US Comments on Draft Aircraft Accident Investigation Report
Ethiopian Airlines Flight 302
Boeing 737-8 MAX, ET-AVJ
Ejere, Ethiopia
March 10, 2019

INTRODUCTION

These comments address the investigation of the accident involving Ethiopian Airlines flight 302, a Boeing 737-8 MAX airplane, registration ET-AVJ, in Ejere, Ethiopia, on March 10, 2019. In accordance with Annex 13 to the Convention on International Civil Aviation, as the representative of the State of Design and Manufacture of the airplane, the US accredited representative and technical advisors assisted with the Aircraft Accident Investigation Bureau of Ethiopia (EAIB) investigation.

On January 12, 2021, the US accredited representative received the EAIB draft final report for review and comment. The US team's comments were provided to the EAIB on February 26, 2021. On May 26, 2021, the US accredited representative received a second draft of the final report. The US team's comments on the second draft were provided to the EAIB on June 11, 2021. On March 30, 2022, the US accredited representative received a third draft of the final report. In response to the third draft report, the US accredited representative hereby submits comments to the EAIB pursuant to section 6.3 of Annex 13 and requests that these comments be appended in their entirety to the final report.

SUMMARY

In response to the accident notification, the US accredited representative and technical advisors traveled to Ethiopia to assist with the EAIB investigation. The US team (National Transportation Safety Board [NTSB], Federal Aviation Administration [FAA], Boeing, and General Electric) participated in the on-scene and immediate local follow-on investigative activities. As permitted by Annex 13, the EAIB chose to have the cockpit voice recorder (CVR) and flight data recorder (FDR) downloaded and read out at the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) and requested that the BEA name an accredited representative to assist throughout the investigation. The BEA subsequently named an accredited representative.

During the investigation, the US team and NTSB senior management made four visits to Ethiopia between March 12 and September 7, 2019, for progress and coordination meetings and provided detailed technical reports concerning the angle-of-attack (AOA) sensor, the Maneuvering Characteristics Augmentation System (MCAS), other airplane systems, and the US aircraft certification process. The US team was not included in any postaccident interviews or on-site data gathering related to the flight crew operations and human performance aspects of the investigation. Nevertheless, to help facilitate a thorough investigation, the NTSB provided support and guidance to the EAIB, including a detailed outline of the NTSB's process for operational factors and human performance investigations, which indicated areas to investigate, documents to request, positions to interview, and questions to ask.

The US team also hosted EAIB and BEA investigators at Boeing's engineering cab simulator and flight control test rig simulator facilities in Seattle, Washington, in December 2019. This visit provided the investigators with an opportunity to observe the 737-8 MAX flight deck cues that were available to the accident flight crewmembers and understand the column and trim wheel forces that they encountered during the accident flight.

In response to the October 29, 2018, Lion Air flight 610 accident in Tanjung Karawang, West Java, Indonesia, and the Ethiopian Airlines accident, the NTSB issued seven recommendations to the FAA on September 19, 2019, related to the aircraft certification process, particularly the assumptions that the FAA allows manufacturers to use for pilot responses to flight control failure conditions, the need for a standardized methodology and/or tools for manufacturers to use in evaluating and validating assumptions about pilot recognition and response to failure conditions, and the need for airplane systems that can more clearly and concisely inform pilots of the highest priority actions when multiple flight deck alerts are presented.[1] The US accredited representative kept the EAIB informed about the progress of the draft recommendations and provided the EAIB with a copy of the final safety recommendation report.

Overall, the US team concurs with the EAIB's investigation of the MCAS and related systems and the roles that they played in the accident. However, many operational and human performance issues present in this accident were not fully developed as part of the EAIB investigation. These issues include flight crew performance, crew resource management (CRM), task management, and human-machine interface. It is important for the EAIB's final report to provide a thorough discussion of these relevant issues so that all possible safety lessons can be learned.

The comments presented below discuss aspects of the accident that were not adequately addressed in the EAIB's draft report. The comments are grouped into three main areas: draft probable cause, airframe/systems aspects, and operational and human factors. The final section of this document describes Boeing's and the FAA's safety actions after the 737-8 MAX accidents and the NTSB's September 2019 recommendations to the FAA.

DRAFT PROBABLE CAUSE

We agree that the uncommanded nose-down inputs from the airplane's MCAS system should be part of the probable cause for this accident. However, the draft probable cause indicates that the MCAS alone caused the airplane to be "unrecoverable," and we believe that the probable cause also needs to acknowledge that appropriate crew management of the event, per the procedures that existed at the time, would have allowed the crew to recover the airplane even when faced with the uncommanded nose-down inputs.

We propose that the probable cause in the final report present the following causal factors to fully reflect the circumstances of this accident:

- uncommanded airplane-nose-down inputs from the MCAS due to erroneous AOA values and
- the flight crew's inadequate use of manual electric trim and management of thrust to maintain airplane control.

In addition, we propose that the following contributing factors be included:

- the operator's failure to ensure that its flight crews were prepared to properly respond to uncommanded stabilizer trim movement in the manner outlined in Boeing's flight crew operating manual (FCOM) bulletin and the FAA's emergency airworthiness directive (AD) (both issued 4 months before the accident) and
- the airplane's impact with a foreign object, which damaged the AOA sensor and caused the erroneous AOA values.

1. AIRFRAME/SYSTEMS ASPECTS

1.1. The EAIB draft report states that the erroneous AOA data resulted from an AOA sensor failure yet omits key findings about the root cause of the AOA erroneous data: damage from impact with a foreign object/bird. Thus, the report misses the opportunity to address improvements for wildlife management at the flight's departure location—Bole International Airport, Addis Ababa, Ethiopia.

- **Cause of the AOA erroneous data:** Collins Aerospace, the manufacturer of the airplane's AOA sensor, was named as a technical advisor to the US team in April 2019 after the EAIB requested assistance investigating the most likely failure modes for the AOA sensor based on the accident data. Although the EAIB draft report acknowledges Collins' factual report, the EAIB draft report does not acknowledge Collins' fault tree analysis, which demonstrated that the recorded FDR data from the accident were not

[1] See https://www.ntsb.gov/investigations/AccidentReports/Reports/ASR1901.pdf for the NTSB's safety recommendation report. The recommendations are also presented in section 4.3 of this document.

consistent with any internal failure of the AOA sensor; instead, those data were fully consistent with previous instances of partial AOA vane separation due to a bird strike.

  - Collins' report addressed the following potential AOA sensor failure modes: (1) manufacturing defects, (2) internal component failures, (3) heater failures, (4) non-impact structural failures of the AOA vane/attachment hardware, and (5) AOA vane impact failures. Through external environment testing (vibration, acceleration, and flight simulation) and physics-based performance modeling, Collins determined the following:
    - The observed performance deviation of the left AOA sensor, which was recorded by the FDR 44 seconds after the beginning of takeoff roll, is consistent with the vane breaking at the hub and separating from the AOA sensor.
    - The LEFT ALPHA VANE fail annunciation on the probe heat panel (indicating vane heater current below the monitor threshold), which was recorded by the FDR 50 seconds after the beginning of takeoff roll, is consistent with the vane breaking at the hub and separating from the AOA sensor 44 seconds after the beginning of the takeoff roll, creating an open circuit for the vane heater.
    - A bird weighing at least 0.5 pound (0.23 kilogram) impacting the vane at 170 knots (the estimated airspeed of the airplane at the time of the left AOA sensor performance deviation) would be sufficient to cause the vane to break at the hub and separate from the AOA sensor.
    - Wind tunnel test data and the AOA dynamic performance model show that the failure mode involving separation of the vane at the hub is consistent with the large and near-instantaneous initial change in the left AOA value and the resulting AOA dynamics observed in the FDR data.
  - Further, the draft report states that, because the EAIB did not participate in the testing in person, it cannot comment on the observations. However, Collins invited the EAIB multiple times to participate in the simulation testing and live demonstration of the testing, but the EAIB did not accept these invitations. Nevertheless, Collins accompanied the US accredited representative to Addis Ababa in September 2019 and presented its analysis to the EAIB; this visit provided the EAIB with an unrestricted opportunity to interact with Collins staff and understand Collins' work in its entirety. Further, the US accredited representative provided the EAIB with Collins' comprehensive report detailing, among other things, its testing method and results.
- **Bird activity at Addis Ababa airport**: The EAIB draft report omits factual information, analysis, findings, contributing factors, and safety recommendations regarding bird hazards and the effectiveness of bird mitigations at Addis Ababa airport.
  - The EAIB draft report provides some details regarding a runway area search after the accident but inappropriately suggests that the lack of bird remains or AOA vane remnants indicates that the airplane was not impacted by a foreign object. The EAIB report fails to state that the search occurred 8 days after the accident and that the search did not include the area surrounding taxiway D, even though FDR data indicated that the airplane would have been positioned above the taxiway when the left AOA sensor data became erroneous.
  - On November 11, 2019, the EAIB published its final report regarding the November 26, 2018, engine failure event involving a Boeing 767-300, registration ET-AMG, caused by engine ingestion of a Steppe or Tawny eagle weighing 2.0 to 3.4 kilograms (4.4 to 7.5 pounds). The report stated that Steppe and Tawny eagles are common around Addis Ababa airport. The EAIB found that a bird strike hazard existed at the airport and made a recommendation in this area.[2]

[2] The EAIB recommended that the Ethiopian Airlines Group Airport authority "take practical measures to minimize/eliminate bird hazards around the airport so that arriving and departing flights are conducted safely without any human and material loss" (EAIB Report No. SI-01/18).

1.2. The EAIB draft report includes multiple findings that question the functionality of the manual electric trim system but presents no facts to support these findings. In addition, the findings contradict the evidence from this investigation indicating that the system was functioning as intended.

- Per the request of the EAIB, Boeing conducted a thorough assessment of potential trim system failures and provided the results to the EAIB in October 2019.
- This assessment found that no trim system failure scenarios were consistent with the FDR data and that the behavior of the electric manual trim parameter recorded on the FDR was consistent with flight crew input.

1.3. The EAIB draft report incorrectly states that design changes to the 737-8 MAX were not official and were not approved by the FAA.

- Boeing's changes to the MCAS design were official in March 2016 and were communicated to the FAA in July 2016, as described in the NTSB System Safety and Certification Specialist's Report, section H, Certification of the MCAS Implementation and Function.[3]
- Boeing applied for and, in March 2017, was granted an amended type certificate for the 737-8 MAX. For further information, see the NTSB System Safety and Certification Specialist's Report.

1.4. The EAIB draft report incorrectly states that Boeing did not respond or failed to respond appropriately to Ethiopian Airlines' request for more information about the MCAS after the Lion Air accident.

- Boeing provided information to all 737 MAX operators in November 2018 (after the Lion Air accident but before the Ethiopian Airlines accident) to address uncommanded MCAS inputs. This information included operations manual bulletin (OMB)/FCOM bulletin ETH-12, FAA emergency AD 2018-23-51, a multi-operator message, dedicated meetings, and email messages.
- Boeing's response to Ethiopian Airlines' request for more information about the MCAS, dated December 3, 2018, provided specific guidance about the OMB and checklist prioritization. In particular, the response indicated, "As is stated in the OMB, 'If uncommanded stabilizer trim movement is experienced in conjunction with the erroneous AOA flight deck effects, the instructed course of action is to use the Stabilizer Cutout switches per the existing [runaway stabilizer] procedure.'"

2. OPERATIONAL AND HUMAN FACTORS ASPECTS

Flight crew performance played a critical role in the accident sequence; however, a discussion of the accident flight crew's performance (including CRM) was not sufficiently developed in the EAIB draft report, which continues to focus heavily on system design issues. The absence of flight crew performance information limits the opportunity to address broader and equally important safety issues. Further, evaluation of the crew's performance would not have been particularly difficult because the relevant data were readily available in the CVR, FDR, airline manuals/procedures, crew training records, and postaccident interviews.

As we have reiterated throughout the investigation, design mitigation must adequately account for expected human behavior to be successful, and a thorough understanding of the flight crew's performance in this accident is required not only for robust design mitigations but also for operational and training safety improvements necessary to achieve multiple layers of safety barriers to trap human errors and prevent accidents.

[3] For more information, see the Certification Specialist's Report in the NTSB's docket for the Lion Air accident, which can be found at https://data.ntsb.gov/Docket?ProjectID=98554.

2.1 The EAIB draft report inappropriately states that the IAS (indicated airspeed) DISAGREE and ALT (altitude) DISAGREE messages were not displayed to the crew during the accident flight, and the EAIB used this incorrect assumption as a basis for its assessment of the crew's performance.

- Although the FDR was not programmed to record the presence or absence of the IAS DISAGREE and ALT DISAGREE messages, all conditions were met for the alerts to be presented to the crew. The systems logic (presented to the EAIB in September 2019) and flight simulations (conducted in December 2019) demonstrated the expected timing for the presentation of these alerts on the crew's primary flight displays.
- The EAIB report improperly states that, because the AOA DISAGREE message did not appear, the IAS DISAGREE and ALT DISAGREE messages also did not appear. As explained in detail in the report, a software discrepancy caused the AOA DISAGREE message not to appear, but the software discrepancy was unrelated to, and had no effect on, the display of the IAS DISAGREE and ALT DISAGREE messages.
- Given that the conditions were met for the IAS DISAGREE and ALT DISAGREE messages to be annunciated to the crewmembers, their lack of conversation or action in response to the annunciations should be explored in the context of the flight deck environment, workload, crew experience, and training. The report's assumption that those messages did not appear, which is contrary to Boeing's description of the alerting system and the results of simulator testing during the investigation, severely limits the opportunity for recognizing and addressing potential crew training and experience improvements.

2.2 The EAIB draft report states that no flight crew reference document explained that autothrottle thrust commands could be affected by erroneous AOA inputs.

- Even if such a reference document did not exist, the flight crew should have been trained on 737-8 MAX non-normal procedures. Because crew response to in-flight anomalies is time critical, these in-flight reference documents are not intended to provide flight crews with an in-depth understanding of a system before responding to an anomaly. Rather, non-normal procedures are designed to provide flight crews with information to diagnose and respond to a system-related issue in a timely manner based on observable flight deck effects.
- Non-normal procedures related to erroneous AOA inputs instruct the crew to disengage both the autopilot and autothrottle, thereby preventing the erroneous AOA inputs from affecting flight control and throttle movements. The observable flight deck effects associated with erroneous AOA inputs include the activation of the stickshaker and the annunciation of the IAS DISAGREE and ALT DISAGREE messages.

2.3 The EAIB draft report incorrectly states (in several locations) that the MCAS made control of the airplane "impossible" but neglects to state that, if the crew had manually reduced thrust and appropriately used the manual electric trim, the airplane would have remained controllable despite uncommanded MCAS input.

- The flight crew's failure to reduce thrust manually and the excessive airspeed that resulted played a significant role in the accident sequence of events.
    - Upon either the activation of the stickshaker or the annunciation of the IAS DISAGREE message, the expected crew response is to turn off the autothrottle. The report could be strengthened if it discussed, from a human performance perspective, possible reasons why the flight crew did not respond as expected to the stickshaker and the IAS DISAGREE message.
    - Because the autothrottle remained engaged and responsive to the erroneous AOA inputs, the autothrottle did not transition to N1 mode and remained in the ARM mode with takeoff thrust. The expected crew response is to manually control thrust in this situation; however, the lack of manual control and the absence of flight crew conversation regarding the thrust settings indicate that the crew did not notice the autothrottle's failure to transition to N1, even when the aural overspeed warning triggered as the airplane accelerated beyond about 340 knots. As airspeed increased, the required control forces increased on both the control column and the manual trim wheel.
- Appropriately countering uncommanded nose-down inputs with manual electric trim nose-up inputs, as was expected per crew procedure described in the FCOM bulletin and the emergency AD, would have resulted

in control column forces remaining in a controllable regime during the flight, including when the stabilizer trim cutout switches were in the CUTOUT position. (See section 2.4 below for further information about the crew moving the switches to the CUTOUT position.) The report could be strengthened if it evaluated, from a human performance perspective, the crew's failure to apply manual electric trim nose-up inputs.

- The draft report does not examine the flight crew's understanding of the effect of airspeed on the control forces required to move the control column and trim wheel.
  - The draft report states that the FCOM did not include details on the higher trim forces required with airspeed. However, the FCOM states that "the effort required to manually rotate the stabilizer trim wheels may be higher under certain flight conditions." Further, even though the FCOM did not include the effect of airspeed on the manual trim wheel forces, that information is specifically noted in the manufacturer's flight crew training manual. For example, that manual states, "if manual stabilizer trim is necessary, ensure both stabilizer trim cutout switches are in CUTOUT prior to extending the manual trim wheel handles. Excessive air loads on the stabilizer may require effort by both pilots to correct the mistrim. In extreme cases it may be necessary to aerodynamically relieve the air loads to allow manual trimming. Accelerate or decelerate towards the in-trim speed while attempting to trim manually."
  - Although the draft report mentioned the dates of the crew's training on the "use of trim wheel," the report does not address whether the training included airspeed effects on the trim wheel or the forces required to trim as airspeed increases.
  - The report misses an opportunity to evaluate the effectiveness of air carrier training related to the relationship between airspeed and manual trim control forces and make safety recommendations, as appropriate, to improve industry training.
- The EAIB draft report incorrectly states (in several places) that the "Summary of FAA's Review of Boeing 737MAX" document indicates that the MCAS denies pilot control and trim authority. However, this document states the opposite: "if MCAS is erroneously activated, <u>the MCAS system preserves the flightcrew's ability, using basic piloting techniques, to control the airplane after the activation</u> [emphasis added]."

2.4 The EAIB report inaccurately states that the crew performed actions "per the procedure." Evidence shows that the crew did not appropriately perform non-normal procedures after receiving annunciations relating to unreliable airspeed, stall warning, and runaway stabilizer. The crew also did not respond as expected to the overspeed warning by disconnecting the autothrottle and reducing power.

- Emergency AD 2018-23-51 and FCOM Bulletin ETH-12 instruct flight crews to conduct the runaway stabilizer checklist, which requires them to "control airplane pitch manually with control column and main electric trim,"
  - If the crew had conducted the procedure in the emergency AD and the FCOM bulletin, the crew would have used manual electric trim to reduce control forces. However, FDR data show minimal crew use of manual electric trim.
  - If the crewmembers had performed the memory items for the airspeed unreliable and/or runaway stabilizer checklists, they would have disengaged the autothrottle. A manual reduction of thrust would have further assisted in reducing control forces. However, FDR data show that the autothrottle remained engaged and that thrust remained at full power.
  - All these actions were expected per procedure and were to be conducted before moving the stabilizer trim cutout switches to the CUTOUT position.
- Even after moving the stabilizer trim cutout switches to the CUTOUT position, the crew decided to return the switches to the NORMAL position, contrary to the FCOM bulletin and the emergency AD, which direct crews to ensure that the switches "stay in the CUTOUT position for the remainder of the flight." The available evidence for this accident did not indicate why the crew performed this action. By not evaluating the human factors associated with this crew action, the report provides a limited understanding of the circumstances leading to the airplane's nose-down pitch before impact.

2.5 The EAIB draft report includes details and analysis of the OMB/FCOM bulletin and emergency AD information provided after the Lion Air accident but does not include details about the effectiveness of the operator's dissemination of the bulletin or flight crew understanding of that information.

- The bulletin and emergency AD provided information to ensure that flight crews were aware of the possibility for repeated nose-down trim commands after an erroneously high single AOA sensor input and had specific guidance for recognizing the event and responding appropriately.
- Performance of the correct action depends on flight crews having access to, understanding, and applying the information presented in those documents.
- The report states that the bulletin and emergency AD were disseminated to Ethiopian Airlines flight crews via the logipad system, but the report does not discuss the effectiveness of this dissemination method or opportunities to improve crew access to, and understanding of, the disseminated information, which could benefit other operators that use a similar system to provide flight crews with critical information.

2.6 The EAIB draft report describes how CRM could have been affected by the flight deck environment but does not fully evaluate the CRM that occurred during the accident flight.

- International Civil Aviation Organization investigative guidance states that a human performance investigation "should be as methodical and complete as any other traditional area of the investigation."
- The CRM aspects not discussed in the report include, but are not limited to, the following:
  - Division of duties
  - Operator CRM training
  - Expected/as-trained CRM performance
  - Flight deck communication
  - First officer's limited flight experience
  - Potential authority gradient

3. ADDITIONAL CONSIDERATIONS

- The format of the document in Appendix H on page 288 (the NTSB737 MAX-8 Systems Description Report) is not consistent with the format of the document that the NTSB provided to the EAIB. The document should appear in the final report in its original format.
- The CVR transcript provided in the EAIB report is not complete, omits key statements related to the flight crew's performance during the accident flight, and inappropriately adds analytical commentary to transcribed statements. Of immense importance is that the original transcript was developed by the entire investigative team, including international team members, whereas the changes to the transcript were made unilaterally by the EAIB. The current presentation of the CVR transcript prevents the reader from having a complete and an objective understanding of the event.

4. SUBSEQUENT ACTIONS

4.1 Boeing Safety Action

After the Lion Air flight 610 and Ethiopian Airlines flight 302 accidents, Boeing made safety improvements to the 737 MAX, including the following:

- Boeing’s updated software (flight control computer [FCC] operational program software [OPS] version P12.1.2) incorporates several enhancements to the speed trim system, which includes the MCAS.
    - The software updates include AOA signal monitoring (from both AOA sensors), MCAS activation and stabilizer resynchronization logic, maximum command limit, and flight deck alerting.
    - These software enhancements provide additional functionality to prevent erroneous MCAS activation and ensure that sufficient maneuvering capability would be provided if multiple MCAS activations were to occur.
- Boeing issued Service Bulletin 737-22A1342 (dated November 17, 2020), which addressed the software changes. FAA AD 2020-24-02 (dated November 20, 2020) required FCC OPS version P12.1.2 for 737-8 and 737-9 airplanes, in accordance with the service bulletin.[4]

4.2 FAA Safety Action

The FAA revised its Boeing 737 *Flight Standardization Board Report* (revision 17) on November 16, 2020, to include, among other things, Appendix 7. This appendix describes flight crewmember training, checking, and currency requirements, including the new ground and flight training requirements associated with pilot qualification on the 737 MAX. Neither the pilot-in-command nor the second-in-command can operate the 737 MAX unless they have completed the ground and flight training documented in this appendix. Further, flight training is required to be conducted in a Level C or D full flight simulator.

According to the FAA’s report, the following maneuvers and objectives are required to be trained:

- Demonstration of MCAS activation for each pilot while acting as the pilot flying.
    - MCAS activation during an impending or a full stall and recovery with the airplane in a clean configuration during manual flight.
    - Demonstrate MCAS activation stabilizer trim responses
        - Stabilizer trim in the nose-down direction when above the threshold AOA for MCAS activation during a stall.
        - Stabilizer trim in the nose-up direction when below the threshold AOA for MCAS activation during a stall recovery.
- Erroneously high AOA during takeoff that leads to an unreliable airspeed condition accomplished by the pilot flying.[5]
    - Demonstrate flight deck effects (aural, visual, and tactile) associated with the failure.
    - Fault (the erroneously high AOA) occurring during the takeoff procedure.
    - Must include a go-around or missed approach flown with an erroneously high AOA condition.
    - Special emphasis placed on flight director behavior “biasing out of view” upon selecting the takeoff/go-around switch.

4.3 NTSB Safety Recommendations to the FAA

The NTSB issued the recommendations below to the FAA on September 19, 2019. The FAA’s actions to address these recommendations and the NTSB’s responses can be found on the Safety Recommendations page at www.ntsb.gov. All recommendations are currently classified “Open–Acceptable Response.”

A-19-10: Require that Boeing (1) ensure that system safety assessments for the 737 MAX in which it assumed immediate and appropriate pilot corrective actions in response to uncommanded flight control inputs, from systems

[4] AD 2020-24-02 superseded AD 2018-23-51.

[5] This scenario occurred during the Ethiopian Airlines flight 302 accident. However, with the installation of the FCC OPS version P12.1.2, an erroneously high AOA will no longer lead to non-normal MCAS operation.

such as the Maneuvering Characteristics Augmentation System, consider the effect of all possible flight deck alerts and indications on pilot recognition and response; and (2) incorporate design enhancements (including flight deck alerts and indications), pilot procedures, and/or training requirements, where needed, to minimize the potential for and safety impact of pilot actions that are inconsistent with manufacturer assumptions.

A-19-11: Require that for all other US type-certificated transport-category airplanes, manufacturers (1) ensure that system safety assessments for which they assumed immediate and appropriate pilot corrective actions in response to uncommanded flight control inputs consider the effect of all possible flight deck alerts and indications on pilot recognition and response; and (2) incorporate design enhancements (including flight deck alerts and indications), pilot procedures, and/or training requirements, where needed, to minimize the potential for and safety impact of pilot actions that are inconsistent with manufacturer assumptions.

A-19-12: Notify other international regulators that certify transport-category airplane type designs (for example, the European Union Aviation Safety Agency, Transport Canada, the National Civil Aviation Agency-Brazil, the Civil Aviation Administration of China, and the Russian Federal Air Transport Agency) of Recommendation A-19-11 and encourage them to evaluate its relevance to their processes and address any changes, if applicable.

A-19-13: Develop robust tools and methods, with the input of industry and human factors experts, for use in validating assumptions about pilot recognition and response to safety-significant failure conditions as part of the design certification process.

A-19-14: Once the tools and methods have been developed as recommended in Recommendation A-19-13, revise existing Federal Aviation Administration (FAA) regulations and guidance to incorporate their use and documentation as part of the design certification process, including re-examining the validity of pilot recognition and response assumptions permitted in existing FAA guidance.

A-19-15: Develop design standards, with the input of industry and human factors experts, for aircraft system diagnostic tools that improve the prioritization and clarity of failure indications (direct and indirect) presented to pilots to improve the timeliness and effectiveness of their response.

A-19-16: Once the design standards have been developed as recommended in Recommendation A-19-15, require implementation of system diagnostic tools on transport-category aircraft to improve the timeliness and effectiveness of pilots’ response when multiple flight deck alerts and indications are present.