NASA/TM—2019–220176

The Role of Alerting System Failures in Loss of Control Accidents

CAST SE-210 Output 2

Report 3 of 6

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March 2019

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Acronyms and Definitions

A/P ....autopilot
A/T ....autothrottle
ADI ....attitude direction indicator
agl ....above ground level
AoA..angle of attack
ASA ....airplane state awareness
ASIAS.....................................Aviation Safety Information Analysis and Sharing
CAST ....Commercial Aviation Safety Team
CFIT......................................controlled flight into terrain
CFR..Code of Federal Regulations
CPDLC ....controller-pilot data link communication
CRM ....crew resource management
CRZ..cruise
CVR ....cockpit voice recorder
DC..Douglas Corporation
EADI......................................electronic attitude direction indicator
ECAM....................................electronic centralized aircraft monitor
EGPWS..................................enhanced ground proximity warning system
EICAS....................................engine indicating and crew alerting system
EIS ....entry into service
FAA ....Federal Aviation Administration
FBW......................................fly by wire
FE...Flight Engineer
FMS ....flight management system
FO ....First Officer
ft...foot (feet)
GA..go around
GPWS ....ground proximity warning system
hr ....hour
IFR ....instrument flight rules
ILS ....instrument landing system
IMC.......................................instrument meteorological conditions
IRS ....inertial reference system
LOC ....localizer
LOC ....loss of control
MCP ....mode control panel
MD..McDonnell-Douglas
NASA ....National Aviation and Space Administration
ND...navigation display
NG...Next Generation
NTSB ....National Transportation Safety Board
PAPI......................................precision approach path indicator
PF ....pilot flying
PFD ....primary flight display
PM...pilot monitoring

RAAS....................................Runway Advisory and Awareness System
SD ....spatial disorientation
SE 210....................................Safety Enhancement #210
TAWS ....Terrain Awareness and Warning System
TCAS RA...............................traffic collision avoidance system Resolution Advisory
TL ....thrust lever
TO ....take off
TO/GA ....take off/go around
UPRT ....upset prevention and recovery training
VMC ....visual meteorological conditions
V_{ref}..landing reference speed
VS ....vertical speed

The Role of Alerting System Failures in Loss of Control Accidents

CAST SE-210 Output 2
Report 3 of 6

Randall J. Mumaw[1], Loran A. Haworth[1], and Michael S. Feary[2]

Executive Summary

This report is part of a series of reports that address flight deck design and evaluation, written as a response to loss of control accidents. In particular, this activity is directed at failures in airplane state awareness in which the pilot loses awareness of the airplane's energy state or attitude and enters an upset condition. In a report by the Commercial Aviation Safety Team, an analysis of accidents and incidents related to loss of airplane state awareness determined that hazard alerting was not effective in producing the appropriate pilot response to a hazard (CAST, 2014). In the current report, we take a detailed look at 28 airplane state awareness accidents and incidents to determine how well the hazard alerting worked. We describe a five-step integrated alerting-to-recovery sequence that prescribes how hazard alerting should lead to effective flight crew actions for managing the hazard. Then, for each hazard in each of the 28 events, we determine if that sequence failed and, if so, how it failed. The results show that there was an alerting failure in every one of the 28 safety events, and that the most frequent failure (20/28) was tied to the flight crew not orienting to (not being aware of) the hazard. The discussion section summarizes findings and identifies alerting issues that are being addressed and issues that are not currently being addressed. We identify a few recent upgrades that have addressed certain alerting failures. Two of these upgrades address alerting design, but one response to the safety events is to upgrade training for approach to stall and stall recovery. We also describe issues that need additional attention: the need for improved alert integration for flight path management hazards, airplanes in the fleet that do not meet the current alerting regulations, a lack of innovation for addressing cases of channelized attention, and existing vulnerabilities in managing data validity.

1. SE-210 Project Overview

The Commercial Aviation Safety Team (CAST) created a team to analyze a set of incidents and accidents associated with the flight crew's loss of awareness of aircraft attitude or energy state. These events are referred to more broadly as a loss of airplane state awareness (ASA), and they are a substantial subset of loss of control (LOC) accidents. A subsequent CAST ASA team developed a set of mitigation strategies—referred to as Safety Enhancements (SEs)—to reduce the likelihood of ASA events occurring in the future. Six of the Safety Enhancements (SEs) (SE 200, 207 through

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211) requested further research on mitigation strategies. Our work was specifically intended to address research identified in SE 210 Output 2 (see https://www.skybrary.aero/bookshelf/books/2540.pdf).

SE-210 Output 2 addresses the contributions from the flight deck interface in shaping pilot awareness. More specifically, the focus is on assessing or *evaluating the flight deck interface to determine how well it supports ASA*. We have produced a series of reports on this topic:

1. In a report titled "Overview of research approach and findings," we introduce our research approach and compile our key observations and findings. This provides a summary of how our research method developed and what we found.
2. Part of our work was a more-detailed analysis of the role of awareness in the ASA events. In a report titled "Factors that influenced Airplane State Awareness accidents and incidents," we describe a number of factors that contributed to the apparent loss of awareness, or to the resulting loss of control. This analysis demonstrates that pilot attention and understanding of the system are important elements of awareness. This report also offers proposals for modifications of the interface to mitigate those factors, and then, describes how you might evaluate the effectiveness of those proposed modifications.
3. In a related report (the current report), titled "The role of alerting system failures in loss of control accidents," we analyze how alerting for LOC-related hazards, such as low airspeed, unreliable airspeed, and approach to stall, can fail to lead to an upset recovery. Alerting is the last line of defense against flight path management hazards; it is there to ensure awareness when pilot-driven attention and awareness fail. This report looks at why alerting does not always save the day.

Through our work, we had the opportunity to become more familiar with current evaluation and certification rules, guidance, and practices that define the process for the applicants (equipment manufacturers) and the Federal Aviation Administration (FAA). Evaluation and certification of flight deck interface elements consider a broad range of flight crew performance topics. We narrowed the focus of our work to flight crew awareness, attention, and understanding, and specifically examined these aspects of human performance in relation to relevant rules (e.g., 14 CFR 25.1302, 25.1322) and advisory material (e.g., AC 25.1302-1). This new material offers a more complete description of flight crew performance issues in the context of the flight deck interface; however, questions about its appropriate application remain.

4. In a report titled "Evaluation issues for a flight deck interface," we attempt to describe the broader scope of flight crew performance issues to show how awareness and attention issues fit within the larger set. We also do an inventory of FAA certification rules to demonstrate that there are not rules that apply to every flight deck issue. AC 25.1302 has improved guidance for addressing evaluation of awareness, attention, and understanding, and we hope that our work can contribute to future updates of the guidance material.
5. A related report, titled "Identification of scenarios for system interface design evaluation," focuses on the operational scenarios that can be used in the context of interface evaluation. It offers several perspectives on how to ensure that flight crew performance is evaluated in an important operational context. Because it is unlikely that evaluation can be performed for the full range of operational settings, this report offers a method for selecting appropriate scenarios.

Finally, the bulk of our work in this project was focused on methods for evaluating a flight deck interface for how well it supports awareness and its critical elements: attention and understanding.

6. A report titled: “Methods for evaluating flight deck interfaces for transport category aircraft with particular relevance to issues of attention, awareness, and understanding” focuses on evaluation techniques and metrics. It considers opportunities to evaluate the interface from early to late stages of development; it considers the various ways in which the interface can fail to support awareness, attention, and understanding; and, it summarizes appropriate evaluation methods for different issues. This report draws on the characterization of issues and of scenario selection presented in other reports that are relevant to awareness.

2. The Role of Alerting in a Safety-Critical System

Successful hazard identification during development of a safety-critical system results in reduced hazards and/or mitigations for managing hazards when they occur, and, therefore, these hazards are unlikely to lead to an airplane upset or loss.

For commercial aviation, hazards can take many forms; for example, there are hazards tied to:

- airplane systems failures; e.g., a hydraulics system failure that could lead to an inability to move control surfaces
- airplane smoke and fire
- external threats; for example, high terrain or obstacles, icing, or windshear
- hazardous changes to the flight path; for example, airspeed dropping too low or rolling to a high bank angle
- ensuring the airplane is configured appropriately prior to initiating certain phases of flight; for example, for take-off

Airplane developers strive to create an alerting system for the hazards that cannot be designed out. Alerting, ideally, can allow the flightcrew to become aware of a hazard’s presence before it becomes a threat to safe flight, or, if it does become a threat, manage it to avoid an airplane upset or loss.

In any safety-critical system, the alerting system should initiate the appropriate flight crew/pilot response for managing a hazard. The alert, along with related elements of the flight deck interface and operational procedures, need to help the pilot do the following:

1. *Orient* to an important change. Some salient element, such as a loud sound or bright light or both, needs to attract the flightcrew’s attention that some important change has occurred.
2. *Understand* the nature of that change. Some interface element needs to describe this important change. Information about the nature of the change, as well as the urgency of response and importance of response, need to be presented clearly and simply. Ideally, the interface and associated procedures should convey the implications for operational decision making.
3. *Identify appropriate actions* to take. When there are flightcrew actions that are recommended to manage the failure or hazard, those actions have to be presented to the pilot although, in some cases, an action or small set of actions is memorized by the pilot. The alert needs to create a link to those actions, either by making them part of the alert or by directing the flightcrew to a set of actions to ensure they perform the right procedure.
4. *Identify the priority* for the actions. In some non-normal situations, there may be a number of actions for the flightcrew to take, especially when there are multiple alerts. The system interface needs to aid the flightcrew in assessing which actions have the highest priority.

5. *Execute the actions* efficiently, accurately, and completely, including a safe recovery. The system interface and the operational documents need to support the flightcrew in executing the prescribed actions in a timely manner (i.e., before there is an airplane upset or loss). Ideally, the interface allows the flightcrew to evaluate how well the hazard is being managed as actions are being taken.

These five steps can be referred to as *the integrated alerting-to-recovery sequence*, and this sequence can be used to analyze how well the alerting system works when hazards are encountered. This approach broadens the usual bounds of alerting to make the point that there needs to be an integrated approach between the initial "alert," the system interface, and operational procedures to ensure all five steps are supported.

These steps in the integrated alerting-to-recovery sequence can also be used to understand the point at which a breakdown in alerting contributes to an accident or incident. For example, there have been aviation accidents and incidents in which the flight crew oriented to a change but did not understand the nature of the change, or, cases in which the flight crew oriented and understood the nature of the change but failed to identify the appropriate actions to respond to it. This type of analysis can aid in identifying vulnerabilities in an airplane's alerting system or in the use of the accompanying procedures.

3. A Surprising Finding about Alerting

In 2010, CAST initiated an activity to look at incidents and accidents in which the pilot experienced a loss of aircraft attitude or energy state awareness that led to a LOC. These were more generally referred to as events that were due to a loss of ASA. The group of government and industry professionals reviewed 18 safety events—either accidents or serious incidents—in an attempt to determine if there were common themes or contributing factors that cut across these ASA events. Table 1 shows those 18 events on the left-hand side of the table (see the CAST, 2014 report for more details: https://www. skybrary.aero/bookshelf/books/2999.pdf). Listed across the top of the table are factors that were present in many of these 18 events. The analysis team kept encountering these factors as each event was reviewed. One of the factors that occurred in every event was called "ineffective alerting," which referred to a variety of issues with the airplane's alerting system or its effectiveness in influencing pilot behavior regarding the response to the alert.

These findings regarding alerting from the CAST ASA analysis triggered a deeper curiosity about the state of alerting in commercial transports. Would a larger set of LOC events show a similar pattern? Specifically, we wanted to answer these questions

- How common is it, across a large set of LOC events, that the alerting system fails to lead to a timely and appropriate response from the flight crew?
- When there is a breakdown in the integrated alerting-to-recovery sequence, where are the failure points?
- Can this analysis help us learn more about how to build a better alerting system, and, more broadly, how to manage the flight crew's attention?

To explore these questions, we reviewed a set of 57 recent safety events to determine how well hazards were alerted and managed by the flight crew. The integrated alerting-to-recovery sequence was used to categorize where alerting broke down. The analysis of 57 events is described in a separate paper (Mumaw, 2017); this report addresses the subset of 28 events that were tied to loss of ASA.

Table 1. The Events Reviewed by CAST and the Twelve Contributing Factors

	Lack of External Visual References	Flight Crew Impairment	Training	Airplane Maintenance	Safety Culture	Invalid Source Data	Distraction	Systems Knowledge	Crew Resource Management	Automation Confusion / Awareness	Ineffective Alerting	Inappropriate Control Actions	Total
Formosa Airlines Saab 340	x	x			x		x	x	x		x		7
Korean Air 747-200F	x			x		x	x		x		x		6
Flash Airlines 737-300	x		x		x		x		x	x	x	x	8
Adam Air 737-400	x		x	x			x	x	x	x	x	x	9
Kenya Airways 737-800	x		x				x		x	x	x	x	7
Aeroflot-Nord 737-500	x	x	x	x	x		x	x	x	x	x	x	11
Gulf Air A320	x		x				x		x		x	x	6
Icelandair 757-200 (Oslo)	x						x		x	x	x	x	6
Armavia A320	x	x			x		x		x	x	x	x	8
Icelandiar 757-200 (Baltimore)	x				x	x	x	x	x	x	x	x	9
Midwest Express 717	x				x	x	x		x		x	x	7
Colgan Air DHC-8-Q400	x	x	x		x		x	x	x	x	x	x	10
Provincial Airlines DHC-8	x		x				x			x	x	x	6
Thomsonfly 737-800	x		x	x	x		x			x	x		7
West Caribbean MD-82	x	x			x		x	x	x	x	x	x	9
XL Airways A320		x	x	x	x	x	x	x	x	x	x		10
Turkish Airlines 737-800	x			x	x	x	x		x	x	x		8
Empire Air ATR-42	x	x			x		x		x	x	x		7
Overall	17	7	9	6	12	5	18	7	16	14	18	12	

4. Alerting System Basics for Commercial Transport Aircraft

Alerting, for the purposes of this report, refers to a change in the interface that is meant to attract attention, which could be a sound or voice (e.g., "pull up"), onset of a light or a message in a specified area (e.g., Master warning light), a pop-up of a message in a central location (e.g., traffic collision avoidance system [TCAS] graphics on the primary flight display [PFD]), or flashing of a display element (e.g., airspeed tape indicator)[3]. Alerting systems in large, commercial transports (i.e., 14 CFR part 25) are complex and widely distributed. In most modern airplanes, alerting for airplane system failures are managed largely through a central alerting system (e.g., Boeing engine indication and crew alerting system [EICAS] or Airbus electronic centralized aircraft monitor [ECAM]). These alerts are prioritized by urgency and can be inhibited (for some alerts in certain flight phases). In addition to centralized aircraft system alerting, other elements of alerting can be found on the PFD, glareshield/mode control panel, the head-up display (HUD), the control column, overhead panel, and other parts of the forward panel.

[3] An indicator moving beyond the normal range and into a red zone is not considered an alert in this case since that red zone can be present when the current value is in the normal range.

14 CFR 25.1322 and Advisory Circular (AC) 25.1322-1 provide regulatory requirements and guidance for aircraft alerting. Airplane alerts are organized into warning, caution, and advisory categories (called Level 1, 2 and 3 in an Airbus airplane) according to 14 CFR 25.1322. The definitions for these are

- Warning: Conditions that require immediate flightcrew awareness and immediate flightcrew response.
- Caution: Conditions that require immediate flightcrew awareness and subsequent flightcrew response.
- Advisory: Conditions that require flightcrew awareness and may require subsequent flightcrew response.

According to 14 CFR 25.1322, Warning- and Caution-level alerting must contain at least two sensory modalities of alerting, typically a visual and an aural alert. Most modern airplanes have a Master Caution/Master Warning system that presents a visual alert in the central field of view and salient aurals. Warning-level visual alerts are red, and Caution-level visual alerts are amber/ yellow. The full text of 14 CFR 25.1322 is contained Appendix A.

Below are some examples of Warnings and Cautions for Part 25 aircraft:

- Warning-level hazards of interest
  - Autopilot Disconnect
  - Engine Fail or Engine Out
  - Windshear
  - Ground Proximity
  - Stall/Stick shaker (approach to stall)
  - TCAS Resolution Advisory (TCASRA)
  - Overspeed
  - Cabin Altitude
  - Take-off Configuration
- Caution-level hazards of interest
  - Autothrottle Disconnect
  - Low Airspeed
  - Unreliable Airspeed
  - Bank Angle

5. Method

As stated above, a study performed by Mumaw (2017) reviewed a broad sample of safety events to determine how well alerting functioned. We pulled a subset of this sample, consisting of 28 ASA-type incidents and accidents; specifically, events that involve loss of energy state awareness or loss of attitude awareness (spatial disorientation). The following section describes the selection of events for the larger study and how the subset was selected for the current study.

5.1 Event Set

A review was conducted of commercial aviation accidents and a few major incidents. Accidents were defined as events with on-board fatalities. While this is a narrower-than-usual definition of an accident[4], it was a practical approach because it was relatively easy to identify events with fatalities. Incidents were events with no fatalities but with a significant upset.

Initially, a list of all recent accidents in large, commercial transports[5] from 2002 through 2015 was compiled. Accidents were drawn from the event database at https://aviation-safety.net and included passenger and cargo operations. Added to this set were events that had been analyzed for the CAST ASA effort: three accidents that occurred between 1998 and 2002 and six incidents[6] from the target period (see Figure 1). Appendix B shows the full set of 230 accidents and six incidents in the initial set. These events represent 8180 on-board fatalities.

In Appendix B, the 236 events are listed by the event date and each is marked in one of three ways:

1. Rows with grey in columns 5–9 were removed from the analysis set for one of the following reasons:
    - The aircraft were not Western-built and their alerting systems and the accidents are less-well documented.
    - The event was judged to be likely the result of an intentional act (e.g., terrorism, suicide).
    - There was no final report on the accident.
    - There was no final report in English.
2. Rows colored green or salmon are the 57 events that were selected for analysis; the salmon-colored rows are the subset of 28 events selected for the present analysis (also, the Operator/Flight is bolded for these events in case you are looking at a black and white version).
3. Rows with no color were not selected for analysis (as described in the following paragraphs).

As Figure 1 illustrates, after removing the “grayed” events in the Appendix B table, a total of 117 of the 236 events remained. This set of 117 “selectable” events was the starting point for selecting events for analysis[7]. Included in the selected set were the 18 events from the CAST ASA effort, which had already been analyzed. Then, selection preference was given to larger and newer airplanes, and those events with higher fatalities.

The first pass through the selectable events focused on the largest airplanes, which create the largest exposure for the flying public. The largest commercial transports—Boeing and Airbus airplanes and the more recent McDonnell-Douglas airplanes (DC-9s, MD-80s, MD-11s)—made up 51% of the selectable events (60/117), and 50 of those 60 were selected for analysis. An additional reason for sampling from these fleets is that these airplanes are more likely to have more complete and better-integrated alerting systems.

[4] For the broader definition of an accident, see pages 3 and 8 of the Boeing annual statistical summary of accidents (http://www.skybrary.aero/bookshelf/books/3811.pdf).

[5] Large, commercial transports included the following: **Airbus** 300, 300-600, 310, 318/19/20/21, 330, 340; **Antonov** 12, 24/25/26/28, 32, 140/148; **ATR** 42, 72; **Avro** RJ-70, -85, -100; **BAC** 1-11; **BAe** 146; **Boeing** 707, 717, 727, 737-100/200, 737-300/400/500, 737-600/700/800/900, 747-100/200, 747-400, 757, 767, 777; **Bombardier** CRJ-100, -200, -700, -900, -1000; **DeHavilland** DHC-8; **Dornier** 228; **Embraer** 120, 170/175, 190/195; **Fokker** 27, 28, 50, 70, 100; **Ilyushin** 62, 76, 86; **Lockheed** L-1011; **MD/Douglas** MD-11, MD-82, DC-3, DC-8, MD-83/DC-9, DC-10; **Saab** 340A/B; **Swearingen** 226/227; **Tupolev** 134, 154, 204; **Yakovlev** 40/42.

[6] Incidents are italicized in the table and have 0 fatalities.

[7] It was not practical to analyze all 117 events.

The remaining events selected for analysis emphasized events with higher fatalities and events involving newer airplanes, which offer more integrated alerting schemes. The final selected set for the larger study includes 57 events. Overall, the set selected for analysis represents 71% of the fatalities in the set of selectable events (3849/5400), and 47% of the fatalities in the full set of 236 events (3849/8180).

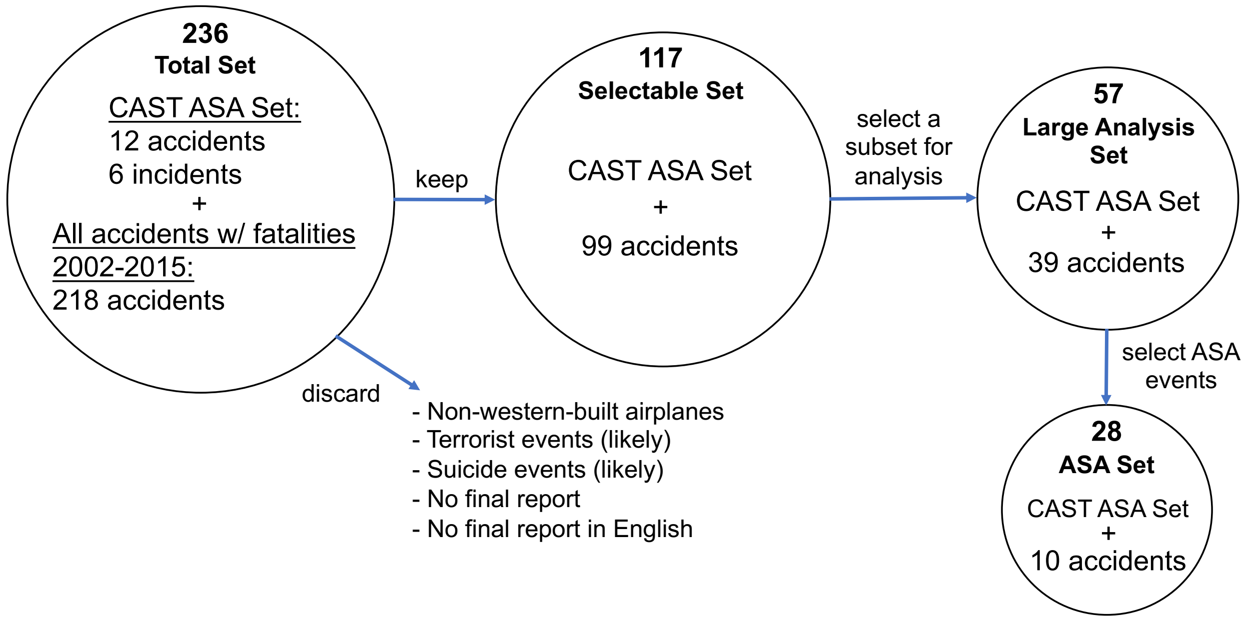

Figure 1. Selection of accidents and incidents for the current analysis.

Finally, from this set of 57 events, we identified those events in which there was an energy-state management issue or a loss of attitude awareness—that is, ASA-type events. This is the subset of 28 events analyzed here.[8]

5.2 Analysis Procedure

5.2.1 Data Gathered

Each of the selected event reports was reviewed to capture the following information:

- event date
- airline/operator and flight number (when the report gave one)
- location of event
- accident category (e.g., controlled flight into terrain [CFIT])
- airplane manufacturer and type (e.g., Boeing 737-800)
- phase of flight when event occurred
- local time when event occurred
- weather/visibility (instrument meteorological conditions [IMC] or visual meteorological conditions [VMC])
- on-board fatalities
- Captain's total flight hours and time on type

[8] Spanair 5022 and UT Air 120 ended from a stall but were not included. Spanair took off without being configured for take-off and was not controllable, crashing shortly after take-off. UT Air was subjected to significant icing prior to take-off and was also not controllable, crashing shortly after take-off.

- First Officer's (FO) total flight hours and time on type
- who was the pilot flying (PF) when the event occurred (Captain or FO)
- what airplane-related hazards occurred during the flight[9]; these included:
  - *Autopilot disengage*. A change from engaged to disengaged, but we only counted the cases in which the flight crew was unaware of the autopilot disengagement since it is often the result of the pilot disengaging it.
  - *Autothrottle disengage*. A change from engaged to disengaged without pilot input.
  - *Ground proximity* (Terrain Awareness and Warning System [TAWS]): sink rate, terrain, pull up). The airplane inappropriately flew near terrain.
  - *Impending collision* (TCAS). The airplane was on course to collide with another airplane.
  - *Bank angle*. the airplane rolled or was rolled beyond 35°.
  - *Low airspeed*. Airspeed dropped below normal operating speeds.
  - *Approach to stall/stall*. Airplane angle of attack increased to a point where the airplane was close to stalling or stalled.
  - *Overspeed*. Airspeed exceeded normal operating speeds.
  - *Unreliable airspeed*. Airspeed indication became erroneous due to a fault in air data; at least one of the airspeed indicators became invalid but was not labeled as invalid.
  - *Airplane icing*. Icing on the airplane sufficient to change the aerodynamic properties of the airplane.
  - *Unreliable attitude information*. One of the attitude indicators became invalid (but was not labeled as invalid).
  - *Take-off configuration*. The airplane was not properly configured for take-off, leading to insufficient lift to fly at the expected take-off speed.
  - *Take-off performance*. There was insufficient thrust for take-off with the available runway length.
  - *Landing configuration/high-energy approach*. The airplane landed fast, or the approach was above the glidepath or fast, making it difficult to manage the landing.
  - *Asymmetric thrust*. Thrust on the engines was not matched on the two engines.
  - *Flap asymmetry*. Flap position was not matched on the two wings.
  - *Windshear*. A change in wind speed—in some cases, a downward microburst of air—that creates sudden shifts in airspeed.
  - *Cabin altitude* (pressure). Pressure was not maintained in the airplane as it climbed, and the airplane could not sustain human life.
  - *Engine fail/engine out*. Loss of an engine in flight.
- whether any hazard that occurred had an alert tied to it
- all the airplane alerts that occurred, in order, during the flight (taken from the flight data recorder [FDR] and cockpit voice recorder [CVR])
- what action(s) the PF should have taken in response to the hazard
- what action(s) the PF actually took
- what action(s) the PM (pilot monitoring) took
- a short synopsis of the event, including a context for the alerting
- whether alerting was mentioned in the report as a factor in the accident

5.2.2 Judgement Regarding Alerting Failure

[9] Note that hazards that occurred *after* the airplane was in an unrecovered upset condition, such as overspeed or ground proximity, were not counted.

For each hazard in each event, we made a judgment, based on the findings from the accident or incident report, about whether and where the integrated alerting-to-recovery sequence broke down. The judgment was applied to each hazard that occurred. The following are the possible ways in which alerting could break down, organized into failure categories by the steps of the integrated alerting-to-recovery sequence[10].

1. The pilot did not *orient to an important change.* This is broken out into cases in which there was no alert in the airplane and cases in which the alert occurred but was not detected by the pilot/flightcrew.
   A. There was no alert
      - no alert exists in the airplane for this hazard
      - an alert existed but failed to perform (e.g., malfunction)
      - alert occurred too late to recover from the hazard so that it was equivalent to not occurring (as determined in the accident report)

   B. Alert was not detected by the PF. The alert was present for more than 5 seconds (actual times ranged from 7 seconds to several minutes), and there was no evidence that the alert was detected; specifically, the pilot took no actions that would be appropriate to respond to the alert, and the flight crew did not discuss the hazard.
      - alert used the visual modality only (when it should have had two modalities)
      - pilot's attentional resources were overwhelmed (e.g., channelized attention) or focused elsewhere, preventing detection
      - alert was masked or hidden
      - alert duration was too short to notice

2. The pilot did not *understand the nature of the change.* The pilot was aware that an alert occurred but did not understand what the alert was conveying about the hazard.
   - the alert message (EICAS or ECAM) did not specify the hazard directly, or it was misleading
   - the alert was easily confused with another alerting condition
   - multiple alerting conditions were tied to a single alert
   - pilot was not sufficiently trained to understand the alert
   - pilot seemed to believe that the problem was something else (based on statements and/or behavior)

3. The pilot did not *identify appropriate actions to take*. The pilot was aware that an alert occurred and understood the nature of that alert but performed actions other than the appropriate actions.
   - appropriate actions were not trained
   - pilot performed actions different from those trained or in operational guidance
   - appropriate actions are not well-specified in procedures
   - there is no explicit link on the interface from the alert to the appropriate actions (for checklists)

[10] The possible ways in which the alerting-to-recovery sequence failed are stated in terms of the pilot's performance. This approach was taken because the pilot's behavior can be used as evidence of a failure. For example, if the pilot's response to the hazard was not appropriate according to training, this was used to indicate a failure at that point in the alerting-to-recovery sequence. We are *not* suggesting that the cause of the failure is the pilot, as will be clear below.

4. The pilot did not *identify the priority for the actions*. The pilot was aware that an alert occurred, understood the nature of that alert, and knew the appropriate actions to take, but did not prioritize the actions appropriately
    - pilot was responding to some other hazard or task that was less important

5. The pilot did not *execute the actions efficiently, accurately, and completely*. The pilot was aware that an alert occurred, understood the nature of that alert, knew the appropriate actions to take, prioritized the actions appropriately, but did not perform those actions well. This is broken out into a performance problem or a decision to not take the appropriate actions (a violation).
    A. The pilot attempted to perform the appropriate actions but failed to perform them adequately to avoid the accident or incident
        - pilot action timing, strength or speed
        - failed to take actions completely (was mostly correct)
        - a mismatch between pilot actions and the autoflight or autothrottle state

    B. The flight crew or pilot chose not to perform the appropriate actions, which is a violation
        - pilot underestimated the risk of not complying or previous experience suggested the actions were not necessary
        - the alert was regarded as a nuisance or invalid alert that did not require action

6. Results

Appendix C provides the judgment results on all 28 events and also provides a short description of each event. Table 2 presents a summary of the failures in the integrated alerting-to-recovery sequence. Hazards are listed down the left side, in the order of how frequently they occurred in the event set. Across the top are the various high-level categories of alerting failure points, which are listed in Section 5.2.2. Note that neither a priority failure (4) nor a violation failure (5B) occurred in this event set and there is, therefore, no column for these two categories. Totals are presented at the end of each row and column, with an overall total of 52 analyzed hazards across 28 accidents/incidents. One of the low airspeed events and one of the approach to stall events were recovered successfully; so, while these hazards occurred, they did not factor into the failure set. Therefore, there were 54 hazards that occurred but only 52 hazards that had a failure in the integrated alerting-to-recovery sequence; the other two were managed or recovered.

We can also look at these failure categories by event. For each event, which might have several hazards, we identified the “earliest” failure category that was marked in the integrated alerting-to-recovery sequence. For example, if there was a failure due to “no alert,” that column was marked even if there were failures in later categories.

Table 2. Categorization of Alerting Failures
(Note: Some events had more than 1 hazard to alert)

	Failure Points in the Integrated Alerting-to-Recovery Sequence					
Hazard	*No Alert (1A)*	*Alert Not Detected (1B)*	*Alert Not Understood (2)*	*Crew Selected Wrong Action (3)*	*Inadequate Crew Performance (5A)*	*Total*
Approach to stall/stall	1		2	9	3	16*
Low airspeed	8	3				12*
Ground prox		5			1	6
Bank angle	2			4		6
Unrel airspeed	1	1	1	2		5
Windshear				1	1	2
Asym thrust	2					2
Engine out/fail	1					1
Flap asym	1					1
Autopilot (A/P) disengage	1					1
Autothrottle (A/T) disengage		1				1
Unrel attitude			1			1
Total	17	10	4	16	5	52

* 1 of the16 stall events and 1 of the 12 low airspeed events were successfully recovered.

Table 3 summarizes the findings from the 28 LOC accidents that were analyzed. Note that each of the 28 LOC accidents had at least one failure. Twenty of the 28 accidents had a failure in the first two categories, which involve a failure to detect an alert.

Table 3. Earliest Failure Category for each LOC Accident

	No Alert (1A)	*Alert Not Detected (1B)*	*Alert Not Understood (2)*	*Crew Selected Wrong Action (3)*	*Inadequate Crew Performance (5A)*	*Total*
# of Accidents	13	7	2	6	0	28

6.1 Categorization of Alerting Failures

A fuller accounting of the failure categories follows. Recall that the placement of each hazard into one of these categories is based on the accident report; also recall that the language used here is not intended to place blame on the pilot.

1A. The pilot did not *orient to an important change* because there was *no alert*. (total of 17).

- no alert exists in the airplane for this hazard (13)
  - — for low airspeed (6)
    - – DHC-8 (2)
    - – MD-82
    - – 737-200
    - – 737-300
    - – ATR-42
  - — for unreliable airspeed (1)
    - – MD-83
  - — for bank angle (2)
    - – 747-200
    - – Saab 340B
  - — for thrust asymmetry (2)
    - – 737-500
    - – Saab 340B
  - — for engine loss (1)
    - – 737-200
  - — for flap asymmetry (1)
    - – ATR-42
- an alert existed but failed to perform (e.g., malfunction) (2)
  - — for low airspeed (1)
    - – 320-200
  - — for autopilot disengage (1)
    - – 737-800
- alert occurred too late to recover from the hazard so that it was equivalent to not occurring (2)
  - —for low airspeed (1)
    - – 777-200
  - — for approach to stall (1)
    - – 777-200

1B. The pilot did not *orient to an important change* because the *alert was not detected* by the flight crew (or just the PF). (total of 10)

- alert used the visual modality only (when it should have had two modalities) (5)
  - — for low airspeed (3)
    - – 737-800 (2)
    - – MD-83
  - — for unreliable airspeed (1)
    - – 320-200
  - — for autothrottle disengage (1)
    - – 737-300
- pilot's attentional resources were overwhelmed (e.g., channelized attention) or focused elsewhere, preventing detection. Note that Ground Proximity events were placed in this category when the pilot's control inputs (e.g., column or stick forward) were established and did not change significantly prior to impact with the ground. (5)

— for ground prox (5)
   – 320-200 (2)
   – 737-500
   – 330-200
   – 757-200
- alert was masked or hidden (0)
- alert duration was too short to notice (0)

2. The pilot did not *understand the nature of the change*. (total of 4)
- the alert message (EICAS or ECAM) did not specify the hazard directly, or it was misleading (2)
  - — for unreliable airspeed (1)
    - – 717-200
  - — for failed attitude direction indicator (ADI) (1)
    - – 747-200
- the alert was easily confused with another alerting condition (0)
- pilot was not sufficiently trained to understand the alert (1)
  - — for approach to stall (1)
    - – 330-200
- pilot held strong belief that the problem was something else (1)
  - — for approach to stall (1)
    - – MD-82
- multiple alerting conditions were tied to a single alert. (0)

3. The pilot did not *identify appropriate actions to take*. (total of 16)
- appropriate actions are not trained (2)
  - — for approach to stall (2)
    - – 320-200
    - – MD-83
- pilot performed actions different from those trained or in operational guidance (14)
  - — for approach to stall (7)
    - – 737-200 (2)
    - – DHC-8 (2)
    - – ATR-42
    - – 737-800
    - – 757-200
  - — for unreliable airspeed (2)
    - – 330-200
    - – 757-200
  - — for bank angle (4)
    - – 737-300, -400, -500 (3)
    - – 737-800
  - — for windshear (1)
    - – 737-200
- appropriate actions are not well-specified in procedures (0)
- there is no explicit link on the interface from the alert to the appropriate actions (for checklists) (0)

5A. The pilot did not *execute the actions efficiently, accurately, and completely* because the pilot attempted to perform the appropriate actions but *failed to perform them adequately* to avoid the accident or incident. (5)

- pilot action timing, strength or speed (3)
  - — for ground prox (1)
    - – 737-200
  - — for approach to stall (1)
    - – 737-200
  - — for windshear (1)
    - – 737-200
- failed to take actions completely (was mostly correct) (0)
- a mismatch between pilot actions and the autoflight or autothrottle state (2)
  - — for approach to stall (2)
    - – 737-800
    - – 320-200

6.2 Detailed Results: Approach to Stall

Approach to stall or full aerodynamic stall is at the heart of many LOC events; indeed, this hazard occurred in 16 of the 28 events analyzed here. Table 4 shows the ways in which this hazard occurred in the 16 events; the columns show the sequence of hazards (the different paths to the 16 occurrences). In six cases (1st grouping), approach to stall followed a low airspeed event that was either not alerted or not detected. In three other cases (2nd grouping) a different hazard preceded the low airspeed → approach to stall sequence, and again low airspeed was not alerted. Note that one of these cases (Thomsonfly) was recovered effectively so it does not get tallied in the alerting failures in Table 2. In two other events (3rd grouping) unreliable airspeed was the specific hazard that preceded the low airspeed → approach to stall sequence. And, in two events (4th grouping) unreliable airspeed directly preceded the approach to stall. The final three cases (5th grouping plus last event) include two in which some hazard other than low airspeed or unreliable airspeed preceded the approach to stall, and one case in which no other hazards preceded the approach to stall.

Table 4. Various Paths to an Approach to Stall Hazard			
	Low airspeed	Approach to stall	Colgan 3407
			West Caribbean 708
			Provincial Airlines
			Turkish Airways 1951
			Ethiopian Airlines 409
			Asiana 214
Other	Low airspeed	Approach to stall	*Empire Airlines 8284*
			Air Algerie 6289
			Thomsonfly
Unreliable airspeed	Low airspeed	Approach to stall	XL Airways 888
			Swift Air 5017
	Unreliable airspeed	Approach to stall	*Iceland Air 662*
			Air France 447
	Other	Approach to stall	ADC 53
			Bhoja Air 213
		Approach to stall	Air Asia 8501

6.3 Detailed Results: Ground Proximity

Ground proximity (TAWS) hazards occurred 6 times. Table 5 shows the relevant events, what TAWS system was installed on the airplane, and a brief account of the event. The judgments for these TAWS cases were more subjective and more nuanced than they were for other hazards (especially in the larger set of 57 events).

Five of the cases (1^{st} grouping in Table 5) were categorized as "not detected." In each of these cases, TAWS alerting was occurring prior to impact with the terrain for 7 or more seconds, and during that period, there were nose-down inputs on the controls or there was a pilot-initiated nose-down attitude that was not corrected. At the extreme, the Tatarstan airplane reached a pitch attitude of 75° nose down. The Icelandair case was actually recovered at a height of 321 feet (ft) above ground level (agl) due to very strong counter-acting inputs from the FO. These cases were categorized as "not detected" because the very salient TAWS alerts failed to change the behavior of the PF. Most of these accident reports identify the potential that the pilot was influenced by spatial disorientation; specifically, the somatogravic illusion.

The sixth case in Table 5 was categorized as "inadequate performance." A judgment was made that the PF was managing a descent poorly and got lower than expected. Specifically, for Bhoja Air 213, the PF was trying to manage a windshear event but his control inputs were inadequate for preventing further descent into terrain.

Table 5. Breakout of Ground Proximity Hazards		
Not Detected	Gulf Air 72	GPWS; Pitched down from a go around (GA)
	Armavia 967	GPWS; Pitched down from a GA
	Icelandair 315	GPWS; Pitched down from a GA
	Afriqiyah 771	GPWS; Pitched down from a GA
	Tatarstan 363	EGPWS; Pitched down from a GA
Inadequate Performance	Bhoja Air 213	GPWS; Encountered windshear on approach; got low; mishandled airplane

6.4 Failure to Orient: Analysis by Year of Manufacture

Figures 2a and 2b organize the events according to when the event airplane was manufactured instead of when the accident occurred. The specific focus is on the events in which there was no alert or the alert was not detected to determine the extent to which only older airplanes fail to orient the flight crew. The oldest airplane in the event set was manufactured in 1980, and the newest airplane was manufactured in 2009.

Each dot on the figure represents an alerting failure from one of the 28 events. A red dot is used when there was no alert; the orange dot is used when the pilot did not detect the alert. Note that several events had two relevant alerting failures (for two different hazards).

Figure 2a shows the hazard associated with each red and orange dot. Figure 2b shows the airplane make and model for the same set of events. These figures show that red and orange dots continue to occur for more-recently manufactured airplanes. Summed by decades—for failure to alert—there were:

- 3 for airplanes manufactured in the 1980s
- 5 for airplanes manufactured in the 1990s
- 4 for airplanes manufactured in the 2000s

Summed by decades—for failure to detect—there were:

- 0 for airplanes manufactured in the 1980s
- 6 for airplanes manufactured in the 1990s
- 4 for airplanes manufactured in the 2000s

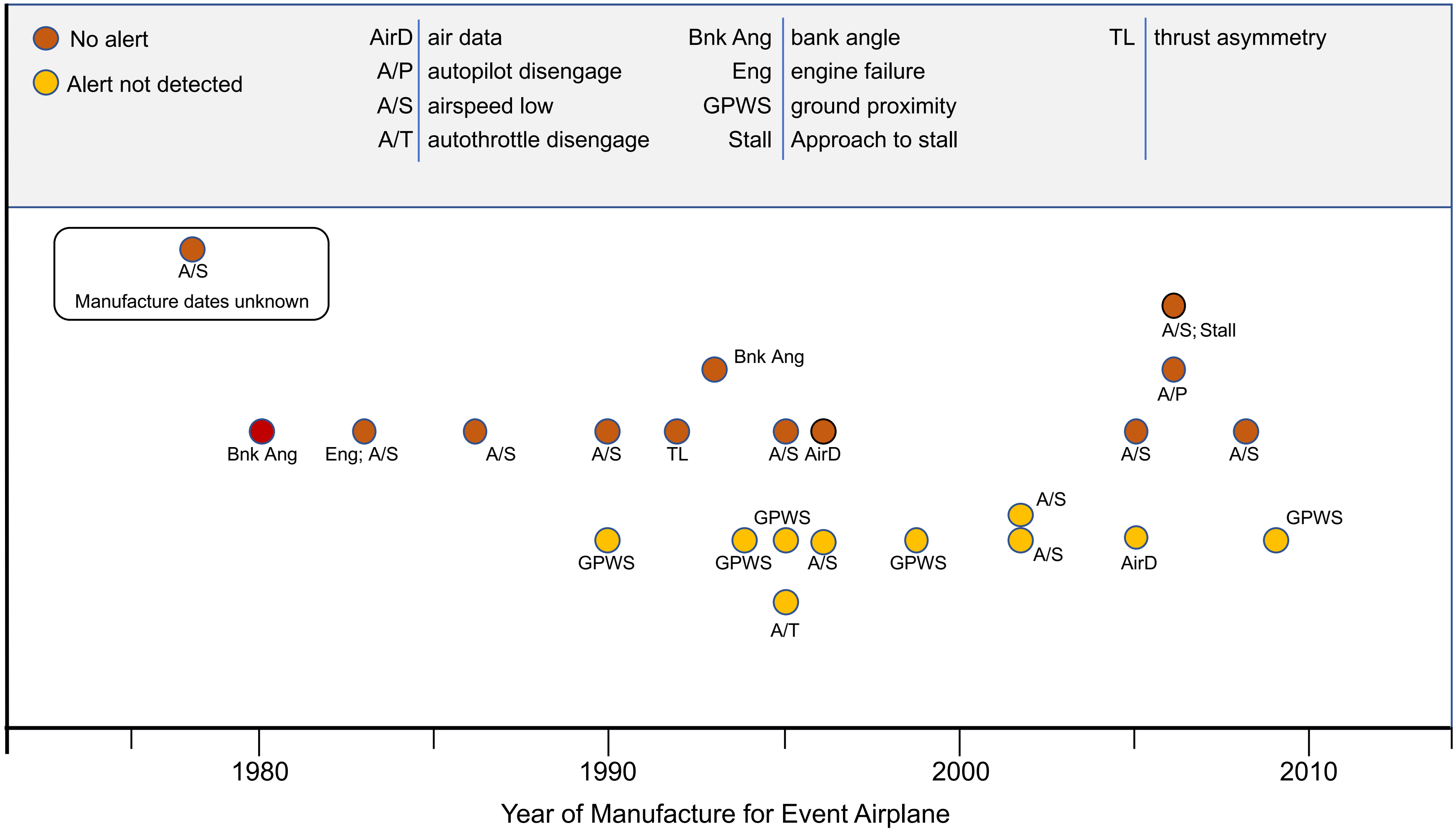

Figure 2a. Fail to orient as it relates to year of manufacture (marked for hazard).

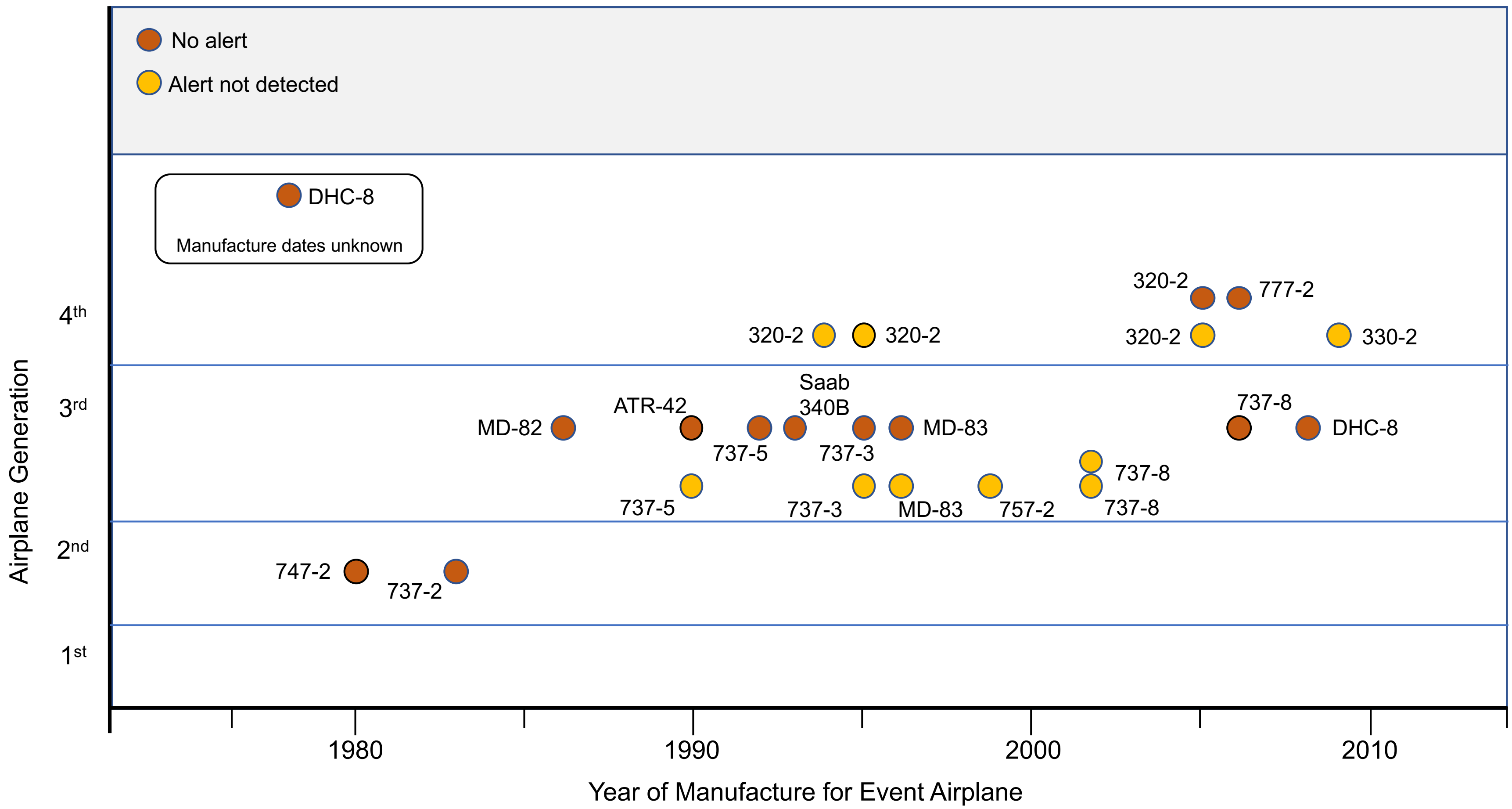

Figure 2b. Fail to orient as it relates to year of manufacture (marked for airplane model).

It is also possible to sort these airplanes into four technology-development generations (see Figure 2b); each generation adds sophistication in the airplane systems (definitions taken from http://www.airbus.com/content/dam/corporate-topics/publications/safety-first/Airbus-Commercial-Aviation-Accidents-1958-2016-14Jun17.pdf):

- First-generation jets were designed in the 1950s and ’60s with system technologies that were limited in their capabilities by the analog electronics of the era. An example is the Boeing 707.
- The second generation of jet aircraft had improved auto-flight systems. Examples are the 737-200 and 747-200.
- The third generation of jets was introduced in the early 1980s. This generation took advantage of digital technologies to introduce ‘glass cockpits’ with Navigation Displays and flight management systems (FMS) as well as TAWS. Examples are the Boeing 737 Classics and NGs and the McDonnell-Douglas MD-80s and -90s.
- The fourth, and latest, generation of jet aircraft was introduced in 1988 with the Airbus A320. Fourth generation aircraft use fly-by-wire (FBW) technology with flight envelope protection functions. More recent examples are the Boeing 787 and Airbus 350.

Using these generational definitions, the events from Figure 2b were re-classified by airplane generation. For failure to alert, there were:

- 0 for 1st-generation airplanes
- 2 for 2nd-generation airplanes
- 9 for 3rd-generation airplanes
- 2 for 4th-generation airplanes

For failure to detect, there were:

- 0 for 1st-generation airplanes
- 0 for 2nd-generation airplanes
- 6 for 3rd-generation airplanes
- 4 for 4th-generation airplanes

6.5 Pilot Flying

The PF is the pilot who is handling the airplane controls. The PM is the other pilot. For most airlines, the two pilots—Captain and FO—take turns in the PF role. We used the accident reports to identify which pilot was PF at the time of the upset/crash [Note that for two of the events, the report did not make clear that it was possible for the FO to serve in the PF role, so these two events were removed from this analysis]. In three of the 26 cases, the Captain took over as the situation worsened, or to perform the recovery; in these cases, the Captain was identified as PF. There were three (of 26) cases in which the report failed to determine which pilot was PF or in which both pilots were making control inputs. For the remaining 23 events, we found the following:

- 22 cases in which the Captain was PF
- 1 case in which the FO was PF

We then looked at the cases in which there was a judgment that the PF performed poorly. Specifically, we looked at any event that fell into one of these three categories:

- 3. The pilot did not identify appropriate actions to take.
- 5A. The pilot did not execute the actions efficiently, accurately, and completely because the pilot attempted to perform the appropriate actions but failed to perform them adequately to avoid the accident or incident.
- 5B. The pilot did not execute the actions efficiently, accurately, and completely because the flight crew or pilot chose not to perform the appropriate actions, which is a violation.

According to Appendix C, there were 15 events in which one of these categories was used and only one pilot was on the controls. For these 15 events, we found the following:

- 14 cases in which the Captain was PF
- 1 case in which the FO was PF

6.6 Flight Hours

Pilot experience can sometimes be an important factor in managing an upset, and for pilots, their experience is tracked precisely in terms of hours (hrs) on the job. Accident reports typically list, for each pilot, his/her total flight time and his/her time in type (hours on that particular airplane type; e.g., A320). We applied a somewhat-arbitrary level of 1,500 hours as a marker of an apprentice period; specifically, we identified when a pilot had less than 1,500 hours (total time or time in type).

Of the 28 events, there was one in which there was no information on pilot total flight hours. For the other 27 events, we found:

- 7 cases in which the FO had less than 1,500 hrs of total flight time

Of the 28 events, there were two in which there was no information on time in type. For the other 26 events, we found:

- 3 cases in which both pilots had *more than* 1,500 hrs of time on type
- 10 cases in which *one* pilot had *less than* 1,500 hrs of time on type
- 13 cases in which *two* pilots had *less than* 1,500 hrs of time on type

Unfortunately, it is hard to establish a baseline to determine whether the number of cases of low-time pilots is representative of overall fleet operations, or that low-time pilots are more likely to get into upsets and accidents.

IMC vs VMC. IMC were associated with 17 of the 18 CAST ASA events. For this larger set of 28 events, we found:

- 3 events occurred in VMC
- 3 events occurred in VMC-Night conditions
- 22 events occurred in IMC

Unfortunately, it is hard to establish a baseline to determine whether the number of cases of IMC and VMC-Night is representative of overall fleet operations, or that upsets and accidents are more likely in these degraded visual conditions.

7. Discussion

The primary findings from these data are the following:

1. *Failures in the integrated alerting-to-recovery sequence played a role in every LOC accident or incident.* As Table 3 shows, in each of the 28 events that we analyzed, there was at least one failure in the integrated alerting-to-recovery sequence; that is, there was not a succession from hazard to alert to appropriate response and recovery, and the hazard or string of hazards resulted in a major upset or accident. Twenty of the 28 events had a failure in the orientation step. The remaining eight had a failure in the understand step or the link to selecting appropriate actions. These early steps are strongly connected to the performance of the alerting system.
2. *Orientation was the most frequent failure.* Slightly more than half of the failures (27/52; 52%) occurred in the first step of the integrated alerting-to-recovery sequence: Orientation. Sixteen failures were due to no alert, and 10 failures were due to an alert that was not detected.
3. *Identifying appropriate actions was the next most frequent failure.* The second most-frequent failure point was identifying the appropriate actions to respond to the hazard (16/52; 31%); 9 of those 16 cases were for approach to stall/stall.
4. *As one might expect since these were identified as LOC accidents, the vast majority of the hazards were tied to basic flight path management*. Approach to stall/stall, low airspeed, unreliable airspeed, bank angle, and ground proximity accounted for 83% (43/52) of the hazards that occurred. Further, 100% of the events included one of those five hazards.
5. *Approach to stall was the most-frequent hazard in the set.* Overall, there were 16 cases in which an approach to stall/stall hazard was handled poorly, resulting in an accident or major upset. Moreover, as Table 4 shows, pilots transitioned into an approach to stall/stall situation in a number of different ways. Eleven of these were preceded by a low airspeed hazard that was either not alerted (8/11) or the alert was not detected (3/11). This finding shows that less problematic hazards that occur initially, but are not detected, can evolve to a more difficult recovery situation.
6. *Ground proximity alerts failed in two different ways.* TAWS alerting is loud and persistent. However, for this set of 28 events, there were six cases in which a ground proximity hazard was not avoided. In five cases, the pilot was presented with a salient alert but seemed unable to detect it, probably due to limitations in attention. In another case, the pilot got an alert and seemed to understand it but did not respond adequately in avoiding the hazard. It is worth noting that in the larger set of 57 events that were analyzed, we also saw a handful of cases in which TAWS alerts failed to occur (no alert).
7. *Newer airplanes have problems as well.* Figures 2a and 2b show that the orientation failures were not just an issue with airplanes built more than 30 years ago, or just with unsophisticated, 2nd-generation airplanes. The majority of these failures occurred in airplanes built in 1990 or later. More than one third (8/22) of the airplanes that failed to present an effective alert for hazards such as low airspeed or ground proximity were built after 2000!
8. *The Captain is the PF in almost every event.* If we start with the assumption that the Captain and FO each fly about half of the time (for those airlines where both pilots can take the role of PF), then it is quite remarkable that the Captain is the one on the controls when a LOC occurs. Recall that for three events, the Captain took the controls just prior to or during the upset. There is an expectation that the Captain is more experienced and has better recovery skills.

9. *Alerting is a key safety system that can be improved*. Although significant safety events are rare, there is value in a thorough analysis of the performance of the alerting system design. The presence of an alert for a known hazard can have significant weight in a system's safety analysis. However, the analysis here shows that there are numerous ways in which that alert may not guarantee an effective recovery. Indeed, one outcome of this analysis was a fuller understanding of how alerts can fail to be detected and understood (see also Bliss, 2003).

Important caveats when considering these findings are:

1. *Accidents are a result of many factors.* Any review of accidents will quickly reveal that accident causality is typically complex, and, arguably, there is never a single factor or cause. Other significant factors that contributed to one or more of these events are CRM (crew resource management), flight deck interface design, pilot training, manual flying skills, fatigue, airline safety culture, non-normal procedures, vestibular illusions and other forms of pilot impairment, air data system design, and pilot's understanding of the autoflight system. This list is certainly not complete, and many of the accident reports provide a much more complete account of the tragic outcomes addressed here.
2. *There are no base-rate data that are publicly available on recovery from these hazards*. It is difficult to extract data on how frequently these hazard alerts are handled well across world-wide operations, and, thus, we cannot know the overall level of system reliability. The CAST team has looked at Aviation Safety Information Analysis and Sharing (ASIAS) data to identify how often some ASA-type situations occur in U.S.-based operations, and, while there is evidence that accident precursors do occur, specific numbers have not been shared publicly.
3. *Effective system operation always involves interface design, pilot training, and operational procedures.* The analysis of these safety events demonstrated that the presence of a hazard alert is not always sufficient to guarantee an effective response. However, a focus solely on alerting system design ignores the other factors that can influence pilot performance—namely, pilot training or performance and non-normal procedure design. In many cases, these other disciplines can mitigate a failure on the interface side.

7.1 Case Study: The Evolution of Alerts for Boeing Aircraft

This analysis of a large set of LOC events revealed that alerting and its related elements failed to orient the pilot to a flight path management hazard and ensure an adequate recovery from that hazard. It is worth looking at the history of how some of these alerts were implemented in commercial jet transports to understand how hazard alerting has evolved. The following is a case study of how alerts were implemented in Boeing airplanes. Using Boeing for a case study is instructive since Boeing has been building airplanes for more than 100 years and this history also reveals the evolution of alerting technology and regulations.

First, it is useful to establish the regulatory foundation. The current 14 CFR 25.1322, flightcrew alerting rule became effective November 2, 2010[11], replacing a 1977 version of the rule that had primarily established the color of discrete warning, caution, and advisory lights. Based on information from aviation industry groups[12], the FAA determined that discrete lights could be replaced with more-effective, logic-based, integrated alerting systems. The new rule also established

[11] Amdt. 25-131, 75 FR 67209, Nov. 2, 2010

[12] The FAA reviewed recommendations from the Commercial Aviation Safety Team and the Aviation Rulemaking Advisory Committee. Information regarding these groups and their recommendations appears later in this NPRM and in the public docket.

that when the alert requires immediate flightcrew awareness—for Warning- and Caution-level alerts—it is required to have at least two different senses (e.g., aural, visual, or tactile). Prior to the current 14 CFR 25.1322 rule, AC 25-11 (16 July 1987) on electronic displays also recommended dual sensory modes for flightcrew alerting.

Although the current 14 CFR 25.1322 establishes standards for the presentation of flightcrew alerting for transport airplanes, other 14 CFR Part 25 rules establish what is required to be alerted (e.g., low airspeed, bank angle exceedance) at each level. At this time, the FAA has not codified specific Part 25 rules for some of these flight path management hazards, but related groups, such as the Avionics Harmonization Working Group and Flight Test Harmonization Working Group, are engaged with addressing these questions. Because the FAA has not established a requirement, transport aircraft manufacturers have taken the role to assign hazards, such as low airspeed, to an alerting category.

Regarding the evolution of alerting for Boeing airplanes, there was a significant advance in alerting system design in the early 1980s for the 757/767 joint entry into service with the introduction of a centralized alerting system (the EICAS display). This change was in response to a proliferation of airplane system alerts in the previous generation of aircraft (see Boucek et al., 1977). The addition of centralized alerting was also seen as one justification for removing the flight engineer role in the flight crew. Centralized alerting meant that alerts were presented on a single display placed in a forward area visible to both pilots instead of being distributed around the flight deck interface, and the visual and aural alerting schemes were well-defined and predictable.

This central alerting advance, however, was applied only to airplane system failures, such as hydraulic system or electrical system failures. Flight path management hazards, on the other hand, continued to evolve without the level of integration brought to the airplane system alerts. Flight path-related alerts such as TCAS RAs, windshear, ground proximity, low airspeed, bank angle, and stall warning are related in that they all require the pilot to make flight control inputs to address a hazardous situation. Even the latest generation of jet transports, pilots are alerted to these conditions using a mix of voices, sounds, master lights, visual alerts, and visual situation information (typically communicated through the PFD, navigational display (ND) or other, more isolated lights near those displays). There are also differences in how guidance information (such as "pull up") is provided, or even if flight control guidance is provided.

To illustrate how these various hazard alerting schemes evolved each in their own way, we lay out the changes over time in a set of tables. Along the side of each table are the different Boeing models organized by their entry into service (EIS) dates. Across the top are a set of generic alerting scheme levels. Note that, as mentioned above, according to the current (2010) 14 CFR 25.1322 rule, Caution-level and Warning-level alerts should both use two perceptual modalities for alerting (from visual, auditory, and tactile).

7.1.1 Low Airspeed

Table 6 shows how low airspeed alerting evolved. Low airspeed, in current thinking, requires Caution-level alerting with two perceptual modalities. In Boeing's early jet transports, there was no alerting for low airspeed. In the mid- to late-1980s, after the 757 and 767 were upgraded with airspeed tapes (from round dials), low airspeed was alerted by a visual change on the airspeed tape. Finally, in 1989, with the 747-400, low airspeed progressed to two-modality alerting using the master caution (MC) aural tone and central light, plus an EICAS message and changes to the airspeed tape. This scheme carried forward to the more recent airplanes: 777, 787, and 747-8.

Interestingly, though, when the 737 Next Generation (NG) was introduced almost 10 years after the 747-400, Boeing retained the 737 Classic scheme: changes only to the airspeed tape, resulting in an airplane of very recent vintage that did not meet the two-modality rule. Then, in 2010, after safety data clearly revealed that pilots did not always orient to the visual alerting, Boeing made a voice aural ("low airspeed") available as an option for the 737 NG. In fact, there was recent talk that other airplanes might move to a voice aural to replace the Caution-level tone.

How can a currently manufactured airplane not comply with the current rule (and its requirement for two-modality cueing)? It depends on whether the airplane is a new design or a "series" airplane, such as the Boeing 737. Although the 737 may change considerably in some ways as it goes from Classic to NG to MAX, the earlier certification basis can be applied[13]. To require application of the newer rule, it has to be shown that there has been a "significant" change between the models. On the other hand, a brand-new airplane, such as the Boeing 787, would normally be required to comply with all the certification requirements at the amendment level when the certification application occurred.

Table 6. Low Airspeed Alerting Schemes

Model and EIS Date	No Alert	Visual Alerting Only	2 Modes of Alerting (Caution)	2 Modes of Alerting (Warning)
737-100/200 (1968)	X			
747 Classic (1970)	X			
767 (1982)	X	Amber indications on airspeed tape (with addition of airspeed tape)		
757 (1983)	X	Amber indications on airspeed tape (with addition of airspeed tape)		
737-300/400/500 (1984)	X			
747-400 (1989)			MC aural/light + EICAS, amber indications on airspeed tape	
777 (1995)			MC aural/light + EICAS, amber indications on airspeed tape	
737-600/700/ 800/900 (1998)		Amber indications on airspeed tape	voice: AIRSPEED LOW + amber indications on airspeed tape (2010)	
747-8 (2011)			MC aural/light + EICAS, amber indications on airspeed tape	
787 (2011)			MC aural/light + EICAS, amber indications on airspeed tape	

[13] Establishing the Certification Basis of Changed Aeronautical Products, March 11, 2016 AC No: 21.101B

7.1.2 Unreliable Airspeed

Unreliable (or misleading) airspeed, also now considered a Caution-level alert, is often another potential precursor to approach to stall/stall and subsequent LOC in the analysis presented above. Table 7 shows that up until the mid-1990s Boeing's jet transports had no alerting for unreliable airspeed. Then the 767 and 747-400 added an advisory message (visual only) on the EICAS to point out an airspeed mismatch. Finally, in 1997 Boeing moved to a two-modality alerting scheme with the Master Caution aural tone and central light plus an EICAS message. However, the EICAS messages did not directly express "airspeed unreliable" and could be overwhelmed by messages from downstream faults that may not seem related. It was hoped that the EICAS messages would get the flight crew to the appropriate non-normal checklist. In 2011 a more robust solution was implemented for the 787. That air data system uses two independent methods to find mismatches between sensors and then presents an "airspeed unreliable" EICAS message.

Table 7. Unreliable Airspeed Alerting Schemes

Model and EIS Date	No Alert	Visual Alerting Only	2 Modes of Alerting (Caution)	2 Modes of Alerting (Warning)
737-100/200 (1968)	X			
747 Classic (1970)	X			
767 (1982)	X	Advisory EICAS (1995)	MC aural/light + EICAS (1997)	
757 (1983)	X		MC aural/light + EICAS (1997)	
737-300/400/500 (1984)	X			
747-400 (1989)	X	Advisory EICAS (1994)	MC aural/light + EICAS (1997)	
777 (1995)			MC aural/light + EICAS (+ voting)	
737-600/700/ 800/900 (1998)		Amber message on PFD		
747-8 (2011)			MC aural/light + EICAS	
787 (2011)			MC aural/light + EICAS (message is explicit) (+ synthetic airspeed as a comparison)	

7.1.3 Approach to Stall/Stall

The hazard that can follow on from the previous two is the approach to stall or stall alert, which is a Warning-level hazard. As Table 8 shows, from the earliest models, this hazard has been alerted fairly consistently. The "stick shaker" has both aural and tactile components. At service entry for the 757/767, Boeing also added red indications on the PFD. The accident and incident analysis above show that, typically, the failure for this hazard is not orientation or understanding but determining the appropriate actions to take. Note that the failure to take the appropriate actions is the result of a failure in training on those actions.

Table 8. Approach to Stall Alerting Schemes

Model and EIS Date	No Alert	Visual Alerting Only	2 Modes of Alerting (Caution)	2 Modes of Alerting (Warning)
737-100/200 (1968)				Stick shaker
747 Classic (1970)				Stick shaker
767 (1982)				Stick shaker + PFD red indications
757 (1983)				Stick shaker + PFD red indications
737-300/400/500 (1984)				Stick shaker + PFD red indications
747-400 (1989)				Stick shaker + PFD red indications
777 (1995)				Stick shaker + PFD red indications
737-600/700/ 800/900 (1998)				Stick shaker + PFD red indications
747-8 (2011)				Stick shaker + PFD red indications
787 (2011)				Stick shaker + PFD red indications

7.1.4 Bank Angle

Alerting for an excessive bank angle (greater than 35°), a Caution-level alert, is laid out in Table 9. There was no alerting on this condition at EIS for any airplane prior to the 747-400 in 1989. A voice aural (“bank angle”) was made available for most of the earlier airplanes in 1987, but the accidents analyzed above show events in which there was no alert, meaning that that upgrade option was not taken. And, these earlier airplanes never did receive an option for upgrading to a true Caution-level alert.

In 1989, the 747-400 was the first airplane to be delivered with a true two-modality alert. Two of the later airplanes (777, 787) added tactile feedback on the wheel so that, as the airplane is rolled beyond 35°, a stronger force is required to push past 35°. This envelope protection mechanism was not implemented in the 737 NG or the 747 upgrade (-8). Boeing has recently developed a second alerting scheme at the 45° threshold, based on the findings on some of the accidents reviewed above. The new scheme consists of control guidance with a voice aural (“roll left”) accompanied by an arrow on the PFD that points in the desired turn direction. This Warning-level scheme is being implemented on the 737 MAX with an option to retrofit on the 737 NG.

Table 9. Bank Angle Alerting Schemes

Model and EIS Date	No Alert	Aural Alerting Only	2 Modes of Alerting (Caution)	2 Modes of Alerting (Warning)
737-100/200 (1968)	X			
747 Classic (1970)	X	voice: BANK ANGLE (1987)		
767 (1982)	X	voice: BANK ANGLE (1987)		
757 (1983)	X	voice: BANK ANGLE (1987)		
737-300/400/500 (1984)	X	voice: BANK ANGLE (1987)		
747-400 (1989)			voice: BANK ANGLE + PFD indication	
777 (1995)			voice: BANK ANGLE + PFD indication + tactile feedback (3 modes)	
737-600/700/ 800/900 (1998)			voice: BANK ANGLE + PFD indication	Additional voice + visual (with guidance at 45°) (option-2017)
737 MAX (2017)			voice: BANK ANGLE + PFD indication	Additional voice + visual (with guidance at 45°)
747-8 (2011)			voice: BANK ANGLE + PFD indication	
787 (2011)			voice: BANK ANGLE + PFD indication + tactile feedback (3 modes)	

7.1.5 Terrain Avoidance and Warning System

The final hazard alerting scheme is the TAWS which is also called the ground proximity warning system (GPWS) or enhanced ground proximity warning system (EGPWS). Table 10 shows that these systems were established at the Warning level even in the earliest 737 models. They use a voice aural that alerts to hazards (“terrain”) or gives direction (“pull up”); later versions (starting in 1982) add guidance to the PFD as well.

The most significant change in alerting was the change from GPWS to EGPWS. GPWS uses a “look ahead” radar to detect high terrain and then alert as you are approaching it. EGPWS added a terrain database that determines the current location of the airplane relative to terrain that is at the same altitude or higher. EGPWS can provide an earlier alert than does GPWS. In terms of attention-getting or orientation, these two schemes are very similar, but there are huge differences in the triggering conditions. Note that the analysis of the larger set of events (Mumaw, 2017) describes 16 TAWS alerting events that failed for various reasons.

Table 10. Ground Proximity Alerting Schemes

Model and EIS Date	No Alert	Aural Alerting Only	2 Modes of Alerting (Caution)	2 Modes of Alerting (Warning)
737-100/200 (1968)				voice: (directive) + red light
747 Classic (1970)				voice: (directive) + red light
767 (1982)				voice: (directive) + red PFD text and light
757 (1983)				voice: (directive) + red PFD text and light
737-300/400/500 (1984)				voice: (directive) + red PFD text and light
747-400 (1989)				voice: (directive) + red PFD text and light
777 (1995)				voice: (directive) + red PFD text and light
737-600/700/ 800/900 (1998)				voice: (directive) + red PFD text and light
747-8 (2011)				voice: (directive) + red PFD text and light
787 (2011)				voice: (directive) + red PFD text and light

As these tables show, alerting schemes, like many other elements of the flight deck interface, have evolved over time. The impression is that the individual alerts were developed in a piecemeal manner; that is, there was not a shift to a more integrated alerting scheme for these flight path hazards as there was for airplane system failures. Because an airplane can be in service 30 years or more, the older alerting technology remains in the operating fleet even when alerting system improvements have been implemented on newer airplanes. In some cases, airline operators are offered a retrofit package, but there is no guarantee that all operators will pick these up. The 737 is an example of newer models (NG) being introduced that preserve the same alerting schemes of much older airplanes.

There are likely two reasons for this piecemeal evolution:

1. The technology to reliably and accurately alert a hazardous condition has evolved over time. Better solutions are developed and implemented as opportunities arise.
2. There seems to have been an assumption that the pilot flying (PF) frequently monitored essential flight path parameters and managed the deviations so that alerting was, therefore, not required. Accidents have shown this assumption to be optimistic for some operations, and recently, there is a new awareness regarding the weaknesses in pilot monitoring (e.g., CAA, 2013). We know of no document revealing this assumption was an influence on earlier

designs. However, the delay of implementing alerting for what are now considered Caution-level hazards suggests there was a basic misunderstanding regarding how much monitoring occurs for these aspects of flight path management.

7.2 Findings that have been Addressed

A number of the findings described here are currently being discussed or addressed by the FAA and airplane manufacturers.

7.2.1 Hazard Alerting: Low Airspeed

In 11 of the events analyzed above, flight crews failed to orient to a low airspeed hazard because there was no alerting, or a visual alert occurred but was not detected. Table 6 reveals that low airspeed was not alerted in older Boeing airplanes, and there were other transport manufacturers, as well, that produced airplanes without low airspeed alerting, as we can see in Figure 2b. There were some cases in which an alert existed but failed to operate. Newer airplanes are much more likely to have low airspeed alerting, and there are additional changes that could improve the effectiveness of low airspeed alerting.

Context and timeliness are also important for effective airspeed alerting. The National Transportation Safety Board (NTSB) accident report for the Asiana 214 accident noted that low airspeed alerting occurred too late for the flight crew to recover from their low-altitude, low-energy state during approach. The alert needs to ensure there is time for pilot awareness, actions, and airplane system performance (e.g., engine spool up). Refinements in airspeed alerting that attempt to provide earlier cues in these types of operational situations are being discussed but are not implemented at this time. Indeed, the FAA has recently organized an Airspeed Harmonization Working Group (ASHWG) to continue to look for ways to make low airspeed alerting more effective.

Instead of altering the low airspeed alert, the design could instead provide different early cues; specifically, it could tie alerting to the airspeed targets that pilots are using. For two of the accidents we analyzed (Turkish 1951 and Asiana 214), the low airspeed failures occurred on approach, when the airplane was normally descending and slowing. In these accidents, the airspeed dropped well below the MCP airspeed target and eventually got to the amber-band-based trigger point.

- For Turkish 1951, the MCP/V_{ref} airspeed was 144 kts, and the low airspeed alert was at 127 knots (kts). The visual alerting (flashing amber box on the airspeed tape) that occurred at 127 was not noticed because the flight crew was behind on completing a checklist. When the airspeed reached 108 kts, 36 kts below the V_{ref} speed, the stick shaker came on and prompted a response. That response was executed badly and failed to recover the airplane.
- For Asiana 214, the MCP/V_{ref} airspeed was 137 kts. The airplane continued to slow down and, at 114 kts, the alerting started. The alert got the pilot's attention, but, at that point, the airplane was roughly 120 ft above the runway and it was not possible to recover.

These examples show that the target airspeed was considerably higher (17 and 23 kts difference in these two cases) than the top of the amber band. Potentially, there could be an additional airspeed alerting trigger when the airplane is on approach and slows considerably below the V_{ref} airspeed. There is alerting when an airplane deviates from the MCP altitude, but this same mechanism is not applied to the airspeed target. It may make sense for the airplane to adopt additional triggers for alerting in different contexts (e.g., below V_{ref} speed during approach). Certainly, an airspeed alert at that point needs to be quite different from the AIRSPEED LOW alert.

7.2.2 Hazard Alerting: Approach to Stall

The most frequent hazard in this accident/incident set was an approach to stall or stall. An upset of this type is typically unexpected and can be difficult to manage and recover. A number of these events occurred close to the ground where there was little or no room for maneuvering the airplane. Others, however, occurred at a high altitude but were not managed appropriately. The findings from this set of safety events largely point to inappropriate or inadequate pilot control inputs for managing these upsets.

In 2009, the Colgan 3407 accident and subsequent investigation brought a strong focus on pilot skills and knowledge for recognizing, preventing and recovering from stalls. This investigation led to rule-making actions in the U.S. (see the FAA Advisory Circulars 120-109A and 120-111, and training requirements in 121.423), and internationally (ICAO Doc 10011). These new requirements include upset prevention and recovery training (UPRT) for all Part 121 (airline transport) pilots. The training will be done in the classroom and full-flight simulator, and it will provide training for stall prevention and post-stall recoveries. All U.S. pilots should receive this training by the end of March, 2020. Outside the U.S., the majority of airline transport pilots will receive only stall-prevention training.

The set of accidents and incidents reviewed here demonstrates that the pilot performance issues identified in the Colgan accident have contributed to a substantial number of fatal accidents. The training now being developed and gradually implemented world-wide is designed to improve pilot effectiveness in responding to a stall or near stall. Note that there have been events in which pilots managed a stall event effectively although it is difficult to determine the number of "saves" that have occurred over a period of time.

7.2.3 Hazard Alerting: Bank Angle

The events analyzed here showed that in four cases, the PF made control inputs away from wings level in response to a bank angle exceedance. The current Caution-level alert calls out the hazard ("bank angle") but does not provide guidance for appropriate control inputs. As mentioned earlier, Boeing has added a second layer of alerting for when the airplane rolls beyond 45°, now considered a Warning-level situation. This new alert provides both aural and visual cues to guide control inputs in the correct direction. This new alert is being delivered on the 737 MAX airplanes and is available for retrofit to 737 NGs.

7.3 Findings that Require Additional Work

7.3.1 Lack of Integration for Flight Path Management Hazard Alerting

As described above, airplane system failures are typically presented through an integrated alerting system, such as EICAS or ECAM. Flight path management hazards, however, are more varied and distributed. Adding to this situation are new alerts, such as Honeywell's Runway Advisory and Awareness System (RAAS) or Controller-pilot Data Link Communication (CPDLC) aurals. RAAS adds new aural alerts regarding landing and runway conditions. Also, recently, Boeing (in collaboration with Honeywell) added a new Warning-level bank angle alert. It is likely that going forward other alerting conditions will be considered, as well. In some cases, these additional alerts are developed by third-party vendors (i.e., not the airplane manufacturer and not the airplane operator) and are added post-production; basically, "tacked on" the airplane.

Although there is typically a valiant attempt to fit new alerts into the overall alerting scheme, there has been no "blank sheet of paper" approach as there was with the airplane system failures. It seems time to consider what a more integrated system should look like. Considerations should be:

- the variety of aural tones and voice-based alerts, and their relative salience
- when a voice is superior to a tone
- how aural alerts are preserved as a visual record, in case they are missed initially
- more generally, how you create a visual, more persistent record of aural alerts
- how hazards can interact; for example, appropriate responses to a roll deviation are affected by the pitch attitude
- how to ensure that there is ample time to recover from the hazard; e.g., low airspeed at low altitude
- the potential value of low airspeed alerts when an airspeed target is being violated

This set of considerations just begins to reveal some of the complexity involved. Considerable effort will be required to develop an adaptable, effective solution.

7.3.2 Commercial Transports that Fall Short of Current 14 CFR 25.1322 Requirements

This analysis has made it clear that the world-wide operational fleet includes a substantial number of airplanes that do not meet the current 14 CFR 25.1322 requirements[14]. There seems to be good agreement (looking at how recent airplanes have categorized hazards) that the following four hazards should be alerted at the Caution-level:

- autothrottle disconnect
- low airspeed
- unreliable airspeed
- bank angle

Specifically, according to the language of 14 CFR 25.1322, caution-level hazards "require immediate flightcrew awareness and subsequent flightcrew response." However, Figures 2a and 2b provide evidence that there have been safety events in which one of these four hazards was not alerted or events in which the alert was only a single modality and was not detected.

Further, the airplanes with the least effective alerting schemes are more likely to be operated in countries where most of these accidents and serious incidents are happening. In those places, it is also generally true that operators have fewer resources, pilot training is less rigorous, and CRM is less consistently practiced. Perhaps a stronger focus on CRM and on monitoring practices could aid these operators to reduce their exposure to the increased risk.

7.3.3 Channelized Attention and Spatial Disorientation

A number of the LOC events analyzed here may be linked to spatial disorientation (SD) in the PF. Pulling from a larger set of accidents and incidents over the last 20 years, the following are events in which SD may have influenced control inputs from the PF:

- March 18, 1998.............**Formosa Airlines Saab 340** at Hsin-Chu, Taipei (13 fatalities)
- December 22, 1999........**Korean Airlines 747-200** at Stansted, London (4 fatalities)

[14] Due to the application of an earlier amendment level, they were not required to satisfy this rule.

- January 10, 2000............CrossAir Saab 340 at Zurich, Switzerland (10 fatalities) (SG)
- August 23, 2000 ....**Gulf Air A320** at Bahrain (143 fatalities) (SG)
- July 4, 2001 ....Vladivostokavia Tu154 at Irkutsk, Russia (145 fatalities)
- January 22, 2002............**Icelandair 757-200** at Oslo, Norway (0 fatalities) (SG)
- January 3, 2004..............**Flash Airlines 737-300** at Sharm el Sheikh, Egypt (148 fatalities)
- May 3, 2006...................**Armavia A320** at Sochi, Russia (113 fatalities) (SG)
- January 1, 2007..............**Adam Air 737-400** at Sulawesi, Indonesia (102 fatalities)
- May 5, 2007...................**Kenya Airways 737-800** at Cameroon (114 fatalities)
- September 14, 2008.......**Aeroflot-Nord 737-500** at Perm, Russia (88 fatalities)
- April 13, 2010................Aerounion A300 at Monterrey, Mexico (6 fatalities) (SG)
- May 12, 2010.................**Afriqiyah A330** at Tripoli, Libya (104 fatalities) (SG)
- December 2, 2010..........Flyveselskap DHC-8 at Svoelvar, Norway (0 fatalities) (SG)
- June 29, 2011.................British Airways 767-300 at Vienna (0 fatalities)
- September 6, 2011.........ANA 737-700 above Japan (0 fatalities)
- January 29, 2013............Scat CRJ-200 at Khazakstan (21 fatalities) (SG)
- November 17, 2013 ....**Tatarstan 737-500** at Kazan, Russia (50 fatalities) (SG)
- March 19, 2016..............FlyDubai 737-800 at Rostov-on-Don, Russia (62 fatalities) (SG)
- December 29, 2016........Private Citation CJ4 at Cleveland, OH (6 fatalities) (SG)

[Those events that are **bolded** are events that were included in the CAST ASA study and/or the set of 28 events analyzed in this report. Those events that are followed by (SG) are events in which the SD may have been the result of a somatogravic illusion.]

In the 11 SG events, the PF, after a go-around or rapid climb in IMC, pitched the airplane down toward the ground. These cases triggered the TAWS alerting which typically generated salient aural alerts for more than 7 seconds. However, in 9 of the 11 cases, these alerts did not change the PF's behavior. The pitch down inputs continued. An interpretation of this finding is that the PF had channelized attention and was unable to actually hear the alert[15].

This failure of the alert to be detected needs to be addressed. These types of events will continue to occur. At this time, research is required to determine how to break through the PF's attentional limitation to alert the impending collision with the terrain. While some work has been done in this area (Dehais et al., 2014), there needs to be a stronger push toward a solution.

Obviously, another approach for addressing this problem is to ensure that the PM intervenes when the PF is non-responsive to the hazard. Further work is also required in this area to identify why intervention does not always happen.

7.3.4 Indications of Data Validity

A specific concern with the occurrence of unreliable airspeed—meaning a loss or degradation of air data to derive airspeed and altitude indications—is that invalid or erroneous data can be presented to the flight crew. When air data sensors are getting different readings, the air data system tries to

[15] Note that channelized attention can occur for reasons other than SD. Channelized attention is a larger phenomenon that has contributed to other types of accidents.

identify which data are correct or it puts up an alert (when the airplane has an alert for this hazard). As we know from some accidents (e.g., Iceland Air 662, Air France 447), the flight deck indications can continue to show invalid airspeed values, and the flight crew can be fooled by this presentation and "chase" a bad airspeed, leading to an upset condition.

In some airplanes, there is a voting scheme between three sensor inputs and, in some cases, two will agree and one will be different. For these cases, the different input is labeled invalid, and the output of the other two is retained. It is possible that this voting scheme can lead to presenting the wrong answer; or, it can be difficult for the PF to quickly determine that the airspeed indication is faulty. Ideally, erroneous indications are made to look different as a strong cue that it may be invalid.

More work is needed here to make invalid or potentially invalid indications look different. Even when there is disagreement across sensors, it might make sense to reveal that uncertainty to the flight crew.

8. Summary and Conclusions

In this report, we have broadened the idea of alerting to include all of the steps of what we are calling the *integrated alerting-to-recovery sequence*. The primary objective of using this level of description is that the flight deck interface, operational procedures, and pilot training should be designed to support the pilot in moving from a hazardous condition to an effective recovery from the hazard. When accidents or significant incidents occur, we should look at how well this integrated alerting-to-recovery sequence worked—did it fail, and, if so, where?

We defined a set of steps in the sequence and then analyzed reports of safety events to identify if a failure occurred along that sequence. These results led us to try to understand why these specific failures occurred. Studying the performance of alerting systems in events in which they failed has helped identify the types of alerting-system design changes (or other changes) that are needed.

We identified a failure point for each of the 28 events. Notably, 20 of 28 failed in the initial step of orienting to a failure, which speaks to the alerting mechanism itself. Clearly, there are still cases in which basic flight path management hazards are not alerted sufficiently to make the PF (and maybe the flightcrew) aware of the hazard. Further analysis showed that these orienting failures are occurring even for recently manufactured airplanes; that is, it is not only a problem for airplanes that were manufactured 30 years ago. The truth is that there are many airplanes in the world-wide operational fleet that do not sufficiently alert some of these basic flight path management parameters (e.g., low airspeed, unreliable airspeed, bank angle).

The failures for alerting hazards such as low airspeed sometimes led to the airplane entering into an approach to stall or full aerodynamic stall situation and a tragic outcome. In these cases, the failure was often tied to the actions of the pilot. The pilot made control actions that run counter to what is recommended for this situation. Training is now being developed and delivered in the U.S. and other parts of the world to address that lack of skill or knowledge.

A significant factor in the current design of alerting systems is that flight path management hazard alerts have evolved in a fragmented or piecemeal fashion, unlike the approach to airplane system failures, which is well-integrated in most airplanes. Recent history has shown that additional alerts are being introduced to the flight deck (e.g., Honeywell's RAAS), and there is a strong need to develop integration schemes to ensure aural and visual alerting fully supports effective alerting-to recovery performance.

The Discussion section ended with a description of which issues are currently being addressed and which issues could benefit from additional resources.

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Appendix A. 14 CFR 25.1322 Text

(a) Flightcrew alerts must:

(1) Provide the flightcrew with the information needed to:

(i) Identify non-normal operation or airplane system conditions, and

(ii) Determine the appropriate actions, if any.

(2) Be readily and easily detectable and intelligible by the flightcrew under all foreseeable operating conditions, including conditions where multiple alerts are provided.

(3) Be removed when the alerting condition no longer exists.

(b) Alerts must conform to the following prioritization hierarchy based on the urgency of flightcrew awareness and response.

(1) Warning: For conditions that require immediate flightcrew awareness and immediate flightcrew response.

(2) Caution: For conditions that require immediate flightcrew awareness and subsequent flightcrew response.

(3) Advisory: For conditions that require flightcrew awareness and may require subsequent flightcrew response.

(c) Warning and caution alerts must:

(1) Be prioritized within each category, when necessary.

(2) Provide timely attention-getting cues through at least two different senses by a combination of aural, visual, or tactile indications.

(3) Permit each occurrence of the attention-getting cues required by paragraph (c)(2) of this section to be acknowledged and suppressed, unless they are required to be continuous.

(d) The alert function must be designed to minimize the effects of false and nuisance alerts. In particular, it must be designed to:

(1) Prevent the presentation of an alert that is inappropriate or unnecessary.

(2) Provide a means to suppress an attention-getting component of an alert caused by a failure of the alerting function that interferes with the flightcrew's ability to safely operate the airplane. This means must not be readily available to the flightcrew so that it could be operated inadvertently or by habitual reflexive action. When an alert is suppressed, there must be a clear and unmistakable annunciation to the flightcrew that the alert has been suppressed.

(e) Visual alert indications must:

(1) Conform to the following color convention:

(i) Red for warning alert indications.

(ii) Amber or yellow for caution alert indications.

(iii) Any color except red or green for advisory alert indications.

(2) Use visual coding techniques, together with other alerting function elements on the flight deck, to distinguish between warning, caution, and advisory alert indications, if they are presented on monochromatic displays that are not capable of conforming to the color convention in paragraph (e)(1) of this section.

(f) Use of the colors red, amber, and yellow on the flight deck for functions other than flightcrew alerting must be limited and must not adversely affect flightcrew alerting.

Appendix B. Accident/Incident Set

	On-board Fatalities	Airplane	Operator/Flight	Boeing	Airbus	Other Jet	Other Prop	Reason Removed
2015								
2/4	43	ATR 72	Transasia 235				x	
3/24	150	A 320-200	Germanwings					Pilot suicide suspected
8/16	54	ATR 42	Trigana Air Service					No final accident report
10/31	224	A 321-200	Metrojet					Terrorism suspected
11/4	41	Antonov 12	Asia Airways					Non-western airplane
2014								
2/21	11	Antonov 26	Libyan Air Cargo					Non-western airplane
3/8	239	B 777	Malaysia					Pilot suicide suspected
5/8	5	Douglas DC-3	ALIANSA Colombia					
7/2	4	Fokker 50	Skyward					
7/17	298	B 777-200	Malaysia					Terrorism suspected
7/23	48	ATR 72	Transasia 222				x	
7/24	116	MD 83	**Swiftair 5017**			x		
8/30	7	Antonov 12	Ukraine Air Alliance					Non-western airplane
8/31	3	Fokker 27	Safari Express Cargo					
12/28	162	A 320-200	**Air Asia 8501**		x			
2013								
1/29	21	Bomb CRJ-200	SCAT					Accident report NOT in English
2/13	5	Antonov 24	South Airlines					Non-western airplane
3/2	7	Fokker 50	CAA					
4/29	7	B 747-400	National Airlines 102	x				
5/24	3	Antonov 25	Valor Air					Non-western airplane
7/6	**3**	**B 777-200**	**Asiana Airlines 214**	**x**				
8/14	2	A 300-600	UPS 1354		x			
9/9	2	Dornier 228	CorpFlite					
10/3	16	Emb 120	Associated Aviation					No final accident report
10/16	49	ATR 72	Lao Airlines					Accident report NOT in English
11/3	5	Swearngn 227	Bearskin Airlines					
11/17	50	B 737-500	**Tatarstan Airlines 363**	x				
11/29	33	Emb 190-100	LAM					Pilot suicide suspected
12/2	2	Swearngn 227	IBC Airways					
12/26	9	Antonov 12	Irkut					Non-western airplane

	On-board Fatalities	Airplane	Operator/Flight	Boeing	Airbus	Other Jet	Other Prop	Reason Removed
2012								
1/30	3	Antonov 28	TRACEP-Congo					Non-western airplane
4/2	33	ATR 72	UT Air 120				x	
4/20	127	B 737-200	**Bhoja Air 213**	x				
5/14	15	Dornier 228	Agni Air					
6/3	153	DC-9/MD-83	Dana Air 992			x		
6/6	2	Swearngn 227	Air Class Lineas Aereas					
6/29	2	Emb 190-100	Tianjian					
7/17	1	Bomb CRJ-200	Skywest					
8/19	32	Antonov 26	Alfa Airlines					Non-western airplane
9/12	10	Antonov 28	Petropavlosk					Non-western airplane
9/28	19	Dornier 228	Sita Air					
10/7	15	Antonov 12	AZZA					Non-western airplane
11/30	7	Ilyushin 76	Air Highnesses					Non-western airplane
12/17	4	Antonov 26	Amazon Sky					Non-western airplane
12/22	1	Swearngn 227	Perimeter					
12/25	1	Fokker 100	Air Bagan					
12/29	5	Tupolev 204	Red Wings					Non-western airplane
2011								
1/1	3	Tupolev 154	Kolavia					Non-western airplane
1/9	77	B 727-200	Iran Air					No final accident report
2/10	6	Swearngn 227	Manx2					
3/5	6	Antonov 148	Varonezh					Non-western airplane
3/21	9	Antonov 12	Trans Air					Non-western airplane
4/4	32	Bomb CRJ-100	Georgian					
5/18	22	Saab 340	SOL					No final accident report
6/20	47	Tupolev 134	RusAir					Non-western airplane
7/6	9	Ilyushin 76	Silk Way					Non-western airplane
7/8	77	B 727-000	Hewa Bora					No final accident report
7/11	7	Antonov 24	Angara					Non-western airplane
7/28	2	B 747-400	Asiana 991	x				
8/9	11	Antonov 12	KnAAPO					Non-western airplane
8/20	12	B 737-200	First Air 6560	x				
9/7	44	Yakovlev 42	YAK Service					Non-western airplane
10/13	28	DHC-8 102	Airlines PNG					

	On-board Fatalities	Airplane	Operator/Flight	Boeing	Airbus	Other Jet	Other Prop	Reason Removed
2010								
1/25	90	B 737-800	**Ethiopian 409**	x				
3/22	2	Emb 120	AirNorth					
4/13	5	A 300-200	Aerounion					No final accident report
4/21	3	Antonov 12	Almaty Aviation					Non-western airplane
5/12	103	A 330-200	**Afriqiyah 771**		x			
5/15	8	Antonov 28	Blue Wing					Non-western airplane
5/17	44	Antonov 24	Pamir					Non-western airplane
5/22	158	B 737-800	Air India Express 812	x				
7/28	152	A 321-200	Airblue 202		x			
8/3	12	Antonov 24	Katekavia					Non-western airplane
8/16	2	B 737-700	Aires 8250	x				
8/24	44	Emb 190	Henan					Accident report NOT in English
8/24	14	Dornier 228	Agni Air					
9/3	2	B 747-400	UPS 6	x				
9/13	17	ATR 42	Conviassa					
11/4	68	ATR 72	Aerocaribbean					No final accident report
11/11	6	Antonov 24	Tarco					Non-western airplane
11/28	8	Ilyushin 76	Sun Way					Non-western airplane
12/4	2	Tupolev 154	Dagestan					Non-western airplane
2009								
1/27	0	ATR 42	***Empire Airlines 8284***				x	
2/12	49	DHC-8 400	**Colgan 3407**				x	
2/20	5	Antonov 12	Aerolift					Non-western airplane
2/25	9	B 737-800	**Turkish 1951**	x				
3/9	11	Ilyushin 76	Aerolift					Non-western airplane
3/23	2	MD 11	FedEx 80			x		
4/9	6	Bae 146	Aviastar			x		
4/29	7	B 737-200	Bako Air					No final accident report
5/26	3	Antonov 26	Services Air					Non-western airplane
6/1	228	A 330-200	**Air France 447**		x			
6/30	152	A 310-300	Yemenia					Accident report NOT in English
7/15	168	Tupolev 154	Caspian					Non-western airplane
7/24	16	Ilyushin 62	Deta Air					Non-western airplane

	On-board Fatalities	Airplane	Operator/Flight	Boeing	Airbus	Other Jet	Other Prop	Reason Removed
2009 (continued)								
8/4	1	ATR 72	Bangkok Airways					
8/26	6	Antonov 12	Aerofret					Non-western airplane
10/17	4	Douglas DC-3	Victoria Air					
10/21	6	B 707-300	AZZA					No final accident report
11/12	1	Bomb CRJ-100	Rwandair					
11/28	3	MD 11	Avient 324			x		
2008								
2/21	46	ATR 42	Santa Barbara Airlines					Accident report NOT in English
4/3	19	Antonov 28	Blue Wing					Non-western airplane
4/9	1	Swearngn 227	Airtex					
4/11	8	Antonov 32	Kata Air					Non-western airplane
4/15	3	DC-9-51	Hewa Bora Airways					No final accident report
5/26	9	Antonov 12	Moskavia					Non-western airplane
5/30	3	A 320-300	TACA International					No final accident report
6/10	30	A 310-300	Sudan Airways 109		x			
6/27	7	Antonov 12	Juba Air					Non-western airplane
6/30	4	Ilyushin 76	Ababeel					Non-western airplane
7/6	1	DC-9-15	USA Jet Airlines					
8/13	3	Fokker 27	Fly 540					
8/20	154	MD 82	Spanair 5022			x		
8/24	65	B 737-200	Itek Air 6895	x				
8/30	3	B 737-200	Conviassa SA					Accident report NOT in English
9/14	88	B 737-500	**Aeroflot-Nord 821**	x				
11/13	7	Antonov 12	British Gulf Int'l					Non-western airplane
11/27	7	A 320-200	**XL Airways 888**		x			
2007								
1/1	102	B737-400	**Adam Air 574**	x				
1/9	34	Antonov 26	Aeriantur					Non-western airplane
3/7	21	B 737-400	Garuda 200	x				
3/17	6	Tupolev 134	UTAir					Non-western airplane
3/23	11	Ilyushin 76	Transavia export					Non-western airplane
5/5	114	B 737-800	**Kenya Airways 507**	x				

	On-board Fatalities	Airplane	Operator/Flight	Boeing	Airbus	Other Jet	Other Prop	Reason Removed
2007 (continued)								
6/25	22	Antonov 24	PMT Air					Non-western airplane
6/28	5	B 737-200	TAAG					No final accident report
7/17	187	A 320-200	TAM Airlines 3054		x			
7/23	1	Antonov 24	Aquiline					Non-western airplane
7/29	7	Antonov 12	ATRAN					Non-western airplane
8/26	14	Antonov 32	GLBC					Non-western airplane
9/7	8	Antonov 12	Transavia Service					Non-western airplane
9/16	90	MD 82	1-2-Go 269			x		
9/23	0	B 737-300	***Thomsonfly***	x				
9/29	7	Antonov 12	KNG Transavia					Non-western airplane
10/4	21	Antonov 26	El Sam Airlift					Non-western airplane
11/30	57	DC-9-83	Atlas Int'nl Airlines					No final accident report
2006								
2/8	1	Swearngn 226	Tricoastal Air					
4/16	1	Fokker 27	TAM					
5/3	113	A 320-200	**Armavia Airlines 967**		x			
7/7	6	Antonov 12	Mango					Non-western airplane
7/9	125	A 310-300	S7 Airlines 778		x			
7/10	45	Fokker 27	PIA					
8/3	17	Antonov 28	TRACEP-Congo					Non-western airplane
8/22	170	Tupolev 154	Pulkovo					Non-western airplane
8/27	49	Bomb CRJ-100	Comair					
9/1	28	Tupolev 154	Iran Air Tours					Non-western airplane
9/29	154	B 737-800	Gol 1907	x				
10/29	96	B 737-200	**ADC 53**	x				
11/18	6	B 727-200	Aerosucre					
2005								
1/8	6	Antonov 12	Services Air					Non-western airplane
2/3	7	Ilyushin 76	Air West					Non-western airplane
2/3	105	B 737-200	Kam Air					No final accident report
3/16	28	Antonov 24	Regional Airlines					Non-western airplane
3/23	8	Ilyushin 76	Airline Transport					Non-western airplane
3/31	3	Antonov 28	Gran Propeller					Non-western airplane
4/20	3	B 707-300	Saha Air					

	On-board Fatalities	Airplane	Operator/Flight	Boeing	Airbus	Other Jet	Other Prop	Reason Removed
2005 (continued)								
5/2	2	Swearngn 227	Airwork NZ					
5/5	10	Antonov 26	Kisangani Airlift					Non-western airplane
5/7	15	Swearngn 227	Aerotropics					
5/12	0	B 717-200	***Midwest Express 490***	x				
5/25	27	Antonov 12	Victoria Air					Non-western airplane
5/27	0	DHC-8-100	***Provincial Airlines***				x	
6/2	7	Antonov 24	Marsland Aviation					Non-western airplane
7/16	60	Antonov 24	Equatorial Express					Non-western airplane
8/6	16	ATR 72	Tuninter					
8/14	121	B 737-300	Helios 522	x				
8/16	160	MD 82	**West Caribbean 708**			x		
8/23	40	B 737-200	TANS-Peru 204	x				
9/5	100	B 737-200	Mandala Airlines 91					Final report not complete
9/5	11	Antonov 26	Galaxy Inc					Non-western airplane
9/9	13	Antonov 26	Air Kasai					Non-western airplane
10/4	2	Antonov 12	Wimbi Dira					Non-western airplane
10/22	117	B 737-200	Bellview Airlines					No final accident report
11/11	8	Ilyushin 76	Royal Airlines Cargo					Non-western airplane
12/10	108	DC-9-32	Sosoliso Airlines 1145			x		
12/23	23	Antonov 140	Azrebaijan Airlines					Non-western airplane
12/23	2	Antonov 28	African Union					Non-western airplane
2004								
1/3	148	B 737-300	**Flash Air 604**	x				
1/13	37	Yakolev 40	Uzbekistan Airlines					Non-western airplane
2/10	43	Fokker 50	Kish Air					
3/4	3	Ilyushin 76	Azov-Avia					Non-western airplane
5/5	5	Swearngn 227	Aerotransporte Petrolero					
5/11	7	Antonov 12	El Magal Aviation					Non-western airplane
5/14	33	Emb 120	Rico Linhas					
5/18	7	Ilyushin 76	Azal Cargo					Non-western airplane
8/24	44	Tupolev 134	Volga-Aviaexpress					Non-western airplane
8/24	46	Tupolev 154	Sibir Airlines					Non-western airplane
10/5	4	Antonov 12	Sarit Airlines					Non-western airplane

	On-board Fatalities	Airplane	Operator/Flight	Boeing	Airbus	Other Jet	Other Prop	Reason Removed
2004 (continued)								
10/14	7	B 747-200	MK Airlines 1602	x				
10/14	2	Bomb CRJ-200	Northwest Airlink					
10/15	3	Douglas DC-3	Aerovanguardia					
11/21	53	Bomb CRJ-200	China Yunnan					Accident report NOT in English
11/30	25	DC-9-82	Lion Air					
12/11	1	Ilyushin 76	Airline Transport					Non-western airplane
2003								
1/8	75	Avro RJ100	Turkish Airlines					Accident report NOT in English
1/9	46	Fokker 28	TANS Airlines					
1/17	7	Antonov 24	Aerocom					Non-western airplane
1/31	6	Ilyushin 76	Euro Asia Aviation					Non-western airplane
2/10	2	Antonov 28	Enimex					Non-western airplane
3/6	102	B 737-200	**Air Algerie 6289**	x				
5/26	75	Yakovlev 42	UM Air					Non-western airplane
6/22	1	Bomb CRJ-100	Brit Air					
7/8	116	B 737-200	Sudan Airways					
7/19	14	Swearngn 226	Ryan Blake Air Charter					
11/17	13	Antonov 12	Sarit Airlines					Non-western airplane
11/29	1	Swearngn 227	Ameriflight					
12/18	3	DC-9-15	LA Sueamericanas					
12/25	141	B 727-200	UTA					
2002								
1/14	3	Emb 120	Ibertrans Aerea					
1/16	1	B 737-300	Garuda					
1/22	0	B 757-200	***Iceland Air 315***	x				
1/28	94	B 727-100	TAME 120					
2/7	8	Antonov 12	Volare					Non-western airplane
2/12	119	Tupolev 154	Iran Air Tours					Non-western airplane
2/15	1	Antonov 12	Tiramavia					Non-western airplane
4/12	2	Swearngn 227	Tadair					
4/15	129	B 767-200	Air China 129	x				
4/19	3	Antonov 32	SELVA Colombia					Non-western airplane
5/4	71	BAC 111	EAS Airlines Nigeria					

	On-board Fatalities	Airplane	Operator/Flight	Boeing	Airbus	Other Jet	Other Prop	Reason Removed
2002 (continued)								
5/7	14	B 737-500	Egyptair 843	x				
5/7	112	DC-9-82	China Northern					Passenger suicide suspected
5/25	225	B 747-200	China Airlines					
6/9	2	Fokker 50	Ethiopian Airlines					
7/1	2	B 757-200	DHL Aviation					
7/1	69	Tupolev 154	Bashkirskie					Non-western airplane
7/1	2	B 757-200	DHL Aviation					
7/4	28	B 707-100	New Gomair					
7/28	14	Ilyushin 86	Pulkovo					Non-western airplane
8/29	16	Antonov 28	Vostok Aviakompania					Non-western airplane
8/30	23	Emb 120	Rico Linhas Aereas					
9/14	2	ATR 42	TOTAL Linhas Aereas					
10/19	0	B 757-200	***Iceland Air 662***	x				
11/6	20	Fokker 50	Luxair					
11/11	19	Fokker 27	Laoag					
12/21	2	ATR 72	TransAsia Airways					
12/23	44	Antonov 140	Aeromist Kharkiv					Non-western airplane
2001								
2000								
8/23	143	A 320-200	**Gulf Air 72**		x			
1999								
12/22	4	B 747-200	**Korean Air 8509**	x				
1998								
3/18	13	Saab 340B	**Formosa B12255**				x	
	8180		TOTAL SELECTED	30	11	9	7	

Appendix C. Results Regarding the Failure Point in the Integrated Alerting-to-Recovery Sequence

This Appendix details the categorization of the *alerting outcome* for each of the hazards that occurred, linked to the 28 events. This accounts only for the flightcrew response to each hazard; it should not be thought of as a full accounting of the cause of the accident. The alerting outcomes for the full set of events is summarized in Table 2 in the report.

For each event, we provide a very brief synopsis of the events around the upset, then a short analysis section describes how hazards were managed. These are from the accident report; not a new analysis. Following these, we list the hazards[16] that occurred in the order in which they occurred. For each hazard, we show how it progressed through the alerting sequence and where the hazard response failed (failure categories are defined in Section 5.2). The failure category is bolded, and there is a short explanation below the failure category. If the hazard was recovered, it is not assigned to a failure category.

Each event also lists all the alerts that occurred during the flight in their order of occurrence; alerts in *red italics* occurred after the upset.

[16] Note that the set of hazards reflect only conditions with the airplane, and not with the pilot; thus, the pilot's state, such as fatigue or spatial disorientation, are not hazards used in this analysis.

12/28/14
Air Asia 8501
Airbus 320-216
162 Fatalities

Synopsis: Due to a nagging fault, flight crew reset 2 circuit breakers (without resetting function), which led to A/P and A/T disengage, and also drop to Alternate Law. Airplane drifted off with roll left. PF got near wings level with inputs but then put in major pitch up inputs, climbing 6000 ft and pulling ip high, leading to full stall. They continued pitch up inputs and never recovered from stall, falling from CRZ.
Analysis: The appropriate stall recovery actions were not trained because it was assumed airplane protections would prevent getting into a stall

Hazards:
1. Approach to Stall → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot actions did not involve nose down and increased thrust

Alerts (in order of occurrence)
- stall warning (came on, went off for a second and then came back on for almost 90 seconds)

7/24/14
Swiftair 5017
MD-83
116 Fatalities

Synopsis: In cruise, the flight crew had apparent ice crystal icing, causing erroneous air data; A/T decreased thrust in response and airspeed decreased. Airplane slowed into a stall; the crew did not respond (in actions) to the SPD LOW alert; they did not react to the STALL warning (they did not disconnect A/P until 25 secs after STALL warning), also they kept in nose-up inputs on the controls, leading to a LOC (there is no CVR so some information is missing regarding flight crew intentions.)
Analysis: The unreliable airspeed hazard was not alerted. Low airspeed alerting was a visual alert (not aural) that was present for 8 seconds before the stick shaker, and there is no evidence that it was detected. For the approach to stall (stick shaker) alert, the appropriate actions were not trained or training did not result in knowing appropriate actions.

Hazards:
1. Unreliable Airspeed → **No Alert**
no alert exists in the airplane for loss of air data

2. Low Airspeed → alert → **Alert Not Detected**
there was no response to low airspeed alerting

3. Approach to Stall → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
Swiftair did not train crew on stall recovery; it was assumed airplane protections would prevent entry into stall

Alerts (in order of occurrence) (Note: no CVR and some of these are from analysis)
- A/T disengage (visual only)
- SPD LOW (visual only)
- stick shaker/stall (continuous)
- altitude (continuous)
- Autopilot disengage (visual only)

11/17/13
Tatarstan 363
Boeing 737-53A
50 Fatalities

Synopsis: Approach to Kazan airport was offset to the right (due to map shift) and high (they saw 4 whites on the PAPI) and unstable, which they discovered late, and they failed to capture the LOC. After they found the PAPI and saw the runway, they decided to do a GA to come back better aligned with the runway. The A/P disengaged for the GA. Initially, as the GA started, there were no significant column inputs for 20 seconds (perhaps he didn't realize A/P was disengaged) and due to the increase in thrust and retraction of flaps the airplane quickly pitched nose up to 25 deg. As they were climbing, they set MCP altitude to 1700 ft. They climbed through it because they set it late (peaked at 2300 ft) and then descended back down to 1700 and started to capture that altitude. As speed decreased on the climb the PF put significant nose down inputs on the column, so that the pitch angle went from 25 deg nose up to level, and then to nose down. Nose down column inputs resulted in 20 deg nose down. Over the last 8 seconds, EGPWS alerts came on before the airplane crashed. Even after the EGPWS alerts started, a third strong nose down input was made and pitch down attitude increased eventually to 75 deg.
Analysis: The TAWS alerting was present for 8 seconds. The pilot's attentional resources were overwhelmed (e.g., channelized attention), preventing detection of the alert. The Capt may have experienced a somatogravic illusion.

Hazards:
1. Ground Prox → alert → **Alert Not Detected**
despite TAWS alerting, pilot continued descending

Alerts (in order of occurrence)
- A/P disconnect (for GA)
- sink rate
- pull up

7/6/13
Asiana 214
Boeing 777-200
3 Fatalities

Synopsis: On approach to SFO, the PF, in an attempt to descend more rapidly (due to being high on approach), selected the pitch mode FLCH. This made the airplane start to climb and increase thrust. The pilot pulled the TLs back to idle, which put the A/T into a HOLD mode. HOLD gives thrust authority to the pilot and will not manage the airspeed. As they were descending below 500 ft, airspeed dropped below Vref. The PF raised the nose to try to maintain the glidepath. They got a low airspeed alert and then stick shaker very close to the ground. An attempt to increase thrust and go around was too late. They crashed just short of the runway.
Analysis: According to the accident report, the low airspeed alert and subsequent stick shaker occurred too late for the flight crew to recover. This is equivalent to a "no alert" situation.

Hazards:
1. Low Airspeed → **No alert**
low airspeed alert occurred too late

2. Approach to Stall → **No alert**
stick shaker alert occurred too late

Alerts (in order of occurrence)
- low airspeed master caution
- stick shaker

4/20/12
Bhoja Air 213
Boeing 737-236A
127 Fatalities

Synopsis: On final approach into Islamabad into heavy weather. On the ILS but airspeed too high and not fully configured. Airspeed slows and airplane pitches up, probably in response to a strong downdraft. They got the windshear alert below 1000 ft (agl); the FO called for a go around, but the Capt took no action. The A/P disengaged but not the A/T and there were no manual inputs on the controls for 6 seconds. The airplane got below the glideslope; they got whoop whoop pull up. They suffered another strong downdraft followed by a second set of Pull up alerts. While the Capt made some nose up inputs they were insufficient to prevent further descent. The downdraft stopped and the airplane, in response, pitched up. Capt inputs were then nose down but he made no changes to thrust. They continued descending until crashing.
Analysis: For these hazards, the Capt generally performed the appropriate actions but did not perform them adequately to prevent the airplane upset.

Hazards:

1. Windshear	→	alert	→	alert detected	→	alert understood	→	**Crew Selected Wrong Actions** Capt did not take action in response to windshear		
2. Approach to stall	→	alert	→	alert detected	→	alert understood	→	crew selected right actions	→	**Inadequate Performance** Capt needed additional thrust to manage the stall
3. Ground Prox	→	alert	→	alert detected	→	alert understood	→	crew selected right actions	→	**Inadequate Performance** Capt's actions did not stop descent

Alerts (in order of occurrence)
- A/P disengage (but then re-engaged A/P)
- Windshear
- A/P disengage again
- Whoop Pull up (on 2 occasions)
- stick shaker
- GPWS

5/12/10
Afriqiyah 771
Airbus 330-202
103 Fatalities

Synopsis: On approach to Tripoli; got a TAWS and started the GA. Not long after initiating the GA, the Capt (PF) transitioned to nose down attitude and continued until airplane crashed; likely a result of a somatogravic illusion.
Analysis: The TAWS alerting was present for 7 seconds. The pilot's attentional resources were overwhelmed (e.g., channelized attention), preventing detection of the alert. The Capt may have experienced a somatogravic illusion.

Hazards:
1. Ground Prox → alert → **Alert Not Detected**
despite TAWS alerting, pilot continued descending

Alerts (in order of occurrence)
- Too low, terrain (before GA)
- Don't Sink (After GA initiated)
- Too low, terrain
- Pull up, pull up

1/25/10
Ethiopian 409
Boeing 737-8AS
90 Fatalities

Synopsis: Shortly after TO from Beirut. The airplane, which was trimmed nose up, began to slow down and pitch up. The pilots did not detect this until stick shaker came on; it stayed on for 27 seconds.
Analysis: The low airspeed alert was visual only and it prompted no flightcrew actions. The pilot poorly managed the upset, leading to a stick shaker. The flightcrew response used inappropriate control actions; specifically not pitching down, never really recovering the initial and then losing control.

Hazards:
1. Low Airspeed → alert → **Alert Not Detected**
there was no response to low airspeed alerting

2. Approach to Stall → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot actions did not involve nose down and increased thrust

Alerts (in order of occurrence)
- Bank angle (several times, early in flight)
- Visual indications of low airspeed on speed tape
- Stick Shaker (several times)
- Bank Angle (several times)
- *Overspeed Clacker*

6/1/09
Air France 447
Airbus 330-203
228 Fatalities

Synopsis: During cruise, icing of air data probes led to erroneous airspeed. Initially, airplane dropped into alternate law and loss of A/P and A/T. The crew identified loss of speed displays and took manual control, getting wings level and pitching up to 11 deg. After comments from PM, PF made a few stick-forward (nose down) inputs but these were not sufficient to stop climbing. Valid airspeed indication returned on Capt's PFD. Thrust was reduced, airplane went into stall. Thrust was then positioned in the TO/GA detent and the PF made nose up inputs. Eventually climbed to FL380. Pitch attitude was 16 deg. Eventually, got valid airspeed on all 3 sources. Also, later correct actions on flight controls (pitching down) led to reoccurrence of the stall warning so they maintained a pitch up attitude.
Analysis: For the initial hazard, the flight crew knew they had airspeed issues but did not refer to the unreliable airspeed checklist. For the approach to stall alert, the pilot did not seem to understand what was happening to the airplane.

Hazards:
1. Unreliable Airspeed → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot performed actions different from those trained or in operational guidance

2. Approach to Stall → alert → alert detected → **Alert Not Understood**
pilot was not sufficiently trained to understand alert

Alerts (in order of occurrence)
- ECAM Messages (these were all generated from the unreliable airspeed): AUTO FLP AP OFF, NAV ADR DISAGREE-AIR SPD…X CHECK, ENG THRUST LOCKED,
  AUTO FLT A/THR OFF, F/CTL ALTN LAW, etc.…
- Stall warning
- *eventually, SINK RATE and PULL UP*

2/25/09
Turkish 1951
Boeing 737-8F2
9 Fatalities

Synopsis: Approach with failed radio altimeter in IMC, leading to change in A/T mode and loss of speed control. They knew the radio altimeter was failed. Crew gets very busy on approach and does not attend to airspeed, which gets low. They get stick shaker at around 500-600 ft (agl). Also, Capt tries to take controls from FO after stick shaker starts.
Analysis: The low airspeed alerting (visual only) was flashing for 10 seconds, and it prompted no flightcrew actions. In the response to the stall, the FO had moved the thrust levers forward appropriately but the A/T was still engaged and brought the thrust levers back to idle (the correct setting for approach and flare).

Hazards:
1. Low Airspeed → alert → **Alert Not Detected**
there was no response to low airspeed alerting

2. Approach to Stall → alert → alert detected → alert understood → crew selected right actions → **Inadequate Performance**
autothrottle was engaged and returned throttles to idle

Alerts (in order of occurrence)
- Airspeed box on speed tape flashing and turning amber
- Stick Shaker
- *EGPWS "Sink Rate and Pull up"*

2/12/09
Colgan 3407
DHC-8-402
49 Fatalities

Synopsis: The flight crew made an input (for icing) that increased the airplane's "approach to stall warning" speed and then used a speed 20 kts lower as their target speed; they then slowed to the stick shaker speed when they weren't paying attention to the airspeed indication, then flew into an actual stall.
Analysis: There was no alert for low airspeed; when the stick shaker occurred the pilot performed actions different from those trained or in the operational guidance.

Hazards:
1. Low Airspeed → **No alert**
no alert exists in the airplane for low airspeed

2. Approach to Stall → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot actions did not involve nose down and increased thrust

Alerts (in order of occurrence)
- Stick Shaker
- Stick Pusher

1/27/09
Empire Airlines 8284
ATR 42-320
0 Fatalities

Synopsis: Initially, there was an unrecognized flap asymmetry due to icing. Captain had taken over the controls from the FO after a stick shaker and A/P disengage. The FO was unable to manage the controls; the airplane was hard to handle due to the flap asymmetry. The airplane slowed down, got to stick shaker and GPWS pull up warnings. The Capt reduced power instead of increasing power per procedure. Then, later pulled back on column leading to another stick shaker, leading to the loss of control.
Analysis: There was no alert for flap asymmetry or low airspeed; for the approach to stall, the pilot performed actions different from those trained or in operational guidance.

Hazards:
1. Flap Asymmetry → **No alert**
no alert exists in the airplane for flap asymmetry

2. Low Airspeed → **No alert**
no alert exists in the airplane for low airspeed

3. Approach to Stall → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot actions did not involve nose down and increased thrust

Alerts (in order of occurrence)
- aural stall (cricket) and Stick Shaker (3 times)
- *EGPWS "Pull up, pull up"*
- *Stick Shaker 1 more time*

11/27/08
XL Airways 888
Airbus 320-232
7 Fatalities

Synopsis: Airspeed was allowed to go very low (99 kts); crew was trying to slow to alpha floor (for testing) but due to frozen AoA vanes, alpha floor was not at the right place on speed tape; airplane pitched up to try to manage the lower airspeed and pilot was unable to overcome pitch because he didn't transition to manual trim.
Analysis: The only "alert" for unreliable airspeed was the visual-only CHECK GW (gross weight) message, which was probably present for several minutes; there was no low airspeed alert; finally, for the approach to stall hazard, the flight crew did not understand they needed manual trim to reduce pitch.

Hazards:

1. Unreliable Airspeed → alert → **Alert Not Detected**
there was no response to the CHECK GW message

2. Low Airspeed → **No alert**
an AoA alert existed but failed to perform due to frozen AoA sensors

3. Approach to Stall → alert → alert detected → alert understood → crew selected right actions → **Inadequate Performance**
pilot didn't use manual trim to reduce pitch

Alerts (in order of occurrence)
- CHECK GW (on MCDU)
- Stall warning
- Direct Law Master Caution
- USE MAN PITCH TRIM message
- Stall warning
- *EGPWS TERRAIN Warning*

9/14/08
Aeroflot-Nord 821
Boeing 737-505
88 Fatalities

Synopsis: The A/T disengaged due to the A/P's inability to use control surfaces to manage thrust. The A/P was compensating for this situation initially but was having trouble managing it. The A/P was disconnected and the PF could not manage the roll left. The airplane was flown into a compromised state because the throttles, although together, were producing different thrust on the 2 engines. The FO handed the controls to the Capt (clumsily) who also could not maintain control. He rolled the airplane further left. The bank angle exceedance alert did not aid their control.
Analysis: There is no alert for asymmetric thrust; the pilot made rolling inputs in the wrong direction (different from those trained or in operational guidance).

Hazards:
1. Asymmetric Thrust → **No alert**
no alert exists in the airplane for thrust asymmetry

2. Bank Angle → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot actions rolled wrong direction

Alerts (in order of occurrence)
- A/T WARN activation and A/T switch to OFF
- A/P disconnect warning
- 12 second aural alert for incorrect approach setup
- Bank Angle aural alerts

9/23/07
Thomsonfly
Boeing 737-3Q8
0 Fatalities

Synopsis: The A/T disconnects during approach and is undetected; airspeed bleeds off to stick shaker, go around is initiated but airplane is trimmed such that pilots don't have enough authority to bring the nose down (they tried to trim) and the airplane pitches up to stick shaker/stall but is recovered.
Analysis: The A/T disengage alert was visual only and was not distinctive (it was similar to the alert for a less-important condition). This alert was present for 55 seconds prior to the stick shaker. There was no alert for low airspeed. Although the pilot struggled, he recovered the approach to stall condition.

Hazards:
1. A/T Disengage → alert → **Alert Not Detected**
there was no response to the A/T disengage alert

2. Low Airspeed → **No alert**
no alert exists in the airplane for low airspeed

3. Approach to Stall → alert → alert detected → alert understood → crew selected right actions → performed adequately

Alerts (in order of occurrence)
- A/T Disconnect (visual only)
- Stick Shaker
- A/P disengage
- stick shaker

5/5/07
Kenya Airways 507
Boeing 737-8AL
114 Fatalities

Synopsis: The A/P was not engaged. The airplane rolled off until bank angle alert. The PF continued rolling in the same direction, away from wings level.
Analysis: The hypothesis put forward is that the A/P switch was pushed but due to force on the wheel, it failed to engage and therefore, there was no A/P disengage alert for this situation, as there is in other airplanes; after the roll off, the pilot performed actions different from those trained or in operational guidance.

Hazards:
1. Autopilot Disengage (failed to engage) → **No alert**
an A/P disengage alert existed but failed to perform

2. Bank Angle → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot action rolled wrong direction

Alerts (in order of occurrence)
- Bank angle aural and sky pointer turns amber

1/1/07
Adam Air 574
Boeing 737-4Q8
102 Fatalities

Synopsis: FL 350, IFR. Failure in IRS system. The crew did not realize that selecting the IRS to "Attitude" (initially in NAV) disengages the A/P, which initiated a roll since the airplane was not trimmed. And, the pilots rendered PF's EADI inoperative due to their response to the IRS malfunction. Different from other bank angle situations because pilots did not actively roll in wrong direction initially, and alert did not cause the crew to pull their attention away from IRS anomalies initially. (pg 42/98). Pilot eventually made inputs in wrong direction and also pulling back on column. Crew ended up breaking up aircraft due to too high load factor.
Analysis: It is believed that the pilots were initially distracted by the IRS problem and then spatially disoriented from the initial slow roll off at night; they performed actions different from those trained or in operational guidance.

Hazards:
1. Bank Angle → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot initially failed to respond then rolled wrong direction

Alerts (in order of occurrence)
- Autopilot Disengaged Aural Warning
- Bank Angle Alert
- *Altitude Deviation Alert*
- *Overspeed Warning*

10/29/06
ADC 53
Boeing 737-2B7
96 Fatalities

Synopsis: The airplane took off in bad weather with gusty winds. Shortly after TO, the airplane experienced a windshear. The Capt (PF) pitched up too high (35 deg) and got into an aerodynamic stall, then crashing.
Analysis: Initially, the pilot put in insufficient power to manage the windshear; for the approach to stall, the pilot performed actions different from those trained or in operational guidance.

Hazards:
1. Windshear → alert → alert detected → alert understood → crew selected right actions → **Inadequate Performance**
pilot failed to add enough power for complete recovery

2. Approach to stall → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot actions did not involve nose down and increased thrust

Alerts (in order of occurrence)
- Windshear
- stick shaker
- *Terrain, terrain, pull up*

5/3/06
Armavia Airlines 967
Airbus 320-211
113 Fatalities

Synopsis: On approach to Sochi, IFR conditions, clouds at 300 ft. Due to a change in conditions, controller asked for go around. The pilots initiated a climb and the A/P gave them a high climb rate, which made airspeed drop. The flightcrew pitched nose down, perhaps to regain speed. Also input a right roll. Bank angle increased and then nose down inputs continued. EGPWS alerts did not change pilot inputs.
Analysis: The TAWS alerting was present for 16 seconds and prompted no actions. The pilot's attentional resources were overwhelmed (e.g., channelized attention), preventing detection of the alert. The Capt may have experienced a somatogravic illusion.

Hazards:
1. Low Airspeed → alert → alert detected → alert understood → crew selected right actions → performed adequately

2. Ground Prox → alert → **Alert Not Detected**
despite TAWS alerting, pilot continued descending

Alerts (in order of occurrence)
- Low Energy Warning
- VFE Overspeed
- Master Warning with aural (continued until end of flight)
- EGPWS "whoop whoop pull up pull up" (continued until end of flight)

8/16/05
West Caribbean 708
MD-82
160 Fatalities

Synopsis: Due to high airplane weight and use of anti-ice, which reduced engine power, they were unable to maintain altitude when trying to fly over a storm; engines could not maintain altitude. They slowed down and pitched up into a stall. They did not pitch down and they started to fall from FL 310.
Analysis: PF believed that the airplane had a dual engine failure, and they were trying to diagnose the engine problem. He did not understand that he needed to pitch down to exit stall.

Hazards:
1. Low Airspeed → **No alert**
no alert exists in the airplane for low airspeed

2. Approach to Stall → alert → alert detected → **Alert Not Understood**
pilot stated to ATC that he had a dual engine failure even though stall alert occurred

Alerts (in order of occurrence)
- Altitude alert (below MCP target altitude)
- Stick Shaker (constant through end of flight; more than 2 min)
- Stall aural and visual (constant through end of flight; more than 2 min)
- *GPWS: terrain; sink rate; whoop, whoop, pull up, pull up (constant through end of flight; about 10 secs)*

5/27/05
Provincial Airlines
DHC-8-100
0 Fatalities

Synopsis: During initial climb, they used a vertical speed (VS) mode, instead of an IAS mode that would protect airspeed. Airplane slowed down into stall during climb. They badly managed the stall. Lost 4200 ft of altitude but did not crash.
Analysis: There was no low airspeed alert; for the approach to stall, the pilot performed actions different from those trained or in operational guidance.

Hazards:
1. Low Airspeed → **No alert**
no alert exists in the airplane for low airspeed

2. Approach to Stall → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot made no increase in thrust and brought the column aft for 22 seconds

Alerts (in order of occurrence)
- Stick Shaker
- Autopilot disengage

5/12/05
Midwest Express 490
Boeing 717-200
0 Fatalities

Synopsis: Pitot icing in marginal weather conditions led to unreliable airspeed. Pilots chased airspeed indications, resulting in several uncontrolled descents and climbs. Initially, the FO got on the controls and pushed the nose down in response to the (erroneous) decreasing airspeed. Then, both pilots on controls, not communicating, led to 5 major dives and climbs, eventually being recovered for safe landing.
Analysis: The alerting scheme in this airplane does not directly state unreliable airspeed and the crew have to identify the situation on their own; in post-event interviews, the pilots both said they thought that they were experiencing heavy weather and were fighting turbulence.

Hazards:
1. Unreliable Airspeed → alert → alert detected → **Alert Not Understood**
the alert messages did not directly state unreliable airspeed and crew stated a different interpretation

Alerts (in order of occurrence)
- CONFIG cue switch with master caution
- RUDDER LIM FAIL
- autopilot disconnect
- *Overspeed Clacker*
- *Control column disconnect*

1/3/04
Flash Air 604
Boeing 737-3Q8
148 Fatalities

Synopsis: During initial climb, there was an unexpected change to the A/P and the Capt (PF) became distracted. In that distracted period, he rolled right about 40 deg. He realized that he had rolled away from wings level (due to callout from FO). His response to the roll off was inappropriate, leading to a LOC and crash.
Analysis: There was no alert for bank angle, but the FO made the Capt aware that he was rolling in the wrong direction. However, Capt seemed confused or spatially disoriented and he rolled in the wrong direction.

Hazards:
1. Bank Angle → No alert → alert detected → alert understood → **Crew Selected Wrong Actions**
no alert exists for bank angle
[but crew member made Capt. aware of hazard]
roll inputs were overwhelmingly in the wrong direction

Alerts (in order of occurrence)
- A/P Disengaged Aural Warning and light
- Overspeed Warning
- Ground proximity warning

3/6/03
Air Algerie 6289
Boeing 737-2T4
102 Fatalities

Synopsis: An engine failed just after rotation on take-off; the PF tried to maintain a normal high rate of climb, which led to loss of airspeed, which was unalerted. Also, they were low, heavy, and they failed to retract the gear, which made maintaining airspeed more difficult. Got into a stall and crashed.
Analysis: This airplane did not have an alert for either engine fail or low airspeed; at approach to stall, the pilot performed actions different from those trained or in operational guidance.

Hazards:
1. Engine Fail → **No alert**
no alert exists in the airplane for engine loss

2. Low Airspeed → **No alert**
no alert exists in the airplane for low airspeed

3. Approach to Stall → alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot tried to maintain TO pitch/climb instead of airspeed; also did not retract gear

Alerts (in order of occurrence)
- Stick Shaker
- GPWS "Don't Sink"

10/19/02
Iceland Air 662
Boeing 757-200
0 Fatalities

Synopsis: Climb during cruise (FL330-FL370). The crew was aware that there were discrepancies in airspeed: the Capt's indication was frequently different from that of the FO and the standby, which were in agreement. They attempted to select the correct air data inputs but failed to configure it to remove bad input. The EICAS messages didn't direct the crew to the UNREL AIRSP checklist and they didn't run the AIRSPEED UNRELIABLE checklist. They got into stall, lost 7,000 ft of altitude but recovered. Boeing Service Bulletin 757-34A0222 had not been applied, but was released to all 757 fleet.
Analysis: The crew seemed to be confused about how to configure the air data system and eventually got into a stall; the pilot performed actions different from those trained or in operational guidance.

Hazards:

1. Unreliable Airspeed→ alert → alert detected → alert understood → **Crew Selected Wrong Actions**
the crew knew they had airspeed issues but did not use unrel airsp checklist

2. Approach to Stall→ alert → alert detected → alert understood → **Crew Selected Wrong Actions**
pilot actions did not involve nose down and increased thrust

Alerts (in order of occurrence)
- RUDDER RATIO EICAS
- MACH/SPD TRIM EICAS
- ELEV ASYM (status) (these first 3 on 3 occasions during climb)
- OVERSPEED - clacker and message (but this is erroneous)
- Stick Shaker

1/22/02
Iceland Air 315
Boeing 757-208
0 Fatalities

Synopsis: On approach, IMC; strong tailwind puts airplane above glidepath; PF elects to do go around; after acceleration, the PF makes nose down column inputs; GPWS aural warning occurs; copilot yells "Pull-up" and helps pilot recover around 350 feet agl.
Analysis: The TAWS alerting was present for 8 seconds and prompted no actions. The FO also spoke out forcefully, eventually getting a response from the PF. The pilot's attentional resources were overwhelmed (e.g., channelized attention), preventing detection of the alert. The Capt may have experienced a somatogravic illusion.

Hazards:

1. Ground Prox → alert → **Alert Not Detected**
despite TAWS alerting, pilot continued descending but was saved by actions of PM

Alerts (in order of occurrence)
- GPWS Aural: pull up, pull up
- GPWS: terrain, too low, terrain

8/23/00
Gulf Air 72
Airbus 320-212
143 Fatalities

<u>Synopsis:</u> Night approach; too fast, not configured; Capt decided to fly a 360 orbit instead of performing a GA; sloppy execution of orbit; missed extended runway centerline so he attempted a GA; pitched down; despite GPWS warnings flew into water.
<u>Analysis:</u> The TAWS alerting was present for 11 seconds and prompted no actions. The pilot's attentional resources were overwhelmed (e.g., channelized attention), preventing detection of the alert. The Capt may have experienced a somatogravic illusion.

<u>Hazards:</u>
1. Ground Prox → alert → **Alert Not Detected**
despite TAWS alerting, pilot continued descending

<u>Alerts (in order of occurrence)</u>
- Flap Overspeed Warning ECAM Master Warning OVERSPEED
- VFE
- GPWS warning - "sink rate" once, then "whoop, whoop pull-up.." from GPWS every second for nine seconds.

12/22/99
Korean Air 8509
Boeing 747-2B5F
4 Fatalities

<u>Synopsis:</u> Taking off, ADI malfunctioned and Capt's ADI didn't indicate roll attitude, Capt commanded long slow roll after takeoff, leading to a significant bank exceedance; FE called out bank but was unheeded. Comparator alert occurred but was turned off and unheeded. Descended from a low altitude, cloudy night with no ground references.
<u>Analysis:</u> The ADI "gyro" flag (for the malfunction) was assumed to be out of view from captain (did not come out); the comparator aural was ignored. The Capt probably didn't realize the extent of his roll.

<u>Hazards:</u>
1. Failed instrument (ADI) → alert → alert detected → **Alert Not Understood**
comparator alert (visual & aural) was silenced by flightcrew, and Capt (PF) continued to use a bad indication

2. Bank Angle → **No alert**
no alert exists in the airplane for bank angle [but crew member made Capt aware]

<u>Alerts (in order of occurrence)</u>
- The Attitude Comparator aural alert sounded at 16.7 secs after TO and was active for 2 brief periods; then at 32.7 secs after TO and remained on for nine consecutive times; it was shut off by the flightcrew during the tenth.
- Flashing red INST WARN comparator light (warning level) and a steady amber ATT light above each ADI (may have been illuminated for 22 secs or cancelled more than once)
- Also, verbal comments from the FE about bank (4 remarks)

3/18/98
Formosa B12255
Saab 340B
13 Fatalities

Synopsis: Significant maintenance issues discovered during pre-flight, including loss of A/P. Airplane should not have dispatched. After TO, there were multiple system failures. Failures led to an asymmetric thrust, causing the airplane to yaw and roll, which led to an overbank. Flight was at night in poor visibility. PF was unable to manage the airplane, rolled off and crashed. Late inputs from the pilot were in the wrong direction.
Analysis: The pilot was probably unaware of the hazards that he was trying to manage.

Hazard:
1. Asymmetric Thrust → No alert

2. Bank Angle → No alert
no alert exists in the airplane for bank angle (or for the asymmetrical force)

Alerts (in order of occurrence)
- *Overspeed*