Commercial Aviation Safety Team (CAST)

Airplane State Awareness (ASA)—Flight Crew Performance Research

Safety Enhancement (SE) 210—Output 1

Final Report—Public Summary

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- National Transportation Safety Board (NTSB); and
- Regional Airline Association (RAA).

INTRODUCTION

The Commercial Aviation Safety Team (CAST) is a partnership of aviation industry and Government organizations with a shared interest in maintaining and improving the safety of U.S. and international commercial air carrier operations. CAST charters technical subteams to review safety events (incidents and accidents) and voluntarily shared safety information, with the objectives of assessing the risks revealed by those events and data, and developing cost-beneficial safety enhancements (SE) designed to mitigate risks through voluntary stakeholder implementation.

In September 2010, CAST chartered the Airplane State Awareness (ASA) study to analyze 18 transport aircraft accidents and incidents associated with flightcrew loss of attitude or energy state awareness. The study team identified significant problems and contributing factors that led to the events, and developed a set of recommended actions, which CAST adopted by adding 19 new SEs to the CAST safety plan. Among those were five that proposed research and development (R&D) into significant questions raised by the study.

The ASA study found aircraft that entered a low-energy state began with a low or unreliable airspeed that progressed into an approach-to-stall, then often into full aerodynamic stall. In most of those events, the pilot flying initially managed the situation improperly, typically making control inputs that made the stall worse; in many cases, the flightcrew never recovered control.

For the attitude-awareness events, the ASA team identified two scenarios. In the first, the pilot flying lost awareness of the aircraft's roll attitude and failed to recover wings-level flight. In the second, occurring during go-around, the pilot flying transitioned from a nose-up to a nose-down attitude and in two of three cases, collided with terrain despite ground proximity warning system (GPWS) alerts indicating an impending impact.

The primary findings from this analysis were—

- The event aircraft were flown into the upsets by the pilot flying;
- After the upset occurred, the flightcrew often made inappropriate control inputs that led to a loss of control; and
- In most cases, the initial upset was not extreme and could have been recovered from with proper commands.

Because most of the events occurred with non-U.S. air carriers, CAST tasked the ASA team with determining how much risk such events posed to U.S. operations. The ASA team examined information from the FAA's Aviation Safety Information Analysis and Sharing (ASIAS) database to understand whether precursor events—similar upsets that were properly recovered—occur in U.S. operations, and, if so, how often.

Working through the ASIAS Issue Analysis Team (IAT), the ASA team developed Flight Operational Quality Assurance (FOQA) profiles to search approximately 8 million flights. These profiles revealed such upsets were not only occurring in U.S. operations, but occurring with more frequency than expected. The ASIAS queries also showed these events did not develop into LOC situations of the same severity observed in the accident data, primarily because the flightcrews effectively managed them.

One limitation of this initial ASIAS data review was the ASA team only observed the state of the aircraft. The team hoped that, with some research, the data analysis capability of ASIAS FOQA data could be pushed beyond the narrow understanding about airplane state to determine what could be learned about pilot performance in these upsets. This led the team to propose, among other R&D concepts, a research project in which FOQA data would be evaluated for its capability to analyze flightcrew performance in response to upsets. More specifically, the team was interested in gathering information related to two primary themes from the ASA study for which tactical mitigations had not been developed:

- Improving the effectiveness of flightdeck alerting, and
- Improving understanding of the phenomenon of flightcrew confusion or awareness of automation states and usage.

The initial goal of this research was the development of a database for use by aircraft designers to inform future flightdeck design philosophy. The team recognized such a database would also be helpful to air carriers by providing feedback on flightcrew performance in daily operational situations. The ASA team incorporated these objectives into CAST SE 210, Flight Crew Performance Data, approved by CAST in December 2014.

As described above, CAST approved SE 210 for the purpose of conducting research into flightcrew responses to situations associated with loss of energy and/or attitude state awareness. To perform ASIAS work related to SE 210, CAST established the SE 210 Flight Crew Performance Research Team (SE 210 Working Group) in 2015. The working group was composed of experienced subject matter experts and human factors researchers from organizations including air carriers, industry associations, pilot labor organizations, the FAA, the NTSB, NASA, aircraft and avionics manufacturers, and data research organizations.

The SE 210 Working Group selected the following four alert types for analysis based on the quality of data available and their well-defined response procedures:

- Stall Warning,
- Terrain Awareness and Warning System (TAWS) Pull-Up Warning,
- Traffic Collision Avoidance System (TCAS) Climb Resolution Advisory (RA), and
- TCAS Descend RA.

For each alert type, the working group specified the hazard, the situation that causes it, the alerting severity, the alert functions, and the documented recovery procedure.

The SE 210 working group also defined the expected responses to these alerts by reviewing documentation, including FAA advisory circulars (AC), Flight Crew Operating Manuals (FCOM), and other documentation available from manufacturers of either the aircraft or the alerting system. Each of the alert types has multiple response components, such as “disconnect autopilot” and “adjust power.”

For each alert type, the study measured whether the flightcrew executed each response component and their response time, in seconds, from the alert’s start to the response component’s beginning. With these measurements, the working group calculated response rates and response times for each component and in aggregate for the alert type as a whole.

PHASE I SUMMARY

CAST issued SE 210 in December 2014 to, among other related goals, “develop a database of historical flightcrew performance response situations associated with loss of energy and/or attitude state awareness ... for use in the design process.”

The SE 210 Working Group performed its work in two phases: Phase I focused on studying alerting effectiveness by monitoring flightcrew response to alerting scenarios, and Phase II explored unexpected autoflight use with an emphasis on mode combinations that can indicate or contribute to loss of energy, altitude, or airplane state awareness.

For the purposes of this study, an alert is considered ineffective if it does not receive the expected response from the flightcrew as defined by FCOMs or FAA ACs. Because flightcrew response is the measure of alert effectivity, the SE 210 Working Group measured flightcrew response to cockpit alerts.

To gauge an alert's effectiveness, the Working Group measured the response time to the alert. It categorized alerts that often receive a quick response as effective alerts, and alerts that receive a slow response or no response as less effective.

Phase I Findings

- For each alert type, there were a small number of response components flightcrews performed at high rates and with short response times. The fact that a small set of recovery components were performed often and quickly while others were performed less often suggests that, with the aid of external information, flightcrews prioritize the most necessary responses to correct the situation.
- Most alerts subsided quickly after flightcrew members performed one or two key actions. Once the alert cleared, it was less likely that the flightcrew would perform additional response components.
- There was a disconnect between flightcrews and the design community regarding what is expected once the alert clears. TCAS guidance from AC 120–55C, Air Carrier Operational Approval and Use of TCAS II, directs the flightcrew to return to the previously assigned air traffic control (ATC) clearance, but the other alert types' expectations are less clear.
- Flightcrews always would be expected to respond to a stall warning, but in the cases of TCAS and TAWS, there are conditions in which a flightcrew may choose not to perform the maneuver expected by the alert because they can see and avoid that conflict. This is reflected in the data as a lower overall response rate for those alert types.

Phase II Summary

The SE 210 Working Group members from Boeing, Airbus, and the NTSB worked with autoflight designers/experts at Airbus and Boeing, as well as data analysts, to develop FOQA-detectable autoflight scenarios that were unexpected or undesirable from an autoflight designer's point of view. These scenarios were selected because the autoflight designers believed each had the potential to lead to an adverse event (such as low airspeed or an unlimited descent), or because they indicated the flightcrew might be out of the loop. Any time one of these events occurs, a safety barrier that is usually provided by the autoflight system is being diminished or removed.

Because autoflight modes vary widely by aircraft type, the study focused on the Airbus A320 and Boeing B737 aircraft families, which allowed the working group to search for specific undesired or unexpected autoflight states in specific operational situations. These airframes were chosen because of their prevalence in National Airspace System (NAS) operations and the working group members' expertise. The study also included Boeing B777 flights to explore an autoflight scenario related to the July 2013 Asiana Airlines B777 accident at San Francisco International Airport (KSFO).

For scenarios with very few events, the working group reviewed each event in detail. For scenarios with many, they reviewed aggregate results and some selected exemplar events in detail. Despite that, none of these events led to a detectable more adverse event, such as a stall warning, sustained GPWS alert, or TCAS RA. These alerts were specified by the autoflight experts as potential adverse outcomes of the unexpected automation use scenarios.

RESULTING SAFETY ENHANCEMENTS

As described above, CAST approved SE 210 for the purpose of conducting research into flightcrew responses to situations associated with loss of energy and/or attitude state awareness. SE 210 consists of three outputs, each of which comprises a deliverable to CAST.

Output 1 tasked the FAA and the aviation community to "[d]evelop a historical database of flight crew [sic] performance in situations associated with loss of energy and/or attitude state awareness, for use in the design process" that would increase the aviation community's knowledge of flight operations. Specifically, the research was conducted to learn how flightcrews respond to alerts and why they seemed to experience confusion about the state of the autoflight system, or used autoflight modes that were different from those the aircraft designer prescribed. The goal of Output 1 was to better understand these two issues through analysis of deidentified FOQA data and to develop a means of communicating results to the design and operations communities.

Output 2 directed NASA and the aviation community to "[e]nhance methods and guidelines used in the design process to assess flight crew [sic] performance in situations associated with loss of energy and/or attitude state awareness." Specifically, NASA will coordinate with the FAA and manufacturer research organizations to develop improved tools and methods for use in the design process to represent flightcrew responses in situations associated with loss of energy and/or attitude state awareness. These methods will incorporate information from the flightcrew performance database developed in Output 1 to enhance or expand beyond current design methodologies, such as qualitative pilot-in-the-loop simulation evaluations.

Output 3 directed NASA and the aviation community to develop and validate prototype technologies to use in design evaluation, for the detection and mitigation of attention issues associated with loss of energy and/or attitude state awareness. Specifically, NASA will coordinate with the FAA Aircraft Certification Service (AIR) and manufacturer research organizations to further develop prototype technologies for the detection and mitigation of attention issues to use in design evaluation. These technologies should include eye tracking, functional Near Infrared Spectroscopy (fNIRS), heart rate variability (HRV), or other physiological measures.

More detailed information on these outputs and the full SE 210 Detailed Implementation Plan (DIP) may be found online at:
https://www.skybrary.aero/index.php/SE210:_Airplane_State_Awareness_-_Flight_Crew_Performance_Data_(R-D)