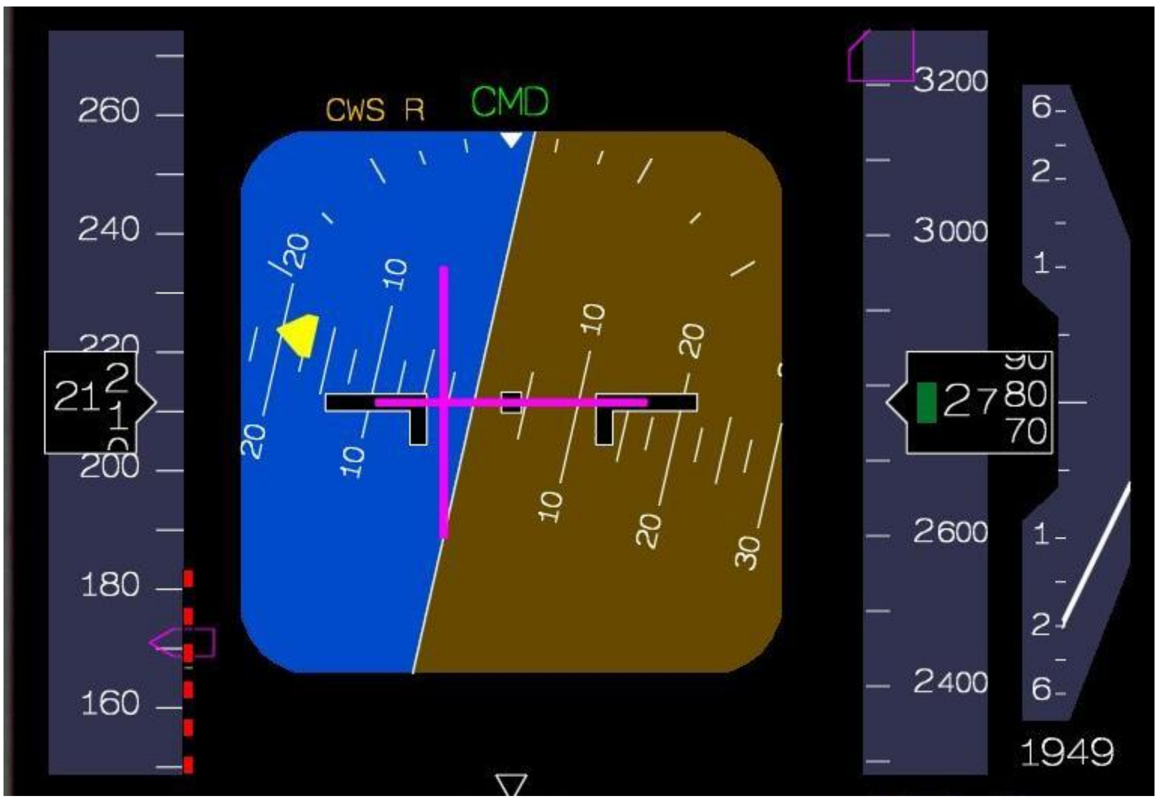
# Airplane State Awareness Joint Safety Analysis Team




## Final Report
## Analysis and Results

## June 17, 2014

# Airplane State Awareness Joint Safety Analysis Team Interim Report

Provided to the Commercial Aviation Safety Team

*from*

The Airplane State Awareness Joint Safety Analysis Team

June 17, 2014

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# BACKGROUND

Loss of Control–Inflight (LOC–I)[1] is, and has historically been, one of the largest categories of commercial aviation fatal accidents. In August 2010, the Commercial Aviation Safety Team (CAST) chartered the Airplane State Awareness (ASA) Joint Safety Analysis Team (JSAT) as a follow-on activity to previous CAST work done by the LOC JSAT in 2000. The primary purpose of the ASA JSAT was to analyze a subset of LOC–I accidents and incidents in which the flightcrew lost awareness of their airplane's state, defined as:

- Attitude (pitch or bank angle or rate), or
- Energy (the combination of airspeed, altitude, vertical speed, thrust, and airplane configuration)

A review of worldwide transport airplane accidents over the past 10 years reveals that more than half of all LOC–I accidents[2] and resulting fatalities involved flightcrew loss of ASA. In figure 1, the impact of lost ASA is shown in the context of worldwide jet transport fatal accidents over the last 10 years, where it was specifically cited in the respective accident reports.

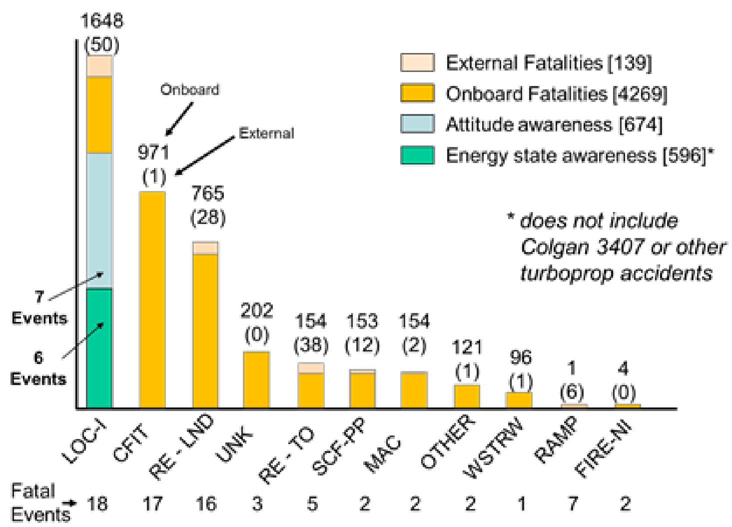


*Figure 1. Worldwide Jet Transport Fatal Accidents, 2001–2010*[3]

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[1] LOC-I is defined for this study per the guidance in the "Aviation Occurrence Categories – Definition and Usage Notes," version 4.2, CAST-ICAO Common Taxonomy Team (CICTT), published November 2011.

[2] Two events referenced in this study, at Bahrain in August 2000 and at Sochi, Russia in May 2006, were classified by the original investigating authorities as Controlled Flight into Terrain. However, CAST assigned these events to the principal category of LOC-I using CICTT guidelines. As the ASA JSAT is a CAST-sponsored activity, the CAST principal event classification is used for these events.

[3] *Boeing Statistical Summary of Commercial Worldwide Jet Transport Accidents*, 2011. Includes only accidents involving turbofan or turbojet airplanes with max takeoff weight > 60,000 lbs.

The ASA JSAT was co-chaired by representatives from industry and government and staffed with subject matter experts from airplane manufacturers and suppliers, pilot unions, airline management, research organizations, data mining organizations, and government aviation safety departments and agencies. Two Analysis Teams studied the events, identified problems and major themes, and developed intervention strategies, which are contained in this report. A third team, the Data Team, complemented the work of the Analysis Teams by undertaking efforts to assess the presence, frequency, and characteristics of ASA precursors in U.S. part 121 operations, based on information available in the Aviation Safety Information Analysis and Sharing (ASIAS) databases. Finally, a Process Control Team (PCT), made up of the ASA JSAT co-chairs and two other team members with significant experience in JSAT activities, provided process monitoring and cross-checking to ensure consistency and compliance with the JSAT process.

The ASA Joint Safety Implementation Team (JSIT), chartered by CAST on December 1, 2011, will study the feasibility of implementing the interventions identified by the ASA JSAT.

# EVENTS

The ASA JSAT studied 18 events. Nine involved loss of attitude awareness and nine involved loss of energy state awareness, as summarized in figure 2.

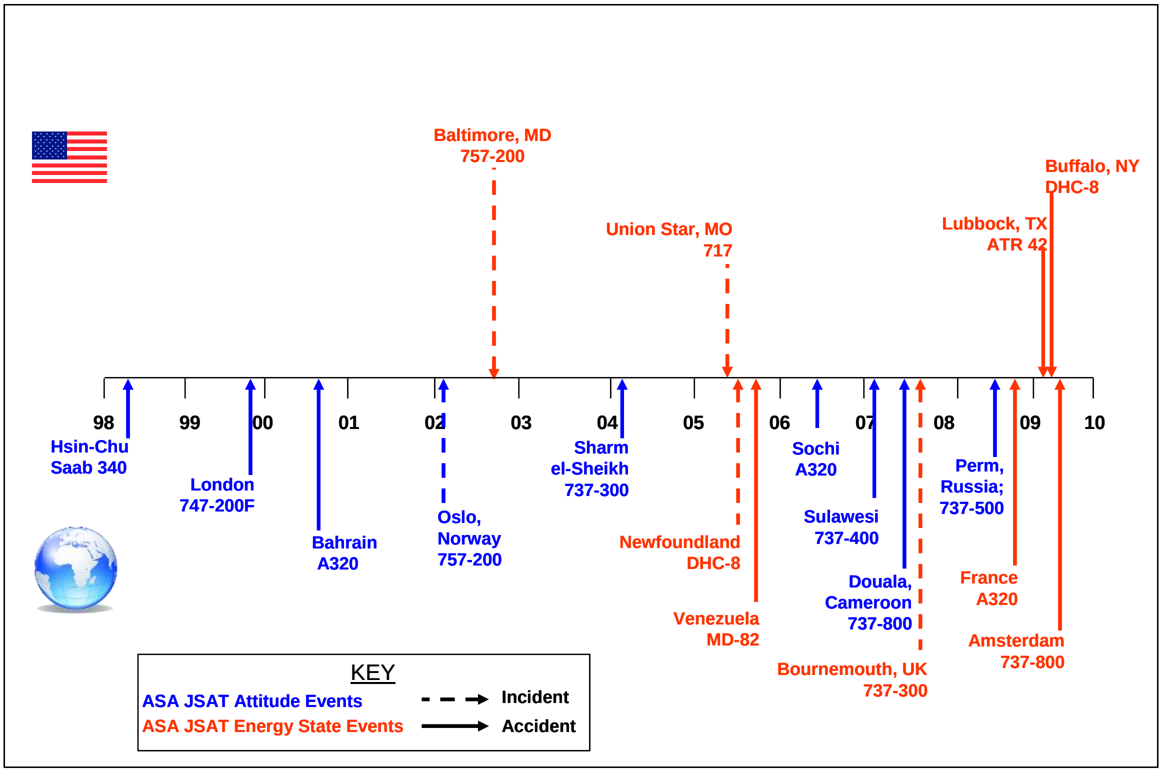


*Figure 2. ASA JSAT Event Dataset*

The events were divided evenly between the two Analysis teams. One Analysis Team focused primarily on attitude awareness events and the other focused primarily on energy state awareness events; however, each Analysis Team also worked two events from the other category to promote consistency and to broaden the expertise brought to the review of both types of event. In the course of the work, the Analysis Teams identified 161 standard problem statements[4] (SPS) based on evaluations of the accident event sequences, of which 117 were common with SPSs identified by previous JSATs and 44 were newly developed by the ASA JSAT. The Analysis Teams then identified a total of 274 intervention strategies (IS) to address these problems, of which 181 had been documented by previous JSATs, and 93 were newly developed by the ASA JSAT.

[4] See the CAST "JSAT Process Handbook," Revision D, July 2, 2007 for details on the development and usage of standard problem statements and intervention strategies.

# THEMES

The ASA JSAT also identified 12 major themes that appeared across a multitude of the events in the ASA dataset, and which may be representative of common issues present in similar events (for example, automation awareness is the focus of a related effort, the Performance Based Operations Aviation Rulemaking Committee (PARC)/CAST Flightdeck Automation Working Group). These themes represent notable correlations only and do not necessarily imply causation. The ASA JSAT did not assign a ranking to these themes, and notes that higher frequency of occurrence (that is, appearance in more events) should not necessarily imply greater importance. The themes are listed here in the order in which they were identified during the study.

**Lack of External Visual References.** In 17 of the 18 events, the event airplane was flying at night, in instrument meteorological conditions (IMC), or in a combination of night and IMC, sometimes at high altitude or over dark land or water. Thus the crew had to rely on their instrumentation to establish and maintain orientation.

**Flightcrew Impairment.** In 7 of the 18 events, at least one member of the flightcrew was affected by fatigue, illness, or alcohol consumption, and in some cases by a combination of factors.

**Training.** In 9 of the 18 events, flightcrew training played a role. In some cases, the crew had not received training that is generally considered industry standard and is widely available. In other cases, the training had taken place but was not recalled properly, or else did not address the scenario encountered. In a few instances, the JSAT felt the crew had received training that was counterproductive or negative.

**Airplane Maintenance.** In 6 of the 18 events, airplane maintenance was an issue. In some cases, maintenance was not performed in a timely manner, allowing problems to persist until they became factors in the accident chain. In other cases, maintenance was performed, but it did not directly address the actual problem, or was performed on the wrong system. Maintenance procedures were not followed appropriately.

**Safety Culture.** Safety culture played a role in 12 of the 18 events. In some cases, the operator had a poor safety record, extending back for months or years. Many of the flights operated with compromised safety barriers, such as with less than fully-functioning systems or with a poorly-defined flight plan. In several events, the coordination and interaction with the air traffic service (ATS) provider, both in flight planning and during the flight, was poor. Schedule pressure was prevalent, resulting in crews pressing on with flights or activities despite warning signals that the situation was deteriorating. Crew pairing, particularly the pairing of pilots with low time in type, was also an issue.

**Invalid Source Data.** In 5 of the 18 events, invalid source data from the air data system sensors or probes, inertial or rate gyro systems, angle-of-attack (AOA) vanes or sensors, or other signals were used as input to primary flight displays, the autoflight system, or the navigation systems with little or no indication the data were invalid.

**Distraction.** Distraction played a role in all 18 events, and manifested itself primarily in two ways. In the first instance, a flightcrew would make a decision based on faulty information or incorrect reasoning (sometimes when task-saturated) and would be distracted by actions or thought processes associated with that decision and would no longer aviate. In the second instance, the flightcrew would become focused on one instrument or one response to the exclusion of all other relevant inputs, comments, or alerts, and would in essence "tune out" any information that may have led them to fully understand the problem they faced.

**Systems Knowledge.** In 7 of the 18 events, the flightcrew lacked understanding as to how major aircraft subsystems (for example, autoflight, air data measurement, navigation, inertial systems) interact, and how information from one system influences another.

**Crew Resource Management (CRM).** In 16 of 18 events, CRM was not effectively practiced. Specifically, flightcrews failed to communicate effectively or work together to understand and resolve problems or confusion. In a number of events, the pilot monitoring (PM) failed to properly perform the monitoring function. Crews also failed in some instances to manage their workload properly. In a few events, an authority gradient between the captain and first officer (FO) likely played a role in preventing the FO from taking control of the airplane from the captain, even when the captain was clearly confused, spatially disoriented, distracted, or otherwise unaware of airplane state.

**Automation Confusion/Awareness.** In 14 of the 18 events, the flightcrew was either confused about the state (on/off) or mode of the autoflight system, or else was unaware of trim or control inputs made by the autoflight system.

**Ineffective Alerting.** In all 18 events, alerting was an issue. The term "ineffective" is meant to convey only that the alert, for any number of potential reasons, did not have its intended effect; that is, it did not result in a level of flightcrew awareness of a problem that changed the crew's course of action in the intended manner. In some cases, alerting was simply not provided on the flightdeck for events where an alert would be warranted. In other cases, alerting took place but was unclear, poorly timed, or lacked appropriate salience (multi-sensory, appropriate level).

**Inappropriate Control Inputs.** In 12 of the 18 events, the flightcrew responded to hazardous airplane states and conditions with control inputs that were opposite to what was necessary to recover the airplane. The term "inappropriate" is intended to convey only that the control inputs were not correct for the purpose of recovering the airplane, and should not be construed to automatically imply "pilot error."

Table 1 presents an overview of the relationship between the 18 ASA JSAT events and the 12 identified themes.

*Table 1. Occurrence of Themes in ASA JSAT Dataset Events*

| Summary of Significant Themes Across All Events | 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 |
| **Icelandair 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 737-300** | 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 | |

# INTERVENTIONS

As previously noted, the ASA JSAT identified 274 intervention strategies to mitigate the standard problems observed in the 18 ASA JSAT events. These ISs were grouped into the following categories, based on how, and by whom, they would be implemented.

**Aircraft Design.** Interventions calling for action on the part of airplane manufacturers or suppliers related to design of current and future airplanes. The highest-rated ISs related to aircraft design fall into these general areas:

- Flight envelope protection,
- Improved alerting,
- Flight path/control guidance on displays,
- Source data integrity,
- "Day-visual meteorological conditions" equivalent display systems,
- Automation design, and
- Energy state management display/prediction systems.

**Flightcrew Training.** Interventions calling for re-emphasis of or changes to current flightcrew training curricula or standards, as well as for additional training and for improved simulator fidelity as needed to support such training. The highest-rated ISs related to flightcrew training fall into these general areas:

- Revised approach-to-stall training;
- Expanded Upset Prevention and Recovery Training (UPRT)—
  - Scenario-based situations,
  - Stall recognition and recovery, and
  - Spatial disorientation recognition and recovery;
- Re-emphasize/expand CRM;
- Flightcrew proficiency; and
- Simulator fidelity.

**Airline Operations and Maintenance.** Interventions calling for action on the part of operators or air traffic service providers to modify and expand operating policies or procedures. The highest-rated ISs related to airline operations, including air traffic control (ATC) issues, and airplane maintenance fall into these general areas:

- Maintenance procedures,
- Flightcrew qualifications,
- Non-standard flight operations,

- Standard operating procedures (SOP) (re-emphasis and rationale for),
- Flightcrew impairment, and
- Safety culture.

**Safety Data.** Interventions calling for expanded data mining and sharing programs, safety management principles. The highest-rated ISs related to safety data fall into these general areas:

- Sharing of safety-related data (for example, ASIAS),
- Operator Safety Management Systems, and
- Sharing of Service Difficulty Reports.

**Research.** Research interventions, per the JSAT process, do not receive an overall effectiveness (OE) score. Ranking of research interventions for priority was based on which research ISs addressed the highest number of high-scoring SPSs. The top research interventions, based on this methodology, fall into these general areas:

- Spatial disorientation (SD)—
  - Displays to prevent SD,
  - Alerting of SD condition;
- Maintaining flightcrew awareness in high-workload environments;
- Automatic systems for error detection, trapping, and recovery;
- Human performance benefits of post-stall recovery training using advanced aerodynamic models.

A broad portfolio of interventions is desired to mitigate the major problems from a variety of angles, and to provide options for near-, mid-, and long-term action based on results of feasibility and cost-benefit analysis in the ASA JSIT. Figure 3 presents the distribution of ISs across these categories.

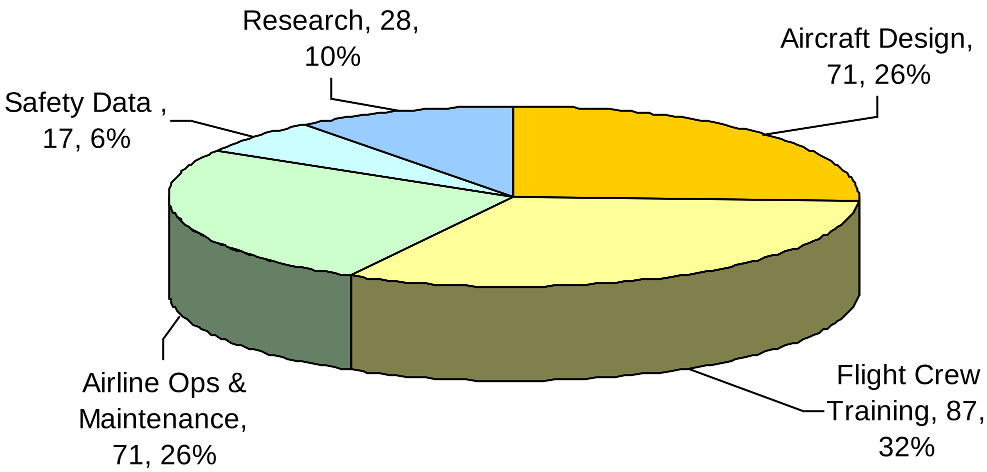


*Figure 3. Distribution of ISs by Category*

Table 2 presents a high-level summary of how the categories address the 12 themes. An uppercase "P" indicates that interventions in this category are the primary means of addressing a theme; a lowercase "s" indicates the interventions in this category are a secondary means of addressing a theme. The key message of this chart is that each theme is addressed by interventions from at least two categories.

*Table 2. Relationship of IS Categories to Themes*

**KEY**
**P** = primary means of mitigation
**s** = secondary means of mitigation
\- = none

| Intervention Categories | 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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aircraft Design IS's** | P | - | - | - | s | P | s | P | s | P | P | P |
| **Flightcrew Training IS's** | s | P | P | - | s | s | P | P | P | P | s | P |
| **Airline Ops & Maintenance IS's** | - | P | s | P | P | s | P | s | P | s | s | s |
| **Safety Data IS's** | - | - | - | s | P | s | - | s | - | s | s | - |
| **Research IS's** | s | - | s | - | s | - | P | P | P | s | P | s |

## CONCLUSION

LOC–I remains the largest category of U.S. and world fatal commercial airline accidents. Loss of ASA plays a significant role in at least half of all LOC–I category events. Preliminary study data set results indicate that precursors to loss of ASA are present in U.S. operations. Taken together, these facts illustrate the urgency of understanding the problems that underlie the loss of ASA and developing effective mitigations against them.

The ASA JSAT has completed its assigned charter by analyzing a relevant and inclusive set of events, identifying specific problems and major themes that played a role in causing the events, and developing, scoring, and ranking a list of prioritized intervention strategies that can address those problems. The proposed ISs cover a broad spectrum of potential solutions in the areas of airplane design, flightcrew training, airline operations and maintenance, and safety data. The ASA JSAT recommends the ASA JSIT perform a feasibility study to determine which ISs are best suited for development into new CAST safety enhancements.