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16. ABSTRACT In this study alerts and cues presented on five aircraft types (Airbus 320, Boeing 737NG, Boeing 777, Canadair Regional Jet (CRJ) 700, and Embraer 190) for 23 initiating conditions leading to one of 10 non-normal events were identified and analyzed. These events and conditions exist in current day operations and are expected to have continued relevance under NextGen operations. The 10 events, meant to be a "representative sample" from the population of possible non-normal events occurring on aircraft, were: <ul style="list-style-type: none"> • Aerodynamic stall • Uncommanded yaw or roll • Hydraulics failure of a single system • Single engine failure/fire • In-flight cargo fire/smoke • In-flight hidden cabin fire/smoke • Loss/degradation of Global Positioning System (GPS) • Traffic conflict • Lateral track or vertical path deviation • Air data system failure We chose events and initiating conditions to illustrate situations that are made known to the flight crews through: alerts only; cues only; both alerts and cues; neither alerts nor cues during the early stages of the event. Data and analyses are presented in the appendices to the report in the form of matrices. We also suggested how the matrices might be used in a training environment with professional pilots..			
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Alerts and Cues for Specific Conditions: Analysis and Application in Training

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EXECUTIVE SUMMARY

In this study alerts and cues presented on five aircraft types (Airbus 320, Boeing 737NG, Boeing 777, Canadian Regional Jet (CRJ) 700, and Embraer 190) for a 23 initiating conditions leading to one of 10 non-normal events were identified and analyzed. These events and conditions exist in current day operations and are expected to have continued relevance under NextGen operations. The 10 events, meant to be a “representative sample” from the population of possible non-normal events occurring on aircraft, were:

- Aerodynamic stall
- Uncommanded yaw or roll
- Hydraulics failure of a single system
- Single engine failure/fire
- In-flight cargo fire/smoke
- In-flight hidden cabin fire/smoke
- Loss/degradation of Global Positioning System (GPS)
- Traffic conflict
- Lateral track or vertical path deviation
- Air data system failure

We identified and analyzed the following alerts and cues that are presented during these events in the five aircraft types:

- Alerts: Visual, Aural, Tactile
- Cues: Visual, Aural, Tactile/Kinesthetic, Olfactory

Alerts are intended to provide the pilots with information that equipment is not performing to required specifications (e.g., degraded accuracy), the aircraft is entering an undesired state (e.g., low airspeed), or the aircraft is encountering an environmental hazard (e.g., windshear). *Cues* that occur due to non-normal situations, such as the smell of smoke during a fire or an indicator pointing to an unusual value for hydraulic pressure, also provide the pilots with information about a situation, although they are not specifically designed by the manufacturer to reliably draw attention and indicate a specific condition.

We chose events and initiating conditions to illustrate situations that are made known to the flight crews through:

- Alerts only
- Cues only
- Both alerts and cues, and
- Neither alerts nor cues during the early stages of the event (i.e., hidden cabin smoke/fire)

Data and analyses are presented in the form of matrices (see Appendices C through G) and suggestions for how the matrices might be used in a training environment with professional pilots are provided.

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DEFINITIONS OF TERMS

For the purposes of our analysis and discussion we used the following definitions:

Aircraft State: The configuration, trajectory, and aerodynamic condition of the aircraft - can be normal or non-normal

Alert: A visual, aural, or tactile/haptic signal designed or designated by the airplane manufacturer to capture pilot attention and provide information about a specific condition or aircraft system state.¹

Alert Cancellation: Manual termination or clearing of a valid alert that has already activated (for example, cancelling a master caution alert by pressing its button). Alert cancellation is performed by the pilots during the normal course of alert response. See also: Alert Inhibition and Alert Suppression.

Alert Inhibition: The automatic or manual prevention of a valid alert from being presented or activated. Alerts can be inhibited automatically by the alerting system (for example, inhibiting a potentially distracting caution light for an air conditioning pack trip when the airplane accelerates through 80 knots during takeoff) or manually by the pilots (for example, setting a "Flap Inhibit" switch to prevent a nuisance ground proximity warning when configuring the aircraft for landing with a non-standard flap setting). See also: Alert Cancellation and Alert Suppression.

Alert Suppression: Automatic prevention, withdrawal from display, or termination of an alert when (1) according to pre-programmed alerting system logic, the data used to trigger the alert are determined to be unreliable or invalid; or (2) the manual termination of an activated invalid alert by the pilots after the alerting system has experienced a malfunction. See also: Alert Cancellation and Alert Inhibition.

Alerting Philosophy: A high level description of the design principles that guide the designer and ensure a consistent and coherent interface is presented to the flightcrew, comprising the underlying design put forth by an airframe manufacturer or avionics manufacturer, as to the display of alerts and cues. This philosophy normally considers the (a) reason for implementing an alert, (b) level of alert required for a given condition, (c) characteristics of each specific alert, including types, modality of presentation, conspicuity, threshold for presentation and extinguishing, and inhibition and suppression, if any, and, (d) integration of multiple alerts.

¹ For an exhaustive list of the definitions for "alert" used in US regulatory and guidance documents see Yeh, Jo, Donovan, & Gabree, (2013), page 101.

Attention-Getting Signals/Methods: Perceptual signals (visual, auditory, or tactile/haptic) designed to attract the flightcrew's attention in order to obtain the immediate awareness that an alert condition exists. Flashing text is an example of an attention-getting signal.

Collector Message: An alert message that replaces two or more related alert messages that do *not* share a common cause or effect. For example, a "DOORS" alert collector message is displayed when more than one entry, cargo, or service access door is open at the same time. See also Umbrella Message.

Command State: The commanded condition or state of an aircraft system or sub-system - can be normal or non-normal. See also System State.

Conspicuity: The characteristics of an alert or cue that attract notice or attention.

Cue: A visual, aural, tactile/kinesthetic, or olfactory signal, which can provide information about the aircraft or system status, but was not designed by the manufacturer to direct the pilot's attention in any specific way (e.g., the smell of smoke, or an instrument indication in a non-normal range, but without a change in color, differentiation, or other attention-getting method).

Dark and Quiet Flight Deck: The concept that no visual or aural alert will be present on the flight deck when all systems are operating normally.

False Alert: An incorrect or spurious alert caused by a malfunction or failure of the alerting system, including a sensor failure.

False Positive Alert: An alert that *is* provided to the pilots when the underlying condition associated with the alert *is not* present.

False Negative Alert: Failure to alert the flightcrew when the underlying condition associated with an alert *is* present and (1) regulations require that an alert be presented or (2) the alert system was designed to present an alert.

Master Aural Alert: A general aural alert that is matched to an alert urgency level (i.e., warning or caution) and is used to bring to the flightcrew's attention that one or more specific alert conditions exist.

Master Visual Alert: A general visual indication that is matched to an alert urgency level (i.e., warning or caution) and is used to bring to the flightcrew's attention that one or more specific alert conditions exist.

Non-Normal: Any situation or condition that falls outside of "normal" operations to include: Abnormal Situations, Non-normal Situations, Emergency Situations, NextGen Off-nominal.

Situations [e.g., when Actual Navigation Performance (ANP) is greater than Required Navigation Performance (RNP)].

Pilot Response: The activity accomplished due to the presentation of an alert or cue as to the existence or potential existence of a situation or condition. Pilot responses may include such things as actions, decisions, consideration of situation/cues/alerts, prioritization of response activities, or search for additional information, among others.

Salience: An aspect of an alert or cue that makes it stand out in the environment and able to be perceived by the pilots.

System State: The actual condition of an aircraft system or sub-system - can be normal or non-normal. See also Command State.

Umbrella Message: An alert message (i.e., primary alert message) that is presented in lieu of two or more alert messages that *do* share a common cause (i.e., secondary/consequential alert messages). Example: A single “Engine Failure” message is displayed in lieu of multiple messages for malfunctioning electrical generators, generator drives, hydraulic pumps, and bleed air, which would otherwise have been displayed when an engine has failed. See also Collector Message.

INTRODUCTION

Alerts and cues are of critical importance in helping flight crews understand the existence of non-normal conditions and situations on board aircraft and to respond appropriately. *Alerts* are designed by aircraft and avionics manufacturers and are intended to attract attention and provide the pilots with information that equipment is not performing to required specifications (e.g., degraded accuracy), the aircraft is entering an undesired state (e.g., low airspeed), or the aircraft is encountering an environmental hazard (e.g., windshear). *Cues* that occur due to non-normal situations, such as the smell of smoke during a fire or an indicator pointing to an unusual value for hydraulic pressure, also provide the pilots with information about a situation, although they are not specifically designed by the manufacturer to reliably draw attention and indicate a specific condition.

In this study we identified the alerts and cues that would be present for 23 specific conditions associated with 10 different non-normal events. The set of events selected for this study are illustrative of the range of events involving the kinds of alerting, including absence of alerting, found on today's airliners (i.e., a "representative set" of events). We specifically considered the level of criticality of the chosen events and their importance to NAS operations both currently and under NextGen. Our 10 events came from four major loci of origin:

- Events external to the aircraft (e.g., wake encounter);
- Major system failures (e.g., engine failure);
- Secondary system failures (e.g., hydraulic system failure); and
- Flight crew errors (e.g., incorrect automation mode selection for RNP approach)

For each of the 10 events we identified one or more initiating condition (IC), each representing a realistic entry into the condition (i.e., reason for or cause of the event), and determined differences in how the condition is experienced and to be handled by flight crews (see Table 1). The 10 study events and 23 ICs analyzed are listed in Table 2. The choice of events is consistent with the ICAO Doc 9995 Manual of Evidence-Based Training (ICAO, 2012) with respect to the characteristics of events used in aircrew training. The study events analyzed consider immediacy, complexity, degradation of aircraft control, loss of instrumentation, and management of consequences. Also, we specifically considered false positive alerts as well as false negative alerts when relevant to the event and the alerting system involved. The events and ICs were chosen to provide at least one example of each:

- Both alerted and cued
- Cued but not alerted
- Neither cued nor alerted

In other words, some of the study events/conditions would be made known to pilots primarily or only through alerts and others primarily or only through cues. Many are both alerted and cued and one (hidden cabin smoke) is neither alerted nor cued on the flight deck, although cues

in the cabin would be evident but only after the event had progressed to a certain degree. Some events have a short timeframe for response (e.g., uncommanded roll due to wake encounter) and others have a much longer timeframe with implications for the rest of the flight through landing (e.g. hydraulics failure). We also analyzed the erroneous alerts presented for some false conditions (e.g., false aerodynamic stall warning), particularly if they have the potential to be highly confusing for flight crews. We included events that might be considered to be abnormal or emergencies, as well as some that are considered off-nominal in NextGen operations (i.e., not desirable, but not necessarily considered an abnormal or emergency event).

For these events we analyzed the alerts and cues presented to pilots in the following sensory modalities:

- Visual alerts
- Aural alerts
- Tactile alerts
- Visual cues
- Aural cues
- Tactile/kinesthetic cues
- Olfactory (smell) cues

We considered these to be representative of what pilots may experience under normal and non-normal conditions in currently operated transport category aircraft.

Table 1. Non-Normal Events and Initiating Conditions (ICs)

Event (Number of Initiating Conditions)	Initiating Conditions
Aerodynamic Stall (4)	<ul style="list-style-type: none"> • High altitude airspeed decay with turbulence, autopilot engaged • Increasing load factor in nose-low, high bank upset, autopilot disengaged • Wing ice accumulation • False stall warning during takeoff rotation
Uncommanded Yaw or Roll (3)	<ul style="list-style-type: none"> • Wake encounter • Uncommanded rudder deflection or rudder pedal kicks • Uncommanded aileron/spoiler/flap/slat deflection
Hydraulics Failure, Single System (1)	<ul style="list-style-type: none"> • Complete fluid loss for the single most critical hydraulic system during cruise flight
Single Engine Failure/Fire (4)	<ul style="list-style-type: none"> • Engine failure after V1 and prior to V2 • Engine failure in cruise flight with autopilot engaged • Engine fire after V1 and prior to V2 • False fire warning from engine bleed leak, during takeoff after V1 and before V2
In-flight Cargo Fire/Smoke (2)	<ul style="list-style-type: none"> • Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise • Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise

Event (Number of Initiating Conditions)	Initiating Conditions
In-flight Hidden Cabin Fire/Smoke (1)	<ul style="list-style-type: none"> • Ignition from short circuit in electrical wiring hidden behind cabin walls or ceiling
Loss/Degradation of GPS (2)	<ul style="list-style-type: none"> • Poor GPS satellite availability or geometry leading to decreased GPS signal integrity • Intentional spoofing leading to false position input from GPS to the FMS
Traffic Conflict (2)	<ul style="list-style-type: none"> • Traffic conflict in ATC radar environment (operational error or pilot deviation) • Traffic conflict in NextGen ATM environment (ground-based sequencing/metering error or DATACOMM error)
Lateral Track or Vertical Path Deviation Beyond Limit (1)	<ul style="list-style-type: none"> • In RNP approach and similar NextGen terminal area operations, the aircraft's failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specifications
Air Data System Failure (3)	<ul style="list-style-type: none"> • Blocked pitot source (captain's or left source) • Blocked pitot source (all sources blocked, first partially and inconsistently, then completely), with at least one blocked pitot drain, during climb • Air data computer failure (single air data module or unit)

Aircraft Types

We selected five aircraft types for use in this study (see Table 2), which encompass different alerting approaches, technology generations, aircraft sizes, and typical mission profiles. Four aircraft manufacturers, designs initiated from the 1960s through the 2000s, with aircraft passenger capacity of 70 through 350, and regional through long haul intercontinental missions are represented. The study sample included aircraft that are and are not fly-by-wire (FBW), single and double aisle, and are typically operated in the United States by both mainline and regional air carriers. As evidenced in Table 2, first and second generation aircraft were not included in the study due to the fewer numbers of these aircraft still in operation today. We included two aircraft types from one manufacturer to facilitate evaluation of design evolution over time. The typically installed avionics (e.g., Flight Management Computer [FMC] and flight displays) found on the study aircraft are listed in Table 3.

Table 2. Study Transport Category Aircraft

Aircraft Type	Description	Generation ¹
Airbus 320	Narrowbody, fly-by-wire, PFD/ND displays, integrated systems and procedural alerting displays	Generation 4 Jet
Boeing 737	Narrowbody, PFD/ND displays, traditional controls, non-integrated systems and procedural alerting displays	Generation 3 Jet
Boeing 777	Long-haul widebody, fly-by-wire, PFD/ND displays, integrated systems and procedural alerting displays	Generation 5 Jet
Bombardier CRJ700	Regional, PFD/ND displays, traditional controls, integrated systems alerting displays, non-integrated procedural alerting displays	Generation 4 Jet
Embraer 190	Regional, PFD/ND displays, traditional controls, integrated systems alerting displays, non-integrated procedural alerting displays	Generation 5 Jet

¹ ICAO Doc 9995 Manual of Evidence Based Training (2012)

Table 3. Study Transport Category Aircraft Avionics Equipment

Aircraft Type	FMC Manufacturer	Primary Display Manufacturer
Airbus 320	Thales/Smiths Industries (GE Aviation Systems) or Honeywell Pegasus	Thales TopFlight Line
Boeing 737	Smiths Industries (GE Aviation Systems)	Honeywell
Boeing 777	Honeywell	Honeywell
Bombardier CRJ700	Rockwell Collins	Rockwell Collins Pro Line
Embraer 190	Honeywell Primus Epic	Thales Avionics S.A.

Brief descriptions of the alerting systems on board the five study aircraft can be found in Appendix A.

Alert Types and Sensory Modalities

To help guide the pilot's actions, alerts are prioritized based upon the urgency of the pilot's awareness and the necessary response. Time critical warnings such as for aerodynamic stall, windshear, and ground proximity are given first priority, while other warnings, caution alerts, and advisories, are given subsequently lower priorities. Additionally, some aircraft have the capability to re-categorize and/or re-prioritize alerts based on phase of flight (A320 Flight Crew Training Manual, 2012; B777 Flight Crew Training Manual, 2012). A substantive revision of regulation 14 CFR 25.1322 in 2009, introduced the standardization of color use in alerting (i.e., "red" for warnings, "amber or yellow" for caution alerts, etc.) and imposed the requirement for warning- and caution-level alerting through two senses (Final rule: 75 FR 97201, effective date 01/03/2011) and provided as design guidance to manufacturers in Advisory Circular (AC) 25.1322-1, (FAA, 2010). AC 25.1322-1 identifies six different alert functional elements: Warning

Alerts, Time-Critical Warning Alerts, Master Visual and Aural Alerts, Caution Alerts, and Advisory Alerts. In practice, these elements are grouped into three major alert types (Warnings, Cautions, and Advisories) and some manufacturers add a fourth type: Status. To meet the requirements of 14 CFR 25.1322, an appropriate combination of alerting system presentation elements must be used; these elements typically include: master visual alerts, visual alert information (most often textual, but also includes failure flag indications and other types of unique indicators on flight deck displays), master aural alerts, voice information, unique tones (unique sounds), and tactile or haptic information (FAA 2010).²

Visual indicators and visual alerts are typically in the flightcrew's expected scan range or field of view, increasing the likelihood that they will be noticed. Some examples of visual alerts are: illuminated lights on annunciator panels, flashing boxes on the electronic flight displays, master warning and master caution lights, and text messages on the flight deck's crew alerting system or flight management system (FMS) displays. Auditory alerts can be stand-alone or may be used in conjunction with a visual alert. The high salience of auditory warnings makes them prevalent in the cockpit. Some examples of auditory alerts are: horns, whistles, sirens, bells, and tones, which vary in pulse and burst (Burt, Bartolome, Burdette & Comstock, 1995), as well as synthetically generated voice alerts (e.g., "Pull up! Pull up!"). Although only used for a small number of conditions, tactile/haptic alerts, such as the stickshaker, are found in many transport category airplanes and are commonly used to alert pre-stall conditions.

METHOD

The primary data sources for the study were systems, training, and crew operations manuals for the five aircraft types (see Table B1 in Appendix B). For comprehensiveness and to facilitate cross-validation of the information, we obtained and referenced the equivalent manuals for each aircraft type from at least two different air carriers. As is customary in our research, we committed to the airline participants that we would not refer to them by name and would de-identify any materials to be specifically quoted or reproduced in our work. Most of the manuals that we obtained had been customized by the air carriers but were based on the production documentation delivered from by the original equipment manufacturers (Airbus, Boeing, Bombardier, and Embraer). They contributed valuable information relative to how the air carriers had tailored the contents of each.

Data Coding

We identified all of the alerts and cues that might be present for each event IC and then populated data fields in matrices for each alert and cue identified (e.g., "threshold for alert or cue to be presented"). The researchers' personal flight operation and human factors expertise was used when defining likely pilot reactions and needed response to alerts and cues for each referenced event. The coding based on these judgments, as well as all other coding, was affirmed through research team review.

² Although haptic and tactile feedback/alerting are different, within the industry they are often confused or a distinction between them is not made. Because of this, no distinction will be made between them in this report.

A member of the research team, who was not involved in initial matrix development, reviewed all completed matrices and identified potential inconsistencies and missing data. Inconsistencies were resolved through consultation of the source documents and consensus judgment, when necessary. Researchers conducting this study have extensive understanding of aircraft display and alerting system architecture and operation. One researcher has extensive training and line operational experience on B777 and B737 aircraft and another has similar expertise with CRJ aircraft. A third researcher involved in matrix development also has extensive airline experience on a variety of aircraft types.

Simulator Observations and Subject Matter Expert Input

For the two study aircraft with which our coders lacked personal flight training and experience (A320 and EMB190), we supplemented printed documentation with site visits to airlines operating these aircraft types. Prior to the visits, we developed a protocol for evaluating the events and initiating conditions using FAA-approved, Level D pilot training simulators operated by the airlines.

During the site visits, we observed the simulation of the events and conditions in the A320 and EMB190 simulators as they were performed by training captains who were line-qualified in the respective type. We recorded video and audio of the simulations, and extracted data from these sources through review by the researchers. To control for the possibility of the simulations being inaccurate or incomplete, we only used the simulation data to supplement and cross-verify the data being obtained from our standard documentation from the manuals. We also held extensive discussions with the training captains, with follow-up communication, to address simulator limitations and how our events and ICs might transpire differently in real aircraft.

When necessary, we supplemented and verified our understanding of the design and function of the five aircraft alerting systems through informal discussions with other airline and aircraft manufacturer personnel. Thus, multiple data sources—text, experiential, observational, and face-to-face and phone inquiries— were utilized to populate the data in the matrices.

Matrices

The 23 completed matrices for each of the five aircraft included in this study can be found in Appendices C through G. Data analyzed and included in each matrix are described in Table 4 and appear in either tabular format or as bullet lists. Cells in the matrix tables that are “not applicable” (e.g., a tactile alert does not exist for an IC) are either left blank or the word “none” appears.

Table 4. Matrix Data

Category	Descriptor
Sensory Modality	Alerts and cues are grouped according to the sensory mode in which they are presented or available with all alert sensory modes listed first followed by the cue sensory modes.
Alert or Cue Name	A description of each visual, aural, tactile/kinesthetic, and/or olfactory alert or cue present for the IC of event
Threshold for alert or cue to be presented	When the alert or cue would be initially presented in the particular IC
Type of Alert	Warning, Caution, Advisory, Status
Other Issues With Regard to Alert or Cue	Issues not considered in other categories, if present
When is Alert Inhibited/Suppressed or When is Cue Masked, if Any	When alerting system inhibits/suppresses an alert or other conditions resulting in the masking of the cue, if present
How Alert or Cue is Terminated	What features in the IC or pilot response would terminate the alert or cue
Expected Pilot Response	Specific procedures or general processes expected of the pilot
How Does Pilot Know Condition is Resolved/Recovered	A description of the change in alerts and cues, if any, signifying to the pilot that the condition is resolved
Issues With Regard to Multiple Concurrent Non-Normal Conditions	Confounding aspects associated with other potential concurrent non-normal conditions, if present

A little more information is warranted with regard to the matrix category of “Expected Pilot Response.” Although it may appear that pilot response to alerts should be a relatively straightforward task, incident and accident reports indicate that this is not so (FDAWG, 2013). Problems may first arise during the initial stage when operators fail to detect the alert, possibly related to insufficient monitoring (FDAWG, 2013; Moray, 1980; Wickens, 1984). There are several systematic reasons as to why this might occur. For example, the alert may not be salient enough to grab the pilots' attention, or the placement of a visual alert may be out of the pilot's normal range of view. Pilots might also not detect an alert because they are dealing with another issue that occupies their attention. Signal detection and the ability to perceive that a specific change has taken place relative to a stimulus within a sensory modality (e.g. visual, auditory, etc.) is obviously essential if adequate and appropriate pilot response is to occur. Pertinent issues associated with these factors and others were considered and are reflected in the matrices.

USE OF MATRICES IN TRAINING

The alerting matrices provide a framework for elements that can be incorporated into various phases of pilot training. The following are suggestions of how they can be used by instructors in developing different training modules for ground school/distance learning and for simulator training.

- Referencing the matrices, develop a ground school or computer-based training module about the basic philosophy of aircraft alerting systems and how, in general, pilots are expected to respond to alerts and cues (in conjunction with guidance set forth in non-

normal checklists). Select an event and an alert that occurs during it, then follow the matrix from the alert through to the pilots' responses:

- Type of alert
 - Sensory modality (channel) through which the alert is delivered, also discussing the advantages and challenges of that channel
 - Triggers/threshold for alert presentation
 - Other alerts and cues that may be presented before, together with, and after the alert
 - The pilots' response to these alerts and any challenges in responding correctly
- The matrices include information about the threshold that must be met for the presentation of some alerts as well as when some alerts are inhibited or suppressed. Discuss these three aspects associated with alerting and consider the pros and cons of alert inhibition and suppression in different conditions.
 - In the matrices, note the number of alerts or cues that are presented in the same sensory modality for a given condition (e.g., visual). Discuss issues associated with attention to alerts, division of attention among alerts and cues, and sensory overload.
 - Develop a ground school or computer-based training module to address how cues can be used to confirm, disconfirm, or refine one's understanding of presented alerts. As part of the module, discuss various cognitive biases that may come into play when presented with alerts and cues (e.g., confirmation bias).
 - The matrices for some events and initiating conditions identify specific issues associated with alerts in multiple failure conditions. Consider likely multiple failure conditions and the range and type of alerts and cues available. Discuss issues in developing an appropriate mental model of the condition(s) and desired crew responses, drawing, in part, upon company philosophy, policies, and procedures.
 - Use the matrix information to consider how pilots may be challenged by Next-Gen operations such as RNP approaches, and specifically train the most effective interpretation and use of the available alerts and cues.
 - Example: Loss/degradation of GPS matrix
 - Example: Track or path deviation matrix
 - Example: Traffic conflict matrix
 - Consider the role that monitoring has with regard to alert and cue identification and response. Are there certain monitoring techniques that are particularly effective in helping to predict the occurrence of some alerts and ways to quickly distinguish false and true alerts from each other? Information in the matrices can then be used to develop simulator scenarios that allow pilots to experience and practice distinguishing false from valid alerts.

- Example: Stall warning during takeoff rotation: compare the alerts and cues of the valid and false warning conditions
 - Example: Fire warning during takeoff rotation and cargo fire warning: compare the alerts and cues of the valid and false warning conditions
- Develop simulator scenarios involving a) unexpected events that may startle if they occur without warning, b) events for which the alerts and cues are subtle and may not reliably grab the pilots' attention, c) failures leading to the absence of an expected alert, d) combinations of alerts and cues presented sequentially or simultaneously, that may themselves be part of what makes a situation unexpected, challenging, or stressful. The matrices provide some examples of such events.
 - Example: Stall without normal stall warning and with subtle secondary cues
 - Example: Multiple air data source failure
- Use the matrix information to develop simulator scenarios that allow pilots to experience and practice recognizing and reacting to loss of automation/automation reversions.
 - Example: Stall event with fly-by-wire system degradation to alternate mode or law
 - Example: Loss of autopilot with air data computer failure
- Develop simulator scenarios that allow pilots to experience and practice interpreting and reacting to alerts that may be generated by secondary conditions (preceding or consequent to a main system failure), depending on the aircraft type
 - Example: Hydraulic system failure matrix,
 - Example: Engine failure in cruise condition matrix
- Use the matrix information to develop simulator scenarios that allow pilots to experience and practice recognizing and reacting to an un-alerted event, particularly one in which the pilots may not readily recognize the condition or condition severity based on the available cues.
 - Example: In-flight hidden cabin fire/smoke matrix.
 - Example: Stall in icing conditions
- Outside of training activities, the matrix format and contents can also be used to guide event analysis within the Safety Management System.

SUGGESTED ACCIDENT CASE STUDIES

Accidents identified in Table 5 can be used as case studies in conjunction with the matrix or matrices that pertain to the alerting components associated with these events. Specific alerts and cues that were reported in the accident reports can be analyzed using the pertinent matrix

as a guide. Group discussions can be generated by focusing on the contributions (both positive and negative) from the alerts and cues generated during the event.

Table 5. Accident Examples

Accident Reference	Synopsis and Pertinent Matrix
<p>Bureau d'Enquêtes et d'Analyses. (2012). Final Report On the accident on 1st June 2009 to the Airbus A330-203, registered F-GZCP, operated by Air France flight AF 447 Rio de Janeiro. Paris. Retrieved from http://www.bea.aero/en/enquetes/flight.af.447/rapport.final.en.php</p>	<p>On May 31, 2009, Air France 447, an Airbus A330 was on a flight from Rio de Janeiro, Brazil to Paris, France. Three and one-half hours into the flight, the reserve captain and first officer experienced unreliable airspeed indications at FL 380 likely due to obstruction of the pitot probes by ice crystals. The aircraft was inadvertently stalled and descended into the ocean in three and one-half minutes. The confusion regarding the flight instrument displays and the aircraft state were evident during the entire event. The flight controls were never moved to reduce the angle of attack and recover aerodynamic stall. See matrices related to air data computer failures.</p>
<p>National Transportation Safety Board. (1996). <i>In-Flight Fire/Emergency Landing Federal Express Flight 1406 Douglas DC-10-10, N68055 Newburgh, New York September 5, 1996</i>. Aircraft Accident Report NTSB/AAR-98/03. Washington, DC: National Transportation Safety Board. Retrieved from http://www.nts.gov/doclib/reports/1998/AAR9803.pdf</p>	<p>About 0554 Eastern Daylight Time on September 5, 1996, a Douglas DC-10-10CF, N68055, operated by the Federal Express Corporation (FedEx) as flight 1406, made an emergency landing at Stewart International Airport (Stewart), Newburgh, New York, after the flightcrew determined that there was smoke in the cabin cargo compartment. See the matrices for cargo fires.</p>
<p>National Transportation Safety Board. (2004). <i>In-Flight Left Engine Fire American Airlines Flight 1400 McDonnell Douglas DC-9-82, N454AA St. Louis, Missouri September 28, 2007</i>. Aircraft Accident Report NTSB/AAR-09/03. Washington, DC: National Transportation Safety Board. Retrieved from http://www.nts.gov/doclib/reports/2009/AAR0903.pdf</p>	<p>On September 28, 2007, about 1313 central daylight time, American Airlines flight 1400, a McDonnell Douglas DC-9-82, N454AA, experienced an in-flight engine fire during departure climb-out from Lambert-St. Louis International Airport (STL), St. Louis, Missouri. The takeoff was uneventful until the airplane reached an altitude of about 1,000 to 1,500 feet mean sea level. At about that altitude, the first officer stated that the Left Engine "ATSV Open" light had</p>

Accident Reference	Synopsis and Pertinent Matrix
	<p>illuminated. A few minutes later, the CVR recorded a sound similar to the Engine Fire warning bell and then, the first officer stating that the Left Engine Fire warning light had illuminated. The Captain stated that they would return to STL. During the return to STL, the nose landing gear failed to extend, and the flightcrew executed a go-around, during which the crew extended the nose gear using the emergency procedure. The flightcrew's unfamiliarity with the initial alerts ("ATSV Open" light) and the alerts generated by of pulling the fire handle created confusion during the event. See matrices for engine failure and fire.</p>
<p>Transportation Safety Board of Canada. (1998). <i>In-Flight Fire Leading to Collision with Water Swissair Transport Limited McDonnell Douglas Md-11 HB-IWF Peggy's Cove, Nova Scotia 5nm SW 2 September 1998</i>. Aviation Investigation Report, Report Number A98H0003. Retrieved from http://www.tsb.gc.ca/eng/rappports-reports/aviation/1998/a98h0003/a98h0003.pdf</p>	<p>On 2 September 1998, Swissair Flight 111 departed New York, United States of America, at 2018 Eastern Daylight Savings time on a scheduled flight to Geneva, Switzerland. About 53 minutes after departure, while cruising at flight level 330, the flightcrew smelled an abnormal odor in the cockpit. They agreed that the origin of the anomaly was the air conditioning system. When they assessed that what they had seen or were now seeing was definitely smoke, they decided to divert. They initially began a turn toward Boston but changed their destination to Halifax International Airport. They leveled off to jettison fuel but were unaware that a fire was spreading above the ceiling in the front area of the aircraft. About 13 minutes after the abnormal odor was detected, the aircraft's flight data recorder began to record a rapid succession of aircraft systems-related failures. The flightcrew declared an emergency and indicated a need to land immediately but ended up crashing into the ocean. See matrices for hidden cabin fires.</p>

Accident Reference	Synopsis and Pertinent Matrix
<p>National Transportation Safety Board.. (1994). <i>In-Flight Icing Encounter and Loss of Control Simmons Airlines, d.b.a. American Eagle Flight 4184 Avions de Transport Regional (ATR) Model 72-212, N401AM Roselawn, Indiana October 31, 1994 Volume 1: Safety Board Report.</i> Aircraft Accident Report NTSB/AAR-96/01. Washington, DC: National Transportation Safety Board. Retrieved from https://www.nts.gov/doclib/reports/1996/AAR9601.pdf</p>	<p>On October 31, 1994, at 1559 Central Standard Time, an Avions de Transport Regional, model 72-212 (ATR 72) leased to and operated by Simmons Airlines, Incorporated, and doing business as American Eagle flight 4184, crashed during a rapid descent after an uncommanded roll excursion. The airplane was in a holding pattern and descending to a newly assigned altitude of 8,000 feet when the initial roll excursion occurred. The loss of control was attributed to a sudden and unexpected aileron hinge moment reversal that occurred after a ridge of ice accreted beyond the deice boots. This report shows how attending to cues can provide information regarding hazards when there is a lack of alerting. See matrices for uncommanded yaw and roll.</p>
<p>National Transportation Safety Board. (1996). <i>Loss of Control on Approach, Colgan Air, Inc., Operating as Continental Connection Flight 3407, Bombardier DHC-8-400, N200WQ, Clarence Center, New York, February 12, 2009.</i> Aircraft Accident Report NTSB/AAR-10/01, PB2010-910401. Washington, DC: National Transportation Safety Board. Retrieved from http://www.nts.gov/investigations/AccidentReports/Reports/AAR1001.pdf</p>	<p>On February 12, 2009, about 2217 eastern standard time, a Colgan Air, Inc., Bombardier DHC-8-400, N200WQ, operating as Continental Connection flight 3407, was on an instrument approach to Buffalo-Niagara International Airport, Buffalo, New York, when it crashed into a residence in Clarence Center, New York, about 5 nautical miles northeast of the airport. Night visual meteorological conditions prevailed at the time of the accident. See matrices for aerodynamic stall.</p>
<p>National Transportation Safety Board. (1992). <i>Aborted Takeoff Shortly After Liftoff Trans World Airlines Flight 843 Lockheed L-1011, N11002 John F. Kennedy International Airport Jamaica, New York July 30, 1992.</i> Aircraft Accident Report NTSB/AAR-93/04. Washington, DC: National Transportation Safety Board. Retrieved from http://libraryonline.erau.edu/online-full-text/nts-aircraft-accident-reports/AAR93-</p>	<p>On July 30, 1992, at 1741 Eastern Daylight Time, Trans World Airlines flight 843 experienced an aborted takeoff shortly after liftoff from John F. Kennedy International Airport. This accident occurred when L-1011 stickshaker erroneously activated just after takeoff rotation, and the First Officer, as pilot flying, perceived the aircraft as stalling. He immediately transferred control to the Captain, who landed the aircraft without enough runway remaining. The captain</p>

Accident Reference	Synopsis and Pertinent Matrix
<p>04.pdf</p>	<p>maintained control of the aircraft throughout the event, managing to turn off of the runway onto a grassy area before hitting the barrier at the end of the runway. The airplane caught fire and was destroyed; however, all occupants escaped. This accident illustrates the difficulty in detecting some false alerts quickly. See matrices for aerodynamic stall.</p>
<p>Air Accidents Investigation Branch (2014). Report No: 1/2014. <i>Report on the accident to Airbus A330-343, registration G-VSXY, London Gatwick Airport on 16 April 2012.</i> Retrieved from http://www.aaib.gov.uk/cms_resources.cfm?file=/AAIB%201-2014%20G-VSXY.pdf</p>	<p>On April 16, 2012, an Airbus A-330 experienced a series of smoke warnings from the aft cargo hold. The cargo smoke procedures were followed, including discharging the fire extinguishers, but the smoke warnings continued. The flight returned to the departure airport and landed. An emergency evacuation was conducted where two passengers were seriously injured. The investigation showed that the warnings were spurious and false. See matrices for cargo smoke and fire.</p>

ACRONYMS

Acronym	Definition
A320	Airbus 320
AC	Advisory Circular
A/C	Aircraft
ADIRU	Air Data Inertial Reference Unit
ADS-B	Automatic Dependent Surveillance - Broadcast
AGL	Above Ground Level
ANP	Actual Navigation Performance
AOA	Angle-of-Attack
AP	Auto-Pilot
APU	Auxiliary Power Unit
ATC	Air Traffic Control
ATM	Air Traffic Management
ASRS	Aviation Safety Reporting System
B737NG	Boeing 737 Next Generation
B777	Boeing 777
BEA	Bureau d'Enquêtes et d'Analyses (France)
CAST	Commercial Aviation Safety Team
CDTI	Cockpit Display of Traffic Information
CDU	Control Display Unit
C-HIP	Communication-Human Information Processing
CFR	Code of Federal Regulations
CRC	Continuous Repetitive Chime
CRJ	Canadair Regional Jet
CRJ700	Bombardier CL-60 CRJ Series Regional Jet
DATAComm	Data Communication
DSP	Display Select Panel
EADI	Electronic Attitude Director Indicator
ECAM	Electronic Centralised Aircraft Monitor
ECL	Electronic Checklist
ED	Electronic Display
EFIS	Electronic Flight Instrument Systems
EICAS	Engine Indication and Crew Alerting System
EGT	Exhaust Gas Temperature
EMB190	Embraer 190
EPE	Estimated Position Error
FAA	Federal Aviation Administration (USA)
FBW	Fly-By-Wire
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Training Manual
FDAWG	Flight Deck Automation Working Group

FMA	Flight Mode Annunciation
FMC	Flight Management Computer
FMGC	Flight Management Guidance Computer
FMS	Flight Management System
FWC	Flight Warning Computer
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
HSI	Heading Situation Indicator
IC	Initiating Condition
ICAO	International Civil Aviation Organization
IRS	Inertial Reference System
LOC-I	Loss of Control-Inflight
MCDU	Multipurpose Control and Display Unit
MFD	Multi-Function Display
NAS	National Airspace System
NextGen	Next Generation
ND	Navigation Display
NG	Next Generation
NM	Nautical Mile
NTSB	National Transportation Safety Board (USA)
OEM	Original Equipment Manufacturer
OI	Operational Improvement
PLI	Pitch Limit Indicator
QRH	Quick Reference Handbook
RA	Resolution Advisory
RNAV	Area Navigation
RNP	Required Navigation Performance
RVSM	Reduced Vertical Separation Minima
SC	Single Chime
SAARU	Secondary Attitude Air Data Reference Unit
SELCAL	Selective Calling System
SME	Subject Matter Expert
TBFM	Time Based Flow Management
TCAS	Traffic Collision and Avoidance System
VSI	Vertical Speed Indicator

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APPENDIX A

Alerting Systems on the Five Study Aircraft: Brief Overview

Airbus A320

The A320 alerting system includes master caution and master warning visual and aural alerts, the Electronic Centralized Aircraft Monitoring (ECAM) system, a variety of other aural alerts (both synthesized speech and sounds), illuminated lights on overhead systems panels, and a variety of indications on the PFD, ND, and the flight management guidance computer multifunction control display unit (FMGC MCDU). As its name implies, the ECAM monitors aircraft systems and displays information about them through two primary cockpit displays, the Upper ECAM and the Lower ECAM (see Figure A1), which are located in the center of forward displays directly in front of the throttle quadrant.



Figure A1. Airbus ECAM Displays

During emergency or abnormal conditions, the ECAM displays text alerts associated with the condition and corrective actions for the crews to take (i.e., checklist steps). For example, in

Figure 2 the title of an abnormal condition (FUEL AUTO FEED FAULT) appears in amber in the lower left section of the upper ECAM display and is followed by one checklist item, in blue type, to be accomplished. The alerts and checklist actions are automatically displayed and prioritized so the most critical alerts and actions, based on algorithms developed by ECAM designers, are always presented first, when more than one emergency/abnormal condition exists. As checklist items are accomplished or the condition that triggered the item is resolved, they disappear from the display and remaining items move up.

System synoptic pages are also automatically displayed, in the lower ECAM display, which show the status of the malfunctioning system and the effect crew actions are having as checklist steps are accomplished (Hicks & DeBrito, 1998). Upon the completion of the displayed checklist items and review of the system synoptic, the pilots are expected to display the Status page on the ECAM. This page includes a list of inoperative equipment, if any, and other information that might be pertinent to the remainder of the flight, such as changes to approach procedures.

The A320 ECAM has three levels of warnings and cautions (see Table A1). Each level is based on the associated operational consequence(s) of the failure. Failures will appear in a specific color, according to a defined color-coding system, that advises the flight crew of the urgency of a situation. In addition, Level 2 and 3 failures are accompanied by a specific aural warning: a Continuous Repetitive Chime (CRC) indicates a Level 3 failure, and a Single Chime (SC) indicates a Level 2 failure. As with all the study aircraft, there are additional visual and aural warnings. Examples of the extent and types of aural alerts used in the A320 can be found in Table A2.

Table A1. A320 Failure Levels

Failure Level	Priority	Color Coding	Aural Warning	Recommended Crew Action
Level 3	Safety	Red	Continuous Repetitive Chime (CRC)	Immediate
Level 2	Abnormal	Amber	Single Chime (SC)	Awareness, then action
Level 1	Degradation	Amber	None	Awareness, then Monitoring

Table A2. A320 Aural Warnings and Meanings

Warning Signal	Condition	Duration
Continuous Repetitive Chime (CRC)	Red warnings	Permanent
Single Chime (SC)	Amber caution	1/2 second
Cavalry charge	A/P disconnection by take-over problem A/P disconnection due to failure	1.5 second
Click	Landing capability change	½ second (three pulses)
Cricket	Stall	Permanent
Intermittent buzzer	SELCAL call	Permanent
Continuous buzzer	Cabin call	Permanent
'C' Chord	Altitude alert	1.5 seconds or Permanent
Auto call-out (synthetic voice)	Height announcement below 400 FT AGL	Permanent
Ground proximity warning system (GPWS) (synthetic voice)	GPWS warning	Permanent

When there are several failures, the flight warning computer (FWC) displays them as text messages on the upper ECAM in order of priority, pre-determined by the manufacturer according to the severity of the operational consequences of the failure. This is intended to ensure that the flight crew addresses the most critical failures first (Airbus Flight Crew Training Manual (FCTM), pg. 2 section 040, Chapter 1). In scenarios where a second, more critical failure occurs while the crew is accomplishing the checklist for the first failure, the checklist will be replaced by the text alert and checklist items for the second, more urgent failure. When those checklist items have been accomplished, the remaining items on the first checklist will be presented for accomplishment (Hicks & DeBrito, 1998).

Boeing 737NG

The B737 Next Generation (NG) alerting system includes master caution visual and master fire warning visual and aural alerts, red and amber visual alerts on the forward, center console, and overhead panels, amber system annunciator lights on the forward glareshield, a variety of aural alerts, various indications on the PFD, ND, and flight management system control display unit (FMS CDU), and a tactile alert for stall warning. Visual alerts on the overhead panels indicate specific system malfunctions.

The master caution/fire warning lights are triggered by malfunctions affecting any of several systems; e.g., amber master caution lights for hydraulic failure and red master fire warning lights for cargo fire. For a subset of system failures, the system annunciator lights on the glareshield panels (see Figure 3) direct attention to the malfunctioning system whose controls and lights are located on the overhead panel or center console, outside of the pilots' normal field of view. For example, an illuminated "FLT CONT" light on the first officer's glareshield informs the pilots to look up at the flight control section of the overhead panel to find the illuminated amber light that pertains to the specific failure that has occurred.



Figure A2. Boeing 737 Master Caution/Fire Warning and System Annunciator Lights

Unlike the other aircraft that we examined in this study, when the B737NG alerting system provides a visual alert for a caution condition, it generally does not also provide a secondary attention-getting alert through another sensory modality, such as an aural alert. This aircraft does provide alerting through two senses for warning conditions such as aerodynamic stall and engine fire.

Boeing B777

The B777 alerting system includes master caution and master warning visual and aural alerts, the engine indication and crew alerting system (EICAS) display, a variety of aural alerts, including a variety of synthesized speech and sounds, illuminated lights on overhead, forward, and center console systems panels, a variety of indications on the PFD, ND, and FMS CDU, and a tactile alert for stall warning.

The EICAS display is located in the center of the forward instrument panel, directly in front of the thrust levers. Text alerts are presented on the EICAS (see Figure A3) and, when multiple alerted conditions exist, their alerts are grouped by level of severity (warning, caution, advisory), and listed chronologically within each group (i.e., the most recent alerts appear at the top of its severity group list). Thus, as new messages are added existing messages are pushed physically lower on the display. Warning level alerts are colored red, caution level alerts are amber, and advisory level alerts are amber and indented. Additional status messages requiring no action by the pilots are presented in blue when manually recalled by the pilots. Any displayed message will remain presented on the EICAS until the condition that triggered it is resolved, if possible. Figure A3 depicts both caution and advisory level text alerts.



Figure A3. Boeing EICAS Display

In contrast to the A320 ECAM, the B777 EICAS is related to, but distinctly separate from the B777 electronic checklist (ECL), and they are displayed on different screens. However, the systems are linked such that a checklist associated with an EICAS alert will automatically be displayed on one of the cockpit multi-function displays (MFD), typically one directly below the EICAS display above the throttle quadrant, when the pilot presses the CHKL button on the cockpit display select panel (DSP).

If multiple EICAS alerts are presented, when the CHKL button is pressed a list of checklists is presented for the pilot to select among. As with the EICAS, the ECL does not prioritize the order in which multiple checklists should be accomplished but it does group them in the queue according to their associated alert message's level of severity (warning, caution, etc.). The pilot interacts with the ECL through the use of a touchpad and mouse and can move back and forth through pages of multiple page checklists. When an item has been accomplished, rather than disappearing as with the A320 ECAM, items turn color from white to green and a green check mark appears in front of the item on the display as shown in Figure A4.

System synoptic displays are also available on the B777 and are called up by pressing separate buttons on the DSP, much in the same way as system synoptics are displayed on the Airbus ECAM but without the automatic display function, i.e., system synoptics must always be manually selected for display on the B777.

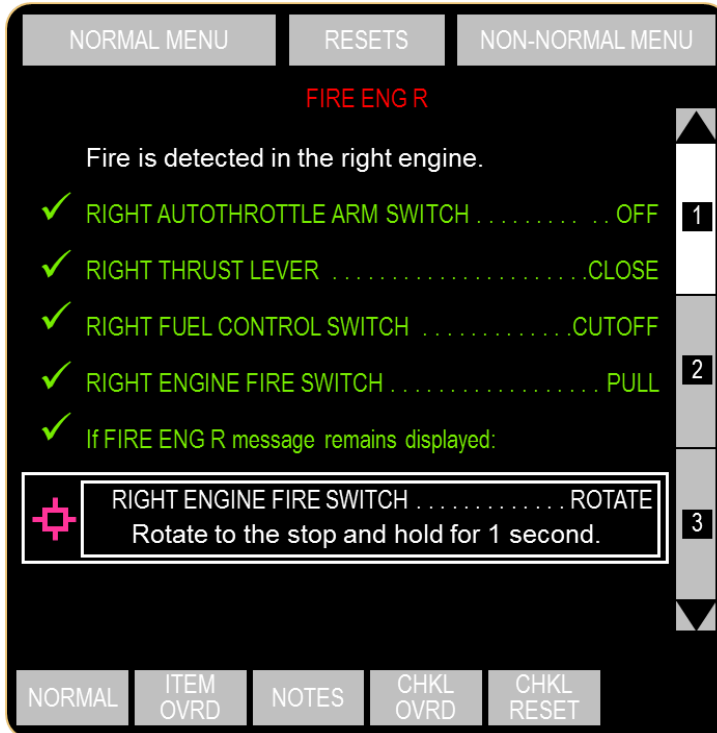


Figure A4. Boeing 777 ECL

Bombardier CRJ700

The CRJ700 alerting system includes master warning and master caution visual and aural alerts, two EICAS displays (ED1 and ED2), a variety of aural alerts including several synthesized speech advisories and sounds or tones, illuminated lights on overhead, forward, and center console panels, a variety of indications on the PFD, ND, and FMS CDU, and a tactile alert for stall warning. The master warning and master caution pushbuttons are located on the glareshield (both sides) within the primary field of view (see Figure A5) and the two EICAS displays (see Figure A6) are located in the center of the instrument panel in front of the thrust levers.



Figure A5. CRJ700 Glareshield Warning and Caution light switches (as seen on the right side of the cockpit)

When illuminated, the master warning and master caution push button is pressed which extinguishes the light and resets the system in the event that additional warning or caution alerts are needed. Pressing the master warning push buttons on the CRJ700 will silence some

aural tone and voice warnings (e.g., “Cabin Pressure,” or “Engine Oil”), but not others (e.g., stall warbler or takeoff configuration warnings such as flaps not in takeoff position). Pressing the master caution push buttons on the CRJ700 will not silence the GPWS and TCAS voice alerts, or the altitude alert C-chord aural.

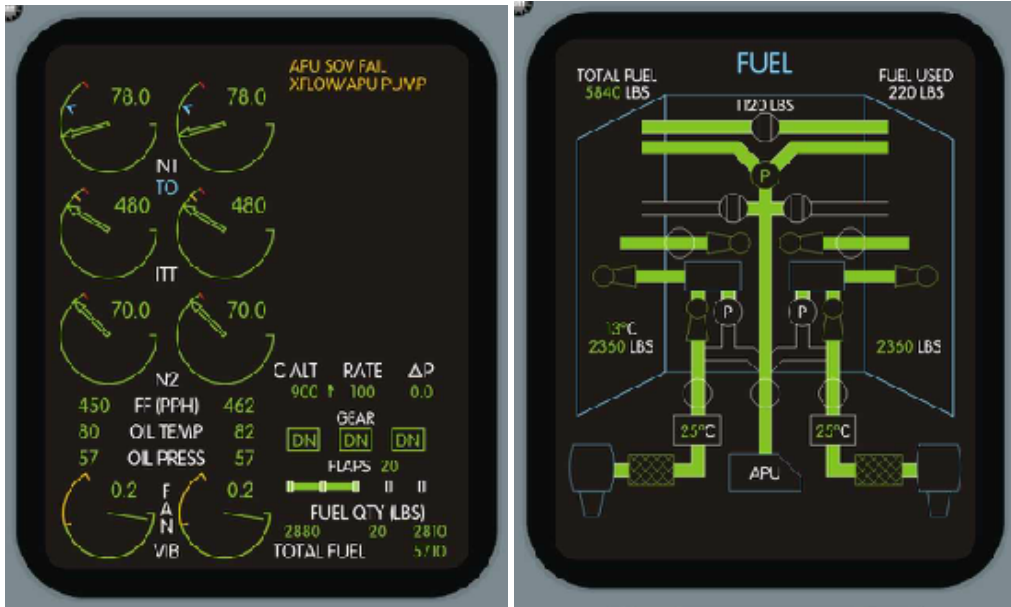


Figure A6. CRJ700 EICAS Displays 1 and 2

The EICAS displays show warning (red), caution (amber), advisory (green), and status (white) messages. ED1 usually displays the warning and caution messages and ED2 displays the advisory and status messages. In the case of a failure of one of the EICAS displays, all messages can be viewed on the remaining display (see Figure A6).

All text messages are grouped by level of severity and also listed chronologically with each group. Thus, as with the B777, the most recent text message is listed at the top of its respective severity level group. Therefore, any new messages are added above the existing messages thereby pushing the rest of the messages physically lower on the screen. Any displayed message will remain presented on ED 1 or ED2 until the condition that triggered it is resolved, if possible.

There is a limit to the total number of text messages that can be displayed within any one severity level grouping. If the number of text messages exceeds the available space, “page 1 of 2” or “page 1 of 3” is displayed next to the associated list. To help decrease clutter caused by excessive EICAS messages (and possibly leave the pilots unaware that some systems have failed), some message lists—such as caution messages (amber) and status messages (white)—can be removed from view, leaving a “MSGS” notation where the list was located. The viewing of both these hidden messages and additional pages beyond the display space provided is manually controlled by the pilots via the EICAS control panel that is located on the center pedestal.

Embraer EMB190

The EMB190 alerting system includes master warning/caution visual and aural alerts, an EICAS, and illuminated lights on overhead, forward, and center console systems panels for system emergency and abnormal conditions. There are additional aural alerts (both synthesized speech and sounds) and visual indications on the PFD, MFD, and FMS MCDU. The airplane's Stall Protection System provides a tactile stickshaker warning.

The EMB190 EICAS (see Figure A7) is located in the center of the five forward displays directly in front of the throttle quadrant. Text alerts are presented on the EICAS and are grouped by level of severity. Warning level alerts are red, Caution level alerts are amber, Advisory level alerts are cyan, and Information/Status messages are white. The Warning level alerts are placed at the top of the EICAS display and are listed chronologically (i.e., the most recent alert appears at the top of the group's list). Caution, Advisory and Status alerts are then presented, in that order, also chronologically within each grouping. The addition of new messages above the existing messages causes the rest of the messages to be pushed physically lower on the display.

In addition to the use of colored text, the master caution/warning systems and the EICAS also incorporate blinking in their alerts. Warning and Caution alerts will cause the blinking of the associated Master Warning or Caution button. Steady illumination of these alerts will occur only after the pilots acknowledge the alert by pressing the associated Master Warning or Caution button. When new Warning, Caution, and Advisory EICAS alert messages are displayed, they also blink and appear in inverse video until crew acknowledgment. Advisory (cyan) messages automatically revert from blinking to steady illumination after five seconds. Status messages do not blink at all.

For redundancy, and as an additional attention-getting feature, aural warnings correspond with each alert category. Continuous chimes at three or five second intervals for Warning and Caution alert messages, respectively, are silenced after the associated button is pressed. Advisory and Information/Status alert messages are accompanied by a single chime.



Figure A7. E190 EICAS Display

APPENDIX B

Study Materials Subjected to Analysis

Table B1. Study Materials, with Revision Dates

Aircraft	Document	Revision	Revision Date
B737NG	Flight Manual	57	6/15/12
B737NG	QRH	14	4/1/12
B737NG	FCTM	10	7/29/11
B737NG	QRH	21	1/24/12
B737NG	Operating Manual Volume 1	62	2/23/12
B737NG	Operating Manual VI. 2	21	4/7/09
B777	Flight Manual	26	10/28/11
B777	FCTM	10	6/30/12
B777	QRH		6/15/12
B777	Operating Manual V2	30	6/27/12
B777	QRH	21	5/17/11
A320	FCOM V1	9	10/15/12
A320	FCOM V2	1	3/14/08
A320	QRH	8	6/1/12
A320	AOM V2	9	6/2/09
A320	Training Manual		4/1/13
CRJ700	FCOM Volume 1	9	3/14/11
CRJ700	FCOM Volume 1	6	5/2/11
CRJ700	FCOM Volume 2	6	5/2/11
CRJ700	Pilot Advanced Qualification Program Manual – Standard Practice	9	11/8/12
CRJ700	CRJ700 QRH	9	11/9/12
CRJ700	FOM		2/2010
E190	FCOM V1	13	6/1/2012
E190	FCOM V2	6	2/23/11
E190	QRH	22	2/1/12
E190	Training Manual		4/1/13
E190	Normal Checklist		No Date
E190	QRH	16	10/12/12

APPENDIX C

Airbus A320 Matrices

A320 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Reversion to alternate law is alerted on ECAM display	Driven by whatever malfunction or failure caused the aircraft to revert to alternate law	Caution			
	Loss of low speed protection is alerted on PFDs by green dash marks on airspeed tapes changing to amber x marks.	Reversion to alternate law	Caution	Salience?		
	At stall onset, In alternate law flashing red MASTER WARN lights on each side of glareshield	AOA adjusted for slat/flap position, speed/mach, and flight control law	Warning		Inhibited on the ground	
	Autopilot disconnect displayed in red on ECAM as "AUTO FLT AP OFF"	A/P disconnects at alpha-prot value plus 1 degree	Warning		Autopilot disconnect may occur earlier if it is driven by whatever caused the reversion to alternate law (e.g., FAC failures)	
	At autopilot disconnect, flashing red MASTER WARN lights on each side of glareshield	A/P disconnects at alpha-prot value plus 1 degree	Warning		Autopilot disconnect may occur earlier if it is driven by whatever caused the reversion to alternate law (e.g., FAC failures)	

A320 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	At stall onset cricket sound and "STALL" aural	AOA adjusted for slat/flap position, speed/mach, and flight control law	Warning		Inhibited on the ground	
Tactile Alerts	None					
Visual Cues	At stall onset, airspeed indicator decreases to VSW (top of red/black barber pole region on PFD)	Airspeed compensated for vertical-g			VSW display inhibited from touchdown until 5 seconds after liftoff	
	In the stall condition, possible uncommanded pitching moment on PFD					
	In the stall condition, possible uncommanded rolling moment on PFD					
	In the stall condition, possible uncommanded descent rate on PFD					
Aural Cues	Autopilot disconnect tone	A/P disconnects at alpha-prot value plus 1 degree		Autopilot disconnect may occur earlier if it is driven by whatever caused the reversion to alternate law (e.g., FAC failures)		

A320 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile/ Somatic Cues	In alternate law, low speed stability function introduces gentle nose-down pitch input which may be noticeable through somatic cues (vertical g)	Threshold for onset is 5-10 knots above stall warning speed, g-compensated to some degree. This function not available in "alternate law without reduced protection" so dependent on the nature of the failure that drove the aircraft into alternate law.				

Expected Pilot Response(s)

- Thrust levers- TOGA.
- Bank angle- roll wings level.
- Speedbrakes- check retracted.
- Avoid ground contact; maintain airspeed close to VSW until safe to accelerate.
- If below 20,000 feet, extend flaps to position 1.
- When out of stall with and clear of obstacles, retract landing gear.

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/sidestick inputs).
- Possible passenger injuries and aircraft damage.

A320 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	Reversion to alternate law is alerted on ECAM display	Driven by whatever malfunction or failure caused the aircraft to revert to alternate law	Caution			
	Loss of low speed protection is alerted on PFDs by green dash marks on airspeed tapes changing to amber x marks.	Reversion to alternate law	Caution	Salience?		
	At stall onset, In alternate law flashing red MASTER WARN lights on each side of glareshield	AOA adjusted for slat/flap position, speed/mach, and flight control law	Warning		Inhibited on the ground	
	VSW moves up towards the indicated airspeed in response to increased vertical g	Airspeed compensated for vertical-g			VSW display inhibited from touchdown until 5 seconds after liftoff	

A320 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	At stall onset cricket sound and "STALL" aural	AOA adjusted for slat/flap position, speed/mach, and flight control law	Warning		Inhibited on the ground	
Tactile Alerts	None					
Visual Cues	At stall onset, airspeed indicator decreases to VSW (top of red/black barber pole region on PFD)	Airspeed compensated for vertical-g			VSW display inhibited from touchdown until 5 seconds after liftoff	
	In the stall condition, possible uncommanded pitching moment on PFD					
	In the stall condition, possible uncommanded rolling moment on PFD					
	In the stall condition, possible uncommanded descent rate on PFD					
Aural Cues	Wind noise					

A320 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile/ Somatic Cues	In alternate law, low speed stability function introduces gentle nose-down pitch input which may be noticeable through somatic cues (vertical g)	Threshold for onset is 5-10 knots above stall warning speed, g-compensated to some degree. This function not available in "alternate law without reduced protection" so dependent on the nature of the failure that drove the aircraft into alternate law.				

Expected Pilot Response(s)

- Thrust levers- TOGA.
- Bank angle- roll wings level.
- Speedbrakes- check retracted.
- Avoid ground contact, maintain airspeed close to VSW until safe to accelerate.
- If below 20,000 feet, extend flaps to position 1.
- When out of stall with and clear of obstacles, retract landing gear.

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/sidestick inputs).
- Possible passenger injuries and aircraft damage.

A320 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	In the stall condition, possible uncommanded pitching moment on PFD			Flight control inputs made by the autopilot and/or flight control systems (without tactile feedback to pilots) could mask the aerodynamic cues of a stall		
	In the stall condition, possible uncommanded rolling moment on PFD			Flight control inputs made by the autopilot and/or flight control systems (without tactile feedback to pilots) could mask the aerodynamic cues of a stall		
	In the stall condition, possible uncommanded descent rate on PFD					
Aural Cues	None					
Tactile/Somatic Cues	None					

A320 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation – Cont.

Expected Pilot Response(s)

- Thrust levers- TOGA.
- Bank angle- roll wings level.
- Speedbrakes- check retracted.
- Avoid ground contact, maintain airspeed close to VSW until safe to accelerate.
- If below 20,000 feet, extend flaps to position 1.
- When out of stall with and clear of obstacles, retract landing gear.
- Note: This procedure is in the FCOM but apparently not in the QRH or ECAM.

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

A320 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Flashing red MASTER WARN lights on each side of glareshield (false indication)	False indication driven by AOA adjusted for slat/flap position, speed/mach, and flight control law	Warning		Inhibited on the ground, so the false alert begins during rotation when the aircraft becomes airborne	
Aural Alerts	Cricket sound and "STALL" aural (false indication)	False indication driven by AOA adjusted for slat/flap position, speed/mach, and flight control law	Warning		Inhibited on the ground, so the false alert begins during rotation when the aircraft becomes airborne	
Tactile Alerts	None					
Visual Cues	Airspeed is above VLS			This is a cue that the aircraft is not actually stalling (although it is possible for the aircraft to stall above VLS due to g-load and/or icing)		

A320 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation – Cont.

Visual Cues	Normal vertical speed, altimeter, and airspeed indications on PFD, as well as view through the windshield of the aircraft climbing (if VMC) are subtle cues that the aircraft is not stalling			This is a cue that the aircraft is not actually stalling		
Aural Cues	None					
Tactile/ Somatic Cues	Normal vertical acceleration from rotation into climb is a subtle cue that the aircraft is not stalling			If present and perceptible, this is a cue that the aircraft is not actually stalling		

Expected Pilot Response(s)

- Ignore false alerts.
- Do not reject takeoff.

How does pilot know condition is resolved/recovered?

- Observe normal takeoff and climb performance

Issues with regard to multiple concurrent non-normal conditions

- None unless pilot takes unneeded actions, such as high speed RTO.

A320 Alerting Issues – Uncommanded yaw or roll

1. Initiating Condition: Wake encounter

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	ECAM red warning AUTO FLT AP OFF	A/P disconnects at bank angle > 45 deg	Warning			
Aural Alerts	Autopilot disconnect tone	A/P disconnects at bank angle > 45 deg	Warning			
Tactile Alerts	None					
Visual Cues	PFD displays roll rate and upset attitude					
	PFD displays chevrons indicating the direction to pitch for recovery	Pitch attitude +/- 15 degrees	Warning			
	PFD symbols disappear (except for attitude, speed, heading, altitude, and vertical speed information)	Bank angle > 45 deg		Removal of normal cue is not a salient cue to the upset, but it does remove potentially distracting information from the PFD helping the pilot to focus on attitude		
	FD bars disappear	Bank angle > 45 deg		Removal of normal cue is not a salient cue to the upset, but it does remove potentially distracting information from the PFD helping the pilot to focus on attitude		

A320 Alerting Issues – Uncommanded yaw or roll

1. Initiating Condition: Wake encounter – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Monitor aircraft's automated roll from upset attitude toward 33 degree maximum.
- Intervene with roll and/or pitch inputs if necessary.
- (no published procedure)

How does pilot know condition is resolved/recovered?

- Return to controlled flight.

A320 Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	PFD displays yaw/roll rates					
	PFD displays skid/sideslip condition on turn coordination indicator					
	PFD symbols disappear (except for attitude, speed, heading, altitude, and vertical speed information)	Bank angle > 45 deg				
	FD bars disappear	Bank angle > 45 deg				

A320 Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Aileron, spoiler, and rudder positions displayed on the ECAM F/CTL (flight control) page			This information must be obtained by performing keyboard selections; thus has zero salience unless the pilot recalls the existence of the page, applies this to the existing situation, and effortfully makes the required entries		
Aural Cues	None					
Tactile/Somatic Cues	Uncommanded rudder pedal movement	Uncommanded rudder pedal deflection (in the direction opposite to that required) may occur if the rudder is jammed and thus cannot fulfill orders from the flight control computers				
	Lateral-g from uncommanded yaw					

Expected Pilot Response(s)

- Monitor aircraft's automated roll from upset attitude toward 33 degree maximum.
- Intervene with roll and/or pitch inputs if necessary.
- Perform F/CTL Rudder Jam procedure if cued by uncommanded rudder pedal movement.

A320 Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks – Cont.

How does pilot know condition is resolved/recovered?

- Pilot can check aileron, spoiler, and rudder positions on the ECAM F/CTL (flight control) page.

Issues with regard to multiple concurrent non-normal conditions

- If rudder deflection continues to subsequent flight phases, there may be implications for control during approach and landing; there is no published procedure to rectify the rudder deflection or mitigate these risks (however unlikely).

A320 Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	PFD displays roll rate					
	PFD symbols disappear (except for attitude, speed, heading, altitude, and vertical speed information)	Bank angle > 45 deg				
	FD bars disappear	Bank angle > 45 deg				
	Aileron, spoiler, and rudder positions displayed on the ECAM F/CTL (flight control) page			This information must be obtained by performing keyboard selections; thus has zero salience unless the pilot recalls the existence of the page, applies this to the existing situation, and effortfully makes the required entries		
Aural Cues	None					
Tactile/Somatic Cues	None					

A320 Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection – Cont.

Expected Pilot Response(s)

- Monitor aircraft's automated roll from upset attitude toward 33 degree maximum.
- Intervene with roll and/or pitch inputs in an attempt to control the rolling moment.
- Recognize that automation and manual roll inputs are ineffective in regaining control, and apply manual rudder pedal inputs to oppose the roll.
- (no published procedure)

How does pilot know condition is resolved/recovered?

- Pilot can check aileron, spoiler, and rudder positions on the ECAM F/CTL (flight control) page.

Issues with regard to multiple concurrent non-normal conditions

- If aileron/spoiler deflection continues to subsequent flight phases, there may be implications for control during approach and landing; there is no published procedure to rectify these uncommanded control surface deflections or mitigate these risks (however unlikely).

A320 Alerting Issues – Hydraulics failure (Single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (Green System) in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	ECAM: HYD G RSVR LO LVL amber caution with associated procedural information	Reservoir fluid quantity < 3.5L	Caution	ECAM amber caution alerts from secondary events (e.g., low hydraulic pressure, PTU failure) are also presented as they occur, but these are clearly delineated as secondary by being indented and underneath the alert for the primary reservoir quantity situation.	Inhibited during takeoff from 80 kt through 1,500 feet and during landing from 800 feet through 80 knots	
	Master caution light	Driven by loss of hydraulic pressure, and subsequently again by associated PTU failure	Caution			Canceled by pressing the light
	HYD page appears on ECAM System/Status Display, with amber green system reservoir quantity and amber "LO" engine pump pressure indication, amber "GREEN" system label and amber/low system pressure reading	Driven by ECAM	Caution			
	Amber ENG1HYD fault light on overhead panel	Green system reservoir quality/pressure low	Caution			

A320 Alerting Issues – Hydraulics failure (Single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (Green System) in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Amber PTU fault light on overhead panel	PTU not able to provide pressure (secondary to green system quantity loss)	Caution			
Aural Alerts	Single chime	Driven by ECAM	Caution			
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Perform G RSVR LO LVL procedure prompted by ECAM.
- Use ECAM status to review follow-on requirements (increased landing distance; gravity landing gear extension; inoperative nosewheel steering on some models; degraded approach capability; inoperative autobrakes, inoperative ENG1 thrust reverser).
- Implement follow-on requirements at the appropriate phase of flight as prompted by ECAM.
- As prompted by ECAM status, recognize operational implications of failures including inability to retract landing gear.

How does pilot know condition is resolved/recovered?

- Completion of procedures results in stable situation but abnormal condition for landing (e.g., longer landing distance); system cannot be recovered to normal operation.

A320 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution lights on glareshield	Engine failure detected by engine core speed below idle with engine master switch on and fire pushbutton not pushed	Caution			Cancelled by pressing the light
	ECAM amber caution ENG 1 or 2 FAIL	Engine failure detected by engine core speed below idle with engine master switch on and fire pushbutton not pushed	Caution			
	Oil pressure needle and digital indication on the Engine/Warning Display turn red	Oil pressure below 60 psi (amber below 80 psi)	Warning	Not immediately salient-- engine page must be manually selected to display, or it is automatically displayed during subsequent ECAM procedure during affected systems review		
	Generator FAULT light on overhead panel (subsequently also Hydraulic and Pack lights)	System sources drop off line due to engine failure	Caution			

A320 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Aural Alerts	Single chime	Engine failure detected by engine core speed below idle with engine master switch on and fire pushbutton not pushed	Caution			
Tactile Alerts	None					
Visual Cues	Low or zero values on E/WD indicators for N1, N2, Fuel Flow, etc.					
	Nose yawing off runway centerline					
Aural Cues	Possible loud noise					
Tactile/ Somatic Cues	Possible vibration/buffet					
	Lateral g					
	Rudder pressure required to stay on runway					
	Reduced longitudinal acceleration					

Expected Pilot Response(s)

- Control the aircraft.
- Execute single engine takeoff/climb profile.
- Execute appropriate ECAM procedure (ENG 1 OR 2 FAIL).
- Perform single engine approach and landing, considering operational limitations as suggested by the ECAM status.

A320 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2 – Cont.

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Uncontained engine failure may present additional multiple alerts and failures.

A320 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution lights on glareshield	Engine failure detected by engine core speed below idle with engine master switch on and fire pushbutton not pushed	Caution			Cancelled by pressing the light
	ECAM amber caution ENG 1 or 2 FAIL	Engine failure detected by engine core speed below idle with engine master switch on and fire pushbutton not pushed	Caution			
	Oil pressure needle and digital indication on the Engine/Warning Display turn red	Oil pressure below 60 psi (amber below 80 psi)		Not immediately salient- -engine page must be manually selected to display, or it is automatically displayed during subsequent ECAM procedure during affected systems review		
	Generator FAULT light on overhead panel (subsequently also Hydraulic and Pack lights)	System sources drop off line due to engine failure				

A320 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Single chime	Engine failure detected by engine core speed below idle with engine master switch on and fire pushbutton not pushed	Caution			
Tactile Alerts	None					
Visual Cues	Low or zero values on E/WD indicators for N1, N2, Fuel Flow, etc.					
Aural Cues	Possible loud noise					
Tactile/Somatic Cues	Possible vibration/buffet					

Expected Pilot Response(s)

- Control the aircraft.
- Execute single engine takeoff/climb profile.
- Execute appropriate ECAM procedure (ENG 1 OR 2 FAIL).
- Perform single engine approach and landing, considering operational limitations as suggested by the ECAM.

A320 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged – Cont.

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Uncontained engine failure may present additional multiple alerts and failures.

A320 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	ECAM red warning ENG 1 or 2 FIRE	Engine fire loop(s) exceed temperature threshold (Dual loop FIRE/FIRE, FIRE/FAIL, or FAIL/FAIL within 5 sec)	Warning			Fire is extinguished to the extent that sensed temperature on loop(s) decreases below threshold, with at least one loop still functional
	Master warning lights (flashing red) on glareshield	Engine fire loop(s) exceed temperature threshold (Dual loop FIRE/FIRE, FIRE/FAIL, or FAIL/FAIL within 5 sec)	Warning			Cancelled by pressing the light
	FIRE light in respective engine's fire pushbutton on overhead fire panel	Engine fire loop(s) exceed temperature threshold (Dual loop FIRE/FIRE, FIRE/FAIL, or FAIL/FAIL within 5 sec)	Warning			
	FIRE light for respective engine on pedestal	Engine fire loop(s) exceed temperature threshold (Dual loop FIRE/FIRE, FIRE/FAIL, or FAIL/FAIL within 5 sec)	Warning			
	ENGINE page appears on ECAM System/Status Display	Engine fire loop(s) exceed temperature threshold (Dual loop FIRE/FIRE, FIRE/FAIL, or FAIL/FAIL within 5 sec)				

A320 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Generator FAULT light on overhead panel (subsequently also Hydraulic and Pack lights)	Only after engine is shut down during ECAM procedure, system sources drop off line due to engine shutdown	Caution			
Aural Alerts	Continuous repetitive chime	Engine fire loop(s) exceed temperature threshold	Warning			Cancelled by pressing the master warning light
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Control the aircraft.
- Execute V1 engine failure/fire flight profile.
- Execute engine fire ECAM.
- Perform single engine approach/landing procedures.
- If fire indication continues despite attempts to extinguish, expedite landing.

A320 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

How does pilot know condition is resolved/recovered?

- Fire warning indication that fire is extinguished

Issues with regard to multiple concurrent non-normal conditions

- Possible confusion between fire with and without engine failure.
- Engine fire will devolve to an engine failure, either as a direct result of and simultaneous with the fire onset or as part of the engine fire procedure.
- Engine fire presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Engine fire may present cascading emergency (e.g., hydraulic failures, smoke in cabin, etc.)
- Uncontrollable fire may present additional, cascading conditions (e.g., structural failure, fuel loss, need to expedite landing or even land off-airport).

A320 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak, during takeoff after V1 and before V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	ECAM red warning ENG 1 or 2 FIRE	Engine fire loop(s) falsely indicate exceeding temperature threshold	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Lower temperature sensed by engine fire loop
	Master warning lights (flashing red) on glareshield	Engine fire loop(s) falsely indicate exceeding temperature threshold	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Cancelled by pressing the master warning light
	FIRE light in respective engine's fire pushbutton on overhead fire panel	Engine fire loop(s) falsely indicate exceeding temperature threshold	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Lower temperature sensed by engine fire loop
	FIRE light for respective engine on pedestal	Engine fire loop(s) falsely indicate exceeding temperature threshold	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Lower temperature sensed by engine fire loop
	ENGINE page appears on ECAM System/Status Display	Engine fire loop(s) falsely indicate exceeding temperature threshold			False fire warning can lead to unneeded RTO, engine shutdown, etc.	

A320 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak, during takeoff after V1 and before V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Aural Alerts	Continuous repetitive chime	Engine fire loop(s) falsely indicate exceeding temperature threshold	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Cancelled by pressing the master warning light
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Control the aircraft
- Execute V1 engine failure/fire flight profile
- Execute engine fire ECAM
- Perform single engine approach/landing procedures

Issues with regard to multiple concurrent non-normal conditions

- False indication of engine fire will likely devolve to an engine failure as part of the engine fire procedure.
- If false indication of fire continues after engine fire NNPs are performed, pilot concerns about inextinguishable fire may prompt risky alternative actions (e.g., rushing, off-airport landing, etc.).

A320 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning lights (flashing red) on glareshield	Smoke detected in cargo compartment (Dual loop FIRE/FIRE, or FIRE/FAIL)	Warning		Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	Master Warn lights are cancelled by pressing the light
	Red FWD or AFT SMOKE light on overhead cargo smoke panel	Smoke detected in cargo compartment (Dual loop FIRE/FIRE, or FIRE/FAIL)	Warning		Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	Smoke alerts do not necessarily terminate after fire has been extinguished, due to lack of venting of the cargo compartment and sensitivity of the smoke detectors to extinguishing agent; cargo compartment temperature can be monitored by manually selecting the ECAM CRUISE or ECAM COND system display pages.
	FWD or AFT CARGO SMOKE warning on ECAM Engine/Warning Display		Warning		Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	Smoke alerts do not necessarily terminate after fire has been extinguished, due to lack of venting of the cargo compartment and sensitivity of the smoke detectors to extinguishing agent; cargo compartment temperature can be monitored by manually selecting the ECAM CRUISE or ECAM COND system display pages.
	Air Conditioning (COND) page automatically appears on ECAM System/Status Display				Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	

A320 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Continuous repetitive chime	Smoke detected in cargo compartment (Dual loop FIRE/FIRE, or FIRE/FAIL)	Warning		Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	CRC is canceled by pressing master warning light
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	Possible reports from flight attendants or cargo supernumeraries about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Perform the appropriate cargo smoke procedure using ECAM.
- Land within the required time limit.
- Advise ground personnel not to open cargo compartments without prior clearance from ARFF.

A320 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise flight – Cont.

How does pilot know condition is resolved/recovered?

- Previously illuminated Fwd or Aft light on cargo smoke panel is extinguished.
- Note: Burnthrough or other failure of Cargo Smoke Detection is monitored and displayed as FWD or AFT CRG DET FAULT ECAM.
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment and (if necessary) the aircraft has been evacuated.

Issues with regard to multiple concurrent non-normal conditions

- Warnings/alerts/cues of other system failures (e.g., electrical, pneumatic, hydraulic) may be presented if these systems or associated detectors receive fire damage; these indications may distract the pilots' attention from responding to the primary fire situation or mask the primary situation.
- On the other hand, these secondary failures may require additional responses by the pilots, and the optimal prioritization of pilot response to these multiple cues may be unclear.

A320 Alerting Issues – In-flight cargo fire/smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning lights (flashing red) on glareshield	Smoke falsely detected in cargo compartment	Warning		Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	Master Warn lights are cancelled by pressing the light
	Red FWD or AFT SMOKE light on overhead cargo smoke panel	Smoke falsely detected in cargo compartment	Warning		Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	
	FWD or AFT CARGO SMOKE warning on ECAM Engine/Warning Display	Smoke falsely detected in cargo compartment	Warning		Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	
	Air Conditioning (COND) page automatically appears on ECAM System/Status Display	Smoke falsely detected in cargo compartment			Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	
Aural Alerts	Continuous repetitive chime	Smoke falsely detected in cargo compartment	Warning		Inhibited during takeoff from 80 knots through 1,500 feet and landing from 800 feet through 80 knots (not this condition)	CRC is canceled by pressing master warning light
Tactile Alerts	None					

A320 Alerting Issues – In-flight cargo fire/smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise flight – Cont.

Visual Cues	None					
Aural Cues	Some indication that alarm is false, though extremely ambiguous, from negative reports from flight attendants or cargo supernumeraries about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- If the fire warning can be ascertained to be false, refrain from performing the cargo smoke procedure; otherwise perform the procedure
- If the fire warning terminates after performing the procedure and can be ascertained to have been false, continue the flight; otherwise land within the specified time limit
- Unless the fire warning can be ascertained to be false, if the fire warning system indicates that the fire has ****not**** been extinguished after performing the procedure, land immediately
- Unless the fire warning can be ascertained to be false, advise ground personnel not to open cargo compartments without prior clearance from ARFF.

How does pilot know condition is resolved/recovered?

- Previously illuminated Fwd or Aft light on cargo fire panel is extinguished
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment, assessing and communicating to the pilots that the fire warning was false.

A320 Alerting Issues – In-flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring hidden behind cabin interior

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	None until smoke reaches the flight deck	Smoke visible		Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Aural Cues	None until flight attendants call pilots on interphone or cargo supernumeraries advise pilots			Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Tactile/Somatic Cues	None					
Olfactory Cues	None until smoke is smelled			Cue may not be presented to pilots		

A320 Alerting Issues – In-flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring hidden behind cabin interior - Cont.

Expected Pilot Response(s)

- Perform SMOKE/FUMES/AVIONICS SMOKE paper QRH procedure (not annunciated).
- Perform appropriate smoke removal (SMOKE/FUMES REMOVAL) procedure if/as directed by the SMOKE/FUMES/AVIONICS SMOKE paper QRH procedure.
- Perform emergency descent as specified by NNP.
- Prepare for emergency landing, off-airport if necessary, as specified by NNP.
- Land immediately as specified by NNP.

How does pilot know condition is resolved/recovered?

- Pilots may receive information from flight attendants who are fighting the fire, including gaining access to hidden areas by removing panels.
- Situation cannot be resolved until aircraft has landed and crew performs emergency evacuation.

Issues with regard to multiple concurrent non-normal conditions

- Pilots may receive alerts/cues from failure conditions secondary to fire damage; it will be unclear to them to what extent they need to respond to these and how to prioritize their response.

A320 Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Accuracy Level "Low" displayed in amber on FMGC PROG page; and on the same page, the displayed EPE value exceeds the RNP value	EPE>RNP	Caution	PROG page must be manually selected by pilots to monitor navigation accuracy level		
	"NAV ACCUR DOWNGRAD" displayed on NDs	EPE>RNP	Caution			Alert cannot be cleared while condition is active
	Amber "NAV ACCUR DOWNGRAD" displayed on MCDU scratchpad	EPE>RNP	Caution			Alert can be cleared on MCDU keypad
	"GPS PRIMARY LOST" amber caution alert on Navigation Displays	GPS input to navigation system rejected when EPE > .28	Caution		Inhibited liftoff through 1500 feet and touchdown through end of flight	Alert cannot be cleared while condition is active
	Amber "GPS PRIMARY LOST" on MCDU scratchpad	GPS input to navigation system rejected when EPE > .28	Caution		Inhibited liftoff through 1500 feet and touchdown through end of flight	Alert can be cleared on MCDU keypad
	"TERR STBY" displayed on ECAM E/WD (green, or amber T-O thru 1500 feet and 800 feet to touchdown)	"FMS position error exceeds a specific limit "	Caution		Inhibited when >8000 feet above local terrain per database	
Aural Alerts	Triple-click alert	GPS primary lost (EPE>.28) while performing non-ILS approach	Caution			
Tactile Alerts	None					

A320 Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Cues	None					
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Perform ECAM procedure for NAV FMS/GPS POS DISAGREE (if it is presented).
- As directed by ECAM, verify position using alternative means (e.g., radar, DME).
- During GPS/RNAV/RNP approach, execute missed approach (also directed by the NNP but timely response is required so may not be able to wait for checklist).
- Using the NNP, consider turning off the terrain clearance warning system using GPWS TERR pushbutton.

How does pilot know condition is resolved/recovered?

- EPE<RNP.

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning.
- False terrain clearance warning.
- Loss of separation from air traffic (ADS or NextGen navigation/surveillance).

A320 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	"GPS PRIMARY LOST" on PFDs and Navigation Displays	Only if EPE>.28, in which case GPS input to navigation system is rejected; this may not happen in a spoofing that involves introduction of false GPS position	Caution		Inhibited liftoff through 1500 feet and touchdown through end of flight	Alert cannot be cleared while condition is active
	Amber "GPS PRIMARY LOST" on MCDU scratchpad	Only if EPE>.28, in which case GPS input to navigation system is rejected; this may not happen in a spoofing that involves introduction of false GPS position	Caution		Inhibited liftoff through 1500 feet and touchdown through end of flight	Alert can be cleared by (xxx)
	Accuracy Level "Low" displayed on FMGC PROG page, and on the same page the displayed EPE value exceeds the RNP value	Does not occur immediately when GPS input is lost, but rather, only if and when EPE degrades to >RNP	Caution	PROG page must be manually selected by pilots to monitor navigation accuracy level		
	On lower ECAM display: NAV FMS/GPS POS DISAGREE (amber) and AC POS...CHECK (blue)	FMC position differs from either GPS position by > .5nm	Caution		Inhibited 80 knots through liftoff	
	Master caution light	FMC position differs from either GPS position by > .5nm	Caution		Inhibited 80 knots through liftoff	
Aural Alerts	Triple-click alert	Only if GPS primary lost (EPE>.28) while performing non-ILS approach	Caution			
	Single chime	FMC position differs from either GPS position by > .5nm	Caution		Inhibited 80 knots through liftoff	

A320 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	None					
Visual Cues	Possible visible map shift, if the system makes a position change or correction while a pilot is looking at the navigation display					
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Perform ECAM procedure for NAV FMS/GPS POS DISAGREE.
- As directed by ECAM, verify position using alternative means (e.g., radar, DME).
- Identify false information.
- Eliminate source of false information from the position solution (de-select GPS).
- During GPS/RNAV/RNP approach, execute missed approach (also directed by the NNP but timely response is required so may not be able to wait for checklist).
- Using the NNP, consider turning off the terrain clearance warning system using GPWS TERR pushbutton.

A320 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS – Cont.

How does pilot know condition is resolved/recovered?

- Verifying position after reverting to alternative navigation.

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning.
- False terrain clearance warning.
- Loss of separation from air traffic (ADS or NextGen navigation/surveillance).

A320 Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	TCAS RA vertical guidance on PFD vertical speed scale: red avoid areas and green target areas	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
Aural Alerts	ATC Traffic Alert	Proximity detected by ATC radar/ conflict alert at system's threshold				
	TCAS RA aural warning	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
Tactile Alerts	None					
Visual Cues	TCAS display of traffic proximity on ND (filled red square for RA)	Proximity detected by TCAS at RA threshold			RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)

A320 Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Cues	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Maneuver vertically in response to TCAS RA directives.
- Prioritize TCAS RA information over ATC and visual detection information.
- Maneuver vertically and/or laterally as instructed by ATC.
- Maneuver vertically and/or laterally as prompted by visual closure rate and direction of movement.
- The system is designed with the expectation that the pilot will respond within 5 seconds.
- In the case of a corrective RA (e.g. a reversal) the system is designed to expect a pilot response within 2.5 seconds
- Pilot is expected to maintain the requested climb/descent until the aural "clear of conflict" is heard
- Report TCAS RA to ATC as soon as possible
- Caution for endangering passengers with unnecessarily abrupt compliance maneuvers

A320 Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation) – Cont.

How does pilot know condition is resolved/recovered?

- TCAS "Clear of conflict" aural.
- TCAS "Clear of conflict" aural.
- Visual detection/evaluation of divergence from previous closure rate.

A320 Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	ADS-In RA vertical guidance on PFD	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning	Future alert/cue designs may differ from current TCAS designs.		
Aural Alerts	ATM Traffic Alert	Proximity detected by ATM system at RA threshold				
	ADS-In RA aural warning	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning			
Tactile Alerts	None	None				
Visual Cues	ADS CDTI with conflict display on ND	CDTI conflict display system threshold				
	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation (N.B., closer traffic tolerances under NextGen)			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Maneuver the aircraft vertically and/or laterally as directed by ADS-In and CDTI systems.
- If aircraft response is automated, evaluate the validity of the ADS-In and CDTI alerts and monitor the aircraft response.
- If response is manual, execute the response within established next-gen collision avoidance system specifications.

A320 Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error) – Cont.

Issues with regard to multiple concurrent non-normal conditions

Cascading effects of RA response on NextGen traffic separation and metering.

A320 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	On the ND, the lateral path deviation value is displayed (in tenths of NM, with "L" or "R") immediately next to the airplane symbol (the RNP limit value is not displayed on the ND)	RNP limit for the aircraft, crew, and specific approach is manually entered by the crew on the FMGC PROG page		This cue requires scanning the ND (there is no color change or other alert when a deviation limit is exceeded) and also performing effortful comparison between the displayed crosstrack error and the limit value		
	On the ND, the aircraft symbol deviates from the dashed green line representing the flight planned track (lateral deviation)	RNP limit for the aircraft, crew, and specific approach				
Aural Cues	None					

A320 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- If not in visual contact with the runway, execute a missed approach.
- Hand fly lateral path during missed approach to within RNP limits (including RF leg) until automation can be re-engaged (1000 feet for 737).

How does pilot know condition is resolved/recovered?

- Flight path is recovered to within limits, as displayed on ND and FMGC PROG page RNP text display.

Issues with regard to multiple concurrent non-normal conditions

- Aircraft making a missed approach in response to this condition may complicate NextGen automated sequencing/metering or traffic separation.

A320 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	Possible ECAM red warning: OVERSPEED.	Indicated airspeed exceeds Vmo/Mmo, if a pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Warning			
	Possible flashing red master warning lights on forward panel	Triggered by OVERSPEED ECAM, if a pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Warning			

A320 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain's or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	Displayed mach/airspeed may become inconsistent with other pilot's and standby airspeed values					

A320 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Displayed mach/airspeed on failed input side may become inconsistent with commanded speed bug					
	Displayed mach/airspeed may become inconsistent with displayed attitude, considering phase of flight, altitude, thrust, and weight					

A320 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain's or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Displayed mach/airspeed may become inconsistent with FMGC ground speed/winds and inertial-derived groundspeed					
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Adjust airplane attitude and thrust to maintain aircraft control.
- Perform the UNRELIABLE AIRSPEED procedure to identify the incorrect airspeed source/display, switch to valid sources, and reference body angle/thrust values for desired performance, as required.
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II/III operations may be affected and destination choices may have to be altered.

A320 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain's or left source) – Cont.

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	ECAM amber caution: NAV ADR DISAGREE	One ADR is faulty or its input has been rejected by the flight control computers, and there is a speed disagreement between the two remaining ADRs	Caution	The system cannot detect airspeed source blockage or ADR failure unless it has at least one source that is different from the others; if all three fail simultaneously the system will not detect or alert.	Inhibited during takeoff from surface to 1,500 feet and during landing from 800 feet to touchdown	
	ECAM amber caution: FCTL ALTN LAW	One ADR is faulty or its input has been rejected by the flight control computers, and there is a speed disagreement between the two remaining ADRs	Caution	The system cannot detect airspeed source blockage or ADR failure unless it has at least one source that is different from the others; if all three fail simultaneously the system will not detect or alert.		
	ECAM red warning: AUTO FLT AP OFF	One ADR is faulty or its input has been rejected by the flight control computers, and there is a speed disagreement between the two remaining ADRs	Warning	This alert may roll the NAV ADR DISAGREE caution alert off the first ECAM screen, flagged only by the overflow arrow		

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	ECAM amber caution: ENG 1/2 EPR MODE FAULT	Loss of air data input to engines	Caution	This alert may roll the NAV ADR DISAGREE caution alert off the first ECAM screen, flagged only by the overflow arrow		
	Master caution lights on forward panels	Multiple ADR failure, EPR mode failure	Caution	The system cannot detect airspeed source blockage or ADR failure unless it has at least one source that is different from the others; if all three fail simultaneously the system will not detect or alert.		Canceled by pressing the master caution light
	EPR indicators turn red and EPR needles/numerics are blanked, on Engine/Warning Display	Loss of air data input to engines	Warning			
	FAULT light on ELAC pushbutton on overhead panel	ECAM ADR DISAGREE	Caution	The system cannot detect airspeed source blockage or ADR failure unless it has at least one source that is different from the others; if all three fail simultaneously the system will not detect or alert.		

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	THR LOCK flashing amber displayed on PFD (flashes every 5 seconds)	Autothrust disconnection due to ADR failure	Caution			
	Master caution lights on forward panels	Triggered by autothrust disconnect	Caution			Canceled by pushing master caution light
	ECAM amber caution: ENG THRUST LOCKED (flashing) and AUTO FLT A/THR OFF	Triggered by autothrust disconnect	Caution			
	ECAM red warning: OVERSPEED.	Sensed airspeed on at least one input channel exceeds $V_{mo}+4$ knots, or $M_{mo} + .006$. This warning may be false if the indicated mach/airspeed on the failed side exceeds V_{mo}/M_{mo} due to pitot system(s) input/ drain blockage and climb, or it may be valid if a pilot follows an incorrectly low airspeed value on a different display to	Warning	False warning may prompt pilots to react with control inputs that actually result in or exacerbate loss of control; a valid warning (such as a stall warning) may not be considered to be valid by the pilots because of this alert and falsely high airspeed on at least one display		(Cannot be canceled)

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
		fly the aircraft into an actual overspeed.				
Visual Alerts	Flashing red master warning lights on forward panel	Based on OVERSPEED ECAM. This warning may be false if the indicated mach/airspeed on the failed side exceeds Vmo/Mmo due to pitot system(s) input/ drain blockage and climb, or it may be valid if a pilot follows an incorrectly low airspeed value on a different display to fly the aircraft into an actual overspeed.	Warning	False warning may prompt pilots to react with control inputs that actually result in or exacerbate loss of control; a valid warning (such as a stall warning) may not be considered to be valid by the pilots because of this alert and falsely high airspeed on at least one display		(Cannot be canceled)

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Single chime	Multiple ADR failure	Caution	The system cannot detect airspeed source blockage or ADR failure unless it has at least one source that is different from the others; if all three fail simultaneously the system will not detect or alert.		
	Continuous repetitive chime	Triggered by autothrust disconnect	Warning			Canceled by pressing the master caution light
	Autopilot disconnect tone	Autopilot disconnect driven by ADR failure (s)	Warning			

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Continuous repetitive chime;	Based on OVERSPEED ECAM	Warning			
	STALL aural warning and cricket sounds (repetitive)	AOA	Warning			

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Tactile Alerts	None					
Visual Cues	Displayed mach/airspeed and/or altitude may fluctuate and/or become inconsistent with the other pilot's display and standby airspeed/altitude					
	Displayed mach/airspeed on failed input side may become inconsistent with commanded speed bug	This may occur as the climb continues with pressure sensed in pitot system(s) for which the input and drain are both blocked occur under certain failure condition, or if a pilot who is hand flying follows false cues from the airspeed/altitude displays on the failed side.		If the FMGC/autopilot is engaged at failure onset, it remains engaged and votes out the failed input, using the remaining two valid inputs until the second and/or third ADR fail due		

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
				to loss of source input		

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)– Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Displayed mach/airspeed may become inconsistent with displayed attitude, considering phase of flight, altitude, thrust, and weight	This may occur under certain failure conditions if the aircraft's altitude changes, or in any case if a pilot who is hand flying follows false cues from the airspeed/altitude displays on the failed side; in contrast, if the FMGC/autopilot is engaged at failure onset, it remains engaged and votes out the failed input, using the remaining two valid inputs until the second and/or third ADR fail due to loss of source input		Aircraft control requires effortful reference to and integration of pitch/power displays, considering multiple additional factors (weight, configuration, etc.) that must be recalled from memory or looked up		
	Displayed mach/airspeed may become inconsistent with FMGC ground speed/winds, inertial-displayed groundspeed	This may occur under certain failure conditions if the aircraft's altitude changes, or in any case if a pilot who is hand flying follows false cues from the airspeed/altitude displays on the failed side; in contrast, if the FMGC/autopilot is engaged at failure onset, it remains engaged and votes out the failed input, using the remaining two valid inputs until the second and/or third ADR fail due to loss of source input		Aircraft control requires effortful reference to multiple displays on the overhead panel and FMGC MCDU, both of which may require switch selections or button pushes to display the relevant data, as well as consideration of multiple additional factors (winds aloft, true airspeed correction, etc.) that must be recalled from memory or looked up		

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Visual Cues	Flight director bars disappear (may reappear)	FD bars are inhibited when two or more of the airspeed sources are failed/inconsistent		Pilots may be dependent on FD guidance		
Aural Cues	None					
Tactile/Somatic Cues	Aerodynamic buffet	Actual overspeed or approach to stall				

Expected Pilot Response(s)

- Disconnect autopilot/autothrust adjust airplane attitude and thrust to maintain aircraft control.
- Perform NAV ADR DISAGREE procedure to identify the incorrect airspeed displays, use secondary airspeed indications of flight path vector and AOA (if installed), and reference body angle/thrust values for desired performance.
- After all airspeed sources are lost, recognize the need for and perform ADR 1+2+3 procedure (unannunciated).
- Per NAV ADR DISAGREE or ADR 1+2+3 procedures, interrupt these procedures to perform the ADR CHECK procedure (unannunciated), including UNRELIABLE AIRSPEED memory items.
- Per the ADR 1+2+3 procedure, assess impact of failure on other systems (e.g., auto pressurization, normal gear extension, landing gear retraction, reversion to alternate law and then to direct law with gear down, rudder travel limiter, windshear detection, GPWS, TCAS, RAT auto extension).
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations may be affected and destination choices may have to be altered.

A320 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Issues with regard to multiple concurrent non-normal conditions

- Normal law protections are lost.
- Issue of multiple alerts generated by this failure condition, including relevant ECAM alerts and procedural actions rolling to overflow pages of the Engine/Warning Display, multiple simultaneous visual alerts generated by primary and secondary failures, and multiple simultaneous aural alerts generated by primary and secondary failures.

A320 Alerting Issues – Air data system failure

3. Initiating Condition: Air data computer failure (single module or unit)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PFD on failed ADR side displays red SPD, ALT, and MACH warnings (flashing then steady)	Loss of source input	Warning			Press master caution light to cancel
	ECAM Amber caution: NAV ADR 1 FAULT	ADR failure detected	Caution			
	ECAM amber caution: TCAS FAULT	ADR failure detected	Caution			
	Master caution amber light	ADR failure detected	Caution			
	Red TCAS warning on ND	ADR failure detected	Warning			
	Amber ADR FAULT light on overhead ADIRS panel	ADR failure detected	Caution			
Aural Alerts	Single chime	ADR failure detected	Caution			
Tactile Alerts	None					

A320 Alerting Issues – Air data system failure

3. Initiating Condition: Air data computer failure (single module or unit) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Airspeed operating ranges are blanked on the failed side PFD	Loss of source input				
	Airspeed indicators (commanded and actual) are blanked on the failed side PFD	Loss of source input for overspeed				
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Turn over control to other pilot, if necessary.
- Re-engage autopilot using other side if it disengaged.
- Perform NAV ADR 1 FAULT procedure to restore displays.
- Per the NAV ADR 1 FAULT procedure, assess impact of failure on other systems (e.g., enhanced GPWS, Cat III dual, TCAS).

APPENDIX D

Boeing 737NG Matrices

B737NG Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Flashing amber box on digital airspeed display	AOA-compensated airspeed, not g-compensated	Caution			Increased airspeed
	PLI on PFD/EADI nears/touches airplane symbol	AOA				Reduction of AOA
Aural Alerts	Airspeed Low (if installed based on EGPWS model)	AOA-compensated airspeed, not g-compensated				Increased airspeed
	Stick shaker (sound of)	AOA	Warning			Reduction of AOA
Tactile Alerts	Stick shaker	AOA	Warning			Reduction of AOA
Visual Cues	Airspeed indication in amber or red/black range	Top of amber band is minimum maneuvering speed (AOA compensated but not g-compensated). Bottom of amber=top of red/black band is stick shaker onset and is g-compensated. (See B737 FCTM p. 1.4)				Reduction of AOA

B737NG Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Amber “LE Devices” on Annunciator Panel	Approaching stall angle of attack	Caution		As the aircraft approaches the stall angle, the slats automatically drive to the FULL EXTEND position prior to stick shaker activation.	The slats return to the EXTEND position when the pitch angle is sufficiently reduced below the stall critical attitude.
	PFD/ADI indications of uncommanded pitch					
	Roll rate on PFD/EADI				Uncommanded roll cues masked by autopilot roll inputs until the a/p disconnects (appears as wheel deflection, see below); however, rapid roll may accompany a/p disconnect at the stall.	

B737NG Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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	Sink rate on vertical speed display					
	Wheel may move opposite the roll if autopilot is engaged					
	Trim wheel motion					
Aural Cues	None					
Tactile/Somatic Cues	Aerodynamic buffet	AOA (natural)	Can be confused with high speed buffet			Reduction of AOA

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

How does pilot know condition is resolved/recovered?

B737NG Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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- Cessation of stall warning alerts.

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

B737NG Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Flashing amber box on digital airspeed display	AOA-compensated airspeed, not g-compensated	Caution			Increased airspeed
	PLI on PFD/EADI nears/touches airplane symbol	AOA				Reduction of AOA
	Red/black band on airspeed indicator rising towards airspeed pointer	Bottom of amber band=top of red/black band is stick shaker onset and is g (AOA) compensated			Airspeed cues depend on proper AOA compensation	Reduction of AOA
Aural Alerts	"Airspeed Low" (if installed based on EGPWS model)	AOA-compensated airspeed, not g-compensated				Increased airspeed
	Stick shaker (sound of)	AOA	Warning			Reduction of AOA
	GPWS "Bank angle"	Bank angle >35 degrees		This is not an alert to the stall, but rather to the excessive bank angle from the roll upset		Reduction of bank angle
Tactile Alerts	Stick shaker	AOA	Warning			Reduction of AOA
Visual Cues	Airspeed indication in amber or red/black band	Top of amber band is minimum maneuvering speed (not g-compensated). Bottom of amber=top of red/black band is stick shaker onset and is g (AOA) compensated			Airspeed cues depend on proper AOA compensation	Reduction of AOA

B737NG Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Visual Cues	PFD/ADI indications of uncommanded pitch			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Roll rate of PFD/EADI			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Sink rate on vertical speed display			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
Aural Cues	Wind noise					
Tactile/Somatic Cues	Unusual wheel/column forces			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		

B737NG Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

	Aerodynamic buffet	AOA (natural)		Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
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Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

How does pilot know condition is resolved/recovered?

- Termination of stall warning alerts.

Issues with regard to multiple concurrent non-normal conditions

- Recovery from stall condition must be followed immediately by recovery from nose-low, high bank upset condition.
- Possible passenger injuries and aircraft damage.

B737NG Alerting Issues – Stall

3. Initiating: Wing ice accumulation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None: PLI is present but may not be touching the aircraft symbol when the stall occurs (suggesting to the pilot that the aircraft is not stalling)				Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Aural Alerts	None				Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Tactile Alerts	None			Pilots are trained extensively to associate stick shaker as trigger to stall recovery; in absence of stick shaker (warning system failure or stall at lower-than-nominal AOA) they may not interpret the secondary cues of buffet, roll, etc. as being related to stall.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Visual Cues	None: airspeed appears to be adequate but is not; airplane may stall while indicated airspeed is in the amber band but not in or touching the red/black band			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	

B737NG Alerting Issues – Stall

3. Initiating: Wing ice accumulation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD/ADI indications of uncommanded pitch			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Roll rate of PFD/EADI			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Sink rate on vertical speed display			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
Aural Cues	None			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	

B737NG Alerting Issues – Stall

3. Initiating: Wing ice accumulation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile/ Somatic Cues	Buffet; unusual wheel/column forces (autopilot off) or displacements (autopilot on)	AOA (natural)		Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	Reduction of AOA

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

How does pilot know condition is resolved/recovered?

- Difficult to know, related to cessation of uncommanded pitch/roll/sink.

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

B737NG Alerting Issues – Stall

4. Initiating: False stall warning during takeoff rotation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PLI touches airplane symbol on PFD/EADI (false indication)	AOA			Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
Aural Alerts	Stick shaker, sound of (false indication)	AOA	Warning		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
Tactile Alerts	Stick shaker (false indication)	AOA	Warning		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
Visual Cues	Normal vertical speed, altimeter, and airspeed indications on PFD, as well as view through the windshield of the aircraft climbing (if VMC) are subtle cues that the aircraft is not stalling					
Aural Cues	None					

B737NG Alerting Issues – Stall

4. Initiating: False stall warning during takeoff rotation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile/ Somatic Cues	Normal vertical acceleration from rotation into climb is a subtle cue that the aircraft is not stalling					

Expected Pilot Response(s)

- Ignore false alerts and cues.
- Do not reject takeoff.

How does pilot know condition is resolved/recovered?

- Observe normal takeoff and climb performance.

Issues with regard to multiple concurrent non-normal conditions

- None unless pilot takes unneeded actions, such as high speed RTO.

B737NG Alerting Issues – Uncommanded yaw or roll

1. Initiating Condition: Wake encounter

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PFD bank pointer turns amber	Bank angle > 35 degrees	Caution			Reduction of bank angle
Aural Alerts	GPWS "Bank Angle"	35, 40, and 45-degree bank angle				
Tactile Alerts	None					
Visual Cues	Roll rate on PFD/EADI					
Aural Cues	None					
Tactile/Somatic Cues	Wheel may move opposite the roll if autopilot is engaged.					

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle.
- Verify symmetrical thrust.
- Confirm spoilers are retracted
- Apply opposing roll and/or yaw inputs to control aircraft attitude.
- Recover from nose-down upset if necessary.

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained.

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset.

B737NG Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PFD bank pointer turns amber	Bank angle > 35 degrees	Caution			Reduction of bank angle
Aural Alerts	GPWS "Bank Angle"	35, 40, and 45-degree bank angle				
Tactile Alerts	None					
Visual Cues	Roll rate on PFD/EADI					
	Yaw rate on ND/EHSI					
Aural Cues	None					
Tactile/Somatic Cues	Lateral-g					
	Rudder pedals may deflect in rudder hardover (but not in yaw damper malfunction)			Interpretation of rudder and wheel deflections can be difficult because the direction of deflection (into or opposite the yaw) depends on the underlying cause		

B737NG Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile/Somatic Cues	Wheel may move opposite the roll if autopilot is engaged			Interpretation of rudder and wheel deflections can be difficult because the direction of deflection (into or opposite the yaw) depends on the underlying cause		

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle.
- Verify symmetrical thrust.
- Confirm spoilers are retracted
- Apply opposing roll and/or yaw inputs to control aircraft attitude, using significant force if necessary.
- Reduce AOA/pitch/altitude as required to regain roll authority.
- Disconnect yaw damper.
- Recover from nose-down upset if necessary.
- Perform "Jammed or Restricted Flight Controls" procedure, selecting the rudder branch of the checklist.

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained and uncommanded control deflections have been either neutralized or compensated for in all anticipated circumstances for the remainder of the flight.
- If there are residual uncommanded control deflections or pressures, there may be operational implications through to landing (e.g., crosswind limitations).

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset.

B737NG Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Amber "LE Flaps Transit" light on forward panel, under some conditions	If condition is a LE slat/flap out of the commanded position, this light illuminates when the LE flap/slat position is inconsistent with the TE flap position	Caution			
	PFD bank pointer turns amber	Bank angle > 35 degrees	Caution			Reduction of bank angle
Aural Alerts	GPWS "Bank Angle"	35, 40, and 45- degree bank angle				
Tactile Alerts	None					
Visual Cues	Roll rate on PFD/EADI, flap/slat gauge indications if involved					
Aural Cues	None					
Tactile/ Somatic Cues	Wheel may move opposite the roll if uncommanded flap/slat/aileron/spoiler deflection and autopilot is engaged; however, wheel may move in same direction as roll if landing gear mechanism interferes with aileron/spoiler controls or other malfunction occurs.			Interpretation of wheel deflection is difficult because the direction of deflection (into or opposite the roll) depends on the underlying cause		

B737NG Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat – Cont.

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle.
- Verify symmetrical thrust.
- Confirm spoilers are retracted
- Apply opposing roll and/or yaw inputs to control aircraft attitude, using significant force if necessary to activate breakout features in the event of control jam.
- Recover from nose-down upset if necessary

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained and uncommanded control deflections have been either neutralized or compensated for in all anticipated circumstances for the remainder of the flight.
- If there are residual uncommanded control deflections or pressures, there may be operational implications through to landing (e.g., crosswind limitations).

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset.

B737NG Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (B), in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution light	Low pump pressure, difference in sensed system A/B pressures at elevator feel computer	Caution			Pressing the M/C light
	Amber Hyd indication on FO annunciator panel	Low pump pressure	Caution			(Alerts/cues are not terminated)
	Amber Flight control indication on CA annunciator panel	Difference in sensed system A/B pressures at elevator feel computer, low system B pressure sensed at flight controls	Caution			(Alerts/cues are not terminated)
	System B engine pump low pressure amber light on overhead panel	Low pump pressure	Caution			(Alerts/cues are not terminated)
	System B electric pump low pressure amber light on overhead panel	Low pump pressure	Caution			(Alerts/cues are not terminated)
	Feel differential pressure amber light on overhead panel	Difference in sensed system A/B pressures at elevator feel computer	Caution			(Alerts/cues are not terminated)
	System B flight control low pressure amber light on overhead panel	Low system B pressure sensed at flight controls	Caution			Terminated as part of the non-normal procedure when System B Flight Control Switch is set to STBY RUD

B737NG Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (B), in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Autopilot disconnect horn if A/P B engaged	Autopilot disconnect driven by loss of hydraulic pressure		Pilot reversion to hand-flying, even for the short period until engaging autopilot A, is a workload spike as well as a distraction.		Pilot pressing autopilot disconnect button twice
Tactile Alerts	None					
Visual Cues	Low pressure and quantity readings on System B hydraulic quantity gauges (pressure indicator needle turns amber/red, quantity shows near zero and "RF" in white) (PFD/ND version= no analog gauge, no amber/red needle) (Page is not normally displayed)					(Alerts/cues are not terminated)
Aural Cues	None					
Tactile/ Somatic Cues	None					

B737NG Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (B), in cruise flight – Cont.

Expected Pilot Response(s)

- Identify condition.
- Identify correct checklist.
- Perform checklist.
- Identify follow-on requirements (flaps, spoilers, landing distance, commitment to destination once LE slats extended).
- Implement follow-on requirements (flaps, spoilers, landing distance, commitment to destination once LE slats extended) at the appropriate phase of flight.

How does pilot know condition is resolved/recovered?

- Completion of procedures results in stable situation but abnormal condition for landing (e.g., longer landing distance); system cannot be recovered to normal operation.

Issues with regard to multiple concurrent non-normal conditions

- Simultaneous hydraulic and flight control system conditions.
- Challenge of dealing with the concurrent and continuing failures resulting from the initiating condition (e.g., flaps, slats, autopilot, etc.).

B737NG Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other Issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	"ENG FAIL" on respective EGT indicator (forward panel upper display unit) or PFD as installed	N2 rpm less than 50%	Warning			ENG FAIL alert is removed when the failed engine recovers or has been secured
	Low Oil Pressure light on forward panel (may precede the ENG FAIL alert, be simultaneous with it, or be seconds after it depending on cause of engine failure)	Loss of oil pressure	Caution		Blinking of amber alert boxes is inhibited during takeoff from 80 knots to 400 RA. Alert still illuminates amber, though	
	Master caution light	Driven by hydraulic and/or source off annunciations	Caution			
	Low oil pressure pointer turns amber/red and enters amber/red band (PFD/ND installations, on lower DU, others on upper DU)	Loss of oil pressure	Warning			
	Hydraulic annunciator with master caution (usually alerts seconds after ENG FAIL as adequate hydraulic pressure is maintained for a while by a wind milling engine)	Loss of engine driven pump output pressure due to reduced N2 rpm	Caution			Alert terminated when/if fire switch is pulled (disarms engine driven hydraulic pump low pressure indication)
	SOURCE OFF light and IDG DRIVE light on overhead panel with ELEC annunciator light with Master Caution (presented after but may be almost simultaneous with ENG FAIL alert)	Engine driven generator (IDG) drops off line due to reduced N2 rpm	Caution			SOURCE OFF alert terminated when respective bus is covered by APU
Aural Alerts	None					

B737NG Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other Issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	None					
Visual Cues	Abnormal EGT, N1, N2, oil temperature, and/or oil pressure gauge indications					
	Nose yawing off runway centerline					
Aural Cues	Sounds of engine malfunction may occur					
Tactile/Somatic Cues	Lateral g					
	Rudder pressure required to stay on runway					
	Reduced longitudinal acceleration					

Expected Pilot Response(s)

- Control the aircraft.
- Execute single engine takeoff/climb profile.
- Identify and execute appropriate non-normal checklist.

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Uncontained engine failure may present additional multiple alerts and failures.

B737NG Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other Issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	"ENG FAIL" on respective EGT indicator (forward panel upper display unit)	N2 rpm less than 50%	Warning			ENG FAIL alert is removed when the failed engine has been secured
	Low Oil Pressure light on forward panel, amber and also three associated boxes blink for first 10 seconds (may precede the ENG FAIL alert, be simultaneous with it, or be seconds after it depending on cause of engine failure)	Loss of oil pressure	Caution			
	Low oil pressure pointer turns amber/red and enters amber/red band (PFD/ND installations, on lower DU, others on upper DU)	Loss of oil pressure				
	Hydraulic annunciator with Hyd master caution (usually alerts seconds after ENG FAIL as adequate hydraulic pressure is maintained for a while by a wind milling engine)	Loss of engine driven pump output pressure due to reduced N2 rpm	Caution			Alert terminated when/if fire switch is pulled (disarms engine driven hydraulic pump low pressure indication)

B737NG Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged – Cont.

Visual Alerts	SOURCE OFF light and IDG DRIVE light on overhead panel with ELEC annunciator light (presented after but may be almost simultaneous with ENG FAIL alert)	Engine driven generator (IDG) drops off line due to reduced N2 rpm	Caution			Source Off alert terminated when respective bus is covered by APU
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	Abnormal EGT, N1, N2, oil temperature, and/or oil pressure gauge indications					
Aural Cues	Sounds of engine malfunction may occur					
Tactile/ Somatic Cues	Wheel may move opposite the roll if autopilot is engaged					Control wheel displacement cues are reduced/eliminated after trimming the rudder

Expected Pilot Response(s)

- Control the aircraft.
- Identify and execute appropriate non-normal checklist.
- Perform single engine approach and landing.

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Uncontained engine failure may present additional multiple alerts and failures.

B737NG Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other Issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master fire warning light (red, forward panel)	Temperature sensed by engine fire loop	Warning			
	Master caution light (amber, forward panel)	Temperature sensed by engine fire loop	Caution			
	OVHT/DET annunciator light (amber, forward panel)	Temperature sensed by engine fire loop	Caution			
	Fire switch light (red, center console)	Temperature sensed by engine fire loop	Warning			
	Engine overheat light (amber, center console)	Temperature sensed by engine fire loop	Caution			
Aural Alerts	Fire bell	Temperature sensed by engine fire loop	Warning			
Tactile Alerts	None unless engine also fails					
Visual Cues	None unless engine also fails					
Aural Cues	None					
Tactile/ Somatic Cues	None unless engine also fails					

B737NG Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

Expected Pilot Response(s)

- Control the aircraft.
- Execute V1 engine failure/fire flight profile.
- Execute engine fire procedure (begin procedure above 400 feet or immediately upon reaching single engine acceleration altitude, this is earlier than for engine failure procedure).
- Perform single engine approach/landing procedures.

How does pilot know condition is resolved/recovered?

- Fire warning indication that fire is extinguished.

Issues with regard to multiple concurrent non-normal conditions

- Engine fire will devolve to an engine failure, either as a direct result of and simultaneous with the fire onset or as part of the engine fire procedure.
- Engine fire presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Engine fire may present cascading emergency (e.g., hydraulic failures, smoke in cabin, etc.).
- Uncontrollable fire may present additional, cascading conditions (e.g., structural failure, fuel loss, need to expedite landing, or even land off-airport).

B737NG Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak, during takeoff after V1 and before V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other Issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master fire warning light (red, forward panel)	Temperature sensed by engine fire loop	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.	Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished	Lower temperature sensed by engine fire loop
	Master caution light (amber, forward panel)	Temperature sensed by engine fire loop	Caution	False fire warning can lead to unneeded RTO, engine shutdown, etc.	Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished	Lower temperature sensed by engine fire loop
	OVHT/DET annunciator light (amber, forward panel)	Temperature sensed by engine fire loop	Caution	False fire warning can lead to unneeded RTO, engine shutdown, etc.	Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished	Lower temperature sensed by engine fire loop
	Fire switch light (red, center console)	Temperature sensed by engine fire loop	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.	Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished	Lower temperature sensed by engine fire loop
	Engine overheat light (amber, center console)	Temperature sensed by engine fire loop	Caution	False fire warning can lead to unneeded RTO, engine shutdown, etc.	Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished	Lower temperature sensed by engine fire loop

B737NG Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak, during takeoff after V1 and before V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other Issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Aural Alerts	Fire bell	Temperature sensed by engine fire loop	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.	Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished	Bell canceled by the pilots as part of procedure
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Control the aircraft.
- Execute V1 engine failure/fire flight profile.
- Execute engine fire procedure (begin procedure above 400 feet or immediately upon reaching single engine acceleration altitude, this is earlier than for engine failure procedure).
- Perform single engine approach/landing procedures.
- If fire cannot be extinguished, expedite landing.

Issues with regard to multiple concurrent non-normal conditions

- False indication of engine fire will likely devolve to an engine failure as part of the engine fire procedure.
- If false indication of fire continues after engine fire NNPs are performed, pilot concerns about inextinguishable fire may prompt risky alternative actions (e.g., rushing, off-airport landing, etc.).

B737NG Alerting Issues – In flight cargo/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other Issues with regard to Alert or Cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master "Fire Warn" red lights on forward panel	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system	Master Fire Warn lights are cancelled by pressing a Master Fire Warn light
	"Aft" or "Fwd" red light on center console cargo fire panel	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system	Illuminated Fwd or Aft light on cargo fire panel is extinguished when the fire detection system assesses that the fire has been extinguished
Aural Alerts	Fire Bell	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system	Fire Bell is cancelled by pressing a Master Fire Warn light
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	Possible reports from flight attendants or cargo supernumeraires about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/Somatic Cues	None					

B737NG Alerting Issues – In flight cargo/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise – Cont.

Expected Pilot Response(s)

- Perform the appropriate cargo fire procedure.
- Perform cargo fire test to verify fire detection system integrity.
- Land within the required time limit.
- Advise ground personnel not to open cargo compartments without prior clearance from ARFF.

Possible sources of confusion with regard to pilot response(s)

- History of false fire/smoke detector alarms can cause pilots to downplay or discount a valid warning.
- Difficult/impossible to distinguish with certainty an active fire from minor or leftover smoke, or from a false alarm caused by dust or other triggers.
- Even once the pilots know that a fire situation is ongoing, they do not necessarily know the seriousness of the situation, the future course of the fire, or the time available for continued safe flight. Consequently, they will have difficulty projecting the best course of action and the time available for implementing it.

How does pilot know condition is resolved/recovered?

- Previously illuminated Fwd or Aft light on cargo fire panel is extinguished.
- Fire damage to fire/smoke detection system can cause pilots to mistakenly believe that a fire has been extinguished when it actually continues to burn; need to test fire detection system, and this may not be included in the NNP.
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment and (if necessary) the aircraft has been evacuated.

Issues with regard to multiple concurrent non-normal conditions

- Warnings/alerts/cues of other system failures (e.g., electrical, pneumatic, hydraulic) may be presented if these systems or associated detectors receive fire damage; these indications may distract the pilots' attention from responding to the primary fire situation or mask the primary situation.
- On the other hand, these secondary failures may require additional responses by the pilots, and the optimal prioritization of pilot response to these multiple cues may be unclear.

B737NG Alerting Issues – In flight cargo/smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise

Sensory Modality	Alert or Cue	Threshold for Alert or Cue to be Presented	Type of Alert	Other Issues with regard to Alert or Cue	When alert is inhibited/ suppressed or when cue is masked	How Alert or Cue is terminated
Visual Alerts	Master "Fire Warn" red lights on forward panel	Smoke falsely detected in cargo compartment	Warning			Master Fire Warning lights are canceled by pressing a Master Fire Warn light
	"Aft" or "Fwd" red light on center console cargo fire panel	Smoke falsely detected in cargo compartment	Warning			Illuminated light on fire panel is extinguished when the fire detection system assesses that the fire has been extinguished
Aural Alerts	Fire Bell	Smoke falsely detected in cargo compartment	Warning			Fire Bell is canceled by pressing a Master Fire Warn light
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	Some indication that alarm is false, though extremely ambiguous, from negative reports from flight attendants or cargo supernumeraries about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/Somatic Cues	None					

B737NG Alerting Issues – In flight cargo/smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise – Cont.

Expected Pilot Response(s)

- If the fire warning can be ascertained to be false, refrain from performing the cargo fire procedure; otherwise perform the procedure
- If the fire warning terminates after performing the procedure and can be ascertained to have been false, continue the flight; otherwise land within the specified time limit.
- Unless the fire warning can be ascertained to be false, if the fire warning system indicates that the fire has not been extinguished after performing the procedure, land immediately.
- Unless the fire warning can be ascertained to be false, advise ground personnel not to open cargo compartments without prior clearance from ARFF.

How does pilot know condition is resolved/recovered?

- Previously illuminated Fwd or Aft light on cargo fire panel is extinguished.
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment, assessing and communicating to the pilots that the fire warning was false.

B737NG Alerting Issues – In flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring hidden behind cabin

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other Issues with regard to Alert or Cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	None until smoke reaches the flight deck	Smoke visible		Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Aural Cues	None until flight attendants call pilots on interphone or cargo supernumeraries advise pilot			Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Tactile/Somatic Cues	None					
Olfactory Cues	None until smoke is smelled			Cue may not be presented to pilots		

B737NG Alerting Issues – In flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring hidden behind cabin – Cont.

Expected Pilot Response(s)

- Perform appropriate cabin fire/smoke procedure (SMOKE, FIRE OR FUMES).
- Perform appropriate smoke removal (SMOKE OR FUMES REMOVAL) procedure if/as directed by the SMOKE, FIRE OR FUMES procedure.
- Perform emergency descent as specified by NNP.
- Prepare for emergency landing, off-airport if necessary, as specified by NNP.
- Land immediately as specified by NNP.

How does pilot know condition is resolved/recovered?

- Pilots may receive information from flight attendants who are fighting the fire, including gaining access to hidden areas by removing panels.
- Situation cannot be resolved until aircraft has landed and crew performs emergency evacuation.

Issues with regard to multiple concurrent non-normal conditions

- Pilots may receive alerts/cues from failure conditions secondary to fire damage; it will be unclear to them to what extent they need to respond to these and how to prioritize their response.

B737NG Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Text Alert "Unable Req'd Nav Perf-RNP" on FMS CDU scratchpad	ANP>RNP	Caution	Text messages on FMS scratchpad can be inadequately salient. Also, once cleared by pilot action, they may not be re-displayed		When ANP<RNP
	"FMC" amber annunciation on forward panel	Driven by UNABLE REQD NAV PERF-RNP message	Caution			When ANP<RNP
	"Msg" amber alert on FMS CDU	Driven by UNABLE REQD NAV PERF-RNP message	Caution	Text messages on FMS scratchpad can be inadequately salient. Also, once cleared by pilot action, they may not be re-displayed		When ANP<RNP
	PFD/EADI Navigation Performance Scales/ANP Bars flash first 10 seconds of exceedence, turn amber if exceeded 10 seconds (if installed)	ANP>RNP	Caution			When ANP<RNP
	RNP/ANP alphanumeric under airplane symbol turns amber (if installed)	ANP>RNP	Caution			
	Amber TERR POS annunciation on Nav Display	ANP>RNP (B737 manuals refer to this only as "positional uncertainty" while B777 manuals specify ANP>RNP)	Caution			When ANP<RNP

B737NG Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	RAIM forecast message from dispatch during preflight planning or update inflight via ACARS	Inadequate satellite availability/ geometry as detected by RAIM forecast analysis performed by dispatch (inflight update can be generated by dispatch or requested by pilots)		May not be provided before flight if RNP approach not anticipated		
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	ANP value greater than RNP value on CDU legs/progress page					When ANP<RNP
Aural Cues	None					
Tactile/ Somatic Cues	None					

B737NG Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity – Cont.

Expected Pilot Response(s)

- Perform procedure for UNABLE REQD NAV PERF-RNP.
- Return to ground-based navigation, if any, as directed by the NNP.
- During RNP approach, execute missed approach (also directed by the NNP but timely response is required so may not be able to wait for checklist).

How does pilot know condition is resolved/recovered?

- Lookup of FMS CDU page displaying ANP/ RNP; inspection of ANP/RNP values.

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning.
- False terrain clearance warning.
- Loss of separation from air traffic (ADS or NextGen navigation/surveillance).

B737NG Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	"VERIFY POSITION-FMC-GPS. IRS-FMC or FMC-RADIO" alert on FMS CDU scratchpad (U10.8 software and later only)	GPS position differs from IRS, Radio, and/or mixed-source FMS position	Caution	Text messages and alerts on FMS scratchpad can be inadequately salient. Also, once cleared they may not be re-displayed. Alerting and cueing depends on continued operation of multi-mode navigation, with at least inertial position inputs. The alerting threshold for "VERIFY POSITION" likely far exceeds RNP values for all but Oceanic procedural separation, so these alerts may be of limited safety value in current RNP or future Next Gen operations.		When position difference has been reduced to within limits or the inaccurate position source has been manually deselected from the FMS solution
	MSG amber annunciation on FMS CDU	Driven by VERIFY POSITION message	Caution			
	"FMC" amber alert on forward panel	Driven by VERIFY POSITION message	Caution			
	PFD/EADI Navigation Performance Scales/ANP Bars flash first 10 seconds of exceedence, turn amber if exceeded 10 seconds (if installed)	Only presented in subset of conditions in which calculated ANP>RNP	Caution			When ANP<RNP

B737NG Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS – cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	RNP/ANP alphanumeric under airplane symbol turns amber (if installed)	Only presented in subset of conditions in which calculated ANP>RNP	Caution			
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	ANP value greater than RNP value on CDU legs/progress page	Only presented in subset of conditions in which calculated ANP>RNP				When ANP<RNP
	Possible visible map shift, if the system makes a position change or correction while a pilot is looking at the navigation display					
Aural Cues	None					
Tactile/ Somatic Cues	None					

B737NG Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS – cont.

Expected Pilot Response(s)

- Verify position using alternative means (e.g. radar, DME).
- Identify false information.
- Eliminate source of false information from the position solution.

How does pilot know condition is resolved/recovered?

- Verifying position after reverting to alternative navigation.

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning.
- False terrain clearance warning.
- Loss of separation from air traffic (ADS or NextGen navigation/surveillance).

B737NG Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	TCAS RA vertical guidance on PFD/EADI: red avoid lines on PFD attitude and/or vertical speed areas	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, wind shear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
	TCAS red TRAFFIC message on ND	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, wind shear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
Aural Alerts	ATC Traffic Alert	Proximity detected by ATC radar/ conflict alert at system's threshold				
	TCAS RA aural warning	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, wind shear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
Tactile Alerts	None					
Visual Cues	TCAS display of traffic proximity on ND (filled red square for RA)	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, wind shear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)

B737NG Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Maneuver vertically in response to TCAS RA directives.
- Prioritize TCAS RA information over ATC and visual detection information.
- Maneuver vertically and/or laterally as instructed by ATC.
- Maneuver vertically and/or laterally as prompted by visual closure rate and direction of movement.
- The system is designed with the expectation that the pilot will respond within 5 seconds.
- In the case of a corrective RA (e.g. a reversal) the system is designed to expect a pilot response within 2.5 seconds
- Pilot is expected to maintain the requested climb/descent until the aural "clear of conflict" is heard
- Report TCAS RA to ATC as soon as possible
- Caution for endangering passengers with unnecessarily abrupt compliance maneuvers

B737NG Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation) – Cont.

How does pilot know condition is resolved/recovered?

- TCAS "Clear of conflict" aural.

B737NG Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	ADS-In RA vertical guidance on PFD/EADI	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning	Future alert/cue designs may differ from current TCAS designs.		
Aural Alerts	ATM Traffic Alert	Proximity detected by ATM system at RA threshold				
	ADS-In RA aural warning	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning			
Tactile Alerts	None	None				
Visual Cues	ADS CDTI with conflict display on EHSI/ND	CDTI conflict display system threshold				
	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation (N.B., closer traffic tolerances under NextGen)			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/ Somatic Cues	None					

B737NG Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error) – Cont.

Expected Pilot Response(s)

- Maneuver the aircraft vertically and/or laterally as directed by ADS-In and CDTI systems.
- If aircraft response is automated, evaluate the validity of the ADS-In and CDTI alerts and monitor the aircraft response.
- If response is manual, execute the response within established next-gen collision avoidance system specifications.

Issues with regard to multiple concurrent non-normal conditions

- Cascading effects of RA response on NextGen traffic separation and metering.

B737NG Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PFD/EADI Navigation Performance Scales/ANP Bars (flash first 10 seconds of exceedence, turn amber if exceeded 10 seconds) (if installed)	Track deviation exceeds RNP as adjusted for ANP. RNP limit for the aircraft, crew, and specific approach is manually entered by the pilots	Caution	Unless the NPS are installed, there is no alert for excessive crosstrack error.		Track restored within limits
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	On the FMS CDU Progress Page 4, the crosstrack error value on exceeds RNP value	RNP limit for the aircraft, crew, and specific approach		These cues require scanning (including obtaining the proper CDU page and incorporating that display into the instrument scan, which is unusual; and interpretation		
	On the ND, the lateral path deviation value is displayed (in tenths of NM, with "L" or "R") immediately below the airplane symbol (if installed)			If this feature is not installed, the lateral track deviation value is only available on the FMS CDU Progress Page 4.		

B737NG Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	On the ND, the aircraft symbol deviates from the magenta line (lateral deviation); and/or the PDI deviates from the center of the path deviation scale (vertical deviation)	RNP limit for the aircraft, crew, and specific approach				
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- If not in visual contact with the runway, execute a missed approach.
- Hand fly lateral path during missed approach to within RNP limits (including RF leg) until automation can be re-engaged (1000 feet for 737).

How does pilot know condition is resolved/recovered?

- Flight path is recovered to within limits, as displayed on EHSI/ND and CDU Progress Page crosstrack error text display.

Issues with regard to multiple concurrent non-normal conditions

- Aircraft making a missed approach in response to this condition may complicate NextGen automated sequencing/metering or traffic separation.

B737NG Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain's or left source)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	IAS DISAGREE displayed in amber under respective mach/airspeed (MASI) indicator	Variance of >5 knots for >5 seconds between Captain and F/O airspeed values	Caution			Decrease of airspeed variance below threshold value
	False flashing box on digital airspeed display	AOA-compensated airspeed, not g-compensated	Caution			
Aural Alerts	False "Airspeed Low" alert from GPWS (if installed)	Sensed airspeed value is below min maneuver speed				
	Possible overspeed clacker warning	Indicated airspeed exceeds Vmo/Mmo, if a pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Warning			

B737NG Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Tactile Alerts	None					
Visual Cues	Displayed mach/airspeed is inconsistent with other pilot's and standby airspeed values			Indicated mach display blanks at <M.38		
	Displayed mach/airspeed is inconsistent with displayed attitude, considering phase of flight, altitude, thrust, and weight					
	Displayed mach/airspeed is inconsistent with FMC ground speed/winds, IRS-displayed groundspeed, flight path vector displays					
	Displayed mach/airspeed is inconsistent with displayed AOA (if installed)					

B737NG Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Adjust airplane attitude and thrust to maintain aircraft control.
- Perform AIRSPEED UNRELIABLE procedure to identify the incorrect airspeed display, use secondary airspeed indications of flight path vector and AOA (if installed), and reference body angle/thrust values for desired performance, as required.
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations may be affected and destination choices may have to be altered.

B737NG Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	IAS DISAGREE displayed in amber under respective mach/airspeed (MASI) indicator while pitot sources are partially blocked, then removed as all are completely blocked and thus become consistent.	Variance of >5 knots for >5 seconds between Captain and F/O airspeed values	Caution			
	Flashing box on digital airspeed display	AOA-compensated airspeed, not g-compensated. Warning could be triggered either as (1) a false indication due to loss of dynamic pressure input to the pitot probe or as (2) a valid indication if pilot follows a different airspeed display that is reading an incorrectly low value into a true underspeed condition.	Caution			

B737NG Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	PLI on PFD/EADI nears/touches airplane symbol	AOA				Reduction of AOA
Aural Alerts	"Airspeed Low" alert from GPWS (if installed)	Sensed airspeed value is below min maneuver speed. Warning could be triggered either as (1) a false indication due to loss of dynamic pressure input to the pitot probe or as (2) a valid indication if pilot follows a different airspeed display that is reading an incorrectly low value into a true underspeed condition.				
	Overspeed clacker alert	Sensed airspeed value is greater than Vmo/Mmo. Warning could be triggered by either (1) pressure trapped in a pitot system by drain	Warning	False warning may prompt pilots to react with control inputs that actually result in or exacerbate		

B737NG Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
		blockage and ambient pressure decrease in the climb (false warning); or (2) a pilot following a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).		loss of control; a valid warning (such as a stall warning) may not be considered to be valid by the pilots because of this alert and falsely high airspeed on at least one display		
	Stick shaker (sound of)	AOA	Warning			Reduction of AOA
Tactile Alerts	Stick shaker	AOA	Warning			
Visual Cues	Displayed mach/airspeed is inconsistent with displayed attitude, considering phase of flight, altitude, thrust, and weight					
Visual Cues	Displayed mach/airspeed is inconsistent with FMC ground speed/winds, IRS-displayed groundspeed,					

B737NG Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
	flight path vector displays					
	Displayed mach/airspeed is inconsistent with displayed AOA (if installed)					
Aural Cues	None					
Tactile/ Somatic Cues	Aerodynamic buffet	Actual overspeed or approach to stall				

B737NG Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Expected Pilot Response(s)

- Adjust airplane attitude and thrust to maintain aircraft control.
- Perform AIRSPEED UNRELIABLE procedure to identify the incorrect airspeed displays, use secondary airspeed indications of flight path vector and AOA (if installed), and reference body angle/thrust values for desired performance.
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations may be affected and destination choices may have to be altered.

B737NG Alerting Issues – Air data system failure

3. Initiating Condition: Air data computer failure (single module or unit) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	On respective MASI the airspeed display is replaced by an amber SPD flag	Loss of source input	Caution			
	Master caution amber light	Loss of airspeed input to yaw damper system	Caution			
	Flight control amber annunciator light	Loss of airspeed input to yaw damper system	Caution			
	Yaw damper amber light on overhead panel	Loss of airspeed input to yaw damper system	Caution			
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	On respective MASI, airspeed cursor is removed	Loss of source input				
	On respective MASI, red/white maximum operating speed range is removed	Loss of source input for overspeed				
Aural Cues	Yaw damper switch "snap" sound"					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Adjust airplane attitude and thrust to maintain aircraft control.

B737NG Alerting Issues – Air data system failure

3. Initiating Condition: Air data computer failure (single module or unit) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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- Perform AIRSPEED UNRELIABLE procedure to identify the incorrect airspeed display, use secondary airspeed indications of flight path vector and AOA (if installed), and reference body angle/thrust values for desired performance, as required.
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations may be affected and destination choices may have to be altered.

APPENDIX E

Boeing 777 Matrices

B777 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PLI nears/touches airplane symbol on PFD	AOA				Reduction of AOA
	"Airspeed Low" amber text line on EICAS (precedes stall warning, approximately halfway through amber speed band)	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall); AOA-compensated airspeed, not g-compensated (See B777 FCTM p. 1.6)	Caution			Increased airspeed
	Indicated airspeed numerical box turns amber (precedes stall warning)	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall); AOA-compensated airspeed, not g-compensated	Caution			Increased airspeed
	When the autopilot is engaged and the aircraft slows to stick shaker speed (assuming autothrottle is not armed or otherwise functional), the autopilot pitch mode reverts to an airspeed mode and the aircraft descends at a speed slightly above stick shaker speed. In this condition an amber line is drawn through the pitch mode on the FMA, the flight director pitch bar is removed from the PFD, and an AUTOPILOT caution is generated on the EICAS	AOA	Caution			Reduction of AOA
Aural Alerts	Stick shaker (sound of)	AOA	Warning			Reduction of AOA

B777 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Caution alert beeper (precedes stall warning, approximately halfway between min maneuver and stick shaker speeds, associated with Airspeed Low EICAS)	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall); AOA-compensated airspeed, not g-compensated	Caution			Increased airspeed
	With autopilot engaged, caution aural beeper is associated with Autopilot EICAS caution, at stick shaker speed.	AOA	Caution			Reduction of AOA
Tactile Alerts	Stick shaker	AOA	Warning			Reduction of AOA
Visual Cues	Indicated airspeed at or below red/black band on PFD	Top of red/black airspeed band is g-compensated matching stick shaker AOA				Reduction of AOA
	PFD/ADI indications of uncommanded pitch			To some extent the primary flight computer compensates for the pitch and roll effects of stall. Not all of these control inputs may be back-driven to the control wheel/columns to make the pilots aware of the inputs being required to maintain control of the aircraft.		

B777 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD/ADI indications of uncommanded roll			Note: Bank angle protection is active at 35 degrees bank angle, primary flight computer system attempts to roll back to 30 degrees bank angle. Bank angle indicator turns amber at greater than 35 degrees.		
	PFD/ADI indications of sink rate on vertical speed display					
	Control wheel deflection (autopilot input)			To some extent the primary flight computer compensates for the pitch and roll effects of stall. Not all of these control inputs may be back-driven to the control wheel/columns to make the pilots aware of the inputs being required to maintain control of the aircraft.		
Aural Cues	None					

B777 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Tactile/ Somatic Cues	Aerodynamic buffet					Reduction of AOA
	In normal flight control mode, when the aircraft slows to near stall speed (approximately halfway through the amber band and same threshold as the "Airspeed Low" EICAS alert), the auto throttles advance to maintain minimum maneuvering speed or the speed set in the MCP command window, whichever is greater	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall); AOA-compensated airspeed, not g-compensated				

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

How does pilot know condition is resolved/recovered?

- Cessation of stall warning alerts

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

B777 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	PLI nears/touches airplane symbol on PFD	AOA		Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		Reduction of AOA
	"Airspeed Low" amber text line on EICAS (may precede stall warning, depending on load factor; approximately halfway through amber speed band)	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall); AOA-compensated airspeed, not g-compensated (See B777 FCTM p. 1.6)	Caution	Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		Increased airspeed
	Red/black airspeed band on PFD rises toward current indicated (centered/boxed) airspeed	Top of red/black airspeed band is g-compensated matching stick shaker AOA		Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		Reduction of AOA

B777 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Indicated airspeed numerical box turns amber (may precede stall warning, depending on load factor)	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall)); AOA-compensated airspeed, not g-compensated	Caution	Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		Increased airspeed
	PFD bank angle indicator turns amber	Bank angle >35 degrees	Caution	This is not an alert to the stall, but rather to the excessive bank angle from the roll upset		Reduction of bank angle
Aural Alerts	Stick shaker (sound of)	AOA	Warning	Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		Reduction of AOA
	Caution alert beeper (approximately halfway between min maneuver and stick shaker speeds, associated with Airspeed Low EICAS; may precede stall warning depending on load factor)	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall)); AOA-compensated airspeed, not g-compensated	Caution	Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	GPWS 'Bank Angle"	Bank angle >35, 40, and 45 degrees		This is not an alert to the stall, but rather to the excessive bank angle from the roll upset.		Reduction of bank angle

B777 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	Stick shaker	AOA	Warning	Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		Reduction of AOA
Visual Cues	Indicated airspeed at or below red/black band on PFD	Top of red/black airspeed band is g-compensated matching stick shaker AOA		Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		Reduction of AOA
	PFD/ADI indications of uncommanded pitch			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		

B777 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD/ADI indications of uncommanded roll			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	PFD/ADI indications of sink rate on vertical speed display			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
Aural Cues	Wind noise					
Tactile/ Somatic Cues	Aerodynamic Buffet	AOA (natural)		Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		

B777 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Tactile/ Somatic Cues	In normal flight control mode, nose-up trim is inhibited at min maneuvering speed, requiring increasing aft column force by the pilot to slow the aircraft into the stall region (when hand flown). This occurs approximately simultaneously with the "autothrottle wake-up."	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall); AOA-compensated airspeed, not g-compensated				
	In normal flight control mode, when bank angle exceeds 35 degrees, the aircraft automatically applies control wheel forces to attempt to restore a 30 degree bank angle. This will present to the pilot as wheel force (can be overridden) and anti-roll wheel deflection.	Bank angle >35 degrees				

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

How does pilot know condition is resolved/recovered?

- Termination of stall warning alerts.

Issues with regard to multiple concurrent non-normal conditions

- Recovery from stall condition must be followed immediately by recovery from nose-low, high bank upset condition.
- Possible passenger injuries and aircraft damage.

B777 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None: PLI is present but may not be touching the aircraft symbol when the stall occurs (suggesting to the pilot that the aircraft is not stalling)				Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Aural Alerts	None				Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Tactile Alerts	None			Pilots are trained extensively to associate stick shaker as trigger to stall recovery; in absence of stick shaker (warning system failure or stall at lower-than-nominal AOA) they may not interpret the secondary cues of buffet, roll, etc. as being related to stall.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Visual Cues	None: airspeed appears to be adequate but is not; airplane may stall while indicated airspeed is in the amber band but not in or touching the red/black band				Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
	PFD/ADI indications of uncommanded pitch					

B777 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD/ADI indications of uncommanded roll					
	PFD/ADI indications of sink rate on vertical speed display					
Aural Cues	None				Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Tactile/Somatic Cues	Aerodynamic Buffet; unusual wheel/column forces (autopilot off) or displacements (autopilot on)	AOA (natural)				Reduction of AOA

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

B777 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation – Cont.

How does pilot know condition is resolved/recovered?

- Difficult to know, related to cessation of uncommanded pitch/roll/sink.

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

B777 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PLI touches airplane symbol on PFD (false indication)	AOA			Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
Aural Alerts	Stick shaker, sound of (false indication)	AOA	Warning		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
Tactile Alerts	Stick shaker (false indication)	AOA	Warning		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
Visual Cues	Normal vertical speed, altimeter, and airspeed indications on PFD, as well as view through the windshield of the aircraft climbing (if VMC) are subtle cues that the aircraft is not stalling					
Aural Cues	None					
Tactile/Somatic Cues	Normal vertical acceleration from rotation into climb is a subtle cue that the aircraft is not stalling					

B777 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation – Cont.

Expected Pilot Response(s)

- Ignore false alerts and cues.
- Do not reject takeoff.

How does pilot know condition is resolved/recovered?

- Observe normal takeoff and climb performance.

Issues with regard to multiple concurrent non-normal conditions

- None unless pilot takes unneeded actions, such as high speed RTO.

B777 Alerting Issues – Uncommanded yaw or roll

1. Initiating Condition: Wake encounter – Cont.

Visual Alerts	PFD bank angle indicator turns amber	Bank angle > 35 degrees	Caution			Reduction of bank angle
Aural Alerts	GPWS "Bank Angle"	35, 40, and 45-degree bank angle				
Tactile Alerts	None					
Visual Cues	Roll rate on PFD/EADI					
Aural Cues	None					
Tactile/ Somatic Cues	In normal flight control mode, when bank angle exceeds 35 degrees, the aircraft automatically applies control wheel forces to attempt to restore a 30 degree bank angle. This will present to the pilot as wheel force (can be overridden) and anti-roll wheel deflection.					

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle
- Turn off flight directors
- Apply opposing roll and/or yaw inputs to control aircraft attitude
- Recover from nose-down upset if necessary

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained.

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset

B777 Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	PFD bank angle indicator turns amber	Bank angle > 35 degrees	Caution			Reduction of bank angle
Aural Alerts	GPWS "Bank Angle"	35, 40, and 45-degree bank angle				
Tactile Alerts	None					
Visual Cues	Roll rate on PFD/EADI					
	Aileron, spoiler, and rudder positions displayed on the MFD FCTL synoptic page			This information must be obtained by performing keyboard selections; thus has zero salience unless the pilot recalls the existence of the page, applies this to the existing situation, and effort fully makes the required entries		

B777 Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Cues	None					
Tactile/ Somatic Cues	Lateral-g					
	Uncommanded rudder deflection may result in pro-yaw rudder pedal deflection or force and/or rudder pedal jam, depending on source of uncommanded control surface deflection; however, in other failure conditions there will be no rudder pedal movement cueing the deflection of the rudder. Also, with autopilot engaged, depending on the lateral mode, it may apply anti-yaw wheel inputs. Other roll control inputs made by the flight control system will not result in wheel movement			Interpretation of rudder and wheel deflections can be difficult because the direction of deflection (into or opposite the yaw) depends on the underlying cause		

B777 Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection – Cont.

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle.
- Turn off flight directors.
- Apply opposing roll and/or yaw inputs to control aircraft attitude, using significant force if necessary to activate breakout features in the event of control jam.
- Recover from nose-down upset if necessary.

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained and uncommanded control deflections have been either neutralized or compensated for in all anticipated circumstances for the remainder of the flight.
- If there are residual uncommanded control deflections or pressures, there may be operational implications through to landing (e.g., crosswind limitations)

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset

B777 Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PFD bank angle indicator turns amber	Bank angle > 35 degrees	Caution			Reduction of bank angle
Aural Alerts	GPWS "Bank Angle"	35, 40, and 45-degree bank angle				
Tactile Alerts	None					
Visual Cues	Roll rate on PFD/EADI					
	Aileron, spoiler, and rudder positions displayed on the MFD FCTL synoptic page			This information must be obtained by performing keyboard selections; thus has zero salience unless the pilot recalls the existence of the page, applies this to the existing situation, and effortfully makes the required entries		
Aural Cues	None					
Tactile/ Somatic Cues	Uncommanded aileron, spoiler, or flap deflection may result in pro-roll wheel deflection or force and/or control wheel jam, depending on source of uncommanded control surface deflection; however, in other failure conditions there will be no wheel movement cueing the deflection of the ailerons			Interpretation of wheel deflection is difficult because the direction of deflection (into or opposite the roll) depends on the underlying cause		

B777 Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
	and/or spoilers. Also, with autopilot engaged, depending on the lateral mode, it may apply anti-roll wheel inputs. Other roll control inputs made by the flight control system will not result in wheel movement.					

B777 Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Tactile/ Somatic Cues	In normal flight control mode, when bank angle exceeds 35 degrees, the aircraft automatically applies control wheel forces to attempt to restore a 30 degree bank angle. This will present to the pilot as wheel force (can be overridden) and anti-roll wheel deflection.			Interpretation of wheel deflection is difficult because the direction of deflection (into or opposite the roll) depends on the underlying cause		

B777 Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection – Cont.

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle.
- Turn off flight directors.
- Apply opposing roll and/or yaw inputs to control aircraft attitude, using significant force if necessary to activate breakout features in the event of control jam.
- Recover from nose-down upset if necessary.

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained and uncommanded control deflections have been either neutralized or compensated for in all anticipated circumstances for the remainder of the flight.
- If there are residual uncommanded control deflections or pressures, there may be operational implications through to landing (e.g., crosswind limitations).

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset.

B777 Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (center system) in cruise

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	EICAS advisory message "HYD QTY LOW C"	Low fluid quantity in center hydraulic reservoir	Advisory		New EICAS advisory message display is inhibited during before/engine start; during takeoff between 80 knots airspeed and 400 feet radar altitude or 20 seconds after takeoff, whichever occurs first; during autoland (LAND 2 or LAND 3) from 200 feet radar altitude to landing; and after engine shutdown	Cancel (and also recall) by pressing the CANC/RCL button. Otherwise the indication remains active as the hydraulic condition continues through the end of the flight.
	EICAS caution message "HYD PRESS SYS C" (may alert simultaneously with or after the low fluid quantity, depending on the rate of fluid loss)	Low pressure in center hydraulic system (may be sensed simultaneously with or after the low fluid quantity, depending on the rate of fluid loss)	Caution		New EICAS caution message is inhibited before/during engine start and after engine shutdown; NOTE: Individual hydraulic pump caution messages are suppressed by EICAS when the system detects and displays the hydraulic system pressure message	Cancel (and also recall) by pressing the CANC/RCL button. Otherwise the indication remains active as the hydraulic condition continues through the end of the flight.
	C1 & C2 ELEC "FAULT" amber lights on overhead panel	Low pressure sensed at center hydraulic system pumps	Caution			
	Master caution lights associated with HYD PRESS SYS C EICAS and beeper	Low pressure sensed at center hydraulic system pumps	Caution			New master caution initiation is inhibited before/during engine start; during takeoff between 80 knots airspeed and 400 feet radar altitude or 20 seconds after takeoff, whichever occurs first; during autoland (LAND 2 or LAND 3) from 200 feet radar altitude to landing; and after engine shutdown

B777 Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (center system) in cruise – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Caution beeper associated with HYD PRESS SYS C EICAS	Low pressure sensed at center hydraulic system pumps	Caution		Beeper inhibited before/during engine start, during takeoff between 80 knots airspeed and 400 feet radar altitude or 20 seconds after takeoff, whichever occurs first; during autoland (LAND 2 or LAND 3) from 200 feet radar altitude to landing; and after engine shutdown	
Tactile Alerts	None					
Visual Cues	Low hydraulic pressure and fluid quantity indications on Status display				These cues are not very salient (absent the associated alerts) because the pilots have to manually select the Status page on the Display Select Panel in order to see the hydraulic pressure/quality readings	
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Execute the Hydraulic Pressure -Center System procedure using the Electronic Checklist, QRH, or flight manual.
- As called out in the procedure, recognize and plan ahead for slower flap operation, alternate landing gear extension, partial flap extension with longer runway requirement for landing, reduced speedbrake effectiveness, main gear scrubbing during taxi turns after landing, inability to retract landing gear and slower flap retraction with speed limits (affects go-around and diversion).
- Per the procedure, suppress performing additional procedures for AUTO SPEEDBRAKE and SPOILERS, which will be new EICAS indications that come on later in the flight. Suppress procedures for FLAPS PRIMARY FAIL and SLATS PRIMARY FAIL EICASs that come on during approach. Suppress arming the speedbrake prior to landing. Suppress performing the procedure for the GEAR DOOR EICAS that comes on after manual gear extension. Remember to perform manual spoiler extension after touchdown.

B777 Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (center system) in cruise – Cont.

How does pilot know condition is resolved/recovered?

- Situation will not be resolved until bringing the aircraft to a stop on the ground.

B777 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	EICAS caution message "ENG FAIL L or R" or "ENG THRUST L or R"	Actual thrust is less than commanded thrust or thrust decreases below idle speed	Caution	The reasoning for inhibition of alerts at v1-5/80 knots is sound, to avoid a mistaken high speed RTO		Engine recovers or fuel control switch is moved to CUTOFF (during NNP)
	On the EICAS for any abnormal engine indications (EGT, N1, N2, Oil Pressure, Oil Temperature), the associated indication's digital readout, box, and pointer turn amber (caution range) or red (operating limit reached or exceeded). For low oil quantity and high vibration indications, the colors reverse to black text on white background (with "LO" appearing next to the indication for the oil quantity). Secondary engine indications are automatically displayed on lower DU in engine failure condition.		Warning			

B777 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	EICAS caution message "AUTOTHROTTLE" (appears later during the ENG FAIL NNP)	Autothrottle arm switch is turned off during NNP	Caution			
Aural Alerts	None			The reasoning for inhibition of alerts at V1-5/80 knots is sound, to avoid a mistaken high speed RTO	Voice alert Inhibited at airspeeds greater than V1 minus 6 knots. Beeper inhibited during takeoff from 80 knots through 400 feet radar altitude or 20 seconds after takeoff.	
Tactile Alerts	None					
Visual Cues	Abnormal EGT, N1, N2, oil temperature, and/or oil pressure gauge indications					
	Nose yawing off runway centerline (minimized by Thrust Asymmetry Compensation (TAC) system)					
Aural Cues	Sounds of engine malfunction may occur					

B777 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Tactile/ Kinesthetic Cues	Lateral g					
	Rudder pressure required to stay on runway (minimized by Thrust Asymmetry Compensation (TAC) system)					
	Reduced longitudinal acceleration					

Expected Pilot Response(s)

- Control the aircraft.
- Execute single engine takeoff/climb profile.
- Identify and execute appropriate non-normal checklist.
- Suppress performing AUTOTHROTTLE procedure; this is specified in the ENG FAIL NNP.
- Perform single engine approach and landing.

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system failures that may require additional action (these should be included in the non-normal procedures and in most cases the EICAS suppresses unnecessary references to the procedures for these secondary failures).
- Uncontained engine failure may present additional multiple alerts and failures.

B777 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution lights on forward panel	Actual thrust is less than commanded thrust or thrust decreases below idle speed	Caution			Extinguish by pressing Master Warning/Caution reset
	EICAS caution message "ENG FAIL L or R" or "ENG THRUST L or R"	Actual thrust is less than commanded thrust or thrust decreases below idle speed	Caution			Engine recovers or fuel control switch is moved to CUTOFF (during NNP)
	On the EICAS for abnormal engine indications (EGT, N1, N2, Oil Pressure, Oil Temperature), the associated indication's digital readout, box, and pointer turn amber (caution range) or red (operating limit reached or exceeded). For low oil quantity and high vibration indications, the colors reverse to black text on white background (with "LO" appearing next to the indication for the oil quantity). Secondary engine indications are automatically displayed on lower DU in engine failure condition.	Sensed value of respective parameter	Warning			
	EICAS caution message "AUTOTHROTTLE" (appears later during the ENG FAIL NNP)	Autothrottle arm switch is turned off during NNP	Caution			
Aural Alerts	Beeper associated with Master Caution light	Actual thrust is less than commanded thrust or thrust decreases below idle speed	Caution			
Tactile Alerts	None					

B777 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Abnormal EGT, N1, N2, oil temperature, and/or oil pressure gauge indications					
	Control wheel deflection (autopilot input)					Control wheel displacement cues are reduced by TAC and further reduced/eliminated after manually trimming the rudder
Aural Cues	Sounds of engine malfunction may occur					
Tactile/ Kinesthetic Cues	High airframe vibration (possible)					

Expected Pilot Response(s)

- Control the aircraft.
- Identify and execute appropriate non-normal checklist.
- Suppress performing the AUTOTHROTTLE procedure; this is specified in the ENG FAIL NNP.
- Perform single engine approach and landing.

B777 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged – Cont.

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system failures that may require additional action (these should be included in the non-normal procedures and in most cases the EICAS suppresses unnecessary references to the procedures for these secondary failures).
- Uncontained engine failure may present additional multiple alerts and failures.

B777 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	EICAS warning message "FIRE ENG L or R"	Temperature sensed by engine fire loop	Warning		Master warning lights (red, forward glare shield panel) are inhibited during takeoff between V1 and 400 feet radar altitude (however the associated EICAS FIRE message is displayed); Also, burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished. However, this condition is monitored and displayed on EICAS as "DET FIRE ENG L or R," if sensed.	Lower temperature sensed by engine fire loop
	EICAS caution message "OVERHEAT ENG L or R" may precede FIRE ENG L or R warning if overheat threshold is sensed some time prior to fire threshold	Temperature sensed by engine fire loop	Caution		Master caution lights (amber, forward glare shield panel), that may precede master warning if overheat is sensed, are inhibited during takeoff between 80 knots and 400 feet radar altitude (however the associated EICAS OVERHEAT ENG L or R caution message is displayed). Also, caution alert is then suppressed when the sensed temperature reaches fire threshold.	Lower temperature sensed by engine fire loop
	Fire switch light on aisle stand/center console illuminates red	Temperature sensed by engine fire loop	Warning		Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished. This condition is monitored and displayed on EICAS as "DET FIRE ENG L or R," if sensed	Lower temperature sensed by engine fire loop
	Engine fuel control switch (L or R) on center control stand illuminates red	Temperature sensed by engine fire loop	Warning		Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished. This condition is monitored and displayed on EICAS as "DET FIRE ENG L or R," if sensed	Lower temperature sensed by engine fire loop

B777 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

Visual Cues	EICAS caution message "AUTOTHROTTLE" (comes on during execution of FIRE ENG NNP)	Autothrottle arm switch is turned off while securing engine as part of the FIRE ENG NNP.	Caution			
Aural Alerts	None	Temperature sensed by engine fire loop			Fire Bell alert is inhibited during takeoff between V1 and 400 feet radar altitude (however the associated EICAS FIRE message is displayed). Also, burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished. This condition is monitored and displayed on EICAS as "DET FIRE ENG L or R," if sensed	Bell canceled by the pilots as part of procedure
	None	Temperature sensed by engine fire loop			Beeper associated with engine overheat EICAS caution message that may precede fire bell if overheat sensed, is inhibited during takeoff between 80 knots and 400 feet radar altitude.	Lower temperature sensed by engine fire loop. Also, caution alert suppressed if sensed temperature reaches fire threshold.
Tactile Alerts	None unless engine also fails					
Visual Cues	None unless engine also fails					
Aural Cues	None					
Tactile/ Kinesthetic Cues	None unless engine also fails					

Expected Pilot Response(s)

- Control the aircraft.

B777 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

- Execute V1 engine failure/fire flight profile.
- Execute engine fire procedure (begin procedure above 400 feet, this is earlier than for engine failure procedure).

How does pilot know condition is resolved/recovered?

- Fire warning indication that fire is extinguished.

Issues with regard to multiple concurrent non-normal conditions

- Engine fire will devolve to an engine failure, either as a direct result of and simultaneous with the fire onset or as part of the engine fire procedure.
- Engine fire presents concurrent electrical, hydraulic, and/or fuel system failures that may require additional action.
- Engine fire may present cascading emergency (e.g., hydraulic failures, smoke in cabin, etc.)
- Uncontrollable fire may present additional, cascading conditions (e.g., structural failure, fuel loss, need to expedite landing, or even land off-airport).

B777 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak during takeoff after V1 and before V2

Type	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	EICAS warning message "FIRE ENG L or R"	Temperature sensed by engine fire loop	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.	Master warning lights (red, forward glare shield panel) are inhibited during takeoff between V1 and 400 feet radar altitude (however the associated EICAS FIRE message is displayed); Also, burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished. However, this condition is monitored and displayed on EICAS as "DET FIRE ENG L or R," if sensed.	
	EICAS caution message "OVERHEAT ENG L or R" may precede FIRE ENG L or R warning if overheat threshold is sensed some time prior to fire threshold	Temperature sensed by engine fire loop	Caution	False fire warning can lead to unneeded RTO, engine shutdown, etc.	Master caution lights (amber, forward glare shield panel), that may precede master warning if overheat is sensed,	

B777 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak during takeoff after V1 and before V2

Type	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
					<p>are Inhibited during takeoff between 80 knots and 400 feet radar altitude (however the associated EICAS OVERHEAT ENG L or R caution message is displayed). Also, caution alert is then suppressed when the sensed temperature reaches fire threshold.</p>	
	<p>Fire switch light on aisle stand/center console illuminates red</p>	<p>Temperature sensed by engine fire loop</p>	<p>Warning</p>	<p>False fire warning can lead to unneeded RTO, engine shutdown, etc.</p>	<p>Burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished. This condition is monitored and displayed on EICAS as "DET FIRE ENG L or R," if sensed</p>	
	<p>Engine fuel control switch (L or R) on center control stand illuminates red</p>	<p>Temperature sensed by engine fire loop</p>	<p>Warning</p>	<p>False fire warning can lead to unneeded RTO, engine shutdown, etc.</p>	<p>Burn through of fire detection can suppress valid warnings, leading</p>	

B777 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak during takeoff after V1 and before V2

Type	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
	EICAS caution message "AUTOTHROTTLE" (comes on during execution of FIRE ENG NNP)	Autothrottle arm switch is turned off while securing engine as part of the FIRE ENG NNP.	Caution		to false indication that fire has been extinguished. This condition is monitored and displayed on EICAS as "DET FIRE ENG L or R," if sensed	
Aural Alerts	None				Fire Bell alert is inhibited during takeoff between V1 and 400 feet radar altitude (however the associated EICAS FIRE message is displayed). Also, burn through of fire detection can suppress valid warnings, leading to false indication that fire has been extinguished. This condition is monitored and	

B777 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak during takeoff after V1 and before V2

Type	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
					displayed on EICAS as "DET FIRE ENG L or R," if sensed	

B777 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak during takeoff after V1 and before V2 – Cont.

Type	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/Kinesthetic Cues	None					

Expected Pilot Response(s)

- Control the aircraft.
- Execute V1 engine failure/fire flight profile.
- In the absence of information that the fire warning is false, execute engine fire procedure (begin procedure above 400 feet, this is earlier than for engine failure procedure).
- Suppress performing the AUTOTHROTTLE procedure; this is specified by the FIRE ENG procedure.
- Perform single engine approach/landing procedures.
- If fire indication continues despite attempts to extinguish, expedite landing.

Issues with regard to multiple concurrent non-normal conditions

- False indication of engine fire will likely devolve to an engine failure as part of the engine fire procedure.
- If false indication of fire continues after engine fire NNPs are performed, pilot concerns about inextinguishable fire may prompt risky alternative actions (e.g., rushing, off-airport landing, etc.).

B777 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master Warning lights on forward glare shield panel illuminate red	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system; however, the detection system is monitored by EICAS and fault/failure, if sensed, should result in a DET FIRE CARGO FWD or AFT caution message	Fire Warn light is cancelled by pressing Master Warning light
	CARGO FIRE FWD or AFT warning light on the overhead panel illuminates red	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system; however, the detection system is monitored by EICAS and fault/failure, if sensed, should result in a DET FIRE CARGO FWD or AFT caution message	Warning light is extinguished when the fire detection system assesses that the fire has been extinguished; this is expected to continue even after fire is extinguished due to continued presence of smoke in the compartment
	EICAS warning message "FIRE CARGO FWD or AFT"	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system; however, the detection system is monitored by EICAS and fault/failure, if sensed, should result in a DET FIRE CARGO FWD or AFT caution message	EICAS warning message is extinguished when the fire detection system assesses that the fire has been extinguished; this is expected to continue even after fire is extinguished due to continued presence of smoke in the compartment
Aural Alerts	Fire Bell	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system; however, the detection system is monitored by EICAS and fault/failure, if sensed, should result in a DET FIRE CARGO FWD or AFT caution message	Fire Bell is cancelled by pressing Master Warning light
Tactile Alerts	None					
Visual Cues	None					

B777 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Cues	Possible reports from flight attendants or cargo supernumeraries about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Perform the FIRE CARGO FWD or AFT non-normal procedure.
- As part of the procedure, have cabin crew evaluate appropriate cabin areas for hot floor surfaces, presence of smoke/fumes, and other evidence of fire/overheat.
- As part of the procedure, suppress execution of the LANDING ALTITUDE (and EQUIP COOLING OVERRIDE if forward cargo fire) NNPs despite the display of EICAS caution messages for these during execution of the cargo fire procedure.
- Land within the required time limit
- After landing, have cabin crew re-assess conditions and advise ground personnel not to open cargo compartments without prior clearance from ARFF.

B777 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise – Cont.

How does pilot know condition is resolved/recovered?

- Previously illuminated CARGO FIRE Fwd or Aft light on overhead panel is extinguished.
- Fire damage to fire/smoke detection system can cause pilots to mistakenly believe that a fire has been extinguished when it actually continues to burn, although the detection system's self-testing function helps to identify this situation.
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment and (if necessary) the aircraft has been evacuated.

Issues with regard to multiple concurrent non-normal conditions

- Warnings/alerts/cues of other system failures (e.g., electrical, pneumatic, hydraulic) may be presented if these systems or associated detectors receive fire damage; these indications may distract the pilots' attention from responding to the primary fire situation or mask the primary situation.
- On the other hand, these secondary failures may require additional responses by the pilots, and the optimal prioritization of pilot response to these multiple cues may be unclear.

B777 Alerting Issues – In-flight cargo fire/smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master Warning lights on forward glare shield panel illuminate red	Smoke falsely detected in cargo compartment	Warning			Master Warning lights are cancelled by pressing either light
	CARGO FIRE FWD or AFT warning light on the overhead panel illuminates red	Smoke falsely detected in cargo compartment	Warning			Illuminated light on fire panel is extinguished when the fire detection system assesses that the fire has been extinguished
	EICAS warning message "FIRE CARGO FWD or AFT"	Smoke falsely detected in cargo compartment	Warning			EICAS message is extinguished when the fire detection system assesses that the fire has been extinguished.
Aural Alerts	Fire Bell	Smoke falsely detected in cargo compartment	Warning			Fire Bell is cancelled by pressing a Master Warning light
Tactile Alerts	None					
Visual Cues	None					

B777 Alerting Issues – In-flight cargo fire/smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Cues	Some indication that alarm is false, though extremely ambiguous, from negative reports from flight attendants or cargo supernumeraries about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- If the fire warning can be ascertained to be false, refrain from performing the cargo fire procedure; otherwise perform the procedure.
- If the fire warning terminates after performing the procedure and can be ascertained to have been false, continue the flight; otherwise land within the specified time limit.
- Unless the fire warning can be ascertained to be false, if the fire warning system indicates that the fire has ****not**** been extinguished after performing the procedure, land immediately.
- Unless the fire warning can be ascertained to be false, advise ground personnel not to open cargo compartments without prior clearance from ARFF.

How does pilot know condition is resolved/recovered?

- Previously illuminated Fwd or Aft light on cargo fire panel is extinguished.
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment, assessing and communicating to the pilots that the fire warning was false.

B777 Alerting Issues – In-flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring hidden behind cabin interior panel leading to inextinguishable cabin fire

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	None until smoke reaches the flight deck	Visible smoke		Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Aural Cues	None until flight attendants call pilots on interphone or cargo supernumeraries advise pilots			Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Tactile/Somatic Cues	None					
Olfactory	None until smoke is smelled			Cue may not be presented to pilots		

Expected Pilot Response(s)

- Perform appropriate cabin fire/smoke procedure (SMOKE, FIRE OR FUMES).
- Perform appropriate smoke removal (SMOKE OR FUMES REMOVAL) procedure if/as directed by the SMOKE, FIRE OR FUMES procedure.
- Perform emergency descent as specified by NNP.
- Prepare for emergency landing, off-airport if necessary, as specified by NNP.

B777 Alerting Issues – In-flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring hidden behind cabin interior panel leading to inextinguishable cabin fire – Cont.

How does pilot know condition is resolved/recovered?

- Pilots may receive information from flight attendants who are fighting the fire, including gaining access to hidden areas by removing panels.
- Situation cannot be resolved until aircraft has landed and crew performs emergency evacuation.

Issues with regard to multiple concurrent non-normal conditions

- Pilots may receive alerts/cues from failure conditions secondary to fire damage; it will be unclear to them to what extent they need to respond to these and how to prioritize their response.

B777 Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated	
Visual Alerts	EICAS caution message "NAV UNABLE RNP"	ANP>RNP (includes RAIM monitoring)	Caution			When ANP<RNP	
	FMS CDU scratchpad message "VERIFY POSITION" (only if large error introduced)	The difference between the FMC position and the updating sensor (GPS) is greater than 12NM for 5 seconds.	Caution	Text messages on FMS scratchpad can be inadequately salient. Also, once cleared by pilot action, they may not be re-displayed		When ANP<RNP	
	RAIM forecast message from dispatch during preflight planning or update inflight via ACARS	Inadequate satellite availability/ geometry as detected by RAIM forecast analysis performed by dispatch (inflight update can be generated by dispatch or requested by pilots)			May not be provided before flight if RNP approach not anticipated		
	PFD Navigation Performance Scales/ANP Bars flash first 10 seconds of exceedence, turn amber if exceeded 10 seconds (if installed)	ANP>RNP	Caution			When ANP<RNP	
	RNP/ANP alphanumeric under airplane symbol turns amber (if installed)	ANP>RNP	Caution			When ANP<RNP	
	Amber TERR POS annunciation on Nav Display and EICAS advisory message "TERR POS"	ANP>RNP	Caution			When ANP<RNP	

B777 Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Beeper associated with EICAS caution message "NAV UNABLE RNP"	ANP>RNP	Caution			When ANP<RNP
Tactile Alerts	None					
Visual Cues	ANP value (labeled "ACTUAL") greater than RNP value on CDU POS REF page 2					
	Navigation source annunciation on Nav Display (and FMS CDU POS REF page 2) changes from "GPS" to backup source (e.g., LOC-DME, ADIRU, etc.)	ANP>RNP		Not highly salient		
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Perform NAV UNABLE RNP procedure.
- Return to ground-based navigation, if any, as directed by the NNP.
- During RNP approach, execute missed approach (also directed by the NNP but timely response is required so pilots may not be able to wait for checklist).

How does pilot know condition is resolved/recovered?

- Lookup of FMS CDU page displaying ANP/ RNP; inspection of ANP/RNP values.
- Removal of multiple alerts driven by ANP>RNP.

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning.
- False terrain clearance warning.
- Loss of separation from air traffic (ADS or NextGen navigation/surveillance).

B777 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	FMS CDU scratchpad message "VERIFY POSITION" (only if large error introduced)	The difference between the FMC position and the updating sensor (GPS) is greater than 12NM for 5 seconds.	Caution	Text messages and alerts on FMS scratchpad can be inadequately salient. Also, once cleared they may not be re-displayed. Alerting and cueing depends on continued operation of multi-mode navigation, with at least inertial position inputs. The alerting threshold for "VERIFY POSITION" likely far exceeds RNP values for all but Oceanic procedural separation, so these alerts may be of limited safety value in current RNP or future Next Gen operations.		When position difference has been reduced to within limits or the inaccurate position source has been manually deselected from the FMS solution
	EICAS advisory message "FMC Message"	Driven by FMS CDU "VERIFY POSITION" message, using its threshold	Advisory			EICAS message is removed when the text message is cleared from the FMS CDU scratchpad
	MSG amber annunciation on FMS CDU	Driven by FMS CDU "VERIFY POSITION" message, using its threshold	Caution			
Aural Alerts	None					
Tactile Alerts	None					

B777 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD Navigation Performance Scales/ANP Bars flash first 10 seconds of exceedence, turn amber if exceeded 10 seconds (if installed)	Only presented in subset of conditions in which calculated ANP>RNP	Caution			When ANP<RNP
	RNP/ANP alphanumeric under airplane symbol turns amber (if installed)	Only presented in subset of conditions in which calculated ANP>RNP	Caution			
	ANP value greater than RNP value on CDU POS REF page	Only presented in subset of conditions in which calculated ANP>RNP				When ANP<RNP
	Possible visible map shift, if the system makes a position change or correction while a pilot is looking at the navigation display					
Aural Cues	None					
Tactile/Somatic Cues	None					

B777 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS – Cont.

Expected Pilot Response(s)

- Verify position using alternative means (e.g. radar, DME).
- Identify false information.
- Eliminate source of false information from the position solution.

How does pilot know condition is resolved/recovered?

- Verifying position after reverting to alternative navigation.

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning.
- False terrain clearance warning.
- Loss of separation from air traffic (ADS or NextGen navigation/surveillance).

B777 Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	TCAS RA vertical guidance on PFD: red avoid lines on PFD attitude and/or vertical speed areas	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
	TCAS red TRAFFIC message on ND	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
Aural Alerts	ATC Traffic Alert	Proximity detected by ATC radar/ conflict alert at system's threshold				
	TCAS RA aural warning	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
Tactile Alerts	None					
Visual Cues	TCAS display of traffic proximity on ND (filled red square for RA)	Proximity detected by TCAS at RA threshold			RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)

B777 Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation) – Cont.

Visual Cues	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Maneuver vertically in response to TCAS RA directives.
- Prioritize TCAS RA information over ATC and visual detection information.
- Maneuver vertically and/or laterally as instructed by ATC.
- Maneuver vertically and/or laterally as prompted by visual closure rate and direction of movement.
- The system is designed with the expectation that the pilot will respond within 5 seconds.
- In the case of a corrective RA (e.g. a reversal) the system is designed to expect a pilot response within 2.5 seconds
- Pilot is expected to maintain the requested climb/descent until the aural "clear of conflict" is heard
- Report TCAS RA to ATC as soon as possible
- Caution for endangering passengers with unnecessarily abrupt compliance maneuver

How does pilot know condition is resolved/recovered?

- TCAS "Clear of conflict" aural.
- Visual detection/evaluation of divergence from previous closure rate.

B777 Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error) – Cont.

Visual Alerts	ADS-In RA vertical guidance on PFD	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning	Future alert/cue designs may differ from current TCAS designs.		
Aural Alerts	ATM Traffic Alert	Proximity detected by ATM system at RA threshold				
	ADS-In RA aural warning	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning			
Tactile Alerts	None	None				
Visual Cues	ADS CDTI with conflict display on ND	CDTI conflict display system threshold				
	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation (N.B., closer traffic tolerances under NextGen)			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Maneuver the aircraft vertically and/or laterally as directed by ADS-In and CDTI systems.
- If aircraft response is automated, evaluate the validity of the ADS-In and CDTI alerts and monitor the aircraft response.
- If response is manual, execute the response within established next-gen collision avoidance system specifications.

Issues with regard to multiple concurrent non-normal conditions

- Cascading effects of RA response on NextGen traffic separation and metering.

B777 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PFD Navigation Performance Scales/ANP Bars flash first 10 seconds of exceedence, turn amber if exceeded 10 seconds (if installed)	Track deviation exceeds RNP as adjusted for ANP. RNP limit for the aircraft, crew, and specific approach is manually entered by the pilots	Caution	Unless the NPS are installed, there is no alert for excessive crosstrack error.		Track restored within limits
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	On the FMS CDU Progress Page 4, the crosstrack error value on exceeds RNP value			These cues require scanning (including obtaining the proper CDU page and incorporating that display into the instrument scan, which is unusual; and interpretation		
	On the ND, the lateral path deviation value is displayed (in tenths of NM, with "L" or "R") immediately below the airplane symbol (all only if installed)			If this feature is not installed, the lateral track deviation value is only available on the FMS CDU Progress Page 4.		

B777 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	On the ND, the aircraft symbol deviates from the magenta line (lateral deviation); and/or the VPDI deviates from the center of the path deviation scale (vertical deviation)					
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- If not in visual contact with the runway, execute a missed approach.
- Hand fly lateral path during missed approach to within RNP limits (including RF leg) until automation can be re-engaged.

How does pilot know condition is resolved/recovered?

- Flight path is recovered to within limits, as displayed on EHSI/ND and CDU Progress Page crosstrack error text display.

Issues with regard to multiple concurrent non-normal conditions

- Aircraft making a missed approach in response to this condition may complicate NextGen automated sequencing/metering or traffic separation.

B777 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- None required - the failed or inconsistent source is automatically deselected and the air data inertial reference unit (ADIRU) continues with the remaining two consistent sources, providing the same airspeed value to both the Captain's and First Officer's PFDs. There are no failure annunciations or indications, so the pilots are not even aware of the change.

B777 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)--Cont

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	"NAV AIR DATA SYS" displayed in amber on EICAS	Air data received by both ADIRU and SAARU are inconsistent during period of partial blockage of all three inputs (neither can vote out a single bad input), and subsequently invalid during period of complete input blockage	Advisory	Pilots may not immediately recall that the NAV AIR DATA SYS condition implies that their airspeed displays may be inconsistent/require resolution of correct vs. incorrect information; by the time they obtain this information from the relevant NNP, control of the aircraft may have been compromised		
	OVERSPEED warning displayed in red on EICAS (1) pressure is trapped in a pitot system by blockage and ambient pressure decreases; or (2) pilot follows a different airspeed display that is reading an incorrectly low value, into a true overspeed.	Indicated airspeed exceeds Vmo/Mmo, because either (1) pressure is trapped in a pitot system by blockage and ambient pressure decreases in the climb; or (2) pilot follows a different airspeed display that is reading an incorrectly low	Warning	Pilots responding to a false overspeed warning may enter or exacerbate a loss of control		

B777 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)--Cont

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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		value into a true overspeed.				

B777 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning lights in red on forward panel	Associated with EICAS OVERSPEED, because either (1) pressure is trapped in a pitot system by blockage and ambient pressure decreases in the climb; or (2) pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed.	Warning	Pilots responding to a false overspeed warning may enter or exacerbate a loss of control		
	Indicated airspeed numerical box turns amber	Indicated airspeed below Min Maneuvering Speed (signifying 1.3g maneuver margin to stall); AOA-compensated airspeed, not g-compensated	Caution			Increased airspeed
	AUTOPILOT DISC warning displayed in red on EICAS	Autopilot disengagement due to flight control mode degrading to secondary mode when indicated airspeed decreases to below 50 knots.	Warning	Reversion to hand flying causes workload spike and is distracting.		
	Master warning lights in red on forward panel	Associated with AUTOPILOT DISC EICAS	Warning			
	AUTO SPEEDBRAKE advisory displayed in amber on EICAS	Auto speedbrake system failure due to flight control mode degrading to secondary mode when indicated airspeed decreases to below 50 knots.	Advisory	NAV AIR DATA SYS procedure advises not to perform this procedure despite its being displayed on EICAS		

B777 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
	FLIGHT CONTROL MODE caution displayed in amber on EICAS	Flight control mode degrades to secondary mode when indicated airspeed decreases to below 50 knots.	Caution	NAV AIR DATA SYS procedure advises not to perform this procedure despite its being displayed on EICAS		
Visual Alerts	THRUST ASYM COMP advisory displayed in amber on EICAS	Thrust asymmetry computer failure due to flight control mode degrading to secondary mode when indicated airspeed decreases to below 50 knots.	Advisory	NAV AIR DATA SYS procedure advises not to perform this procedure despite its being displayed on EICAS		
Aural Alerts	Autopilot disengagement siren	Autopilot disengagement due to flight control mode degrading to secondary mode when indicated airspeed decreases to below 50 knots.	Warning	Reversion to hand flying causes workload spike and is distracting.		
	Caution beeper	Associated with FLIGHT CONTROL MODE EICAS	Caution			
	Overspeed siren	Associated with EICAS OVERSPEED, because either (1) pressure is trapped in a pitot system by blockage and ambient pressure decreases in	Warning	Pilots responding to a false overspeed warning may enter or exacerbate a loss of control		

B777 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
		the climb; or (2) pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed.				

B777 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Stick shaker (sound of)	AOA	Warning			
Tactile Alerts	Stick shaker	AOA	Warning			
Visual Cues	Different airspeed values may be displayed on Captain, F/O, and Standby indicators.	In this condition the Captain's airspeed indicator displays ADIRU air data from the left pitot static system, the FO's airspeed indicator displays SAARU air data from the right pitot static system, and the standby airspeed indicator displays air data from the center pilot static system.				

B777 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Displayed mach/airspeed may be inconsistent with displayed attitude, considering phase of flight, altitude, thrust, and weight					
	Displayed mach/airspeed may inconsistent with FMC ground speed/winds, IRS-displayed groundspeed, flight path vector displays					
	Displayed mach/airspeed may be inconsistent with displayed AOA (if installed)					
Aural Cues	None					
Tactile/Somatic Cues	Aerodynamic buffet	Actual overspeed or approach to stall				

B777 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Expected Pilot Response(s)

- When autopilot automatically disengages, revert to hand flying and maintain control. Reversion to hand flying causes workload spike and is distracting. When abnormal airspeed is recognized, immediately return the airplane to the previously memorized target pitch attitude and thrust setting for the phase of flight.
- If reacting to airspeed anomalies prior to display of NAV AIR DATA SYS on EICAS, recall that the Airspeed Unreliable procedure is relevant to this event (it is unannounced so not automatically delivered to the EICAS queue), and perform the Airspeed Unreliable procedure.
- When NAV AIR DATA SYS is displayed on EICAS, perform the relevant procedure (this includes linkage to the Airspeed Unreliable procedure if necessary).
- Ground speed information is available from the FMC and on the instrument displays. These indications can be used as a crosscheck.
- Use the Flight Path Vector (FPV) display (selecting it if necessary on the EFIS control panel). (Note: FPV is inertial based and continues to be reliable in this event.)
- For airplanes equipped with an Angle of Attack (AOA) indicator, maintain the analog needle at approximately the three o'clock position. This approximates a safe maneuver speed or approach speed for the existing airplane configuration.
- Per the NAV AIR DATA SYS procedure, recognize that for the remainder of the flight, the autopilot, flight directors, autothrottles, flight envelope protections, PFD flap maneuvering speed indications, auto-speedbrakes, and thrust asymmetry computer are inoperative. Yaw damping is degraded, and elevator feel and rudder ratios are changed.
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II/III operations may be affected and destination choices may have to be altered.
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Issues with regard to multiple concurrent non-normal conditions

- This failure has cascading effects all the way through to the subsequent landing; e.g., the pilots must hand fly, set power manually, follow LNAV courses by visual reference to ND map (or manually tune VORs for navigation), use a non-normal landing flap setting, and manually extend speedbrakes after touchdown. These are specified in the NAV AIR DATA SYS procedure.

B777 Alerting Issues – Air data system failure

3. Initiating Condition: Air data computer failure (single module or unit; i.e., all air data outputs of ADIRU missing/invalid but SAARU is functional)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	NAV AIR DATA SYS displayed on EICAS.	Advisory				
Aural alerts	None					
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- None required: after failure of ADIRU air data output, the SAARU automatically provides the same air data to both PFDs.

APPENDIX F

Bombardier CRJ700 Matrices

CRJ-700 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Stall push light switch on glareshield will illuminate	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	None	None	Reduction of AOA
	Auto-pilot disconnect cavalry charge will occur with stick shaker activation causing the green "AP" on PFD to change to red then disappear	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	None	None	None, will flash twice then red "AP" will disappear from PFD
Aural Alerts	Stick shaker	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	Could be a malfunctioning stall protection system	None	Reduction of AOA
	Stall warbler	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Caution	Could be a malfunctioning stall protection system	None	Reduction of AOA
	Auto-pilot disconnect cavalry charge will occur with stick shaker activation	Stick shaker	Caution			none, will sound once and stop
Tactile Alerts	Stick shaker	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	Could be a malfunctioning stall protection system	None	Reduction of AOA

CRJ-700 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Cues	Current airspeed into low airspeed cue (i.e. lower checker board)	Current speed at or below lower airspeed cue		None	None	Reduction of AOA
	Current airspeed below "green line" Low Speed Awareness Indicator (i.e. 1.25 times V_{S1})	Current speed at or below lower airspeed cue		None	None	Reduction of AOA/Thrust increase
	Airspeed trend predictor indicating into the checker board	Current aircraft configuration including AOA, thrust and lift device deployment will show the predicted airspeed in 10 seconds		None	None	Reduction of AOA/Thrust increase
	Cont Ignition on EICAS (white message)	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Status	Not easily visible and attention is drawn to other more salient alerts/cues	None	Reduction of AOA
	Continuous ignition push/light switch is illuminated on overhead panel	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Status	Not easily visible and attention is drawn to other more salient alerts/cues	None	Reduction of AOA

CRJ-700 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD/ADI indications of uncommanded pitch					
	Roll rate on PFD/EADI				Uncommanded roll cues masked by autopilot roll inputs until the a/p disconnects (appears as wheel deflection, see below); however, rapid roll may accompany a/p disconnect at the stall.	
	Sink rate on vertical speed display					
	Wheel may move opposite the roll if autopilot is engaged.					

CRJ-700 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Cues	None					
Tactile/ Somatic Cues	Stick pusher	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	Could be a malfunctioning stall protection system	None	Reduction of AOA; Turn off STALL PTCT PUSHER switch; Press and hold AP/SP button
	Aircraft handles poorly (mushy)/wing drop	Subjective & variable		None	None	Unknown, subjective & variable
	Airframe buffet	Specific angle of attack (AOA) is reached.		Could be confused with high speed buffet; Severe engine or airframe damage could also produce this sensation		Reduction of AOA

CRJ-700 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Expected Pilot Response(s)

- (1) AutopilotDisengage, if required
- (2) Pitch attitude Lower nose to reduce angle of attack
- (3) Thrust leversAdvance to MAX POWER
- (4) Roll attitude Wings level
- (5) FLIGHT SPOILER leverRETRACT

After airspeed increases and stall warning is extinguished:

- (6) Pitch attitudeAdjust to minimize altitude loss

NOTE

1. It is essential that the AOA be immediately reduced, even if this means a loss of altitude.
2. Avoid abrupt or aggressive pitch control inputs during recovery. Inappropriate recovery inputs can result in a secondary stall.
3. Height loss resulting from high AOA recovery, especially at cruise altitude and/or low initial thrust conditions, can be significant.

How does pilot know condition is resolved/recovered?

- Termination of stall warning alerts

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

CRJ-700 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Stall push light switch on glareshield will illuminate	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning			Reduction of AOA
Aural Alerts	Stick shaker	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	Could be a malfunctioning stall protection system		Reduction of AOA
	Stall warbler	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Caution	Could be a malfunctioning stall protection system		Reduction of AOA

CRJ-700 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	Stick shaker	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	Could be a malfunctioning stall protection system		Reduction of AOA
Visual Cues	Current airspeed into low airspeed cue (i.e. lower checker board)	Current speed at or below lower airspeed cue				Reduction of AOA
	Current airspeed below "green line" Low Speed Awareness Indicator (i.e.1.25 times V_{S1})	Current speed at or below lower airspeed cue				Reduction of AOA/Thrust increase
	Airspeed trend predictor indicating into the checker board	Current aircraft configuration including AOA, thrust and lift device deployment will show the predicted airspeed in 10 seconds				Reduction of AOA/Thrust increase
	Cont Ignition on EICAS (white message)	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Status	Not easily visible and attention is drawn to other more salient alerts/cues		Reduction of AOA
	Continuous ignition push/light switch is illuminated on overhead panel	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Status	Not easily visible and attention is drawn to other more salient alerts/cues		Reduction of AOA

CRJ-700 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD/ADI indications of uncommanded pitch					
	Roll rate on PFD/EADI				Uncommanded roll cues masked by autopilot roll inputs until the a/p disconnects (appears as wheel deflection, see below); however, rapid roll may accompany a/p disconnect at the stall.	
	Sink rate on vertical speed display					

CRJ-700 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Aural Cue	Wind noise					
Tactile/ Somatic Cues	Stick pusher	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	Could be a malfunctioning stall protection system	None	Reduction of AOA; Turn off STALL PTCT PUSHER switch; Press and hold AP/SP button
	Aircraft handles poorly (mushy)/wing drop	Subjective & variable				Unknown, subjective & variable
	Airframe buffet	Specific angle of attack (AOA) is reached.		Could be confused with high speed buffet or sever engine or airframe damage		Reduction of AOA

CRJ-700 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Expected Pilot Response(s)

- (1) Pitch attitude Lower nose to reduce angle of attack
- (2) Thrust leversAdvance to MAX POWER
- (3) Roll attitude Wings level
- (4) FLIGHT SPOILER leverRETRACT

After airspeed increases and stall warning is extinguished:

- (5) Pitch attitudeAdjust to minimize altitude loss

NOTE

- 1. It is essential that the AOA be immediately reduced, even if this means a loss of altitude.
- 2. Avoid abrupt or aggressive pitch control inputs during recovery. Inappropriate recovery inputs can result in a secondary stall.
- 3. Height loss resulting from high AOA recovery, especially at cruise altitude and/or low initial thrust conditions, can be significant.

How does pilot know condition is resolved/recovered?

- Termination of stall warning alerts

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

CRJ-700 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None			Pilots are trained extensively to associate stick shaker as trigger to stall recovery; in absence of stick shaker (warning system failure or stall at lower-than-nominal AOA) they may not interpret the secondary cues of buffet, roll, etc. as being related to stall.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Aural Alerts	None					
Tactile Alerts	None: airspeed appears to be adequate but is not; airplane may stall while indicated airspeed is in the amber band but not in or touching the red/black band			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	

CRJ-700 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD/ADI indications of uncommanded pitch			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Roll rate on PFD/EADI			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Sink rate on vertical speed display			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
Aural Cues	None					

CRJ-700 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation – Cont.

Tactile/ Somatic Cues	Unusual wheel/column forces			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Aerodynamic buffet	AOA (natural)		Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		

Expected Pilot Response(s)

- (1) AutopilotDisengage, if required
- (2) Pitch attitude Lower nose to reduce angle of attack
- (3) Thrust leversAdvance to MAX POWER
- (4) Roll attitude Wings level
- (5) FLIGHT SPOILER leverRETRACT

After airspeed increases and stall is avoided or recovered:

- (6) Pitch attitudeAdjust to minimize altitude loss

NOTE

- 1. It is essential that the AOA be immediately reduced, even if this means a loss of altitude.
- 2. Avoid abrupt or aggressive pitch control inputs during recovery. Inappropriate recovery inputs can result in a secondary stall.
- 3. Altitude loss resulting from high AOA recovery, especially at cruise altitude and/or low initial thrust conditions, can be significant.

CRJ-700 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation – Cont.

How does pilot know condition is resolved/recovered?

- Difficult to know, related to cessation of uncommanded pitch/roll/sink

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

CRJ-700 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Stall push light switch on glareshield will illuminate	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning	None	None	Reduction of AOA
Aural Alerts	Stick shaker, sound of (false indication)	AOA	Warning		Inhibited on the ground, so the false alert begins during rotation when the aircraft becomes airborne	Alert or cue is not terminated as it is invalid
	Stall warbler	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Caution	Could be a malfunctioning stall protection system	Inhibited on the ground, so the false alert begins during rotation when the aircraft becomes airborne	Reduction of AOA
Tactile Alerts	Stick shaker (false indication)	AOA	Warning		Inhibited on the ground, so the false alert begins during rotation when the aircraft becomes airborne	Alert or cue is not terminated as it is invalid
Visual Cues	Normal vertical speed, altimeter, and airspeed indications on PFD, as well as view through the windshield of the aircraft climbing (if VMC) are subtle cues that the aircraft is not stalling					

CRJ-700 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Cues	None					
Tactile/ Somatic Cues	Normal vertical acceleration from rotation into climb is a subtle cue that the aircraft is not stalling					

Expected Pilot Response(s)

- Ignore false alerts and cues.
- Do not reject takeoff.

How does pilot know condition is resolved/recovered?

- Observe normal takeoff and climb performance.

Issues with regard to multiple concurrent non-normal conditions

- None unless pilot takes unneeded actions, such as high speed RTO.

CRJ-700 Alerting Issues – Uncommanded yaw or roll

1. Initiating Condition: Wake encounter

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	"BANK ANGLE"	When bank angle exceeds predetermined value as determined by radio altitude.30 ft and below (10 degrees bank) 30 to 150 ft (linear from 10 degrees to 40 degrees bank). Above 150 ft AGL (excess of 40 degrees of bank)				Reduction of bank angle
Tactile Alerts	None					
Visual Cues	Roll rate on PFD/EADI			Pilots may be warned about the pending possibility of a wake encounter by ATC or actually see the aircraft and deduce this themselves		
Aural Cues	None					
Tactile/Somatic Cues	Wheel may move opposite the roll if autopilot is engaged.					

CRJ-700 Alerting Issues – Uncommanded yaw or roll

1. Initiating Condition: Wake encounter – Cont.

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle. Apply thrust as required depending on the nature of the roll upset (nose low vs. high)
- Verify symmetrical thrust
- Apply opposing roll and/or yaw inputs to control aircraft attitude
- Recover from nose-down upset if necessary
- Confirm spoilers are retracted

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained.

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset

CRJ-700 Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	"BANK ANGLE"	When bank angle exceeds predetermined value as determined by radio altitude.30 ft and below (10 degrees bank) 30 to 150 ft (linear from 10 degrees to 40 degrees bank). Above 150 ft AGL (excess of 40 degrees of bank)				Reduction of bank angle
	Single chime caution message for "YAW DAMP"	Unknown if the rapid rudder movement will disengage the yaw damp system	Caution			Re-engage both channels of yaw damp system
Tactile Alerts	None					
Visual Cues	Roll rate on PFD/EADI					
	Yaw rate on PFD/EADI slip/skid indicator					

CRJ-700 Alerting Issues – Uncommanded yaw or roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks – Cont.

Aural Cues	None					
Tactile/ Somatic Cues	Wheel may move opposite the roll if autopilot is engaged.					
	In the case of rudder kick, might be felt if feet on rudder pedals as movement on one side will move the other side					

Expected Pilot Response(s)review reference flight control disconnects

- Disconnect autopilot/autothrottle
- Verify symmetrical thrust
- Apply opposing roll and/or yaw inputs to control aircraft attitude, using significant force if necessary
- Reduce AOA/pitch/altitude as required to regain roll authority
- Disconnect yaw damper if cause is a jammed rudder. Other causes such as rudder limiter jammed or rudder trim runaway do NOT call for yaw damp to be disconnected.
- Recover from nose-down upset if necessary
- Confirm spoilers are retracted

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained and uncommanded control deflections have been either neutralized or compensated for in all anticipated circumstances for the remainder of the flight.
- If there are residual uncommanded control deflections or pressures, there may be operational implications through to landing (e.g., crosswind limitations)

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset

CRJ-700 Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution light will flash until selected	When any of the following caution messages appear: FLT SPLR DEPLOY GND SPLR DEPLOY	Caution			Pressing the master caution switchlight
Aural Alerts	Caution message single chime	When Master caution light is illuminated	Caution			None, only a single chime, does not repeat unless another caution message is presented.
	"BANK ANGLE"	When bank angle exceeds predetermined value as determined by radio altitude.30 ft and below (10 degrees bank) 30 to 150 ft (linear from 10 degrees to 40 degrees bank). Above 150 ft AGL (excess of 40 degrees of bank)				
Tactile Alerts	None					Reduction of bank angle
Visual Cues	Roll rate on PFD/EADI					
	Yaw rate on PFD/EADI slip/skid indicator					

CRJ-700 Alerting Issues – Uncommanded yaw or roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Cues	None					
Tactile/ Somatic Cues	Wheel may be deflected in opposite direction if autopilot is engaged					

Expected Pilot Response(s) review reference flight control disconnect

- Disconnect autopilot/autothrottle
- Verify symmetrical thrust
- Apply opposing roll and/or yaw inputs to control aircraft attitude, using significant force if necessary to activate breakout features in the event of control jam
- Recover from nose-down upset if necessary
- Confirm spoilers are retracted

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained and uncommanded control deflections have been either neutralized or compensated for in all anticipated circumstances for the remainder of the flight.
- If there are residual uncommanded control deflections or pressures, there may be operational implications through to landing (e.g., crosswind limitations)

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or alerts/cues as they cope with a roll or yaw/roll upset

CRJ-700 Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (3), in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution light will flash	Yellow EICAS message "HYD 3 LO PRESS"	Caution	The pilots have to be aware that there are separate QRH checklists for multiple hydraulic system failures.	All hydraulic messages are inhibited during takeoff except "HYD LO PRESS"	Pressing the master caution switchlight will stop flashing
	Yellow EICAS message "HYD 3 LO PRESS"	When both pumps have a pressure output below 1800 psi	Caution	The pilots have to be aware that there are separate QRH checklists for multiple hydraulic system failures. ; Other downstream failures may occur as the result of this failure. For example, hydraulic temp. increase and/or pump failure. All of these produce corresponding indications on the EICAS and hydraulic synoptic page in addition to a single caution chime; Since there is no low quantity EICAS message it is possible to mis-diagnose the original issue if viewed first from the synoptic page. There is no low quantity checklist.	All hydraulic messages are inhibited during takeoff except "HYD LO PRESS"	The single chime caution switch light will be flashing until pushed. The malfunction is not terminated until repaired. Otherwise the indication remains active as the hydraulic condition continues through the end of the flight.
Aural Alerts	Master caution message single chime	When system pressure is below 1800 psi	Caution			None, only a single chime, does not repeat unless another caution message is presented.
Tactile Alerts	None					

CRJ-700 Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (3), in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	On the hydraulic synoptic page the reservoir will change color and show a lower quantity when low or empty.	When the system pressure drops below 1800 psi.		The QRH procedure will cause additional EICAS indications to occur as a normal part of managing the system. Pilot action is required to display the synoptic page on the MFD.		
	On the hydraulic synoptic page the hydraulic line from the reservoir will change color when pressure is too low.	When the system pressure drops below 1800 psi.		Pilot action is required to display the synoptic page on the MFD.		
	On the hydraulic synoptic page below the hydraulic lines, the current pressure is displayed and as it decreases, the numbers and the box they are in will change different colors depending on the amount of pressure.	When the system pressure drops below 1800 psi.		Pilot action is required to display the synoptic page on the MFD.		
	On the hydraulic synoptic page below the pressure reading, any systems that are no longer operative, the system names will turn yellow. Showing what you have lost.	When the system pressure drops below 1800 psi.		Pilot action is required to display the synoptic page on the MFD.		

CRJ-700 Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (3), in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	On the hydraulic synoptic page above the system pressure reading and the quantity indicator, the current brake line pressure is indicated. If it drops below 1800 psi, the numbers will turn yellow. Both inboard and outboard brake line pressures are indicated.			Pilot action is required to display the synoptic page on the MFD.		
Aural Cues	None					
Tactile/Somatic Cues	Nosewheel shimmy may be felt in addition to reduced braking effectiveness					

Expected Pilot Response(s)

- Identify condition
- Follow the correct QRH procedure and comply with any stated restrictions.
- Pilots will need to plan for operational challenges as part of the failure of this system. These include, L & R ground spoilers inop, inboard brakes inop once the accumulator is depleted, normal landing gear extension and retraction are inop, nose wheel steering is inop, and the parking brake is inop. The procedure also requires a flaps 20 landing.
- Due to the failures listed above, pilots will need to increase landing distances by 100% without thrust reversers and 70% with one thrust reverser. These will have implications for landing, potential go-around, terrain considerations with gear out, and diversion requirements with gear out and max speed of 250kts.
- Instead of crews figuring landing distance based on highest weight allowed, now they will have to figure actual landing distance and apply corrections for spoiler failure, brake failure, and flap 20 landing. None of these required calculations are mentioned in the QRH with the exception of the HYD Press low recalculation of 1.7Xs or 2.0xS.

CRJ-700 Alerting Issues – Hydraulics failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (3), in cruise flight – Cont.

How does pilot know condition is resolved/recovered?

- Situation will not be resolved until bringing the aircraft to a stop on the ground.

Issues with regard to multiple concurrent non-normal conditions

- Not realizing that there are separate checklists when multiple hydraulic systems have failed. Even if another system fails while still completing a single system failure checklist, FCOM states stop and go to multiple system failure checklist.
- System 3 failure will also produce "IB GND SPLRS" and "IB BRAKE PRESS" messages which require no action on the part of the pilot. No need to follow those QRH checklists.

CRJ-700 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning lights on glareshield flash	Presence of "L or R ENG FLAMEOUT" trigger for amber caution message	Warning			Cancelled by pressing the light switch
	EICAS "L or R ENG FLAMEOUT"	N ₂ core speed drops below a determined speed triggering this alert if FADEC unable to re-light and thrust lever not in shut-off.	Warning			
	"APR" icon appears inside thrust gauge	Engine N ₁ speed decreases below 15% of the set power. APR system activates	Caution			
	"APR CMD SET" amber message	Indicates an uncommanded APR activation	Caution			
	Master warning lights on glareshield	Presence of "L or R ENG OIL PRESS" trigger for red warning message	Warning			Cancelled by pressing the light
	EICAS "L or R ENG OIL PRESS"	Oil pressure below 25 psi	Warning			
Aural Alerts	"Engine Oil" aural (voice)	Oil pressure below 25 psi	Warning			
Tactile Alerts	None					

CRJ-700 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Cues	Abnormal EGT, Abnormal N1 and/or N2, Abnormal oil pressure and temperature (low), Abnormal fuel flow (low).	Sensed value of respective parameter				
	Nose yawing off runway centerline					
Aural Cues	Sounds of engine malfunction may occur					
Tactile/Somatic Cues	Lateral g					
	Rudder pressure required to stay on runway					

Expected Pilot Response(s)

- Control the aircraft e.g. maintain runway centerline and adjust pitch for reduced performance
- Ensure max thrust has been set by APR and FADEC system
- Execute V1 engine failure/fire flight profile
- Execute single engine takeoff/climb profile
- Identify and execute appropriate non-normal checklist
- Perform single engine approach and landing, considering operational limitations as suggested by the QRH
- APR thrust is limited to 10 minutes only or engine damage may occur.
- Start APU if available
- If fire cannot be extinguished, expedite landing

CRJ-700 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2 – Cont.

How does pilot know condition is resolved/recovered?

- In the case of a simple flameout, successful re-starting of the engine resolves the immediate situation. Otherwise, the situation will not be resolved until the aircraft is landed.

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Uncontained engine failure may present additional multiple alerts and failures.
- Uncontained engine failure may damage pressure vessel thus causing depressurization and a whole host of other issues.

CRJ-700 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in flight with autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning lights on glareshield flash	Presence of "L or R ENG FLAMEOUT" trigger for amber caution message	Warning			Cancelled by pressing the light switch
	EICAS "L or R ENG FLAMEOUT"	N ₂ core speed drops below a determined speed triggering this alert if FADEC unable to re-light and. Unable to find what core speed that this occurs.	Warning			
	"APR" icon appears inside thrust gauge if aircraft still considered being in takeoff mode. Determined by the TOGA as the last selection.	Engine N ₁ speed decreases below 15% of the set power. APR system activates	Caution			
	"APR CMD SET" amber message	Indicates an uncommanded APR activation	Caution			
	Master warning lights on glareshield	Presence of "L or R ENG OIL PRESS" trigger for red warning message	Warning			Cancelled by pressing the light switch
	EICAS "L or R ENG OIL PRESS"	Oil pressure below 25 psi	Warning			
Aural Alerts	"Engine Oil" aural	Oil pressure below 25 psi	Warning			
Tactile Alerts	None					

CRJ-700 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in flight with autopilot engaged – Cont.

Visual Cues	Abnormal EGT, Abnormal N1 and/or N2, Abnormal oil pressure and temperature (low), Abnormal fuel flow (low).	Sensed value of respective parameter				
	Slip/skid indicator showing uncoordinated flight					
Aural Cues	Sounds of engine malfunction may occur					
Tactile/Somatic Cues	Lateral g					

Expected Pilot Response(s)

- Control the aircraft, trim in required amount of opposite rudder. In this aircraft AP needs help with trim in this situation.
- Ensure max thrust has been set by APR and FADEC system
- Execute single engine takeoff/climb profile if right after takeoff or consider drift down altitude if at cruise.
- Identify and execute appropriate non-normal checklist
- Start APU if available, if not must consider max altitude for single pack operations (FL250)
- Perform single engine approach and landing, considering operational limitations as suggested by the QRH

How does pilot know condition is resolved/recovered?

- In the case of a simple flameout, successful re-starting of the engine resolves the immediate situation. Otherwise, the situation will not be resolved until the aircraft is landed.

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Uncontained engine failure may present additional multiple alerts and failures.
- Uncontained engine failure may damage pressure vessel thus causing depressurization and a whole host of other issues.

CRJ-700 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning lights on glareshield flash	Presence of "L or R ENG FIRE" trigger for red warning message	Warning	Many other EICAS warning messages could push this off the bottom of the screen and then could but seen upon page 2 manual selection. From the FCOM <i>"If the number of warning messages exceeds the available message area, only the most recent will be displayed."</i>	NOT inhibited during any part of flight	Cancelled by pressing the light switch
	EICAS warning message "FIRE ENG L or R"	Temperature sensed by both engine fire loops	Warning		If both loops are burned through, will change to "L or R FIRE FAIL" amber message and corresponding amber caution and single chime.	Lower temperature sensed by both engine fire loops
	LH or RH ENG Fire push switchlight illuminated	Temperature sensed by both engine fire loops	Warning		If both loops are burned through, will change to "L or R FIRE FAIL" amber message and corresponding amber caution and single chime.	When push light switch is selected
	EICAS Caution "ENG BTL 1 or 2 (eventually) LO"	Pressure in bottle decreases below a preset value.	Caution			Does not until MX is performed
Aural Alerts	Triple chime master warning	Presence of "L or R ENG FIRE" trigger for red warning message	Warning			Selection of master warning switchlight

CRJ-700 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Fire bell	Presence of "L or R ENG FIRE" trigger for red warning message	Warning			Selection of fire push switchlight
	Single chime master caution	Presence of "L or R BTL 1 or 2 LO" EICAS message	Caution	This only occurs once a fire bottle has been discharged and the internal pressure drops below a preset value		Selection of master caution switchlight
Tactile Alerts	None unless engine also fails					
Visual Cues	Possible abnormal EGT, Possible abnormal N1 and/or N2, Possible abnormal oil pressure and temperature (low), Possible abnormal fuel flow (low)	Sensed value of respective parameter and depends on the degree of fire suppression and extent of damage.				
	Slip/skid indicator showing uncoordinated flight if the engine has partially or completely failed					
Aural Cues	Sounds of engine malfunction may occur					
Tactile/Somatic Cues	None unless engine also fails					

CRJ-700 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

Expected Pilot Response(s)

- Control the aircraft, trim in required amount of opposite rudder. In this aircraft AP needs help with trim in this situation if the engine has failed. Or upon shut-down, adjust trim as needed
- Ensure max thrust has been set by APR and FADEC system if engine has failed as well. If not, upon shut down, ensure correct thrust set for remaining engine
- Execute V1 engine failure/fire flight profile
- Execute single engine takeoff/climb profile
- Execute memory items for engine fire after reaching safe altitude
- Identify and execute appropriate emergency checklist
- Start APU if available as directed by checklist
- Perform single engine approach and landing, considering operational limitations as suggested by the QRH
- If fire cannot be extinguished, expedite landing

How does pilot know condition is resolved/recovered?

- After completion of emergency checklist, hopefully fire will be extinguished and acute situation resolved. However, if after checklist completion including both bottles being discharged, fire may still be present. Then, situation is not resolved until landing and extinguishment by ARFF crews.

Issues with regard to multiple concurrent non-normal conditions

- Engine fire will devolve to an engine failure, either as a direct result of and simultaneous with the fire onset or as part of the engine fire procedure.
- Engine fire presents concurrent electrical, hydraulic, and/or fuel system failures that may require additional action.
- Engine fire may present cascading emergency (e.g., hydraulic failures, smoke in cabin, etc.)
- Uncontrollable fire may present additional, cascading conditions (e.g., structural failure, fuel loss, need to expedite landing or even land off-airport).
- Uncontained engine failure may present additional multiple alerts and failures.

CRJ-700 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak, during takeoff after V1 and before V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning lights on glareshield flash	Presence of "L or R ENG FIRE" trigger for red warning message	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Cancelled by pressing the light switch
	EICAS warning message "FIRE ENG L or R"	Temperature sensed by both engine fire loops	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Lower temperature sensed by both engine fire loops
	LH or RH ENG Fire push switchlight illuminated	Temperature sensed by both engine fire loops	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		When push light switch is selected
	EICAS Caution "ENG BTL 1 or 2 (eventually) LO"	Pressure in bottle decreases below a preset value.	Caution			Does not until MX is performed
Aural Alerts	Triple chime master warning	Presence of "L or R ENG FIRE" trigger for red warning message	Warning			Selection of master warning switchlight
	Fire bell	Presence of "L or R ENG FIRE" trigger for red warning message	Warning			Selection of fire push switchlight
	Single chime master caution	Presence of "L or R BTL 1 or 2 LO" EICAS message	Caution	This only occurs once a fire bottle has been discharged and the internal pressure drops below a preset value		Selection of master caution switchlight

CRJ-700 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak, during takeoff after V1 and before V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Control the aircraft, trim in required amount of opposite rudder. In this aircraft AP needs help with trim in this situation when an engine is shut-down
- Ensure max thrust has been set by APR and FADEC system when engine is shut-down
- Execute V1 engine failure/fire flight profile
- Execute single engine takeoff/climb profile
- Execute memory items for engine fire after reaching safe altitude
- Identify and execute appropriate emergency checklist
- Start APU if available as directed by checklist
- Perform single engine approach and landing, considering operational limitations as suggested by the QRH
- If fire cannot be extinguished, expedite landing

Issues with regard to multiple concurrent non-normal conditions

- If crew performs the NNP in response to the false warning of an engine failure, either as a direct result of and simultaneous with the fire onset or as part of the engine fire procedure.
- If false indication of fire continues after engine fire NNPs are performed, pilot concerns about inextinguishable fire may prompt risky alternative actions (e.g., rushing, off-airport landing, etc.)

CRJ-700 Alerting Issues – In flight cargo/fire smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning switchlight flashing	"SMOKE AFT CARGO" or "SMOKE FWD CARGO" EICAS message	Warning		Alert can be suppressed by fire damage to the fire detection system. However, this damage should be indicated by an EICAS message of "FIRE SYS FAULT"	Master warning light will extinguish once pushed and will reset
	"SMOKE AFT CARGO" or "SMOKE FWD CARGO" EICAS message	Smoke detected in cargo compartment by at least two detectors providing that many are operational	Warning		Alert can be suppressed by fire damage to the fire detection system	
	AFT CARGO SMOKE or FWD CARGO SMOKE push lights will illuminate	Smoke detected in cargo compartment by at least two detectors providing that many are operational	Warning	Once either are selected the "BOTTLE ARMED PUSH TO DISCH" switchlight will illuminate	Alert can be suppressed by fire damage to the fire detection system	Once bottles are fired in either compartment, light will extinguish once bottle pressure depletes below a predetermined level
	"BOTTLE ARMED PUSH TO DISCH" switchlight will illuminate	When either AFT CARGO SMOKE or FWD CARGO SMOKE push lights are selected	Status			Once bottles are fired in either compartment, light will extinguish once bottle pressure depletes below a predetermined level
Aural Alerts	Triple Chime Master Warning	"SMOKE AFT CARGO" or "SMOKE FWD CARGO" EICAS message	Warning		Alert can be suppressed by fire damage to the fire detection system	None
	"Smoke - Smoke"	"SMOKE AFT CARGO" or "SMOKE FWD CARGO" EICAS message	Warning			

CRJ-700 Alerting Issues – In flight cargo/fire smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise flight – Cont.

Tactile Alerts	None					
Visual Cues	None					
Aural Cues	Possible reports from flight attendants about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Perform the appropriate cargo fire procedure.
- Land within the required time limit
- Advise ground personnel not to open cargo compartments without prior clearance from ARFF.

How does pilot know condition is resolved/recovered?

- Previously illuminated Fwd or Aft light on cargo fire panel is extinguished
- Fire damage to fire/smoke detection system can cause pilots to mistakenly believe that a fire has been extinguished when it actually continues to burn; no guidance on how to test integrity of fire detection system. Focus is on firing the bottles and landing ASAP
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment and (if necessary) the aircraft has been evacuated

Issues with regard to multiple concurrent non-normal conditions

- Warnings/alerts/cues of other system failures (e.g., electrical, pneumatic, hydraulic) may be presented if these systems or associated detectors receive fire damage; these indications may distract the pilots' attention from responding to the primary fire situation or mask the primary situation
- On the other hand, these secondary failures may require additional responses by the pilots, and the optimal prioritization of pilot response to these multiple cues may be unclear

CRJ-700 Alerting Issues – In flight cargo/fire smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master warning switchlight flashing	Smoke falsely detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system	Master warning light will extinguish once pushed and will reset
	"SMOKE AFT CARGO" or "SMOKE FWD CARGO" EICAS message	Smoke falsely detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system	
	AFT CARGO SMOKE or FWD CARGO SMOKE push lights will illuminate	Smoke falsely detected in cargo compartment	Warning	Once either are selected the "BOTTLE ARMED PUSH TO DISCH" switchlight will illuminate	Alert can be suppressed by fire damage to the fire detection system	Once bottles are fired in either compartment, light will extinguish once bottle pressure depletes below a predetermined level
	"BOTTLE ARMED PUSH TO DISCH" switchlight will illuminate	When either AFT CARGO SMOKE or FWD CARGO SMOKE push lights are selected	Status			Once bottles are fired in either compartment, light will extinguish once bottle pressure depletes below a predetermined level
Aural Alerts	Triple Chime Master Warning	"SMOKE AFT CARGO" or "SMOKE FWD CARGO" EICAS message	Warning		Alert can be suppressed by fire damage to the fire detection system	None
	"Smoke - Smoke"	"SMOKE AFT CARGO" or "SMOKE FWD CARGO" EICAS message	Warning			
Tactile Alerts	None					

CRJ-700 Alerting Issues – In flight cargo/fire smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	None					
Aural Cues	Some indication that alarm is false, though extremely ambiguous, from negative reports from flight attendants about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- If the fire warning can be ascertained to be false, refrain from performing the cargo fire procedure; otherwise perform the procedure
- If the fire warning terminates after performing the procedure and can be ascertained to have been false, continue the flight; otherwise land within the specified time limit
- Unless the fire warning can be ascertained to be false, if the fire warning system indicates that the fire has ****not**** been extinguished after performing the procedure, land immediately
- Unless the fire warning can be ascertained to be false, advise ground personnel not to open cargo compartments without prior clearance from ARFF.

How does pilot know condition is resolved/recovered?

- Previously illuminated Fwd or Aft light on cargo fire panel is extinguished
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment, assessing and communicating to the pilots that the fire warning was false.

CRJ-700 Alerting Issues – In-flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring hidden behind cabin interior panel leading to inextinguishable cabin fire

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	None until smoke reaches the flight deck	Smoke visible		Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Aural Cues	None until flight attendants call pilots on interphone			Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Tactile/Somatic Cues	None					
Olfactory Cues	None until smoke is smelled			Cue may not be presented to pilots		

CRJ-700 Alerting Issues – In-flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring hidden behind cabin interior panel leading to inextinguishable cabin fire – Cont.

Expected Pilot Response(s)

- Perform appropriate checklist after performing memory items (3) and then on step 13. "determine source of smoke" to continue. Air-conditioning smoke, Electrical smoke or fire, galley smoke or fire, cabin smoke or fire, cabin smoke or fire, smoke aft cargo, smoke fwd cargo, smoke aft lav. It stipulates that if source unknown, assume electrical
- Perform emergency descent as specified by QRH
- Prepare for emergency landing, off-airport if necessary, as specified by QRH
- Land immediately as specified by QRH
- Suppress performing checklists for EICAS messages that are secondary to procedural actions, as directed by the QRH

How does pilot know condition is resolved/recovered?

- Pilots may receive information from flight attendants who are fighting the fire, including gaining access to hidden areas by removing panels
- Situation cannot be resolved until aircraft has landed and crew performs emergency evacuation

Issues with regard to multiple concurrent non-normal conditions

- Pilots may receive alerts/cues from failure conditions secondary to fire damage; it will be unclear to them to what extent they need to respond to these and how to prioritize their response

CRJ-700 Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Amber "MSG" appears on PFD	ANP>RNP	Caution	Also is displayed for many non-urgent FMS messages and thus is frequently ignored or not recognized		When ANP<RNP
	Amber "LOW POSITION ACCURACY" message appears on FMS CDU message line	ANP>RNP	Caution	Can be replaced by another FMS message. Then to review the previous message you have to enter the FMS via the MSG page to see all messages; Once removed from CDU message line, can not be displayed again		When ANP<RNP
	If GPS APPR is not seen, goes away, or shows NO APPR, then this means that you do not have the approach RNP (0.3).	ANP>0.3				
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	ANP value greater than RNP value on CDU legs/progress page	RNP limit for the aircraft, crew, and specific approach		This cue requires effortful scanning (including obtaining the proper FMS page and incorporating that display into the instrument scan, which is unusual); and interpretation		When ANP<RNP

CRJ-700 Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Examine the FMS further to see what message(s) are being displayed
- For the GPS approaches, a white GPS APPR is required to be seen in the nav data block prior to the FAF for the approach (should come on 2NM prior). If this is not seen, goes away, or shows NO APPR, then this means that you do not have the approach RNP (0.3). Hence a missed approach.
- If unable to perform the procedure with the current required RNP, must choose another type of navigation or one with higher RNP tolerance
- Return to ground-based navigation, if any, as directed by the NNP
- During RNAV or RNAV/RNP approach, execute missed approach
- Hand fly lateral path during missed approach to within RNP limits (including RF leg) until automation can be re-engaged.

How does pilot know condition is resolved/recovered?

- In FMS ANP will be displayed less than RNP
- "MSG" message on both the PFD and FMS CDU will extinguish

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning
- False terrain clearance warning
- Loss of separation from air traffic (ADS or Next-Gen navigation/surveillance)

CRJ-700 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional interference or spoofing (intentional introduction of false position into the receiver) leading to decreased GPS signal integrity

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Amber "CHK POS" appears on PFD	When predetermined values for the specific phase of flight are exceeded between the GPS and FMS location	Caution	Once removed from CDU message line, can not be displayed again		When disagreement is resolved
	"GPS- FMS DISAGREE" in FMS on messages page		Status			When disagreement is resolved
	Amber "MSG" appears on PFD	ANP>RNP	Caution			ANP<RNP
	Amber "LOW POSITION ACCURACY" message appears on FMS CDU message line	ANP>RNP	Status			ANP<RNP
Aural Alerts	None					
Tactile Alerts	None					

CRJ-700 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional interference or spoofing (intentional introduction of false position into the receiver) leading to decreased GPS signal integrity – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	ANP value greater than RNP value on CDU legs/progress page	RNP limit for the aircraft, crew, and specific approach		This cue requires effortful scanning (including obtaining the proper FMS page and incorporating that display into the instrument scan, which is unusual); and interpretation		When ANP<RNP
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- To examine FMS further to see what message(s) are being displayed in regard to which sensors are disagreeing. (e.g. GPS- FMS DISAGREE)
- Verify position using alternative means (e.g. radar, DME)
- Identify false information
- Eliminate source of false information from the position solution

CRJ-700 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional interference or spoofing (intentional introduction of false position into the receiver) leading to decreased GPS signal integrity – Cont.

How does pilot know condition is resolved/recovered?

- "CHK POS" message and "GPS-FMS DISAGREE" message in FMS will extinguish
- Verifying position after reverting to alternative navigation

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning
- False terrain clearance warning
- Loss of separation from air traffic (ADS or Next-Gen navigation/surveillance)

CRJ-700 Alerting Issues – Traffic conflict

1. Initiating Condition: TCAS resolution advisory

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Red "traffic" warning flashing on PFD between HSI and VSI	Proximity detected by TCAS at RA threshold. Intruding aircraft is within 30 sec from closest point of approach	Warning	System knows configuration of aircraft and will take this into account when determining best choice of RA. However, does not notice abnormal aircraft operations such as single engine operations.	RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures; Increase descent RAs inhibited below 1450 ft. AGL; Descent RAhs inhibited below 1000 ft. AGL; All RAs inhibited below 500 ft. AGL	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
	Red and green bands, pointer and rate on VSI showing needed climb or decent to comply with TCAS RA		Warning			
	Target symbology on TCAS or MFD screen shows trend information and altitude					
Aural Alerts	ATC Traffic Alert	Proximity detected by ATC radar/ conflict alert at system's threshold	Warning			

CRJ-700 Alerting Issues – Traffic conflict

1. Initiating Condition: TCAS resolution advisory – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Aural Alerts	"Traffic, traffic" aural	Proximity detected by TCAS at TA threshold. Intruding aircraft is within 30 sec from closest point of approach	Warning			
Tactile Alerts	None					
Visual Cues	Red square and data tag on MFD showing exact bearing, altitude (relative or absolute as selected by pilot) and climb or descent for intruder aircraft. Can be displayed on both navigation and TCAS screens	Proximity detected by TCAS at RA threshold. Intruding aircraft is within 30 sec from closest point of approach				
	Visual contact with traffic					
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- The system is designed with the expectation that the pilot will respond within 5 seconds.
- Maneuver vertically in response to TCAS RA directives
- Prioritize TCAS RA information over ATC and visual detection information
- Maneuver vertically and/or laterally as prompted by visual closure rate and direction of movement
- In the case of a corrective RA (e.g. a reversal) the system is designed to expect a pilot response within 2.5 seconds
- Pilot is expected to maintain the requested climb/descent until the aural "clear of conflict" is heard
- Report TCAS RA to ATC as soon as possible
- Caution for endangering passengers with unnecessarily abrupt compliance maneuvers

CRJ-700 Alerting Issues – Traffic conflict

1. Initiating Condition: TCAS resolution advisory – Cont.

How does pilot know condition is resolved/recovered?

- Aural "clear of conflict" will be annunciated
- Red traffic indication between HSI and VSI will extinguish
- Red-boxed traffic squares turn amber and/or diverge from own aircraft position
- Visual detection/evaluation of divergence from previous closure rate

Issues with regard to multiple concurrent non-normal conditions

- When TCAS RA is accompanied by a GPWS or STALL warning, RA compliance is to be discontinued

CRJ-700 Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	ADS-In RA vertical guidance on PFD/EADI	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning	Future alert/cue designs may differ from current TCAS designs.		
Aural Alerts	ATM Traffic Alert	Proximity detected by ATM system at RA threshold				
	ADS-In RA aural warning	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning			
Tactile Alerts	None	None				
Visual Cues	ADS CDTI with conflict display on EHSI/ND	CDTI conflict display system threshold				
	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation (N.B., closer traffic tolerances under Next-Gen)			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/Somatic Cues	None					

CRJ-700 Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error) – Cont.

Expected Pilot Response(s)

- Maneuver the aircraft vertically and/or laterally as directed by ADS-In and CDTI systems
- If aircraft response is automated, evaluate the validity of the ADS-In and CDTI alerts and monitor the aircraft response
- If response is manual, execute the response within established next-gen collision avoidance system specifications.

Issues with regard to multiple concurrent non-normal conditions

- Cascading effects of RA response on Next-Gen traffic separation and metering

CRJ-700 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: Autopilot failure Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	On the MFD map display, the aircraft symbol deviates from the magenta line (lateral deviation)			Detecting lateral track deviation from the aircraft symbol/magenta line display is ambiguous because display of the deviation depends on the range setting on the EHSI/ND display.		
Aural Cues	None					
Tactile/Somatic Cues	None					

CRJ-700 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: Autopilot failure
Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft's failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs - Cont.

Expected Pilot Response(s)

- Recognize track/path deviation exceeds RNP lateral/vertical limits
- If not in visual contact with the runway, execute a missed approach.
- Hand fly lateral path during missed approach to within RNP limits (including RF leg) until automation can be re-engaged.

How does pilot know condition is resolved/recovered?

- Flight path is recovered to within limits

Issues with regard to multiple concurrent non-normal conditions

- Aircraft making a missed approach in response to this condition may complicate Next-Gen automated sequencing/metering or traffic separation.

CRJ-700 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: Autopilot failure Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft's failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs - Cont.

Footnote:

- Rockwell Collins introduces new Performance-based Navigation capabilities to its FMS-4200 on
- CRJ700/CRJ900/CRJ1000 Next-Gen Aircraft NASHVILLE, Tenn. (May 19, 2011)
- With the latest version of the Rockwell Collins FMS-4200, operators of CRJ700/CRJ900/CRJ1000 Next-Gen aircraft will be able to automatically fly Performance-based Navigation procedures, including Required
- Navigation Performance (RNP) and RF (radius to fix) legs - a first for CRJ* aircraft. This will reduce track distance, flight time and fuel consumption when compared to conventional routes.
- Additional enhancements to the FMS-4200 for CRJ700/CRJ900/CRJ1000 Next-Gen aircraft include:
- LPV approach capability
- WAAS lateral navigation guidance and messaging
- Enablement of coupled VNAV
- Full NAV to NAV transitions
- Multiple approach indication (XYZ approaches)
- Step down fixes
- Temperature compensated barometric altitudes for use with VNAV operations
- The FMS-4200 is an integral component embedded within the Pro Line 4(tm) avionics system for in-service and current production CRJ regional jets. The latest version of the FMS is available through a software upgrade for CRJ700* and CRJ900* aircraft.
- Other FMS-4200 enhancements include: WAAS lateral navigation guidance and messaging; Full NAV to NAV transitions; LPV approach capability; step down fixes; enablement of coupled VNAV; VNAV operations temperature compensated barometric altitudes; and multiple approach indication. Rockwell Collins' FMS-4200 is part of the company's Pro Line 4 avionics system. Operators can get the new FMS version by upgrading their software.

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

1. Initiating Condition: Blocked pitot source (captain's or left source)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution light, flashing amber	Yellow EICAS message "EFIS COMP MON"	Caution		None	Pressing the master caution switchlight will stop flashing
	"EFIS COMP MON" amber message on EICAS	When difference between the Capt's and F/O's airspeed is more than 10 kts.	Caution		None	Switching to the ADC on the operative side
	Capt's. airspeed tape shows an amber IAS in a box parallel to the tape	When difference between the Capt's and F/O's airspeed is more than 10 kts.	Caution		None	Switching to the ADC on the operative side
	On the PFD, "ADC 1 or 2" displayed in amber letters	Single ADC operation	Caution	Single ADC loss will render stick pusher inactive. Shaker will still be functional		Both ADC's operating correctly
	The following status messages will be displayed after switching to correct ADC: L FADEC FAULT (1 OR 2), SPLR/STAB FAULT, RUD LIMIT FAULT	Single ADC operation	Status			Both ADC's operating correctly
Aural Alerts	Master caution message single chime	Yellow EICAS message "EFIS COMP MON"	Caution			None, only a single chime, does not repeat unless another caution message is presented.

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	None					
Visual Cues	Significant deviations between the airspeed readings on the Capt's./F/O's/Standby indicators					Switching to the ADC on the operative side
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Adjust airplane attitude and thrust to maintain aircraft control
- Follow QRH procedures to switch ADC to operable side
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations may be affected and destination choices may have to be altered.
- Switch FD and transponder to side with operative ADC

How does pilot know condition is resolved/recovered?

- After selection of ADC on correct side the "EFIS COMP MON" EICAS message will be removed, as will the amber IAS on the airspeed tape

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	Master caution light, flashing amber	Yellow EICAS message "EFIS COMP MON"	Caution	This will be temporary as any differences beyond the 10 kts. is detected. May come and go as "EFIS COMP MON" is presented and removed.	None	Pressing the master caution switchlight will stop flashing
	"EFIS COMP MON" amber message on EICAS	When airspeed between the capt's and F/O's is more than 10 kts.	Caution	This will be temporary as any differences beyond the 10 kts. is detected. May come and go depending on the blockage and differences in perceived airspeed.	None	When the airspeeds either are within 10 kts and/or they reach zero the alert will terminate.
	Airspeed tape, altitude tape, and vertical speed indicator all disappear and are replaced with red IAS, ALT and V/S flags respectively as the ADC are interpreted to have failed (really because of blockage)	ADC are determined to no longer be functioning and providing data to displays	Caution	With both ADCs considered inoperative, neither the stick shaker or pusher will be operational		Switching to the ADC on the operative side if only one ADC failure is currently shown. However, with all three pitot input sources blocked, both ADCs will be interpreted to have failed.

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	The following EICAS caution messages are displayed; MACH TRIM, RUD LIMITER, STALL FAIL, AUTO PRESS. The following status messages are displayed when both ADC are interpreted to have failed: GPWS FAIL, WINDSHEAR FAIL, L and R FADEC FAULT 2, SPLR/STAB FAULT, RUD LIMIT FAULT	Both ADCs are interpreted by the system to have failed due to the blockage.	Caution	With both ADCs considered inoperative, there will be a "slight" difference between the Capt's and F/O's altimeters		Both ADC's operating correctly
	On the PFD, both "ADC 1 and 2" will be displayed in amber letters	Both ADCs are interpreted by the system to have failed due to the blockage.	Caution	GPS will go off line and stop comparing latitude.		Both ADC's operating correctly
	Stall push light switch on glareshield will illuminate	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning			Reduction of AOA
Aural Alert	Auto-pilot disconnect cavalry charge will occur with stick shaker activation causing the green "AP" on PFD to change to red then disappear	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning			None, will flash twice then red "AP" will disappear from PFD

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Master caution message single chime	Yellow EICAS message "EFIS COMP MON"	Caution			None, only a single chime, does not repeat unless another caution message is presented.
	Overspeed clacker will not be present with both ADC's inoperative	Associated with indicated airspeed greater than 3 knots faster than Vmo/Mmo, because either (1) pressure is trapped in a pitot system by blockage and ambient pressure decreases in the climb; or (2) pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed.		Despite airspeed possibly going into the overspeed band on the A/S tape, if both ADCs are out, the overspeed clacker will not trigger		Alert terminates when indicated airspeed is reduced to at least 3 knots slower than Vmo/Mmo

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Stick shaker (sound of)	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning		Based on system design, the stall warning system and related alerts are inhibited when all ADC inputs are blocked/invalid, so this alert may start and stop unexpectedly as pitot sources block and unblock	Reduction of AOA
	Stall warbler	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Caution		Based on system design, the stall warning system and related alerts are inhibited when all ADC inputs are blocked/invalid, so this alert may start and stop unexpectedly as pitot sources block and unblock	Reduction of AOA

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
	Auto-pilot disconnect cavalry charge sound	Stick shaker activation	Caution			none, will sound once and stop
Tactile Alerts	Stick shaker	Predetermined angle of attack (AOA) is reached or predicted to be reached.	Warning		Based on system design, the stall warning system and related alerts are inhibited when all ADC inputs are blocked/invalid, so this alert may start and stop unexpectedly as pitot sources block and unblock	Reduction of AOA

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Significant deviations between the airspeed readings on the Capt's./F/O's/Standby indicators; All of these will go to zero as the pressure in the system is decreased.					Switching to the ADC on the operative side
Aural Cues	None					
Tactile/Somatic Cues	Aerodynamic buffet	Actual overspeed or approach to stall				

Expected Pilot Response(s)

- Follow QRH procedures to switch ADC to operable side when the event begins. However, as both ADCs are believed to have failed, the QRH re-directs the crew to focus on manual cabin pressurization.
- Adjust airplane attitude and thrust to maintain aircraft control
- Follow QRH procedures to Accomplish "Manual Cabin Pressurization Control Procedure"
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations will be affected and destination choices may have to be altered.
- Will not be able to switch FD and transponder to side with operative ADC as there both have failed

How does pilot know condition is resolved/recovered?

- The tapes and indicators will be returned and red IAS, ALT and/or V/S will be removed if the occlusion is removed.

Issues with regard to multiple concurrent non-normal conditions

- It will not be obvious that GPS is now off-line and system will revert to DME-DME processing of navigation solutions. Implications for NextGen operations and the types of procedures accepted after this type of failure.

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

3. Initiating Condition: Air data computer failure (single module or unit)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution light, flashing amber	Yellow EICAS message "EFIS COMP MON"	Caution		None	Pressing the master caution switchlight will stop flashing
	"EFIS COMP MON" amber message on EICAS	When difference between the Capt's and F/O's airspeed is more than 10 kts.	Caution	Crew needs to look at PFD to be sure they understand which EFIS comparator value is being flagged.	None	Switching to the ADC on the operative side
	Airspeed tape, altitude tape, and vertical speed indicator all disappear and are replaced with red IAS, ALT and V/S respectively	ADC no longer functioning and providing data to displays	Warning			Switching to the ADC on the operative side
	The following EICAS status messages will be displayed after switching to correct ADC: L FADEC FAULT (1 OR 2), SPLR/STAB FAULT, RUD LIMIT FAULT	Single ADC operation	Status			Both ADC's operating correctly
	On the PFD, "ADC 1 or 2" will be displayed in amber letters	Single ADC operation	Caution			Both ADC's operating correctly
Aural Alerts	Master caution message single chime	Yellow EICAS message "EFIS COMP MON"	Caution			None, only a single chime, does not repeat unless another caution

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

3. Initiating Condition: Air data computer failure (single module or unit)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
						message is presented.

CRJ-700 Alerting Issues – Pitot/static/air data computer system failure

3. Initiating Condition: Air data computer failure (single module or unit)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	None					
Visual Cues	Significant deviations between the airspeed readings on the Capt's./F/O's/Standby indicators					Switching to the ADC on the operative side
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Adjust airplane attitude and thrust to maintain aircraft control
- Follow QRH procedures to switch ADC to operable side
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations may be affected and destination choices may have to be altered.
- Switch FD and transponder to side with operative ADC

How does pilot know condition is resolved/recovered?

- After selection of ADC on correct side the airspeed & altitude tapes in addition to the vertical speed indicator will return

APPENDIX G

Embraer EMB190 Matrices

EMB190 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	When the current deceleration rate will cause airspeed to be below minimum safe speed (i.e., in the low speed awareness region of the PFD speed tape) within the next 10 seconds, the airspeed trend arrow turns from green to amber	Airspeed trend projection of 1.13 Vs within the next 10 seconds	Caution			Airspeed increase
	When the current deceleration rate will cause airspeed to be below minimum safe speed (i.e., in the low speed awareness region of the PFD speed tape) within the next 10 seconds, or when slowing below actual minimum safe speed, PFD digital airspeed readout turns from green to amber	Airspeed trend projection of 1.13 Vs within the next 10 seconds, or at approximately 1.13 Vs (g-compensated)	Caution			Airspeed increase
	Slowing below minimum safe speed, the PFD pitch limit indicator appears and turns from green to amber	AOA equivalent to approximately 1.13 Vs (g-compensated)	Caution			AOA reduction
	When the current deceleration rate will cause airspeed to approach stall (be at or below stickshaker speed) within the next 10 seconds, the digital indicated airspeed readout turns from amber to red inverse	Airspeed trend projection at or below stickshaker speed (g-compensated)	Warning			Airspeed increase
	Approaching stall, the PFD pitch limit indicator turns from amber to red inverse	Stickshaker limit value of AOA	Warning			AOA reduction
	Approaching stall, the PFD digital mach readout turns from green to amber	Stickshaker limit value of AOA	Caution			AOA reduction

EMB190 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Approaching stall, the PFD "AP" FMA turns from green to red (flashing for the first five seconds)	Stickshaker limit value of AOA	Warning	Reversion to manual flying can be a workload spike and distraction		Cancelled by pressing an AP disconnect button
	Approaching stall, MFD EICAS caution message AP FAIL	Stickshaker triggers autopilot disconnect	Caution	Reversion to manual flying can be a workload spike and distraction		
	At stall onset, PFD digital mach readout turns from amber to red inverse	Approximately stall speed (g-compensated)	Warning			Airspeed increase
Aural Alerts	Stick shaker (sound of)	Stall protection system limit value of AOA	Warning			AOA reduction
	Voice alert "Autopilot"	Stall protection system limit value of AOA (stickshaker threshold)		Reversion to manual flying can be a workload spike and distraction		

EMB190 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Tactile Alerts	Stick shaker	Stall protection system limit value of AOA	Warning			AOA reduction
Visual Cues	When slowing below minimum safe speed, the indicated airspeed enters the amber region of the speed tape	Approximately 1.13 Vs (with less than the indicated Vs margin when > .45 Mach), with g-compensated movement of the speed band				
	Approaching stall, indicated airspeed enters the red region of the speed tape	Stickshaker speed, with g-compensated movement of the speed band				
	PFD indications of uncommanded pitch					
	Roll rate on PFD				Uncommanded roll cues masked by autopilot roll inputs until the a/p disconnects (appears as wheel deflection, see below); however, rapid roll may accompany a/p disconnect at the stall.	

EMB190 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Sink rate on PFD vertical speed display					
	Wheel may move opposite the roll.	Wheel movement from autopilot inputs in response to uncommanded roll, if roll occurs prior to stickshaker/autopilot disconnect				
Aural Cues	None					
Tactile/ Somatic Cues	Aerodynamic buffet	AOA (natural)				Reduction of AOA
	Heavier column forces to increase AOA	Stickshaker limit value of AOA		This is a fly-by-wire function in Normal mode; failure of this function is annunciated on EICAS		

EMB190 Alerting Issues – Stall

1. Initiating Condition: High altitude airspeed decay with turbulence, autopilot engaged – Cont.

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

How does pilot know condition is resolved/recovered?

- Cessation of stall warning alerts

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

EMB190 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	When the current deceleration rate will cause airspeed to be below minimum safe speed (i.e., in the low speed awareness region of the PFD speed tape) within the next 10 seconds, the airspeed trend arrow turns from green to amber	Airspeed trend projection of 1.13 Vs within the next 10 seconds	Caution			Airspeed increase
	When the current deceleration rate will cause airspeed to be below minimum safe speed (i.e., in the low speed awareness region of the PFD speed tape) within the next 10 seconds, or when slowing below actual minimum safe speed, PFD digital airspeed readout turns from green to amber	Airspeed trend projection of 1.13 Vs within the next 10 seconds, or at approximately 1.13 Vs (g-compensated)	Caution			Airspeed increase
	Slowing below minimum safe speed, the PFD pitch limit indicator appears and turns from green to amber	AOA equivalent to approximately 1.13 Vs (g-compensated)	Caution			AOA reduction
	When the current deceleration rate will cause airspeed to approach stall (be at or below stickshaker speed) within the next 10 seconds, the digital indicated airspeed readout turns from amber to red inverse	Airspeed trend projection at or below stickshaker speed (g-compensated)	Warning			Airspeed increase
	Approaching stall, the PFD pitch limit indicator turns from amber to red inverse	Stickshaker limit value of AOA	Warning			AOA reduction
	Approaching stall, the PFD digital mach readout turns from green to amber	Stickshaker limit value of AOA	Caution			AOA reduction

EMB190 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	At stall onset, PFD digital mach readout turns from amber to red inverse	Approximately stall speed (g-compensated)	Warning			Airspeed increase
Aural Alerts	Stick shaker (sound of)	Stall protection system limit value of AOA	Warning			AOA reduction
	GPWS "Bank angle"	Bank angle >35 degrees		This is not an alert to the stall, but rather to the excessive bank angle from the roll upset		Reduction of bank angle
Tactile Alerts	Stick shaker	Stall protection system limit value of AOA	Warning			AOA reduction
Visual Cues	When slowing below minimum safe speed, the indicated airspeed enters the amber region of the speed tape	Approximately 1.13 Vs (with less than the indicated Vs margin when > .45 Mach), with g-compensated movement of the speed band				
	Approaching stall, indicated airspeed enters the red region of the speed tape	Stickshaker speed, with g-compensated movement of the speed band				

EMB190 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD indications of uncommanded pitch			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Roll rate on PFD			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Sink rate on vertical speed display			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
Aural Cues	Wind noise					
Tactile/ Somatic Cues	Unusual wheel/column forces			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		

EMB190 Alerting Issues – Stall

2. Initiating Condition: Increasing load factor in nose-low, high bank upset, autopilot disengaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Tactile/ Somatic Cues	Aerodynamic buffet	AOA (natural)		Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

How does pilot know condition is resolved/recovered?

- Termination of stall warning alerts

Issues with regard to multiple concurrent non-normal conditions

- Recovery from stall condition must be followed immediately by recovery from nose-low, high bank upset condition.
- Possible passenger injuries and aircraft damage.

EMB190 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None: Pitch limit indicator is present on the PFD but may not be touching the aircraft symbol when the stall occurs (suggesting to the pilot that the aircraft is not stalling)				Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Aural Alerts	None				Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Tactile Alerts	None			Pilots are trained extensively to associate stick shaker as trigger to stall recovery; in absence of stick shaker (warning system failure or stall at lower-than-nominal AOA) they may not interpret the secondary cues of buffet, roll, etc. as being related to stall.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	
Visual Cues	None: airspeed appears to be adequate but is not; airplane may stall while indicated airspeed is in the amber band but not in or touching the red band			Pilots do not usually receive simulator training for stall at increased load factor/during roll upset so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.	Alerts and cues are masked by the icing condition which causes the aircraft to stall at lower-than-normal AOA	

EMB190 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	PFD/ADI indications of uncommanded pitch			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Roll rate on PFD/EADI			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
	Sink rate on vertical speed display			Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		
Aural Cues	None					
Tactile/Somatic Cues	Buffet; unusual wheel/column forces (autopilot off)	AOA (natural)		Pilots do not usually receive simulator training for stall at reduced AOA so they are not accustomed to recognizing/reacting to these cues in the stress, novelty, and workload of a roll upset.		Reduction of AOA

EMB190 Alerting Issues – Stall

3. Initiating Condition: Wing ice accumulation – Cont.

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Apply nose down pitch control until stall warning is eliminated
- Apply nose-down trim as needed
- Roll wings level
- Adjust thrust as needed
- Check speedbrakes retracted
- Return to the desired flightpath

How does pilot know condition is resolved/recovered?

- Difficult to know, related to cessation of uncommanded pitch/roll/sink

Issues with regard to multiple concurrent non-normal conditions

- Condition may devolve to engine surge and/or wing-walking (roll reversals from stall exacerbated by pilot rudder/wheel inputs).
- Possible passenger injuries and aircraft damage.

EMB190 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Slowing below minimum safe speed (falsely indicated), the PFD pitch limit indicator appears and turns from green to amber	AOA equivalent to approximately 1.13 Vs (g-compensated)	Caution		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
	When the current deceleration rate will cause airspeed to approach stall (be at or below the falsely calculated stickshaker speed) within the next 10 seconds, the digital indicated airspeed readout turns from amber to red inverse	Airspeed trend projection at or below stickshaker speed (g-compensated)	Warning		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
	Approaching the falsely calculated AOA limit value for stall, the PFD pitch limit indicator turns from amber to red inverse	Stickshaker limit value of AOA	Warning		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
	Approaching the falsely calculated AOA limit value for stall, the PFD digital mach readout turns from green to amber	Stickshaker limit value of AOA	Caution		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid

EMB190 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Stick shaker, sound of (false indication)	Stall protection system limit value of AOA	Warning		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
Tactile Alerts	Stick shaker (false indication)	Stall protection system limit value of AOA	Warning		Inhibition/suppression not relevant because the alert is false	Alert or cue is not terminated as it is invalid
Visual Cues	Normal vertical speed, altimeter, and airspeed indications on PFD, as well as view through the windshield of the aircraft climbing (if VMC) are subtle cues that the aircraft is not stalling					Alert or cue is not terminated as it is invalid
Aural Cues	None					

EMB190 Alerting Issues – Stall

4. Initiating Condition: False stall warning during takeoff rotation – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Tactile/Somatic Cues	Normal vertical acceleration from rotation into climb is a subtle cue that the aircraft is not stalling					Alert or cue is not terminated as it is invalid

Expected Pilot Response(s)

- Ignore false alerts and cues.
- Do not reject takeoff.

How does pilot know condition is resolved/recovered?

- Observe normal takeoff and climb performance

Issues with regard to multiple concurrent non-normal conditions

- None unless pilot takes unneeded actions, such as high speed RTO.

EMB190 Alerting Issues – Uncommanded Yaw or Roll

1. Initiating Condition: Wake Encounter

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	GPWS "Bank Angle"					
Tactile Alerts	None					
Visual Cues	Roll rate on PFD					
Aural Cues	None					
Tactile/ Somatic Cues	Wheel may move opposite the roll if autopilot is engaged.					

Expected Pilot Response(s)

- Add thrust as necessary
- Disconnect autopilot
- Verify symmetrical thrust
- Confirm spoilers are retracted
- Apply opposing roll and/or yaw inputs to control aircraft attitude
- Pitch to horizon
- Recover from nose-down upset if necessary

EMB190 Alerting Issues – Uncommanded Yaw or Roll

1. Initiating Condition: Wake Encounter – Cont.

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained.

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or secondary alerts/cues as they cope with a roll or yaw/roll upset

EMB190 Alerting Issues – Uncommanded Yaw or Roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	GPWS "Bank Angle"					
Tactile Alerts	None					
Visual Cues	Roll rate on PFD					
	Yaw rate on Map/MFD					
	Rudder deflection graphically displayed on MFD Flight Controls Synoptic page			This page must be manually selected by the pilots and thus the depiction of rudder deflection would be effortful to obtain		
Aural Cues	None					
Tactile/Somatic Cues	Lateral-g					

EMB190 Alerting Issues – Uncommanded Yaw or Roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Tactile/ Somatic Cues	Rudder pedals may deflect in rudder hardover			Interpretation of rudder and wheel deflections can be difficult because the direction of deflection (into or opposite the yaw) depends on the underlying cause		
	Wheel may move opposite the roll if autopilot is engaged.			Interpretation of rudder and wheel deflections can be difficult because the direction of deflection (into or opposite the yaw) depends on the underlying cause		

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle
- Verify symmetrical thrust
- Confirm spoilers are retracted
- Apply opposing roll and/or yaw inputs to control aircraft attitude, using significant force if necessary
- Reduce AOA/pitch/altitude as required to regain roll authority
- Recover from nose-down upset if necessary

EMB190 Alerting Issues – Uncommanded Yaw or Roll

2. Initiating Condition: Uncommanded rudder deflection or rudder pedal kicks – Cont.

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained and uncommanded control deflections have been either neutralized or compensated for in all anticipated circumstances for the remainder of the flight.
- If there are residual uncommanded control deflections or pressures, there may be operational implications through to landing (e.g., crosswind limitations)

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or secondary alerts/cues as they cope with a roll or yaw/roll upset

EMB190 Alerting Issues – Uncommanded Yaw or Roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	GPWS "Bank Angle"					
Tactile Alerts	None					
Visual Cues	Roll rate on PFD					
	Aileron/spoiler deflection graphically displayed on MFD Flight Controls Synoptic page			This page must be manually selected by the pilots and thus the depiction of aileron/spoiler deflection would be effortful to obtain		
Aural Cues	None					
Tactile/Somatic Cues	Wheel may move opposite the roll if uncommanded flap/slat/spoiler deflection and autopilot is engaged; however, wheel may move in the direction of roll if uncommanded aileron deflection or other causes			Interpretation of wheel deflection is difficult because the direction of deflection (into or opposite the roll) depends on the underlying cause		

EMB190 Alerting Issues – Uncommanded Yaw or Roll

3. Initiating Condition: Uncommanded aileron/spoiler/flap/slat deflection – Cont.

Expected Pilot Response(s)

- Disconnect autopilot/autothrottle
- Verify symmetrical thrust
- Confirm spoilers are retracted
- Apply opposing roll and/or yaw inputs to control aircraft attitude, using significant force if necessary
- Recover from nose-down upset if necessary

How does pilot know condition is resolved/recovered?

- Condition is resolved when aircraft control is regained and uncommanded control deflections have been either neutralized or compensated for in all anticipated circumstances for the remainder of the flight.
- If there are residual uncommanded control deflections or pressures, there may be operational implications through to landing (e.g., crosswind limitations)

Issues with regard to multiple concurrent non-normal conditions

- Pilots may be confronted with unusual flight control difficulties and/or secondary alerts/cues as they cope with a roll or yaw/roll upset

EMB190 Alerting Issues – Hydraulic failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (2), in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Master caution blinking amber lights on L&R glareshield	Triggered by EICAS Caution Messages AUTOBRAKE FAIL and HYD 2 LO PRESS	Caution			Blinking terminates when the Master Caution light/pushbutton is pressed
	EICAS Caution Message (Amber, flashing, reverse video): AUTOBRAKE FAIL	Triggered by loss of hydraulic quantity	Caution		Inhibited from 80 knots up to 400 feet agl (takeoff)	Flashing/reverse video of the text ceases when the Master Caution light/pushbutton is pressed
	EICAS Advisory Message (Cyan, flashing/reverse video for 5 seconds): HYD 2 LO QTY		Advisory		Inhibited from thrust lever advancement up to 80 knots (takeoff roll), 80 knots up to 400 feet agl (takeoff), and 200 feet agl down to 30 seconds after touchdown (landing)	Flashing/reverse video of the text ceases after 5 seconds
	EICAS Advisory Message (Cyan, flashing/reverse video for 5 seconds): BRK RH FAULT	Triggered by loss of hydraulic quantity	Advisory		Inhibited from 80 knots up to 400 feet agl (takeoff)	Flashing/reverse video of the text ceases after 5 seconds

EMB190 Alerting Issues – Hydraulic failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (2), in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	EICAS Advisory Message (Cyan, flashing/reverse video for 5 seconds): BRK LH FAULT	Triggered by loss of hydraulic quantity	Advisory		Inhibited from 80 knots up to 400 feet agl (takeoff)	Flashing/reverse video of the text ceases after 5 seconds
	EICAS Caution Message (Amber, flashing, reverse video): >HYD 2 LO PRESS (">" denotes Root EICAS message)		Caution		Inhibited from 80 knots up to 400 feet agl (takeoff)	Flashing/reverse video of the text ceases when the master caution light/pushbutton is pressed
	EICAS Caution Message (Amber, flashing, reverse video): HYD PTU FAIL		Caution		Inhibited from 80 knots up to 400 feet agl (takeoff) and 200 feet agl down to 30 seconds after touchdown (landing)	Flashing/reverse video of the text ceases when the master caution light/pushbutton is pressed
	EICAS Caution Message SPOILER FAULT	Loss of Hydraulic System 2	Caution	The Loss of Hydraulic System 2 directs the pilots not to accomplish the associated SPOILER FAULT procedure	Inhibited from thrust lever advancement up to 80 knots (takeoff roll), 80 knots up to 400 feet agl (takeoff), and 200 feet agl down to 30 seconds after touchdown (landing)	

EMB190 Alerting Issues – Hydraulic failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (2), in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Single chime repeated every five seconds	Master caution	Caution			Repetition of chime terminates when master caution pushbutton is pressed
Tactile Alerts	None					
Visual Cues	On the MFD Hydraulic Synoptic Page, the digital quantity value and the analog quantity scale/pointer for the failed system turn cyan.			Pilot action is required to display the synoptic page on the MFD.		
	On the MFD Hydraulic Synoptic Page, the digital pressure value and the analog pressure scale/pointer for the failed system turn amber.			Pilot action is required to display the synoptic page on the MFD.		
	On the MFD Hydraulic Synoptic Page, the font size increases for the text inside the distribution box for the failed hydraulic system			Pilot action is required to display the synoptic page on the MFD.		
	On the MFD Hydraulic Synoptic Page, the schematic hydraulic line into the distribution box for the failed hydraulic system turns white.			Pilot action is required to display the synoptic page on the MFD.		
	On the MFD Hydraulic Synoptic page, low pressure and quantity readings on System 2 hydraulic system's digital readouts and analog gauges			Pilot action is required to display the synoptic page on the MFD.		

EMB190 Alerting Issues – Hydraulic failure (single system)

1. Initiating Condition: Complete fluid loss for the single most critical hydraulic system (2), in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Identify condition (low quantity followed by low pressure alerts/indications)
- Perform HYD 2 LO QTY procedure (no actions) followed by HYD 2 LO PRESS procedure, which internally calls for and leads into the Hydraulic System 2 Loss procedure
- Perform checklist
- As specified by the Hydraulic System 2 Loss procedure, identify follow-on requirements (PF assignment, landing distance requirement, alternate landing gear extension (included in the procedure), recommendations for coping with loss of nosewheel steering, commitment to destination once gear extended)
- Per the Loss of Hydraulic System 2 procedure, do not accomplish the SPOILER FAULT or LANDING GEAR ABNORMAL EXTENSION procedures
- Implement follow-on requirements (PF assignment, landing distance requirement, abnormal landing gear extension (included in the hydraulic procedure), recommendations for coping with loss of nosewheel steering, commitment to destination once gear extended) at the appropriate phase of flight

How does pilot know condition is resolved/recovered?

- Completion of procedures results in stable situation but abnormal condition for landing (e.g., longer landing distance); system cannot be recovered to normal operation.

Issues with regard to multiple concurrent non-normal conditions

- Simultaneous hydraulic and flight control system conditions
- Challenge of dealing with the concurrent and continuing failures resulting from the initiating condition (e.g., flaps, slats, autopilot, etc.)

EMB190 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Amber boxed FAIL text on the EICAS panel N1 indicator of the failed engine	FADEC detects engine flamed out or shut down without pilot action	Caution			Alert is removed when the failed engine's master has been turned off as part of the engine failure procedure
	Red boxed value on the EICAS panel oil pressure indicator of the failed engine	Oil pressure below operating limit (< 24 psi)	Warning	Low oil pressure alert may precede the engine FAIL alert, be simultaneous with it, or be seconds after it depending on cause of engine failure		
	EICAS caution ENG 1 or 2 FAIL (Amber, flashing, reverse video)	FADEC detects engine flamed out or shut down without pilot action	Caution	This alert is inhibited during takeoff roll, so in this condition it is first presented during climb.	Inhibited during takeoff from 80 knots through 400 feet	Flashing/reverse video of the text ceases when the master caution light/pushbutton is pressed; Alert is removed when the failed engine's master has been turned off as part of the engine failure procedure
	Master caution blinking amber lights on L&R glareshield	Triggered by EICAS Caution Message ENG 1 or 2 FAIL	Caution	This alert is inhibited during takeoff roll, so in this condition it is first presented during climb.	Inhibited during takeoff from 80 knots through 400 feet	Blinking terminates when the Master Caution light/pushbutton is pressed
Aural Alerts	Repetitive chime	Triggered by EICAS Caution Message ENG 1 or 2 FAIL	Caution	This alert is inhibited during takeoff roll, so in this condition it is first presented during climb.	Inhibited during takeoff from 80 knots through 400 feet	Chime terminates when the Master Caution light/pushbutton is pressed
Tactile Alerts	None					

EMB190 Alerting Issues – Single engine failure/fire

1. Initiating Condition: Engine failure after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Abnormal ITT, N1, N2, oil temperature, and/or oil pressure gauge indications					
	Nose yawing off runway centerline					
Aural Cues	Sounds of engine malfunction may occur					
Tactile/ Somatic Cues	Lateral g					
	Rudder pressure required to stay on runway					
	Reduced longitudinal acceleration					

Expected Pilot Response(s)

- Control the aircraft
- Execute single engine takeoff/climb profile
- Identify and execute appropriate non-normal checklist (above 400 feet agl)
- Perform single engine approach and landing

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system failures or issues that may require additional action.
- Uncontained engine failure may present additional multiple alerts and failures.

EMB190 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Amber boxed FAIL text on the EICAS panel N1 indicator of the failed engine	FADEC detects engine flamed out or shut down without pilot action	Caution			Alert is removed when the failed engine's master has been turned off as part of the engine failure procedure
	Red boxed value on the EICAS panel oil pressure indicator of the failed engine	Oil pressure below operating limit (< 24 psi)	Warning	Low oil pressure alert may precede the engine FAIL alert, be simultaneous with it, or be seconds after it depending on cause of engine failure		
	EICAS caution ENG (1 or 2) FAIL (Amber, flashing, reverse video)	FADEC detects engine flamed out or shut down without pilot action	Caution		Inhibited during takeoff from 80 knots through 400 feet	Flashing/reverse video of the text ceases when the master caution light/pushbutton is pressed; Alert is removed when the failed engine's master has been turned off as part of the engine failure procedure
	Master caution blinking amber lights on L&R glareshield	Triggered by EICAS Caution Message ENG (1 or 2) FAIL	Caution		Inhibited during takeoff from 80 knots through 400 feet	Blinking terminates when the Master Caution light/pushbutton is pressed
Aural Alerts	Repetitive chime	Triggered by EICAS Caution Message ENG (1 or 2) FAIL	Caution		Inhibited during takeoff from 80 knots through 400 feet	Chime terminates when the Master Caution light/pushbutton is pressed
Tactile Alerts	None					

EMB190 Alerting Issues – Single engine failure/fire

2. Initiating Condition: Engine failure in cruise flight with autopilot engaged – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Abnormal ITT, N1, N2, oil temperature, and/or oil pressure gauge indications					
Aural Cues	Sounds of engine malfunction may occur					
Tactile/ Somatic Cues	Wheel may move opposite the roll if autopilot is engaged.					Control wheel displacement cues are reduced/eliminated after trimming the rudder

Expected Pilot Response(s)

- Control the aircraft
- Identify and execute appropriate non-normal checklist
- Perform single engine approach and landing

Issues with regard to multiple concurrent non-normal conditions

- Engine failure presents concurrent electrical, hydraulic, and/or fuel system alerts, cues that may require additional action.
- Uncontained engine failure may present additional multiple alerts and failures.

EMB190 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	Fire extinguisher handle illuminates in red on overhead panel	Temperature sensed by one or more engine fire loops	Warning			Alert terminates if the fire detection system senses that the fire has been extinguished, or the fire detection system has failed (burnthrough)
	Master Warning blinking red lights on L&R glareshield	Temperature sensed by one or more engine fire loops	Warning			Blinking terminates when the Master Warning light/pushbutton is pressed
	Red boxed FIRE text on the EICAS panel ITT indicator of the affected engine	Temperature sensed by one or more engine fire loops	Warning			Alert terminates if the fire detection system senses that the fire has been extinguished, or the fire detection system has failed (burnthrough)
	EICAS warning ENG (1 or 2) FIRE (Red, flashing, reverse video)	Temperature sensed by one or more engine fire loops	Warning			Flashing/reverse video of the text ceases when the Master Warning light/pushbutton is pressed; Alert terminates if the fire detection system senses that the fire has been extinguished, or the fire detection system has failed (burnthrough)

EMB190 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	EICAS caution ENG (1 or 2) FIRE DET FAIL	Fire detection built-in test determines that the fire detection system has been compromised (e.g., due to fire damage/burnthrough)	Caution		Inhibited during takeoff from 80 knots through 400 feet and during landing from 200 feet through 30 seconds after touchdown	
	Master caution blinking amber lights on L&R glareshield	Triggered by EICAS Caution Message ENG (1 or 2) FIRE DET FAIL	Caution		Inhibited during takeoff from 80 knots through 400 feet and during landing from 200 feet through 30 seconds after touchdown	Blinking terminates when the Master Caution light/pushbutton is pressed
Aural Alerts	Continuous fire bell with repetitive triple chime	Temperature sensed by one or more engine fire loops	Warning			Bell and triple chime terminates when the Master Warning light/pushbutton is pressed; Alert terminates if the fire detection system senses that the fire has been extinguished, or the fire detection system has failed (burnthrough)

EMB190 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Aural Alerts	Repetitive chime	Triggered by EICAS Caution Message ENG (1 or 2) FIRE DET FAIL	Caution		Inhibited during takeoff from 80 knots through 400 feet and during landing from 200 feet through 30 seconds after touchdown	Chime terminates when the Master Caution light/pushbutton is pressed
Tactile Alerts	None unless engine also fails					
Visual Cues	None unless engine also fails					
Aural Cues	None					
Tactile/Somatic Cues	None unless engine also fails					

Expected Pilot Response(s)

- Control the aircraft
- Execute V1 engine failure/fire flight profile
- Execute engine fire procedure (begin procedure above 400 feet AFE)
- Perform single engine approach/landing procedures

How does pilot know condition is resolved/recovered?

- Fire warning indication that fire is extinguished

EMB190 Alerting Issues – Single engine failure/fire

3. Initiating Condition: Engine fire after V1 and prior to V2 – Cont.

Issues with regard to multiple concurrent non-normal conditions

- Engine fire will devolve to an engine failure, either as a direct result of and simultaneous with the fire onset or as part of the engine fire procedure.
- Engine fire presents concurrent electrical, hydraulic, and/or fuel system issues that may require additional action.
- Engine fire may present cascading emergency (e.g., hydraulic failures, smoke in cabin, etc.)
- Uncontrollable fire may present additional, cascading conditions (e.g., structural failure, fuel loss, need to expedite landing or even land off-airport).

EMB190 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak, during takeoff after V1 and before V2

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	Fire extinguisher handle illuminates in red on overhead panel	Temperature sensed by one or more engine fire loops	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Alert terminates if the fire detection system senses that the fire has been extinguished
	Master Warning blinking red lights on L&R glareshield	Temperature sensed by one or more engine fire loops	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Blinking terminates when the Master Warning light/pushbutton is pressed
	Red boxed FIRE text on the EICAS panel ITT indicator of the affected engine	Temperature sensed by one or more engine fire loops	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Alert terminates if the fire detection system senses that the fire has been extinguished
	EICAS warning ENG (1 or 2) FIRE (Red, flashing, reverse video)	Temperature sensed by one or more engine fire loops	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Flashing/reverse video of the text ceases when the Master Warning light/pushbutton is pressed; Alert terminates if the fire detection system senses that the fire has been extinguished

EMB190 Alerting Issues – Single engine failure/fire

4. Initiating Condition: False fire warning from engine bleed leak, during takeoff after V1 and before V2 – Cont.

Aural Alerts	Continuous fire bell with repetitive triple chime	Temperature sensed by one or more engine fire loops	Warning	False fire warning can lead to unneeded RTO, engine shutdown, etc.		Bell and triple chime terminates when the Master Warning light/pushbutton is pressed; Alert terminates if the fire detection system senses that the fire has been extinguished
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Control the aircraft
- Execute V1 engine failure/fire flight profile
- Execute engine fire procedure (begin procedure above 400 feet)
- Perform single engine approach/landing procedures

Issues with regard to multiple concurrent non-normal conditions

- False indication of engine fire will likely devolve to an engine failure as part of the engine fire procedure.
- If false indication of fire continues after engine fire NNPs are performed, pilot concerns about inextinguishable fire may prompt risky alternative actions (e.g., rushing, off-airport landing, etc.)

EMB190 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Flashing red "CRG (FWD or AFT) SMOKE" EICAS warning message	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system, but failure of all fire detectors in a compartment is separately annunciated with the flashing amber "CRG (FWD or AFT) FIRESYS FAIL" EICAS caution message	Flashing terminated by pressing a Master Warning reset pushbutton; alert terminated when the fire detection system assesses that the fire has been extinguished
	Flashing cyan "CRG (FWD or AFT) FIREX HI ARM" EICAS advisory message	Extinguisher armed as a result of smoke detected in cargo compartment	Advisory		Alert can be suppressed by fire damage to the fire detection system, but failure of all fire detectors in a compartment is separately annunciated with the flashing amber "CRG (FWD or AFT) FIRESYS FAIL" EICAS caution message	Advisory message is removed when smoke is no longer detected
	Red extinguishing button for the respective cargo compartment illuminates on the overhead panel	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system, but failure of all fire detectors in a compartment is separately annunciated with the flashing amber "CRG (FWD or AFT) FIRESYS FAIL" EICAS caution message	
Aural Alerts	Fire Bell	Smoke detected in cargo compartment	Warning		Alert can be suppressed by fire damage to the fire detection system, but failure of all fire detectors in a compartment is separately annunciated with the flashing amber "CRG (FWD or AFT) FIRESYS FAIL" EICAS caution message	Cancelled by pressing a Master Warning reset pushbutton

EMB190 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	Repetitive triple chime	Triggered by EICAS level 3 warning	Warning		Alert can be suppressed by fire damage to the fire detection system, but failure of all fire detectors in a compartment is separately annunciated with the flashing amber "CRG (FWD or AFT) FIRESYS FAIL" EICAS caution message	Cancelled by pressing a Master Warning reset pushbutton
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	Possible reports from flight attendants or cargo supernumeraries about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/Somatic Cues	None					

EMB190 Alerting Issues – In-flight cargo fire/smoke

1. Initiating Condition: Ignition of cargo leading to extinguishable belly cargo compartment fire, in cruise flight – Cont.

Expected Pilot Response(s)

- Perform the appropriate CRG (FWD or AFT) SMOKE QRH procedure.
- As suggested in the CRG SMOKE QRH procedure, perform the Smoke/Fire/Fumes QRH procedure if required
- Land at nearest suitable airport (or sooner if necessary)
- Verify fire has been extinguished considering any continued smoke indications and any indications of fire detection system failure
- Advise ground personnel that halon has been discharged and not to open cargo compartments without prior clearance from ARFF.

How does pilot know condition is resolved/recovered?

- Previously illuminated cargo smoke indications are extinguished (however, may not extinguish due to residual smoke)
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment and (if necessary) the aircraft has been evacuated

Issues with regard to multiple concurrent non-normal conditions

- Warnings/alerts/cues of other system failures (e.g., electrical, pneumatic, hydraulic) may be presented if these systems or associated detectors receive fire damage; these indications may distract the pilots' attention from responding to the primary fire situation or mask the primary situation
- On the other hand, these secondary failures may require additional responses by the pilots, and the optimal prioritization of pilot response to these multiple cues may be unclear

EMB190 Alerting Issues – In-flight cargo fire/smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise flight

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Flashing red "CRG (FWD or AFT) SMOKE" EICAS warning message	Smoke falsely detected in cargo compartment	Warning			Flashing terminated by pressing a Master Warning reset pushbutton; alert terminated when the fire detection system assesses that the fire has been extinguished
	Flashing cyan "CRG (FWD or AFT) FIREX HI ARM" EICAS advisory message	Extinguisher armed as a result of smoke falsely detected in cargo compartment	Advisory			Advisory message is removed when smoke is no longer detected
	Red extinguishing button for the respective cargo compartment illuminates on the overhead panel	Smoke falsely detected in cargo compartment	Warning			
Aural Alerts	Fire Bell	Smoke falsely detected in cargo compartment	Warning			Cancelled by pressing a Master Warning reset pushbutton
	Repetitive triple chime	Triggered by false EICAS level 3 warning	Warning			Cancelled by pressing a Master Warning reset pushbutton
Tactile Alerts	None					
Visual Cues	None					

EMB190 Alerting Issues – In-flight cargo fire/smoke

2. Initiating Condition: Dust/moisture leading to false indication of smoke in a cargo compartment, in cruise flight – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Aural Cues	Some indication may be available that alarm is false, though extremely ambiguously, from negative reports from flight attendants or cargo supernumeraries about hot floor surfaces, presence of smoke or fumes, other evidence of fire/overheat	(No specific threshold; depends on flight attendants' inquisitiveness, persistence, communications abilities, as well as pilots' skills in prompting flight attendant investigation/communication)				
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- If the fire warning can be ascertained to be false, refrain from performing the cargo fire procedure; otherwise perform the procedure
- If the fire warning terminates after performing the procedure and can be ascertained to have been false, continue the flight; otherwise land within the specified time limit
- Unless the fire warning can be ascertained to be false, if the fire warning system indicates that the fire has ****not**** been extinguished after performing the procedure, land immediately
- Unless the fire warning can be ascertained to be false, advise ground personnel not to open cargo compartments without prior clearance from ARFF.

How does pilot know condition is resolved/recovered?

- Previously illuminated cargo smoke indications are extinguished (however, may not extinguish due to residual smoke)
- Situation is not fully resolved until the aircraft has been returned to the ground and the ARFF response has been applied to the involved compartment, assessing and communicating to the pilots that the fire warning was false.

EMB190 Alerting Issues – In-flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring behind cabin interior panel leading to inextinguishable cabin fire – Cont.

Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	None until smoke reaches the flight deck	Smoke visible		Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Aural Cues	None until flight attendants call pilots on interphone or cargo supernumeraries advise pilots			Cue may not be presented to pilots	Extent/seriousness of the fire may be masked by being hidden behind panels	(Cue will not be eliminated because the fire is not extinguishable)
Tactile/Somatic Cues	None					
Olfactory Cues	None until smoke is smelled			Cue may not be presented to pilots		

Expected Pilot Response(s)

- Perform SMOKE/FIRE/FUMES QRH procedure
- Perform SMOKE/FUMES REMOVAL procedure if/as directed by the SMOKE/FIRE/FUMES procedure
- Perform emergency descent as specified by NNP
- Prepare for emergency landing, off-airport if necessary, as specified by NNP
- Land at nearest suitable airport or immediately as specified by the NNP and as pilot judgment suggests

How does pilot know condition is resolved/recovered?

EMB190 Alerting Issues – In-flight (hidden) cabin fire/smoke

1. Initiating Condition: Ignition from short circuit in electrical wiring behind cabin interior panel leading to inextinguishable cabin fire – Cont.

- Pilots may receive information from flight attendants who are fighting the fire, including gaining access to hidden areas by removing panels
- Situation cannot be resolved until aircraft has landed and crew performs emergency evacuation

Issues with regard to multiple concurrent non-normal conditions

- Pilots may receive alerts/cues from failure conditions secondary to fire damage; it will be unclear to them to what extent they need to respond to these and how to prioritize their response

EMB190 Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	Text messages "UNABLE RNP NEXT WPT," "GPS RAIM UNAVAILABLE," and "UNABLE RNP" on FMS scratchpad	EPU>RNP	Caution	Text messages on FMS scratchpad can be inadequately salient. Also, once cleared by pilot action, they may not be re-displayed		When EPU<RNP
	Amber "DGRAD" alerting text on PFD	EPU>RNP	Caution			When EPU<RNP
	Amber "MSG" alerting text on PFD	Driven by FMS scratchpad messages	Caution			When scratchpad has been cleared using the CLR key on the keypad.
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	Displayed EPU (Estimated Position Uncertainty) value greater than displayed RNP value on FMC Progress Page 1			Requires effortful selection of the appropriate page and comparison of the two numbers		When EPU<RNP
Aural Cues	None					
Tactile/Somatic Cues	None					

EMB190 Alerting Issues – Loss/degradation of GPS

1. Initiating Condition: Poor GPS satellite availability or geometry leading to decreased GPS signal integrity – Cont.

Expected Pilot Response(s)

- Return to ground-based navigation, if any, as directed by the NNP
- During RNAV or RNAV/RNP approach, execute missed approach

How does pilot know condition is resolved/recovered?

- Lookup of FMS page displaying EPU/RNP; inspection of EPU/RNP values.

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning
- False terrain clearance warning
- Loss of separation from air traffic (ADS or NextGen navigation/surveillance)

EMB190 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	FMS CDU scratchpad text message "CHECK (IRS1 or IRS 2) POSITION"	GPS-derived FMS position differs from IRS and/or Radio positions by more than 10 miles	Caution	Text messages and alerts on FMS scratchpad can be inadequately salient. Also, once cleared they may not be re-displayed. Alerting and cueing depends on continued operation of multi-mode navigation, with at least inertial position inputs. The alerting threshold for this alert (10 miles) likely far exceeds RNP values for all but Oceanic procedural separation, so these alerts may be of limited safety value in current RNP or future Next Gen operations.		When position difference has been reduced to within limits or the inaccurate position source has been manually deselected from the FMS solution
	Amber "MSG" alerting text on PFD	Driven by FMS scratchpad message	Caution			When scratchpad has been cleared using the CLR key on the keypad.
Aural Alerts	None					
Tactile Alerts	None					

EMB190 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Map shift is likely when the spoofed position is introduced, because the FMS position equals the GPS position (unless the system detects a degraded GPS solution or the pilots manually deselect GPS input to the FMS)	Cause of the map shift will be unclear and it will not be evident whether the shift was to a more or less accurate position.				
	On the FMS CDU Position Source page, the displayed latitude/longitude values for the various navigation sources (GPS, IRS, Radio) show discrepancies.					
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Verify position using alternative means (e.g. radar, DME)
- Identify false information
- Eliminate source of false information from the position solution

EMB190 Alerting Issues – Loss/degradation of GPS

2. Initiating Condition: Intentional spoofing (intentional introduction of false position into the GPS receiver) leading to false position input from GPS to the FMS – Cont.

How does pilot know condition is resolved/recovered?

- Verifying position after reverting to alternative navigation

Issues with regard to multiple concurrent non-normal conditions

- Loss of terrain clearance warning
- False terrain clearance warning
- Loss of separation from air traffic (ADS or NextGen navigation/surveillance)

EMB190 Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	TCAS RA vertical guidance on PFD: red avoidance zones and green "fly-to" zones replace flight director bars on PFD attitude indicator and vertical speed areas	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
	Popup TCAS display of traffic proximity on MFD map display (filled red square for RA)	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
Aural Alerts	ATC Traffic Alert	Proximity detected by ATC radar/conflict alert at system's threshold				
	TCAS RA aural warning	Proximity detected by TCAS at RA threshold	Warning		RA automatically suppressed by higher order warnings (e.g., stall, windshear, terrain) and in certain altitude regimes; pilots must manually suppress RA in certain conditions, e.g., closely spaced parallel approaches and engine failures	TCAS removes visual alerts/cues and annunciates clear of conflict (aural)
Tactile Alerts	None					

EMB190 Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- Maneuver vertically in response to TCAS RA directives
- Prioritize TCAS RA information over ATC and visual detection information
- Maneuver vertically and/or laterally as instructed by ATC
- Maneuver vertically and/or laterally as prompted by visual closure rate and direction of movement
- The system is designed with the expectation that the pilot will respond within 5 seconds.
- In the case of a corrective RA (e.g. a reversal) the system is designed to expect a pilot response within 2.5 seconds
- Pilot is expected to maintain the requested climb/descent until the aural "clear of conflict" is heard
- Report TCAS RA to ATC as soon as possible
- Caution for endangering passengers with unnecessarily abrupt compliance maneuvers

EMB190 Alerting Issues – Traffic conflict

1. Initiating Condition: Traffic conflict in ATC radar environment (operational error or pilot deviation) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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How does pilot know condition is resolved/recovered?

- TCAS "Clear of conflict" aural
- Red-boxed traffic squares turn amber and/or diverge from own aircraft position
- Visual detection/evaluation of divergence from previous closure rate

EMB190 Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	ADS-In RA vertical guidance on PFD	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning	Future alert/cue designs may differ from current TCAS designs.		
	ADS CDTI with conflict display on MFD map display.	CDTI conflict display system threshold	Warning	Future alert/cue designs may differ from current TCAS designs.		
Aural Alerts	ATM Traffic Alert	Proximity detected by ATM system at RA threshold				
	ADS-In RA aural warning	Proximity detected by ATM system and/or CDTI (TCAS-like) processing at RA threshold	Warning			
Tactile Alerts	None	None				
Visual Cues	Visual contact with traffic	Human visual search, detection, selective attention, personal subjective evaluation (N.B., closer traffic tolerances under NextGen)			Visual traffic cues can be masked by weather and aircraft structure	
Aural Cues	None					
Tactile/Somatic Cues	None					

EMB190 Alerting Issues – Traffic conflict

2. Initiating Condition: Traffic conflict in Next-Gen ATM environment (ground-based sequencing/metering error or datacom error) – Cont.

Expected Pilot Response(s)

- Maneuver the aircraft vertically and/or laterally as directed by ADS-In and CDTI systems
- If aircraft response is automated, evaluate the validity of the ADS-In and CDTI alerts and monitor the aircraft response
- If response is manual, execute the response within established next-gen collision avoidance system specifications.

Issues with regard to multiple concurrent non-normal conditions

- Cascading effects of RA response on NextGen traffic separation and metering

EMB190 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	None					
Aural Alerts	None					
Tactile Alerts	None					
Visual Cues	On the FMS Progress Page 3, the crosstrack error value exceeds RNP value	RNP limit for the aircraft, crew, and specific approach		This cue requires effortful scanning (including obtaining the proper FMS page and incorporating that display into the instrument scan, which is unusual); and interpretation		
	On the PFD, the course deviation indicator is at full scale deflection	Full scale deflection equals the RNP limit				
	On the MFD map display, the lateral path deviation value is displayed (in tenths of NM, with "L" or "R") immediately below the airplane symbol					

EMB190 Alerting Issues – Lateral track or vertical path deviation beyond limits

1. Initiating Condition: In RNP approach and similar Next-Gen terminal area operations, the aircraft’s failure to follow the centerline of the lateral track and/or vertical path within the required deviation limits (e.g., RNP value for lateral track), due to excess wind, autopilot failure, failure to engage autopilot/mode, or specific FMS/autopilot inability to meet specs – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Cues	On the MFD map display, the aircraft symbol deviates from the magenta line (lateral deviation)					
Aural Cues	None					
Tactile/ Somatic Cues	None					

Expected Pilot Response(s)

- If not in visual contact with the runway, execute a missed approach.
- Hand fly lateral path during missed approach to within RNP limits (including RF leg) until automation can be re-engaged.

How does pilot know condition is resolved/recovered?

- Flight path is recovered to within limits

Issues with regard to multiple concurrent non-normal conditions

- Aircraft making a missed approach in response to this condition may complicate NextGen automated sequencing/metering or traffic separation.

EMB190 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	"IAS" displayed in amber on the Capt and F/O PFD airspeed tapes (automatically swaps and displays “ADS 2”	Airspeed miscompare sensed between Capt and F/O PFDs	Caution			Decrease of airspeed variance below threshold value
	PFD airspeed tape enters the amber, then red low speed bands.	Warning could be triggered by either (1) a false indication due to loss of dynamic pressure input to the pitot probe, or (2) a valid indication if pilot follows a different airspeed display that is reading an incorrectly low value into a true underspeed condition.		High and low speed warnings may occur simultaneously (one valid, the other false) which could be especially confusing to the pilots		Low and high speed warnings may begin and end based on changes in altitude as well as airspeed

EMB190 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Visual Alerts	PFD airspeed tape possibly enters the red/white striped high speed band	Indicated airspeed exceeds Vmo/Mmo, if a pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).				
	PFD digital airspeed display possibly turns red	Indicated airspeed exceeds Vmo/Mmo, if a pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Warning			

EMB190 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain's or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
	Possible PFD annunciation OVSP	Indicated airspeed exceeds Vmo/Mmo, if a pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Warning			
Aural Alerts	Possible "High Speed" aural warning if a pilot follows a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Indicated airspeed exceeds Vmo/Mmo	Warning			

EMB190 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Tactile Alerts	None					
Visual Cues	Displayed mach/airspeed is inconsistent with other pilot's and standby airspeed values					
	Displayed mach/airspeed is inconsistent with displayed attitude, considering phase of flight, altitude, thrust, and weight					
	Displayed mach/airspeed is inconsistent with FMC ground speed/winds, IRS-displayed groundspeed, flight path vector displays					

EMB190 Alerting Issues – Air data system failure

1. Initiating Condition: Blocked pitot source (captain’s or left source) – Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
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Aural Cues	None					
Tactile/Somatic Cues	None					

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Adjust airplane attitude and thrust to maintain aircraft control
- Identify the incorrect airspeed display
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations may be affected and destination choices may have to be altered.

How does pilot know condition is resolved/recovered?

- IAS miscompare indications on PFDs are no longer displayed, and airspeed indications are consistent with attitude/thrust/aircraft performance parameters

EMB190 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/suppressed or when cue is masked	How alert or cue is terminated
	"IAS" displayed in amber on the Capt and F/O PFD airspeed tapes	Airspeed miscompare sensed between Capt and F/O PFDs	Caution			Decrease of airspeed variance below threshold value
Visual Alerts	PFD airspeed tape enters the amber, then red low speed bands	Warning could be triggered by either (1) a false indication due to loss of dynamic pressure input to the pitot probe, or (2) a valid indication if pilot follows a different airspeed display that is reading an incorrectly low value into a true underspeed condition.		High and low speed warnings may occur simultaneously (one valid, the other false) which could be especially confusing to the pilots. During period of climb with ram air pressure trapped in the pitot system, low and high speed warnings may begin and end based on changes in altitude as well as airspeed		

EMB190 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)– Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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Visual Alerts	PFD airspeed tape enters the red/white striped high speed band	Warning could be triggered by either (1) pressure trapped in a pitot system and ambient pressure decrease in the climb (false warning); or (2) a pilot following a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).		High and low speed warnings may occur simultaneously (one valid, the other false) which could be especially confusing to the pilots. During period of climb with ram air pressure trapped in the pitot system, low and high speed warnings may begin and end based on changes in altitude as well as airspeed		
	PFD digital airspeed display turns red	Warning could be triggered by either (1) pressure trapped in a pitot system and ambient pressure decrease in the climb (false warning); or (2) a pilot following a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Warning	High and low speed warnings may occur simultaneously (one valid, the other false) which could be especially confusing to the pilots. During period of climb with ram air pressure trapped in the pitot system, low and high speed warnings may begin		

EMB190 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)– Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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				and end based on changes in altitude as well as airspeed		
	PFD annunciation OVSP	Warning could be triggered by either (1) pressure trapped in a pitot system and ambient pressure decrease in the climb (false warning); or (2) a pilot following a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Warning	High and low speed warnings may occur simultaneously (one valid, the other false) which could be especially confusing to the pilots. During period of climb with ram air pressure trapped in the pitot system, low and high speed warnings may begin and end based on changes in altitude as well as airspeed		

EMB190 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)– Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
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	Stick shaker aural warning	AOA	Warning	False warning may prompt pilots to react with control inputs that actually result in or exacerbate loss of control. During period of climb with ram air pressure trapped in the pitot system, low and high speed warnings may begin and end based on changes in altitude as well as airspeed		
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EMB190 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)– Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
Aural Alerts	"High Speed" aural warning	Indicated airspeed exceeds V _{mo} /M _{mo} . Warning may be triggered by either (1) pressure trapped in a pitot system and ambient pressure decreases (false warning); or (2) a pilot following a different airspeed display that is reading an incorrectly low value into a true overspeed (valid warning).	Warning	Pilots responding to a false overspeed warning may enter or exacerbate a loss of control. During period of climb with pitot drain blocked, low and high speed warnings may begin and end based on changes in altitude as well as airspeed		
Tactile Alerts	Stickshaker warning	AOA	Warning	False warning may prompt pilots to react with control inputs that actually result in or exacerbate loss of control. During period of climb with pitot drain blocked, low and high speed warnings may begin and end based on changes in altitude		

EMB190 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with ram air pressure trapped in at least one pitot system during climb (e.g., blocked pitot drain)– Cont.

Sensory Modality	Alert or cue	Threshold for alert or cue to be presented	Type of Alert	Other issues with regard to alert or cue	When alert is inhibited/ suppressed or when cue is masked	How alert or cue is terminated
				as well as airspeed		
Visual Cues	Until complete blockage of all pitot probes, displayed mach/airspeed is inconsistent with other pilot's and standby airspeed values					

EMB190 Alerting Issues – Air data system failure

2. Initiating Condition: Blocked pitot sources (all sources blocked, first partially and inconsistently, then completely), with at least one blocked pitot drain, during climb – Cont.

Visual Cues	Displayed mach/airspeed is inconsistent with displayed attitude, considering phase of flight, altitude, thrust, and weight					
	Displayed mach/airspeed is inconsistent with FMC ground speed/winds, IRS-displayed groundspeed, flight path vector displays					
Aural Cues	None					
Tactile/Somatic Cues	Aerodynamic buffet	Actual overspeed or approach to stall				

Expected Pilot Response(s)

- Disconnect autopilot and autothrottle
- Adjust airplane attitude and thrust to maintain aircraft control
- Perform UNRELIABLE AIRSPEED procedure to identify the incorrect airspeed displays and reference body angle/thrust values for desired performance
- RVSM altitudes no longer allowed. Hence, lower altitudes must be used which may affect fuel burn and range. Consideration for fuel stop must be considered.
- Cat II operations may be affected and destination choices may have to be altered.

EMB190 Alerting Issues – Air data system failure

3. Initiating Condition: Air data computer failure (single module or unit) – Cont.

Visual Alerts	On the Captain's PFD (normally fed by the failed ADS), amber "ADS3" indication in upper left corner	Sensed loss of source input from on-side ADS (ADS1) and automatic switch to first reversionary mode (ADS3)	Caution			
	Master caution blinking amber lights on L&R glareshield	Triggered by EICAS Caution Messages ADS 1 FAIL	Caution		EICAS inhibited 80kt to 400ft and 200 ft to landing roll	Blinking terminates when the Master Caution light/pushbutton is pressed
	EICAS caution message ADS 1 FAIL (amber, flashing/reverse video)		Caution		EICAS inhibited 80kt to 400ft and 200 ft to landing roll	Flashing/reverse video of the text ceases terminates when the Master Caution light/pushbutton is pressed
	ADS sensor reversion button on the reversionary panel (forward instrument panel) is illuminated in white.	Sensed loss of source input from on-side ADS (ADS1) and automatic switch to first reversionary mode (ADS3)				
Aural Alerts	Single chime	Triggered by EICAS Caution Messages ADS 1 FAIL	Caution			
Tactile Alerts	None					
Visual Cues	None					
Aural Cues	None					
Tactile/Somatic Cues	None					

EMB190 Alerting Issues – Air data system failure

3. Initiating Condition: Air data computer failure (single module or unit) – Cont.

Expected Pilot Response(s)

- Perform ADS1 FAIL QRH procedure
- As prompted by the QRH procedure, consider whether continued flight in RVSM airspace is permitted.
- Cat II operations may be affected and destination choices may have to be altered.