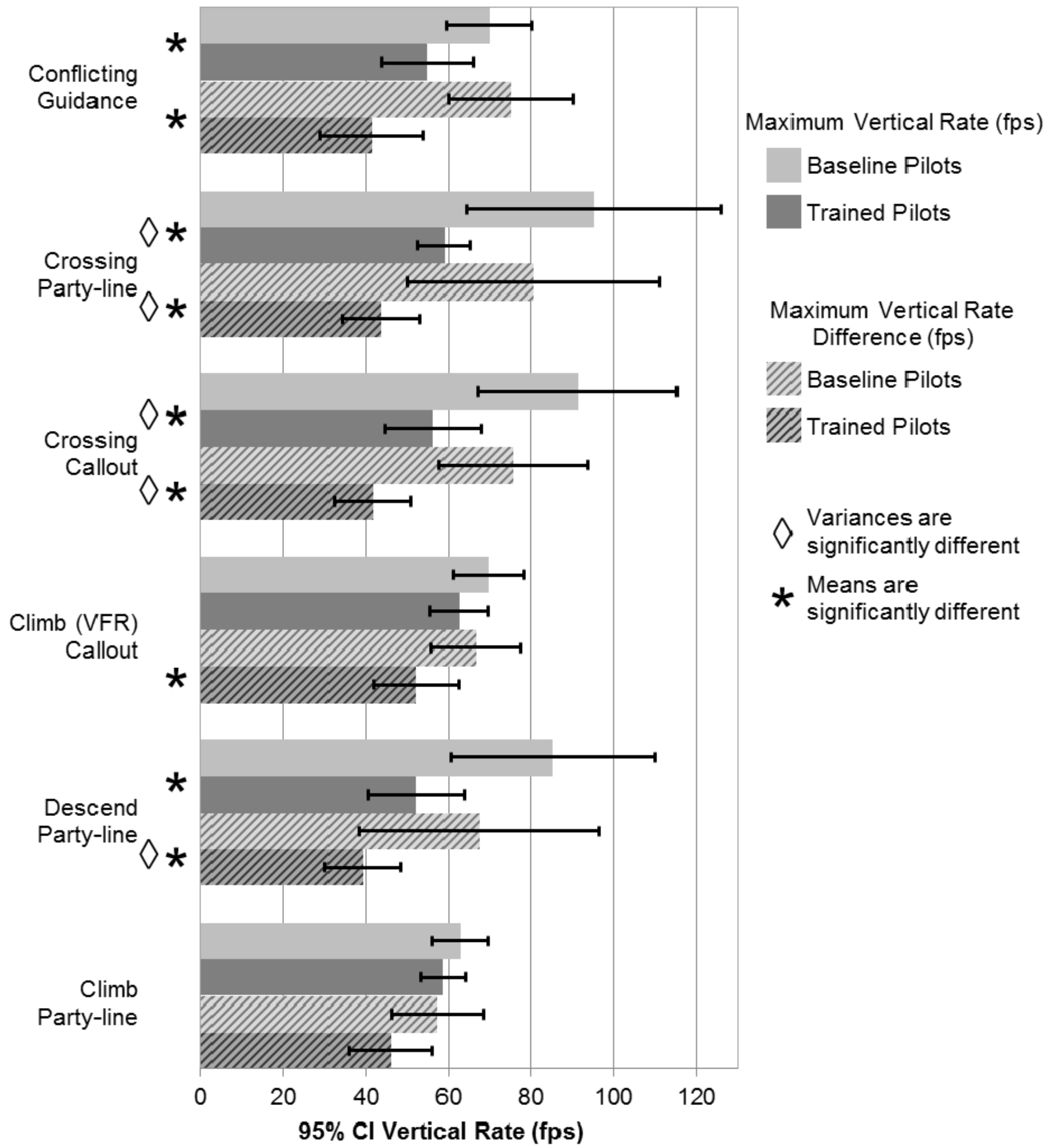

Figure 4. Mean and 95% confidence interval of the Maximum Vertical Rate Difference and Maximum Vertical Rate within each experiment event, comparing trained pilot responses to prior baseline study

Conclusions

This research adds to the discussion regarding current TCAS training objectives outlined by the FAA. As evident through reported injuries caused by eager pilots, response to TCAS RAs should be sufficient but not overly aggressive. However, current training objectives do not include the need for preventing aggressive responses. Results of the study presented in this paper concluded that aggressive responses to TCAS RAs could be significantly decreased through the inclusion of a training objective related mitigating aggressive responses to RAs.

Current TCAS training objectives reflected in FAA Aircraft Circular (AC) 120-55C, Appendix 6 include language related to understanding the various RA types and thresholds. However, language is also needed to stress the potential negative impacts of aggressive responses. Additionally, language could be added about the criteria for issuing a weakening RA; i.e. weakening RAs are given when a safe vertical separation is achieved before a safe range separation and are intended to minimize the aircraft's altitude deviation. For the training objectives related to flight training, language is already included focusing on pilot responses to weakening RAs. However, in the implementation of TCAS flight training, instructors should ensure the need to reduce the aircraft's vertical speed with a weakening RA is stressed appropriately.

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